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Long-term morphotectonic evolution of the Southern Apennines

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Questi 3 anni di durata del mio dottorato hanno rappresentato un momento fondamentale per la mia crescita culturale riguardo tematiche di interesse attuale quali l'evoluzione morfotettonica degli orogeni, in particolare permettendomi di ampliare le mie conoscenze teoriche e di proporre nuove chiavi di lettura per quanto concerne la ricostruzione delle tappe morfoevolutive dell'Appennino Meridionale, nonché di implementare la mia conoscenza pratica dei software maggiormente utilizzati in questo tipo di ricerche, con particolare riferimento al programma Arcgis.

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ABSTRACT

The main goal of this work is the study of the morphological and morphometrical features of the Southern Apennines thrust belt – foredeep system, carrying out both a large scale and a small scale analyses of areas of high relevance, with the aim to determine new morphological and morphometrical constraints to the reconstruction of the main morphotectonic events that have interested the chain. This type of research has been based on the idea to compare such data with new thermochronological data that have been produced in many areas of the chain (Aldega et al., 2003; Mazzoli et al., 2006; Mazzoli et al., 2008), which highlighted the role of the exhumation processes in the evolution of the thrust belt. The thermochronological data indicate that the exhumation processes started about 10Ma and they have been active since recent time (in the last million years), resulting contemporary to the main morphogenetic events responsible of the actual morphostructural setting of the chain.

The Southern Apennines chain formed has a consequence of the Neogene collision of the African (and in particular, the Adria microplate) and Euroasiatic plates, with the subduction of the Adria microplate beneath the Euroasiatic plate. The morphostructural setting of the Southern Apennines has been determined by its complex tectonic history (with the occurrence of both thrust faults and normal faults) and by the erosional processes that have sculptured the topography, also considering that the landforms are strongly influenced by the rock type too.

In the last years the development of new techniques of analysis has provided new constraints useful to the reconstruction of the morphotectonic history of the Southern Apennines. This techniques are based on thermochronological analysis, and in particular on the Apatite Fission Tracks, the Ur-Th-He series, the Vitrinite Reflectance, the Clay Mineralogy and the Fluid Inclusions. These data, that have been extensively produced in the whole chain, have pointed out the attention on tectonic exhumation processes (we mean by rock exhumation a variation of the position of a rock in relation to the air-topograhy interface), which have determined rock uplift of thousands of meters in the last 2-3Ma (Aldega et al., 2003; Mazzoli et al., 2006; Mazzoli et al., 2008). The individuation of so enhanced vertical and horizontal tectonic motions in recent times has expected to have interacted with the processes responsible of the exogenic modelling of the topography, and they have probably played an important role in the morphotectonic evolution of the chain, leaving their signature in the topography.

The research has been based on large scale geomorphological and morphometrical techniques of analysis, that have been used with the aim to describe the main morphological and morphometrical features of the chain, to compare the features of the Tyrrhenian, Adriatic and Ionian slopes of the Southern Apennines, and to relate these features with the proposed morphotectonic events. The large scale analysis has been accompanied by the small scale analysis of a selected transect namely the Noce-Sirino-Alpi-Sant'Arcangelo transect. This transect has been chosen because of the particular features that make this area one of the most relevant portion of the chain in order to reconstruct the morphotectonic evolution of the Southern Apennines, and in particular, to investigate the role played by the rock exhumation processes in the evolution of the relief. This transect assumes a high relevance because:

- *it includes tectonic units which have been exhumed in recent times;*
- *it preserves a stratigraphical and morpho-stratigraphical record which is almost continuous both temporally (from the Middle Pliocene to the whole Quaternary) and spatially (from the Tyrrhenian to the Adriatic coasts);*
- *the topography, in this portion of the Southern Apennines, has been only slightly dismembered by the post-orogenic extensional tectonic, and may be considered resulting by the major geodynamic processes (shortening, thrusting, extension and exhumation).*

One of the main parameters that can influence the geomorphological and morphometrical features of a determined region is the lithology, or more correctly the bedrock resistance to erosion. In fact, parameters such as the elevation, local relief, steepness, presence of knickpoints are

strongly controlled by bedrock erodibility. As a result, the first step in the analysis of the landscape is represented by a clear depiction of the space distribution of the rock types with different erodibility. For the above mentioned reason, a "Map of the Morphostructural Units of the Southern Apennines" has been created. This map is a simplification of the "Geological Map of the Southern Apennines" in scale 1:250000, in fact the 81 formations distinguished in the "Geological Map of the Southern Apennines" have been reduced into the 20 morphostructural units which have been grouped based on the estimation of erodibility of each rock type relative to other rock types. The erodibility degree was basically assigned by the observations of the features (e.g. steepness, degree of development of the upper convexity/basal concavity of hillslopes, average elevation, etc.) associated with the various bedrocks. As regards the Quaternary deposits, these were grouped based on different criteria. Taking into account the main goal of this study, which consists in the reconstruction of the Plio-Quaternary relative/absolute vertical motions of the Southern Apennines, the grouping of the different Quaternary stratigraphical units was based on the depositional environment (marine vs continental), degree of correlation of the different units with the original depositional environment (i.e. whether and to what degree they are displaced/dissected), and tectonic context (e.g. peri-tyrrhenian grabens, foredeep and intramontane basins deposits).

The large scale geomorphological analysis of the Southern Apennines has been based on the determination of the following parameters: elevation map and the derived maximum, medium and minimum elevation maps, swath profiles and the derived relief curves, analysis of the river long profiles and the derived parameters (drainage area vs distance, Stream Gradient Index, steepness (ks) and concavity (Θ) indexes, slope of the first order channels). This type of analysis enhance a series of particular feature of the Southern Apennines that can be summarized as follows:

- *the minimum elevation map can be separated in two different sector, respectively located north and south of the hereinafter named "Sele-Ofanto line": the north sector is characterized by the coincidence of the highest values with the apenninic divide, while the southern sector is characterized by the presence of a wide area with high values in the minimum elevations, which moves from the apenninic divide to the east, involving the foredeep (and the Lavello high) and the Murge-Salento area ;*
- *this data regarding the minimum elevation map is very interesting in particular when compared with the "Map of the Morphostructural Units of the Southern Apennines": this comparison show that the valleys on the Adriatic flank are higher than the valleys on the Tyrrhenian flank despite the Adriatic flank is characterized by the outcropping of very weak lithologies (external flyschs and Quaternary filling of the foredeep);*
- *the minimum elevation map could be so considered a good representation of the differential uplift at the orogen scale; this fact let the maximum elevation map to play a less relevant role when we want to interpret it in terms of uplift, and it can be more correctly considered as a good representation of the distribution of the tectonic Quaternary lows;*
- *the medium elevation map clearly enhance the presence of the hard carbonatic highs on the Tyrrhenian slope respect to more eroded surrounding areas where weaker lithologies crop out. This means that the Tyrrhenian slope has experienced a more intense erosion, or even that it is experiencing erosion since older times than the Adriatic flank (where the same weak lithologies crop out), and that the amount of eroded rock volumes is higher on the Tyrrhenian flank than on the Adriatic flank. If this two sectors were experiencing erosion since the same time, than we cannot explain why the external flank of the chain is higher than its inner flank despite this two sectors are characterized by the same rock-type;*

- *the analysis of the maximum, medium and minimum elevation maps suggests that the Adriatic flank of the Southern Apennines has experienced more enhanced uplift in recent times than the Tyrrhenian flank;*
- *the Tyrrhenian and the Adriatic flanks of the chain have also other different morphological and morphometrical features, in particular the Tyrrhenian flank becomes steeper than the Adriatic flank as we move to the south, giving the typical asymmetrical feature to the Southern Apennine;*
- *this asymmetrical feature of the chain is clearly showed by the envelop of the minimum elevation line of the five swath profiles, which enhance the presence of a Tyrrhenian steep slope and of an Adriatic gentle slope;*
- *there is an important difference regarding the elevation of the valleys on Tyrrhenian and the Adriatic flanks, with a mean gradient that bring the valleys to reach elevations a.s.l. higher on both the flanks as we move to the south, but in general the valleys on the Tyrrhenian flank are always lower than the valleys on the Adriatica flank: such a difference suggest a more recent uplift on the Adriatic flank than on the Tyrrhenian one;*

The analysis of the river system shows how there is a spatial variations of the morphological and morphometrical features of the Southern Apennine rivers. If we consider the shape of the river long profiles we notice that the Tyrrhenian rivers have a clear concave-up shape with no important knickpoints, while the Adriatic rivers show a more rectilinear shape and the Ionian rivers show a less evident concave-up shape, in same cases close to the rectilinear, with evident knickpoints along the profiles. The Θ *(concavity index) values show a difference among the three sectors, with the Tyrrhenian rivers showing the highest value (*Θ*=0.52), the Adriatic rivers showing a lower value (*Θ*=0.45) and with the Ionian rivers showing the lowest value (*Θ*=0.43). This data confirm what we noticed by the analysis of the river long profiles, in particular the Tyrrhenian rivers have a more evident concave-up shape and the Ionian rivers the less evident concave-up shape. The clear concave up shape of the Tyrrhenian rivers can be related to a more enhanced uplift on the Adriatic and Ionian slopes than on the Tyrrhenian slope. If we consider the Ks (steepness index) values, we suggest that in a geological setting such as the Southern Apennines, that is characterized by important lithological variations also in very close areas, the Ks index seems to reflect such variations more than recent rock uplift*

The geomorphological, morphometrical and sedimentological analysis of the Noce-Sirino-Alpi-Sant'Arcangelo transect allowed the individuation of two low relief landforms which are located on the western sector of the Sant'Arcangelo basin (700-900m a.s.l.) and in the area between the north side of Mt. Sirino, Mt. Raparo and Mt. Alpi (1200-1400m a.s.l.). The lowest surface (700-900m a.s.l.) corresponds to the eroded depositional surface of the Serracorneta Conglomerate, so it is temporally constrained at about 0.6Ma. The morphological relationships among this lower paleosurface and the highest one are not clear, we can anyway affirm that it is recognized in the area north of the Mt. Sirino and it involves both carbonates units than Lagonegro Units, so its modelling took place after the exhumation of the Mt. Sirino ended and so, considering the data we are going to talk about soon, it could temporally constrained in the Middle-Late Lower Pleistocene, and in particular between 1.5-0.6Ma.

The field analysis let us to recognize the oldest units of the Qquaternary filling of the Sant'Arcangelo basin that contains clasts of the Lagonegro Units coming from the Mt. Sirino area: this unit is the subsynthem A2a (Benvenuti et al., 2006) which should be not older than 1.5Ma, so this means that at this time the Mt. Sirino was already a morphostructural highs that was experiencing erosion. This data agrees with the thermochronological analysis, which suggested that the rock exhumation of the Mt. Sirino started since 2.5Ma, and it has allowed us to give a lower temporal limit to the formation of the highest paleosurface.

The analysis of the "map of the slope of the 1^{st} *order channels", carried out within the Sant'Arcangelo basin, suggests that the area comprised between the Serrapotamo and the Sarmento* *river shows the highest values: these high slope values could be related to a more enhanced uplift that this area has experienced respect to the rest of the Sant'Arcangelo basin. If we combine this data with the uplift data obtained by the analysis of the marine terraces on the Ionian coast (Amato, 2000), we have that the southwestern portion of the Sant'Arcangelo basin seems to be aligned with the southernmost Ionian coast, that is the portion of the Ionian coast which has experienced a more enhanced uplift: this data could suggest a connection between these two sectors, highlighting the presence of this NW-SE oriented portion of the Southern Apennines that has been strongly uplifted.*

The analysis of the river terraces inside the Sinni valley has allowed the individuation of 7 orders of river terraces. The highest order, the 7th, doesn't correspond to a real river terrace but it corresponds with the eroded depositional surface of the Serracorneta Conglomerates, whose age is of about 0.6Ma (Benvenuti et al., 2006). To date the lowest terraces we can try to correlate them with the dated marine terraces on the Ionian coast (Amato, 2000), this analysis let us to propose a late Upper Pleistocene for the 1st order terraces of the Sinni valley Considering the age of the highest river terraces and the actual elevation of the Sinni valley it is also possible to establish an incision rate of about 1mm/yr: the incision rate is always greater or equal to the uplift rate, so we can say that the uplift rate of the Sinni valley since 0.6Ma doesn't exceed 1mm/yr. This uplift rate agrees with the uplift rate that have been proposed by Amato (2000) for the marine terraces on the Ionian coast, where the author proposed an uplift rate comprised between 0.3-1.6mm/yr.

The analysis of the Noce valley river terraces has allowed the grouping of the several mapped fluvial terraces into three main orders: pre-lake, syn-lake and post-lake terraces. There are no absolute date available to date the lake time, so the age of the syn-lake terraces has been obtained using methods of relative chronology, by trying to correlate such terraces with dated marine terraces on the Tyrrhenian coast at the mouth of the Noce river: an Emilian-Sicilian age is proposed for the highest marine terraces at 170m and 140m a.s.l., while a Middle Pleistocene age is proposed for the 80m a.s.l. marine terrace. The oldest marine terraces are extended inside the Noce valley, so it means that at that time the Noce valley was already individuated. In addiction to this we have to consider that, on the basis of morphometrical considerations, such marine terraces are correlable with the river terraces at about 200m a.s.l. individuated in locality Feliceta, inside the Noce valley, and that are referred to the post-lake river terraces. Another important issue is given by the presence of Lagonegro clasts into this marine deposits and, considering that the only area from which these clasts could come from is Mt. Sirino, this data suggests that at the time of the formation of the oldest marine terraces (about 1Ma), Mt. Sirino was already experiencing erosion, so it was very close to the actual morphostructural setting.

The combination of the sedimentological data of the SAnt'Arcagenlo basin and the analysis of the Noce river terraces allowed us to affirm that about 1.5-1Ma Mt. Sirino was already a morphological high which was experiencing erosion, so it means that the rock exhumation processes was finished: the comparison of these data with the thermochronological data suggest that in the period between 2.5Ma and 1.5-1Ma Mt. Sirino has experienced an enhanced rock exhumation that has brought it from an initial situation where it was covered by about 4km of rocks (2.5Ma) to a final situation where it outcrops on the Earth surface and it was subject to the exogenic processes (1.5-1Ma).

This study has highlighted the importance of the morphotectonic approach in the reconstruction of the tectonic events occurred either at a regional scale or at a local scale. In particular, the numerical analysis of digital topographic data has been very useful to the large scale characterization of the Southern Apennines chain landscape. Furthermore, the integration of data provided by the digital analysis technique (e.g. swath profiles, river long profiles and the derived metrics), with the data obtained through the "classical" geomorphological approach, based on morphostructural and morphostratigraphical analyses, has provided new constraints to the reconstruction of the vertical motions which affected the entire chain during the Quaternary.

The main results of this study can be summarized as follows:

- *long profiles, elevation of the valley bottoms and the minimum elevation map show that the outer portion of the Southern Apennines (Adriatic and Ionian slopes) has been uplifted more recently and with higher rates than its inner side (Tyrrhenian slope). These data agree with data provided by the analysis of the shorelines, marine terraces and coastal deposits observed on the Ionian belt (Amato, 2000) and the Tyrrhenian margin (Romano, 1992; Caiazzo et al., 2006), which indicate that the Ionian flank has experienced larger uplift, since the Middle Pleistocene, than the Tyrrhenian flank;*
- *the Ionian rivers show a very steep long profile when they flow into the Sant'Arcangelo basin. This suggests that the post-orogenic uplift recognized by the marine terraces in the foredeep affected also the outer portion of the chain, involving at least the Sant'Arcangelo area;*
- *by the comparison of the Agri and the Sinni long profile, by the map of the gradient of the first order channel, and by the Ks values (which are higher on the southern portion of the Sant'Arcangelo basin and that decrease moving towards its northern portion) it appears that the uplift in the Sant'Arcangelo area follows a N-S trend. However, further studies are necessary to discern about the reason of such different uplift;*
- *as regards to the Middle Pleistocene to Present uplift trend, the above observations indicate that the uplift increases towards the west, probably reaching the chain axis. Coeval uplift in the Tyrrhenian margin (as estimated by elevation of Middle to Late Pleistocene marine terraces shorelines; Romano, 1992; Caiazzo et al., 2006; Filocamo, 2006) was much lower, not exceeding about 100 m. These evidences suggest that the uplift trend of the outer flank of the chain is not recognizable in the whole orogen. The western boundary of the more rapidly uplifting belt can be tentatively located in correspondence to the deep-seated normal faults that have formed the several Quaternary intramontane basins;*
- *the stronger post-orogenic uplift occurred on the outer side of the chain since the Middle Pleistocene has determined a minor ability of the Adriatic and Ionian rivers (which experienced a continuous downcutting) to compete with the Tyrrhenian rivers. This fact is enhanced by the comparison of the valley bottoms, which are higher for the rivers flowing on the outer flank than for the rivers flowing on the inner flank of the chain. This has probably contributed, together with regressive river erosion due to the extensional tectonics on the Tyrrhenian margin (see sec. 3.5), in the decoupling between the maximum elevation line and the main divide, which is one of the peculiar features of the Southern Apennines chain;*
- *the combination of the field analysis together with the morphological and morphometrical analysis of the Noce-Sirino-Alpi-Sant'Arcangelo transect allowed us to affirm that during the late Lower Pleistocene Mt. Sirino was already a morphological high which was experiencing erosion, so it means that the rock exhumation processes was finished;*
- *this data is confirmed by the analysis of the river terraces of the Noce valley: the lacustrine conditions have been dated (by methods of relative chronology on the basis of the morphological relationships among the fluvial terraces of the Noce valley and dated marine terraces on the Tyrrhenian coast close to the Noce mouth) to the middle Lower Pleistocene, and the recognition of Lagonegro clasts inside the oldest marine deposits (Lower Pleistocene) suggests that at that time there was an active drainage from Mt. Sirino to the south, and so Mt. Sirino was already a morphological high subject to the erosional processes and able to produce debris, and the lake didn't exist anymore;*

- *in addiction to this, we have to consider that since its exhumation, Mt. Sirino corresponds to the location of the Apennine divide, representing one of the few portion of the Southern Apennines where there is a coincidence between the maximum elevation line and the divide location. This situation is partly recognized also in Monti Picentini area, where the two lines (divide and maximum elevation lines) are very close. The Sirino and the Picentini ridge are two areas that have experienced enhanced uplift in recent times: this data suggest that such uplift has locally not allowed the retreat of the divide towards the outer portion of the chain;*
- *the concavity index, at a regional scale of investigation, is a useful tool in the comparison of rivers of the same hierarchic order, we cannot compare the concavity of the main trunks (such as it could be the Voltunro river) with that one of a small tributary (such as it could be the Vandra river), because there are other local parameters (drainage areas, discharge, climate, lithology) that have a strong influence on the concavity too. The Ks index is, in the same way, not very useful to discern among a lithological and tectonic control at a regional scale: anyway, if we use it for detailed analysis, we can see how the Ks peaks correspond with the location of the knickpoints, so, once we are sure that such knickpoint doesn't show a lithological control, we can interpret it in term of active tectonics (this is the case of the knickpoint in the upper reaches of the Sele and Platano rivers, which are linked to the San Gregorio Magno fault-line, which is a clear active fault). The Ks index, from this point of view, seem to assume the same meaning of the SLI, but the rapidity of the determination of the Ks index and its easy representation on thematic map, let us to prefer it to the SLI;*
- *a final consideration regards the long profile shape again: we can see that all the Southern Apennines rivers are far from the graded profile (we have "false graded profiles" for the Tyrrhenian rivers, and steep long profiles for the Adriatic-Ionian rivers), and this data give us an idea about the time necessary to reach a steady-state condition in the landscape: evidently, time in the order of 10^5 years are not enough long for the river system to reach a dynamic equilibrium among the uplift and the erosion in high erodibility areas. This is also confirmed by the landforms in the Sant'Arcangelo basin and in the foredeep, where it has not yet been reached a landscape with the alternance of crests and valleys (see the presence of several depositional plateau on the regressive conglomerates of Irsina, in the foredeep, and of Serracorneta, in the Sant'Arcangelo basin), which is the pre-condition to have an equilibrium among uplift and the lowering of the crests.*

INTRODUCTION

AIM OF THE PAPER

The main goal of this work is the study of the morphological and morphometrical features of the Southern Apennines thrust belt – foredeep system, carrying out both a large scale and a small scale analyses of areas of high relevance, with the aim to determine new morphological and morphometrical constraints to the reconstruction of the main morphotectonic events that have interested the chain. This type of research has been based on the idea to compare such data with new thermochronological data that have been produced in many areas of the chain (Aldega et al., 2003; Mazzoli et al., 2006; Mazzoli et al., 2008), which highlighted the role of the exhumation processes in the evolution of the thrust belt. The thermochronological data indicate that the exhumation processes started about 10Ma and they have been active since recent time (in the last million years), resulting contemporary to the main morphogenetic events responsible of the actual morphostructural setting of the chain.

The following research has been carried out in the context of the PRIN project "*Analisi della deformazione e dei processi di esumazione tettonica associati a zone di taglio crostali nell'orogene sudappenninico (Analysis of the deformation and of the tectonic exhumation processes connected with crustal shear zones in the Southern Apennines orogen)".*

The Southern Apennines chain formed has a consequence of the Neogene collision of the African (and in particular, the Adria microplate) and Euroasiatic plates, with the subduction of the Adria microplate beneath the Euroasiatic plate. Cello and Mazzoli (1999) distinguished three different stages into the geodynamic history of the Southern Apennines. The first stage is characterized by the oceanic subduction (Late Cretaceous-Oligocene) during which the Liguride accretionary prism was formed. The second stage is the obduction stage, during which the previous oceanic subduction stopped, and that is followed by the onset of accretion of the continental margin (it covers a time interval comprises between the Oligocene-Miocene boundary and the Early Tortonian). The third stage is the collisional to post-collisional stage (Tortonian-Quaternary), and it is related to the rifting and drifting processes as a response to collisional processes involving continental subduction and flexural retreat of the Apulian lithosphere (Malinverno and Ryan, 1986).

The morphostructural setting of the Southern Apennines has been determined by its complex tectonic history (with the occurrence of both thrust faults and normal faults) and by the erosional processes that have sculptured the topography, also considering that the landforms are strongly influenced by the rock type too.

The study of the morphotectonic history of the Southern Apennines has been carried out for a long time, with a progressive growth of the state of knowledge. The first results on this topic where obtained in the '60s-'70s with the "*Progetto Finalizzato Geodinamica-Sottoprogetto Neotettonica*". The morphotectonic evolution of the Southern Apennines was related to three different phases, the first one called "*tettogenesi*" (Upper Miocene-Lower Pliocene) dominated by thrusting tectonics related to the subduction of the Adria microplate beneath the Euroasiatic plate. This compressive dominated phase was considered to be followed by a second phase characterized by a substantial tectonic quiescence. In this interpretation, during the tectonic quiescence, the erosional processes became dominant, leading to the formation of the "*Paleosuperfice Auct.*", a regional scale paleosurface whose remnants were recognized in the whole chain (Bartolini, 1980) and whose age was considered to became younger moving from the inner side of the orogen to the outer side (Brancaccio & Cinque, 1988; Cinque *et alii*, 1981). The third phase was dominated by extensional tectonic processes that dismembered the earlier smooth landscape and determined the current morphostructural setting of the chain.

The proceeding of the researches has shown the limits of such a model, and in particular the temporal distinction between a compressive tectonic phase (*tettogenesi*) and an extensional one is overpassed, because of the individuation of both extensional syn-orogenic tectonic events (opening of the Tyrrhenian basin) and compressive tectonic events coeval to the normal faulting phase (thrusts still active during the Lower Pleistocene). In this normal faulting phase we have to separate two different periods, a first one which started during the Lower Pleistocene and that was responsible of the formation of the peri-Tyrrhenian grabens (Garigliano plain, Campana plain, Sele plain, gulf of Policastro), whit lowering in the order of thousands of meters, and a second one which determined the formation of the intramontane basins (Volturno plain, Vallo di Diano, Val d'Agri etc.). The formation of such intramontane basins is related to the ceasing of the shortening and to the beginning, at Lower Pleistocene/Middle Pleistocene boundary, of an extensional tectonic regime that is still active and that controls the seismicity in the Southern Apennines chain (Hyppolite, 1992; Cinque et al., 1993; Caiazzo et al., 2006). The study of the marine terraces and coastal deposits in the whole chain-foredeep system showed that the uplift on the Tyrrhenian coast is strongly uneven, being conditioned by the development of the horst-graben structures (Brancaccio et al., 1991; Romano, 1992; Caiazzo et al., 2006); on the other side, the outer flank of the Southern Apennines chain and the neighbouring foredeep areas have been interested by tectonic uplift since the Middle Pleistocene (0.6Ma), with the uplift that has been related to the isostatic rebound of the flexured Apulian slab (Amato, 2000). The *Paleosuperfice Auct.* is not anymore considered to testify a unique morphogenetic cycle. The paleosurface remnants widespread across the entire chain have, in fact, been related to landscape evolution stages non coeval at the regional scale (Amato & Cinque, 1999). The post-orogenic uplift is estimated, it results to be greater on the outer portion of the chain and to decrease moving towards the inner side of the orogen, and it has been interpreted as the response to the isostatic rebound of the flexured Apulian slab (Cinque, 1992a; Cinque et al., 1993; Patacca et al., 1987).

In the last years the development of new techniques of analysis has provided new constraints useful to the reconstruction of the morphotectonic history of the Southern Apennines. This techniques are based on thermochronological analysis, and in particular on the Apatite Fission Tracks, the Ur-Th-He series, the Vitrinite Reflectance, the Clay Mineralogy and the Fluid Inclusions. These data, that have been extensively produced in the whole chain, have pointed out the attention on tectonic exhumation processes (we mean by rock exhumation a variation of the position of a rock in relation to the air-topograhy interface), which have determined rock uplift of thousands of meters in the last 2-3Ma (Aldega et al., 2003; Mazzoli et al., 2006; Mazzoli et al., 2008). The individuation of so enhanced vertical and horizontal tectonic motions in recent times has expected to have interacted with the processes responsible of the exogenic modelling of the topography, and they have probably played an important role in the morphotectonic evolution of the chain, leaving their signature in the topography.

The research has been based on large scale geomorphological and morphometrical techniques of analysis, that have been used with the aim to describe the main morphological and morphometrical features of the chain, to compare the features of the Tyrrhenian, Adriatic and Ionian slopes of the Southern Apennines, and to relate these features with the proposed morphotectonic events. The large scale analysis has been accompanied by the small scale analysis of a selected transect namely the Noce-Sirino-Alpi-Sant'Arcangelo transect. This transect has been chosen because of the particular features that make this area one of the most relevant portion of the chain in order to reconstruct the morphotectonic evolution of the Southern Apennines, and in particular, to investigate the role played by the rock exhumation processes in the evolution of the relief. This transect assumes a high relevance because:

- it includes tectonic units which have been exhumed in recent times;
- it preserves a stratigraphical and morpho-stratigraphical record which is almost continuous both temporally (from the Middle Pliocene to the whole Quaternary) and spatially (from the Tyrrhenian to the Adriatic coasts);

- the topography, in this portion of the Southern Apennines, has been only slightly dismembered by the post-orogenic extensional tectonic, and may be considered resulting by the major geodynamic processes (shortening, thrusting, extension and exhumation).

PHASES OF THE WORK

The work has been subdivided into six chapters, that have been written with the idea to initially describe the large scale analysis of the morphological and morphometrical features of the Southern Apennines, and then to move to the small scale analysis of the Noce valley-Mt. Sirino-Mt. Alpi-Sant'Arcangelo basin transect, describing the morphological, morphometrical and field analysis that have been applied in this area.

The first chapter is an introductive chapter where a revision of the literature data regarding the geodynamic, geological and geomorphological settings of the Southern Apennines are discussed, together with the discussion about the thermochronological analysis applied in the whole chain

In the second chapter the morphological and morphometrical methods of investigation followed in this research are described: in a first paragraph the main morphostructural elements of the landscape and their relevance in the morphotectonic reconstruction are discussed, while the following paragraph is based on the description of the type of analysis and the parameters we have to determine when we approach to the morphotectonic analysis of an orogen.

The third chapter is dedicated to the large scale analysis of the topography. The chapter begins with the description of the "*Map of the Morphostructural Units of the Southern Apennines*" and it proceeds with the discussion about the elevation map and its derived maps (the maximum, minimum and medium elevation maps), to move then to the analysis of the topography along five transects oriented perpendicular to the main morphostructural elements of the Southern Apennines and the description and interpretation of five swath profiles created along the previously named transects, to move then to the analysis of the derived relief curves (they have obtained from every swath profile). The chapter ends with a final paragraph where considerations about the divide and maximum elevation line of the Southern Apennines location are exposed.

The fourth chapter is dedicated to the large scale analysis of the river system, in particular the analysis has been focused on the reconstruction of the long profile of the main trunks of the Southern Apennines and some of their main tributaries, and to the determination of same metrics related to the river long profile such as the Stream Gradient Index (SLI, Hack, 1957), the drainage area vs distance graph, and the slope vs area analysis. The latter method is very important in morphotectonic studies because it allows the determination of the concavity (Θ) and steepness (Ks) indexes, that are two indexes that are considered to be sensitive to many parameters, and in particular the concavity index seems to be strongly influenced by the rock type, climate, drainage area, discharge, while the steepness index seems to be strongly influenced by the uplift rate (Whipple & Tucker, 1999; Snyder & alii, 2000; Kirby & Whipple, 2001; Roe & alii, 2002; Duvall & alii, 2004; Spagnolo & Pazzaglia, 2005; Zaprowsky & alii, 2005). The Ks indexes calculated for all the rivers have been then used to create the "*Ks map of the Southern Apennines*" to show how this parameter vary at the scale of the orogen and to verify if a regional trend is present.

The fifth chapter has been dedicated to the detailed analysis of the Noce valley-Mt. Sirino-Mt. Alpi-Sant'Arcangelo basin transect. In the first five paragraphs the reason of the choice of the transect and the geological setting of the Noce valley, the Mt. Sirino, the Mt. Alpi and the Sant'Arcangelo basin are described. The sixth paragraph is dedicated to the exposition of the thermochronological data produced for the Mt. Sirino and the Mt. Alpi, then the chapter moves the discussion to the field analysis of the quaternary filling of the Sant'Arcangelo basin. The following paragraph is dedicated to the morphometrical analysis of the transect. The last two paragraphs are dedicated to the geomorphological analysis of the Noce and the Sinni valleys, in particular with the individuation and mapping of the river terraces which are considered a good proxy to constraints the geomorphological history of the related areas, in particular by the analysis of the alluvial deposits and the determination of the incision rate, and to correlate these data with the exhumation processes involving the Mt. Sirino and the Mt. Alpi and to determine the rate at which such processes have occurred.

In the sixth chapter the discussion about the produced data and the conclusive considerations are exposed.

CHAPTER 1

THE SOUTHERN APENNINES

1.1 GEODYNAMICS OF THE CENTRAL MEDITERRANEAN

The Southern Apennines are located in the central Mediterranean area, that is the youngest portion of the entire Mediterranean basin (Stanley and Wezel, 1985). This portion of the Mediterranean basin is characterized by the occurrence of both compressive and extensional geodynamic settings: the first one are represented by the inherited pre-Neogene Alpine-Betic orogen and by the Apennine chain, while the second one are represented by several V-shaped sub-basins, in particular the Valencia through, the Liguro-Provencal and the Tyrrhenian basins. The lithosphere thickness variations of the entire Mediterranean region let Gueguen et al. (1997) to propose a lithospheric boudinage of this area: they pointed out that the original lithosphere has been thinned to less than 60 km in the basins, while it remains to 65-80 km thick below the continental boudins (Calcagnile and Panza, 1981; Banda and Santanach, 1992; Blundell et al., 1992) (fig. 1.1).

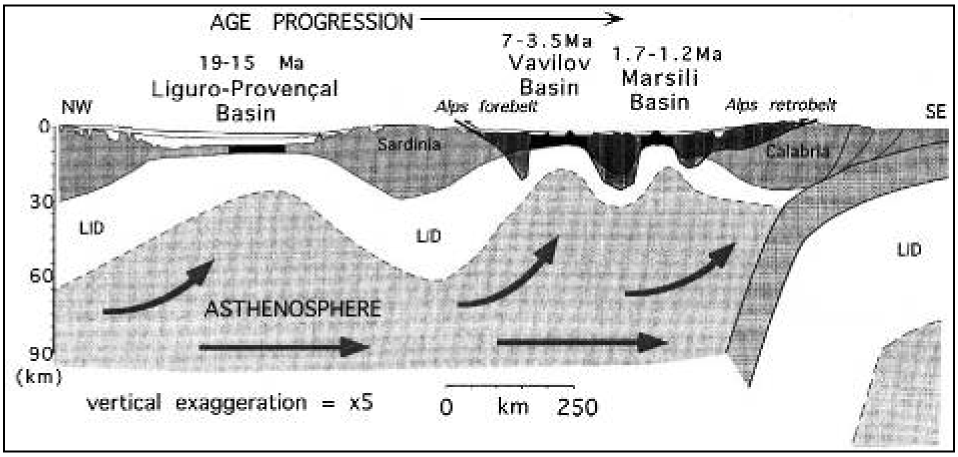


fig. 1.1 = The western Mediterranean consists of several sub-basins progressively opening toward the east, in the hangingwall of the Apennine subduction zone. (from Zito et. al., 2003).

Seismic and gravity data indicate that the crust is thinner than 15 km in correspondence of the sub-basins (the Valencia through, the Alboran sea, the Ligurian sea and the Tyrrhenian sea; Bethoux et al., 1986; Pascal et. al., 1992), whereas the Moho is 25-35 km deep underneath the Balearic promontory and the Corsica-Sardinia block (Egger et al., 1988; Tornè et al., 1992; Fernandez et al., 1995; Gueguen et al., 1997). The boudinage-like shape has been due to jumps in the thinning process and to the rejuvenation of the basins towards E-SE. The wavelength of these Neogene to Quaternary boudins or necks varies in the range of 100 and 400 km: the jumps in the thinning process appear to occur when the difference between the direction of opening of the basins and the direction of extensional stress overpass a critical angle (30°-40°) due to the contemporaneous rotation of blocks. (Gueguen et al., 1997).

Extension in the back arc basin started about 19-15 Ma ago with the opening of the Liguro-Provencal basin (involving the stretching of an Hercynian continental crust). This basin is actually characterized by oceanic crust within the central abyssal plain surrounded by narrow (except the Gulf of Lions) older sedimentary basins. About 15 Myr ago extension shifted east of the Sardinia-Corsica block determining the opening of the actual Tyrrhenian basin. The extension and the opening of the Tyrrhenian basin has proceeded in steps, as it is testified by the individuation of diverse sub-basins (the Vavilov and Marsili basins). A good scheme to explain this geodynamic setting is proposed by Zito et al. (2003) (fig. 1.2).

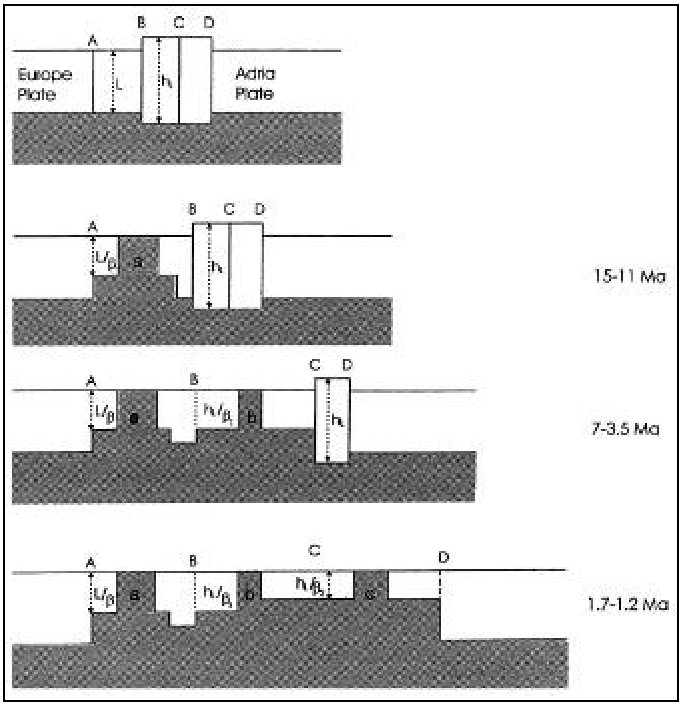


Fig. 1.2 = during Oligocene time, the European and Adriatic plates were sutured by the Alpine orogen giving a thickened lithosphere hL, ideally comprising two sectors BC and CD, to the east of sector AB of the Alpine foreland where the thickness of the plate is L. In the Early Miocene, between 19 and 15 Ma ago, sector AB first stretched by a factor β so that it thinned to L/β. Further stretching caused the laceration of the thinned lithosphere, favouring the passive rising at the surface of an asthenospheric body (a). As a consequence, blocks BC + CD rifted and drifted by [AB · (β - 1) + a]. During Late Miocene – Early Pliocene times (7 and 3.5 Ma ago), sector BC stretched by the factor β_1, and thinned to hL/β_1. At 3.5 Ma ago, further stretching caused laceration of the thinned lithosphere, favouring the passive rising of an asthenospheric body of width b. As a consequence, block CD further drifted and rifted by [BC · (β_1 - 1) + b] (Vavilov basin). During Pleistocene times (1.7 and 1.2 Ma ago), block CD stretched by a factor β_2 and thinned to hL/β_2. At 1.2 Ma ago further stretching caused the laceration and the rising of another asthenospheric body (c). Point D further drifted and rifted by [CD · (β_2 - 1) + c] (Marsili basin). These latter two extensions formed the southern Tyrrhenian Sea basins (modified after Zito et al., 2003).

Faccenna et al. (1997) identified different styles of extension in the central Mediterranean. They distinguished between a single-rift style (Liguro-Provencal basin, characterized by narrow, linear, and localized spreading centres) and a multi-rift style (Tyrrhenian basin, characterized by short lived spreading centres and volcanism distributed over a wide area).

If we just consider the Tyrrhenian-Apennine system (which is the geodynamic setting where the study area is located), we know that the Apennine chain formed as a consequence of the convergence between the European and African plates. The west directed subduction of the Adria plate (that is considered both as a promontory of North Africa, Channell & Horvath, 1976, and as an independent microplate between Europe and Africa, Dercourt et al., 1986) beneath the European plate started in the Oligocene and continued up to the early Pleistocene, being characterized by an eastward migration of the whole system (Zito et al., 2003). The amount of N-S Africa/Europe relative motion was about 135 km in the last 23 Myr, more than five times slower respect to the eastward migration of the Apenninic arc, which migrated eastward about 775 km during the last 23 Myr (Gueguen et al., 1997).

The Apennine thrust front is not homogenous but we can separate it in two sectors, the first one that moves from the Po plain to the central Adriatic sea, and the second one that involves the southern Adriatic sea. The reason of such a separation is due to different rates of eastward migration of the retreating slab, that are more enhanced in the central Adriatic area than in the southern Adriatic area: such a difference has been interpreted as due to the involving of thick continental lithosphere into the subduction of the Southern Apennines (Doglioni et al., 1994, 1996; Gambini and Tozzi, 1996), hindering the rollback of the subducting plate in the Apulian region (Scrocca, 2006). This two sectors are separated by the Tremiti lineament, a W-E strike-slip fault interpreted as the main right-lateral transfer zone between the northern and the southern portions of the subducting Adriatic plate (Scrocca, 2006) (fig. 1.3).

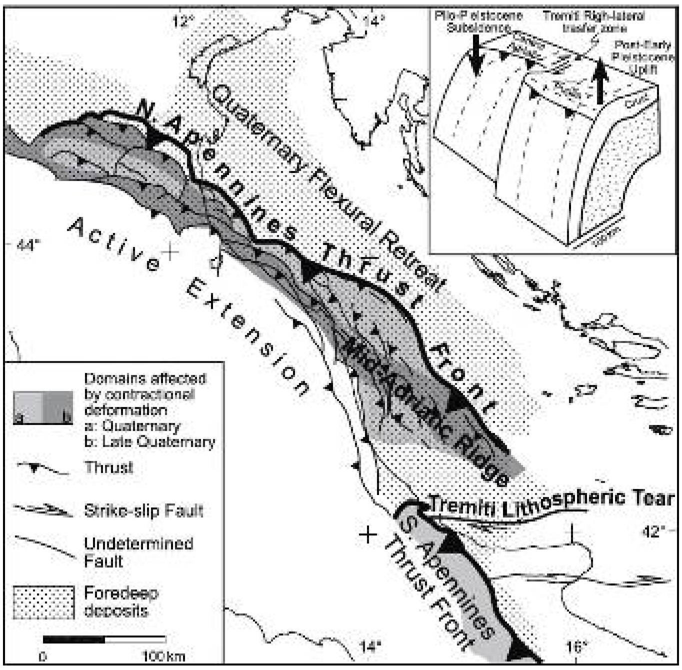


Fig. 1.3 = Tectonic scheme of the Adriatic domain and cartoon showing the 3D slab geometry of the subducting Apulo-Adriatic plate (modified after Doglioni et al., 1994). The Apennine thrust front is located on the NE side of the Mid-Adriatic Ridge. The differential slab retreat between the central and southern sectors of the subducting Adriatic plate has been accompanied by a different tectonic evolution of the related segments of the accretionary prism that ended up with a segmentation of the Apennine thrust front (from Scrocca et al., 2006).

The Tyrrhenian sea is considered the back arc basin of the orogenic system represented by the Apennine fold and thrust belt. The V-shape of the Tyrrhenian sea is centred in its north side which is the narrower sector of the Tyrrhenian basin, while the southern sector of the Tyrrhenian basin is the widest. This two sectors show different styles of extension: in particular in the northern side both magmatism and the locus of the extension progressively shifted away from the rift axis towards ENE, interesting the Northern Apennines chain and inhibiting continental break-up and drifting. In the southern side, the migration of the magmatism and the locus of the extension occurred inside the basin inducing continental break-up, oceanic-type spreading, drifting and arching of the Calabrian margin (Faccenna et al., 1997). This asymmetry is also interpreted by Faccenna et al. (1997) as due to different subduction regimes: in the northern Tyrrhenian basin the subducting lithosphere was continental since, at least, the Oligocene, determining a roll-back velocity and back-arc extension velocity of about 2 cm yr^{-1}; in the southern Tyrrhenian basin the subducting lithosphere remains oceanic until now, so that the roll-back velocity and the back-arc extension velocity are about 6 cm yr^{-1}, 3 times faster than in the northern sector (Dercourt et al., 1986; Malinverno and Ryan, 1986; Bigi et al., 1989; Sartori, 1989; Patacca et al., 1990; Royden, 1993; Serri et al., 1993; Kastens et al., 1998; Savelli, 2001).

The timing of the extension decreases moving from west (Sardinia-Corsica) to the east (Calabria), as it is shown by the age of the volcanic rocks individuated in the previously named sub-basins. In particular, the Vavilov basin has an age of about 4.1 Ma (with MORB type volcanism, Sartori 1989), whereas the Marsili basin has an age of about 1.8 Ma (with calcalkaline volcanism, Beccaluva et al., 1994; Kastens et al., 1988). In correspondence of these sub-basins, they have been recognized high values of heat flow, which are the highest of the entire Tyrrhenian region (>200 mW m^{-2}) (Zito et al., 2003) (fig. 1.4).

Zito et al. (2003) don't recognize a correlation between stretching of the Tyrrhenian sea (it decreases from south to the north) and heat flow (high values in the northern and southern sectors of the Tyrrhenian sea, and lowest value in the central sector). They however suggest a correlation between active magmatism and heat flow, with the magmatism directly correlated to the rate of subduction of the slab in the Apennines. In fact, as they pointed out, the most active subducting part of the Apennines is in the southern Tyrrhenian-Calabria area, where the foreland is the oceanic Ionian crust while, to the north, the foreland is almost locked by the thick lithosphere of the Puglia area, which is barely subducting and buckled (Doglioni et al., 1994). This area of slow, if any, subduction is recorded in the back-arc basin where extension is minimal, there is low or absent magmatic activity and low heat flow. In the central-northern part of the Apennines the subduction is more rapid, generating seismicity and latent magmatism in Latium and Tuscany, and relatively high heat flow (Mongelli and Zito, 2000 and reference therein).

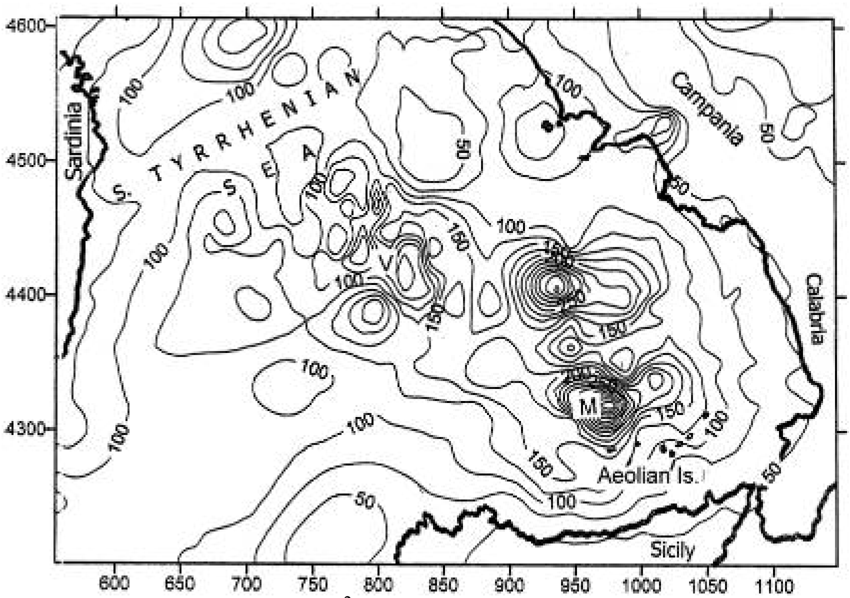


Fig. 1.4 = contour map of the heat flow (mW m^{-2}) of the Tyrrhenian sea, the highest values correspond with the Vavilov and Marsili sub-basins (from Zito et al., 2003).

Several authors have tried to determine the geometry of the subducting slab by geophysical methods. Selvaggi and Chiarabba (1995) have described a continuous slab having a gentle slope down to 50 km of depth, with an abrupt change in correspondence of the hinge of the subducting plate, where the slope reaches 70°, thereafter remaining constant down to 500 km (Zito et al., 2003).

Mostardini and Merlini (1986) applied geophysical methodologies to determine the type of magnetic and gravimetric fields characterizing the Southern Apennines. The main magnetic anomalies are located in correspondence of the main volcanoes (Roccamonfina, Vesuvius and Vulture volcanoes: these are narrow and intense magnetic anomalies), and in the areas of Campobasso, the Salento region, the Adriatic offshore and the area between Potenza and the Ionian offshore (Sant'Arcangelo basin, these anomalies are wider and less intense then the previous one). The study of these anomalies let the authors to reconstruct the magnetic basement (it doesn't always correspond with the geological basement, and it is defined as the lower limit of high magnetic susceptibility bodies, under which it is not possible to identify other sedimentary units): the magnetic basement has a general decreasing trend which moves from the Adriatic coast (9km b.s.l.) towards the Tyrrhenian coast (13km b.s.l.), with a little increase in correspondence of the volcanic areas individuated close to the Tyrrhenian margin(12km b.s.l.). The regular trend of the magnetic basement is interrupted in the area between Potenza and the Sant'Arcangelo basin, where it has been recognized an important positive structure NE-SW oriented, with the basement uplifted until 8.5km b.s.l., and that can be interpreted either as a magnetic differentiation or as a portion of basement uplifted by faults (fig. 1.5).

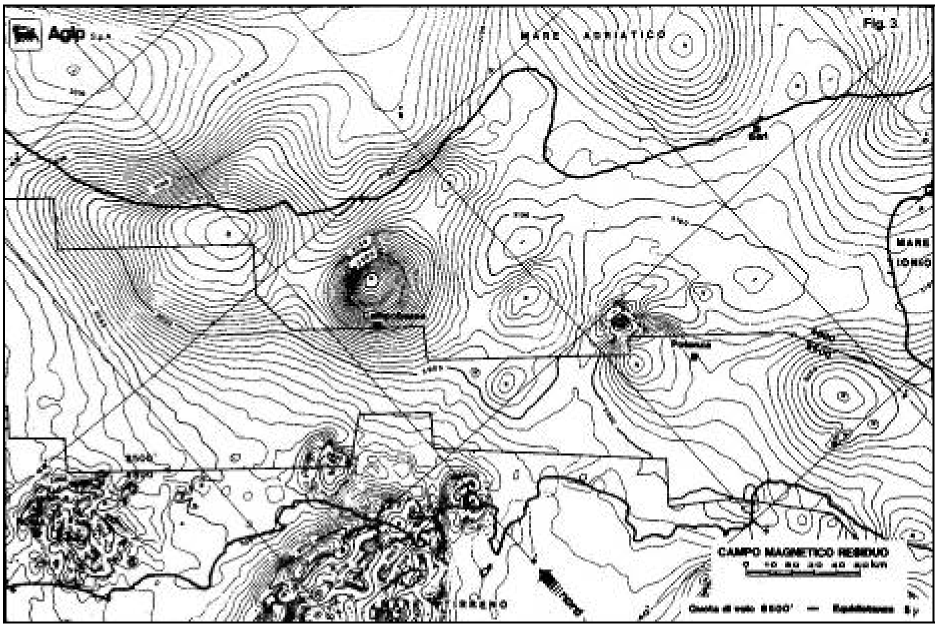


Fig. 1.5 = residual magnetic field anomalies of the Central and Southern Apennines obtained by the subtraction of the regional field (that in Italy is characterized by a gradient of +3,232γ/km from South to North and of +0,726 γ/km from West to the East) from the real values (from Mostardini and Merlini, 1986).

The gravimetrical studies carried out by Mostardini and Merlini (1986) allowed the recognition of a wide (about 100km) and intense (70mgal) negative Bouguer anomalies in the Southern Apennines, with an apennine orientation. This negative anomaly is maximum in correspondence of the chain s.s., and tends to increase towards the Adriatic and Tyrrhenian coast, with a mean gradient of about 1.5mgal/km: it connects the Abruzzo region to the north with the Taranto gulf to the south, and its minimum is located in correspondence of the Molise basin and the Sant'Arcangelo basin (fig. 1.6).

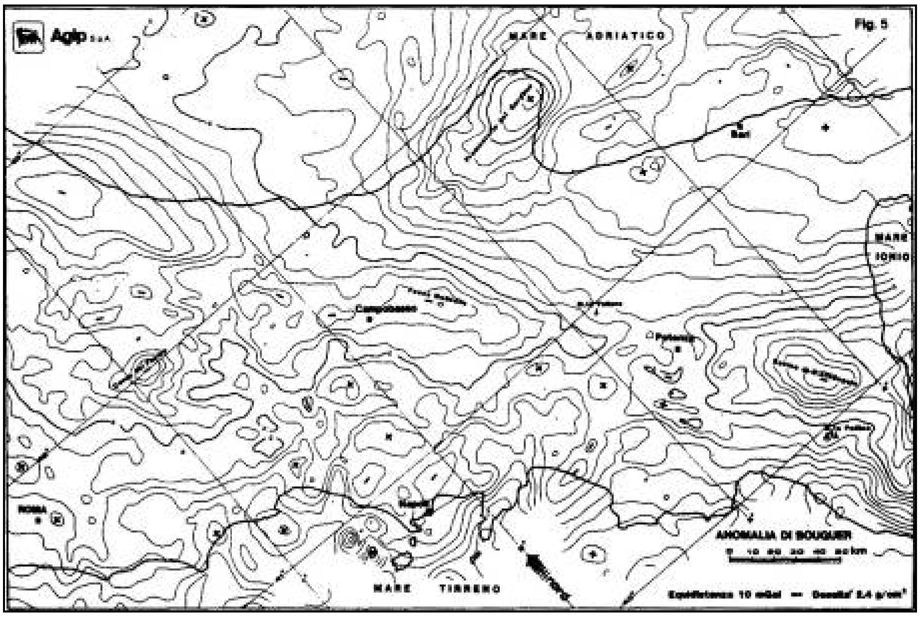


Fig 1.6 = map of the Bouguer anomalies of the Central and Southern Apennines, it has been calculated using as a reference value 2,4g/cm^3, that is considered to be the most representative value of the chain, considering its strong lithological heterogeneity (from Mostardini and Merlini, 1986).

There is also an intense Bouguer anomaly located in correspondence of the Tyrrhenian sea (<250 mgal): Cella et al. (1998) interpreted it as the indicators of a very thin crust in this area. This data is confirmed by the map of depth of the Moho (Nicolich, 1989; Nicolich and Dal Piaz, 1991), showing values lower than 15-20 km in the batyal plain, with two minima of 10 km centred on the Vavilov and Marsili basins, that are also the areas with the highest heat flow (Zito et al., 2003) (fig. 1.7).

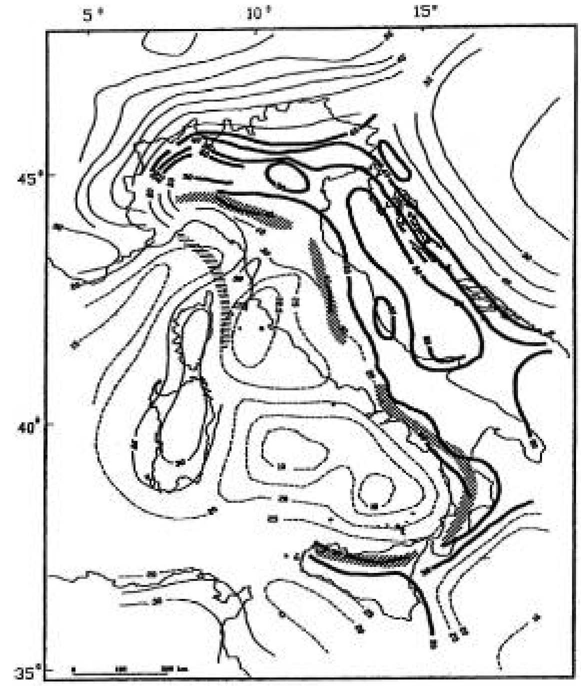


Fig. 1.7 = Moho isobaths (km) in Italy and surrounding areas. Adriatic plate, thick lines; European plate, fine lines; stretched continental crust, dashed lines (from Zito et al., 2003)

If we consider the distribution of topography and gravity in the Southern Apennine, D'Agostino and McKenzie (1999) show that, at short wavelengths, topography and gravity anomalies are supported by elastic stresses within the lithosphere, while at long wavelengths the topography and gravity anomalies are dynamically supported and are the surface expression of convective circulation in the mantle: in particular they pointed out that areas overlying mantle upwelling are usually characterized by positive gravity and topographic anomalies, and by melt generation and extension.

1.2 GEOLOGY OF THE SOUTHERN APENNINES

1.2.1 The fold and thrust belt

The Southern Apennines is a fold and thrust belt builds up as a consequence of the collision of the African plate (and in particular the Adria microplate) and the Euroasiatic plate in Neogene time. The chain is constituted by the justapposition of four main tectonic units: the uppermost unit is represented by the Liguride complex, a Jurassic-early Miocene set of heterogeneous units that are the accretionary complex of the former subduction zone (Catalano et al., 2004); underneath the Liguride complex there is the Apennine platform, a Triassic-Miocene shallow water carbonates interpreted by some author as a Bahamas-like set of carbonate banks (Cello and Mazzoli, 1999; Ciarapica and Passeri, 2005); structurally below the Apennine platform we find the Lagonegro complex (that represents the filling of the deep-water basin separating the Apennine and the Apulia platforms), that can be separated in two different sequences, a lower one made of Permian rift basin facies to Early Triassic deep water facies (Mostardini and Merlini, 1986), and an upper one made of Late Cretaceous deep-water facies to Miocene terrigenous flysch (Steckler et al., 2008); the lowermost complex is represented by the Apulia platform, which is composed by 5 to 7 km of shallow water carbonates and dolomites overlying more than 1 km of Permian to Late Triassic clastics deposits (Steckler et al., 2008). In the middle between the Lagonegro units and the Apulian units we find a melange zone up to a several hundred meters thick: it consists mainly of intensely deformed and overpressured deepwater mudstones and siltstones of Miocene to Lower Pliocene age, including blocks of material derived from the overlying allochthonous (Mazzoli et al., 2008). The structure of the chain is then completed by the presence of Miocene flyschs deposited on top of the carbonates of the Apulia platform and diffuse normal faults on the Tyrrhenian flank which control the formation of several peri-tyrrhenian grabens (the Campana plain, the Sele plain, the Policastro gulf) and intramontane basins (such as the Volturno valley, the Alife plain, the Vallo di Diano basin) filled up by quaternary continental deposits.

One of the main problems about the paleogeographical reconstruction of the Southern Apennines is related to the number of carbonate platforms that are represented in the sedimentary pile. Selli (1962) and Accordi (1966) thought that there was just one carbonate platform connecting the non-tectonized apulian foreland and the tectonized Apennine chain: in this reconstruction, the Lagonegro basin was considered allochthonous, coming from the internal Tyrrhenian area (Mostardini and Merlini, 1986). During the 70's, the geologist of the Neapolitan School (D'Argenio, Ippolito, Pescatore, Scandone, Sgrosso) hypothesized the presence of three different platforms, the Campano-Lucana or internal, the Abruzzese-Campana or intermediate and the Apulo-Garganica or external, respectively separated by the Lagonegro basin and by the Molise basin: the intermediate platform was considered to outcrop north of the Matese massif and, to the south, on the Mt. Alpi, that was interpreted as a tectonic window of the Lagonegrese succession. With this interpretation the Lagonegro basin was considered to be autochthonous and to extend to the north beneath the sedimentary filling of the Latina valley, an area where the internal and intermediate platforms were considered to be in contact. In the same time, most of the author (Pieri, 1966; Ogniben, 1969; Vezzani, 1973; Carbone, 1984; Mostardini, 1986) carried out the idea of the presence of just two platforms, the Apennine or Panormide platform and the Apulian platform, considering not clearly demonstrated the differences between the internal and the intermediate platform of the neapolitan geologist. Sgrosso (1983) had hypothesized the occurrence of a fourth platform (the Abruzzese-Molisana platform), separating the Molise basin in two portion, and that should outcrop in the Maiella massif (Mostardini and Merlini, 1986).

Mostardini and Merlini (1986) did a detailed stratigraphical and tectonic analysis of the Southern Apennines, thanks to the use of wells data and seismic profiles. They distinguished the following paleodomain: the Tyrrhenian basin, the Apennine platform, the Lagonegrese-Molisano basin, the inner Apulia platform, the Apulia basin and the outer Apulian platform (fig. 1.8).

The Tyrrhenian basin is not well known because of the lacking of studies regarding it, what is sure is its location. It was, in fact, located west of the Apennine platform, as it is testified by the presence of slope facies on the west margin of the Apennine platform. This is the area of provenance of the Liguridi units (they comprise both the metamorphic sequence of the Frido unit and the terrigenous units of the Cilento Flysch).

The Apennine platform comprises the carbonatic sequences (Trias - Lower Miocene) cropping out on the Apennine chain, except that in the areas of the Maiella massif. This carbonatic sequences comprises all the facies that is possible to recognize in a platform environment and that are always juxtaposed to the Lagonegro basin domain. This unit comprises the Mt Alpi, that in this interpretation is considered a klippe of the Apennine platform such as the close Mt. Raparo.

The Lagonegrese-Molisano basin comprises the Lagonegro succession, the Molise flyschs, the Sicilide units and other flyschs untis. It is possible to distinguish a lower succession (Middle Trias - Lower Cretaceous, made by a calcareous-siliceous-marly succession cropping out in the southern portion of the Southern Apennines, and locally in the Benevento and Mt. Forcuso areas) and an upper succession (Upper Cretaceous - Lower Miocene, made by the Molisan flysch, the Lagonegro Flyschs, such as the Flysch Rosso, the Pecorone unit and the Toppo Camposanto unit, and the Sicilide complex). In the palinspastic reconstruction the author did, the Lagonegro Basin should be 200km wide and extended from the Molise region to the north until the Ionian offshore to the south.

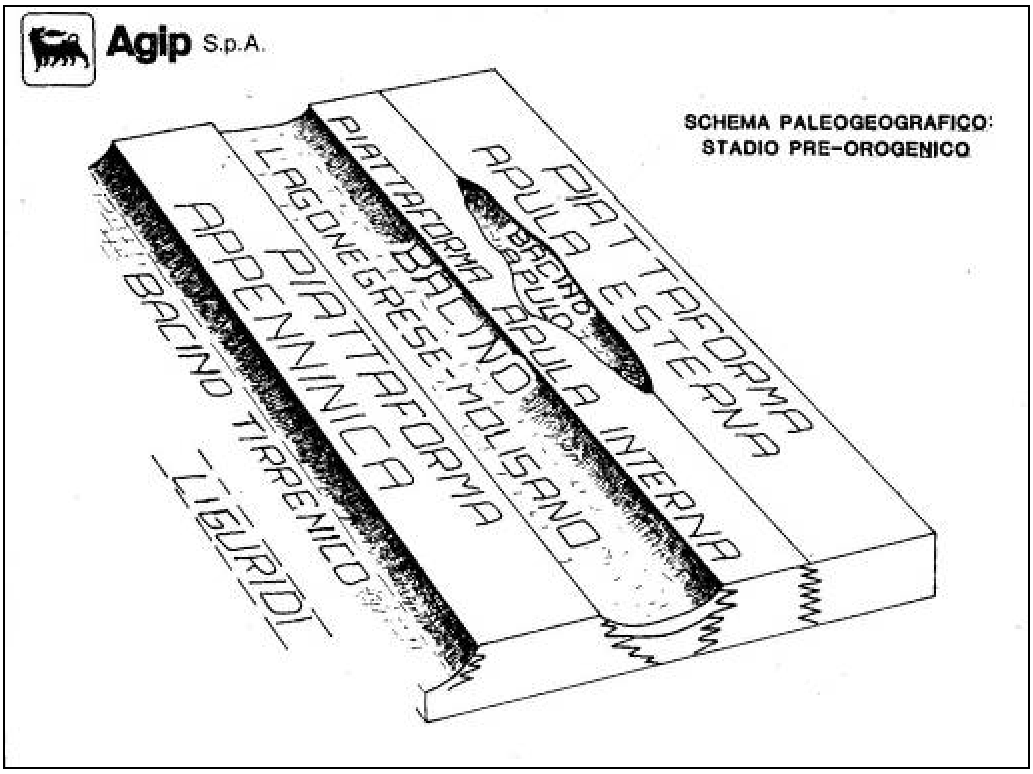


Fig. 1.8 = pre-orogenic reconstruction of the Southern Apennines (from Mostardini and Merlini, 1986).

The Inner Apulian platform is recognized by seismic profiles. It has been distinguished from the Outer Apulian platform because it is strongly deformed, forming a series of nappes with an Adriatic vergence. In addiction to this, it is separated from the Outer Apulian platform by the Apulian basin, which is located north of the Vulture volcano. The sedimentary succession is made by a Cretaceous sequence with, at the top, thin Paleogene and Miocene layers, covered either by the Lower Pliocene or by internal units of the Lagonegrese-Molisano basin. This unit extends from the Ionian offshore to the south until the Maiella unit to the north (it represents the Outer Apulian platform).

The Apulian basin extends north of the Vulture volcano until the Biferno river valley, an area about 100km long, it has been individuated by seismic profiles because it interrupts the continuity of the Apulian platform s.l.. The palinspastic reconstruction gives a maximum width of about 50-70km to this basin. This basin should be Jurassic in age, so it is younger of the Late Triassic Lagonegro basin.

The Outer Apulian platform represents the undeformed foreland of the Apenninic orogenic system. It is made by a carbonatic sequence covered by thin Tertiary layers. Transitional to slope facies have been recognized on its western margin, where the Apennine units (here represented by the Lagonegrese-Molisano basin, the Inner Apulian platform and the Apulian basin) juxtaposed to the Outer Apulian platform sequence. It is mainly interested by normal faulting, that is one of the typical features that allows the distinction between this platform and the Inner Apulian platform, also if some thrust faults is hypothesized in the area of the Sant'Arcangelo basin (individuated by the analysis of seismic profiles) because of the presence of a positive structure in the basement deduced by the magnetic field reconstruction the author did.

In fig. 1.9 the geodynamic setting of the Southern Apennines proposed by Mostardini and Merlini (1986) is shown.

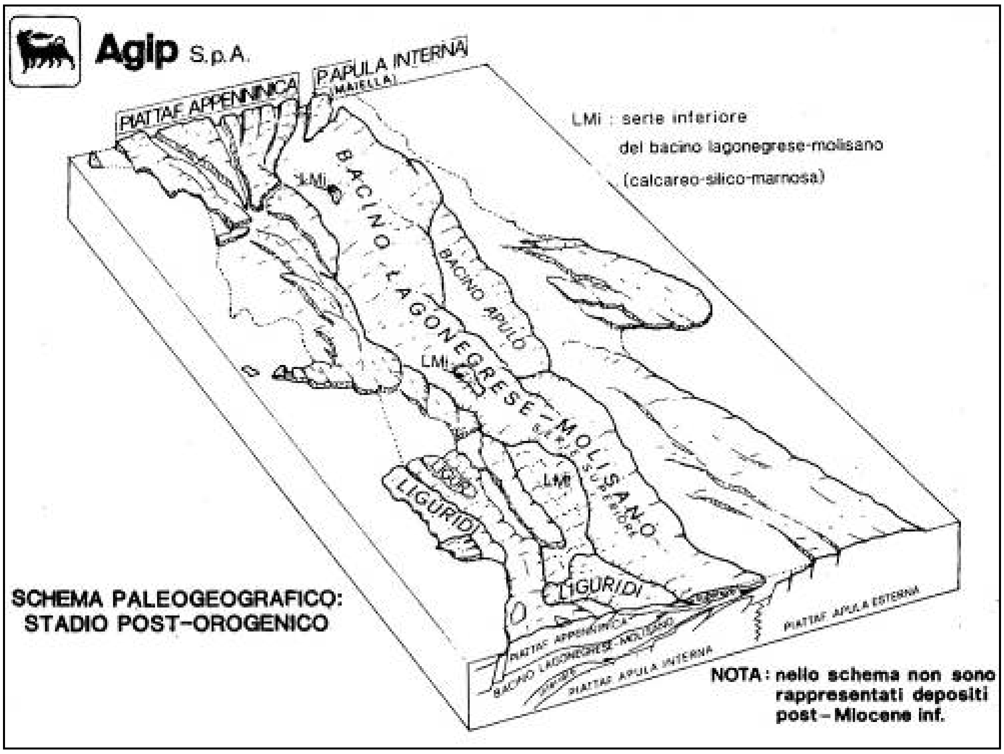


Fig. 1.9 = Southern Apennines geodynamic setting (from Mostardini and Merlini, 1986).

If we consider the tectonic history of the Apennine chain, the occurrence of either thick-skinned or thin-skinned structural style of shortening has been long debated: in the first case, the thrusting involves also the basement (the metamorphic core underlying the Apulian unit), while in the second case the thrusting is limited to the sedimentary pile covering the basement (fig. 1.10).

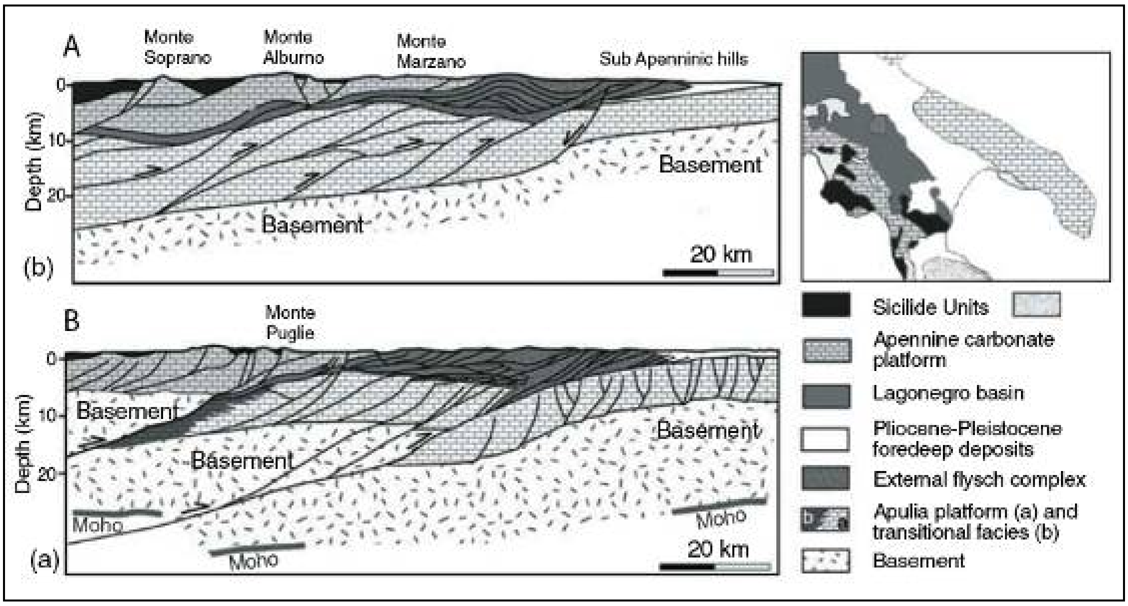


Fig. 1.10 = comparison of the thin-skinned (A, Mazzoli et al., 2000) and thick-skinned (B, Menardi-Noguera and Rea, 2000) models (from Steckler et al., 2008).

Subsurface data recently developed have provided evidence that deep-seated reverse faulting within the Apulian Platform carbonates is characterized by steep reverse faults, a lack of thrust flats and involvement of the underlying basement, emphasizing the idea of a thick-skinned structural style (Mazzoli et al., 2008). In particular, Shiner et al. (2004), thanks to cross-section balancing and restoration of the Apulian Platform carbonates based on high-quality seismic data and well logs, proposed an inversion tectonic models involving reactivation of the Permo-Triassic basement normal faults. Therefore, in Late Pliocene times a switch from thin-skinned to thick-skinned shortening style has occurred in the Southern Apennines, as the Apulian carbonates (and the underlying thick continental lithosphere) were shortened (Mazzoli et al., 2008).

The amounts of shortening differs between the Apennine units and the Apulian units. Butler et al. (2004) identified an horizontal shortening of about 14km for the Apulian Platform units and an horizontal shortening of about 50km for the allochthonous units: because the Apennine shortening exceeds the total shortening that could be transmitted by the Apulian carbonates to the upper units, it means that the total shortening the Apennine units have experienced is linked to the additional occurrence of other processes. In particular, Mazzoli et al. (2008), in their reconstruction of the tectonic evolution of the Southern Apennines, propose the occurrence of large gravitational collapses on the inner side of the chain that have enhanced the eastward migration of the Apennine units, gravitational collapses that the author think may be related to the presence of structural highs (large antiforms and pop-ups) within the Apulian Platform, or to an increase of the wedge slope, or to the tilting of the weak layer overlying the Apulian carbonates (the melange zone). The authors also interpreted as gravitational collapses the large and fast pulses of forward displacement of the allochthonous documented by Patacca and Scandone (2001) at 3.70-3.30 and 1.83-1.5 Ma.

Cello and Mazzoli (1999) recognized four different phases of deformation in the tectonic history of the Southern Apennines, on the base of their structural data compared with structural information regarding both the Liguride complex, the Apennine platform and basin units, and the foredeep sequences cropping out in the southern portions of the chain. The four phases (respectively named D1 to D4) does not correspond with the tectonic history of every single tectonic unit, and only the oldest units (Liguride complex) have experienced all the four phases of deformation (fig. 1.11).

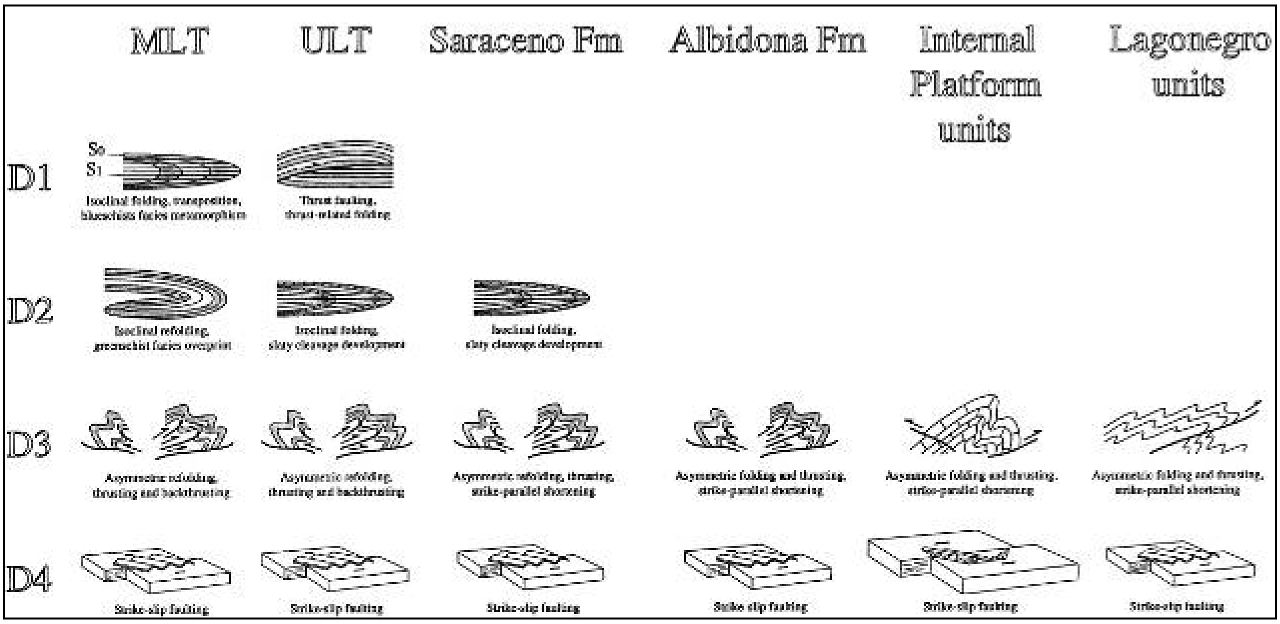


Fig. 1. 11 = Correlation of structural assemblages and related regional deformation phases observed in the main tectono-stratigraphic units of the Southern Apennines (from Cello and Mazzoli, 1999).

The first phase, D1, is recorded only in the Liguride complex, with a difference between the metamorphosed and unmetamorphosed units, that are characterized by different pressure-temperature conditions. In general, in this phase there is the development of NW trending, tight to isoclinal intrafolial folds affecting the original layering, a pervasive schistosity affecting mainly metasedimentary cover rocks, a mostly SSW plunging mineral lineation, millimetre-thick veins cutting at a high angle across the schistosity and oriented roughly perpendicular to the main stretching lineation, NE dipping shear bands, deflecting the main schistosity, indicating a general top-to-the-NE sense of shear.

The second phase of deformation, D2, involves the metamorphic Liguride complex determining the occurrence of mostly NW trending, tight to isoclinal folds refolding the D1 isoclines and the related schistosity. In the unmetamorphosed Liguride complex, the D2 phase determines the development of mostly NW trending, tight to isoclinal folds, folding D1-related thrust surfaces. This phase also involves the lowermost part of the synorogenic deposits (Saraceno formation) with the development of isoclinal folds and slaty cleavage.

The third phase of deformation, D3, is individuated in the Liguride complex by mostly NW trending, open to tight folds with variably inclined axial surfaces and a roughly NW trending crenulation lineation with a discontinuous crenulation cleavage mostly confined to pelitic succession. This structures also affect the underlying Saraceno and Albidona formations, where NE and SW vergent thrusts and associated asymmetric, open to tight folds and kink bands occur (refolding D2-related structures in the Saraceno formation). In the carbonates of the internal platform, main folds are generally associated with NE-vergent thrusts and subordinate backthrusts: they range from map-scale to outcrop-scale and mainly consist of upright to recumbent, mostly asymmetric and double-plunging folds showing NE or subordinate SW vergence.

The fourth phase of deformation, D4, include both gentle folds involving the Upper Pliocene-Pleistocene deposits and brittle features consisting of faults, cataclastic zones, and related minor fractures and extension veins affecting all the tectono-stratigraphic units cropping out in the Calabria-Lucania borderland area.

Cello and Mazzoli (1999) related the four different phases of deformation to three different stages in which the geodynamic history of the Souther Apennines - Tyrrhenian sea system can be subdivided: stage 1 comprises the D1 phase, this is the moment of the oceanic subduction stage (Late Cretaceous-Oligocene) during which the Liguride accretionary wedge formed; stage 2 comprises the D2 and the D3 phases, this is the moment of the obduction of the previous oceanic subduction stage and the following onset of accretion of the continental margin (it covers a time interval comprises between the Oligocene - Miocene boundary and the Early Tortonian); stage 3 comprises the D4 phase, this is the collisional to post-collisional stage (Tortonian - Quaternary), it is related to the rifting and drifting processes occurring in the Tyrrhenian area (Kastens et al., 1998) as a response to collisional processes involving continental subduction and flexural retreat of the Apulian lithosphere (Malinverno and Ryan, 1986).

1.2.2 The Bradanic foredeep

The Bradanic foredeep represents the southern portion of the Adriatic foredeep, a NW-SE elongated foredeep separating the Apennine chain from the Apulia foreland and that can be subdivided in several sub-basins, respectively named the Abruzzo, the Molise, the Puglia and the Lucanian basins. These sub-basins are similar from a litho-stratigraphical point of view, but the timing of the sedimentation follows a NW-SE trend, with the deposits becoming progressively younger towards SE. This feature is clearly shown by the paleo-geographical reconstruction of the sea location: in the early Lower Pliocene the sea is present just in the Abruzzo basin; during the late Lower Pliocene the sea invades the Molise and the Puglia basins and the southern sector of the Lucanian basin; during the Middle Pliocene, there is the junction of the Lucanian basin with the northern basins (fig. 1.12, Casnedi et al., 1982).

The filling of the foredeep can be distinguished in three different moments: a pre-thorbiditic phase, a thorbiditic phase and a post-thorbiditic phase. The pre-thorbiditic phase is everywhere characterized at the base by a clayey-marly sedimentation (transgressive on a Miocene-Cretaceous substrate), whose age varies from the early Lower Pliocene (Abruzzo basin) to the late Pliocene-Early Pleistocene (Lucanian basin). The thorbiditic phase characterizes the filling of the sub-basins by huge fan delta turbidites, often including allochthonous olistostromes. The post-thorbiditic phase determines the complete filling of the sub-basins with shallow water deposits passing upward to a continental sedimentation.

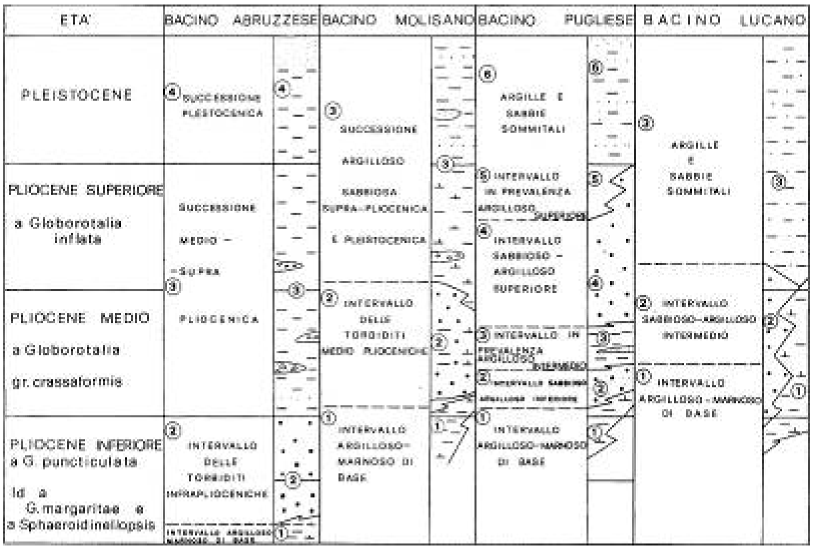


fig. 1.12: scheme of the stratigraphical relationship between the different sub-basins forming the Adriatic foredeep (from Casnedi et al., 1982)

The filling of the sub-basins is mainly due to the ceasing of the subsidence (this is also a time-spatial variable event, being older in the northern sectors and younger in the southern portions of the Adriatic foredeep). Several normal faults and thrusts faults involve the substrate of the area, determining the occurrence of diverse structural highs, some of which assume a high relevance in the individuation of the sub-basins. In particular, the Chieuti high separates the Molise and the Puglia basin being aligned with the destral strike-slip fault of the Gargano, and the Sella di Lavello high separates the Puglia and the Lucanian basins (Casnedi et al., 1982).

The filling of the foredeep is then followed by a translation of the whole system towards NE, as a consequence of the orogenic transport due to the compression between the European and Adria plates: we actually find the thickest Plio-Pleistocene sequences shifted NE respect to their original location (Casnedi, 1988).

The Bradanic foredeep has been long considered an overfilling basin (molasse), such as the Po plain, but this two Apennine foredeeps greatly differ each other: in fact, during the Quaternary, the Bradanic foredeep is characterized by an erosional regression ("cannibalization", *sensu* Tropeano et al., 2002) in an uplifting basin, while the Po plain is characterized by a depositional regression (filling and overfilling) in a subsiding basin (Tropeano et al., 2002).

Balduzzi et al. (1982a, 1982b) did a detailed stratigraphical reconstruction of the filling of the Puglia and Lucanian sub-basins (which are the two sub-basins forming the Bradanic foredeep), thanks to the analysis of core stratigraphies, electric and seismic profiles. The Puglia basin (Balduzzi et al., 1982a) is characterized by a substrate made by Cretaceous platform carbonate at the bottom, passing upward to Miocene carbonates covered by Messinian evaporates. The Paleogene is individuated just in a few cores in the southern portion of the Puglia basin (Lavello 6 well of Balduzzi et al., 1982a). The thinning and the lateral reduced extension of the substrate towards SE testify an emersion of this area (southern Puglia basin) that was still occurring during the early Lower Pliocene. The substrate is also affected by several faults, in same case connected to superficial faults such as in the case of the southern Gargano destral strike-slip fault. The contact of the Plio-Pleistocene succession on the substrate is transgressive (fig. 1.13).

The Plio-Pleistocene succession of the Puglia basin is characterized by the following units (from the top to the bottom):

6- clayey-sandy upper unit (Lower Pleistocene, estimated thickness 800m);

5- clayey with irregular sandy bodies unit (Upper Pliocene, characterized by the presence of a reworked cineritic layer);
4- sandy-clayey upper unit (late Middle Pliocene – Upper Pliocene, estimated thickness 100m);
3- intermediate clayey unit (Middle Pliocene, in the upper part is present a calcarenitic layer 10m thick);
2- sandy-clayey lower unit (early Middle Pliocene, estimated thickness 1200m);
1- clayey-marly basal unit (late Lower Pliocene, estimated thickness 100m).

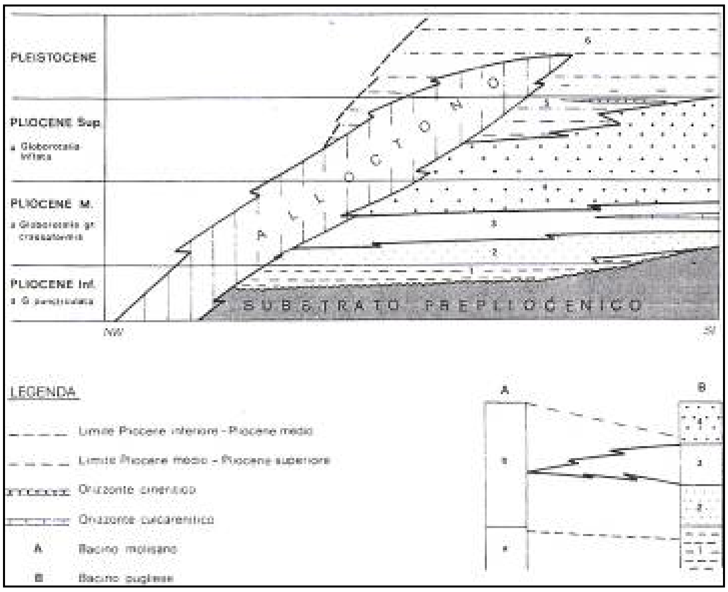


Fig. 1.13: stratigraphic scheme, from NW to SE among the units representing the filling of the Puglia basin and lithostratigraphical correlation with the Molise basin. The basal Pliocene transgression become younger towards the external zone, as well as the allochthonous cover. A) Molise basin: a) silty-marly basal level - b) Middle Pliocene turbidites; B) Puglia basin: 1) silty -marly basal level – 2) sandy- silty lower level – 3) prevailingly silty intermediate level – 4) sandy- silty upper level – 5) prevailingly silty upper level – 6) clays and sands at the top (from Balduzzi et al., 1982).

As we can see by the thickness of the different units, the thickest unit is the second one, that means that in this time (Middle Pliocene) we have the maximum subsidence of the basin.

If we consider the timing of the advancing of the chain towards NE, we can say that the allochthonous front is sutured by the Upper Pliocene unit, so in this period the advance of the Apennine units ceases (Balduzzi et al.,1982).

Crostella & Vezzani (1964) identified two Plio-Pleistocene succession outcropping in the Puglia basin, respectively named the Panni Formation (unit 1-4 of Balduzzi et al., 1982a, estimated thickness 1560m, cropping out in the Ruvo del Monte, Melfi, area) and the Ofanto Formation (unit 5-6 of Balduzzi et al., 1982a, cropping out in the Masseria Canestrello area, SE of the town of Candela, Foggia).

Aucelli et al. (1997) did a detailed stratigraphical reconstruction of the area comprises between the Fortore and the Saccione river, that is located in the northern portion of the Puglia basin, at the boundary with the Molise basin. In this area the base of the filling of the foredeep is represented by marine clayey-marly and clayey-sandy deposits (assuming often a torbiditic facies). From the Late Pliocene - Early Pleistocene, the sedimentation is not anymore compensated by the subsidence. The direct consequence of this is the instauration of a regressive sedimentary cycle responsible of the progressive filling of the area. This cycle starts with platform shale (Argille di Montesecco), it passes upward to sandy littoral deposits (Sabbie di Serracapriota) and it ends with continental conglomeratic bodies of non specified age (Conglomerati di Campomarino) (fig. 1.14, Aucelli et al., 1997).

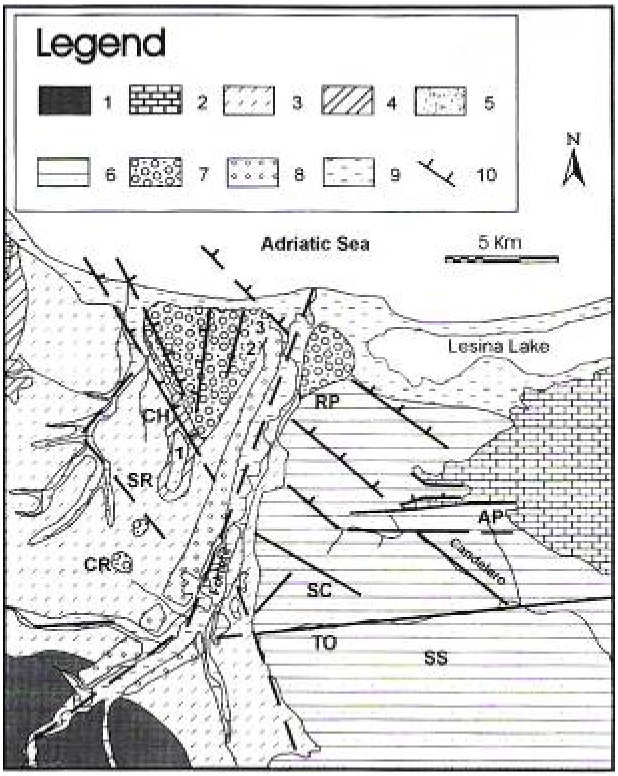


Fig. 1.14 : geological sketch map of the studied area. Legend: 1) allochthonous; 2) foreland; 3) Montesecco clays (Middle Pliocene-Lower Pleistocene); 4) Serracapriola sands (Santernian); 5) Serracapriola conglomerates (Emilian); 6) undifferentiated gravels and sands of marine and continental environment (Late Lower Pleistocene?); 7) Chieuti conglomerates (Middle Pleistocene?); 8) terraced alluvial deposits (Middle and Upper Pleistocene); 9) clastic deposits of the present coastal and alluvial plains (post glacial – Holocene); 10) faults; AP – Apricena; SR – Serracapriola; CR – Colle Ruggiero; CH – Chieuti; RP – Ripalta; SC – San Paolo di Civitale; TO – Torremaggiore; SS – San Severo (from Aucelli et al., 1997).

The Lucanian basin is separated by the Puglia basin from the structural high of Lavello and it is limited to the south-west by the Nocara ridge, which separates the Lucanian basin from the Plio-Pleistocene Sant'Arcangelo basin (Balduzzi et al., 1982b). The substrate of this sub-basin is made by Cretaceous carbonates, passing upward to Eocene dolomitic limestones, limestones, red marls, dark basalts and calcareous breccia, ending with Miocene calcarenites. The Eocene facies are limited to the north-eastern portion of the basin. The Plio-Pleistocene succession is made by three major units, that are correlable with those one cropping out in the Puglia basin:

3- clayey-sandy upper unit (late Upper Pliocene - Lower Pleistocene, estimated thickness 1400m);
2- intermediate sandy-clayey unit (Middle Pliocene – Upper Pliocene);
1- clayey-marly basal unit (late Lower Pliocene, thickness variables towards the basin).

The thickness of these three units testify a maximum sedimentation occurred during the Lower Pleistocene, so it means that in this time we have the maximum subsidence in the Lucanian basin. If we compare this data with those one regarding the Puglia basin, we see that the maximum subsidence (and consequently the maximum sedimentation) of the Lucanian basin occurred later respect to the Puglia basin. Balduzzi et al. (1982b) also identify a migration of the subsidence axe towards NE.

The advancing of the allochthonous front in the Lucanian basin ceases in the Lower Pleistocene, as it is testified by the Lower Pleistocene unit suturing the allochthonous front, so also this event occurred later if compared to the Puglia basin (Upper Pliocene) (Balduzzi et al., 1982).

The quaternary depositis cropping out in the Bradanic foredeep represents the regressive cycle responsible of its progressive filling. The lowest unit is represented by the *Calcarenite di Gravina Formation*: this units became younger moving from the Murge area (Middle and Upper Pliocene - Lower Pleistocene) towards the Salento region (Lower Pleistocene) and it is constituted by biocalcarenites and biocalcirudites with the intercalation of calcilutitic layers and its total thickness is of about 70-80m. Above the *Calcarenite di Gravina Formation* there is the *Argille Subappennine Formation*: it represents the deepest facies of the entire quaternary succession, it crops out on the western margin of the Murge area, and it is constituted by clays and silty-marly clays, locally well stratified, for a total thickness of about 250m. The *Argille Subappennine Formation* is followed by the *Sabbie di Monte Marano* Formation: it has a total thickness of about 35m, it is constituted by well stratified, quartzy and calcareous sands, with the intercalation of clayey layers. The uppermost unit is represented by the *Conglomerati di Irsina Formation*: this unit represents the closure of the regressive cycle of the Bradanic foredeep, it is constituted by polygenic conglomerates with the intercalation of silico-clastic sandy layers, for a total thickness of about 20m (Ciaranfi et al., 1988).

1.2.3 The Apulia foreland

The Apulia foreland represents the undeformed carbonatic platform that is actually part of the Adria microplate. It crops out in the eastern portion of the Southern Apennines, and in particular in the Gargano, Murge and Salento areas (Puglia region).

The portion of the Apulian foreland cropping out in the Puglia region represents the highest peak of a wide anticline structure, WNW-ESE oriented. This positive structure is limited to the west (Bradanic foredeep) and to the east (Adriatic sea) by normal faults (Ricchetti & Mongelli, 1980). The occurrence of strike-slip faults determines the separation of the foreland in three different blocks (the Gargano, the Murge and the Salento areas respectively) with peculiar tectonic features. The stratigraphical succession of the Apulia foreland is well represented in the Puglia 1 well (Mostardini and Merlini, 1986) and it is characterized by the presence of a Permo-Triassic terrigenous units, showing a fluvio-deltaic facies, for a maximum thickness of about 1000m, passing upward to a Jurassic - Cretaceous carbonatic succession showing platform facies (Apulian platform, D'Argenio, 1974), that passes in the Gargano area (East Garganico Basin, D'Argenio, 1974) to basinal facies. The most recent deposits are represented by Paleocene to Oligocene calcarenites and by Neogene to Quaternary shallow water carbonatic and terrigenous units. The total estimated thickness of the sedimentary pile is of about 7000m (Ciaranfi et al., 1988) (fig. 1.15).

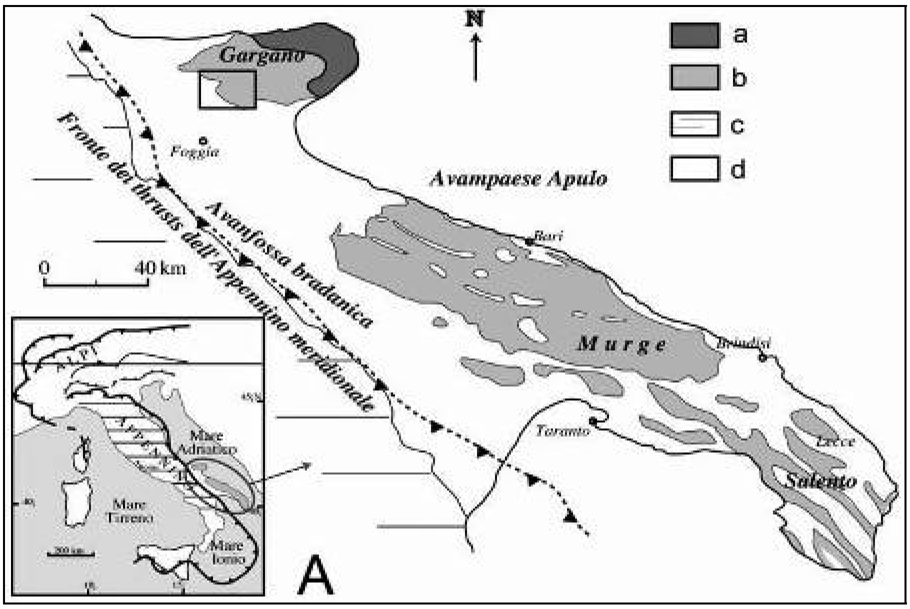


Fig. 1 15 : geological simplified setting of the Apulian Foreland: a) Mesozoic slope and basin carbonate units; b) Mesozoic platform units; c) Meso-Cenozoic allochthonous units of the Southern Apennines; d) Plio-Pleistocene foredeep and foreland units (from Spalluto et al., 2005).

The main units cropping out in the Murge and the Salento areas have been described in detail by Ciaranfi et al. (1988). The Permo-Triassic terrigenous units have never been recognized in the field, they have just been identified in the wells, and in particular in the Puglia 1 well (Mostardini and Merlini, 1986). The oldest units cropping out in the Murge and the Salento areas are represented by Cretaceous carbonatic units, and in particular the *Calcare di Bari* and the *Calcare di Altamura* formations (Valduga, 1965; Ricchetti, 1975). The *Calcare di Bari* formation (Valanginian - Lower Turonian) crops out in the north-western portion of the Murge area, for a total thickness of about 2000m: it is constituted by microfossiliferous micritic limestones and by well stratified dolomitic limestones, with intercalated Rudist limestones and microfossiliferous limestone with layers showing a subsiding platform facies, with episodic reef conditions. The limit between the Calcare di Bari and the Calcare di Altamura is marked by a Turonian stratigraphic lack (Crescenti and Vighi, 1964), and in some cases either by continental bauxite deposits (Spinazzola location) or by continental sandy-marly-clay layers in the areas of Corato – Ruvo di Puglia (Maggiore et al., 1978a; Iannone and Laviano, 1980) and in the area of Fasano – Ostuni (Maggiore et al., 1978b). The *Calcare di Altamura* formation has a total thickness of about 1000m: it is constituted by well stratified microfossiliferous micritic and Rudist limestones. This formation was deposited in an internal platform environment, with a low subsidence testified by the presence of laminated micritic limestones above the Rudist limestone with the occurrence of patch reef facies. This formation is characterized by the occurrence of two stratigraphical lack, dated at the Lower Campanian and the Lower Maastrichtian respectively.

Above the Mesozoic carbonatic units there is the deposition of Tertiary deposits, both Paleogene and Neogene in age. The Paleogene units are represented by the *Calcari di Castro* and the *Calcareniti di Porto Badisco* formations: the *Calcari di Castro* (Paleocene - Oligocene) formation crops out on the eastern side of the Salento region (in the area comprises between the towns of Otranto and Santa Maria di Leuca), it is constituted by well stratified bioclastic and organic limestones, deposited on a platform margin environment. The *Calcarenite di Porto Badisco* formation (Ologocene) crops out in the central-eastern Salento, it is constituted by bioclastic calcirudites and calcarenites with abundant benthic foraminifera, for a total thickness of about 50m. The Neogene deposition is represented by the *Pietra Leccese* and *Calcareniti di Andrano* formations. The *Pietra Leccese* (Burdigalian - Lower Messinian) formation has a total thickness of about 300m, it is constituted by calcarenites and calcilutites with abundant planctonic foraminifera, the lower part of the succession is characterized by the presence of a glauconitic micritic limestones known in literature with the name of "*piromafo*", the facies vary from the submerged beach to the open platform environment. The Pliocene deposits are transgressive on the oldest formations and they are represented by two sedimentary cycles, the first one dated to the Lower Pliocene (*Leuca Formation*) and the second one dated to the Middle-Upper Pliocene (*Uggiano la Chiesa Formation*). The *Leuca Formation* is characterized by a lower interval made by calcareous breccias and conglomerates in a sandy-silty carbonatic matrix, and by an upper interval made by marls and glauconitic biomicrites. The *Uggiano la Chiesa Formation* is characterized by biomicrites and calcarenites rich in benthic foraminifera, Briozoi and red algae, with the occurrence of a well sorted calcareous conglomerate at the bottom of the succession.

1.2 GEOMORPHIC FEATURES OF THE CHAIN

The Southern Apennines geographically starts in correspondence of the Bocca di Forlì (891m a.s.l.) at the boundary between the Abruzzi and the Molise regions. It covers an area of about 42795.44 km^2. The maximum elevations are located in correspondence of the hardest lithologies, and in particular the highest peaks are individuated on the Matese massif (Mt. Miletto, 2050m a.s.l.), the Alburno-Cervati ridge (Mt. Cervati, 1898m a.s.l.), the Sirino massif (Monte del Papa, 2005m a.s.l.) and the Pollino massif (Mt. Serra Dolcedorme, 2249m a.s.l.). The average elevation of the whole chain is of about 421m a.s.l..

The location of the Apennine divide (separating the Tyrrhenian side from the Adriatic and the Ionian sides) and the Adriatic-Ionian divide (separating the Adriatic and Ionian flanks of the Southern Apennines) allows the identification of three different sectors, respectively named Tyrrhenian, Adriatic and Ionian. The Tyrrhenian flank is extended for 15160.65 km^2, representing the 35.42% of the total area of the Southern Apennines, with the elevations ranging between 0m and 2166m a.s.l. and with an average elevation of about 469.44m a.s.l.. The Adriatic flank covers an area of 16948.59 km^2, that represents the 39.60% of the whole chain (this is more extended sector of the Southern Apennines), its elevations range between 0m and 2031m a.s.l. with an average elevation of about 335.35m a.s.l. (the lowermost value between the three sectors). The Ionian side is extended on an area of 10686.20 km^2, that represents the 24.97% of the whole orogen (it is the smallest sector), its elevations range between 0m and 2249m a.s.l. with an average elevation of 487.91m a.s.l., that is the highest value between the three sectors. The average elevation of the three sectors is strongly controlled by their morphostructural settings and by their rock-type. The Adriatic flank lowermost average elevation value is strongly due to the presence of weak lithologies, such as the quaternary sedimentary filling of the foredeep and by the presence of the undeformed carbonates of the apulian platform (Murge area). On the other side, the average elevation of the Ionian side, that is the highest value among the three sectors, is due to the presence of several peaks reaching the 2000m a.s.l. (and in particular the Pollino massif, the Sirino massif and the Mt. Alpi), and to the high elevation reached by the main valleys (that are located at an elevation higher than 600m a.s.l. close to the axial sector of the chain) if compared with the elevation of the Tyrrhenian and Ionian valleys.

The Southern Apennines are an asymmetric chain, with an internal flank (Tyrrhenian) steeper than the external flank (Adriatic), as it can be easily recognized by the analysis of a topographic profile of the chain in every portion of it (fig. 1.16).

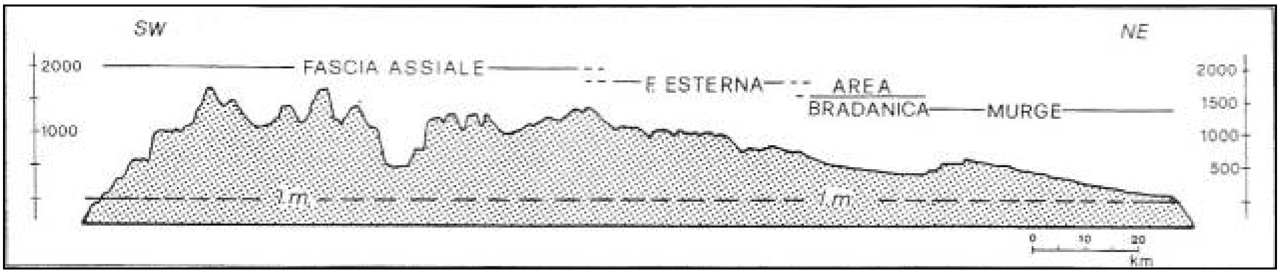


Fig. 1.16: topographic profile through the Southern Apennines, from the Cilento coast on the Tyrrhenian flank to the Murge coast on the Adriatic flank: notice the marked asymmetry of the chain and the tilting toward NE of the Murge (from Cinque, 1992).

The location of the divide and the maximum elevation line don't correspond along the entire chain: in particular the divide is located eastern of the highest peaks in the area extended from the Calore Beneventano river to the Vallo di Diano basin.

The Tyrrhenian side is also different from the other portions of the chain because of the presence of large coastal grabens (represented by the Campania, the Sele plain, the Policastro gulf), separated by and limited to the east by steep carbonatic massifs. Diffuse normal faulting on the Tyrrhenian slope determines the occurrence of a large number of intramontane basins filled up with quaternary continental deposits.

The outer flank of the chain, where the weaker lithologies of the Lagonegro units and several flysch units crop out, is gentler than the inner side, with a landslides dominated landscape. This is the boundary between the chain s.s. and the Bradanic foredeep, a very gentle clay to conglomerate landscape whit diffuse landslides, limited to the east by the carbonate of the Apulia platform. In correspondence of the Apulian carbonates, the topography arise with the individuation of a gentle massif: the elevation of the Apulia region is anyway lower than the elevation of the carbonatic inner areas, this feature is due to the lack of tectonic deformation of the Apulian carbonates.

Rivers have different orientations in the different sectors, with the occurrence of both apenninic (NW-SE) and antiapenninic (NE-SW) oriented rivers on the Tyrrhenian flank, while rivers on the Adriatic flank have a dominant antiapenninic orientation and rivers on the Ionian flank show a mainly apenninic orientation. The drainage density is strongly controlled by the lithology, and in particular by the different permeability of the different lithotypes, being lower where carbonate of the Apulia and the Apennine platforms crop out, and being higher where terrigenous units crop out.

Cinque et al.(1993), moving along a Cilento - Murge transect, separated the Southern Apennine into three different sectors, with peculiar morphological features, and that, moving from the Adriatic to the Tyrrhenian side, are respectively named outer, axial and inner belts (fig. 1.17).

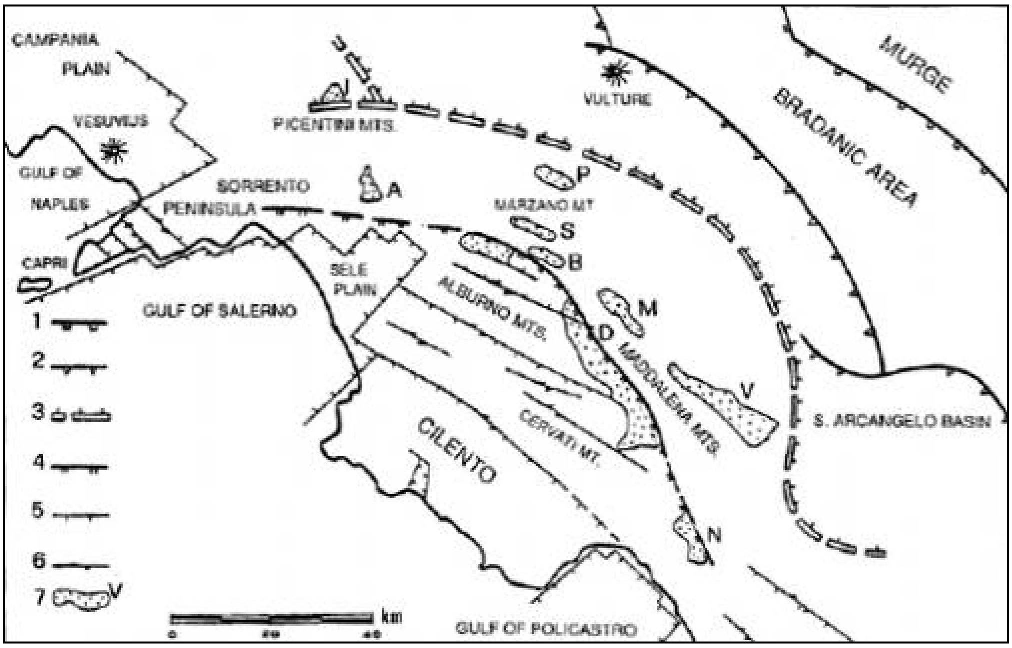


Fig. 1.17: morphostrucutural scheme of the Southern Apennine- 1) western scarp of the Apulia foreland plateau; 2) eastern boundary of the outer belt; 3) approximate boundary between outer and axial belts; 4) possible boundary between axial and inner belts; 5)-6) main fault scarps of the Tyrrhenian margin: dots for vertical throw, arrows for transcurrent activity; 7) main intramontane basins of the Campania-Lucania segment of the Southern Apennine: I) Volturara Irpina; A) Acerno; P) Muro Lucano; B-S) Buccino-San Gregorio; T) Tanagro; M) Sant'Angelo delle Fratte-Brienza; D) Vallo di Diano; V) Val d'Agri; N) Noce (from Cinque et al., 1993)

The outer belt is limited to the east by the Bradano clayey deposits and to the west by the highest peaks of the chain, that in same cases are close to 2000 meters of elevation (Mt. Volturino). The landscape is characterized by the presence of broad remnants of an hanging mature landscapes, whose modelling took place at the boundary between the Lower Pleistocene and the Middle Pleisotcene: their elevation (up to 1000 meters a.s.l.) and the strong fluvial incision of this portion of the chain suggest that this sector has experienced a strong uplift after the end of the Lower Pleistocene. The axial belt is characterized by the presence of hard and morphologically conservative rock units, that has allowed the preservation of ancient erosional surfaces some of which date as back as to Late Miocene - Early Pliocene times. The Late Pliocene - Lower Pleistocene erosional surfaces lie at an elevation of about 1500 and 800 meters a.s.l., and they have been displaced by fault scarps. In the northwestern side of the sector (Sorrento Peninsula and Capri) the Late Pliocene - Lower Pleistocene remnants lie at an elevation of about 1100 meters a.s.l., while the highest Pleistocene marine terraces reach an elevation of about 300 meters: quaternary marine deposits and terraces testify that block faulting and uplift have ceased, or anyway strongly decreased, since the end of the Middle Pleistocene. The inner belt is limited to the east by diffuse intramontane basins (that extends from the lower reach of the Tanagro valley to the south until the Noce valley) and to the north by the fault scarps dissecting the southern slopes of the Picentini ridge and the Sorrento peninsula. In this sector, hanging and dissected remnants of ancients mature landscapes have been found up to 600 - 700 meters a.s.l. in Cilento, and up to 1000 meters a.s.l. in the Alburno and in the Bulgheria massifs. Their old age doesn't allow to correlate them with the erosional surfaces located at the same elevation in the axial belt, which are Sicilian in age. Middle Pleistocene marine terraces have been scarcely uplifted (few tens of meters) along the Tyrrhenian coast, while Tyrrhenian marine terraces lie at an elevation of about +8m a.s.l. along the Cilento and Sorrento Peninsula coast, testifying a tectonic stability of these areas, while they are recognized up to +25m a.s.l. in the Sele plain which has so experienced an enhanced uplift since the Tyrrhenian (135 Ky) if compared to the previously named border areas of the Cilento region to the south and the Sorrento Peninsula to the north.

1.4 PREVIOUS KNOWLEDGE ABOUTH THE GEOMORPHOLOGICAL EVOLUTION OF THE OROGEN

The aim of this section is to resume the evolution of the state of the art about the knowledge of the different phases in which the geomorphological evolution of the Southern Apennines can be subdivided.

The first studies that gave important results to this type of investigation were developed with the "Progetto Finalizzato Geodinamica-Sottoprogetto Neotettonica", during the '60s-'70s.

The main results reached at the time are summarized in Brancaccio e Cinque (1988) ed in Cinque (1992). From the geological point of view the main results can be so described:

- the Southern Apennines formed as a consequence of a compressive stress field, mainly occurred during the Miocene and decreasing in the Early and Middle Pliocene;
- a cylindrical progression of the deformation has occurred, with not so arched fronts moving towards the external areas;
- there is a temporal separation between a compression-dominated period (Mio-Pliocene) and an extension-dominated period (Pleistocene) during which the orogen was also affected by uplift that was thought to be related to an isostatic rebound of the subducting slab.

On the other hand, the geomorphological researches, often using as base of data the previously mentioned geological studies, allowed a first reconstruction of the different phases through which the actual geomorphological setting of the chain has been reached. The main results are now described.

Several gentle landscape have been recognized on top of the ridges in different portions of the chain, representing the remnants of a wider erosional surface recognized in all the Southern Apennines (Bartolini, 1980), and named "*Paleosuperficie Auct*". This paleosurface testify a period of tectonic quiescence, during which the uplift processes are less enhanced than the denudational processes, occurred between the Middle Pliocene and the Lower Pleistocene. The area interested by this erosional phase extends to all the Tyrrhenian flank where, at this moment, the graben of Salerno is already formed while ,to the north, the Campana plain didn't exist in its total extension, as testified by the distribution of the Messinian deposits that is not coincident with the perimeter of the actual plain and that are absent on the border ridges and in the southern sector of the plain (Balducci *et alii*, 1985).

The considered paleosurface results to be younger in the axial sector of the chain, where it cuts Middle Pliocene marine deposits (Ortolani & Pagliuca, 1988) and to be older on the external flank of the chain: this diachrony seems to testify a migration of the pre-quaternary uplift movements from the Tyrrhenian border to the external areas (Cinque *et alii*, 1981).

During the Lower Pleistocene the chain has assumed a morphological configuration similar to the actual one with the individuation of several subsiding basins (coastal plains and marine basins of the Mt. Bulgheria and the Cilento, that will successively be uplifted, Ippolito *et alii*, 1973; Ortolani & Aprile, 1979; D'Elia *et alii*, 1987) and with an orography very close to the present one. In this time the vertical movements was confined in two main events, occurred during the Early Lower Pleistocene and 0.75Ma respectively and that, being occurred after the formation of the *Paleosuperficie Auct.*, were part of an extensional stress field characterizing the post-orogenic uplift.

The effects of such tectonic events on the landscape are relevant: in fact, during the first phase we have the individuation of the main rivers, some little lacustrian basins (S. Massimo, Isernia, Camerota), the configuration of the border of the main massifs, the first phases of volcanism in the Campana plain (Roccamonfina volcano). In this period the two main peri-tyrrhenian coastal plain showed a different behaviour, with the Campana plain progressively enlarged as a consequence of the retreat of the bordering fault scarps, while the Sele plain went under a centripetal reduction for the uplift of some of its portions and the advancing of the mountain front; the second tectonic phase was responsible of the formation of several lacustrian basins (such as the middle and high Volturno valley, the Calore valley, the Melandro valley, the Tanagro valley). In this phase a rapid evolution of the fault scarps occurred, following the evolutionary model proposed by Lehmann (Brancaccio *et alii*, 1979), as a consequence of the alternance of glacial and interglacial periods: this rapid evolution determines the accumulation of huge amount of debris at the base of the scarps, debris that was then transported by the rivers into the previously mentioned lacustrian basins determining the filling of these basins and the occurrence of the thick terraced deposits we actually recognize in these valleys. In this phase it has also occurred an intense travertine deposition as a consequence of the mobilization of deep water during the tectonic uplift (D'Argenio *et alii*, 1983), and an intense volcanic activity in the Campana plain. The two mentioned tectonic phases are separated by a period of intense debris production, testified by the thick continental deposits of the Conglomerati di Eboli (they have been dated with the K/Ar method, with an estimated age of 1.5-0.9 Ma, Cinque *et alii*, 1988).

During the Lower-Middle Pleistocene the Southern Apennines have reached a morphology very close to the actual. The youngest tectonic phases, occurred during the Late Pleistocene-Holocene, are testified by the elevation of the marine terraces: these geomorphological features are recognized at an elevation of about +8m a.s.l. on the Sorrento Peninsula and the Cilento region indicating a tectonic stability of these areas (Brancaccio *et alii*, 1978; Lippmann-Provansal, 1987), while they reach an elevation of about +25m a.s.l. in the Sele plain and an elevation of about -25m a.s.l. in the Campana plain (Cinque *et alii*, 1987) testifying a different behaviour of the two coastal plain due to vertical movements still active in the Sele plain and to an enhanced subsidence in the Campana plain, that is due to the thick accumulation of both alluvial deposits (Volturno, Sele and Sebeto rivers) and pyroclastics deposits ejected by the volcanic district of the Plhegrean Fields and by the Somma-Vesuvio volcano: in this period is, in fact, concentrated the volcanic activity of the two volcanic areas with, in addiction, the occurrence in the Plhegrean Fields of a pronounced volcano-tectonic activity responsible of the uplift of the Versilian (5 Ka) marine deposits up to +35m a.s.l.

On the inner areas of the chain we have in this time an active seismicity with vertical movements of also a few decimetres in a few decades (Arca et al., 1983) and an intense morphogenesis of the areas where terrigenous successions are.

The proceeding of the researches after this important project pointed out on its limits, so that it couldn't be considered still acceptable: the revision of the previously produced data gave an important input to the identification of such limits, revision that was carried out with the aim to combine the information obtained by the "Progetto Finalizzato Geodinamica-Sottoprogetto Neotettonica" with the new geomorphological, stratigraphical, structural and geophysical data

In particular, the idea of an unique erosional phase occurred during the Middle Pliocene and the Lower Pleistocene and responsible of the formation of the *Paleosuperficie Auct.* was strongly criticized because there were no clear chronological constraints to verify that all the different remnants of such paleosurface were modelled in the same erosional phase; the fault scarps dislocating the gentle landscapes recognized on top of the Apennine massifs and mountains are not considered to have occurred just in an extensional tectonic setting, while, on the other hand, the compressive tectonic events are not considered to be just older than the *Paleosuperficie Auct.* and to be occurred during the so-called Mio-Pliocene "*tettogenesi*"; the vertical quaternary movements recognized on the chain are not considered to be due to an isostatic uplift post-*Paleosuperficie Auct.* because of the lacking of crustal roots underneath the Southern Apennines.

A good summary of the new working ideas developed in the '80s-early '90s is described in Cinque (1992). The author suggest a new temporal subdivision of the main morfoevolutive phases of the orogen, by comparing both geomorphological and geological data.

The main geological indicators that allowed a revision of the "Progetto Finalizzato Geodinamica-Sottoprogetto Neotettonica" ideas are the following:

- the compressive "*tettogenesi*" is made younger up to the Sicilian, as testified by the opening and deformation of piggy-back basins occurred during all the Emilian;
- a non-cylindrical progression of the thrust fronts is recognized, while such thrusts fronts seemed to proceeds separately each other (Molisano-Sannitico arc, Campanian-Lucanian arc and Calabrian arc), so the thrust propagation in the Southern Apennine followed alternatively piggy-back and over-step styles, with diffuse out-of-sequence, differently from the Central Apennine that is considered to be formed in a piggy-back style;
- several strike-slip quaternary faults are recognized, probably responsible of the formation of subsiding basins both on the Tyrrhenian coast than on the inner areas of the chain;
- following the distribution of the youngest marine deposits the researchers noticed that the internal portion of the chain was still emerged in the Messinian, the axial zone is mainly emerged from the Lower Pliocene, the external flank emerged between the Late Pliocene-Early Pleistocene (Santernian), while the Bradanic sector emerged after the Sicilian, during the post-orogenic uplift of the foredeep;

These new geological data allowed a reformulation of the geomorphological studies. In particular, considering the too short time involved and the irregular migration of the thrust fronts, the idea of a unique erosional phase involving the whole chain and that was responsible of the formation of the *Paleosuperficie Auct.* seemed to be hard to accept: this concept is also criticized by the fact that many of the gentle landscapes recognized in the Southern Apennines are considered to be syn-orogen, their formation is linked to local base level e so they cannot be interpreted in a regional context, but their relevance can be extended just to a local scale. In addiction, the ages available for these remnants of paleosurfaces showed that such remnants are younger on the external flank of the chain (being temporally constrained between the Emilian and the Sicilian). These remnants are less diffuse moving towards the internal areas, where they are confined between massifs characterized on their top by older erosional gentle landscapes: these older paleosurfaces are in same cases dated as back as to the Late Miocene, but in most cases they have been formed in a time interval comprises between the Pliocene and the Early Lower Pleistocene. Anyway, it's not easy to determine the total uplift the considered sin-orogen paleosurfaces have experienced, because they are probably linked to some local base level more than to the global base level.

The post-orogen paleosurfaces have better constraints that allow a good estimation of the uplift the Southern Apennines have experienced since the Sicilian. First of all, the age of the "*tettogenesi*" has been made younger until the Sicilian, second, the vertical post-orogen movements, that were previously thought to be related to an isostatic rebound of the chain, are more pronounced on the external areas of the orogen than on its internal areas, and they are related to the roll-back of the subducting apulian slab (Malinverno and Ryan, 1986; Cinque et al., 1993). The previously proposed isostatic rebound is also contrasted by the lacking of crustal roots and by the shape of the topographic profile of the Southern Apennines, that looks strongly asymmetrical, with the maximum elevation line very close to the Tyrrhenian coast, and an Adriatic flank wider and gentler than the Tyrrhenian flank, a shape very different from the theoretical Gaussian profile that a chain isostatically uplifted should show.

The hypotheses of an more pronounced uplift on the Adriatic flank that is related to the roll-back of the sinking lithospheric adriatic slab is confirmed by morphostructural constraints, in particular, the tilting of the Murge area and of the Irsina Conglomerates (that represent the filling of the Bradanic foredeep) towards the NE: in particular the Irsina Conglomerates reach an elevation of about 800-850m along the NE border of the Southern Apennines chain and an elevation of about 300-350m along the western border of the exposed Apulian carbonates (Cinque et al., 1993).

Good indicators of the uplift experienced by the chain are available in the inner, axial and outer portions of the chain, and in particular in the S. Arcangelo and Calvello basins, the Mt. Marzano, the Sorrento Peninsula and the Cilento. If we consider the elevation of the top of the quaternary filling of the Sant'Arcangelo basin, the erosion that some post-orogen paleosurfaces have experienced (Calvello basin and Mt. Marzano), and the elevation of the marine terraces that are Lower Pleistocene in age on the Sorrento Peninsula and more exactly Emilian in age on the Cilento, we have an enhanced uplift on the outer side (about 600m of uplift), that slightly decreases on the axial sector (400-500m of uplift) and that is the smallest on the inner side of the Southern Apennines (about 300m of uplift): these data represents another proof to validate the hypotheses of an enhanced uplift on the outer side of the Southern Apennine that is related to the roll-back of the sinking Adriatic slab.

Another innovation is represented by the non-temporal separation between tectonic compression and extension, that in same cases brought to consider as related to normal faults all the quaternary fault scarps, also when there were no kinematical indicators of the type of movement, without considering that a morphological convergence could occur between fault scarps related to different tectonic regime. From this point of view, an important role has been played by a series of researches on the inner areas: in particular, it has been recognized a recent uplift also in same of these areas (Sele plain, with the Tyrrhenian coast line recognized at an elevation of about +25m a.s.l.); in addiction, several studies on the opening of the back-arc Tyrrhenian basin showed that its opening occurred in two different rifting phases, dated about 4.4Ma and 2Ma, testifying an extensional tectonic regime that was already acting on the inner areas in the same time while the outer chain was dominated by a compressive tectonic regime.

This advance in the researches has brought to an important improvement about the identification and the timing of the main morphotectonic phases responsible of the actual morphostructural setting of the Southern Apennines because:

- a more detailed chronological constraints have been developed;
- it has been overpassed the wrong idea that the Southern Apennines built up in three different phases, temporally separated, and in particular a first compressive event (named "*tettogenesis*"), followed by a period of tectonic quiescence with the formation of the *Paleosuperficie Auct.*, then followed by the instauration of an extensional tectonic regime;
- the proposed idea of a recent uplift connected with the roll-back of the lithospheric adriatic slab fits better than the proposed isostatic rebound with the available morphostructural data.

Neverthless, there are still open problems on which the future studies should be concentrated, and in particular: the different behaviour of the two coastal plain, that, also if they are spatially very close, show an enhanced subsidence and volcanism in the Campana plain, while the Sele plain has no volcanism and has experienced uplift since recent time; the meaning of some W-E oriented faults identified in several sectors of the chain, in same cases located in correspondence of some of the piggy-back basins of the chain (such as the Ofanto basin, the Calvello basin and the S. Arcangelo basin), faults that seem to end abruptly against the thrust front and whose age has not still been determined.

1.5 THERMOCHRONOLOGICAL DATA

In the last years, new methods of analysis have been developed, allowing the production of very detailed chronological constraints to better understand the type of processes responsible of the actual morphostructural setting of the chain and their timing: these methods are based on thermochronological analysis, a kind of analysis that allows a reconstruction of the thermal history of a rock, that is influenced by the sedimentary load it has been subjected before it crops out, determining also the timing of the lithostatic loading.

The thermochronological analysis (Apatite Fission Tracks, Ur/Th/He, Clay Mineralogy, Vitrinite Reflectance, Fluid Inclusions) give good chronological constraints about the reconstruction of the vertical movements of the chain, with particular regard to the reconstruction of the *rock exhumation* processes, that, at the actual state of art, seem to have played a fundamental role in the morphostructural evolution of the Southern Apennines, and that were no considered in the previous studies mainly because of the lacking of available means.

When we talk about rock exhumation, we have to pay attention to don't confuse this process with the rock uplift and the surface uplift processes, three concepts whose meaning is not always clear and that are sometimes used in the wrong way. By surface uplift we mean a variation of the position of the topography respect to the geoid, by rock uplift, in the same way, we mean a variation of the position of a rock respect to the geoid, while by rock exhumation we mean a variation of the position of a rock respect the air/topography interface (fig. 1.18). We can easily understand that the three concepts involve different processes, and in particular a compressive tectonic regime is required in the case of the surface uplift and the rock uplift, while the rock exhumation can be related either to the erosion or to the activation of detachment (low angle normal faults), with the two processes that can act both separately than together.

The mentioned rock exhumation processes are most of time due to the activation of detachment faults, the main responsible of the outcropping of deep structural units, such as the Lagonegro Units (they crop out on the outer side of the chain and on its southern sector, on the Mt. Sirino and on the high Agri valley and, locally, in the axial zone, in correspondence of the tectonic window of Campagna in the Picentini ridge) and the carbonate of the apulian platform (Mt. Alpi, located in the southern portion of the Southern Apennines), sometimes forming morphological highs with a maximum elevation that reaches also 2000m a.s.l. in the case of the Sirino and Alpi mounts: the activity of these, mainly east-dipping, detachment faults appears to be coeval, and probably kinematically linked, with thin-skinned thrusting in the frontal part of the orogen (Mazzoli et al., 2006, 2008).

Some of the more applied thermochronological analysis are the Apatite Fission Track and the Ur/Th/He series.

The apatite is a phosphate very diffuse in nature, both in igneous, metamorphic and sedimentary rocks. For what regards the sedimentary rocks (that are the type of rocks from which the Apatite Fission Tracks data available for the Southern Apennines have been produced), the apatite is common in terrigenous sediments. The importance of this phosphate is due to the presence of radioactive elements inside its structure, and in particular the uranium: the decay of such element determines the ejection of electrons from its atom, electrons that are ejected with a huge energy and that can hit the wall of the crystal leaving signs of this contact represented by the tracks. The method is based on the principle that if the crystal of apatite is experiencing temperatures greater than 120°C, then the fission tracks will be quickly reabsorbed by the crystal, and it will be impossible to notice them; on the other hand, if the crystal is experiencing temperatures smaller than 120°C, then the fission tracks, whose formation is a continuous process, will not be absorbed anymore, and they will be so visible on the wall of the crystal: the counting of the number of tracks present on the wall of the apatite and their length, and being the time of decay of the uranium known, allow us to determine how much time is passed since the studied crystal has overpassed the 120°C isotherm and it has reached the surface. If we imagine a normal geo-thermal gradient of about 30°C/Km, then it means that when a rock has overpassed the 120°C isotherm it was subject to a sediment load of about 4km of rocks over it.

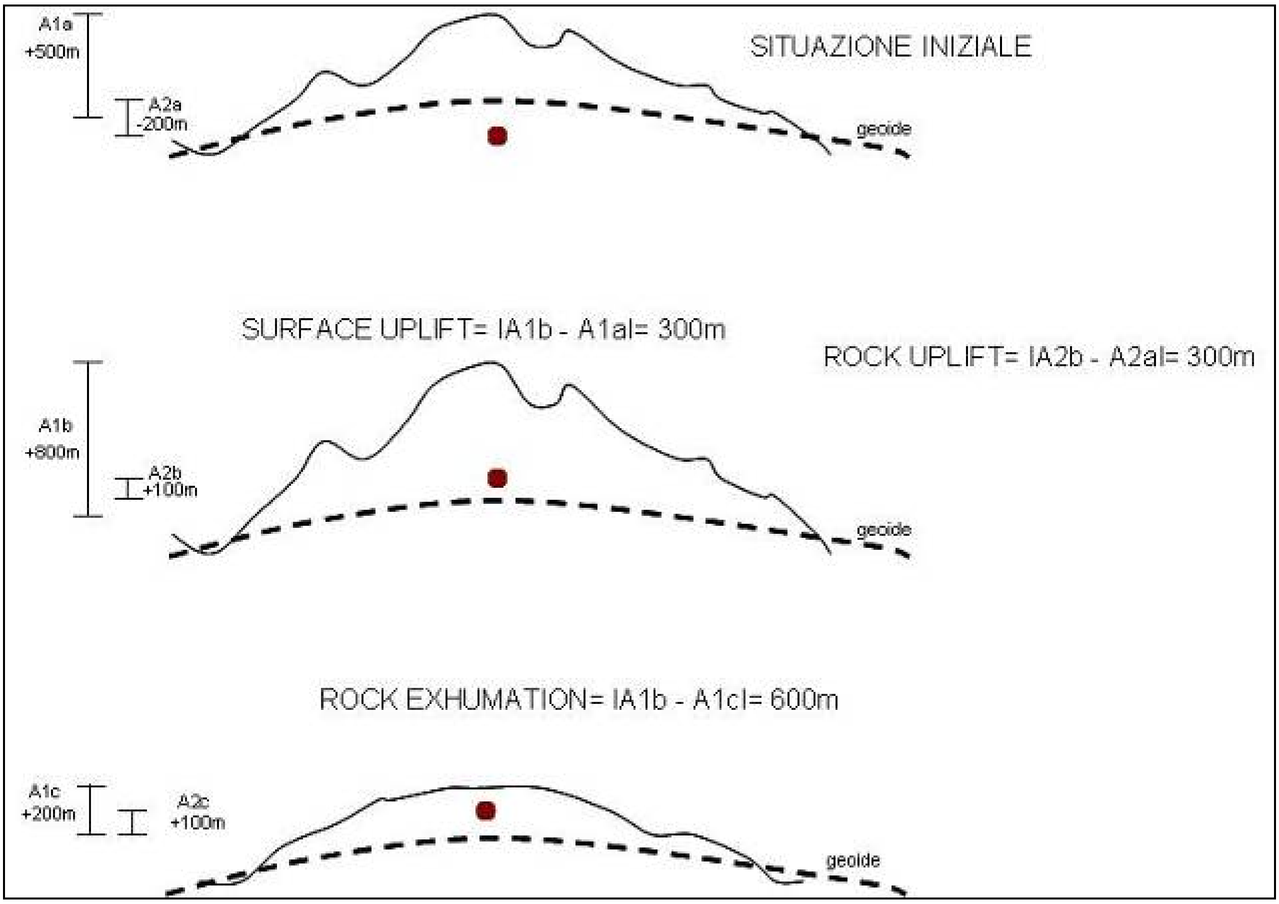


Fig. 1.18: scheme to explain the differences between surface uplift, rock uplift and rock exhumation: surface uplift = variation of the position of the topography with respect to the geoid; rock exhumation = variation of the position of a rock with respect to the geoid; rock exhumation = variation of the position of a rock with respect to the air/topography interface.

The Ur/Th/He series analysis is based on the decay of the uranium atoms in its radioactive sons represented by the thorium atoms and, successively, the helium atoms. This type of analysis is also carried out on the apatite crystals, but the main difference with the previous methods is represented by the closing temperature, that in this case in of about 60°C: it means that the atomic watch starts when the analyzed rock passes the 60°C isotherm, that means, always considering a normal geo-thermal gradient of 30°C/Km, that the rock was subject to a sediment load of about 2km of rocks over it.

Other thermochronological methods are the Clay Mineralogy, the Vitrinite Reflectance and the Fluid Inclusions: the description of these three methods is well exposed in Corrado et al. (2002).

In siliciclastic sediments, clay minerals are the only inorganic phases that provide pieces of information on their thermo-baric evolution (diagenesis–anchimetamorphism–epizone). The parameters generally used are the crystallinity index of some phases (e.g. illite), the *b*0 value and the variation in the relative ratio between the pure phases that form mixed layers: in particular, the illite/smectite (I/S) mixed layers are widely used in petroleum exploration as a geothermometer and, thus, as indicators of the thermal evolution of sedimentary sequences. The passage from smectite to illite follows this scheme of progressive thermal evolution that has been correlated with the stages of hydrocarbon generation: smectite—disordered mixed layers (R0)–ordered mixed layers (R1 and R3)—illite.

The vitrinite reflectance method is based on the analysis of the vitrinite, that is also common in the sedimentary rocks. The vitrinite derives from the thermal degradation of the wooden fragments of continental origin that can be dispersed inside the sediments. Its reflectance strictly depends on the thermal evolution of the hosting sediments and it is correlated with the stages of hydrocarbon generation. If the vitrinite is not present into the rock, it is possible to determine the bitumen reflectance and then to convert it into the vitrinite reflectance by using the Jacob's equation:

$$Rb = Roeq \cdot 0.618 + 0.40 \quad (1)$$

where Rb is the value of reflectance measured on bitumen and $Ro_{eq.}$ is the value that autochtonous vitrinite would have acquired if it would have been present in the same sample.

Fluid inclusions are very common in all the type of rocks, being related to the circulation of fluids in the environment where the rock is forming. Different type of fluid inclusions can be recognized into a rocks, so it is important to distinguish their genesis before deriving quantitative informations using microthermometers. Microthermometry allows one to measure the homogenization temperatures which are indicative of the minimum trapping temperatures and the melting temperatures and that give informations about the fluid composition. Limitations to this method derive from: the small size of the inclusions (usually between 2 and 10 μm in sedimentary rocks), and the possibility that the system was not closed (isoplethic) and/or isochoric (i.e. constant volume inclusions) since the time of entrapment. In the second case, fluid inclusions would record thermal re-equilibration at some stage of the tectonic evolution. This represents a common limitation for the study of carbonate rocks where non-isoplethic and non-isochoric conditions can be frequently be reached, due to the presence of 'soft' minerals like gypsum and calcite.

The thermochronological data produced in the Southern Apennines are summarized in Mazzoli et al. (2008) (fig. 1.19). The main observation that can be made is the distinction between an upper thermotectonic plate and a lower one: the first one (represented by the Apennine Platform units and the tectonically overlying Liguridi and Sicilidi units) records a limited burial and heating history, while the second one (represented by the Lagonegro, Monte Croce and Apulian units) has been extensively buried and heated. In particular, the upper plate show an illite contents in the illite/smectite layers, an Ro% values in the range of the early diagenetic zone, immature to early mature stage of hydrocarbon generation, homogenization temperatures of both primary and secondary fluid inclusions never exceeding 70°C and no annealing of Apatite Fission Tracks: the thermal modelling of this units suggests a non intense burial (never exceeding 2km) they have ezperienced. The lower plate thermal constraints indicate late diagenetic conditions and overmature hydrocarbon generation. The homogenization temperatures of the fluid inclusions ranges between 120° and 160°C, illite crystallinity ranges from 0.60 to 1.10 $\Delta°2\Theta$, Apatite fission tracks are completely annealed: the thermal modelling suggest that rocks belonging to the lower plate were affected by maximum temperatures always higher than the total annealing temperature, so the ages reflect time of recent cooling through the isotherm 110°C, dating the exhumation of the previously buried succession.

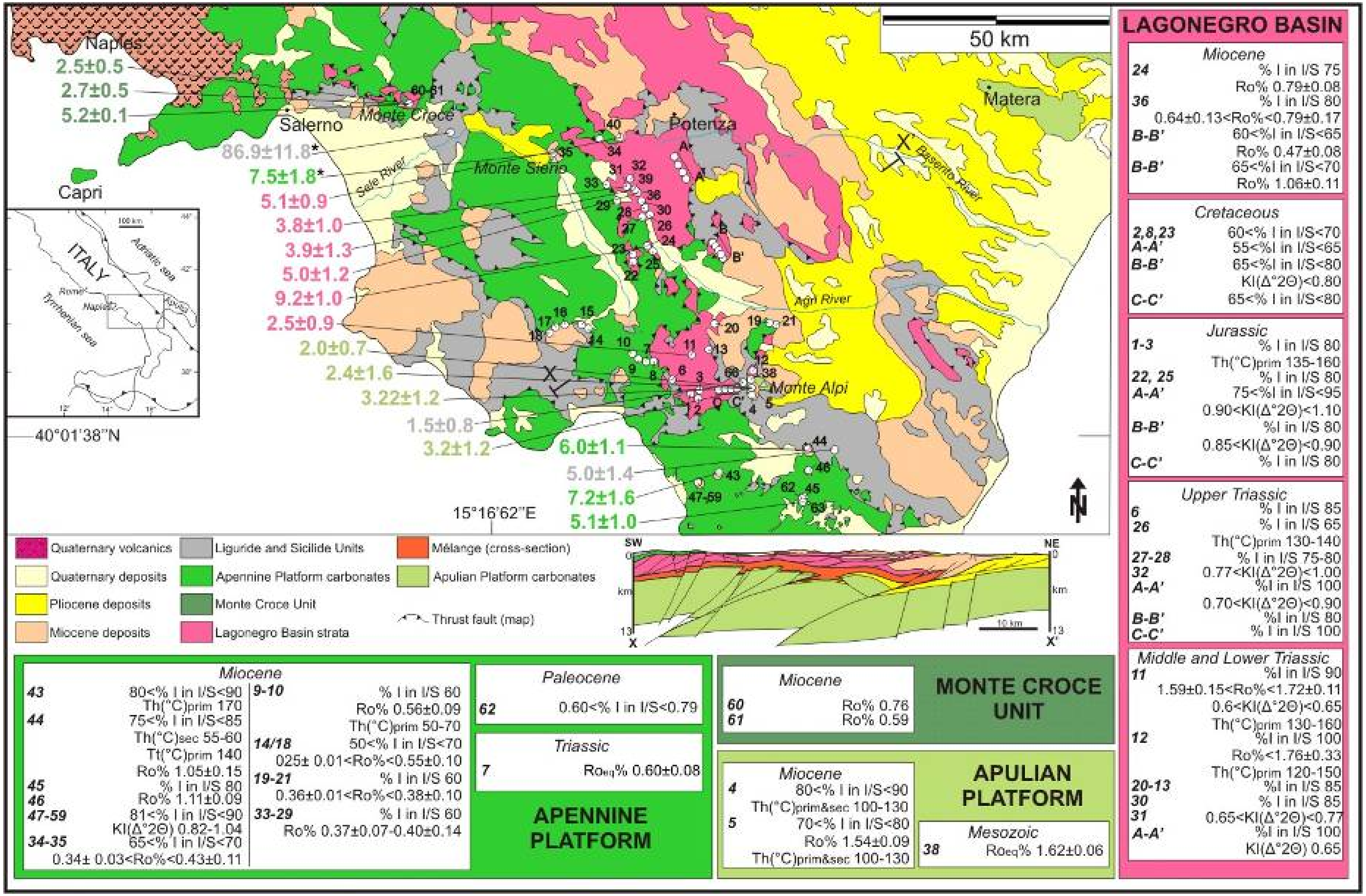


Fig. 1.19 = geological sketch map of the Southern Apennines with location of the regional cross-section and analyzed samples. Thermochronological data (from Corrado et al., 2005) and AFT cooling ages (Ma ± σ) are shown in different coloured blocks to distinguish the main tectonic units (from Mazzoli et al., 2008).

CHAPTER 2

METHODS OF INVESTIGATION

2.1 LARGE SCALE LANDSCAPE ANALYSIS: METHODOLOGICAL APPROACH

In the geomorphological research a huge relevance is given to the morphometrical analysis of the landscape. The main goal of the quantitative geomorphology is the determination of some morphometrical parameters and their analysis in the search of possible correlations among them, and the mathematical modelling of the geomorphological processes acting at diverse scales of investigation (Scheidegger, 1970; Doornkamp and King, 1971).

The first morphometrical studies have been carried out in the middle 20th century: they were initially proposed by Horton and then they were then developed by Strahler (1952). The main idea that is at the base of this type of analysis is the attempt to describe the landscape through the definition of a series of parameters which could allow an objective description of the Earth surface and the production of objective models which could be either accepted by the scientific community or used as the base to develop new studies.

The morphometrical studies (in the way Horton developed them) were initially developed in the analysis of the fluvial system, using the idrographic basin as the reference landform: because of its characteristics of objectivity, precision and quantification of some metrics, the morphometrical approach was quickly extended to all the fields of the modern geomorphology (in particular it has been extensively used in tectonic geomorphology and fluvial geomorphology).

If we consider the tectonic geomorphology analysis in large scale studies, e.g. orogens, we need to focus our investigation on the determination of some metrics that could allow a parameterization of the system, and the comparison of the considered system with other similar contexts. Objective quantitative data useful to emphasize the main features of the analyzed system are, for instance, represented by the maximum, medium and minimum elevation, the swath profiles, the relief curves, the slope map, the envelop map, the river network indexes, the long profiles and their indexes (average slope, drainage area, SLI, concavity and steepness indexes).

In studies aiming at unravelling the morphotectonic history of a portion of the landscape, the morphometrical approach may provide useful constraints when it is combined with a classical geomorphological approach, which is based on analysis of the aerial photos and topographic maps, and field analysis.

The comparison of the classical geomorphological methods of investigation and the morphometrical approaches allow us to:

- determine the history of the vertical movements affecting the investigated area and their timing;
- separate portions of the landscape with a different behaviour in terms of vertical motions;
- identify the main tectonic structures responsible for such different behaviour of different portions of the landscape.

In particular, the studies of the vertical motions affecting a determined area and the recognition of areas with different behaviours in terms of vertical movements, can be done both on the large scale and on the small scale. The considered vertical motions can be both absolute (related to the global base level) and relative (related to local base levels) vertical motions. If the displaced morphologies or lithologies are chronologically constrained, then it is possible to estimate the timing of the vertical motions and to determine their rate.

In this type of analysis it is fundamental to recognize the main landforms representative of both absolute and relative past base levels. These landforms are the most useful indicators in the reconstruction of the vertical motions affecting a determined area. In particular, the landforms that are indicative of past base levels are:

- marine terraces;
- river terraces;
- hanging valleys;
- paleosurfaces;
- accordant peaks.

In addiction to this type of indicators, it is important the recognition of the main faults dismembering the landscape and the timing of their activity. This can be done by the analysis of the tectonic scarps, discerning between fault scarps and fault line scarps.

In the next sections we analyze the several geomorphic elements which are used in tectonic geomorphology, first describing the geomorphic features that could be recognized by the analysis of either a topographic map or with the field analysis, and then we move to the morphometrical metrics which could be determined by the analysis of the digital topographic data (DEM).

2.2 THE GEOMORPHOLOGICAL MARKERS OF TECTONIC VERTICAL MOTIONS

2.2.1 Fault scarps and fault line scarps

The fault scarps and the fault line scarps are two of the most diffuse morphostructural elements of the landscape: their genesis is due to the activity of a fault but, in the case of the fault scarps the fault exerts an active control on their formation, while in the case of the fault line scarps the fault exerts a passive control on their formation.

When we talk about a fault scarp, and we affirm that the fault actively control the creation of the fault scarp, we mean that the topographic height of the fault scarp is just due by the vertical fault offset, unless some deposition occurs on the hangingwall block determining a reduction of the scarp height. Another exception is represented by fault scarps created by pure horizontal slip (Ascione & Cinque, 1997) (fig. 2.1).

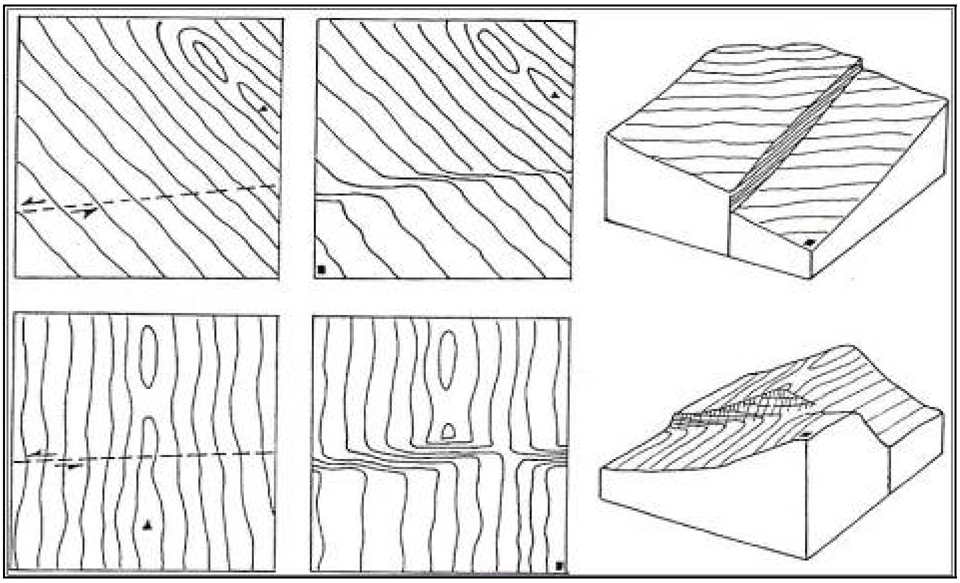


Fig. 2.1: possible cases of fault scarps generated by horizontal tectonic movements: A- fault scarp created by horizontal dislocation of an inclined surface whose orientation differs from that one of the strike-slip fault; B- two opposite fault scarps created by the horizontal dislocation of a ridge oriented perpendicular to the direction of the strike-slip fault (from Ascione & Cinque, 1997).

Another case in which the scarp height doesn't correspond with the fault offset is when the two blocks, hangingwall and footwall blocks, are made by different lithologies, and in particular there is the contact between “hard” lithologies and “soft” lithologies. In these cases the topographic height of the fault scarp is not given just by the sum of the vertical dislocations, but a relevant role is also played by the different rate of the erosional processes acting on both sides of the fault, which are strongly influenced by the rock-type cropping out in this areas, being higher in correspondence of the weaker lithologies. In these cases we don’t talk about fault scarp but we use the term fault-line scarp.

Anyway, it is not always easy to separate the erosional component from the tectonic component in the case of the fault line scarp: for the cases where this issue results particularly hard, it can be used the term “scarpate su faglia” (or fault related scarps) (Ascione and Cinque, 1997) (fig. 2.2).

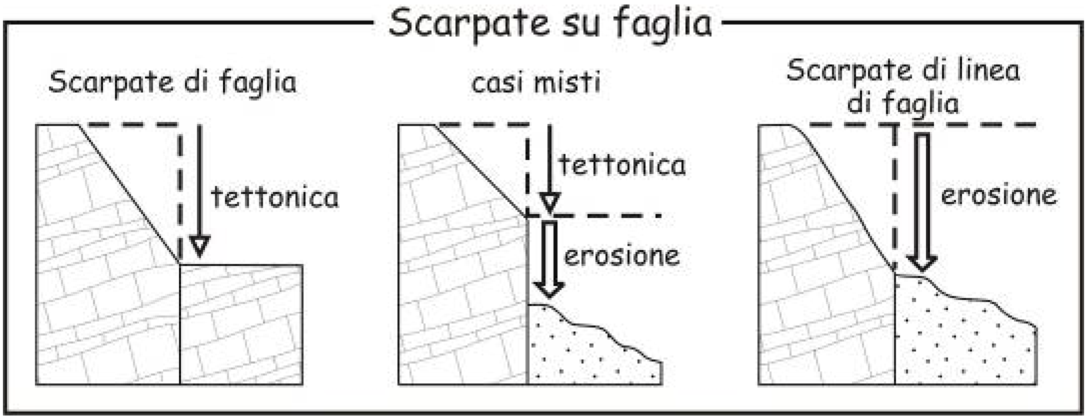


Fig. 2.2: scheme of the possible types of structural scarps (from Ascione and Cinque, 1997).

Both the fault scarps and the fault line scarps are markedly rectilinear in plan view (this shape is due to the geometry of the fault plane, and so it is due to the activity of either vertical normal faults or strike-slip faults), and its slope angle is influenced by the lithology and by the grade of evolution of the scarp. In the case of the fault line scarp, the elevation of the scarp toe varies along strike as a result of a variable erosional lowering of the hangingwall.

If we look at the form of the fault scarps, we notice how they are initially characterized by the presence of a prominent *free face* (erosional upper part of scarp steeper than the angle of repose of the lithologies interested by the fault) and an adjacent *debris slope* (area of colluvial deposition) (fig. 2.3): the debris slope is initially formed by slumps and rockfalls from the free face (Bull, 2007).

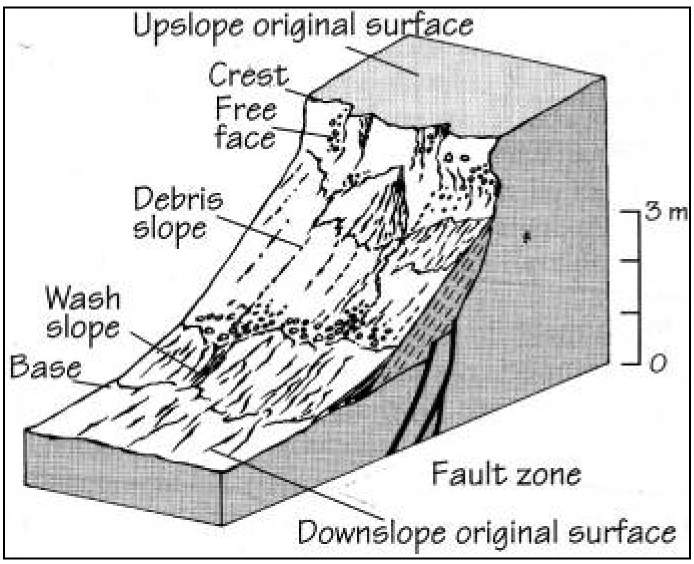


Fig. 2.3: Topographic elements of a diagrammatic single-rupture event fault scarp. Each element has a characteristic morphology formed by different processes (from Bull, 2007)

The evolution of a fault scarp is then characterized by a progressive reduction and disappear of the upper *free face* and by a progressive increase of the lower *debris slope*, with a general lowering of the whole system until the fault scarp reaches a slope which is equal to the angle of repose of the lithology in which the scarp has formed: the duration of this processes depends on the lithology and on the repeat of tectonic dislocation.

The proposed evolution models for the fault scarps are different as a function of the lithology: in alluvial and uncohesive sediments the *diffusion-equation model* is accepted (Bull, 2007), while in carbonatic settings, such as in the case of the Southern Apennines, both the *Lehmann model* than the *Richter model* are accepted (Brancaccio et al., 1978, 1979).

The *diffusion-equation model* predicts the rate of change in altitude of any points along a fault scarp as a function of the time, and it is governed by the following equation:

$$\delta y/\delta t = c\ \delta^2 y/\delta x^2$$

where $\delta^2 y/\delta x^2$ is the slope curvature, and x and y are the horizontal and vertical coordinates of a point, and c (the diffusivity coefficient) represents the rates of fluvial degradation and aggradation, which are assumed to not vary with time or space (Bull, 2007).

The *Lehmann model* predict the progressive retreat of the upper free face and the contemporaneous accumulation of the debris produced by the retreating free face at the base of the scarp, with the formation of a debris slope: the process will continue until the free face will disappear.

The *Richter model* could be considered a modification of the *Lehmann model* because it considers the case in which the lower debris slope is not formed: this could be due either to the presence of a river at the base of the scarp of the a limited extension of the basal flat element, which is required to accumulate the debris (Brancaccio et al., 1978, 1979).

2.2.2 River morphology

Alluvium is usually assumed to hide the underlying geology, but rates of active tectonic movement may be sufficiently rapid to affect the morphology and behaviour of alluvial rivers. Rivers being the most sensitive components of the landscape will provide evidence of even, slow, aseismic tectonic activity. For example, evidence of active tectonics is as follows (from Schumm et al., 2002):

- deformation of valley floor longitudinal profile;
- deformation of channel longitudinal profile;
- change of channel pattern;
- change of channel width and depth;
- conversion of a floodplain to a low terrace;
- reaches of active channel incision or lateral shift;
- effects both upstream and downstream of the zone of deformation (degradation, aggradation, flooding, bank erosion);
- formation of lakes.

The geomorphological response of a river to a tectonic event depends on the relative ratios among the tectonic displacement rate, the erosion rate and the depositional rate (Keller et al., 1999; Hovius, 2000). Depending on which factors is dominant on the others, we can have cases of rivers that are either parallel or discordant to the tectonic active structure (Villani, 2005).

The formation of oro-idrographic discordances, in many cases represented by gorges, could be due to relative uplift of a determined portion of the landscape or to a large scale vertical movements (lowering of the base level in the areas downstream the gorge). The elevations cut by the gorges could preserve remnants of ero-depositional river morphologies (strath and/or depositional terraces, alluvial fans, paleosurfaces), which could allow a reconstruction of the valley bottom lowering in the context of the relief evolution.

River terraces are one of the more diffuse geomorphological response of a river system to a tectonic uplift, both strath (erosional) and depositional terraces: in this case there is often a problem that is due to the occurrence of a climatic component in the formation of a river terrace which can overwhelm the tectonic component and that must be recognized and not considered in the reconstruction of the vertical movement history of the river system (Tyracek, 2001; Brocard et al., 2003: Starkel, 2003).

The river terraces formation is strongly influenced by the ratio between the incision rate and the lateral shifting rate of the valley floor: if the first one is higher that the second one we can have the *paired* terraces, which represent a brake of the incision processes; if the second one is higher than the first one we can have the *unpaired* terraces, which talk about a continuous incision, with no relevant stops.

The river terraces are usually *convergent*, that means that the longitudinal slope (parallel to the main valley) of the different terrace orders decrease as we move from the headwater to the mouth; in most cases, anyway, the river terraces are *divergent*, that means that the longitudinal slope (parallel to the main valley) of the different terrace orders decrease as we move from the headwater to the mouth. The second case could be to the occurrence of more pronounced tectonic uplift in the lowest portions of the river valleys than in its higher portions

A regional scale uplift has a strong influence on the whole river network of a chain, with the time of response that depends on the size of the chain: it could determine variations in the shape of the drainage basins, with a modification of the regional divide location. It is also important the temporal distribution of the regional scale uplift: Kunhi and Pfiffer (2001) show that the type of vertical movements and their timing has determined the disjunction of the maximum elevations line and the divide location in the Swiss Alps. This situation is also typical in the whole Apennines, and in particular the maximum elevation line is located west of the divide in the Southern Apennines, with the two lines that are coincident just in the southern portion of the Southern Apennines (Amato et al., 1995; Villani, 2005 and reference therein). A regional scale uplift has a strong influence on the river long profile too, as it will discussed in detail in the section 2.3.6.

Another geomorphological feature that allows the recognition of tectonic vertical movements is given by the hanging valleys: they are valleys located on top of the relief bordering a valley floor, so they are not anymore linked to the local base level and they indicate a relative vertical displacement of the relief where they are located respect to the valley bottom. We have anyway to consider that the formation of an hanging valley could be also related to the different response to the erosion of the two lithologies cropping out on both the hangingwall and the footwall blocks: an accurate analysis of the hangingwall can allow to discern between the two possible situation. The hanging valleys are very diffuse in several portion of the Southern Apennines, and in particular in the northern portion of the Noce valley (see sec. 5.9.4).

Another type of geomorphic response of the river system is given by the variation of the channel pattern of the alluvial rivers as a consequence of vertical tectonic movements: five basin channel patterns exist, (1) straight channels with either migrating sand waves or (2) with migrating alternate bars forming a sinuous talweg, (3) two types of meandering channels, a highly sinuous channel of equal width (pattern 3a) and channels that are wider at bends than crossing (pattern 3b), (4) the meandering-braided transition and (5) the braided pattern. Alluvial rivers will be very sensitive indicators of valley slope change: in order to maintain a constant gradient, a river that is being steepened by a downstream tilt will increase its sinuosity or braid, whereas a reduction of valley slope will lead to a reduction of sinuosity or aggradation (Schumm et al., 2002).

2.2.3 Marine morphology

The marine terraces are very useful in tectonic geomorphology because they allow the recognition and the estimation of the rate of the vertical motions of a determined area respect to the global sea level, and so they allow us to recognize processes of surface uplift (see sec. 1.5).

A marine terrace is formed when the relative height between the Earth surface and the sea level changes, and so the system composed by the abrasion platform and the sea cliff tends to emerge; it is typical to find such marine morphologies along all the Southern Apennines slopes close to the coastline.

The marine terraces are one of the most important morphologies in the reconstruction of the vertical motions that a determined area has experienced, because they could present different elevations also in very narrow areas, and they could so testify a different tectonic behaviour of adjacent coastal areas. From this point of view, the Holocene marine terraces are used to study the more recent tectonic events. The elevation of a marine terrace is due to the combination of both tectonic and eustatic vertical motions, so in morphotectonic studies the eustatic components must be separated to make considerations acceptable from a morphotectonic point of view. This separation is possible just in areas where there are detailed reconstruction of the glacio-eustatic sea level variations (fig. 2.4-2.5).

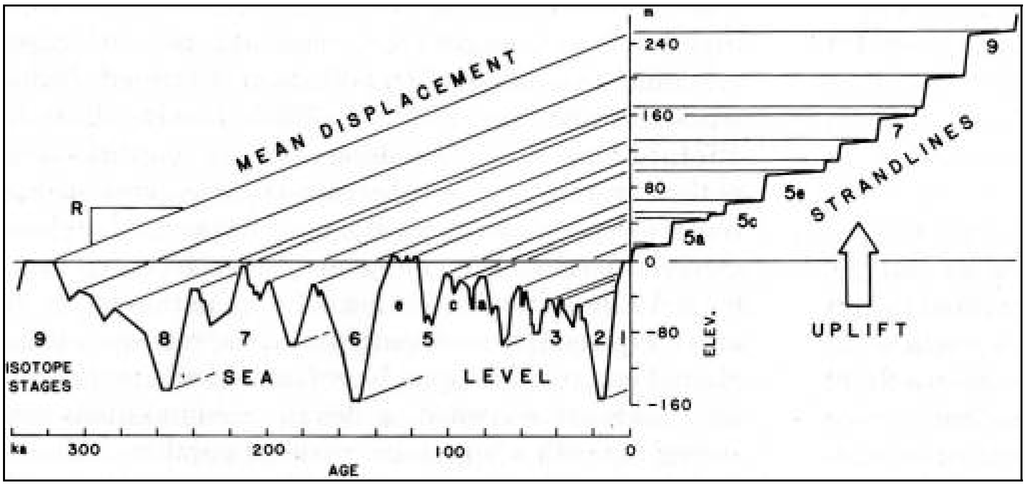


Fig. 2.4: Pleistocene sea-level fluctuations and origin of emergent Pleistocene strandlines. Emergent strandlines simultaneously record tectonic uplift and major sea-level highstands. The rising coastline is a moving strip chart on which sea-level highstands are recorded sequentially as strandlines whose ages increase with elevation. The slope (R) of the diagonal line connecting each highstand to the elevation of its strandline is the average uplift rate. If the uplift rate was constant, the uplift lines for all strandlines are parallel. Strandlines formed during lowstands are usually destroyed by subsequent sea-level fluctuations and rarely appear in the emergent geologic record. Strandlines younger than 60 ka appear above sea level only where the uplift rate is greater than 1m/ka. The sea level fluctuations curve was derived from a sequence of U-series dated coral reef strandlines on the Huon Peninsula, Papua New Guinea, by subtracting tectonic uplift from the relative strandline record (from Lajoie, 1986).

The marine terraces have been widely used on the entire Central and Southern Apennines for the morphotectonic reconstruction of both the local coastal systems and areas regionally extended (Parea, 1986; Cinque and Romano, 1990; Antonioli, 1991; De Rita et al., 1992; Dramis, 1992; Westaway, 1993; Ascione, 1997; Bordoni and Valensise, 1998; Amato and Cinque, 1999; Ascione and Romano, 1999; Basili, 1999; Calamita et al., 1999; Amato, 2000; Giordano et al., 2003; Antonioli et al., 2006; Ferranti et al., 2006).

If we are able to recognize the differential vertical movements by using the marine terraces and we want to figure out what are the rate of such movements, we then need to date the marine terrace: we can date a marine terrace either by using methods of absolute chronology (biostratigraphy, geochemistry, magnetostratigraphy) on the deposit present on the marine terrace or by using methods of relative chronology (trying to correlate the different marine terraces recognized in a certain area with the peaks of the eustatic curves) (Villani, 2005).

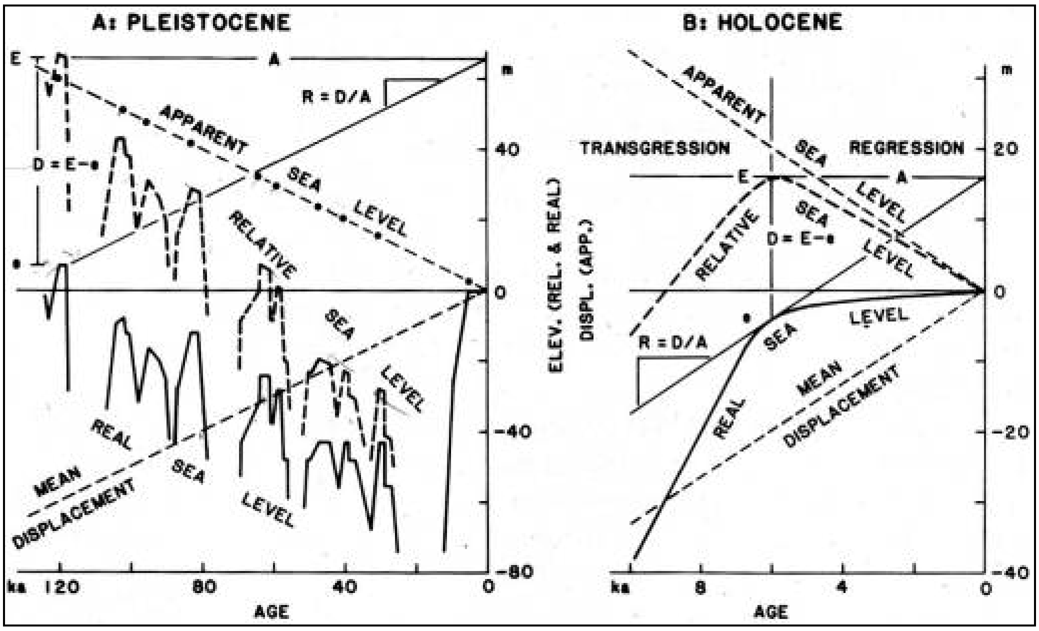


Fig. 2.5: Relative, apparent and real sea-level changes. A-Pleistocene; B-Holocene. All sea-level records (strandlines or tide-gauge measurements) are relative, which means they potentially represent both apparent and real sea-level changes (relative = real + apparent). Apparent sea-level changes are the inverse of the vertical crustal (or ground) movements that produce them and, therefore, are the focus of all the coastal tectonic studies. The apparent sea-level history is obtained by algebraically or graphically subtracting the real sea-level history from the relative record of marine strandlines. In effect, the real sea-level history is a composite tectonic datum. The real sea-level history is obtained by subtracting apparent sea level changes from a relative sea level record. In this case, the uplifting coastline is a moving sea-level datum. *E* is the present elevation of a strandline; *e* is the original elevation of a strandline; *D* is the vertical displacement ($D = E - e$); *A* is the age of a strandline; *R* is the crustal displacement rate ($R = D/A$) (from Lajoie, 1986)

Dated marine terraces could be very useful in the reconstruction of the tectonic history on the inner areas, in particular by trying to recognize what are the morphological relationships between the dated marine terraces with the fluvial terraces. This method will be used in this study with the aim to correlate and to date the river terraces of the Sinni and the Noce valley with the dated marine terraces on the Ionian and Tyrrhenian coast-line respectively (see sect. 5.10).

2.2.4 Paleosurfaces

In geomorphology the term paleosurfaces is used to indicate erosional surfaces and/or low relief landscapes hanging above the present base levels. The modes of formation of these landforms are strongly debated (see Davis, Peck and Budel theories), and they can be related to fluvio-denudational or to karst processes (Amato, 1995).

If we want to identify a paleosurface we have to focus our studies on the individuation of a series of particular feature, which can all be present in this landform, or it could be characterized by just one of them; this features are: the altimetrical position of the considered landform, which must be not correlated to the actual base level; the maturity of the landscape, which must be characterized by a very gentle topography with low relief and with valleys long profiles gentler than in the surrounding areas; a discordance among the paleosurface and the bedding of the rocks cropping out in the area where the paleosurface is individuated (Villani, 2005).

The paleosurfaces have been widely used in literature to reconstruct the tectonic history either of areas where there are just a few geomorphic markers (marine morphologies) that don't allow a good and detailed reconstruction of the tectonic history of the considered area or to reconstruct the uplift history of a chain: we can cite the papers of Bartolini (1980), Amato & Cinque

(1999), Bosi (2002) and Villani (2005, and reference therein) for an overview of the use of the paleosurfaces as a morphotectonic marker.

The paleosurfaces have been also used in the reconstruction of the morphotectonic history of the Southern Apennines: as it has been explained in the section 1.4, the first studies about this topic, carried out during the "Progetto Finalizzato Geodinamica – Sottoprogetto Neotettonica" (1960-1970) proposed a period of tectonic quiescence during which the formation of a regional scale paleosurface, the so-called *Paleosuperfice Auct.*, took place; the proceedings of the research showed the limit of this interpretation, because the several remnants of this paleo-landscape where recognized to be of different age and not to be coeval in the whole chain (Cinque, 1992; Amato & Cinque, 1999).

2.3 THE LARGE SCALE ANALYSIS OF THE LANDSCAPE

2.3.1 The analysis of the digital elevation models (DEM) in the morphometrical analysis of the landscape

The digital elevation models are based on a statistic investigation of the landscape: the topography is considered a bi-dimensional function of coordinate H(x,y), which is analyzed following a determined sampling interval (which determines the DEM resolution). The DEM is obtained by the attribution of a precise elevation value to each sampled area, value that corresponds to the average absolute elevation of all the points of the Earth surface included in the considered portion of the landscape. The elevation data are then organized in a matrix with M rows and N columns, and they can be analyzed following the typical methods of the statistical investigation.

The statistical analysis of the DEM allows the quick determination of several morphometrical parameters, with a particular attention that is given to the Hypsometry, that is the particular sector of the quantitative geomorphology that is devoted to the analysis of the relationships among area and elevation of a given territory (Strahler, 1952; Pike and Wilson, 1971).

The use of the DEM in the quantitative geomorphology has given arise to the knowledge in this branch of the geomorphology. There are several examples about the use of the digital elevation models in literature, such as Deffontaines et al. (1994), Fielding et al. (1994), Oakey (1994), Merritts et al. (1994), Kunhi and Pfiffner (2001), Montgomery et al. (2001), Amato et al. (2003), Radoane et al. (2003), Colombo et al. (2007).

In this study the 90m resolution DEM of the Nasa has been used, this digital elevation model can be freely downloaded over the web at the following address: http://seamless.usgs.gov/.. This digital elevation model has been used in the large scale analysis of the entire Southern Apennines and in the study of the Noce-Sirino-Alpi-Sant'Arcangelo transect. In addiction to this DEM, the 20m DEM has been initially used in the analysis of the previously named transect, but the many errors that are present in this DEM didn't allow an its useful use, this is the reason why the 90m DEM has been used also in the analysis of this transect. The study of the Noce valley, carried out on detailed topographic map in scale 1:5000, has been then based on the realization of a 5m DEM of the area, which will be shown in the section 5.10.2.

The investigation of the Southern Apennines topography by the 90m DEM has allowed the creation of the elevation map and the derived medium, maximum and minimum elevation maps. The topography has been also investigated along five transects distributed on the whole chain, with the creation of five swath profiles and the derived relief curves. Moreover, the analysis of the river system has been based on the creation of the long profile of the main trunks and tributaries of the whole chain and with the calculation of some derived metrics, such as the SLI, the drainage area vs distance, the steepness (Ks) and concavity indexes (Θ), and the calculation of the slope of the first order channels.

2.3.2 The elevation map and the derived maximum, medium and minimum elevation maps

The elevation map is a very useful tool in the morphometrical study of a determined area because it is a representation of the topography of an investigated region and it so allows the identification of the highest and the lowest peaks and their distribution: the elevation map is the first metric that could be derived by the DEM analysis, this is true if we consider that every single cell in the DEM contain the value of elevation of that determined portion of the landscape.

The elevation is intended as *absolute elevation*, i.e. it is referred to the global base level: the amount of topography that is reached in a particular portion of the Earth surface is given by the balance among forces that tends to uplift the landscape (tectonic and isostatic vertical movements) and forces that tends to lower the landscape (denudational processes).

There are other important elements that play an important role in the amount of topography reached by a determined area, and in particular we have to consider the depositional processes and the lithology: the depositional processes are responsible of the transport and accumulation of the products of the erosional processes on the Earth surface, while the lithology influences the amount of topography because of the different response to the erosion of the different rock-types, response to the erosion that depends on the geomechanical characteristics of the rocks which are strongly influenced by other parameters such as the number and distribution of fractures, the water content, the grain size, etc.

The maximum, medium and minimum elevation maps are derived from the elevation map by applying a filter to the original DEM and calculating the maximum, medium and minimum elevation in a moving window along the investigated area. The shape of a window can vary from case to case, but it is usually preferred a squared or circular window. In this study a squared moving window 5x5km wide has been chosen to derive these maps.

The maximum elevation map can be considered as the representation of an uplifted topography not subject to denudation. Of course it is a mere theoretical concept because there are no places in the world where the eroso/depositional processes don't take place and because the maximum elevation map is strongly affected by the rock-type cropping out in a determined area. Anyway, areas with different tectonic behaviour (either uplift or subsidence) result clearly in the maximum elevation map.

The medium elevation map is probably one of the most relevant parameters in the regional scale studies. In fact the medium elevation contains informations about both the total amount of vertical movements (both tectonic and isostatic) that a determined area has experienced and the total amount of the eroso-depositional processes too. Each variation of the medium elevation is proportional to the variation of potential energy of a determined area (England and Molnar, 1990), and so the regions with the highest values of medium elevation have experienced more work against the gravitational field which is usually linked to the geodynamic setting of the analyzed area (see D'Agostino et al., 2001).

The minimum elevation map is given by the lowest topographic point inside every moving windows: if we consider that the lowest topographic points of a determined area usually correspond to the valley bottom, the minimum elevation map represents the ideal surface of the local base level.

2.3.3 Swath profile

The swath profile represents one of the most powerful means of investigation of the landscape, because it allows to quickly recognize the main morphological and morphometrical element of the area of interest (wavelength; maximum, minimum and medium elevation a.s.l.; local relief; position of the maximum elevation line and the divide), highlightening possible anomalies on which focus the attention.

The main difference between a topographic profile and a swath profile is that while with a topographic profile we can analyze the features of the topography along a linear element (which could be represented either by a rectilinear or a non-rectilinear line), with the swath profile we can analyze the large scale variations of the topography, following a transect of width and length set by the author: this characteristic allows us to determine how the maximum, medium and minimum elevation vary in the area of interest determining, for example, how the relief varies in the same area.

The principle of construction of a swath profile is the following: once determined the transect of interest (it should be oriented perpendicular to the main tectonic and morphostructural elements of the landscape, such as thrusts front, intramontane basins, etc.), we have to define the offset, or width, of the transect: it must be dimensioned so that it can include both the topographic highs (ridges) and lows (valleys). It is important the choice of the swath profile width, it must be not too large if compared to the elongation of the morphostructural units crossed by the swath. Once we have defined the transect and its offset, we have to set the sampling interval (the equidistance between two sampled points along the profile): also in this case the sampling interval must be set to have a profile as smoothed as possible without loosing any information regarding the topography (maximum elevation, elevation of the valley bottom). At this point we are ready to start creating the swath profile: the sampling will occur along lines perpendicular to the selected transect, for each of them the maximum, medium and minimum elevation will be calculated. The data so obtained for the whole transect will be then plotted in an excel sheet, allowing the creation of the maximum, medium and minimum elevation curves, plotted in the same graph, that will be then analyzed to derive the morphometrical informations.

Unfortunately there is a limit to the creation of a swath profile: it can just be created following a rectilinear transect (fig. 2.6).

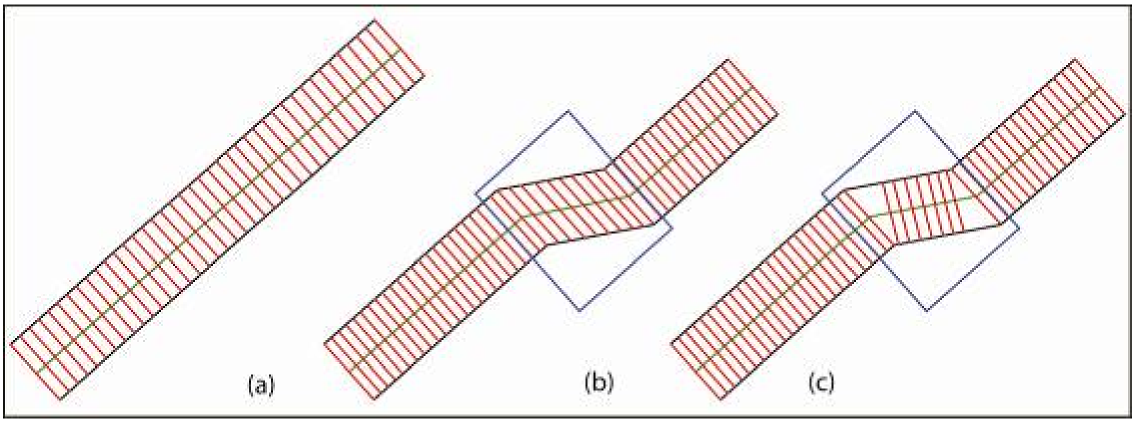


Fig. 2.6: principles of construction of a swath profile along a rectilinear (**a**) and a non-rectilinear (**b**) line: the green line represent the selected transect along which we want to create the swath profile, the black lines represent the buffer, or the total width of the investigated area, the red lines represent the sampling intervals. Notice that while in the case **a** the sampling occurs along line always perpendicular to the transect, this is not true for the case **b** where the red lines don't modify their orientation at the variation of the transect direction (blue box), being not perpendicular to the transect; in the same way, if we modify the orientation of the red lines positioning them perpendicular to the transect, the sampling will be more dense on the internal ray of the transect than on its external ray (**c**), determining to loose of data close the point of curvature. This simple scheme clarify the limits of construction of a swath profile, limits that must be considered when we work with a swath profile to don't make wrong considerations in the phase of analysis.

If we try to create a swath profile along a non-rectilinear line we have the problem that in the point of curvature the sampling will not occur along lines perpendicular to the transect, not respecting the basal principle of a swath profile: in fact, after the variation of the transect direction, the sampling will occur along lines inclined of an angle

$$\beta=(90°- \alpha)$$

where α represents the angle the original direction of the transect and its new direction (fig. 2.7).

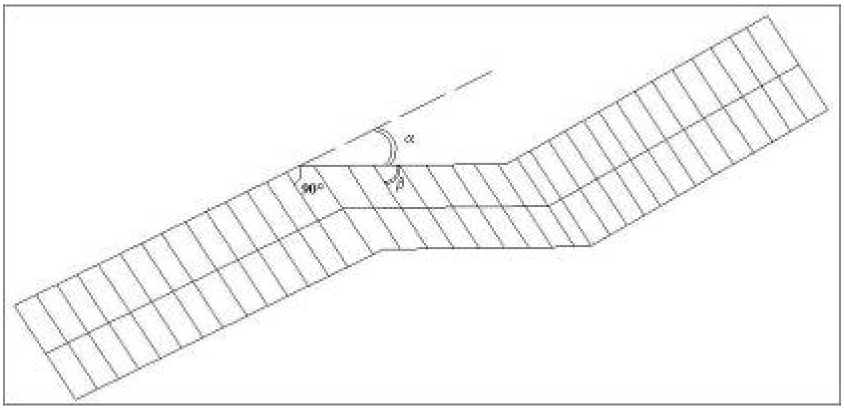


Fig. 2.7: variation of orientation of the sampling lines at the variation of the transect direction

2.3.4 Relief curve

The relief is intended as the difference between the highest and the lowest point in a given area. In this study the relief has been calculated as the difference between the maximum elevation line and the minimum elevation line obtained by the swath profiles, so this important metric has been analyzed along several linear transects covering the entire Southern Apennines.

The amount of relief increases as the analyzed area becomes wider (Ascione, 1997): this occurs because as the analyzed area increase it could involve regions topographically either higher or lower of the initial studied area, as it is shown in fig. 2.8.

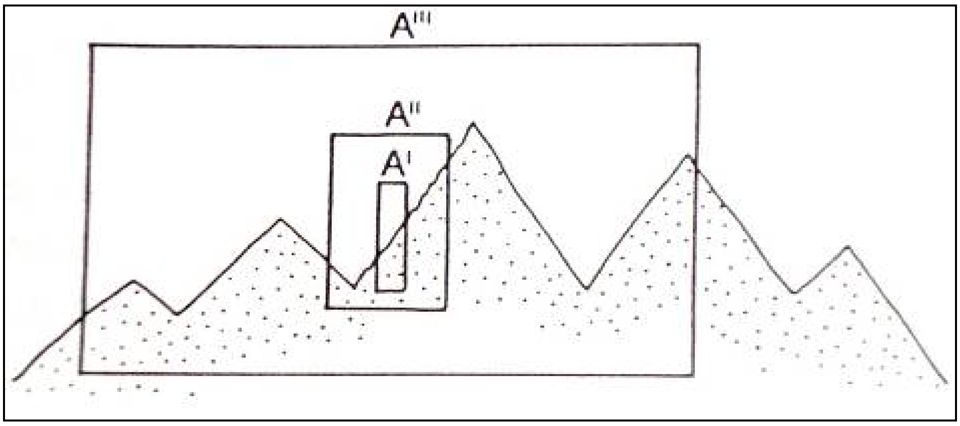


Fig. 2.8: the relief of a considered area increase as the analyzed area becomes wider because the widest area will be more representative of the real topography of the studied region; in the sketch, the relief will increase as the studied area will pass from A^{I} to A^{II} and to A^{III} (from Ascione, 1997).

The relief is the product of the combination of both the endogenic and exogenic processes which continuously tend to modify the Earth surface. Budel (1982) suggests that it is not possible to create relief without the emersion of the considered area. We can anyway consider that tectonics is the primary process responsible of the creation of the relief, while the eroso-depositional processes tend to modify the relief created by the tectonics. The tectonic processes could be also the only process responsible of the creation of the relief, this occurs when there are differential vertical movements between adjacent areas (fig. 2.9); in theory, if the ero-depositional processes couldn't occur, the relief of the Earth surface would result just by the tectonic processes, and we'll have what Budel call "*endogenic raw form*".

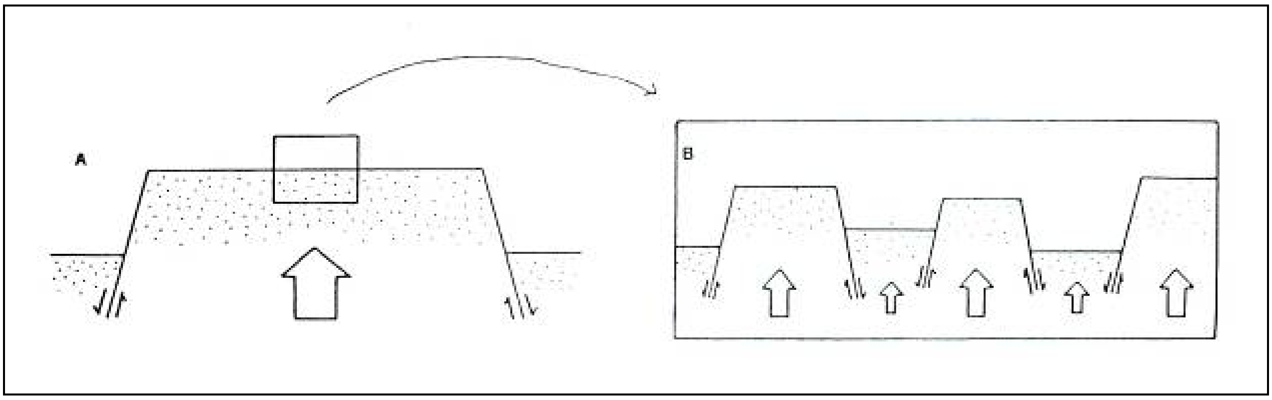


Fig. 2.9: large scale differential vertical movement will create the relief in a determined area (A), and low scale vertical movements can dismember the uplifted region in case A and could create relief inside the uplifted area (B) (from Ascione, 1997).

2.3.5 River long profile

The river long profile is a plot of the channel elevation with respect to the distance. It must not be confused with the valley long profile, which is a plot of the medial valley elevation with respect to the distance. Some authors consider the valley long profile a better average reflection of the long-term long profile responsible for carving the valley (Spagnolo and Pazzaglia, 2005).

The river long profile shape is given by the combination of several factors: tectonics, climate and lithology. Rivers usually tend to have a concave upward long profile. The reason of this concave up shape is related to the downstream increase of the drainage area (because of the increase of the numbers of tributaries) and, consequently, to the downstream increase of the discharge, to the downstream fining of the debris transported by the river and to the downstream increase in channel width in alluvial channels (Zaprowski et al., 2005 and reference therin).

A synthesis good summary of the river response to modification of the long profile is provided by Schumm (1993). The river long profile have been widely used to study the effects on the landscape of tectonic processes (Snyder et al., 2000; Zaprowski et al., 2001; Duval et al., 2004; Molin et al., 2004; Frankel and Pazzaglia, 2005; Spagnolo and Pazzaglia 2005; Zaprowski et al., 2005)

The natural tendency of a river long profile is to reach the so-called "*graded profile*", which is a profile where the gradient of the valley floor progressively decreases moving towards the mouth and where all the debris is transported to the mouth and it is not accumulated within the valley (Spagnolo and Pazzaglia, 2005; Zaprowski et al., 2005).

Deviations from a smooth, concave-up form may indicate that the fluvial system is in a transient state of adjustment to a base-level, tectonics, climatic or rock-type perturbation. In particular, convex segments called knickpoints or knickzones (depending upon their length compared to the total stream length) can be specifically investigated to evaluate their coincidence with tectonic perturbations at scales ranging from massif-wide doming, to local faults offsets (Molin et al., 2004).

If a tectonic event affects a given portion of a river valley, the river will respond by changing its long profile (this is the case of the occurrence of either a normal of thrust fault, or to a growing fold). The latter profile will result steeper in this area, with the individuation of a knickpoint. The knickpoint is associated to local deformation (e.g. normal faults or thrust faults). On the other side, a knickzone may results from long wavelength deformation. If, again, the tectonic event is represented by a large scale uplift the river long profile will modify its shape, by moving towards either a rectilinear or a convex upward shape of the whole profile.

Knickpoints or knickzones can be formed also by other processes, and in particular by glacio-eustatic variations of the sea level. In this cases, the lowering of the sea level will first create a steeper valley floor segment close to the river mouth. Subsequently it will generate processes of regressive erosion which will extents also in the whole drainage basin. It is also important the rate of the base-level lowering: in response to a fast lowering, a stream incises vertically with little lateral migration, whereas when the rate of lowering is low, considerable lateral migration takes place (Schumm, 1993).

The morphology of the valley in which the river flows is important in determining the ability of a river to adjust to base-level change: if the channel is in a wide valley or flowing across a plain, it has the ability to shift laterally; a channel confined within a narrow valley can only aggrade or degrade (Schumm, 1993).

Experimental studies in low cohesion sediments have shown that knickpoint will not migrate indefinitely upstream. In fact, as the knickpoint reach lengthtens, its slope is reduced until it is nearly equal to the slope of the stream. The knickpoint cannot be identified if its slope reaches approximately 20% of the average slope of the river. As slope reduction takes place, stream competence declines to the point that bedload movements cease; considerable bank erosion takes place in cohesionless sediment so that widening of the channel occurs and stream competence declines (Schumm, 1993).

2.3.6 SLI (Stream Gradient Index)

The Stream Gradient Index was introduced by Hack (1973) in his studies on the North-American rivers. The author found that a simple logarithmic graph of the stream profile provides the basis for a useful system of analysis. In this graph, the origin of the profile is at the drainage divide, which forms the source of the stream. The vertical coordinate, is an arithmetic scale and represents the altitude or height above sea level. The horizontal coordinate is a logarithmic scale and represents the stream length or distance from the source. Where the stream profile is a straight line on such a plot, the profile equation is:

$$H = C - K \log_e L \qquad (1)$$

where H is altitude at a point on the profile and L is stream length (horizontal distance from the drainage divide to the same point on the principal stream measured along the channel). C and K are constants. The tangent to the profile or slope, S, of the stream at a point is the derivative of equation l and it is given by:

$$dH/dL = K\,L^{-1} \qquad (2)$$

which can be arranged as

$$K = S\,L \qquad (3)$$

The gradient index is a significant value because it is crudely related to the power of a stream to transport material of a given size and to the characteristics of the channel flow.
The gradient index can be measured on topographic maps, on aerial photographs using photogrammetric methods, or by ground surveys. The parameters measured are shown in figure 2.10: L is the stream length measured from the drainage divide at the source of the longest stream in the drainage basin above a locality on a reach. $\triangle H$ is the difference in elevation between the ends of the reach, and $\triangle L$ is the length of the reach.

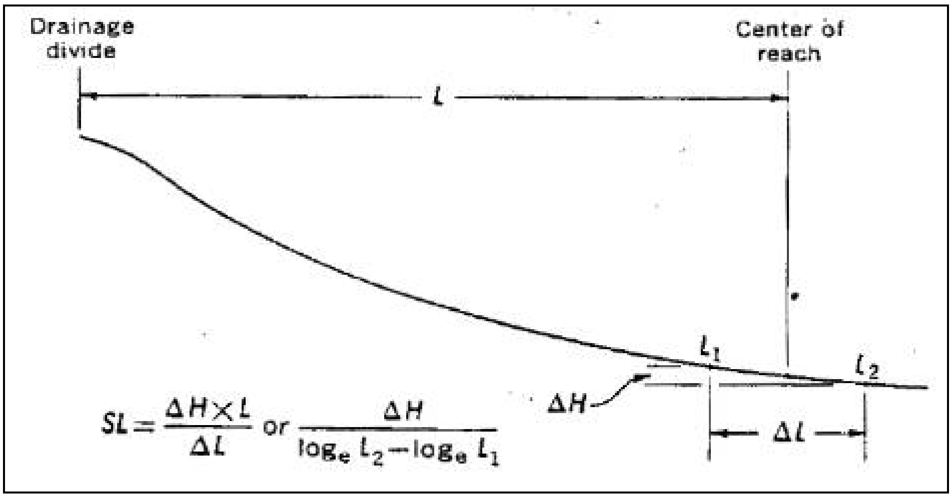


Fig. 2.10: measured parameters used in the calculation of the stream gradient index (from Hack, 1973).

The importance of the Stream Gradient Index and its variations along a river long profiles is due to the facility of its calculation, which allow a quick first analysis of the river long profile, enhancing the presence of steeper portion of the long profile (knickpoint) that will be then analyzed in detail to recognize what is the main process responsible of these steep sectors (tectonics, lithology or climate).

2.3.7 Slope vs area: steepness (Ks) and concavity (Θ) indexes

Rivers long profiles (of both alluvial, mixed, and bedrock channels) tend to have a concave-up shape as a consequence of the downstream decrease of grain size and increase of discharge. The rate at which a river incise into the bedrock depends on several factors, in particular: climate, lithology, rock uplift rate, sediment load. Two different approaches have been developed in modelling the river incision rate, the first one considers the river incision rate proportional to the stream power (Spagnolo and Pazzaglia, 2005), which can be defined as the rate of energy expenditure by the flow (Seidl and Dietrich, 1992); the second one considers the incision rate proportional to the shear stress on the bed (Howard, 1971; Howard and Kerby, 1983). Both approaches bring to a similar equation for the river incision rate:

$$E = K\,A^{m}\,S^{n} \qquad (1)$$

where E is the river incision rate, K is a dimensional constant that varies as a function of rock type, climate, channel width and hydraulics and sediment load; A is the drainage area (considered a good proxy for the discharge); S is the channel gradient, m and n are dimensionless parameters.
The rate of change of the channel bed elevation is given by the following equation:

$$dZ/dT = U - E \qquad (2)$$

where dZ/dT is the rate of change of the channel bed elevation, U is the rock uplift rate and E is the river incision rate.

Substituting equation 1 into equation 2 we obtain:

$$dZ/dT = U - K\,A^{m}\,S^{n} \qquad (3)$$

Under steady-state conditions (dZ/dT = 0) with uniform U and K and constant m and n, solving equation 3 for S bring us to the following equation:

$$S = (U/K)^{1/n} A^{-(m/n)} \qquad (4)$$

with S being the equilibrium slope. This equation predict what should be the channel gradient in a steady-state conditions.

Many studies have been focused on the analysis of the slope/area relationships (Hack, 1957; Flint, 1974; Moglen & Bras, 1995; Slingerland & alii, 1998; Hurtrez et alii, 1999; Snyder et alii, 2000; Kirby & Whipple, 2001): they show that the river gradient is inversely proportional to the drainage area, following an hyperbolic equation of the form:

$$S = K_s A^{-\Theta} \qquad (5)$$

with K_s representing the steepness index and Θ representing the concavity index.

If we compare equation 4 and 5 we can write:

$$Ks = (U/K)^{1/n} \qquad (6)$$

and

$$\Theta = m/n \qquad (7)$$

As shown by equation 6, the K_s index is proportional to the rock uplift rate, while there are no field values for the exponent m and n, although if their ratio (Θ) is more easy to be determined (Kirby and Whipple, 2001). Θ is strongly influenced by the other factors that control the long profile shape, and in particular lithology (Duvall & alii, 2004; Spagnolo & Pazzaglia, 2005), climate (Roe & alii, 2002; Zaprowsky & alii, 2005), drainage area and discharge, ranging between 0.35-0.6 (Whipple & Tucker, 1999; Snyder & alii, 2000; Kirby & Whipple, 2001). Notwithstanding, some authors have also shown a relationship between the concavity index and the rock uplift rate (Kirby & Whipple, 2001), suggesting that Θ is also strongly influenced by the rock uplift rate.

2.3.8 Slope of the first order channels

The first order channels analysis provides useful informations to locate areas of more recent uplift. This type of approach has been used in the reconstruction of the morphotectonic history of different areas , as it is shown by the paper of Merritts and Vincent (1989) and Frankel and Pazzaglia (2005).

Merritts and Vincent (1989), in particular, are the first authors to use this type of morphotectonic indicators. They have studied the main geomorphologic feature of an area of recent tectonic uplift, close to the Mendocino Triple Junction (MTJ). This area has been chosen because it can be considered homogeneous from both a lithological point of view and a tectonic point of view, so that the uplift can be considered the only factors influencing the geomorphic features of the area (this is the basis assumptions of this type of studies).The authors found that the slope of the first order channel is the geomorphic feature that show the best correlation with the uplift rate, as it is described in table 3 of Merritts and Vincent (1989) and in the fig. 2.11.

The authors propose the following interpretation of this data: during rapid uplift streams are rejuvenated, channels are downcut, stream gradient increase and valley walls become oversteepened; larger streams are able to maintain their profile forms through time by incising rapidly enough to adjust to lower base levels; smaller tributaries are unable to incise an amount equal to the base level fall; hence, they accumulate the effects of net base level fall over a period of time and have steepest profiles in the areas of highest uplift rates.

This consideration suggest that studies of gradient of lowest magnitude streams will be very useful in identifying tectonically active areas (Merritts and Vincent, 1989).

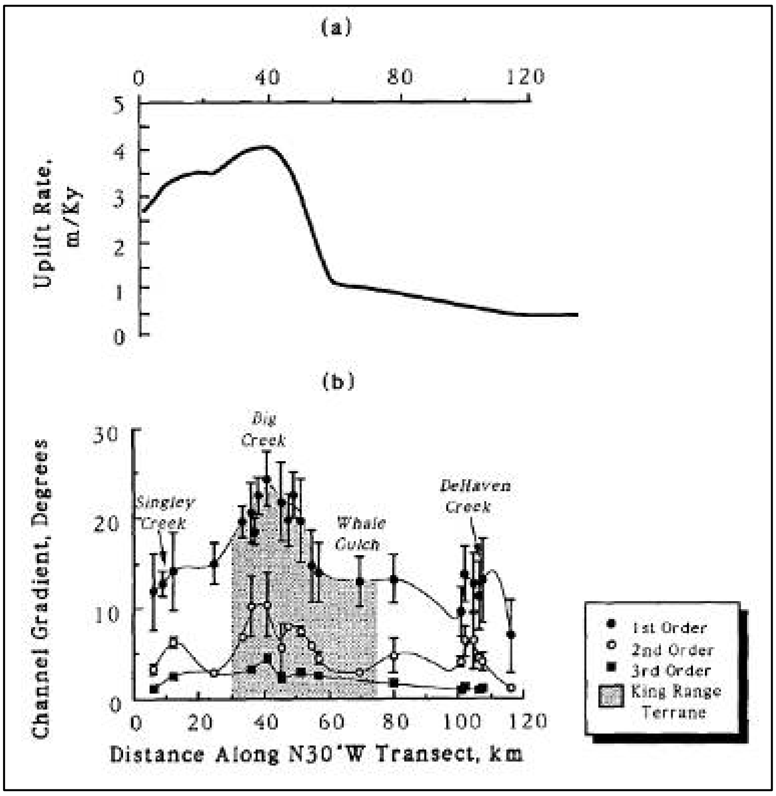


Fig. 2.11: uplift curve (a) and variation in mean values of first-, second- and third-order channel gradient (b) for each coastal drainage basin, plotted along a N30°W coastal transect (from Merritts and Vincent, 1989).

CHAPTER 3

GEOMORPHOLOGICAL ANALYSIS OF THE SOUTHERN APENNINES

3.1 MAP OF THE MORPHOSTRUCUTURAL UNITS OF THE SOUTHERN APENNINES

One of most relevant parameters on controlling the geomorphological features of a determined area is the lithology. The landscape ability to preserve through time the indicators of paleo-processes (both tectonic and eroso/depositional) is a function of the resistance to erosion of the outcropping rocks. The resistance to erosion, in its turn, is a function of the geomorphic processes acting in a given morphoclimatic zone, i.e. it is controlled by climate. In temperate regions, hard bedrocks favourable to a long preservation of erosional landforms are represented by carbonate rocks and by some well cemented both igneous rocks and metamorphic rocks (e.g. granite and gneiss). Soft, or highly erodible rocks, are conversely represented by quaternary deposits, flysch units and some poor cemented both igneous and metamorphic rocks such as pyroclastic deposits, slate and phyllite.

The bedrock resistance to erosion (or, conversely, the erodibility) strongly affects the landforms features. In fact, parameters such as the elevation, local relief, steepness, presence of knickpoints are strongly controlled by bedrock erodibility. As a result, the first step in the analysis of the landscape is represented by a clear depiction of the space distribution of the rock types with different erodibility. For the above mentioned reason, a "Map of the Morphostructural Units of the Southern Apennines" has been created. The grouping of different bedrock types and the distinction of different groups was in fact based on the estimation of erodibility of each rock type relative to other rock types. The erodibility degree was basically assigned by the observations of the features (e.g. steepness, degree of development of the upper convexity/basal concavity of hillslopes, average elevation, etc.) associated with the various bedrocks. As regards the Quaternary deposits, these were grouped based on different criteria. Taking into account the main goal of this study, which consists in the reconstruction of the Plio-Quaternary relative/absolute vertical motions of the Southern Apennines, the grouping of the different Quaternary stratigraphical units was based on the depositional environment (marine vs continental), degree of correlation of the different units with the original depositional environment (i.e. whether and to what degree they are displaced/dissected), and tectonic context (e.g. peri-tyrrhenian grabens, foredeep and intramontane basins deposits).

The "Map of the Morphostructural Units of the Southern Apennines" is a simplification of the "Geological Map of the Southern Apennines" in scale 1:250000. In fact the 81 formations distinguished in the "Geological Map of the Southern Apennines" have been reduced into the 20 morphostructural units of the map of fig. 3.1, following the previously described considerations. The main morphostructural units that have been distinguished are the following:

- peri-tyrrhenian and peri-adriatic coastal plains (they comprise the huge peri-tyrrhenian graben of the Campana plain and the Sele plain, and the smallest Alento plain in Cilento and the coastal plains on the north side of the Gargano promontory);
- marine deposits (they are marine terraced deposits located far from the main coastal plain, such as the terraced marine deposits of Punta Licosa (Cilento), and the marine deposits in the Murge region);
- dislocated alluvial deposits (such as the "Conglomerati di Eboli" and the "Conglomerati di Centola" formations, alluvial deposits that actually form important morphological highs, that in such case are clear example of relief inversion, such as the "Conglomerati di Centola" hill close to the archaeological site of Velia);

- quaternary deposits of the intramontane basin (they usually generate low-relief or even flat landscapes);
- quaternary deposits of the foredeep;
- glacial deposits (they have been just recognized on top of the Alburno-Cervati ridge);
- pyroclastic deposits (they cover the mountains bordering the Campana plain, being the main responsible of the large number of landslides affecting this area);
- volcanic areas (the volcanic area of the Phlegrean Fields and the Roccamonfina, Somma-Vesuvio and Vulture volcanoes);
- pre- to late-orogenic Neogene deposits (they represent the flysch units deposited on top of the Apennine carbonates);
- Numidian Flysch (this flysch represents the closing cycle of the Lagonegro basin, it is considered a flysch also if it has an aeolian origin);
- Monte Sacro formation (igneous rocks cropping out on top of the Mt. Sacro, Cilento);
- Ophiolitic olistoliths of the Monte Centaurino (directly in contact with the Monte Sacro formation, they only crop out in the Cilento region);
- Apennine carbonatic units (they represent the carbonatic platform deformed during the Euro-African collision);
- Foreland carbonatic units (they represent the carbonates of the Apulian platform, that form the foreland of the Tyrrhenian-Apennine orogenic system);
- Monte Alpi unit (they are the carbonate of the Apulian Unit cropping out inside the Apennine chain);
- Lagonegro Unit (they represent the filling of the sedimentary basin separating the Apennine and the Apulian platforms);
- Liguridi Units (a Jurassic-early Miocene set of heterogeneous units that are the accretionary complex of the former subduction zone);
- North-Calabrian Units (a set of metamorphic rocks cropping out in the southern portion of the chain, at the Basilicata-Calabria border);
- Sicilidi Units (soft lithologies cropping out on the southern portion of the external side of the Apennine, and in the high Sele valley).

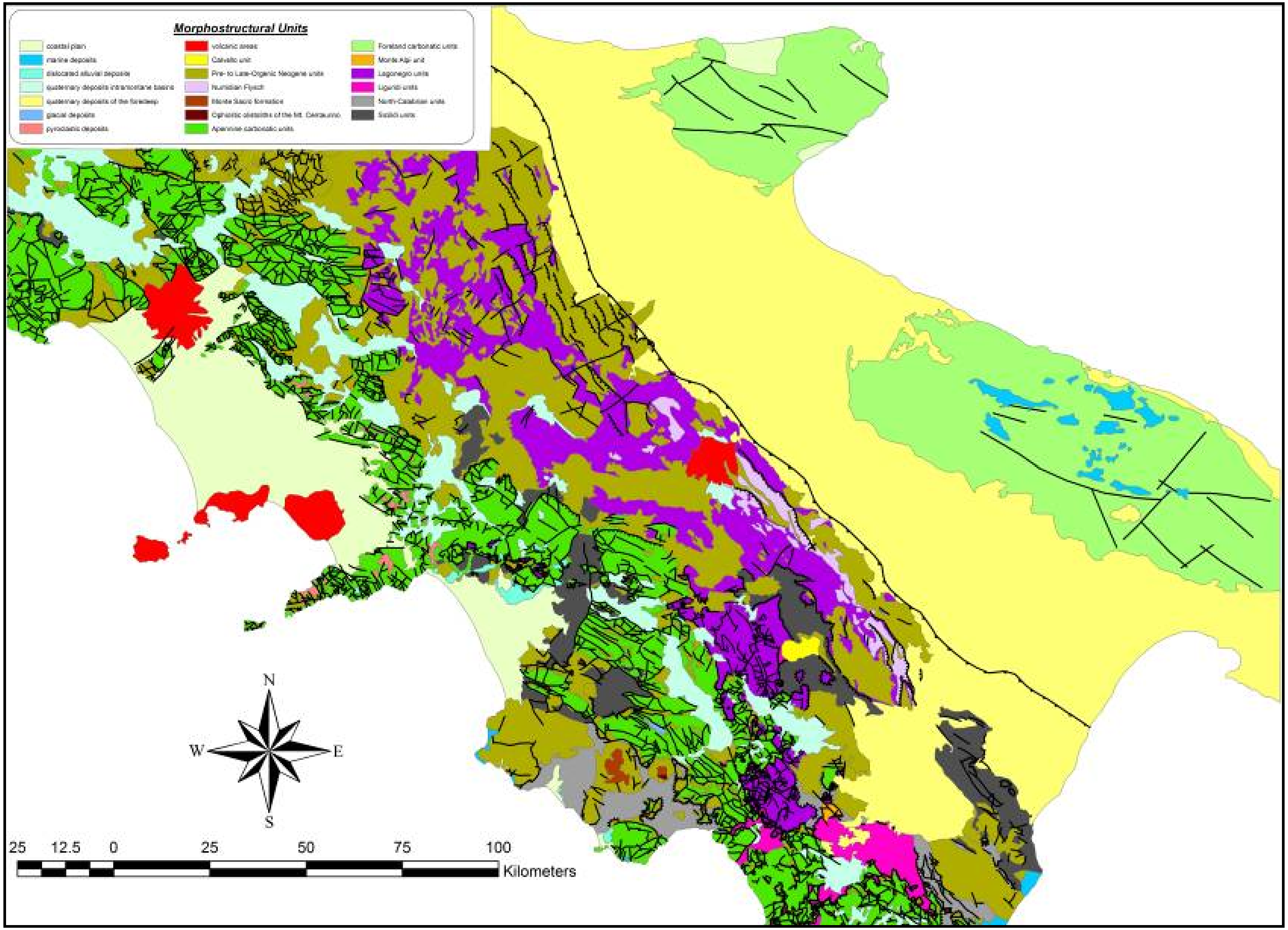


Fig. 3.1: Map of the morphostructural units of the Southern Apennine chain (derived from the Geological Map of the Southern Apennine, scale 1:250000), the units have been assembled by merging formations with similar morphological and morphometrical parameters.

3.2 THE ELEVATION MAPS

3.2.1 The elevation map

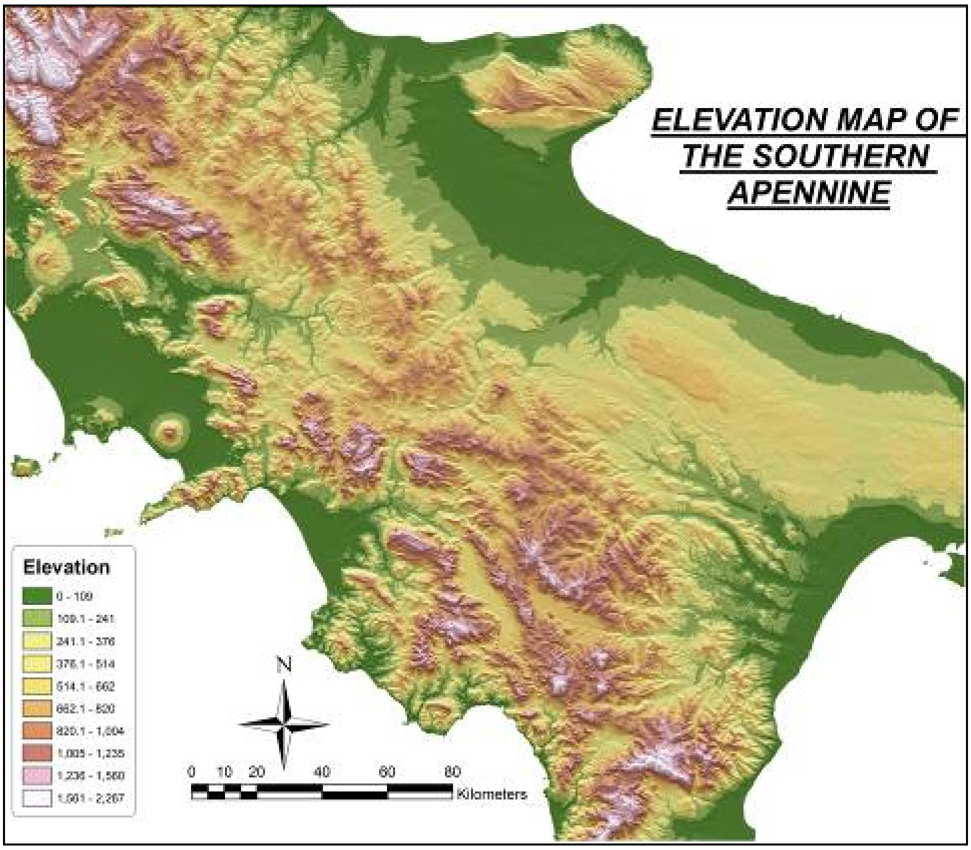


Fig. 3.2 : elevation map of the Southern Apennines

The elevation map of the Southern Apennines has a clear relationship with the “Morphostructural Map of the Southern Apennine” of fig. 3.1: if we compare the two maps, we can notice how the highest peaks of the chain are located in correspondence of the hardest lithologies, in particular the carbonates of the Apennine platform. The highest elevations are shown in the map by the dark brown to whitish colours, they are reached on the Matese massif (Mt. Miletto, 2050m a.s.l.), the Alburno-Cervati ridge (Mt. Cervati, 1898m a.s.l.) and the Pollino massif (Mt. Serra Dolcedorme, 2249m a.s.l.). In this map the highest peak is of 2267m a.s.l., this elevation is reached in correspondence of the Mainarde massif, a carbonatic massif that belongs to the Central Apennine system. The only exception to the rule “limestone = highest peaks” is in correspondence of the Murge region. In this area an almost undeformed limestones of the Apulian platform crop out, which represents the foreland of the Apennine orogenic system, and feature an almost flat landscape. Highest peaks are reached also where the hardest units of the Lagonegro Basin crops out, and in particular in correspondence of the Sirino massif (Monte del Papa, 2005m a.s.l.) and the Mt. Volturino (1835m a.s.l.), and in correspondence to the only outcropping of the carbonates of the Apulian platform (Mt. Alpi, 1900m a.s.l.).

The lithological control is also shown by the lowest elevations: the brownish-yellowish colours indicates areas lower than the dark brown to whitish colours. These areas correspond with outcrops of the Flysch Units, the Liguridi Units and the Sicilidi Units, which are mostly composed of sandy-silty-clayey successions. In this altimetrical range the Lavello high (see sect. 1.2.2) is also included, that separates the foredeep into the Puglia and Lucanian sub-basins (Balduzzi et al., 1982a). The greenish colours correspond to the lowest elevations, they are found in the coastal plains and, in same cases, in some intramontane basins, e.g. the Venafro plain, the Airola plain, and also in same valley, e.g. the Calore Beneventano and the Tanagro valleys.

3.2.2 The maximum elevation map

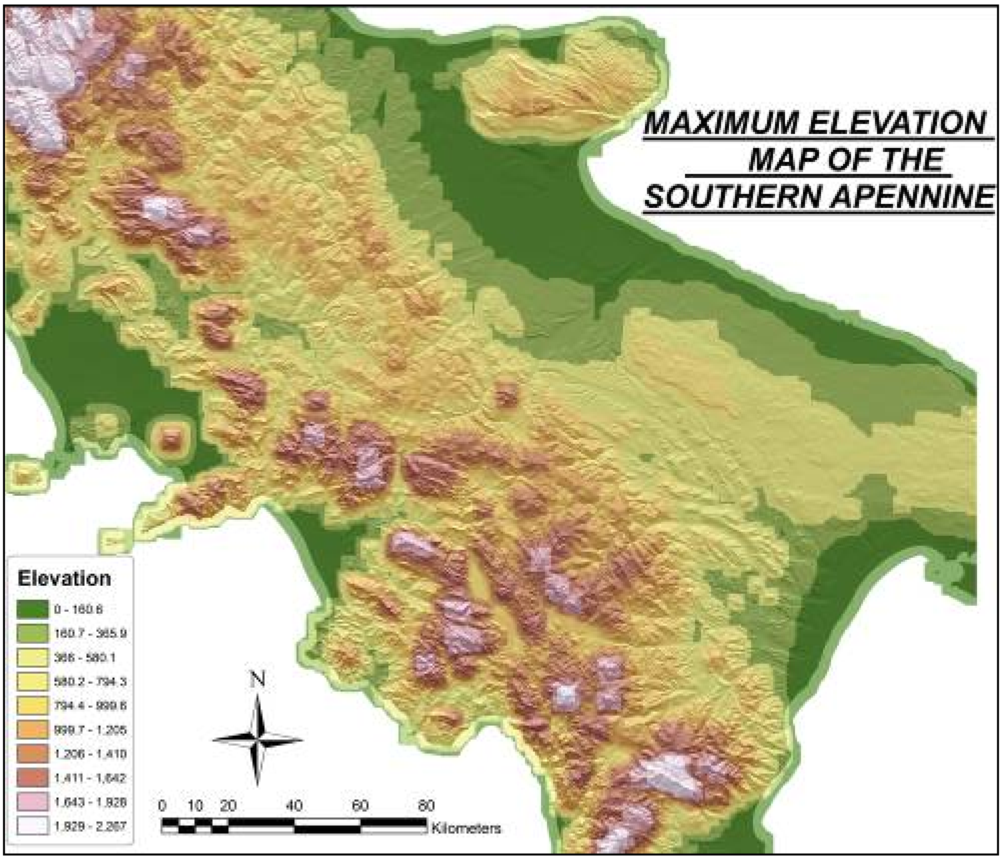


Fig. 3.3 : maximum elevation map of the Southern Apennines

The maximum elevation map has been created by using the 3D Analyst tool, and in particular by using the Neighbourhood Statistic function: the maximum elevation has been calculated in a 5x5km rectangular moving window. In the coastal areas this window involved also part of the sea (it corresponds with a no-data area in the dem), this is the reason why the maximum elevation map exceeds the dem limits in these regions, assuming values greater than 0 in particular where the coast line is characterized by high cliffs and mountains, such as in the case of the Sorrento Peninsula, the Cilento and the Gargano promontory.

The highest peaks of the maximum elevation map (fig. 3.3.) correspond to the highest peaks of the elevation map (fig. 3.2): moving from the north to the south we can recognize the Matese massif, the Picentini ridge, the Alburno-Cervati ridge, the Mt. Volturino-Mt. S. Enock ridge, the Mt. Sacro, the Mt. Sirino, the Mt. Alpi, the Mt. Raparo and the Pollino massif. Other important morphostructural highs, showed by the dark brownish colours, are the Taburno-Camposauro ridge, the Monti di Avella ridge, the Mt. Marzano ridge, the Mt. della Maddalena ridge, the Mt. Cocuzzo and the Mt. Coccovello.

A relevant feature of the maximum elevation map is represented by the reduction of the sizes of the river valleys and in particular by the closure of some of them. This is the case of the medium Volturno valley, if we look at the elevation map (fig. 3.2) this river cross over the Monti di Caserta ridge and it then flows into the Campana plain until its mouth, while in the maximum elevation map (fig. 3.3) the valley is limited by the Monti di Caserta ridge to the west, and by the Taburno-Camposauro ridge to the east and the Matese massif to the north, assuming the feature of an intramontane basin. A similar consideration can be extrapolated for the Calore Beneventano valley: in the elevation map this river flows in the area between the Matese massif and the Taburno-Camposauro ridge, while in the maximum elevation map these ridges are the western limit of the Calore Beneventano valley that so assumes the feature of an intramontane basin too.

If we pay attention to the Cilento region, we can notice how the dimensions of the Cilento river decrease in same case (Alento river), while, in other cases, the rivers valleys are not showed in the maximum elevation map (this is the case of the Lambro, Mingardo and Bussento rivers).

The Vallo di Diano and the Val d'Agri basin are stiil evident but, while the Vallo di Diano is clearly limited to the north by the Monti della Maddalena and the Alburno-Cervati ridges, and it seems to be separated in two distinct sub-basins, the Val d'Agri is still connected with the Sant'Arcangelo basin by the Agri river, and the gorge that it cuts in the lower portion of the Agri basin is still clear.

In the southern portion of the Southern Apennine the Noce valley assume the feature of an intramontane basin too, being limited to the south by the Monti di Trecchina-Monte Messina ridge, to the west by the Mt. Coccovello and the Mt. Cocuzzo and to the east by the Sirino massif.

In the foredeep region there are the major differences in terms of valleys sizes, in particular in the northern portion (Puglia basin of Balduzzi et al., 1982) the Ofanto, Carapelle, Cervaro, Celone, Fortore and Biferno valleys seem to merge in a unique landscape gently dipping towards the adriatic coast, while in the southern portion of the foredeep (Lucanian basin of Balduzzi et al., 1982), the Lavello high is more extended to the south, the Bradano valley is still evident but it has a very reduced dimensions, the Basento valley is not shown in the map while the Cavone valley is shown.

3.2.2 The medium elevation map

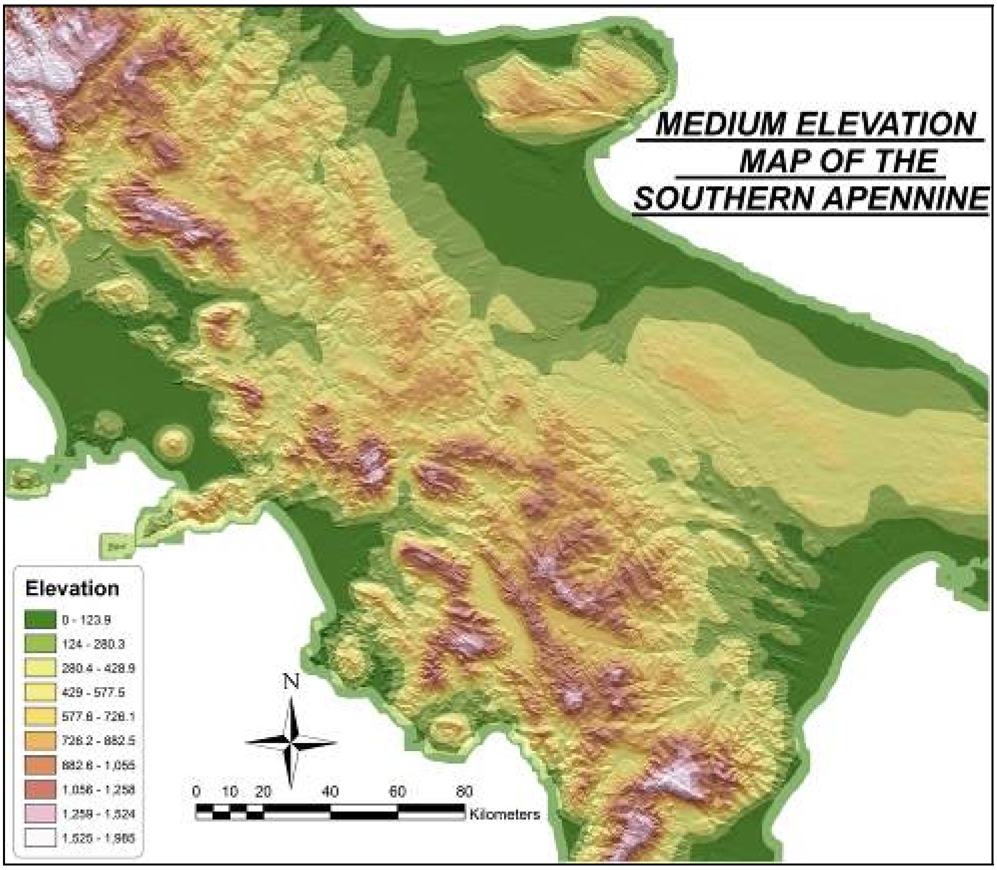


Fig. 3.4 : medium elevation map of the Southern Apennines

The medium elevation map has been created by using the 3D Analyst tool, and in particular by using the Neighbourhood Statistic function: the medium elevation has been calculated in a 5x5km rectangular moving window. In the coastal areas this window involved also part of the sea (it corresponds with a no-data area in the dem), this is the reason why the medium elevation map exceeds the dem limits in these regions, assuming values either equal to or greater than 0 as a function of the type of coast.

The main feature of the medium elevation map (fig. 3.4) is represented by maximum elevations that are lower than the maximum elevations calculated in the map of fig. 3.3.

The highest peaks and the main ridges showed by the elevation map (fig. 3.2) are still evident in the medium elevation map, also if they are smaller than on the maximum elevation map, so it is possible to recognize, moving from the north to the south, the Matese massif, the Picentini ridge, the Alburno-Cervati ridge, the Mt. Volturino-Mt. S. Enock ridge, the Mt. Sacro, the Mt. Sirino, the Mt. Alpi, the Mt. Raparo and the Pollino massif, they are all highlighted by the whitish colours in the map. Other important morphostructural highs, showed by the dark brownish colours, are the Taburno-Camposauro ridge, the Monti di Avella ridge, the Mt. Marzano ridge, the Mt. della Maddalena ridge, the Mt. Cocuzzo and the Mt. Coccovello.

In the medium elevation map the river valleys are more evident than on the maximum elevation map, in particular the Volturno and Calore rivers don't assume the feature of intramontane basin anymore, but the confluence of the Calore Beneventano river into the Volturno river is clear and the Volturno river crosses over the Monti di Caserta ridge flowing into the Campana plain until its mouth.

In the Cilento region the main trunks are evident, in particular it is possible to notice the Calore Salernitano river, the Alento river, the Lambro river, the Mingardo river and the Bussento river (greenish areas in the map).

The Vallo di Diano is not divided into two sub-basins anymore and it is separated by a narrow area from the Noce valley: this valley is not limited to the south by the Monti di Trecchina-Monte Messina ridge and it flows to the south until its mouth. The Val d'Agri is larger than in the map of fig. 3.3.

In the foredeep area the main trunks are now evident, in particular in the northern portion the Ofanto, Fortore and Biferno valleys are shown in the medium elevation map, while in the area comprises between the Carapelle, Cervaro and Celone rivers, the three valleys are not shown in the map, but the whole area gently dipping toward the east; the Lavello high is smaller than in the maximum elevation map and in the southern portion of the Bradanic foredeep the main trunks are shown, so it is possible to recognize the Bradano, Basento, Cavone, Agri and Sinni valleys: in particular the Basento river reaches the Calvello basin in its upper reach where it is possible to notice its junction with the Camastra river, while the Sinni river seem to begin in correspondence of the confluence with the Cogliandrino river, and its main tributaries (Serrapotamo, Frida and Rubbio rivers) are not shown in the map.

3.2.4 The minimum elevation map

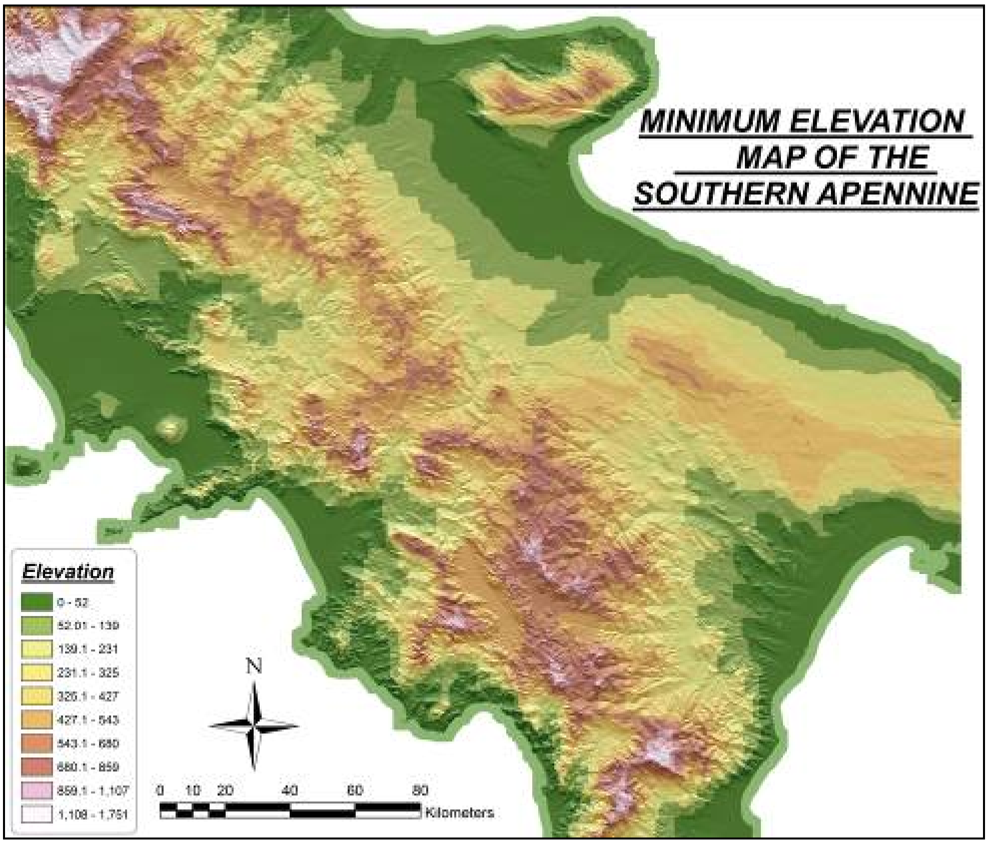


Fig. 3.5 : minimum elevation map of the Southern Apennines

The minimum elevation map has been created by using the 3D Analyst tool, and in particular by using the Neighbourhood Statistic function: the minimum elevation has been calculated in a 5x5km rectangular moving window. In the coastal areas this window involved also part of the sea (it corresponds with a no-data area in the dem), this is the reason why the mimimum elevation map exceeds the dem limits in these regions, assuming in this map values equal to 0 (it occurs also in the areas where high cliffs are present, in this case the value 0 is obtained because of the sea).

In the minimum elevation (fig. 3.5) the highest peaks of the elevation map (fig. 3.2) are still clear, also if they are lower than in the elevation map, reaching a maximum value of 1751m a.s.l.. Moving from the north to the south, it is possible to recognize the Matese massif, the Picentini ridge, the Mt. Cervati, the Mt. Volturino-Mt. S. Enock ridge, the Mt. Sirino, the Mt. Alpi and the Mt. Raparo (whose sizes strongly decreases if compared with the maps of fig. 3.x and 3.x) and the Pollino massif, they are all highlighted by the whitish colours in the map. Other important morphostructural highs, showed by the dark brownish colours, are the Marzano massif, the Alburno ridge (in this map it is separated by the Mt.Cervati), the Mt. della Maddalena ridge. In the central portion of the Southern Apennines it is also possible to notice a brownish area that moves NE of the Matese massif and the Picentini ridge, following a NW-SE trend, and then changes abruptly its direction following a NE-SW trend until the Picentini ridge: this area corresponds with the Tyrrhenian-Adriatic divide that is easy to recognize and to locate in this map.

The river valleys are the largest if compared to the other maps. The Volturno-Calore Beneventano system completely overwhelms the main ridges of the area, in particular the Monti di Caserta and Monti di Avella ridges, while the Mt. Taburno is still evident, also if it is reduced to a very small ridge. The Sorrento Peninsula is reduced to a very narrow ridge, while the Sele and the Ofanto rivers are separated by a thin ridge.

The Cilento rivers are more evident, they overwhelm the main mountains of the area, reducing the Mt. Stella, Mt. Sacro and the Mt. Bulgheria to small peaks.

The Vallo di Diano is larger than in the previous maps and the gorge that separates the Agri valley from the Sant'Arcangelo basin is not shown in the map, so that the Val d'Agri is directly connected with the Sant'Arcangelo basin.

The Noce basin is larger and it completely overwhelm the Monti di Trecchina ridge, while the other peaks that border the Noce valley (Mt. Sirino, Mt. Messina and Mt. Coccovello) are still evident in the map: two narrow ridges separate the Noce river from the Mercure river to the south, and from the Sinni river to the east.

In the northern portion of the foredeep the main trunks are shown in the map (Ofanto, Fortore and Biferno), while in the area between the Celone, Cervaro and Carapelle rivers, the three valleys don't appear, so that this area gently dipping towards the east, in the same way it occurs in the map of fig. 3.3 and 3.4. The Lavello high is smaller than in the previous map, being reduced to a narrow ridge, while in the southern portion of the foredeep all the main trunks are shown in the map (Bradano, Basento, Cavone, Agri and Sinni rivers).

3.3 THE SWATH PROFILES AND RELIEF CURVES ANALYSIS

The complex morphology of the Southern Apennines, that changes also for areas very close each other and that is due to the huge lithological heterogeneity of the chain and to the different tectonic evolution that different sectors of the orogen have experienced, doesn't allow the analysis of the main topographical characteristics of the whole chain through the construction of just one swath profile. To better investigate the spatial variations of the morphological and morphometrical features of the Southern Apennines, it has been chosen to create five swath profiles so that most of the studied area could be covered by them: their orientation has been always chosen to be more perpendicular as possible to the main morphostructural and structural elements of the landscape.
The location of the five swath profiles is shown in fig. 3.6.

In a first phase of the work, it were be analyzed just four swath profiles, and in particular the so-called *northern*, *central* and *southern* transect (characterized by a main NNW-SSE orientation of the tectonic elements, and that are so SSW-NNE oriented), and the *Noce-Sirino-Alpi-Sant'Arcangelo* transect (in this area the main tectonic and morphostructural elements are N-S oriented, so this swath profile is oriented W-E). Successively, the presence of some important morphostructural element such as the Sacro mount, the Vallo di Diano and Calvello basins and the Murge area (Apulia foreland) not represented in the previous four swath profiles, bring me to the creation of an additional profile, the so-called *Pisciotta-Bari* transect, with a main SW-NE orientation.

The length of the swath profiles vary from zone to zone, from a minimum of 90km for the Noce-Sirino-Alpi-Sant'Arcangelo transect, to a value of about 140km for the northern transect and about 160km for the central and southern transect, until a maximum length of about 180km on the Pisciotta-Bari transect. The width of every profile has been chosen to be of 10km because using this value the swath profile is considered to be representative of the main morphological and morphostructural element of the considered area (several attempts have been done to analyze swath profiles wider than 10km, in particular by choosing a width of 20km, but in this cases, the swath profiles involved areas to far with very different morphological and morphometrical features, so this attempts have been considered not useful to the study). The sampling of the maximum, mean and minimum elevation along every profile has been chosen to be of 100 sampled points for every profile.

The relief curves have been then obtained by using the maximum elevation line and the minimum elevation line calculated for each swath profile: the difference between the maximum and minimum elevations along the whole transect indicates the relief in that point of the swath profile (because they have obtained by the swath profiles, the sampling window is the same than the swath profiles, so 100 sampled points along every profile).

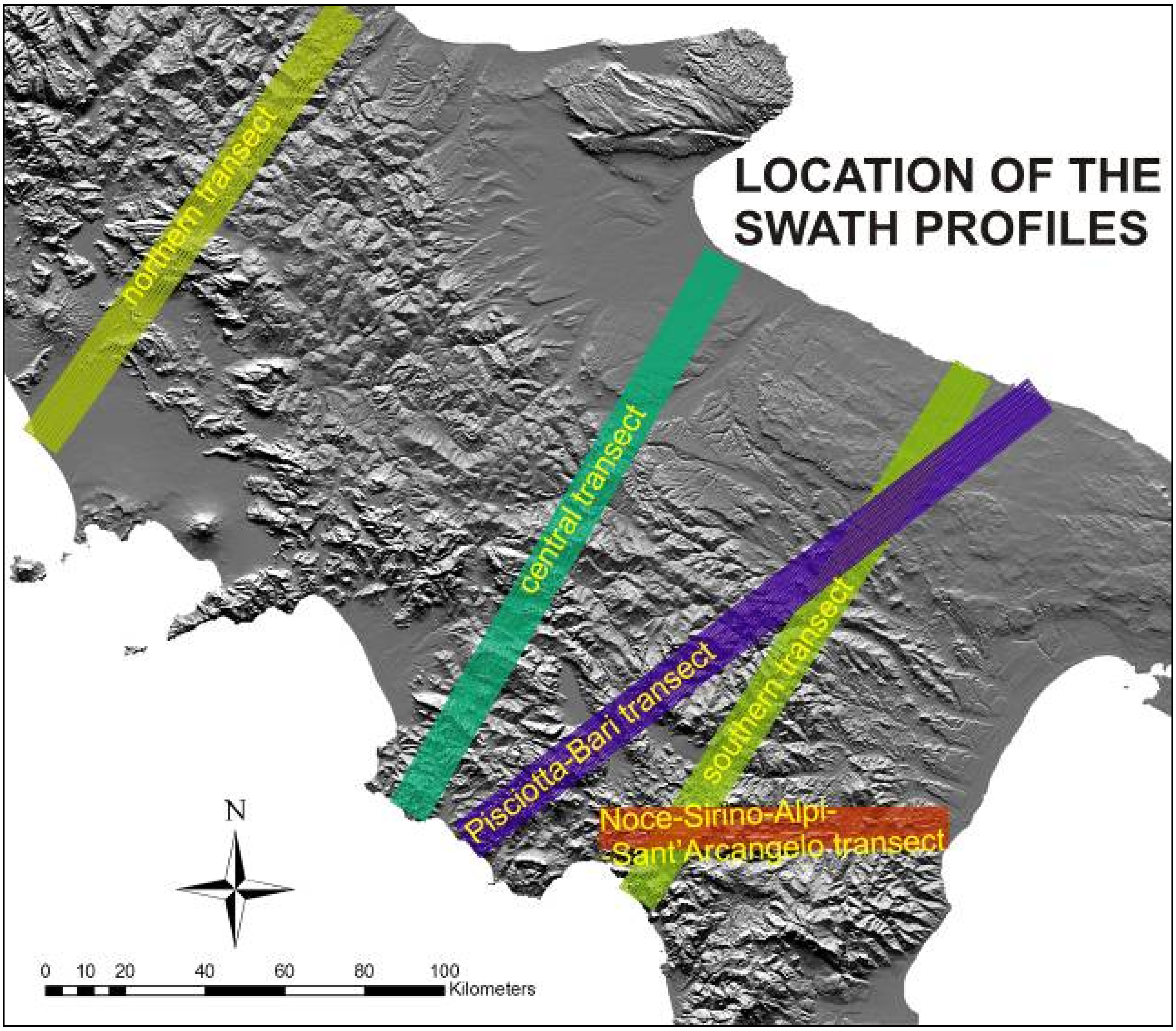


Fig. 3.6 = location of the analyzed swath profiles for the Southern Apennine chain: notice that in the southern portion of the chain there are three swath profiles very close each other, this choice has been due to the complex tectonic and morphostructural setting of this area, with different orientation of the main structural elements that determine the different orientation of the three swath profiles.

3.3.1 Northern transect

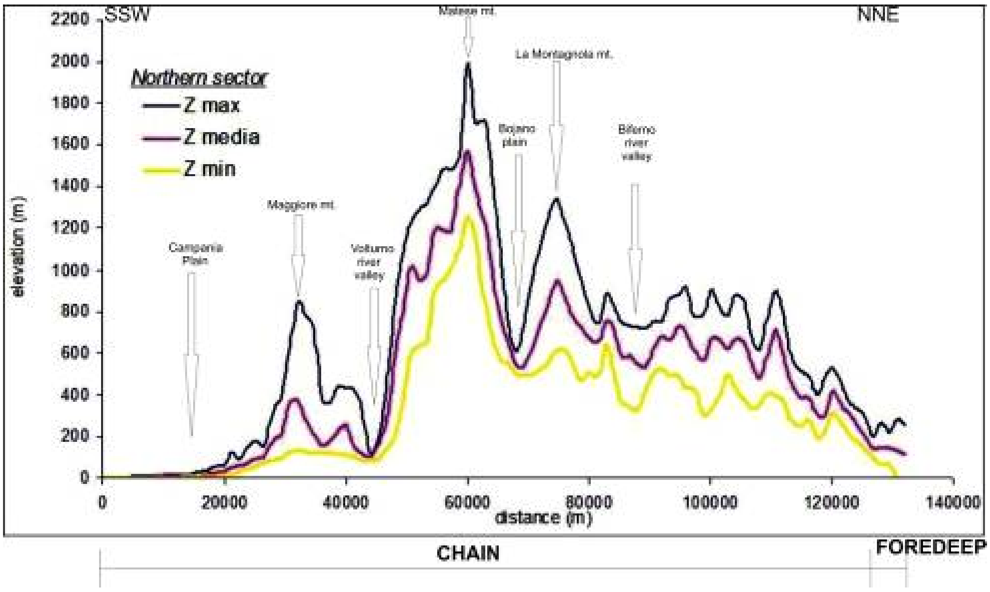


Fig. 3.7 = swath profile relative to the northern sector of the Southern Apennine

The northern transect (fig. 3.7) crosses the Southern Apennines from the northern portion of the Campana plain to the divide separating the Trigno and Biferno rivers basins. It is SSW-NNE oriented, perpendicular to the main morphostructural and tectonic elements of this portion of the chain. From a geological point of view, the profile moves for the first 20km in the peri-tyrrhenian graben of the Campana plain, filled by quaternary deposits of both volcanoclastic (coming from the volcanic areas of the Somma-Vesuvio and Roccamonfina Volcanoes and the Phlegrean Fields) and fluvial origin (this area coincides with the lower Volturno valley). The following 50km of the profile are characterized by the carbonatic highs of the Mt. Maggiore and the Matese massif, separated by the Volturno valley, with the Matese massif limited to the east by the Bojano plain, one of the many intramontane basins of the Southern Apennines. Moving from the Bojano plain for the next 40km, the profile crosses the external flyschs of the Molise basin. The last 5-6km of the profile are developed into the foredeep units.

Considering the geodynamic setting of this portion of the Southern Apennine, about 97% of the profile moves into the chain s.s., while the remaining 3% moves into the foredeep domain.

The chain has a length of about 120km. The maximum elevation are located in correspondence of the Matese massif, where they reach 2000m a.s.l.: in this sector of the orogen, the maximum elevation line corresponds with the location of the divide.

There is a clear difference between the Tyrrhenian and the Adriatic flanks. The Tyrrhenian side is characterized by a flat topography in the Campana plain area, followed by two main morphostructural highs (the Mt. Maggiore and the Matese massif, with a maximum elevation of 2000m a.s.l.) separated by a morphostructural low (the Volturno valley, with a maximum elevation of about 100m a.s.l.); the valleys (including also the Bojano plain) are spaced of about 25km; the mean slope of this flank is of about 1.9°. The Adriatic flank is characterized by an articulated morphology, with maximum elevations never exceeding 1000m a.s.l. and minimum elevations ranging between 600m and 100m a.s.l.: the valleys are very close, being spaced of about 10km in the areas close to the divide, and 5km in the external areas; the mean slope of this sector is of about 1.7°, comparable with those one obtained for the Tyrrhenian flank.

The maximum, minimum and medium elevation lines are almost parallel along the whole profile: in the first sector of the profile (Campana plain) the three lines are almost coincident, confirming the flat features of this area; in the Maggiore mount area there is a huge difference on their trend, with the three lines clearly not coincident: this difference is due to the width of the swath profile, that involves both portion of the Campana plain (responsible of the flattening of the minimum elevation line) than the bordering carbonatic ridges (in particular the Mt. Maggiore, that influences the maximum elevation line). Moving east of the Volturno valley it doesn't seem to exist important differences in the trend of the three lines, except for the more external areas, where the differences on their trend can be interpreted as related to a lithological control (being this area characterized by weak flysch units with limited outcrops of more resistant units).

Another difference between the Tyrrhenian and the Adriatic flanks is given by the distribution of the valleys and, in particular, their elevation: on the Tyrrhenian side the valleys never rise at elevation greater than 150m a.s.l., while on the Adriatic flank they reach an elevation of about 500m a.s.l. in the areas close to the divide, decreasing until 200m a.s.l. as we move towards the external areas.

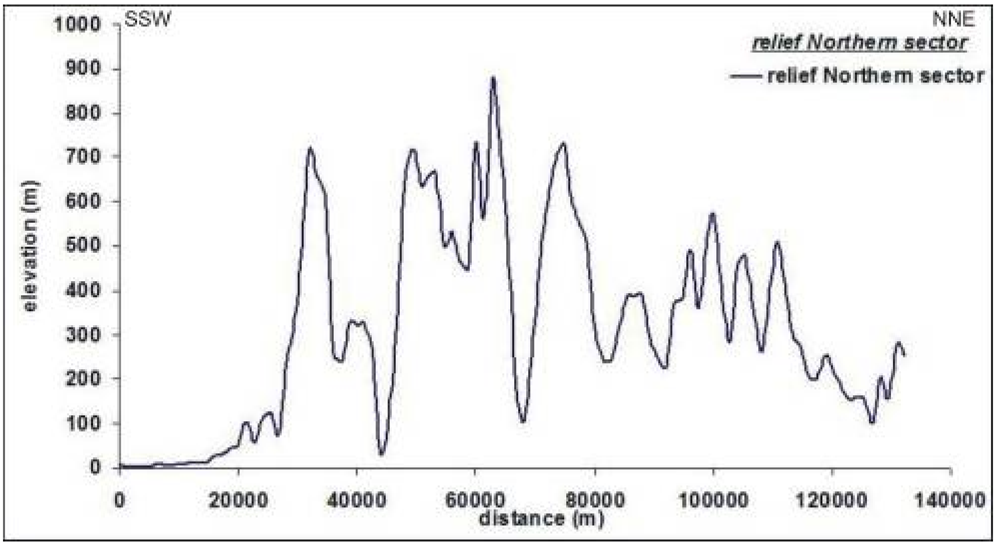


Fig. 3.8 = relief curve relative to the northern sector of the Southern Apennine

The relief curve (fig. 3.8) shows a Gaussian-like shape. The relief is minimum in the first 20km of the profile, where the profile moves into the Campana plain and it then tend to increase reaching a maximum of 700m about 30-35km from the beginning of the profile: we are at the border of the Campana plain and this value is given by the closeness of the flat Campana plain and the high Mt. Maggiore, so the relief is due to the morphostructural setting of this portion of the chain and to the different lithologies cropping out in this portion of the profile (apennine carbonates of the Mt. Maggiore in contact with the quaternary filling of the Campana plain)

. The relief curve decrease from this point down to a minimum in correspondence of the Volturno valley: this trend is interrupted by a positive peak in the curve (300m) that is due to presence of the Mt.Monaco-Mt. della Costa ridge, and so the relief value is due the different lithologies cropping out in the area (apennine carbonates of the Mt. Monaco-Mt. della Costa ridge in contact with the quaternary filling of the Campana plain).

The relief curve then tend to increase, reaching a maximum value of 900m about 65km from the beginning of the profile: in this point the profile moves in the northeastern portion of the Matese massif, an area characterized by the outcropping of weak flysch units, so the high relief obtained in this area is due to the closeness of different lithologies (Apennine carbonate of the Matese massif and flysch units cropping out in the valleys located in this area. The increasing trend showed by this portion of the relief curve is locally interrupted about 2-3km before the highest peak, this negative value is individuated inside the Matese massif and it is due to presence of the Matese lake polje, an area of low relief inside the Matese massif, showing a tectonic control on the relief curve.

Moving from the Matese massif, the relief curve abruptly decreases reaching a minimum value in correspondence of the Bojano plain, and it then increase again, with a maximum value of about 700m about 75-80km from the beginning of the profile: this high value is due to the closeness of the Mt. Pesco la Messa (where Molisan Units crop out) and the Petroso river valley (where

Flysch units crop out), and so it is due to the lithological contrast between the two units. From this point to the NE the profile moves into the External Flysch Units, an area characterized by enhanced river incision and local lithological contrast, so the relief values obtained in this part of the curve are mainly due to the river incision.

3.3.2 Central transect

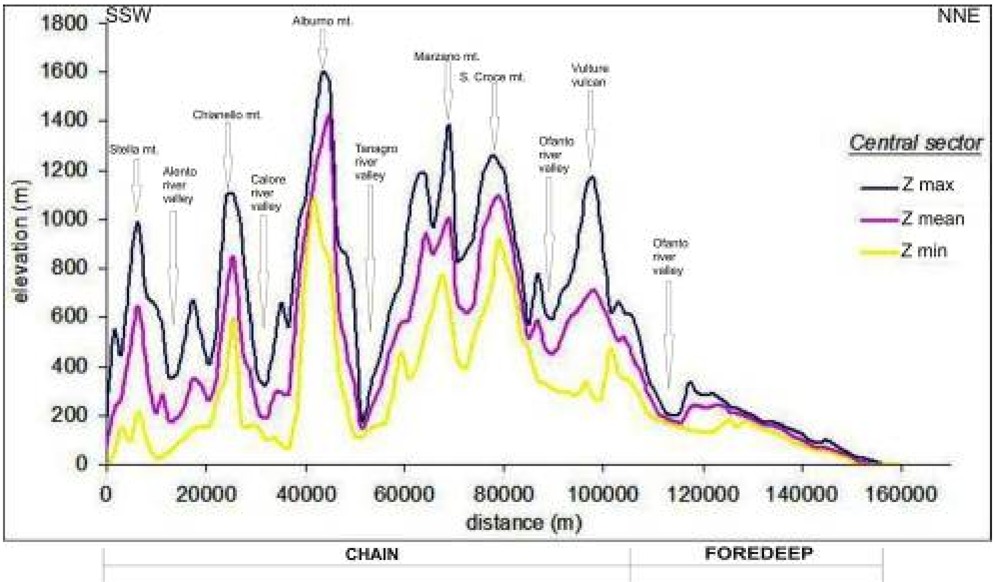


Fig. 3.9 = swath profile relative to the central sector of the Southern Apennine

The central profile (fig. 3.9) crosses the Southern Apennines in the area comprises between the Cilento region (Stella mount) and the Bradanic foredeep (here represented by the Ofanto river valley), it is SSW-NNE oriented so that it is perpendicular to the main tectonic and morphostructural elements of this portion of the chain. From a geological point of view, the profile moves for the first 20km into the silicoclastics units of the Cilento Flysch (Stella mount) and the North Calabrian units (Alento valley). The following 50km are characterized by the carbonatic highs represented by the Chianello mount, the Alburni and the Marzano massifs, separated by two main morphostructural lows, the Calore valley (separating the Chianello mount from the Alburni massif) and the Tanagro valley (separating the Alburni and Marzano massifs). Moving from the Marzano massif to the north-east, the profile crosses the external portion of the chain, where weak silicoclastics outcrops, with local outcropping of more resistant lithologies determining the occurrence of the morphostructural highs of the S. Croce mount (Lagonegro units) and the Vulture volcano. The profile crosses the quaternary filling of the Bradanic foredeep in the last 30km, characterized by a gentle topography dipping towards the north-east.

One of the first features to notice is the extension of the foredeep that in this profile represents about the 30% of the whole profile, while the remaining 70% is represented by the chain s.s.

The chain s.s. has a length of about 110km, with the maximum elevations shifted toward the Tyrrhenian flank, in correspondence of the Alburni massif: an important feature of this profile is the not correspondence of the maximum elevation line and the divide, with the latter located 40km east of the Alburni massif, on the S. Croce mount, recalling one the main characteristics of the Southern Apennine.

The Tyrrhenian flank has a mean slope of 0.9° while the Adriatic flank has a mean slope of 2.3°, showing a clear asymmetry of this portion of the orogen towards the north-east.

There are important differences from a morphological point of view between the Tyrrhenian and the Adriatic flanks: the Tyrrhenian side is characterized by a continue alternation of topographical highs and lows, the maximum elevation is reached in correspondence of the Alburno massif (1600m a.s.l.), while the valleys show a mean elevation of about 200m a.s.l., with a maximum in correspondence of the divide (400m a.s.l.), they are spaced of about 20km; the adriatic flank show a gentle landscape, almost entirely represented by the Ofanto valley, interrupted by the Vulture volcano where the maximum elevation are reached (1200m a.s.l.), in this area there is a not correspondence between the peaks in the maximum and minimum elevation line, in particular the peak on the minimum elevation line is located eastern than the peak in the maximum elevation line because in this area the profile doesn't cross the axial portion of the Ofanto valley but its right flank; the same difference is shown at about 120km along the profile, with a peak in the maximum elevation line and a low in the minimum elevation line, again this difference is due to the not perfect location of all the width of the profile into the Ofanto valley, so the peak in the maximum elevation line represent on the hills bordering the river; the only valley located in this sector, the Ofanto valley, move from an elevation of about 300m a.s.l. in correspondence of the divide to an elevation of about 200m a.s.l. east of the Vulture volcano, showing an elevation greater than that one of the Tyrrhenian valleys; because this is the only valley of this portion of the orogen, it is not possible to talk of spacing of the valley in the same way it has been done for the other profiles.

The maximum, medium and minimum elevation lines seem to proceed almost parallel along the whole profile, with the only exception of the Vulture area, where the different trend of the maximum and minimum elevation lines is due to the close location of the Vulture volcano and the Ofanto valley, two morphostructural very different settings.

I finally want to point the attention on the trend of three elevation curves in the last portion of the profile, where the foredeep deposits outcrops, with the three lines proceeding clearly parallel each other, showing the gentle landscape of this sector of the Southern Apennine, as testified also by its mean slope of about 0.6°.

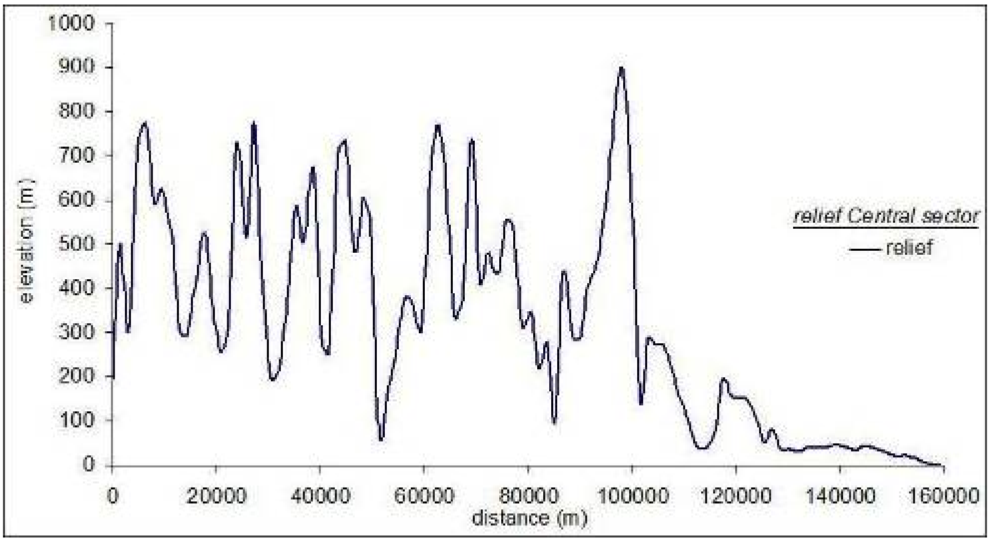


Fig. 3.10 : relief curve relative to the central sector of the Southern Apennine

The relief curve (fig. 3.10) shows the continue alternation of positive and negative peaks, around a mean value of about 450m, with the highest peak (900m) individuated about 100km from the beginning of the profile, and an abrupt decrease from this point to the end of the profile.

The first peak, about 800m, is located about 10km from the beginning of the profile: this area is characterized by the closeness of the Mt. Stella (where the Cilento Flysch crops out) and the Alento valley (where the North-Calabrian units crop out), the relief is so due to the lithological contrast between the two units, with the North-Calabrian Units weaker than the Cilento Flysch. From this point until 50km from the starting point of the profile, the relief curve decrease, a general trend interrupted by several positive peaks: the first positive peak is located about 17-20km from the beginning of the profile with a relief value of 500m, this value is due to the Alento river incision, being this area characterized by the presence of a hills (where the Cilento Flysch crops out) that reach a maximum elevation of about 600m a.s.l., while the Alento valley is at an elevation of about 100m a.s.l..

The next positive peak, about 800m of relief, is located about 25-30km from the beginning of the profile: this peak is due to a lithological control because of the closeness of Apennine carbonates (Mt. Chianello) with the Piaggine-Racanello formation (it crops out in the northeastern flank of the Mt. Chianello). The following positive peak is located about 38-40km from the beginning of the profile with a relief value of about 700m: we are the southern side of the Alburni ridge, this value is due to the lithological contrast between the Apennine carbonates cropping out on the Alburni massif and the North-Calabrian Units cropping out in the adjacent Sele plain.

At about 45km from the beginning of the profile we find the last positive peak that interrupts the decreasing trend of the relief curve, this peak shows a relief value of about 750m: the relief is given again by the contrast of competence between different lithologies, and in particular the Apennine carbonates cropping out on the Mt. Forloso and the North-Calabrian Units cropping out on the northwestern flank of the Mt. Forloso.

Moving from this point we find a negative peak (50m of relief) that corresponds with the Tanagro river valley, after which the relief curve tends to increase reaching a maximum value of about 800m: this relief is due to closeness of different lithologies, in particular in this area Apennine carbonates crop out (Mt. Paratiello) in contact with the External Flysch Units (Ariano Unit) that crop out in the Forra di Muro Lucano river valley.

After this positive peak, the relief curve tend to decrease again, reaching a new negative peak (about 100m) in correspondence of the Ofanto river valley. Then, the relief curve increase again, reaching the maximum relief value at about 100km from the beginning of the profile: in this point the Vulture volcano is located, and so this positive peak the is due to the closeness of the Vulture volcano with the Ofanto river valley.

From this point, the relief curve moves into the foredeep domain, this is the reason of the abrupt decrease of the curve, a general trend that is interrupted by two minor positive peaks due to the Ofanto incision into the quaternary filling of the foredeep.

3.3.3 Southern transect

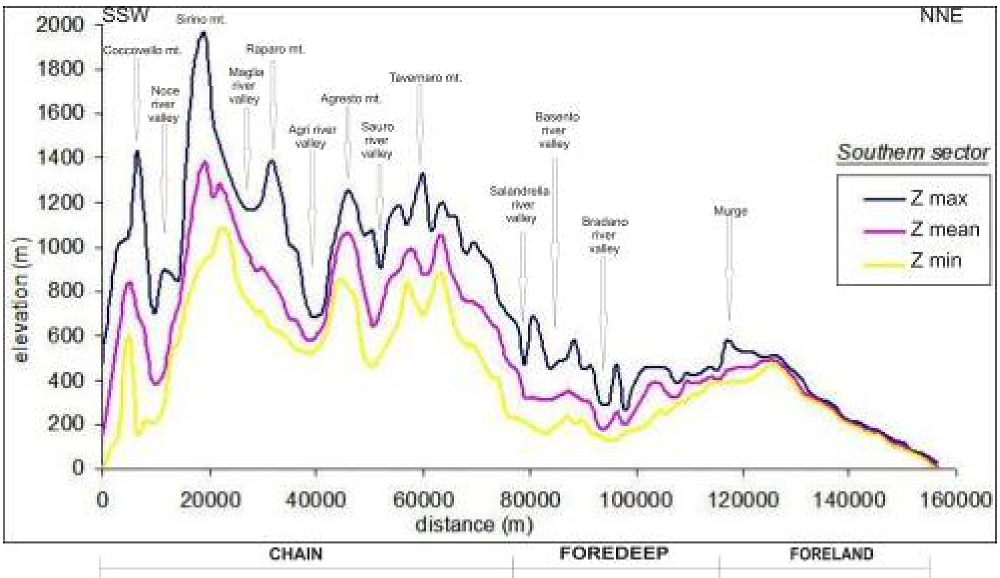


Fig. 3.11 = swath profile relative to the southern sector of the Southern Apennine

The southern profile (fig. 3.11) crosses the Southern Apennines in the area comprises between the Coccovello mount on the Tyrrhenian flank and the Murge region on the Adriatic flank, it is SSW-NNE oriented, such as the previous profiles, being perpendicular to the main tectonic and morphostructural elements of the landscape. From a geological point of view, this profile is characterized in the first 40km by three morphostructural highs, the carbonatic ridges of the Coccovello and Raparo mounts and the Sirino massif (where Lagonegro units outcrop), separated by two river valleys, the Noce valley (separating the Coccovello mount from the Sirino massif, where North-Calabrian units outcrop, with local carbonatic ridges outcropping as fault line scarp) and the Maglia valley (separating the Sirino massif from the Raparo mount, characterized by the presence of both North-Calabrian units and flyschs units, here represented by the Albidona Flysch). East of the Raparo mount, there is another important morphostructural low, represented by the Agri valley, that separates the mount Raparo from the mount Agresto (where Lagonegro units outcrop). From this point to the east the profile moves into the External Flysch units and Sicilidi units, exposed in this portion of the chain until the Salandrella valley. In this point the chain s.s. ends, and the profile come into the foredeep domain, here represented by the quaternary filling of the Bradanic foredeep, with a gentle topography characterized by some important river incision, such as the Basento and Bradano valleys. The last portion of the profile, from 118km to the end, is developed into the foreland domain, here represented for the first time compared to the previously described swath profiles, characterized by the gentle landscape of the Murge where carbonates of the Apulia foreland outcrops.

In this profile, the chain s.s. represents about the 50% of the whole profile, while the remaining 50% is equally divided between the foredeep and the foreland domains. The length of the chain is of about 80km. The highest peaks are shifted towards the west, very close to the Tyrrhenian sea (Sirino mount, 2000m a.s.l.): the location of the maximum elevation line corresponds with the location of the divide.

Because of the anomalous position of the divide, shifted towards the west, there is a huge difference in the slope of the two flank of the Southern Apennines, with the Tyrrhenian side steeper (about 5°) than the Adriatic side (about 2°): this difference is the reason of the particular shape of the profile, that looks like a Gaussian with a strong left asymmetry.

The profile can be separated in two portions from a morphological point of view: the first sector is comprised between the Tyrrhenian coast and the Agri valley, it is characterized by two important morphostructural highs (the Coccovello and the Sirino mounts) separated by the Noce rive valley, with the Sirino massif limited to the east by the Agri valley: the Noce and the Agri valleys are spaced of about 30km. East of the Agri valleys the topography abruptly changes, being more articulated with the continue alternation of topographic highs and lows due to outcropping of weak flysch units. In this area it is possible to recognize three important morphological lows, the Sauro, Basento and Bradano valleys

The maximum, medium and minimum elevation lines proceed almost parallel each other, except in the area of the Raparo mount, where the closeness of different morphological settings, and in particular the “high” Raparo mount and the “low” Agri valley, let the maximum and minimum elevation line to not coincide. Another similar anomaly is individuated in the area between the Salandrella and Basento valleys, and it can be interpreted in the same way of the previous one, as the adjacency of different lithologies, and in particular the alluvial filling of the two mentioned valleys separated by a ridge builds up on the Irsina Conglomerates, that represent the closing cycle of the filling of the Bradanic foredeep.

The valleys on the Tyrrhenian flank, here represented by the Noce valley, are developed to an elevation never exceeding 200m a.s.l., while the valleys on the Adriatic side (Agri and Sauro river valleys) are comprises in an altimetrical range between 500-600m a.s.l., and the Basento and Bradano valleys have an elevation of about 200m a.s.l., similar to that one of the Noce valley on the Tyrrhenian flank.

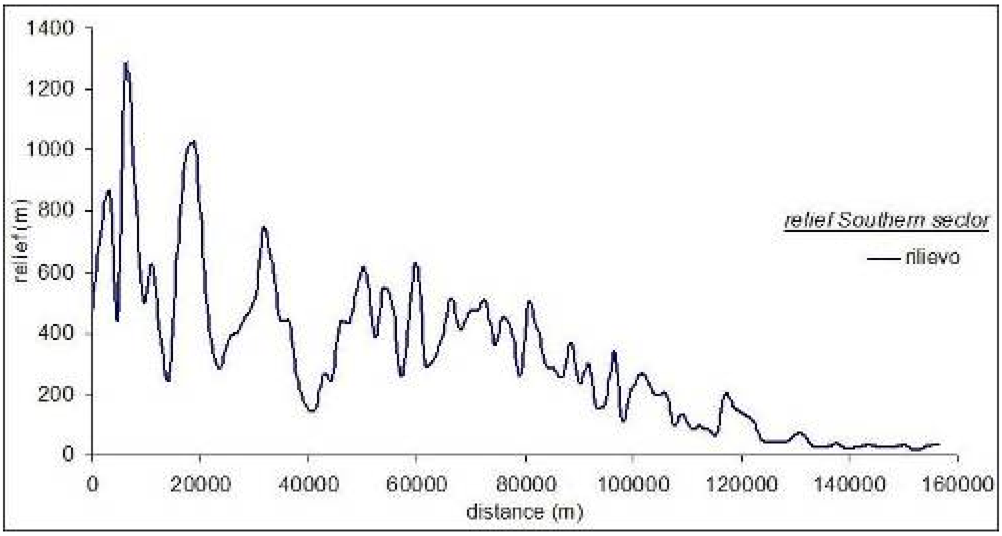


Fig. 3.12 : relief curve relative to the central sector of the Southern Apennine

The relief curve (fig. 3.12) looks like a power function, with a maximum value (about 1300m) that is reached at the beginning of the curve followed by a general decreasing trend, until the minimum value (about 20m) that is reached at the end of the curve.

In the first 10km of the curve there are two important positive peaks, the first one showing a relief value of about 800m and the second one showing a relief value of about 1300m: both the peaks are the result of the closeness of different lithologies, in particular the "hard" carbonates of the Apennine platform (they crop out on the Mt. Coccovello) and "weak" Nort-Calabrian Units (they crop out on the Noce valley). The two positive peaks are followed by a negative peak (relief value of about 200m) that is individuated inside the Noce river valley, then the relief increase again reaching a new positive peak of about 1000m at about 20km from the beginning of the profile: this peak is due again to the closeness of different lithologies, in particular in this case they are represented by the Lagonegro Units (they crop out on the Mt. Sirino) and the North-Calabrian Units (they crop out on the Cogliandrino valley). This positive peak is followed by another negative peak (about 300m) that is individuated in the Maglia river, and then there is a new positive peak, with a relief value of about 700m: in this case the relief is due to the lithological contrast between the Apennine carbonates (Mt. Raparo) and the Albidona Flysch and the Lagonegro Units (they crop out on the right and left side of the Maglia river respectively). After this peak, the lowest peak inside the Apennine chain is reached at 40km from the beginning of the transect, in correspondence of the Agri river valley.

Moving from the Agri river valley until 80km from the starting point of the transect, the relief curve comes into the outer flank of the Southern Apennines, an area dominated by the External Flysch Units, with the occurrence of Sicilidi Units in valleys (such as on the Sauro river valley): the relief in this area vary around a mean value of about 400m, there are no important lithological variations (except for the presence of the Sicilidi Units in the Sauro valley, that generates a relief value of 400m reached inside the same valley) or tectonic structures that could be considered responsible of the obtained values, so we can say that the relief values reached in this portion of the chain are mainly due to the incision of the many rivers dissecting the area.

From this point until about 120km from the beginning of the profile, the curve moves into the foredeep domain, the relief decrease in a continuous way, also in this case the relief values are due to the river incision because of the lack of important lithological variations in this portion of the chain.

The last part of the curve shows an abrupt decrease of the profile curve, this is the area of the foreland domain and the very low relief values are due to the flat topography of the area and to the lack of important lithological contrast and tectonic elements.

3.3.4 The Pisciotta-Bari transect

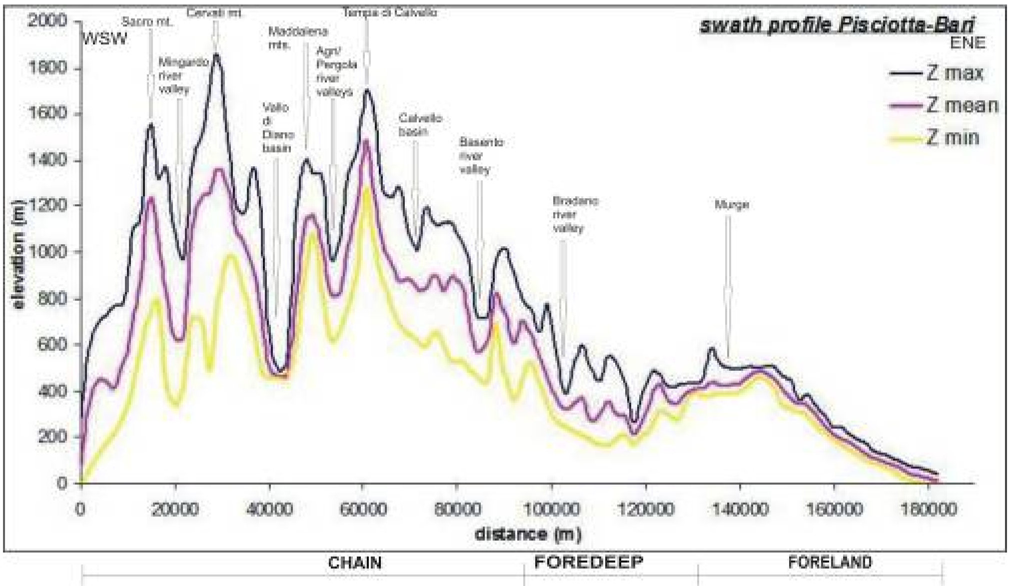


Fig. 3.13 = swath profile relative to the Pisciotta-Bari transect of the Southern Apennine

The Pisciotta-Bari transect (fig. 3.13) crosses the Southern Apennines in the area between the Cilento region on the Tyrrhenian flank and the Murge region on the Adriatic flank, it is WSW-ENE oriented, a different orientation respect the previous profiles, to highlight the presence of some tectonic and morphostructural elements not shown with the previous profiles, such as the Cervati ride, the Vallo di Diano intramontane basin and the Maddalena ridge. From a geological point of view this profile moves for the first 20km into the Cilento Flyschs units and the North Calabrian units: the two different lithologies are recognizable by the morphology of the profile, with the Cilento units making the ridges and the North Calabrian units making the valleys. The top of the mount Sacro is characterized by the outcropping of the Olistostrome of the Mt. Sacro formation. Moving from the Mingardo valley (a narrow valley where North Calabrian units outcrop) to the east, the profile moves into the carbonate ridges of the Cervati mount (mainly calcareous) and the Maddalena ridges (mainly calcareous-dolomitic), separated by the intramontane quaternary basin of the Vallo di Diano. East of the Maddalena ridges the high Agri valley and the Pergola valley marks the passage to the Lagonegro units outcropping on the morphological high of Tempa di Calvello. Moving east of Tempa di Calvello mount, the profile crosses the Plio-Quaternary piggy-back basin of Calvello, that is the west limit of the External Units that outcrop from this point to the left flank of the Basento river. From the Basento river until 130km the profile moves into the foredeep domain, characterized by the continue alternation of valleys and ridges, as a consequence of lithological variations into the filling of the foredeep. The last 50km of the profile move into the foreland domain, a low relief region gently dipping towards the NE.

In this profile the chain s.s. represents about the 50% of the whole profile, while the foredeep represents about the 20% of the whole profile and the foreland is about the 30% of the whole profile. The chain s.s. has a length of about 95km. The maximum elevations are located in correspondence of the Cervati ridges, where they reach 2000m a.s.l., clearly shifted towards the Tyrrhenian side of the Southern Apennines: in this case there is no correspondence between the location of the maximum elevation line and the divide, with the latter located in the area comprises between the Maddalena ridges and the Tempa di Calvello mount, separating the high Agri valley (draining to the east) and the Pergola valley (draining to the west).

Because of the anomalous location of the divide, that is shifted towards the Tyrrhenian coast, the Tyrrhenian flank of this portion of the Southern Apennine is steeper (with a slope value of 1.6°) than the Adriatic flank (with a slope value of 0.61°): the profile looks like a Gaussian with an asymmetry to the left.

The profile can be separated in two sectors that show different morphological features: the first one moves from the Tyrrhenian coast to the Tempa di Calvello mount, it is characterized by the continue alternation of ridges and valleys, with the top of the ridges at a mean elevation of about 1400m a.s.l. and a maximum elevation reached on the Cervati ridge (2000m a.s.l.), the valleys on this side are spaced of about 20km; from Tempa di Calvello to the east the profile moves into the second sector, it is characterized by the lacking of high ridges, with a gentler landscape than that one on the Tyrrhenian flank because of the outcropping of erodible lithologies (External Flyschs), with a mean elevation of about 500-600m a.s.l. and valleys that are very close each other.

The maximum, medium and minimum elevation lines seem to proceed almost parallel each other, the main difference on their trend are in correspondence of the Cervati ridge and the Calvello basin, and that can be interpreted as the closeness of different lithologies with a different response to the erosion. A particular trend is recognizable in the Vallo di Diano area, the three lines abruptly drop off on both side of the basin, in particular on the east side they are almost perfectly parallel, enhancing the fault scarp like features of this portion of the Maddalena ridge, that is also the side of the basin where the master fault of the Vallo di Diano is located. It is also interesting to point out the trend of the minimum elevation line on the Adriatic flank, its envelop looks almost rectilinear, recalling the same trend obtained for the same area in the Central profile.

The valleys on the Tyrrhenian flank are at an elevation of about 400-500m a.s.l., higher than the Tyrrhenian valleys analyzed in the previous profiles, with a maximum of about 600m a.s.l. in correspondence of the high Agri valley and the Pergola valley, where the divide is located; on the other hand, the valleys on the Adriatic flank range from an elevation of about 800m a.s.l. (Calvello basin) down to 200m a.s.l. (on the Bradanic foredeep), an elevation that is comparable with that one of the Tyrrhenian valleys, except that for the area closest to the divide, where the Adriatic valleys are higher than the Tyrrhenian one.

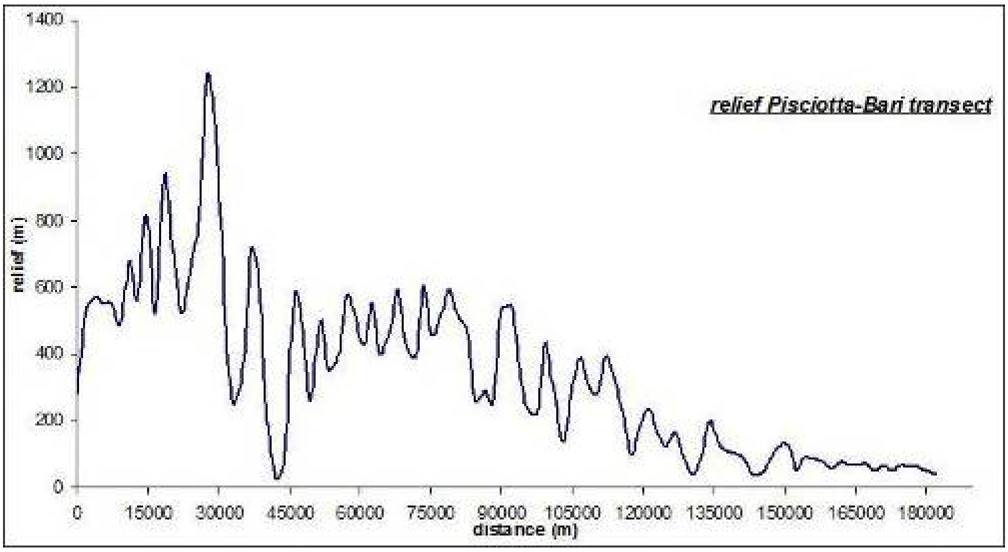


Fig. 3.14 : relief curve relative to the Pisciotta-Bari transect of the Southern Apennine

The relief curve (fig. 3.14) looks like a power function, but it looks slightly different from the relief curve of fig. 3.12 because the maximum value is shifted 30km from the beginning of the profile, but anyway there is a general decreasing trend moving from the beginning of the profile towards the end of the same.

The first 30km are characterized by a progressive increase of the relief curve, until the highest peak that is reached about 30km from the beginning of the profile, with a relief value of about 1200m: this value is reached inside the Cervati massif, it is due to the morphostructural setting of the massif because the transect comprises both the highest peak of the massif than its marginal areas, so there are no important lithological variations while the many faults individuated in this area may have same relevance on the generation of the relief.

Moving from this point until the 45km from the beginning of the transect, the relief curve tends to decrease until the minimum value of almost zero relief that is reached in correspondence of the Vallo di Diano basin: this general trend is interrupted by a positive peak at about 40km with a relief value of about 700m, and that is due to the lithological contrast between the Apennine carbonates of the Alburno-Cervati massif bordering the western side of the Vallo di Diano basin and the quaternary deposits of the same basin.

Immediately after this zero relief sector, there is a new positive peak with a relief value of about 600m, also this peak is due to the lithological contrast between the Apennine carbonates now bordering the eastern side of the Vallo di Diano basin (they crop out on the M.ti della Maddalena ridge) and the quaternary filling of the same basin: in this case an important role is also played by the tectonics, in fact the master fault of the Vallo di Diano is located on this side of the basin, so that we can say that in this case the relief is due to the combination of the lithological and tectonic factors.

After this positive peak and until 80km from the beginning of the profile, the relief curve oscillates around a mean value of about 500m: in this area the profile moves initially into the deposits of the Lagonegro Units, to pass then to the deposits of the External Flysch Units, there are no important lithological variations along the profile, but there is a diffuse river incision, with important rivers flowing perpendicular to the transect (such as the Agri and the Basento river), and there are many normal and thrust faults that could be considered the two main factors generating the relief in this portion of the transect.

The relief curve then follows a decreasing trend moving towards the end of the profile, this decreasing trend is reached in the sectors where the profile moves into the foredeep deposits (with the relief curve abruptly decreasing from 600m to about 100m, there are no important lithological variations or tectonic structures, so the relief is mainly due to the river incision) and into the foreland deposits (with the relief curve laying at a mean value of about 50-100m, the low values are due to the flat morphology of this area and to the lack of important lithological contrast and tectonic elements).

3.3.5 The Noce-Sirino-Alpi-Sant'Arcangelo transect

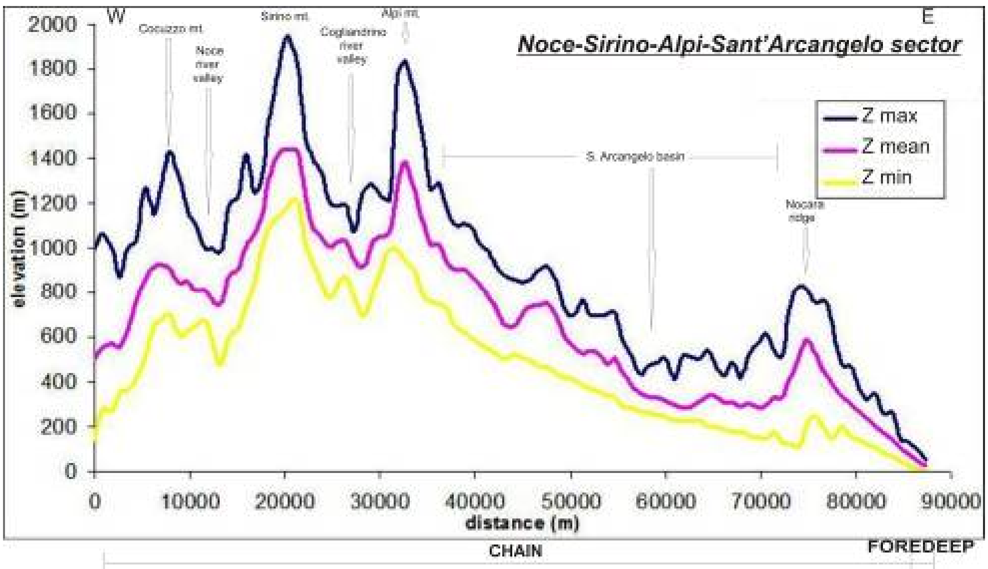


Fig. 3.15 = swath profile relative to the Noce-Sirino-Alpi-Sant'Arcangelo transect of the Southern Apennine

This transect (fig. 3.15) crosses the Southern Apennines in the area comprises between the Noce valley on the Tyrrhenian flank and the Nocara ridge on the Adriatic flank, it is W-E oriented, so this is the only profile with a non-antiapenninic orientation because of the presence in this area of important morphostructural and tectonic elements N-S oriented (such as the Noce valley, the Sirino massif, the Alpi mount and the Nocara ridge). The profile crosses in the first 10 km the carbonatic Alburno-Cervati unit, here represented by the Cocuzzo mount; it is limited to the east by the Noce valley, a morphological low with a very complicated tectonic setting, with prevalent rocks referring to the North Calabrian Units, and local outcropping of carbonates rocks as fault-line scarp. The Noce valley is limited to the east by the Sirino massif, a dome-like structure with the entire Lagonegro succession outcropping; east of the Sirino massif there is the Cogliandrino valley, characterized in its north sector by the outcropping of flyschs units (Albidona Flysch) and in its southern sector by the presence of North Calabrian units. On the east flank of the Cogliandrino valley there is the Alpi mount, a carbonatic morphostructural high where carbonates of the Apulian platform outcrops, which passes to the east to the Plio-Quaternary deposits of the Sant'Arcangelo basin, which is characterized by a marine to continental succession representing the progressive filling of the basin. The profile ends with the Nocara ridge, a NNW-SSE elongated ridges with the outcropping of both flyschs units (Gorgoglione Flysch and Albidona Flysch) and Sicilidi Units.

In this transect the chain s.s. represents the 95% of the whole profile, whit the remaining 5% represented by the foredeep domain. The wavelength of the chain is of about 85km, it looks like a Gaussian with a left asymmetry as a consequence of the closeness of the divide to the Tyrrhenian coast (the divide is located in correspondence of the Sirino massif), with a mean slope of the Tyrrhenian flank of 5.1°, while the Adriatic flank has a slope of 1.4°. In this portion of the Southern Apennines there is a coincidence with the location of the divide and the maximum elevation line.

The profile can be subdivided in two different sectors from a morphological point of view, the first one comprises between the beginning of the transect and the Alpi mount, and the second one extended from the Alpi mount to the end of the transect. In the first sector the topography is characterized by the presence of three morphostructural highs of relevance (Cocuzzo mount, Sirino massif and the Alpi mount) separated by the Noce valley and the Cogliandrino valley respectively, with the two valleys spaced of about 15km. In this sector there are the highest peaks in correspondence of the Sirino and Alpi mounts, with a maximum elevation of about 2000m a.s.l.: it is important to notice that the valleys are higher than the other Tyrrhenian valleys in the northern profiles, with an elevation of about 500-600m a.s.l. for the Noce valley and an elevation of about 800m a.s.l. for the Cogliandrino valley, located immediately east of the divide, a difference of elevation that cannot be interpreted as due to a lithological control, being the two valley characterized by the presence of the same lithologies. The second sector is characterized by a gentle topography, there is a progressive lowering of the elevation towards the foredeep, that seem to proceed with a constant slope of about 1°. The peaks in the elevation lines represent the divides between the Sinni river and its tributaries. This gentle trend abruptly ends against the Nocara ridge that represent the only morphostructural high of this sector.

The three elevation lines proceed almost parallel each other, without important differences in their trend, that are individuated in correspondence of highest peaks for the closeness of different lithologies, with a different morphological characteristics. It is particular the trend of the minimum elevation line east of the Alpi mount, that looks almost rectilinear, with a progressive lowering that seem to proceed almost constant. On the east flank of the Alpi mount it is possible to recognize a flat surface at an elevation of about 800m a.s.l., that represents one the flat surfaces where the Serracorneta Conglomerates outcrop, the sedimentary cycle that represents the closure of the Sant'Arcangelo basin succession.

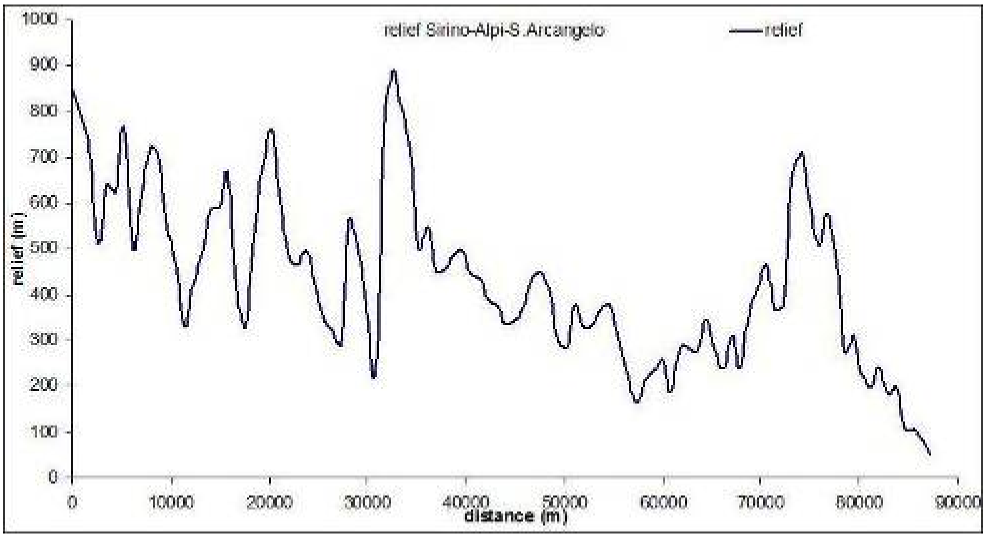


Fig. 3.16 : relief curve relative to the Noce-Sirino-Alpi-Sant'Arcangelo transect of the Southern Apennine

The relief curve (fig. 3.16) can be separated in three different sectors, a first one that runs from the beginning of the transect until 30km (Mt. Alpi), a second one that runs from the 30km until the 75-80km, and a third one that runs from the 75-80km until the end of the profile.

The first part of the curve is characterized by a relief value oscillating around a mean value of about 500-600m: this portion of the curve is characterized by a continue alternation of both positive and negative peaks, that are equi-spaced of about 5km along the whole sector. In the first 10km the relief is due both to the closeness of different lithologies, and in particular the carbonates of the Apennine platform (they crop out on the Mt. Cocuzzo and the Serrralunga ridge) and the Albidona Flysch and North-Calabrian Units (they crop out on the morphological low), and to occurrence of a complex tectonic setting, with several faults dismembering the calcareous mountains and in same case responsible of the closeness of the previous considered lithologies.

There are then two negative peaks between the 10 and 20km, both showing a relief value of about 300m, that corresponds with the Noce river valley, separated by a positive peak, with a relief value of about 700m: this high value is due to the presence of the Sirino massif, that represents on of the few Southern Apennines 2000m a.s.l. peaks, in this sector the profile moves entirely into the Sirino massif, moving into the Lagonegro Units, the relief in this area could be due to the morphostructural setting of the Sirino massif (it is characterized by a dome structure).

The relief curve tends to decrease from the 20 until the 30km, and it then reaches its highest peak, with a relief value of about 900m: this peaks is reached in correspondence of the Mt. Alpi and it is due to the different competence of the carbonate of the Apulian platform that crops out on the Mt. Alpi and the North-Calabrian units that crop out north of the Mt. Alpi, in the Racanello valley.

The relief curve then show an abrupt decrease, with the relief value oscillating around a mean value of about 300m, reaching a minimum value of about 150m: the curve moves in this sector into the Sant'Arcangelo basin, there are no important lithological variations that could be considered the main responsible of the generation of the relief, so the relief is in this portion of the chain is mainly due to the river incision.

The relief curve reaches a new positive peak at about 75-80km from the beginning of the transect, with a relief value of about 700m: in this case the profile moves into the Nocara ridge, a ridge characterized by the outcropping of the Sicilidi Units and the Numidian Flysch, there is a slight difference between the two units, in fact the topography is higher where the Numidian Flysch crops out (highest peaks at about 800m a.s.l.) respect to the Sicilidi Units (600m), but the relief value of 700m is due to presence of the Sinni river, with the Sinni valley reaching an elevation of about 100m a.s.l..

The last part of the curve is characterized by an abrupt decrease of the relief curve, this is the foredeep domain, the decrease of the curve is due to the flat topography of the area, with no important lithological variations, and with the river incision that is the mainly factors responsible of the relief generation.

3.3.6 Comparison of the five transects

The comparison of the five transect give important informations on how the topography varies along the Southern Apennines, and in particular on the variation of the morphometrical and morphological parameters that have been calculated (maximum elevation, location of the divide, elevation of the valley, valleys spacing, maximum, medium and minimum elevation lines, relief curve). The main differences highlighted by the comparison of the five profiles are the following:

- the wavelength of the chain is maximum in the Northern profile (120km), it slightly decreases in the Central profile (110km), and it is minimum in the southern profiles, with a value of 95km for the Pisciotta-Bari profile, 85km for the Noce-Sirino-Alpi-Sant'Arcangelo profile and a value of 75km for the Southern profile;
- in the Northern profile the profile is almost entirely developed into the chain s.s. domain, with a very small part of it extended into the foredeep; moving to the southern profiles, the foredeep domain becomes more relevant, except that for the Noce-Sirino-Alpi-Sant'Arcangelo transect (whose orientation doesn't allow to involve the Bradanic foredeep deposits that are present in this portion of the chain), with the addiction of the presence of the foreland domain into the Pisciotta-Bari and Southern profiles;
- moving from north to the south there is a progressive migration of the maximum elevations towards the west, with a value of about 2000m a.s.l. in the Northern, Southern and Noce-Sirino-Alpi-Sant'Arcangelo profiles, and a value of 1800m a.s.l. for the Pisciotta-Bari profile and 1600m a.s.l. for the Central profile;
- in the Northern, Southern and Noce-Sirino-Alpi-Sant'Arcangelo profile there is a correspondence between the location of the highest peaks and the divide, while this correspondence doesn't occur in the Central and the Pisciotta-Bari profiles, with the divide that is in both cases shifted of about 40km east of the maximum elevations;
- the location of the divide has a strong influence on the shape of the profile, as it is highlighted also by the slope values on the Tyrrhenian and Adriatic flank of the various transects: in general the topography looks like a unimodal Gaussian function, with a light left asymmetry in the Northern profile, that changes into a right asymmetry in the Central profile, to return with a more evident left asymmetry for the southern profiles and an enhanced right asymmetry for the Noce-Sirino-Alpi-Sant'Arcangelo transect;
- the Tyrrhenian and the Adriatic flanks differ each other in all the profiles: the Tyrrhenian flank is characterized by a continue alternation of topographical highs and lows, that seem to proceed in a constant way moving from the coast line to the divide; the Adriatic flank has a gentler topography, with maximum elevations always lower than those one obtained on the Tyrrhenian flank e valleys that are very close each other,
- there are relevant differences between the five profiles for what concerning the distribution of the valleys: in the Northern profile the valleys are spaced of about 25km on the Tyrrhenian flank and 10km on the Adriatic flank; in the Central profile the valleys are spaced of about 20km on the Tyrrhenian flank, while it is not possible to talk of valley spacing on the Adriatic flank because in this sector of the chain the profile move parallel to the main valley of the area, the Ofanto valley, as it is shown by the trend of the minimum elevation line that recalls the Ofanto longitudinal profile, except for the area of the Vulture volcano; in the Southern

profile the only valley present on the Tyrrhenian flank is the Noce valley, so it is not possible to talk about valley spacing on the Tyrrhenian flank, while the valleys are spaced of about 10km on the Adriatic flank; in the Pisciotta-Bari profile the valleys are spaced of about 20km on the Tyrrhenian flank, while they are closer on the Adriatic flank, being spaced of about 10km; in the Noce-Sirino-Alpi-Sant'Arcangelo profile the only two valleys (the Noce and Cogliandrino valleys) are spaced of about 15km, this is the only considerations that can be extrapolated in this portion of the chain, considering that the two mentioned valleys are located respectively west and east of the divide;

- another important feature regarding the distribution of the valleys is their elevation. In the portion of the Southern Apennine comprises between the Campana plain and the Vallo di Diano basin, the valleys on the Tyrrhenian flank are located at an elevation never exceeding 200m a.s.l., clearly lower than the elevation that the valleys on the Adriatic flank reach in the same area (their elevation range between 300m and 600m a.s.l.); a similar situation is individuated in the area south of the Vallo di Diano basin, with the valleys that anyway are higher, if compared to the previous sectors, on both the Tyrrhenian and the Adriatic flanks: in fact, in this sector of the Southern Apennines the valleys on the Tyrrhenian flank range between 500-600m a.s.l., while the valleys on the Adriatic flank range between 600-800m a.s.l.;
- the relief curve looks like a Gaussian function in the northern portion of the Southern Apennines, it is characterized by a continue alternation of positive and negative peaks in the central sector of the chain and along the Noce-Sirino-Alpi-Sant'Arcangelo transect, and it looks like a power function along the southern sector of the chain and along the Pisciotta-Bari transect;
- the relief is due to three different factors, and in particular to the closeness of different lithologies ("hard-weak" contrast), to the presence of tectonic elements (mainly normal faults) and to the river incision (in the case of lithologically homogeneous context and absence of tectonic structures);
- the highest relief values are reached on the southern transect and on the Pisciotta-Bari transect with a maximum value of about 1300m, while on the other transects the maximum relief values are of about 900m;
- the highest relief values are reached inside the Apennine chain domain, the relief then tend to decrease as the profiles move into the foredeep domain, and it reaches its lowest values in the foreland domain: the flat topography of this area and the lack of important lithological variations and tectonic elements make the foreland domain almost a zero-relief sector.

The particular features of the Southern Apennines are also clear by a comparison of these swath profiles with two swath profiles created for the Central and the Northern Apennines (fig. 3.17).

If we look carefully, we can notice how the Northern and the Central Apennines show an asymmetrical topographic profile, which is anyway opposite to the Southern Apennines topographic profile, with the outer side that is steeper than the inner side. The Central Apennines corresponds to the highest peaks of the entire Apennines, while the Northern Apennines is pretty low if compared to the Central and the Southern Apennines. The topography is characterized in both case by the alternation of morphological highs and lows, which is strongly controlled by the normal faulting occurred on the Tyrrhenian flank. In particular, the valley bottom are very low close the Tyrrhenian coast, while it rise up in the axial portion of the chain, reaching their maximum in correspondence of the main divide: this data could suggest that a more recent uplift has occurred on the outer portion of this part of the Apennines, and it has involved also the areas west of the main divide, being recognizable also in the axial portion of the chain.

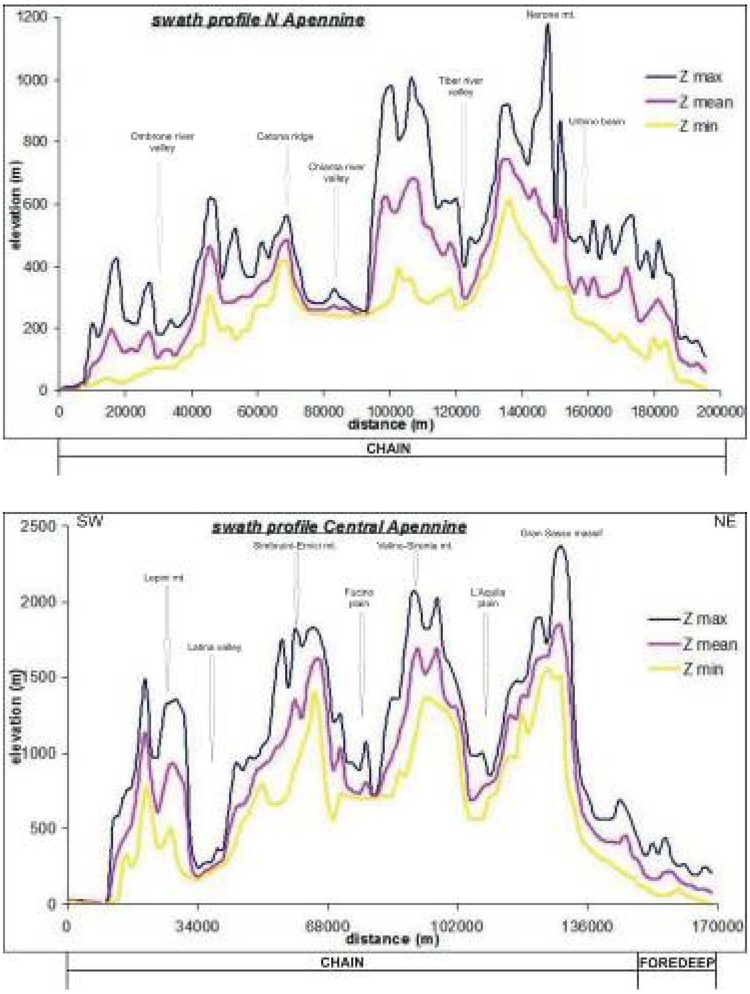


Fig. 3.17: swath profiles relative to the Northern and the Central Apennines.

3.4 DISCUSSION

There are several considerations to do about the morphometrical analysis of the whole chain. They could summarized as it follows:

- the Tyrrhenian slope is characterized by low values in the minimum elevation map also within the chain s.s., while this doesn't occur on the Adriatic slope (e.g. the elevation of the valley bottoms is higher on the Adriatic flank than on the Tyrrhenian flank);
- considering that the Adriatic slope is characterized by the outcropping of weak lithologies, and that the valleys on the Tyrrhenian slope coincide either with morphotectonic lows (peri-tyrrhenian grabens and intramontane basins) or with the outcropping of weak lithologies, we have that the comparison of the elevation of the valley bottoms on both flanks is a measure of the degree of incision of the same valleys. This means that there is no lithological control on the elevation of the valley bottoms, and so the only process that could influence this parameter is a different uplift between the Tyrrhenian and the Adriatic flanks. In particular the Adriatic flank has experienced more pronounced uplift in recent times;
- the minimum elevation map can be separated in two different sector, respectively located north and south of the hereinafter named "Sele-Ofanto line": the north sector is characterized by the coincidence of the highest values with the apenninic divide, while the southern sector is characterized by the presence of a wide area

with high values in the minimum elevations, which moves from the apenninic divide to the east, involving the foredeep (and the Lavello high) and the Murge-Salento area (which must not be considered in this analysis because it is geologically characterized by the only outcropping of carbonate rocks, with a lack of important tectonic deformation, and so there are no important valleys in these areas);

- this data regarding the minimum elevation map is very interesting in particular when compared with the "Map of the Morphostructural Units of the Southern Apennines" (fig. 3.1): this comparison show that the valleys on the Adriatic flank are higher than the valleys on the Tyrrhenian flank despite the Adriatic flank is characterized by the outcropping of very weak lithologies (external flyschs and Quaternary filling of the foredeep);
- the minimum elevation map could be so considered a good representation of the differential uplift at the orogen scale; this fact let the maximum elevation map to play a less relevant role when we want to interpret it in terms of uplift, and it can be more correctly considered as a good representation of the distribution of the tectonic Quaternary lows;
- the medium elevation map clearly enhance the presence of the hard carbonatic highs on the Tyrrhenian slope: this suggests that these carbonatic massifs and ridges crop out respect to more eroded surrounding areas where weak lithologies crop out. This means that the Tyrrhenian slope has experienced a more intense erosion, or even that it is experiencing erosion since older times than the Adriatic flank (where the same weak lithologies crop out), and that the amount of eroded rock volumes is higher on the Tyrrhenian flank than on the Adriatic flank. If this two sectors were experiencing erosion since the same time, than we cannot explain why the external flank of the chain is higher than its inner flank despite this two sectors are characterized by the same rock-type;
- the analysis of the maximum, medium and minimum elevation maps suggests that the Adriatic flank of the Southern Apennines has experienced more enhanced uplift in recent times than the Tyrrhenian flank;
- the Tyrrhenian and the Adriatic flanks of the chain have also other different morphological and morphometrical features, in particular the Tyrrhenian flank becomes steeper than the Adriatic flank as we move to the south, giving the typical asymmetrical feature to the Southern Apennine;
- this asymmetrical feature of the chain is clearly showed by the envelop of the minimum elevation line of the five swath profiles, which enhance the presence of a Tyrrhenian steep slope and of an Adriatic gentle slope;
- the distribution of the valleys is strongly controlled by the extensional tectonic on the Tyrrhenian flanks, in fact the valley, that are almost constantly equi-spaced of about 20km, are located in correspondence of morphostructural lows due to normal faulting;
- on the other hand, the distribution of the valleys on the Adriatic flank is strongly controlled by the lithology, in fact the valley are very close each other, being spaced of about 5-10km, as a consequence of the soft terrigenous lithologies cropping out in this portion of the chain;
- there is an important difference regarding the elevation of the valleys on Tyrrhenian and the Adriatic flanks, with a mean gradient that bring the valleys to reach elevations higher on both the flanks as we move to the south, but in general the valleys on the Tyrrhenian flank are always lower than the valleys on the Adriatica flank: such a difference suggest a more recent uplift on the Adriatic flank than on the Tyrrhenian one, this idea fits with the bibliographic data if we consider

that several authors have proposed a more enhanced uplift on the Adriatic flank (Cinque, 1992; Romano, 1992; Amato, 1995) and that such uplift is thought to be related to the roll back of the sinking Adriatic slab (Malinverno and Ryan, 1986; Cinque, 1993);

- another data to validate the hypotheses of more recent uplift on the outer side of the chain is the morphostructural setting of the foreland, that is characterized by a gently dipping of the Murge region towards the NE, as it is testified by the swath profiles of fig. 3.11 and 3.9, and to the dipping towards the NE of the foredeep deposits showed by the swath profile of fig. 3.9;
- the relief in the Southern Apennines is mainly due to the river incision, with an important role that is also played by the tectonics (responsible both of the closeness of different lithologies than to the dismembering of lithologically homogenous context, such as the calcareous massifs), and a less relevant role that is played by the lithological contrast between lithologies with a different competence.

CHAPTER 4

THE ANALYSIS OF THE DRAINAGE NETWORK

4.1 LONG PROFILE, DRAINAGE AREA, SLI AND SLOPE AREA ANALYSIS

The long profile analysis has been carried out by using the software Arcgis 9.2, and in particular the Hydrology extension. The studied area comprises the whole Southern Apennines chain, the analysis has been based on the use of the NASA 90m resolution dem. This dem has been modelled (creating the filled dem, the flow direction and the flow accumulation), to obtain a shapefile of the river network of the chain: this shapefile has been then investigated thanks to the use of the Easy Profiler extension of Arcgis 9.2, this extension allows us to select every single river we want to analyze, to extract it and to create the graphs we need (long profile, SLI curve and basin area curve). The studied rivers are shown in fig. 4.1 and their name are reported in tab. 4.1.

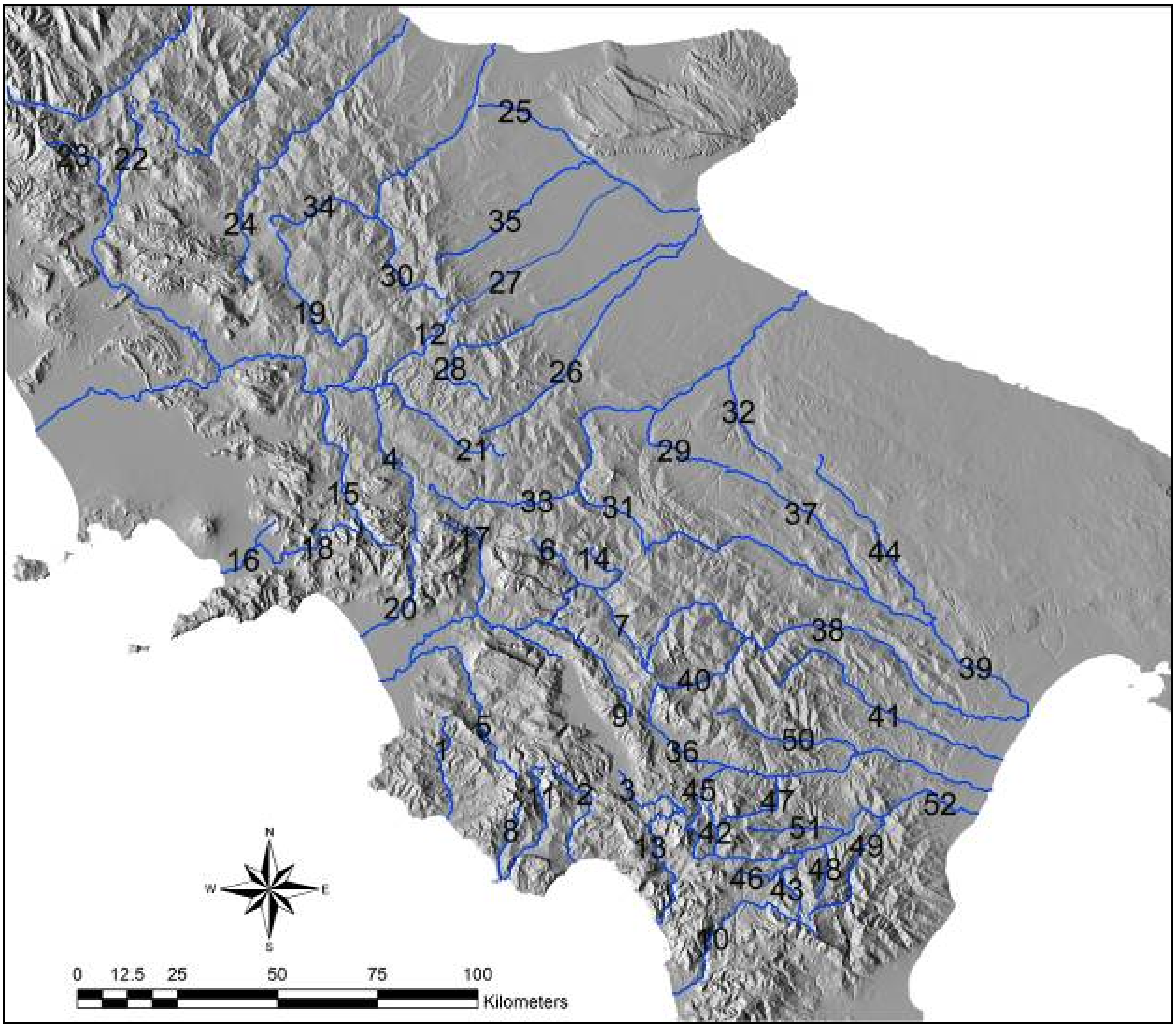


Fig. 4.1: map of the river network of the Southern Apennine, labels are referred to table 4.3.

Tyrrhenian rivers		Adriatic rivers		Ionian rivers	
id	river	id	river	id	river
1	Alento	24	Biferno	36	Agri
2	Bussento	25	Candelaro	37	Basentello
3	Calore	26	Carapelle	38	Basento
4	Calore_beneventano	27	Celone	39	Bradano
5	Calore_salernitano	28	Cervaro	40	Camastra
6	Forra_di_muro	29	Forra_di_venosa	41	Cavone
7	Forra_di_tito	30	Fortore	42	Cogliandrino
8	Lambro	31	Fosso_di_stroppito	43	Frida
9	Melandro	32	Locone	44	Gravina_di_picciano
10	Mercure	33	Ofanto	45	Maglia
11	Mingardo	34	Tappino	46	Peschiera
12	Miscano	35	Vulgano	47	Racanello
13	Noce			48	Rubbio
14	Platano			49	Sarmento
15	Sabato			50	Sauro
16	Sarno			51	Serrapotamo
17	Sele			52	Sinni
18	Solofrana				
19	Tammaro				
20	Tusciano				
21	Ufita				
22	Vandra				
23	Volturno				

Tab. 4.1= list of the analyzed rivers of the Southern Apennines

Using the Easy Profiler extension we are able to obtain the long profile and the drainage area vs distance graphs (we use respectively the filled dem and the flow accumulation grid for the two graphs) (fig. 4.2). One of the main parameter to set is the sampling interval, I have chosen to sample 100 equally spaced points along rivers that are longer than 50km, and 50 equally spaced points along rivers that are shorter than 50km. This choice has been due to the necessity to create graphs as smoothed as possible in order to eliminate errors that are still present in the 90m dem and so to have a better view of the main morphological elements of the profile.

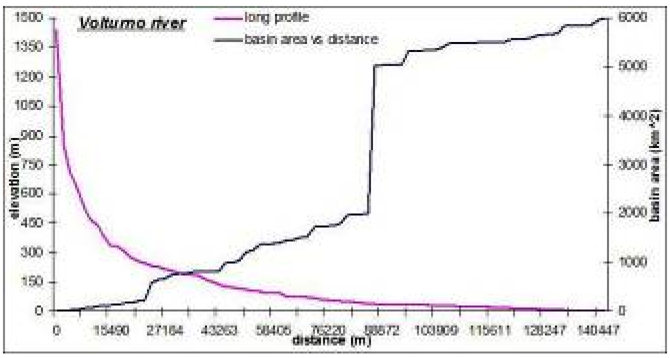


Fig. 4.2 = long profile and basin area vs distance of the Volturno river.

These first steps allow us to create the long profile of every selected river, and then to start their analysis by determining their shape (concave upward, convex upward, rectilinear) and pointing the attention on the presence or not of knickpoints. The elevation data obtained by the long profile have been then used to create the SLI curve: the Stream Gradient Index is calculated as SLI = $(\Delta Z/\Delta X) \cdot L$, with ΔZ= difference between the highest and lowest elevation of every reach in which the profile has been subdivided, ΔX= length of the considered reach, L= distance from the beginning of the profile to the mid-point of the considered reach.

The following step has been the analysis of the same rivers by Matlab, using the Arcgis extension Profiler Tollbar v5.1. By this extension we are able to pick up a point on the dem (that corresponds to the headwater of a river) and to send this point to Matlab and then, using the Matlab Profile51 and Profile51_batch functions, to create new graphs starting from that point (in particular, we focused our attention on the slope vs drainage area graph, but we are also able to create two new shapefiles, the first one shows the exact location of a knickpoint along the considered river, while the second one contains the values of the Ks index for every analyzed river, showing how it varies along the profile) (Whipple et. al., 2007).

In this case we set as sampling parameters the following (tab. 4.2):

Theta ref.	0.45
Smoothing window (m)	250
Contour sampling interval (m)	12.192
Auto K_sn window (km)	0.5
Search distance (pixel)	10
Minimum accumulation (pixel)	10

Tab. 4.2= Theta ref. is the reference Θ we use to calculate the Ks value (usually ranging between the value 0.4-0.6); Smoothing window is the length of a moving average window over which Matlab will smooth raw profile data (in meters); Contour sampling interval is the vertical distance Matlab will use to calculate raw slopes; Auto k_sn window is the width of a moving window Matlab uses to calculate normalized steepness indices along the entire length of a profile; Search distance is the distance Matlab will search downstream from your selected channel head (in pixels) to make sure it's actually in the channel; Minimum Accumulation helps Matlab to define where the actual channel head is, it is the number of pixels that contribute to the uppermost pixel in your channel (description from Whipple et al., 2007). These values are the default values that, after several attempts, we consider useful to our analysis.

The slope/area graph looks like that one of fig. 4.3. The great utility of this graph is the opportunity to automatically calculate the values of Ks (the Y intercept of the regression line) and Θ (the angle the X axe forms with the regressed line) as shown in the figure.

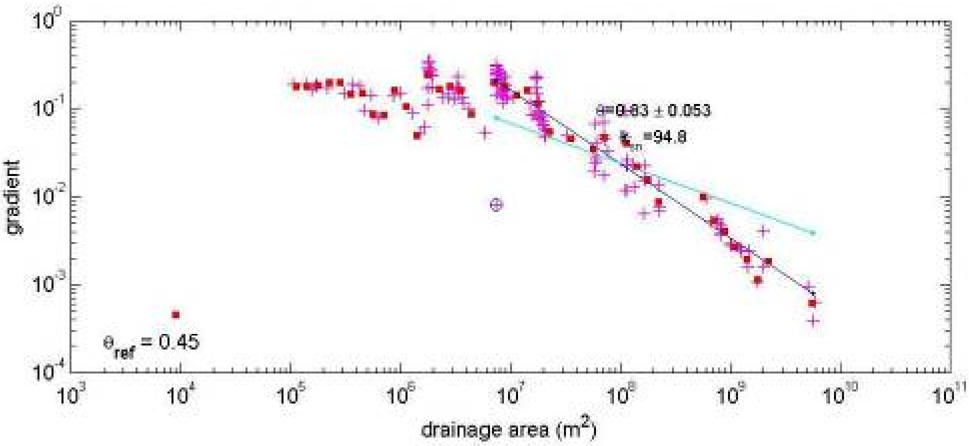


Fig. 4.3 = slope vs drainage area graph of the Volturno river. In this graph the blue line shows the regressed concavity, the cyan line shows the reference concavity, purple crosses are the slope and areas values plotted in the graph, red squares are the log-bin averages of the S-A analysis, the open circles show the location of the knickpoints as plotted on the long profile (from Whipple et al., 2007).

In some cases, however, this graph looks different, in particular we could find different clouds of dots through which apply different regression lines: this case is typical for rivers with knickpoints, with the end of a cloud and the beginning of the following that correspond with the location of a knickpoint. This is the case, for example, of the Tusciano river (fig. 4.4)

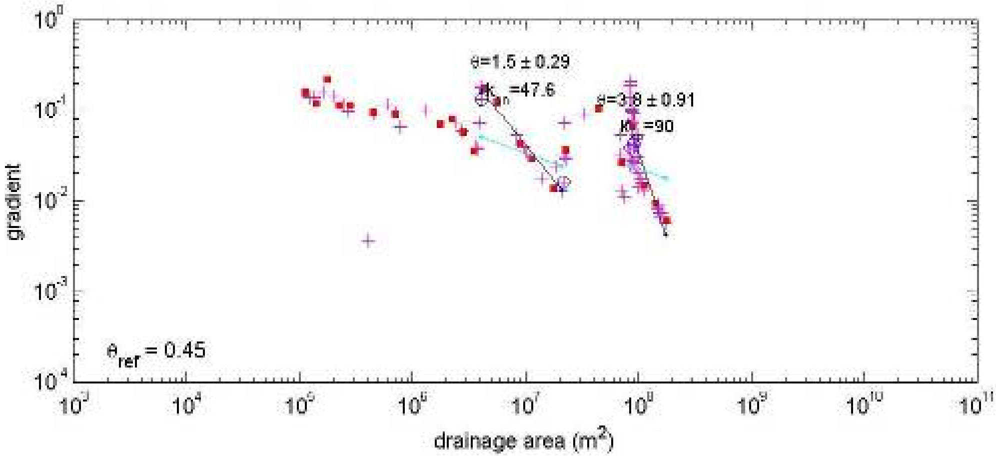


Fig. 4.4 = slope vs drainage area graph of the Tusciano river: it is evident as the location of the knickpoints (open circles) corresponds with the starting and ending point of the regressed clouds.

In these cases we have the problem that we obtain a value of Ks and Θ for every regression line, while we need just one value of them that is representative of the whole profile, so that we can compare single rivers, and not different sectors of different rivers. We have two possibilities: the first one is to apply only one regression line through the different clouds of dots considering that the R^2 values we obtain will be very low, the second one is to modify the sampling window, in particular the Contour Sampling Interval (tab. 4.1) to have less data in the slope vs drainage area graph so that the different clouds of dots are not evident. The results are shown in tab. 4.3.

Tusciano river			
contour sampling (m)	Θ	**Ks**	**R^2**
12.921	0.31±0.21	86.2	0.13
50	0.33±0.53	90	0.14
75	0.21±0.32	75.8	0.22
100	0.18±0.5	91.8	0.15
200	0.19±4.5	78.9	0.22

Tab. 4.3: variations of Θ and Ks modifying the Contour Sampling Interval: the first class is relative to the regression applied to all the original points, while the other classes are relative to the regression with less data, where the different clouds of dots are not evident.

As we can see from the table, there are no important variations in the values of Θ, Ks and the R^2. Considering also that the standard deviation is lowest for the first class, we consider representative of the whole profile the values we obtain from the regression applied to all the data, so in the cases shown in fig. 4.4, when there are more than one cloud of dots, the regression line has been applied to the whole data, without varying the contour sampling interval.

In the following discussion about the long profile, SLI curve, basin area vs distance graph and slope/area analysis, the considerations about either a lithological control or tectonic control on the river morphology and morphometrical parameters have been done by using the "Morphostructural Map of the Southern Apennines" (fig. 3.1).

4.1.1 Tyrrhenian rivers

- Alento river

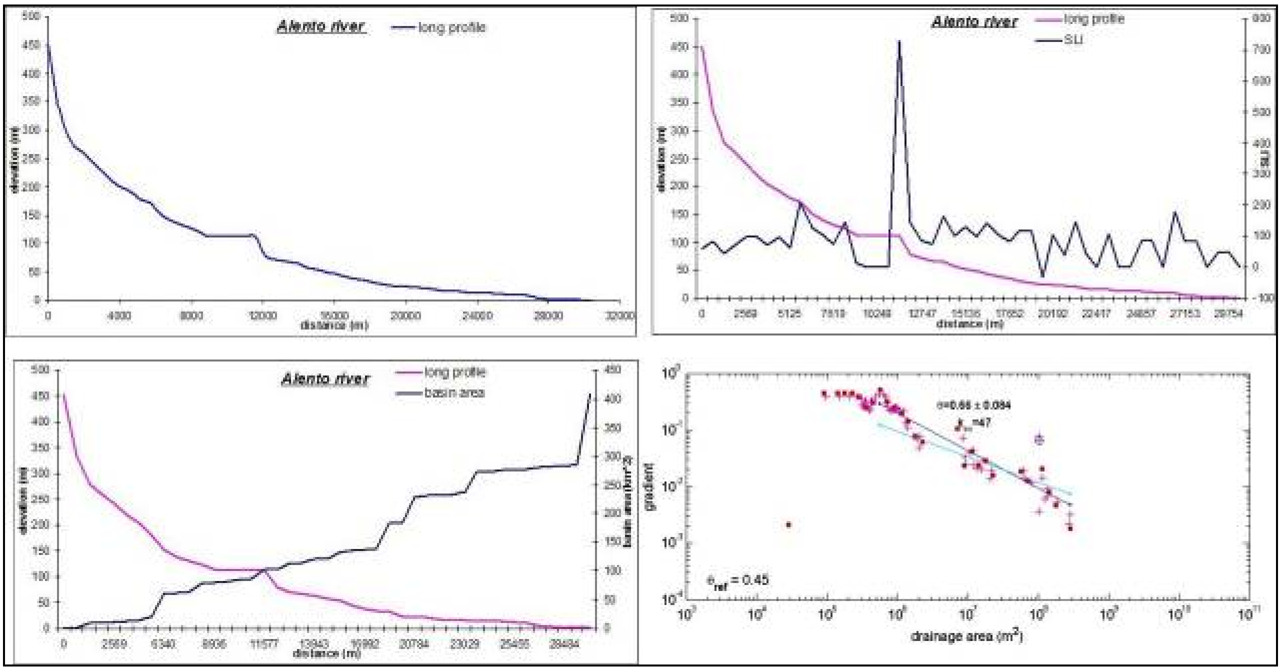


Fig. 4.5: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Alento river.

The Alento river springs on the southern slope of the Chianello and Sottano ridges, in the area comprises between the town of Trentinara and Monteforte Cilento, and it flows for about 30km following a prevalent N-S direction, with local variation of direction, until its mouth that is located in the area comprises between the town of Ascea and Casalvelino (Cilento region).

The long profile of the Alento river shows a general concave up shape, with no important slope variation, there is just one big knickpoint that is located at an elevation of about 130m a.s.l., but this is not a true knickpoint because it is due to the presence of a dam, and if we try to connect the points at the beginning and at the end of the knickpoint we notice that the long profile proceeds almost constantly. There is some little slope variations at an elevation comprises between 150-200m a.s.l.: in this case some faults are individuated in the reference area, and they are probably the responsible of the individuation of such knickpoints.

The homogeneity of the Alento long profile is also shown by the SLI curve: this curve is in fact characterized by almost constant values in the first 20km, with the highest peak that is due to the presence of the dam, while in the last 10km the SLI values seem to vary more than in the upstream reaches, with anyway the highest peaks that have values very similar to those one reached in the first part of the profile.

The basin area graph is characterized by a progressive growth of the curve that seems to proceed in an almost constant way: this feature is due to an equal dimension of the main tributaries, in particular regarding their fluvial order and drainage area. An important jump in the curve is individuated in correspondence of the confluence with the La Fiumara creek, about 20km from the beginning of the profile, whit another relevant jump that is individuated in correspondence of the mouth, where there is the confluence with the Palistro river.

The slope/area analysis shows a concavity value of 0.66, testifying the clear concave up shape of the long profile, while the Ks value is of 47.

- Bussento river

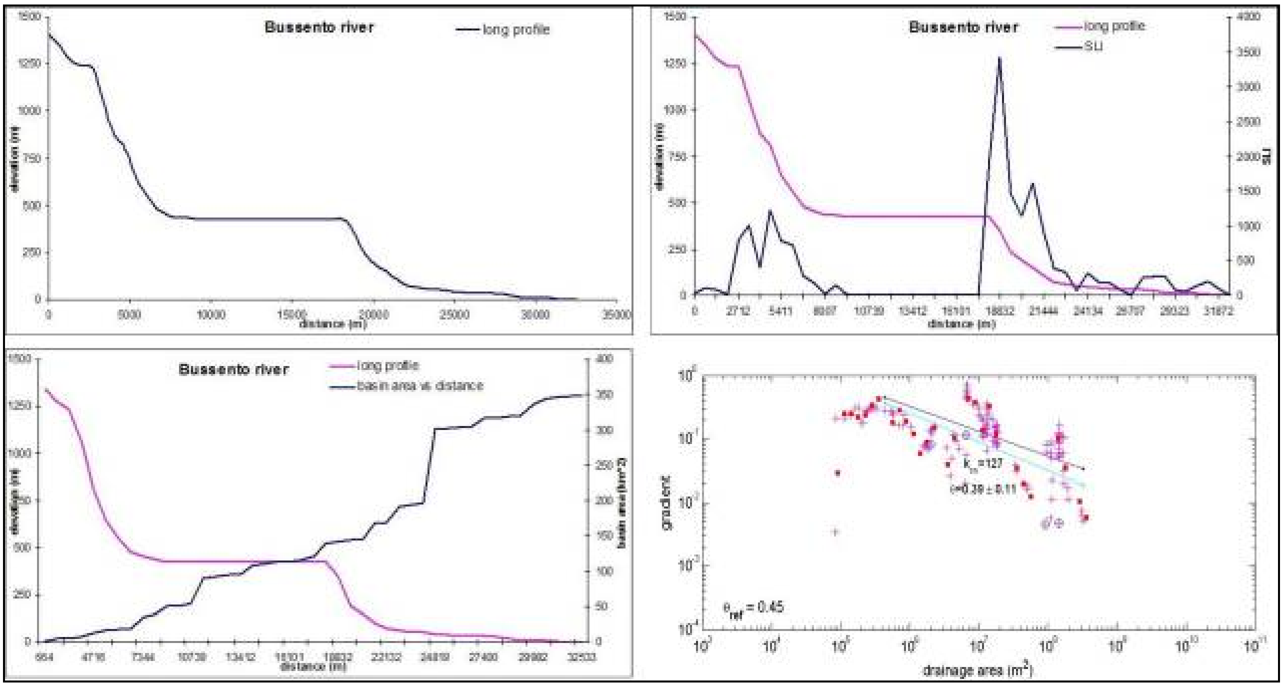


Fig. 4.6: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Bussento river.

The Bussento river springs on the southern side of the Cervati ridge, it flows for about 35km following a NW-SE direction in the first 13km of its course, it then follows a NNE-SSW direction until the 25km and it finally follows an almost N-S direction until its mouth. This river has a particular feature that is common in the areas where calcareous rocks crop out: after about 15km of its course, the Bussento start flowing inside the calcareous reliefs of the Mt. Pittari (close to the town of Caselle in Pittari) because of carsic processes, and it then flows again outside the mounts in the area close to the town of Morigerati, after a subterranean course of about 6km.

The Bussento long profile has a concave up shape, but this shape is strongly influenced by the subterranean part of its course: this part occurs between the 16km and 22km from the beginning of the profile, that is the part of the profile where the long profile flattens and the main knickpoint is located, so in this case the knickpoint is not related to the real course of the Bussento river, and it must not be considered a real knickpoint. Some little slope variations are individuated in the uppermost reach of the profile, at an elevation of about 1200m a.s.l.: in this area there is a tectonic contact between the carbonates of the Cervati ridge and the Neogene terrigenous units (Bifurto and Cerchiara formation), so this knickpoint is probably due to the lithological contrast among the two different lithologies, also if an important role could have been played by the fault that put in contact the two mentioned lithologies. Another small knickpoint is located at an elevation of about 750m a.s.l., in this case the profile moves here in the carbonates of the Cervati ridge, there are no important lithological variation or tectonic element that it is possible to recognize at the scale of investigation, so that this knickpoint should deserve more detailed analysis to be explained.

The SLI curve shows almost no variations, the highest peak is individuated in correspondence of the big knickpoint, so, because of the reason previously discussed, this peak is not considered relevant. The only peaks in the SLI curve are individuated in correspondence of the two previously described knickpoints, while some little peak is individuated in the lowermost reach of the profile, very close to the mouth, an area where the Bussento river flows into the North-Calabrian Units, so this peaks could be due either to some lithological variation inside this Units or to the occurrence of some minor tectonic element, that are the two main elements that could determine a slope variation along the profile.

The basin area graph is characterized by the occurrence of two main jumps, which are located at a distance of about 10km and 25km from the beginning of the profile respectively.

The slope/area analysis shows a concavity value of 0.39, which is anyway strongly influenced by the false knickpoint, and a steepness value of 127, that is the highest among all the Tyrrhenian rivers.

- Calore river

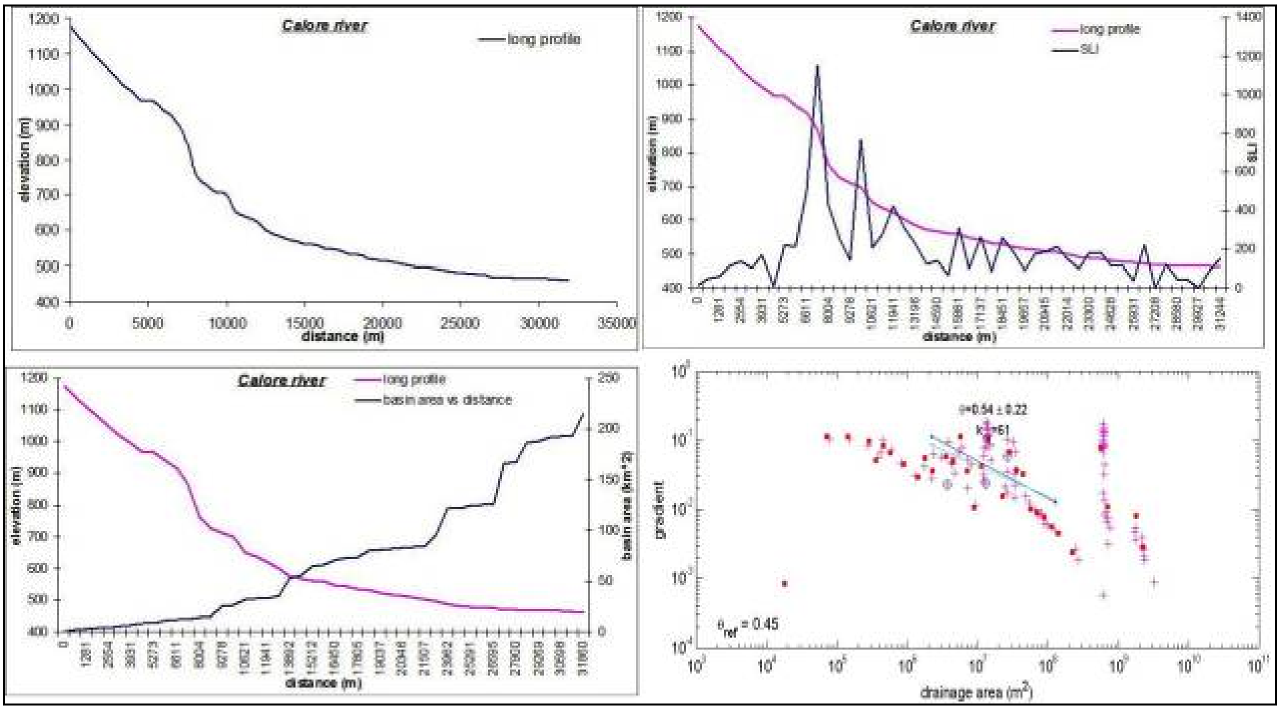


Fig. 4.7: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Calore river.

The Calore river springs on the north side of the Sirino massif, its course is characterized by several variations of direction, following a mean SE-NW trend, with the occurrence of many gorges in the uppermost reach of the valley, it flows for about 31km until its confluence with the Tanagro river into the Vallo di Diano intramontane depression.

The Calore long profile has a general concave up shape with the occurrence of several knickpoints in the uppermost reach of the profile: these knickpoints are located at an elevation comprises between 600m and 1000m a.s.l., here the Calore river flows on the northern side of the Sirino massif, this is a very complex area because the river moves both on the Lagonegro Units and the Apennine carbonates, with the addiction of the occurrence of several normal faults and thrust faults, so that the contact between the two lithologies is always tectonic. The knickpoints individuated in this portion of the profile are due to the presence of the faults, with the lithological variations that play a less relevant role in the individuation of such knickpoints. It is also interesting to notice that in this area the Calore river cuts several gorges into the both the Apennine carbonates than the Lagonegro Units.

The occurrence of the knickpoints is also shown by the SLI graph, with the highest peaks that are located in correspondence of the previously analyzed knickpoints, and with lower values in the areas upstream and downstream the knickzone.

The basin area curve arise almost constantly as the profile moves downstream, with the occurrence of two main jumps that are individuated at a distance of about 23km and 27km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.54, that is very close to the average value of all the Tyrrhenian rivers, and a steepness value of 61.

- Calore Beneventano river

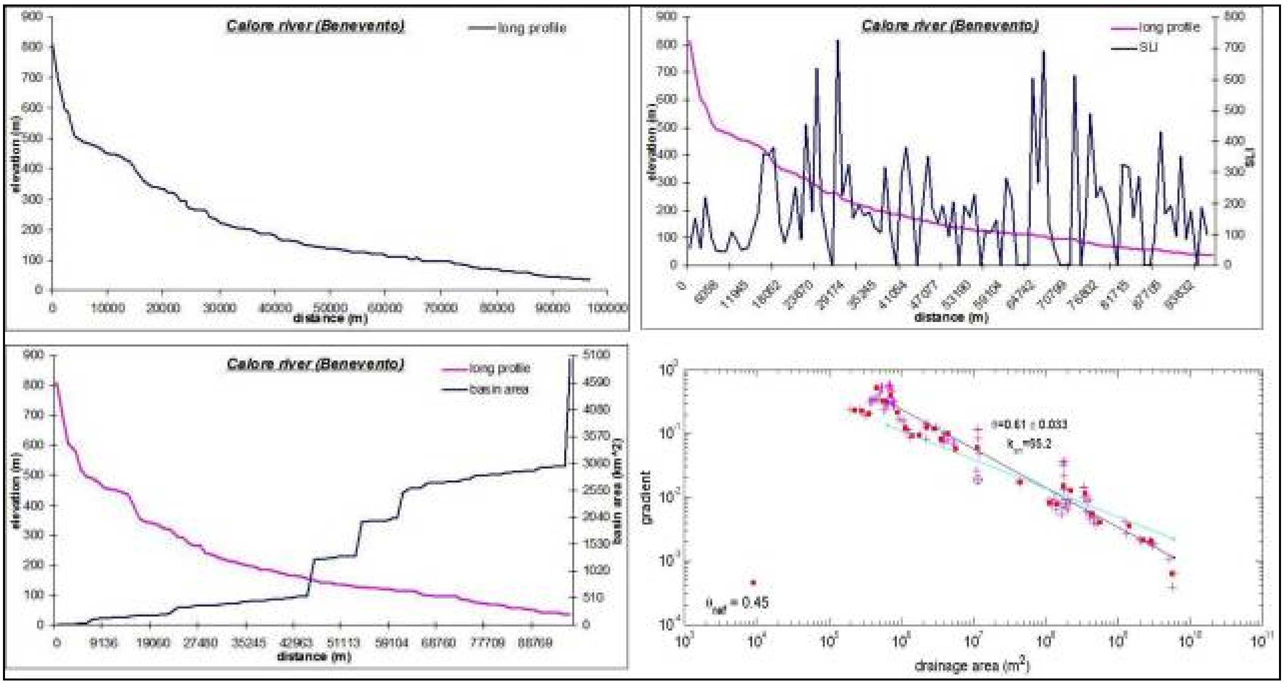


Fig. 4.8: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Calore Beneventano river.

The Calore Beneventano river springs from the northern side of the Picentini ridge, its course is about 100km length, it flows following a mean SE-NW direction until its confluence with the Volturno river, with several variations of direction that locally bring the river from a S-N direction to an E-W direction.

The long profile shows a concave upward shape, in the first 5km the Calore Beneventano proceeds with a constant steepness, then the profile changes with the individuation of four main knickpoints: they are comprised between 250m and 500m a.s.l.: the first small knickpoint is at an elevation between 450m and 500m a.s.l., in this area the river valley substrate changes from the Sicilidi units cropping out in the upper reach of the valley to the quaternary deposits of the Montella plain, so this knickpoint is due to this lithological variation; the other knickpoints, individuated between 450m and 250m a.s.l., are located in an area where the river flows into the Neogene terrigenous units, there are no important tectonic elements to justify the occurrence of such a knickpoints, but there is some lithological variation inside the Neogene terrigenous units, in particular the valley moves at the stratigraphic contact between the Ariano-Altavilla Unit (a sandy-clayey unit) and the Castelvetere-Caiazzo-Gorgoglione-San Bartolomeo Flyschs (a conglomerate to sandy unit), so the occurrence of these knickpoints could be due to some lithological variation that is not possible to appreciate at the scale of the map of fig. 3.1.

The SLI curve is very articulated, with the continue alternation of high and low peaks, that are very close spaced along the whole profile: in particular the SLI curve clearly shows the location of the previously analyzed knickpoints, also if the first one is not so enhanced, but the curve presents some high peaks also in the lowermost reach of the Calore Beneventano valley, in correspondence of the confluence with the Volturno river, these peaks don't correspond to kncikpoints in the long profile, but nevertheless they suggest the occurrence of same slope variation that should be analyzed in more detail to be explained.

In the upper reach of the valley the basin area curve shows a slow arise, while in the sector comprised between 45km and 70km from the beginning of the profile, the curve abruptly increase: here there are three important jumps that are due to the confluence of some important tributaries, and in particular the Ufita, Tammaro and Sabato rivers; downstream this area the curve doesn't show important jumps anymore.

The slope/area analysis shows a concavity value of 0.61, that confirms the concave up shape of the profile, and a steepness value of 55.20.

- Calore Salernitano river

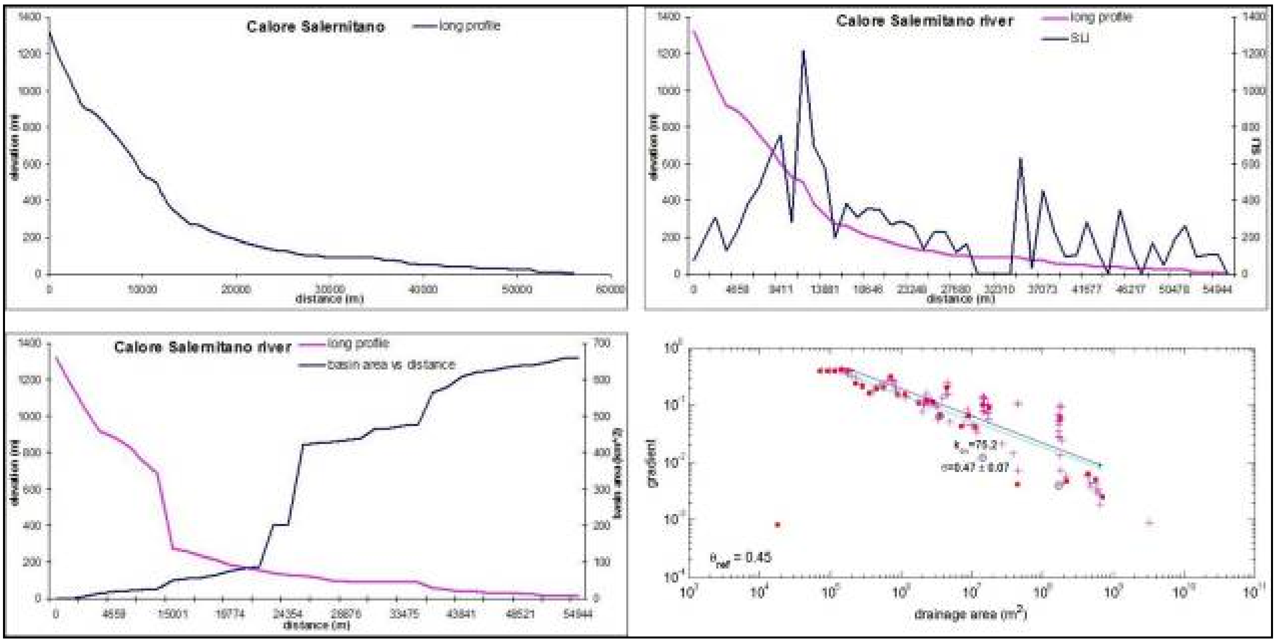


Fig. 4.9: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Calore Salernitano river.

The Calore Salernitano river springs on the Mt. Mercori, that is located NE of the Mt. Cervati, it flows for about 55km following a SE-NW direction in the first 25km of its course, it then changes its direction following a SSW-NNE one in the next 15km and it finally follows a ENE-WSW direction in the lowermost part of its course, until the confluence into the Sele river.

The Calore Salernitano long profile shows a concave upward shape, the profile is not characterized by the occurrence of relevant knickpoints, but it is possible to recognize two sectors of interest, in particular there is a slightly convex up part of the profile at an elevation comprises between 300m and 900m a.s.l. and there is a small knickpoint at an elevation of about 100m a.s.l., about 35km from the beginning of the profile. The first convex up portion of the profile is located in the upper part of the profile where there is a lithological contact between the carbonates of the Cervati ridge and the Piaggine-Racanello Formation and between the Piaggine-Racanello Formation and the Sicilidi Units: the second contact is due to the presence of a thrust fault. This convex up sector could testify a recent uplift that has occurred in this part of the profile. The second knickpoint is located in correspondence of another tectonic contact between the Piaggine-Racanello Formation and the Sicilidi Units: in this case this knickpoint is probably due to the occurrence of the thrust fault, also if an important role could have been played also by the lithological contrast between the two different units.

The SLI graph is characterized by the highest peaks in correspondence of the convex up sector, in particular the highest peak of the curve is individuated at the end of this sector, then the curve tends to decrease and it is characterized by another peak in correspondence of the knickpoint previously described: it is relevant to notice that as the profile moves into the Sele plain the SLI curve presents several peaks despite of the flat topography of this area, this particular feature is very interesting and it should suggest that some slope variation occurs into the Sele plain, slope variations that are not easy to recognize at this scale of investigation and that should deserve more detailed analysis.

The basin area curve is characterized by an important jump at a distance of about 25km from the beginning of the profile, in the area close to the town of Felitto, because of the presence of the main tributary on the idrographic left of the Calore Salernitano, an area where it is also possible to observe the wonderful gorge that the river cuts into the carbonates of the Chianello ridge.

The slope/area analysis shows a concavity value of 0.47, that is pretty close to the average value of all the Tyrrhenian rivers, and a steepness value of 75.20.

- Forra di Muro river

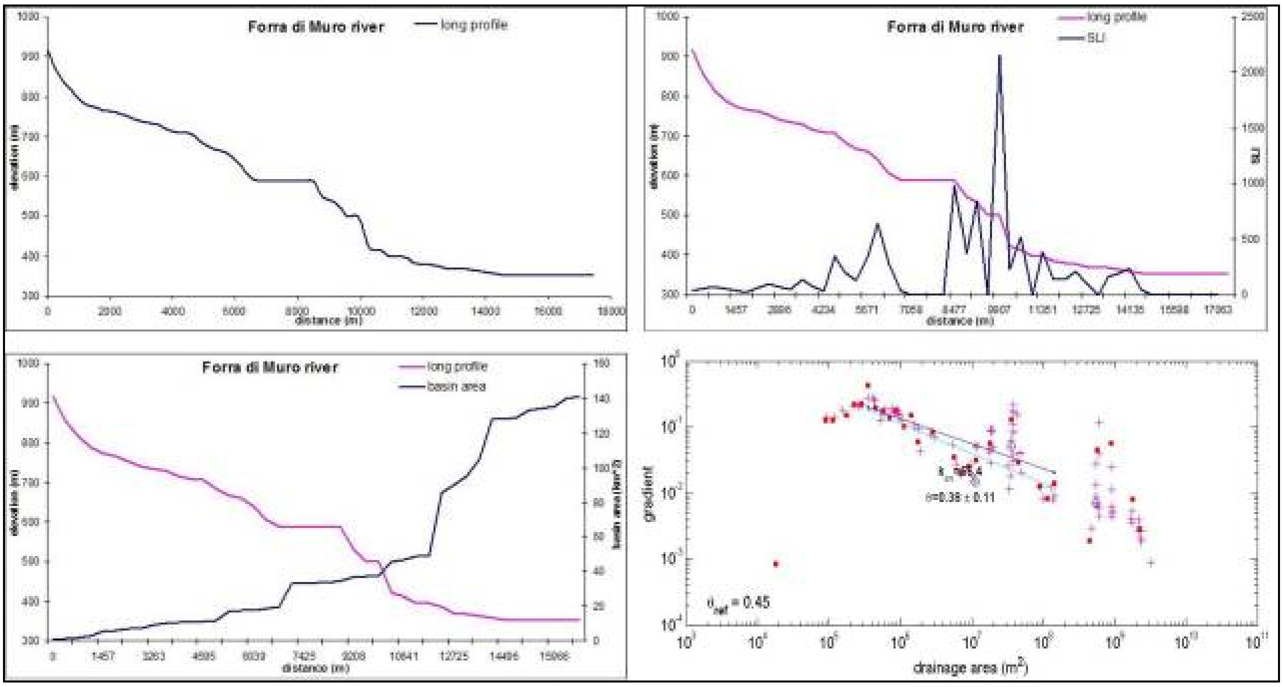


Fig. 4.10: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Forra di Muro river.

The Forra di Muro river springs on the Mt. Carruozzo, north of the Marzano massif, it flows for about 18km following a mean NW-SE direction, with little variations of direction, until its confluence into the Platano river.

The long profile of the Forra di Muro river shows a general concave up shape, that is interrupted by a long convex upward sector, with the occurrence of a relevant knickpoint: this convex up sector is individuated at an elevation comprises between 400m and 800m a.s.l., in this area the river flows into different lithologies, in particular the substrate vary from the Ariano Unit to the Flysch Rosso Formation, and then it flows into the Apennine Carbonates and into the Castelvetere-Caiazzo-Gorgoglione-San Bartolomeo Units: the contact between the four mentioned lithologies are mostly stratigraphic, while the only tectonic contact is between the Flysch Rosso Formation and the Apennine Carbonate, and it is responsible of the individuation of a knickpoint (about 580m a.s.l.) inside this convex upward sector. The occurrence of such a convex upwrd sector could testify that a recent uplift has occurred in this portion of the valley. Another small knickpoint is individuated inside this convex up sector, at an elevation of about 470m a.s.l., and it is due to a tectonic contact between the Apennine Carbonates and the terrigenous Units.

The SLI graph is characterized by very low values in the uppermost and in the lowermost reach of the long profile, where the river flows into the previously mentioned terrigenous units: the highest peaks are located in correspondence of the convex up sector, and in particular in the areas where the river flows into the Apennine carbonates, it is interesting to notice that the highest peak is not in correspondence of the biggest knickpoint, but it is in correspondence of the lowest one.

The basin area graph is characterized by the occurrence of one main jump, at a distance of 11km from the beginning of the profile, and it is due to the confluence with the Malta river.

The slope/area analysis shows a concavity value of 0.38, that is one of the lowest between all the Tyrrhenian rivers, and a steepness value of 56.40.

- Forra di Tito river

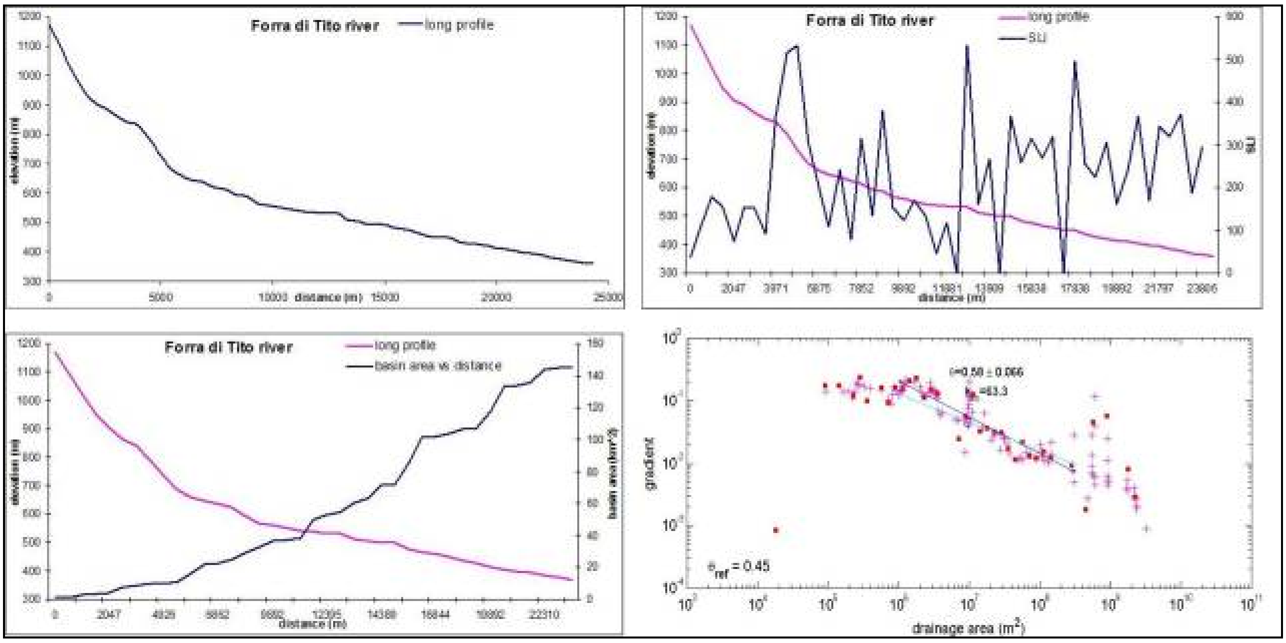


Fig. 4.11: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Forra di Tito river.

The Forra di Tito river springs on the Mt. La Cerchiara, north of the Agri valley, it flows for about 25km following an almost constant SSE-NNW direction, with no relevant variations of direction, until its confluence with the Platano river.

The Forra di Tito long profile shows a general concave up shape, but the profile can be subdivided in two different portions, the first one comprises between 1200m and 600m a.s.l. and the second one comprises between 600m a.s.l. and the confluence with the Platano river (at about 300m a.s.l.): the first sector is characterized by a steep upper reach that is followed by the individuation of a knickpoint at an elevation of about 800m a.s.l., this knickpoint is individuated just north of the Mt. La Cerchiara, in an area where the river flows into the different lithologies of the Lagonegro Units, with the occurrence of normal faults that put in contact the different formations, and that are probably the responsible of the individuation of such a knickpoint; the second sector has a more rectilinear shape, it is reached in the area where the river flows into the terrigenous units cropping out on the outer flank of the Southern Apennines (Ariano Unit) and it is characterized by the occurrence of small knickpoints due to some local outcropping of different lithologies, in particular the Lagonegro Units.

The SLI graph is characterized by a huge variability of the SLI values: the highest peak is reached in the first sector of the profile, in correspondence of the knickpoint at 800m a.s.l., it is interesting to notice that in the lower part of the second sector, at an elevation lower than 500m a.s.l., the SLI is characterized by high peaks, in same case with values very close to the highest one, that seem to be equi-spaced of about 2-4km, and that suggest that in this rectilinear part of the profile some important slope variation occurs.

The basin area graph is characterized by an almost constant arise of the curve, that is just interrupted by the individuation of two main jumps that are located at a distance of about 15km and 20km from the beginning of the profile respectively.

The slope/area analysis shows a concavity value of 0.58, slightly higher than the average value among all the Tyrrhenian rivers, and a steepness value of 63.30.

- Lambro river

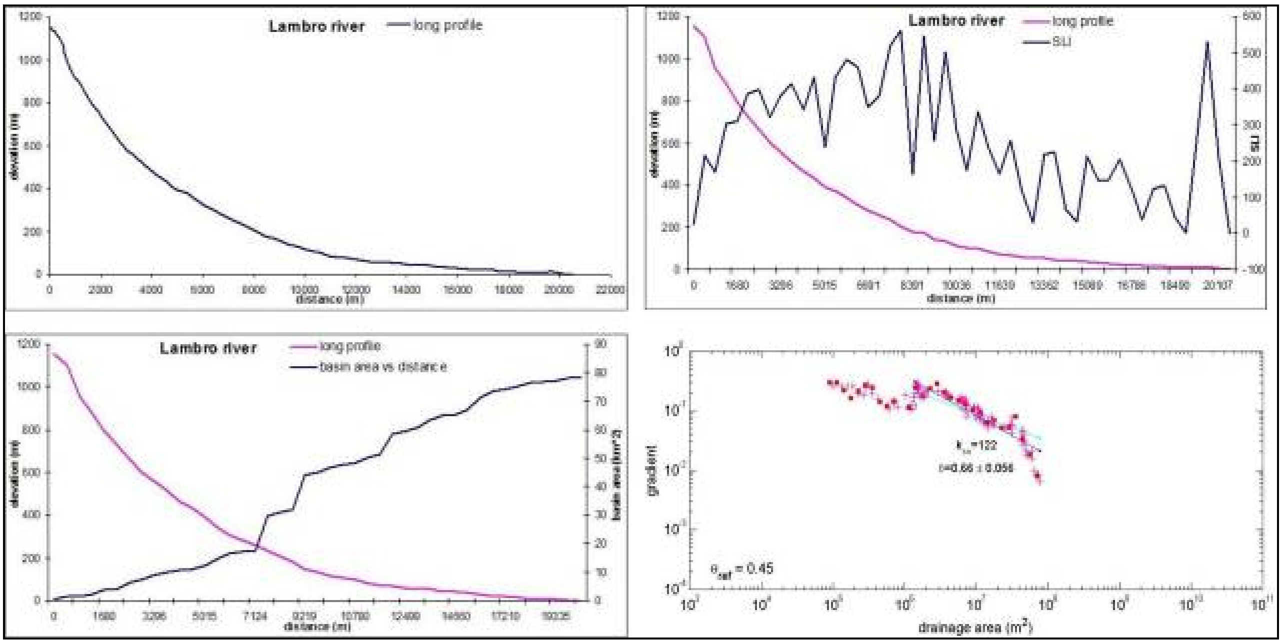


Fig. 4.12: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Lambro river.

The Lambro river springs on the southern side of the Mt. Sacro, in the Cilento region, it flows for about 20km following a NNW-SSE direction, with no important variation of direction until its mouth close to Capo Palinuro.

The Lambro long profile has a concave upward shape that is characterized by the complete lack of knickpoints: the reason of such a lack could be different, and in particular it can be due to the absence of tectonic elements in this area, or to the lack of important lithological variation (the river flows into the Cilento Flysch in the first 3km of its course and it then flows into the North-Calabrian Units until its mouth), or again to the high erodibility of the North-Calabrian Units.

The lack of a knickpoint has no correspondence in the SLI graph, the curve is in fact characterized by the continue alternance of high and low peaks, with the curve that looks like a Gaussian function. One of the highest peaks is located in the lowermost reach of the profile, very close to the mouth: this data suggest that the Lambro long profile is not so homogeneous as it seems to be, and that more detailed analysis should be carry on to understand this anomaly.

The basin area graph is characterized by a progressive arise of the curve, with just one important jump that occurs at a distance of about 7km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.66, that is one of the highest among all the Tyrrhenian rivers, and a steepness value of 122.

- Melandro river

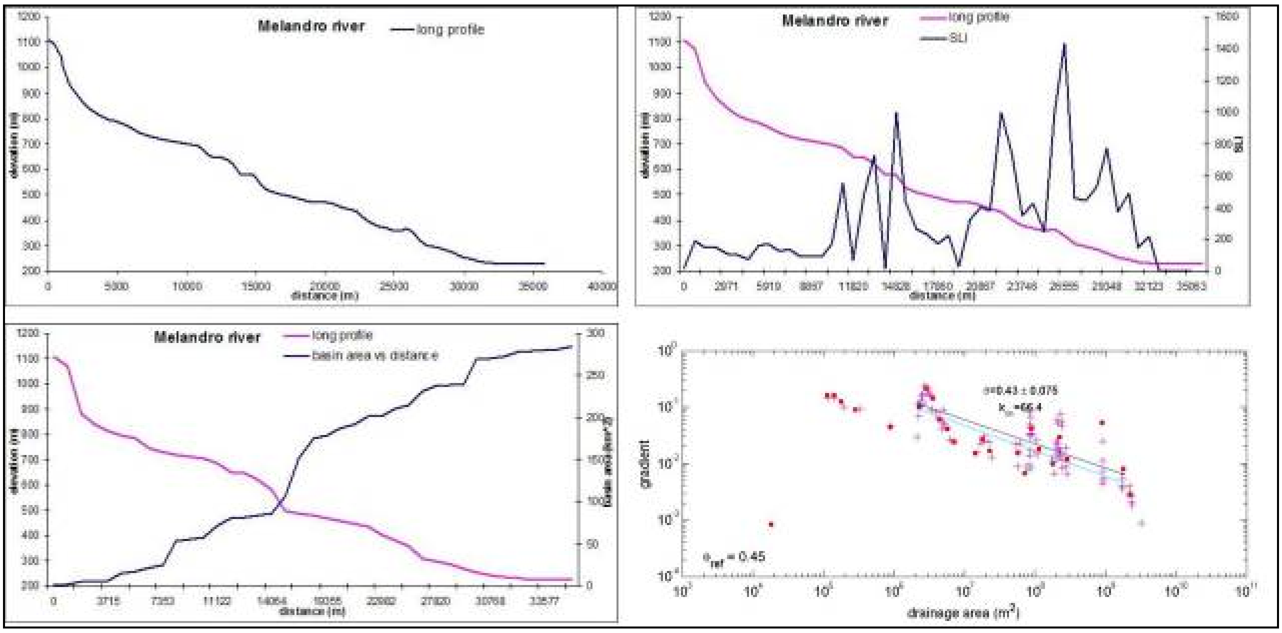


Fig. 4.13: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Melandro river.

The Melandro river springs on the western side of the Monti della Maddalena ridge, it flows for about 35km following a mean SE-NW direction, with local variation of direction, until its confluence with the Platano river.

The Melandro long profile shows an almost rectilinear shape, which is just interrupted by a small concave upward sector in the uppermost reach of the profile. This rectilinear shape is characterized by the occurrence of three relevant knickpoints: the first one is located at an elevation of about 700m a.s.l., and it is followed by two small knickpoints at an elevation of about 650m and 600m a.s.l., these knickpoints are individuated in correspondence of the Pergola-Brienza basin and the Melandro basin, two intramontane basins filled up with quaternary deposits, so these knickpoints are due to the lithological contrast between the Lagonegro Units and these quaternary deposits. These first knickzone is characterized by a slightly convex upward shape that should suggest that some recent uplift has occurred in this area. The second one knickpoint is located at an elevation of about 450m a.s.l. while the third one is located at an elevation of about 350m a.s.l.: both knickpoints are probably due to the occurrence of normal faults that put in contact the Apennine Carbonates with the Lagonegro Units.

The SLI graph shows very low values in the uppermost reach of the profile, while the highest peaks are located in correspondence of the three knickpoints, and with the SLI values that become higher as the profile moves downstreamfrom the uppermost knickpoint to the lowermost knickpoint.

The basin area graph is characterized by an almost constant arise of the curve, with the occurrence of just one main jump, which is located at a distance of about 15km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.43 while the steepness index has a value of 66.40.

- Mercure river

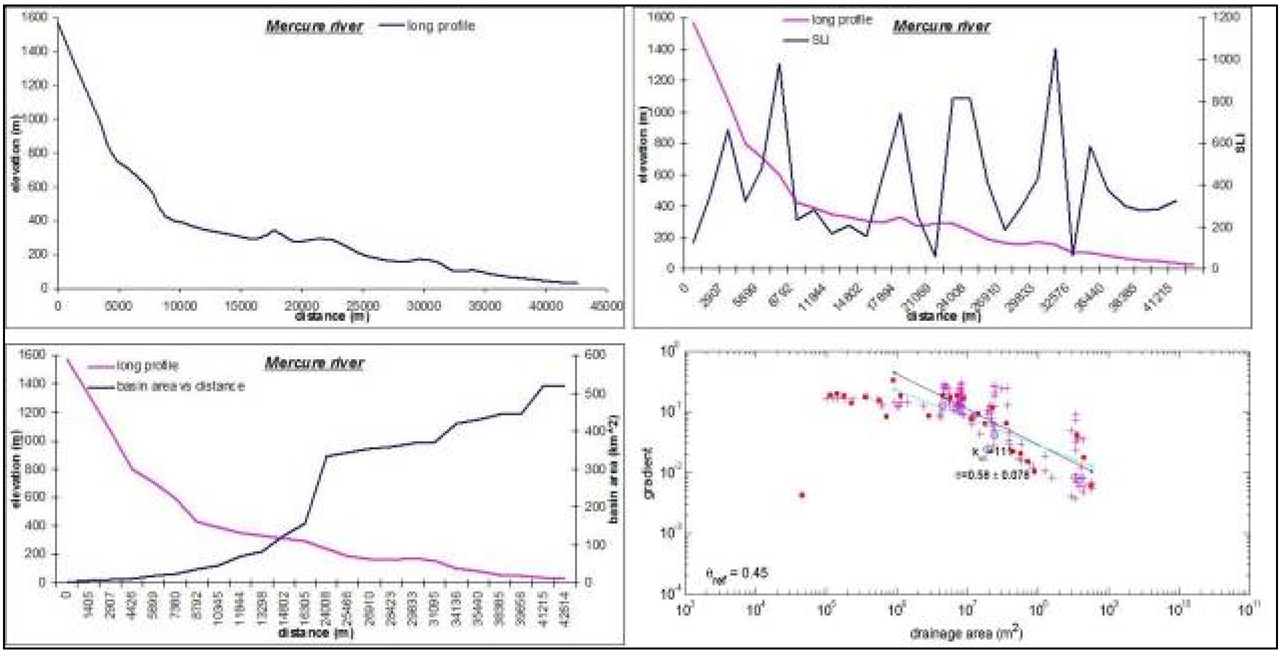


Fig. 4.14: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Mercure river.

The Mercure river springs on the northern side of the Pollino massif, it flows for about 45km following a SE-NW direction in the first 15km and then it flows following a NE-SW direction until its mouth.

The Mercure long profile shows a concave upward shape, the slope is almost constant in the first 5km, then the long profile is characterized by the occurrence of three main knickpoints that are individuated at an elevation comprises between 100m and 600m a.s.l.: all the three knickpoints are located in correspondence of tectonic elements, in particular the first two knickpoints are located in an area where thrust faults put in contact the Liguridi Units with the carbonates of the Pollino massif, while the third knickpoint is due to the tectonic contact between metamorphic rocks of the San Donato Unit with Apennine carbonates. There are two other small knickpoints in the lower reach of the Mercure long profile, in this area the profile moves into the carbonate of the Pollino massif, its complex tectonic setting, with the occurrence of a large number of normal faults, is probably the main responsible of the individuation of these knickpoints.

The SLI curve recalls the occurrence of the knickpoints on the long profile, in fact the curve is characterized by several peaks, with each one of them located in correspondence of the previously recognized knickpoints.

The basin area graph is characterized by just one major jump that is individuated at a distance of about 25km from the beginning of the profile and that is due to the confluence with the Iannello river.

The slope/area analysis shows a concavity value of 0.58, that is slightly higher than the average value among all the Tyrrhenian rives, and a steepness value of 111.

- Mingardo river

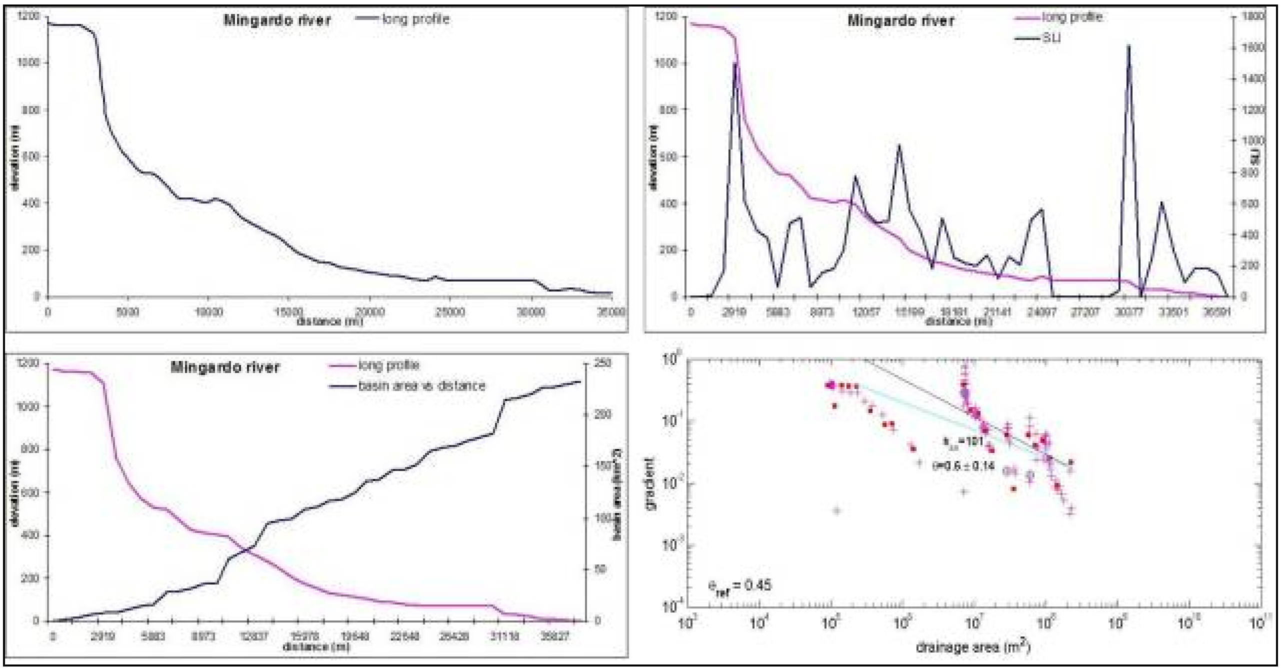


Fig. 4.15: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Mingardo river.

The Mingardo river springs on the west side of the Cervati ridge and it flows for about 35km until its mouth following a N-S direction in the first 18km of its course and a NE-SW direction in the last 17km.

The Mingardo long profile shows a concave upward shape. First of all we have to say that the uppermost reach of the profile is non correct: here the long profile looks almost perfectly flat but this is due to an error in the dem, in fact in this case the river shapefile created by Arcgis doesn't follow the true course of the Mingardo river in its uppermost reach, so we can say that the Mingardo long profile starts downstream this flat area. The long profile is characterized by the occurrence of three knickpoints: the first one is individuated at an elevation of about 500m a.s.l. and it is due to the passage from the Bifurto-Cerchiara Formation to the Apennine Carbonates; the second knickpoint is individuated at an elevation of about 400m a.s.l., in this case the knickpoint is due to the presence of a thrust fault that put in contact the North-Calabrian Units on the Cerchiara-Bifurto Formation; the third knickpoint is individuated at an elevation of about 70m a.s.l., this knickpoint is located inside the Mt. Bulgheria and it could be due to a lithological variation, in particular the passage from the carbonate of the Mt. Bulgheria to the alluvial deposits of the lowermost reach of the Mingardo profile.

The SLI curve is characterized by the highest peaks in correspondence of the previously analyzed knickpoints: in particular, it is interesting to notice that one of the highest peaks is individuated in correspondence of the false knickpoint in the uppermost reach of the long profile, while the first knickpoint (500m a.s.l.) doesn't correspond with a relevant peak in the SLI curve. In addiction, it is interesting to notice the occurrence of other peaks in the portion of the long profile immediately downstream the second and the third knickpoints, suggesting that some other slope variation occurs also in this areas.

The basin area graph shows a curve that tends to arise in an almost constant way, with no important jumps, the only noticeable jump is individuated in the lowermost part of the profile, at a distance of about 31km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.60, higher than the average value of all the Tyrrhenian rivers, and a Ks value of 101.

- *Miscano river*

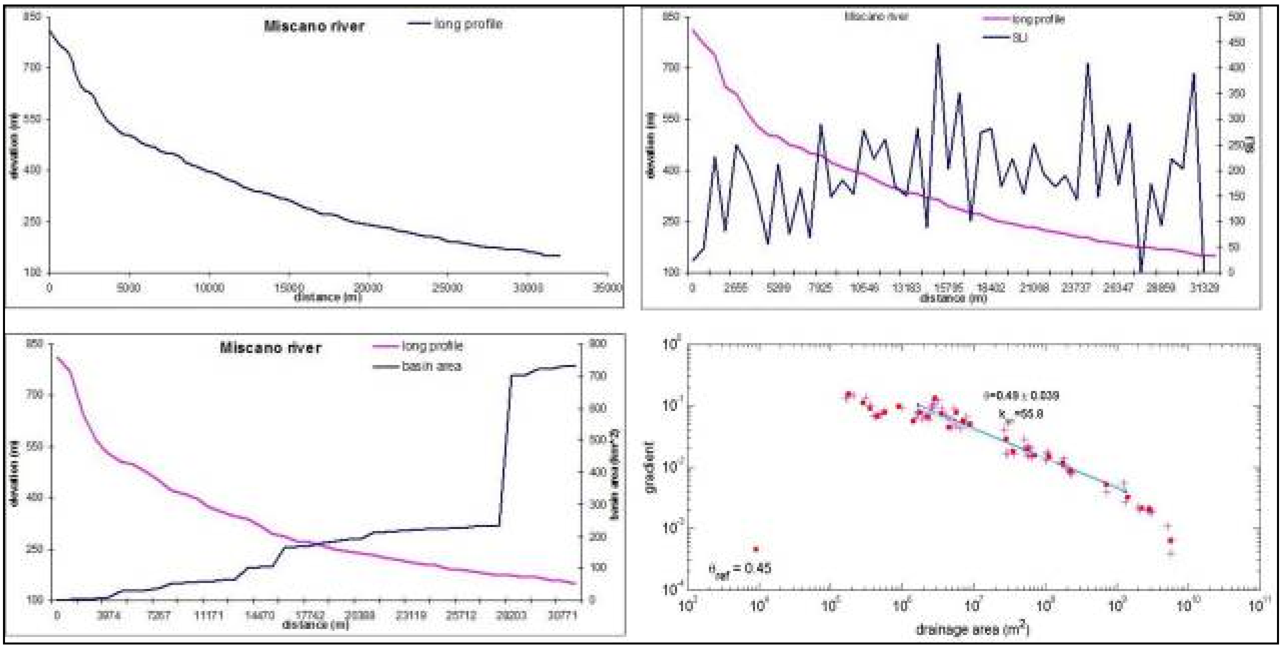


Fig. 4.16: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Miscano river.

The Miscano river springs on the outer flank of the Southern Apennine, very close to the Tyrrhenian-Adriatic divide, and it flows for about 35km following a mean NE-SW direction, with little variations of direction, until its confluence with the Calore Beneventano river.

The Miscano long profile has a concave upward shape, which is anyway very close to a rectilinear shape. It is possible to subdivide the long profile in two different portions, in particular an upper reach that is comprises between 400m and 850m a.s.l. and that shows a more enhanced concave upward shape, and a lower reach that is comprises between 400m and 150m a.s.l. and that shows a more rectilinear shape. The upper reach is also characterized by the presence of two small knickpoints at an elevation of about 750m and 600m a.s.l., that is the area where the river flows into the Flysch Rosso Formation, and that are probably due to the occurrence of some small faults that is not possible to recognize at this scale of investigation. The change of shape from one reach to the other is not due to some lithological variations, in fact in the first reach the Miscano flows into the Flysch Rosso Formation, while in the second reach the Miscano flows both into the Flysch Rosso Formation and the Ariano Unit.

The SLI curve is characterized by the highest values that are individuated in the lower part of the Miscano long profile, in particular it is interesting to notice that the peaks in correspondence of the two mentioned knickpoints are not as high as the peaks in the lower reach: this data suggest that the lower reach of the Miscano river is not characterized by a perfect rectilinear shape, but it presents several slope variations that could be due either to some lithological variation inside the units cropping out in this area or to the presence of some tectonic elements, and that these variations should be investigated with more detailed analysis.

The basin area graph is characterized by low values along until the whole profile, that are probably due to an elongated shape of the drainage basin and to a low order of the main tributaries, and by the presence of a high jump at a distance of about 28km from the beginning of the profile and that is due to the confluence with the Ufita river.

The slope/area analysis shows a concavity value of 0.49, which is slightly lower that the average value of all the Tyrrhenian rivers, and a steepness value of 55.80.

- Noce river

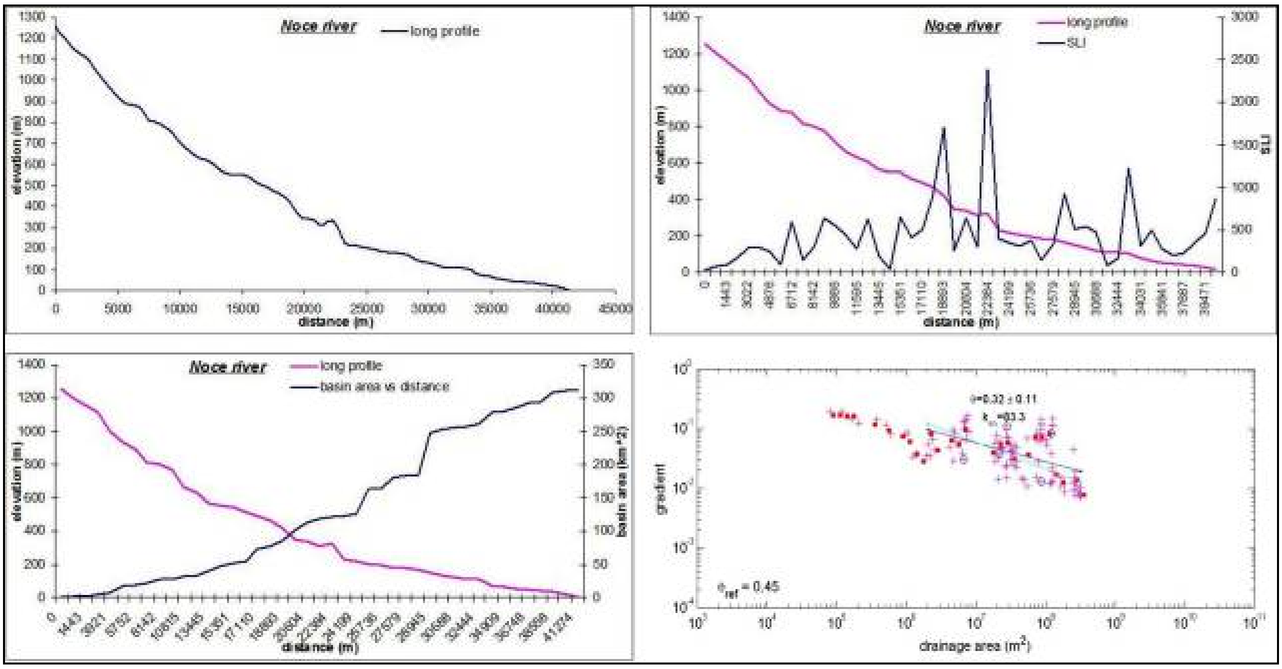


Fig. 4.17: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Noce river.

The Noce river starts on the north side of the Sirino massif, its course is characterized by continue variations of its direction, following a mean antiapenninic direction in the first 14km of its course, to then change towards an apenninic direction until 32km from the beginning of the profile, and to finally follow an antiapenninic direction again until its mouth.

The Noce river shows one of the less concave upward long profile among all the Tyrrhenian rivers, with a long profile that is very close to a rectilinear shape. The long profile is interrupted by the occurrence of several knickpoints, which are individuated at an elevation comprises between 200m and 1100m a.s.l.: all this knickpoints are due to the individuation of several tectonic elements (both thrust faults and normal faults), in particular the knickpoints located at the elevations of 1100m, 900m, 800m, 600m and 500m a.s.l. are located in the uppermost reach of the Noce valley, where the Noce river cuts into the Lagonegro Units and the Apennine carbonates, the contacts between the two lithologies are almost everywhere tectonic, and in many cases there are normal faults interesting the single units; the lowermost knickpoint is located inside the Noce basin, at an elevation of about 300m a.s.l., where it cuts the North-Calabrian Units, the knickpoint is located in correspondence of a normal fault that determines the contact between the previously mentioned North-Calabrian Units and the Apennine carbonates.

The SLI curve reflects the so individuated knickpoints, but we have to notice that just the lowermost knickpoint (300m a.s.l.) is clearly represented by an important peak, while the other knickpoints are represented by smaller peaks.

The basin area curve shows an almost constant arise that is interrupted by the occurrence of two relevant jumps that are located at about 25km and 28kmfrom the beginning of the profile, in correspondence of the confluence with the Prodino creek and Fosso il Vallone creek, the two main tributaries of the Noce valley on the idrographic right and left respectively.

The slope/area analysis shows a concavity value of 0.32, that is one of the lowest among all the Tyrrhenian rivers, confirming the not so enhanced concave up shape, and a steepness value of 83.30.

- Platano river

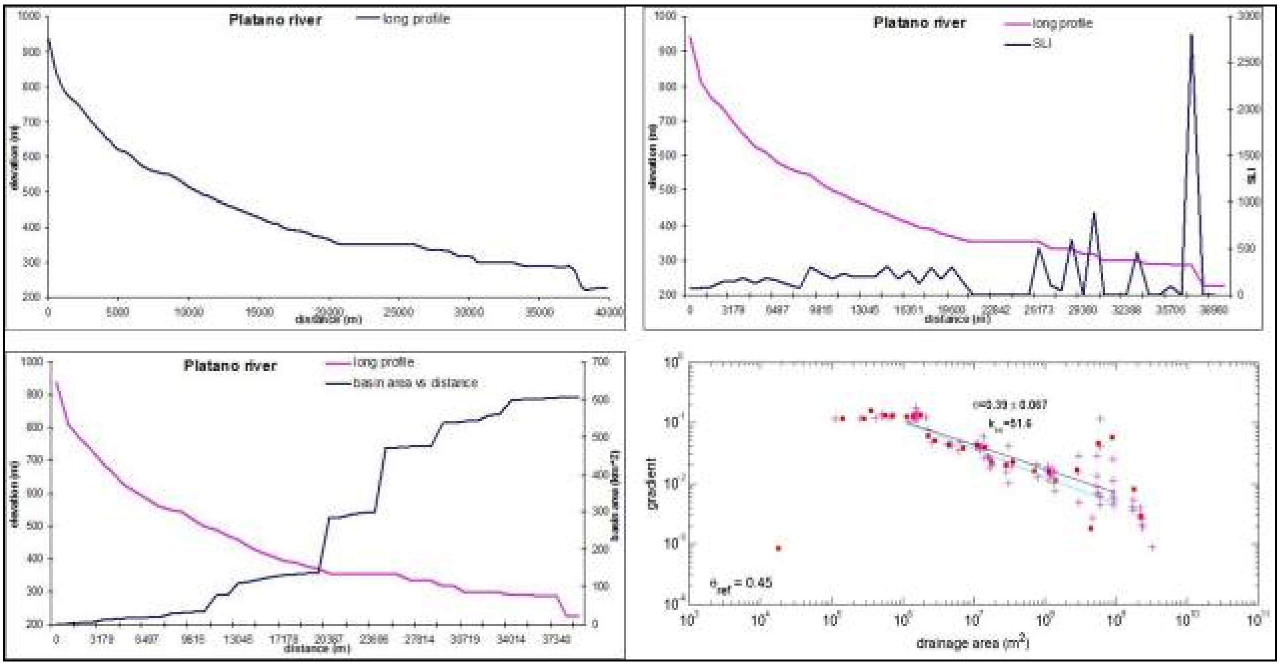


Fig. 4.18: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Platano river.

The Platano river springs from the Mt. S. Croce, northeast of the Marzano massif, and it flows for about 40km until its confluence with the Melandro river, following a NW-SE direction in the first 11km of its course, it then changes its direction towards a ENE-WSW direction in the next 10km, and it finally follows a NNE-SSW direction in the last part of its course.

The Platano long profile shows a concave upward shape, which is anyway very close to an almost rectilinear shape. The long profile is characterized by the occurrence of several small knickpoints in the uppermost reach of the profile (at an elevation comprises between 500m and 800m a.s.l.), while there are two more evident knickpoints in the lowermost reach of the profile: the uppermost knickpoints are individuated in an area where the Platano river flows into the Ariano Unit deposits and there are no important tectonic elements, so these knickpoints are probably due to some lithological variation inside this unit; the knickpoint located at an elevation of about 350m a.s.l. is due to a normal fault that put in contact the carbonates of the Marzano massif with the deposits of the Ariano Unit; the lowermost knickpoint is individuated in the area where the Platano river starts flowing into the Tanagro valley, and so it is due to the lithological contrast between the carbonates of the Marzano massif and the continental filling of the Tanagro valley.

The SLI graph is characterized by very low values along the whole profile, with no relevant peaks in correspondence of the small knickpoints individuated in the uppermost reach of the long profile, while the highest peaks are individuated in correspondence of the lowermost part of the profile, with the highest peak that is reached in correspondence of the lowermost knickpoint.

The basin area graph is characterized by the occurrence of several jumps that are confined between 10km and 25km from the beginning of the profile, with the highest jumps that are due to the confluence of the Forra di Tiro and Forra di Muro rivers.

The slope/area analysis shows a concavity value of 0.39, that is one of the lowest among all the Tyrrhenian rivers, and a steepness value of 51.60.

- Sabato river

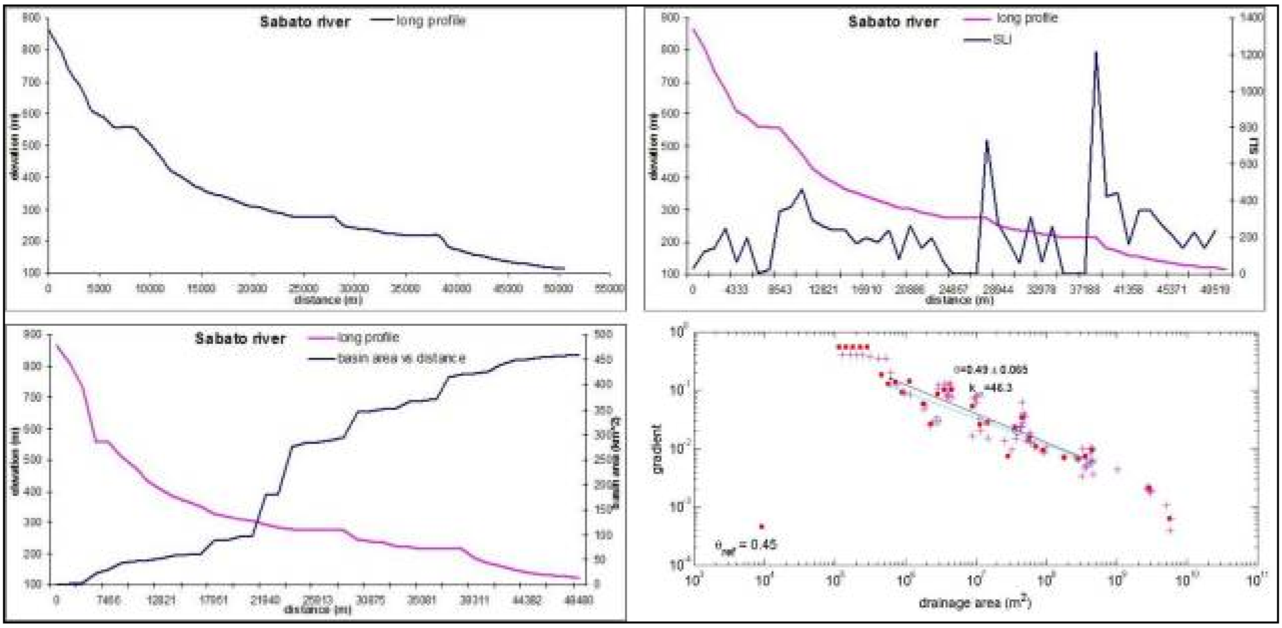


Fig. 4.19: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Sabato river.

The Sabato river springs in the area comprises between the Mt. Felascosa and the Mt. di Pizzautolo, inside the Mt. Picentini ridge, it flows for about 55km following a mean SE-NW direction, with little variations of direction, until its confluence with the Calore Beneventano river.

The Sabato long profile is characterized by a not so enhanced concave upward shape, with the individuation of three important knickpoints: the first one is individuated at an elevation of about 550m a.s.l., in this area the Sabato river axe shifts from the alluvial deposits of the high Sabato valley and it is located very close to carbonates of the Picentini ridge, also if it is not clear if it cuts a gorge or not into this carbonates units, so the knickpoint is probably due to this lithological variation; the second knickpoint is individuated at an elevation of about 250m a.s.l., it is reached in the part of the profile where the river flows into the Avellino basin, an intramontane basin filled up with continental deposits, with a large amount of volcanoclastic deposits, there are no evident tectonic elements, so this knickpoint is probably due to some lithological variation inside the Avellino basin that is not possible to appreciate at this scale of investigation; the lowermost knickpoint is individuated at an elevation of about 200m a.s.l., in this case the knickpoint is due to the presence of a fault that interests different terrigenous units cropping out on both flanks of the valley.

The SLI curve is characterized by the occurrence of the main peaks in correspondence of the previously described knickpoints, with the peaks that become higher moving from the uppermost knickpoint to the lowermost, and with a decreasing trend after every single peak that is interrupted by the individuation of the following peak.

The basin area graph is characterized by just one main jump at a distance of about 20km from the beginning of the profile, inside the Avellino basin.

The slope/area analysis shows a concavity value of 0.49, which is pretty close to the average value of all the Tyrrhenian rivers, and a steepness value of 46.30.

- Sarno river

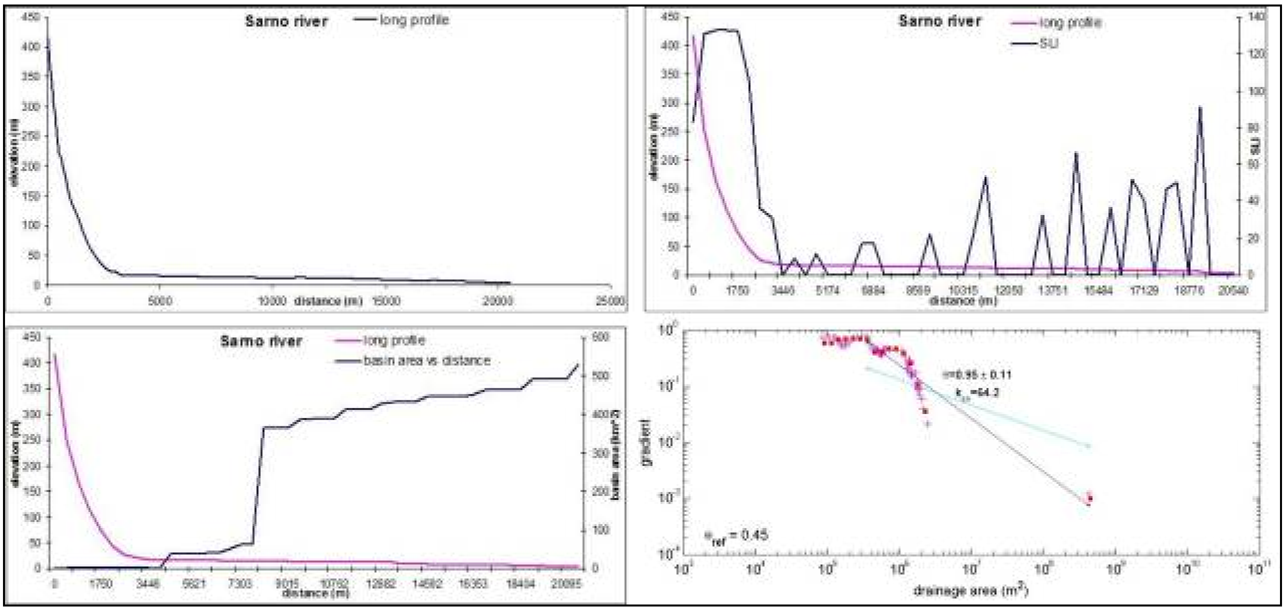


Fig. 4.20: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Sabato river.

The Sarno river springs on the south-western side of the Monti di Sarno ridges, that is one of the carbonatic ridges bordering the southern portion of the Campana plain, it flows for about 20km following a NE-SW direction, with no important variation of direction, until its mouth into the gulf of Naples.

The Sarno long profile is clearly concave upward, with the absence of knickpoints of relevance. This so enhanced concave up shape is probably due to the fact that the Sarno river flows for a large part of its course into the quaternary filling of the Campana plain, so that it flows into very erodible lithologies and it is not hard for the river, and it doesn't need a long time, to reach a concave up shape. The steep reach at the beginning of the long profile is located in the uppermost part of the Sarno course, where it is still a low order trunk, and it flows into the carbonates of the Picentini ridge.

The so enhanced concave upward shape of the Sarno river should result in very low values of the SLI curve, but this doesn't occur, in particular there is a high peak, the highest of the whole profile, in the uppermost steep reach, and there are other small peaks in the lower reach of the profile, where it flows into the Campana plain, suggesting that the Sarno long profile is anyway characterized by some slope variation that could be related to some lithological variation inside the quaternary deposits of the Campana plain that is not possible to recognize at this scale of investigation.

The basin area graph in generally characterized by a a very low arise of the drainage area in the uppermost reach of the profile, while a relevant jump is individuated at a distance of about 8km from the beginning of the profile and it is due to confluence with the Solofrana river.

The slope/area analysis shows a concavity value of 0.95, that is the highest value among all the Southern Apennines rivers, but that is strongly influenced by the weak lithologies in which the Sarno river flows in, and a steepness value of 64.20.

- Sele river

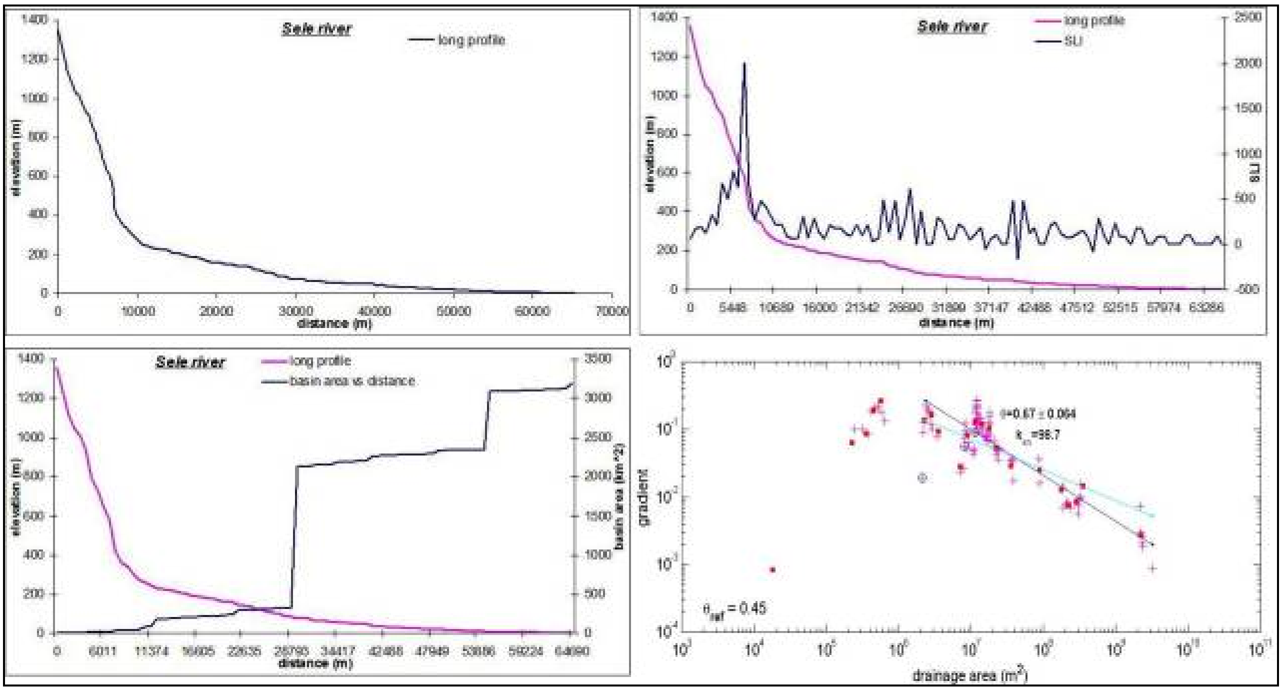


Fig. 4.21: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Sele river.

The Sele river represents, together with the Volturno river, the biggest Tyrrhenian rivers: it starts on the northeastern side of the Picentini ridge, it flows following a WNW-ESE direction for the first 10km, it then changes its direction following a N-S direction for the following 30km, and it finally follows a NE-SW direction until its mouth that is located south of the town of Salerno.

The Sele long profile is one of the most concave upward profiles, the profile proceeds with no important slope variations, so that is not possible to recognize the occurrence of a knickpoint. Anyway, in the upper reach of the valley, at an elevation comprises between 400m and 1000m a.s.l. it is possible to recognize a convex up sector more than a knickzone, in this sector the profile moves from the Apennine carbonates to the Neogene terrigenous units, the contact between the two lithologies is tectonic (thrust faults) and the Picentini ridge is also interested by several normal faults, so this convex sector could be due to the combination of the lithological variation and to the occurrence of the previously mentioned tectonic elements.

This convex sector is also clear to recognize in the SLI curve, because it corresponds with the highest peak of the curve, while the SLI values don’t vary in a relevant way in the areas upstream and downstream this convex sector.

The basin area graph is characterized by two major jumps, these are individuated in correspondence of the confluence with the Tanagro and the Calore Salernitano rivers, which are the biggest tributaries of the Sele river.

The slope/area analysis shows a concavity value of 0.67, confirming the enhanced concave up shape of the Sele river, and a steepness value of 98.70.

- Solofrana river

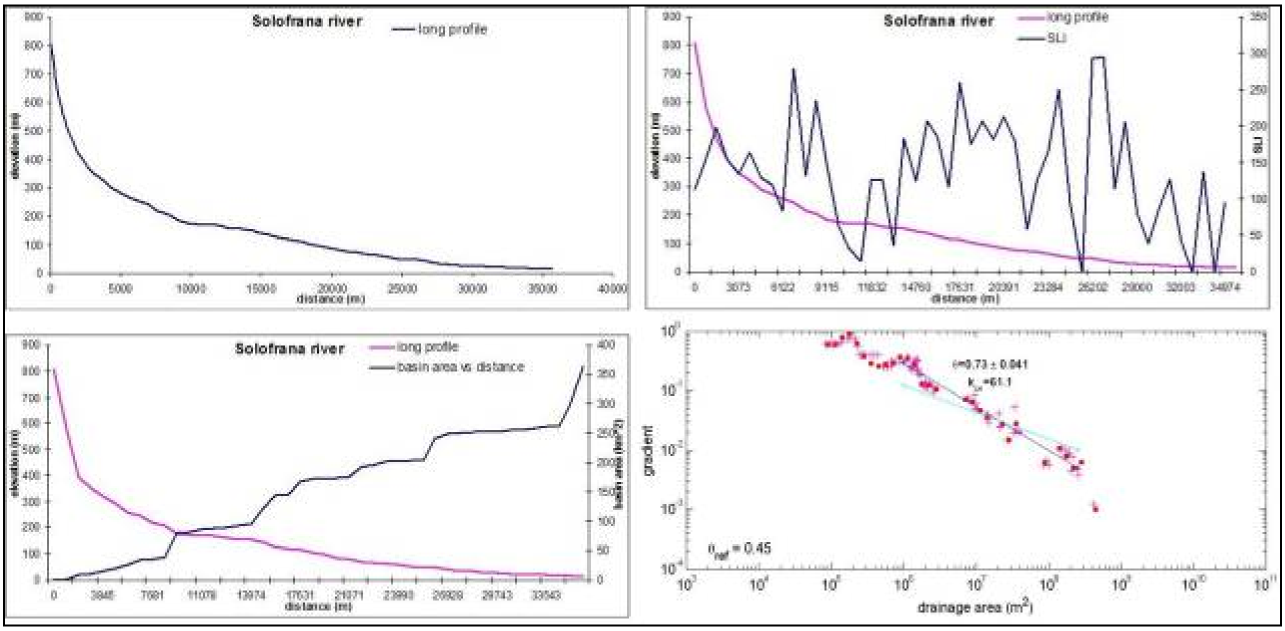


Fig. 4.22: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Sabato river.

The Solofrana river spring inside the Picentini ridge, close to the town of Solofra, it flows for about 35km until its confluence with the Sarno river, its course is characterized by several variations of direction that bring the river to change its direction from W-E to N-S different times in the first 28km, and to follow a SE-NW direction in the last portion of the profile.

The Solofrana long profile shows a concave upward shape, with the occurrence of three small knickpoints: the firs one is individuated at an elevation of about 250m, it is individuated in a part of the long profile where there are no lithological variations and tectonic elements and the river cuts a gorge into the carbonates of the Picentini ridge so in this case it's just the gorge that determines the individuation of the knickpoint; the second knickpoint is at an elevation of about 200m a.s.l., this knickpoint is individuated in an area where the Solofrana valley becomes narrower, also if it doesn't assume the feature of a gorge, there are no lithological variations (the profile moves into the alluvial deposits of the Solofrana river) and tectonic elements, so this small knickpoint could be due to the narrowing of the valley; the third knickpoint is located at an elevation of about 60-70m a.s.l., also in this case this knickpoint is individuated in an area where the valley becomes narrower, here assuming the feature of a gorge, there are no lithological variations and tectonic elements, so also this knickpoint could be due to the narrowing of the valley.

The SLI graph is characterized by the continue alternation of high and low peaks, with the highest peaks that are located in correspondence of the previously analyzed knickpoints, in particular in correspondence of the first and the third knickpoint, while the second knickpoint is characterized by a relatively small peak, and other relevant peaks are individuated in the portion of the profile comprises between the second and the third knickpoints, also if they don't correspond to clear slope variation on the long profile.

The basin area graph is characterized by a slow arise of the curve, that is interrupted by the occurrence of three important jumps, at 9km, 13km and 26km respectively.

The slope/area analysis shows a concavity value of 0.73, that is one of the highest values among all the Tyrrhenian rivers, and a steepness value of 61.10.

- Tammaro river

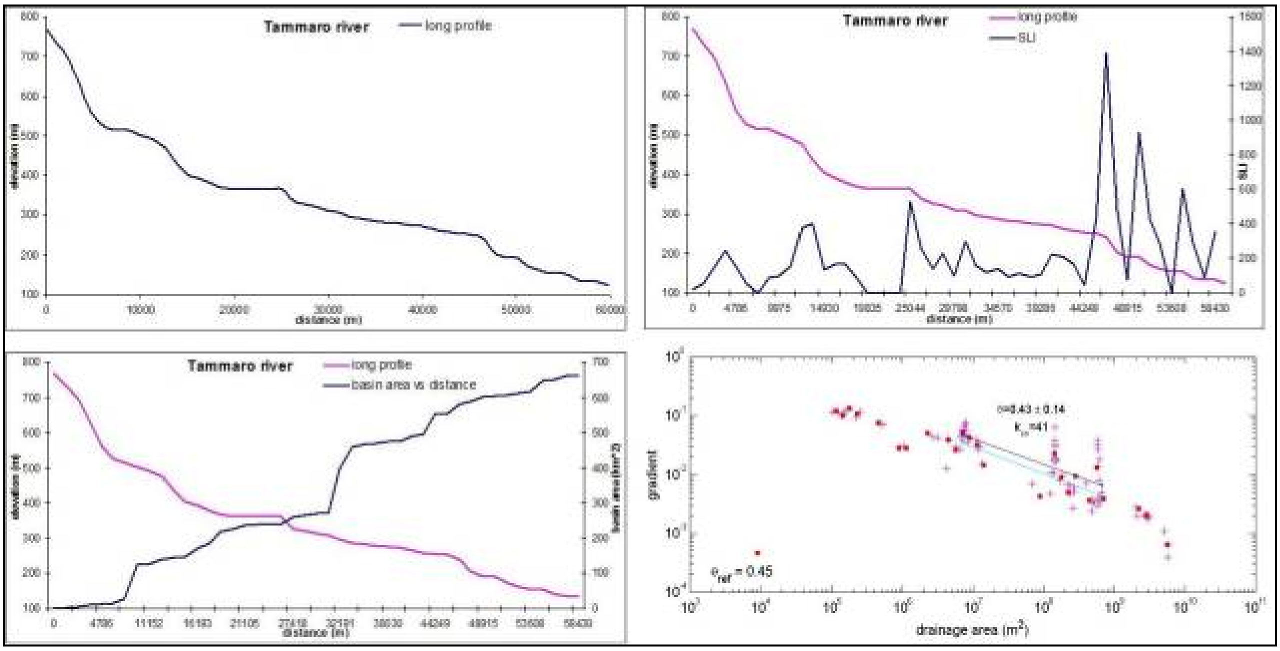


Fig. 4.23: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Tammaro river.

The Tammaro river springs on the outer side of the Southern Apennines, about 6km south of the town of Campobasso, it flows for about 60km until its confluence with the Calore Beneventano river, following a NNW-SSE direction in the first 35km of its course, it then changes it towards a SW-NE direction in the following 5km and it finally follows a NNE-SSW direction until its confluence with the Calore Beneventano river.

The Tammaro long profile shows a slightly concave upward shape that is interrupted by the individuation of several knickpoints, and in particular it is possible to recognize three main knickpoints: the first two knickpoints are individuated at an elevation of about 500m a.s.l. and about 350m a.s.l. respectively, both the knickpoints are individuated in the point where the Tammaro river flows out from two intramontane basins filled up with continental quaternary deposits, so both knickpoints are due to the lithological contrast between the mentioned deposits and the terrigenous units cropping out as the river moves out from this intramontane basins; the third knickpoint is individuated at an elevation of about 250m a.s.l., and it is followed by two smaller knickpoints at an elevation of about 180m and 150m a.s.l. respectively, in this case the area where the river flows is characterized by the presence of three normal faults interesting the terrigenous units here cropping out, so these three normal fault can be considered the responsible of the generation of this knickpoints.

The SLI graph is characterized by values that are very low along most of the profile, with some small peaks just in correspondence of the first two knickpoints, while the highest peaks are individuated in the lowermost reach of the long profile, in correspondence of the last three knickpoints.

The basin area graph is characterized by the presence of two main jumps that are located at a distance of about 7km and 30km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.43. that is lower than the average value among all the Tyrrhenian rivers, while the steepness value is 41.

- *Tusciano river*

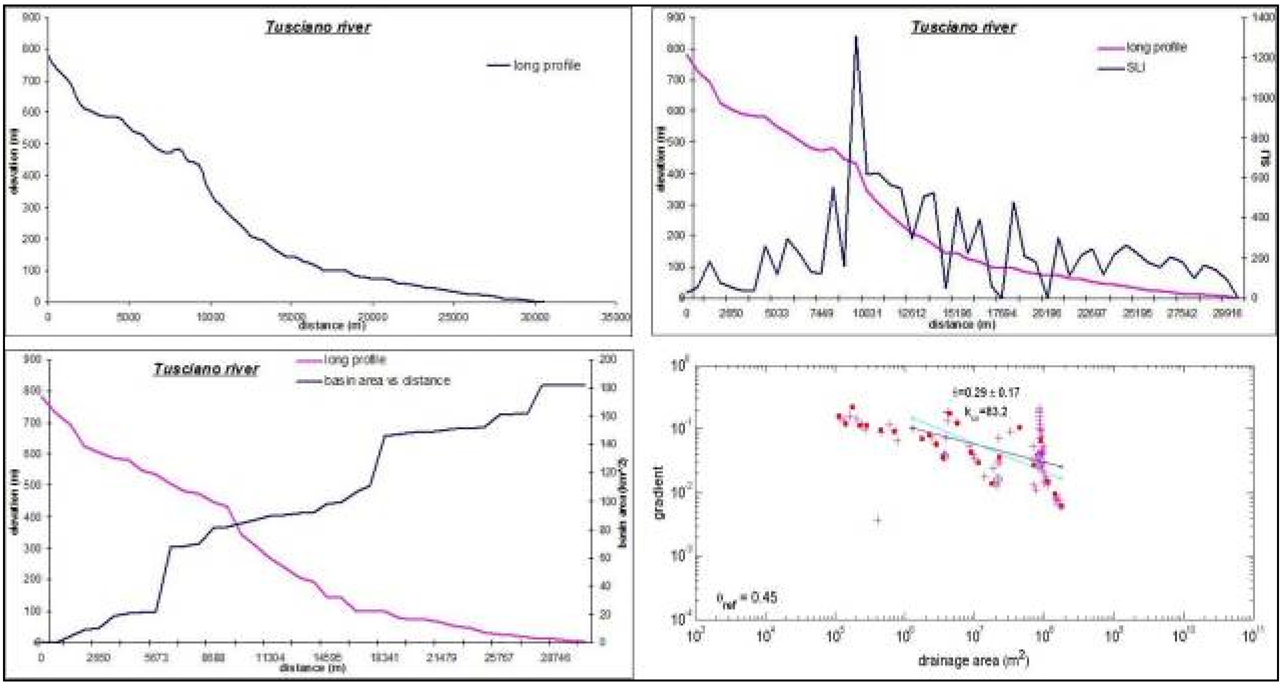


Fig. 4.24: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Tusciano river.

The Tusciano river springs inside the Picentini ridge, on the carbonatic slopes surrounding the Acerno basin, and it then flows for about 30km following a mean N-S direction in the first 13km, to then vary its flow towards a NE-SW direction until its mouth in the Salerno gulf.

The Tusciano long profile is concave upward, but this is one of the less concave up Tyrrhenian rivers, with a long profile shape that tends to a rectilinear one. The profile is articulated with the occurrence of several knickpoints that are individuated in the area comprises between 400m and 600m a.s.l.: the first knickpoint is at an elevation of about 600m a.s.l., the profile flattens in this area because of the individuation of the Acerno basin, so this knickpoint is due to the lithological contrast between the quaternary deposits of the Acerno basin and the carbonatic rocks cropping out on the Picentini ridge; there are three other knickpoints at an elevation comprises between 400m and 550m a.s.l., in this area the Tusciano valley crosses different lithologies, and in particular it moves from the carbonates of the Picentini ridge to the Lagonegro units and to the Neogene terrigenous units, the contact between the different units is tectonic, so this knickpoints are due to the occurrence of both thrust faults and normal faults, with a relevant role that is also played by these lithological variations. From 400m a.s.l. until it mouth, the Tusciano long profile is more clearly concave upward, with no important slope variations that could determine the individuation of a knickpoint.

The SLI curve shows a not so enhanced variation of the SLI values, the only exception is represented by the knickpoints individuated at an elevation comprises between 400m and 600m a.s.l., and in particular the highest peak in the curve is in correspondence of the lowest knickpoint: a relevant feature to notice is that the highest knickpoint individuated on the long profile doesn’t correspond to a peak in the SLI curve, but the value reached in this point is completely comparable with other values reached in the lowermost reach of the profile.

The basin area graph shows two major jumps in the curve at a distance of about 5km and 18km from the beginning of the profile, in correspondence of the two main tributaries of the Tusciano river.

The slope/area analysis shows a concavity value of 0.29, that is one of the lowermost value among all the Tyrrhenian rivers and that testifies the not so enhanced concave upward long profile, while the Ks index has a value of 83.20.

- Ufita river

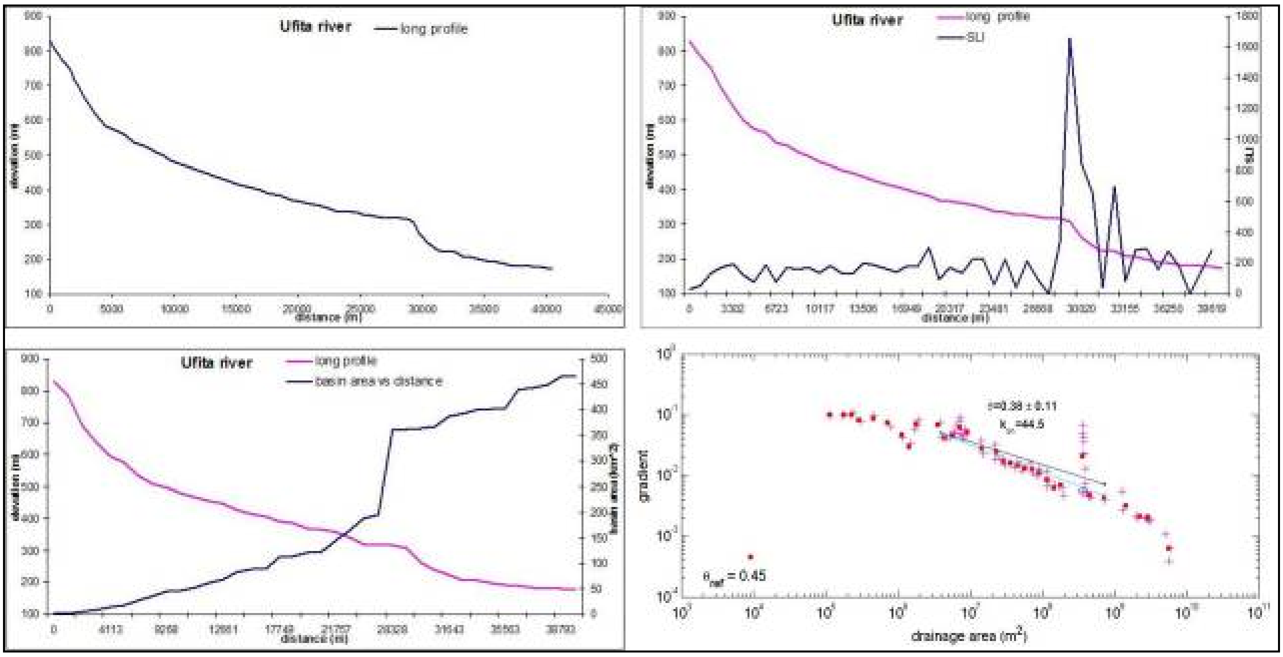


Fig. 4.25: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Ufita river.

The Ufita river springs on the outer side of the Southern Apennines on Mt. La Toffa, about 25km southeast of the town of Ariano Irpino, it flows for about 40km following a mean SE-NW direction, with a few variation of direction.

The Ufita long profile shows a slightly concave upward shape, it is possible to recognize just one knickpoint of relevance, it is individuated at an elevation of about 300m a.s.l., in the area where the Ufita river moves out from the intramontane basin of the Ufita valley, an intramontane basin filled up with quaternary continental deposits, so this knickpoint is due to the lithological contrast between the quaternary deposits of the Ufita basin and the terrigenous lithologies of the Ariano Unit cropping out outside the Ufita basin.

The SLI graph is characterized by very low values in the part of the profile upstream the knickpoint, while the highest peak is individuated in correspondence of the only knickpoint that has been possible to recognize along the long profile.

The basin area graph shows a curve that tends to arise almost in a constant way, with the only jump that is individuated at a distance of about 28km from the beginning of the profile, in correspondence of the confluence of the Fiumarella creek with the Ufita river.

The slope/area analysis shows a concavity value of 0.38, that is one of the lowest among all the Tyrrhenian rivers, and a steepness value of 44.50.

- Vandra river

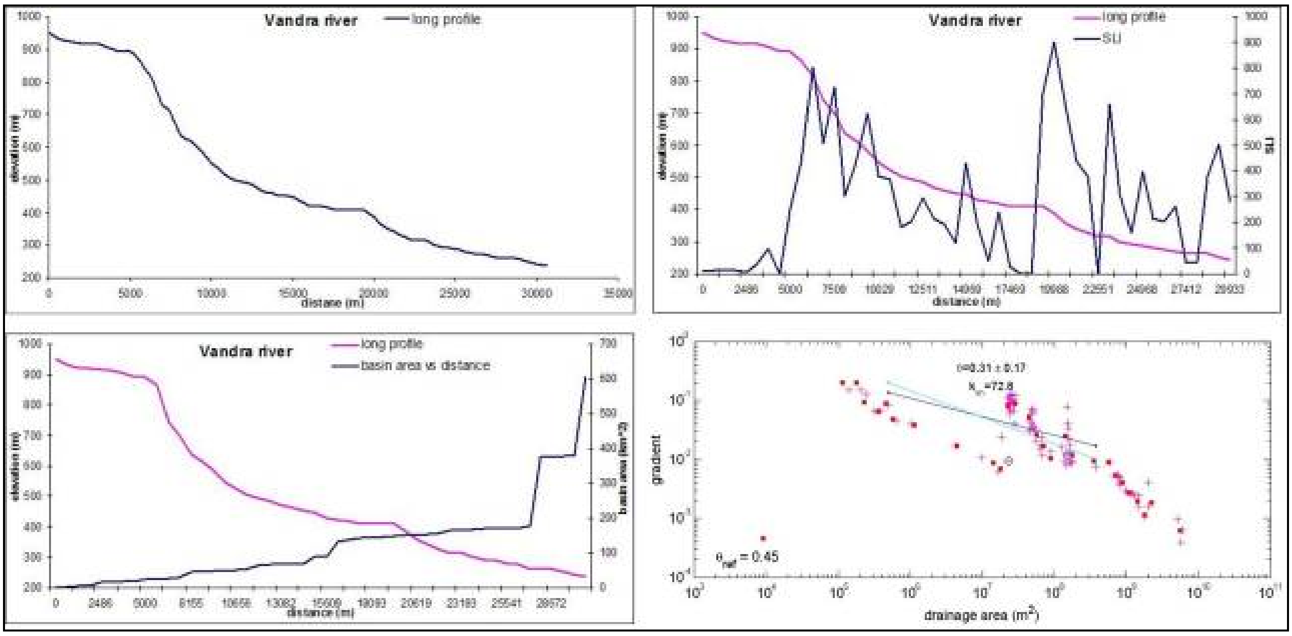


Fig. 4.26: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Vandra river.

The Vandra river springs on the outer flank of the Southern Apennines, about 25km north-east of the Mainarde massif, it flows for about 35km until its confluence into the Volturno river, following a mean NNE-SSW direction, with little variations of direction.

The Vandra long profile shows a slightly concave upward shape. The long profile could be subdivided in two different sectors, a first one comprises between 1000m and 600m a.s.l. and a second one comprises between 600m and 200m a.s.l.: the first sector presents a clear convex upward shape, in this area the Vandra river flows into the terrigenous units of the External Flysch and there are no tectonic elements of relevance, this convex up shape could testify a recent uplift that has interested this part of the long profile, but it deserves more detailed analysis; the second sector of the long profile presents a more clear concave upward shape, with the individuation of several small knickpoints and one major knickpoint: this knickpoint is individuated at an elevation of about 400m a.s.l., in an area where the valley becomes narrower and the Vandra cuts a gorge into the Molise Units, it is probably the occurrence of this gorge that determines the individuation of the mentioned knickpoint.

The SLI graph is characterized by the individuation of several high peaks, the highest of which are individuated in correspondence of the convex upward sector and in correspondence of the main knickpoint in the lower reach of the Vandra long profile.

The basin area graph is characterized by a slow arise of the curve that presents a relevant jump just in the lowermost part of the profile, after about 27km from the beginning of the profile, and that is due to the confluence with the Cavaliere creek.

The slope/area analysis shows a concavity value of 0.31, which is very close to the lowermost value among all the Tyrrhenian rivers, and a steepness value of 72.80.

- *Volturno river*

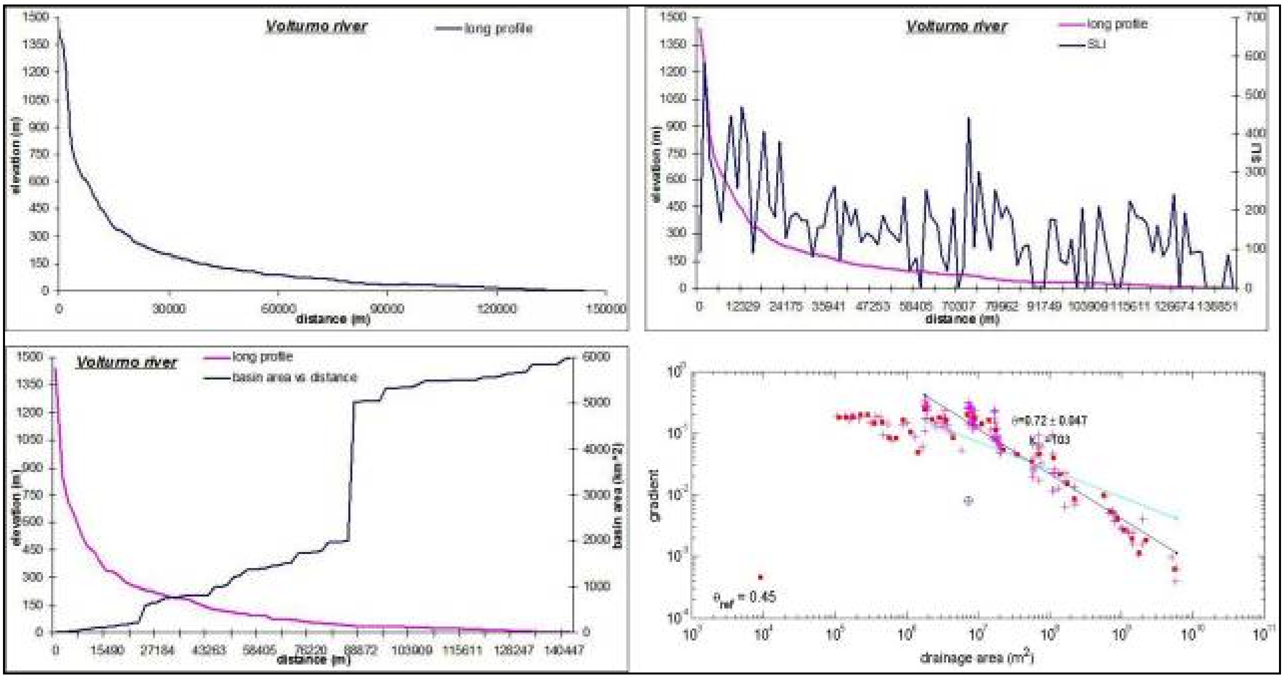


Fig. 4.27: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Volturno river.

The Volturno river is the longest trunks of the Tyrrhenian flank, it starts in the Molise region, in the area around the town of Colli al Volturno, NE of the Mainarde massif, and it then flows into the intramontane basins of the Venafro plain and the Alife plain, to then cross over the Monti di Caserta ridge in correspondence of the Mt. Tifata and flowing into the Campana plain until its mouth.

The Volturno long profile is clearly concave upward, this is the one of the most concave up river of the whole Southern Apennines, and surely it is the most concave upward river if we just consider the main trunks of the chain. This clearly concave up shape could indicate that the Volturno river is an old river, so that it has had a long time to modify its profile towards the hypothetical equilibrium profile, but it is more probably due to the fact that the Volturno valley is developed inside big intramontane basins filled up by quaternary deposits, the river so flows into very erodible lithologies and it doesn't need so many energy and a large amount of time to incise this units and to assume a concave up profile.

The clear concave upward profile is also shown by the SLI curve, in fact, in the hypotheses of a perfectly concave up long profile, the SLI index should decrease as we move downstream until the mouth, this is what happens for the Volturno river, the SLI curve tends to quickly decrease in the first 30km of the profile, and it then seems to be almost constant: the only exception is represented by a peak in the curve at about 75km from the beginning of the profile, this peak doesn't correspond to a knickpoint in the long profile, so it could be matter of a more detailed investigation.

The basin are graph shows a curve that tends to increase in an almost constant way, with the individuation of one enhanced jump at a distance of about 90km from the beginning of the profile, and that is due to the confluence with the Calore Beneventano river.

The slope area analysis shows a concavity value of 0.72, one of the highest values in the whole chain, testifying the clear concave upward shape of the Volturno long profile, while the steepness index is of 103.

4.1.2 Adriatic rivers

- Biferno river

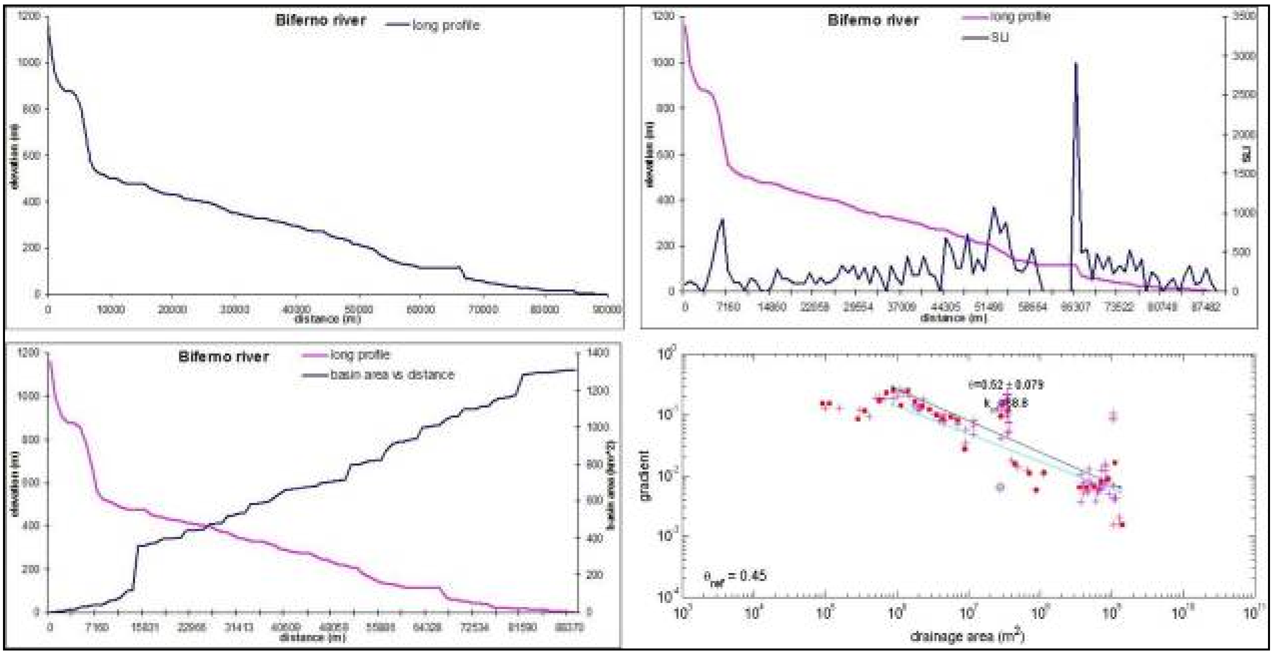


Fig. 4.28: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Biferno river.

The Biferno river springs on the Mt. Mutria, on the eastern side of the Matese massif, it flows for about 90km until its mouth following a S-N direction in the first 20km of its course to then move towards a SW-NE direction until its mouth.

The Biferno long profile shows a concave upward shape, it is anyway possible to separate the long profile in different sectors, in particular it is possible to recognize an upper steep reach located at an elevation comprised between 1200m and 500m a.s.l., that is followed by a more rectilinear to slightly convex upward reach developed at an elevation comprises between 500m and 200m a.s.l., with a lower reach that shows a concave upward shape that is very close to a rectilinear one. The profile is characterized by the occurrence of three knickpoints: the first one is individuated in the uppermost reach at an elevation of about 900m a.s.l., this knickpoint is located at the passage from the carbonates of the Matese massif to the quaternary filling of the intramontane Bojano plain, so it is due to a lithological contrast between the two different units; the second knickpoint is located at an elevation of about 250m a.s.l., in the lowermost part of the central reach, the profile here moves into the terrigenous units cropping out on the outer flank of the Southern Apennines and this knickpoint could be due either to a lithological variation inside these units or to the occurrence of a tectonic element; the lowermost knickpoint is located at an elevation of about 100m a.s.l., in the lowermost reach of the profile, in this case there are no geological data to constraint the origin of this knickpoint (the "Morphostructural Map of the Southern Apennine" doesn't cover these area), but this knickpoint looks like the false knickpoint due to the presence of a dam that have been recognized along some of the Southern Apennines rivers, so it is possible to hypothesize that this knickpoint is due to the presence of a dam too.

The SLI graph shows the highest peaks in correspondence of the false lowermost knickpoint, so this peak must not be considered in the analysis. The highest peaks are reached in correspondence of the two previously described knickpoints, with the SLI curve that shows a general arising trend moving from the beginning of the profile toward the second knickpoint, a trend that is just interrupted by the individuation of the first knickpoint. In the part of the long profile downstream the third knickpoint the SLI values are low again, being comparable with the values reached in the uppermost reach of the long profile.

The basin area graph is characterized by a main jump at a distance of about 15km from the beginning of the profile, after which the curve arises almost in a constant way: this jump is due to the confluence with the Callore creek, which is the main trunk flowing into the Bojano plain.

The slope/area analysis shows a concavity value of 0.52, higher than the average value of all the Adriatic rivers, and a steepness value of 68.80.

- Candelaro river

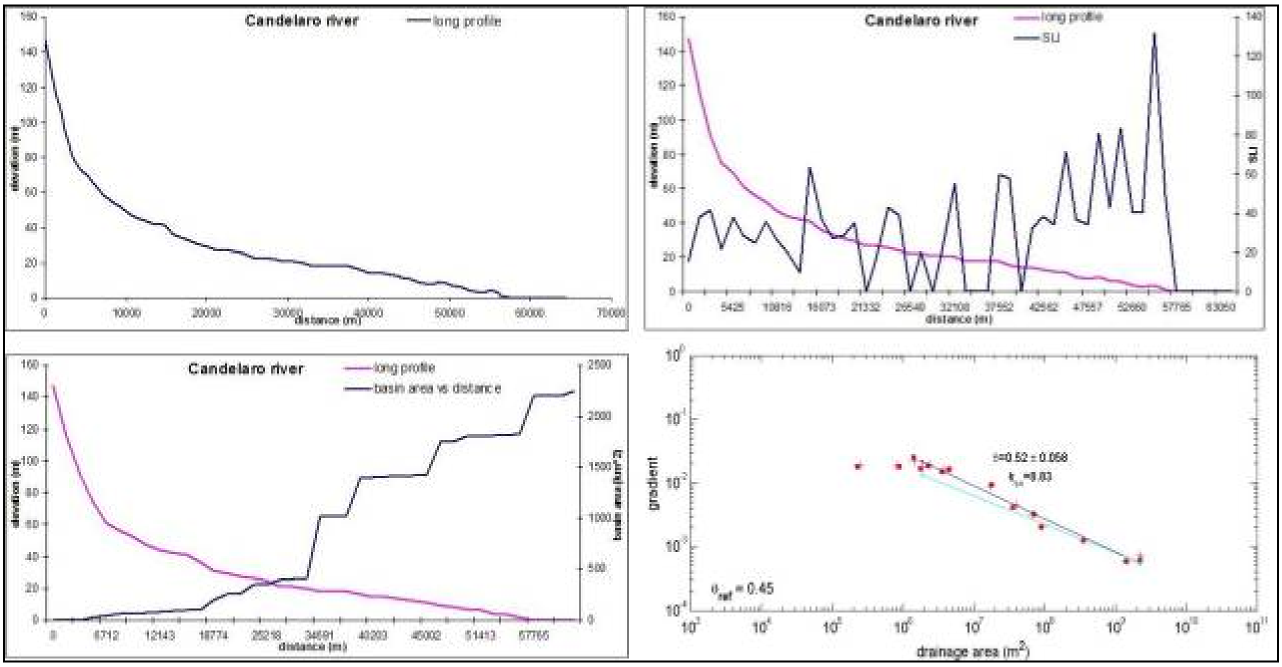


Fig. 4.29: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Candelaro river.

The Candelaro river flows entirely into the foredeep domain (Puglia basin of Balduzzi et al., 1982), it springs north of the town of San Severo and it flows for about 70km until its mouth following a NW-SE direction in the first 55km of its course, flowing parallel to the west side of the Gargano promontory, and it change its direction in the last 10km following a W-E direction.

The Candelaro long profile shows a concave upward shape; in particular this concave upward shape is clear in the portion of the profile comprised between 140m and 20m a.s.l., while the lowermost reach of the long profile seems to shows a slightly convex upward shape. The concave upward part of the long profile is characterized by the occurrence of a knickpoint at an elevation of about 40m a.s.l., in this case there are no lithological variation and tectonic elements that is possible to recognize at the scale of investigation, so this knickpoint could be due either to minor lithological variation or to the presence of small tectonic elements, anyway it deserves more detailed analysis to be understood. The slightly convex upward reach is developed in the area where the Candelaro flows very close to the west side of the Gargano promontory, while the long profile flattens as the river flows far from the Gargano promontory and it changes its direction.

The SLI curve is characterized by low values in the uppermost reach of the long profile that are interrupted by a higher peak in correspondence of the knickpoint, while the SLI value are higher in the lower reach of the long profile, with the highest peak that is reached at the end of the slightly convex upward portion of the profile.

The basin area graph is characterized by several jumps that are confined between 30km and 55km from the beginning of the profile and that are due to the confluence of the Triolo, Vulgano and Celone creeks.

The slope/area analysis shows a concavity value of 0.52, higher than the average value among all the Adriatic rivers, and a steepness value of 8.83, that is the lowest value in the whole Southern Apennines.

- Carapelle river

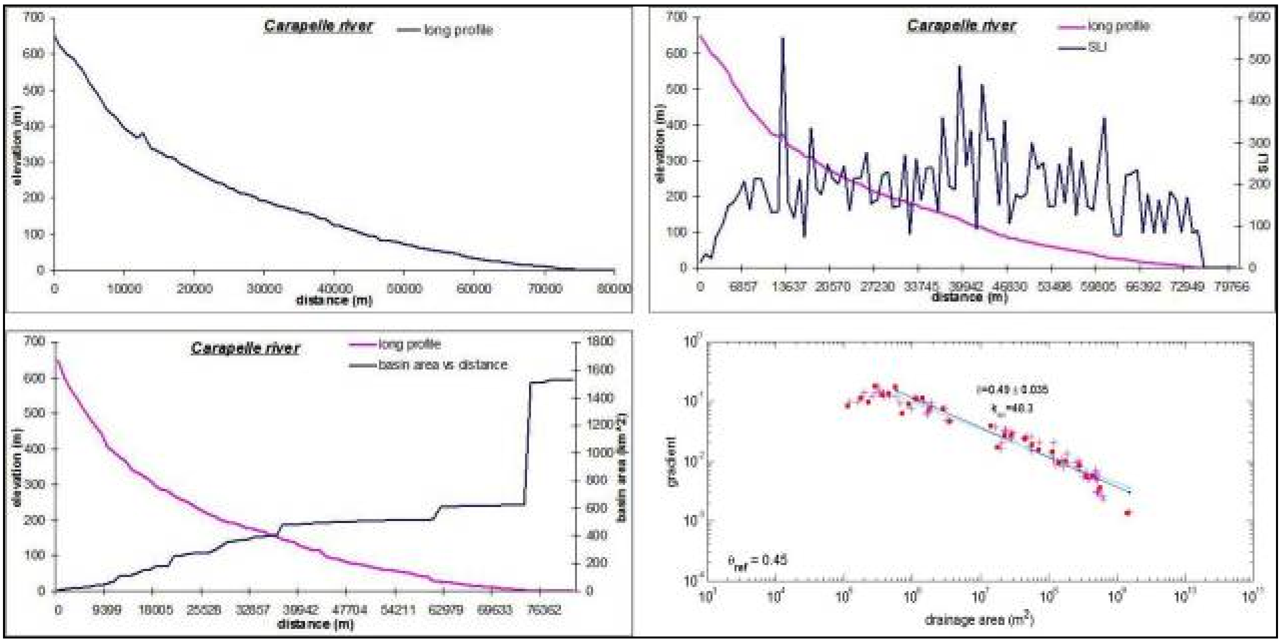


Fig. 4.30: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Carapelle river.

The Carapelle river starts on the hills bordering the north-eastern side of the Ufita valley, close to the town of Trevico, and it flows for about 80km following a general antiapenninic direction, with little variations of direction that changes from SW-NE to SSW-NNE.

The long profile is very close to a rectilinear one, it seems to maintain its slope almost constant until its mouth, there are no important knickpoints, just in the uppermost reach of the profile a small convex sector is present (the peak in the profile at an elevation of about 350m a.s.l. is not a real knickpoint but it is due to an error in the dem): this convex sector is probably due to the presence of a thrust fault that interest the Numidian Flysch formation, but in the map of fig. 3.1 it is also signed an antiapenninic normal fault which is not sure but it is inferred, the valley follow this fault assuming the feature of a subsequent valley so, if this fault will be confirmed, it could be the responsible of the individuation of this convex sector.

The rectilinear shape with the absence of clear knickpoints of the long profile is not confirmed by the SLI curve: this curve, in fact, is characterized by several peak, the first one of which is not representative because it is located in correspondence of the false knickpoint previously described: this peaks suggest that there are some important slope variations along the whole profile that is not possible to recognize at this scale of analysis, and that should deserve a more detailed analysis.

The basin area graph bring to the light one of the main problems I've encountered in the analysis of the Adriatic rivers, that is the false confluences that the 90m dem creates in the flat landscape of the Adriatic coast comprises between the Murge region and the Gargano peninsula: this means that the huge jump individuated in the lowermost reach of the long profile is not due to a real confluence of a tributary, but the 90m dem is not enough detailed to separate the single valleys in this flat landscapes, so that some valleys merge in the flat areas creating this type of false confluence: we so have to exclude this jump from the basin area analysis. We can so say that the basin area graph of the Carapelle river is characterized by a progressive arise of the drainage area, as a consequence of the elongated shape of the drainage basin and to the lack of big tributaries.

The slope/area analysis shows a concavity value of 0.49, which is high enough if we consider how the long profile looks like, and a steepness value of 48.30.

- Celone river

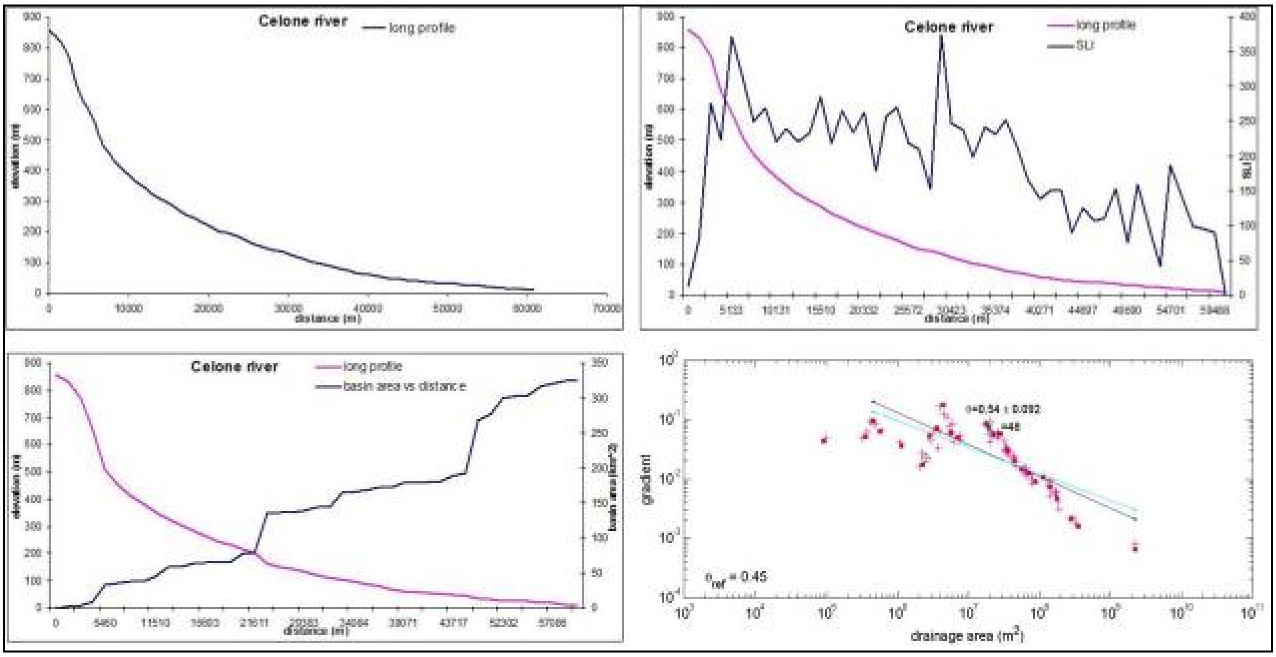


Fig. 4.31: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Celone river.

The Celone river springs on the southern side of Mt. S. Vito, on the outer side of the Southern Apennines, and it flows for about 60km following a mean SW-NE direction until its confluence with the Candelaro river.

The Celone long profile shows a clear concave upward shape. The long profile looks almost perfectly smoothed, there are no knickpoints of relevance if we except two small knickpoints in the uppermost reach of the long profile, at an elevation of about 800m and 500m a.s.l.: in this area it is possible to recognize a few thrusts faults, these thrust faults are very diffused on the external flank of the chain, so these knickpoints are due to the presence of the previously mentioned thrusts.

The SLI curve is characterized by two different sectors, the first one is developed between the beginning of the profile and 35km and it is characterized by a mean SLI value that is clearly higher than the values obtained in the second sector, which one moves from 35km until the end of the profile. It is interesting to notice that the highest peaks are individuated in correspondence of the second knickpoint and downstream of it, at an elevation of about 150m a.s.l., where it is not possible anyway to recognize a knickpoint along the long profile.

The basin area graph is characterized by the occurrence of two main jumps that are individuated at about 20km and 45km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.54, that is one of the highest values among all the Adriatic rivers, and a steepness value of 48.

- Cervaro river

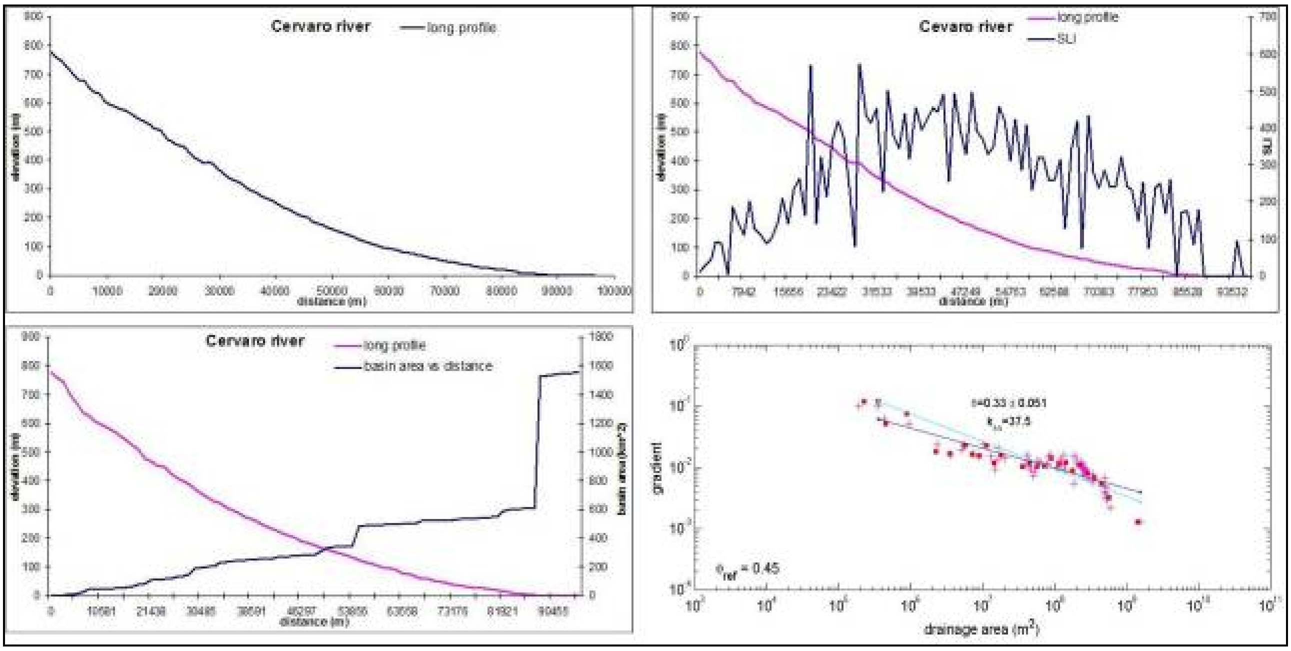


Fig. 4.32: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Cervaro river.

The Cervaro river springs on the eastern side of Mt. Malara, in the area comprised between the towns of Zungoli and Anzano di Puglia, it flows for about 100km until its mouth following a mean SSE-NNW direction in the first 20km of its course, with a few variations of direction, and it then follows a mean SW-NE direction until its mouth.

The Cervaro long profile shows a slightly concave upward long profile, which is very close to a rectilinear shape, with the lack of relevant knickpoints. Some little slope variation seems to occur at an elevation comprised between 800m and 400m a.s.l., here the Cervaro river moves on the terrigenous units cropping out on the outer flank of the Southern Apennines, so it is possible that there is some lithological variation and/or some tectonic element that is not possible to recognize at this scale of investigation that determine the occurrence of these small slope variations.

The SLI curve shows a Gaussian-like shape, with the highest peaks that are shifted upstream the centre of the curve at about 45km from the beginning of the profile, and that are reached about 20km and 30km from the beginning of the profile.

The basin area graph is characterized by a slow arise of the curve along most of the long profile, that should testify the lack of high order tributaries because of the elongated shape of the drainage basin, while there is a major jump that is located at the end of the profile that is not correct because it is due to an error of dem, that is not enough detailed to enhance the rivers valleys that are present on the coastal plains and, in this case, it determines the false confluence of the Cervaro and the Carapelle river.

The slope/area analysis shows a concavity value of 0.33, that is one of the lowest value among all the Tyrrhenian rivers, and a steepness value of 37.50.

- Forra di Venosa river

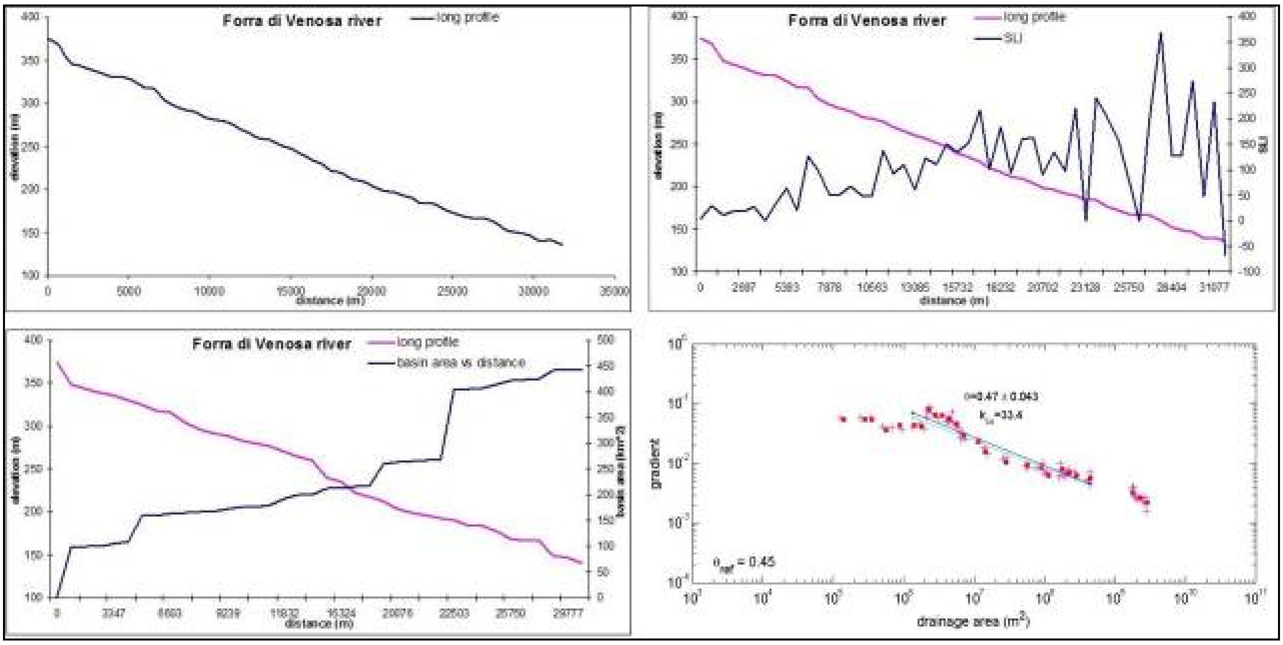


Fig. 4.33: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Forra di Venosa river.

The Forra di Venosa river springs in the area located about 10km east of the town of Venosa, it flows for about 30km until the confluence with the Ofanto river following a mean ESE-WNW direction in the first 20km of its course, and it then changes following a SSW-NNE direction in the last part of the profile.

The Forra di Venosa long profile shows an almost perfect rectilinear shape. The long profile is characterized by the occurrence of several small slope variations that anyway don't correspond with the identification of a clear knickpoint. It is possible to recognize just a small knickpoint at an elevation of about 330m a.s.l., in this area there are no lithological variations and/or tectonic elements that is possible to recognize at this scale of investigation, so this small knickpoint is probably due to some local effects that should deserve more detailed analysis.

The SLI curve is characterized by a progressive arise of the SLI values that reach their maximum in the lowermost reach of the long profile, it is anyway possible to distinguish two different sectors that are separated at about 15km from the beginning of the profile: in the first sector the SLI values are very low and the highest and the lowest peaks don't show a great difference in their values, in the second sector the SLI values are higher than the previous sector and the highest and the lowest peaks show very different values.

The basin area graph is characterized by the occurrence of several jumps, in particular the first one is located very close to the beginning of the profile, the second one is individuated after 5km and the third one is individuated at about 22km.

The slope/area analysis shows a concavity value of 0.47, which is very close to the average value of all the Adriatic rivers, and a steepness value of 33.40.

- Fortore river

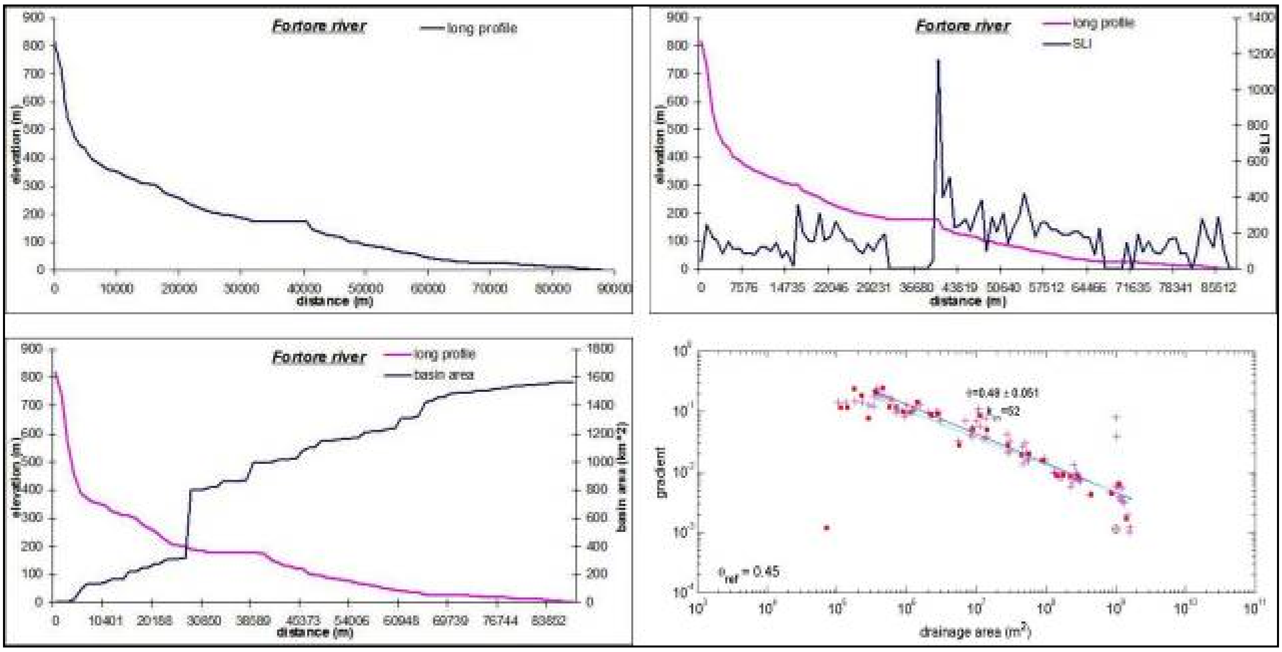


Fig. 4.34: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Fortore river.

The Fortore river springs on the outer flank of the Southern Apennine, in the area close to the town of Montefalcone di Valfortore, its course could be separated in two different sectors, the first one moves from the beginning of the profile until about 35km and it is characterized by a SSE-NNW direction, the second one moves from 35km until the mouth and it is characterized by a SW-NE flow direction.

The long profile shows a concave upward shape, and it is not characterized by the occurrence of relevant knickpoints. There is just one important knickpoint at an elevation of about 200m a.s.l. but this is not a real knickpoint because its individuation is due to the presence of a dam. A small knickpoint is recognizable at an elevation of about 300m a.s.l., about 18km from the beginning of the profile: in this area a normal fault is signed on the map of fig. 3.1, it cuts the Neogene terrigenous units and it is probably the responsible of the individuation of this knickpoint.

The lack of important knickpoints is also shown by the SLI graph: the curve is in fact characterized by very low values along the whole profile, with the only relevant peak that is individuated in correspondence of the false knickpoint due to the dam.

The basin are graph is characterized by the occurrence of just one relevant jump, that is located at a distance of about 30km from the beginning of the profile, and that is due to the confluence with the Catola creek, a right tributaries of the Fortore river whose valley is almost perfectly parallel oriented to the Fortore valley until their confluence.

The slope/area analysis shows a concavity value of 0.48, very close to the medium value among all the Adriatic rivers, and a steepness value of 52.

- Fosso di Stroppito

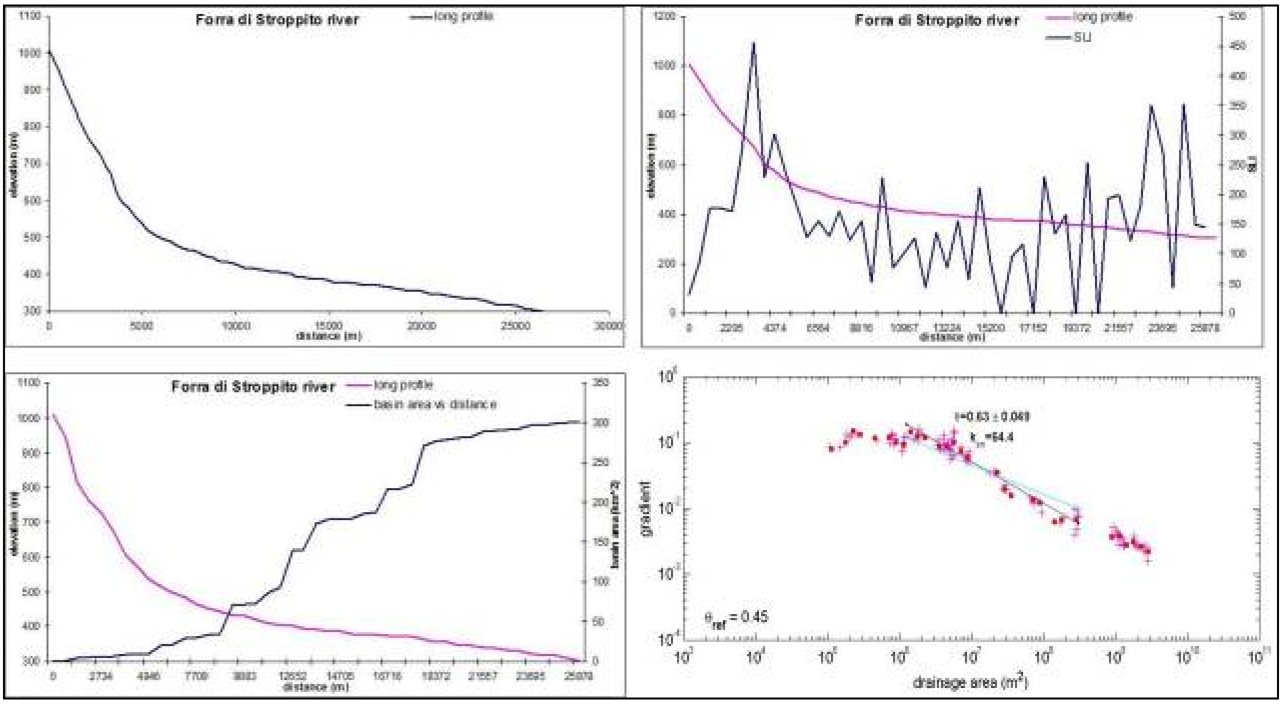


Fig. 4.35: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Fortore river.

The Fosso di Stroppito river springs on the north side of the Mt. Caruso, on the outer side of the Southern Apennines about 15km south of the Vulture volcano, and it flows for about 30km until the confluence with the Ofanto river following a mean SE-NW direction, with local variations of direction that bring the river flowing SSE-NNW and E-W in a short portion of its course.

The Fosso di Stroppito long profile shows a clear concave upward shape that seems to be not interested by any relevant slope variations so that it is not possible to recognize a clear knickpoint on it. There are anyway two little portion of the long profile where a knickpoint seems to exit: the first one is individuated at an elevation of about 700m a.s.l., in this area the river flows into the Flysch Rosso Formation and there are no lithological variations or tectonic elements of relevance, so this small knickpoint should deserve more detailed investigation to be explained; the second knickpoint is individuated at an elevation of about 330m a.s.l., almost in correspondence of the Ofanto confluence, also in this case the river moves into a lithologically homogeneous area (Ariano Unit) and there are no tectonic elements of relevance, so this knickpoint should deserve more detailed analysis too.

The SLI curve is characterized by a huge variability of the SLI values, with the highest peaks that are located in correspondence of the previously mentioned knickpoints and with the lowest values that are individuated in the part of the long profile comprised between the two small knickpoints.

The basin area doesn’t present some important jump, but it abruptly arise in the portion of the profile between 8km and 19km because of the confluence with several tributaries such as the Orvivo, Vonchia and Bradano creeks.

The slope/area analysis shows a concavity value of 0.63, that is one of the highest values among all the Adriatic rivers, and a steepness value of 64.40.

- Locone river

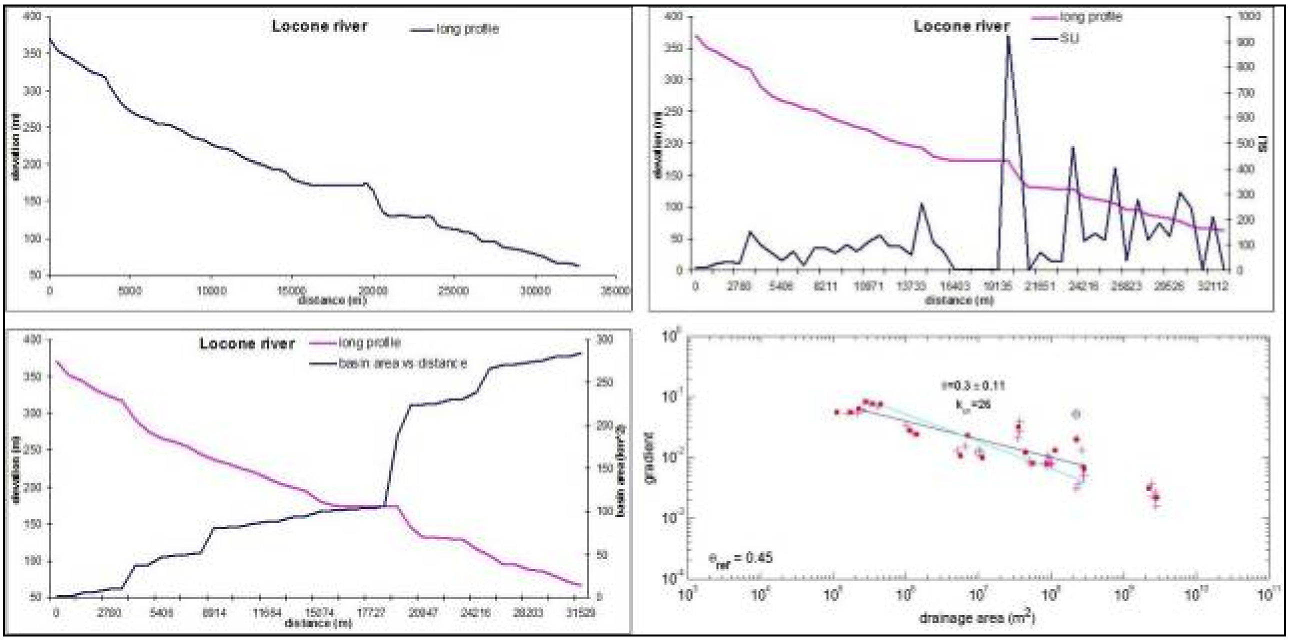


Fig. 4.36: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Locone river.

The Locone river springs in the Bradanic foredeep, in the area located about 5km east of the town of Spinazzola, it flows for about 35km until its confluence into the Ofanto river and it follows a mean SSE-NNW direction letting the river valley to be parallel to the northeastern side of the Murge region.

The Locone long profile shows an almost perfect rectilinear shape that is characterized by the occurrence of several knickpoints: the first knickpoint is individuated at an elevation of about 330m a.s.l. in the uppermost reach of the long profile: in this area the valley moves into the Bradanic Cycle deposits, there are no relevant lithological variations and/or tectonic elements, so this knickpoint should deserve more detailed analysis to be understood; the second knickpoint is individuated at an elevation of about 150m a.s.l., in this case there is a lithological control on the origin of this knickpoint, in fact in this portion of the long profile the lithology changes from the Bradanic Cycle deposits to the alluvial deposits of the Ofanto valley, and so it is probably this lithological variation that determines the occurrence of such knickpoint.

The SLI curve is characterized by the occurrence of two different sectors that are separated almost in correspondence of the second knickpoint: in the first sector the SLI values are very low and also the knickpoint here recognized doesn't correspond with a relevant peak in the curve; the second sector is instead characterized by higher values, the highest of which is recognized in correspondence of the second knickpoint, and with the SLI values that then tend to decrease downstream the knickpoint but they still show values higher than in the first sector.

The basin area graph is characterized by three small jumps at a distance of about 4km, 8km and 25km respectively, while the highest jump is individuated at a distance of about 18km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.30, which is one the lowest values among all the Adriatic rivers, and a steepness value of 26.

- Ofanto river

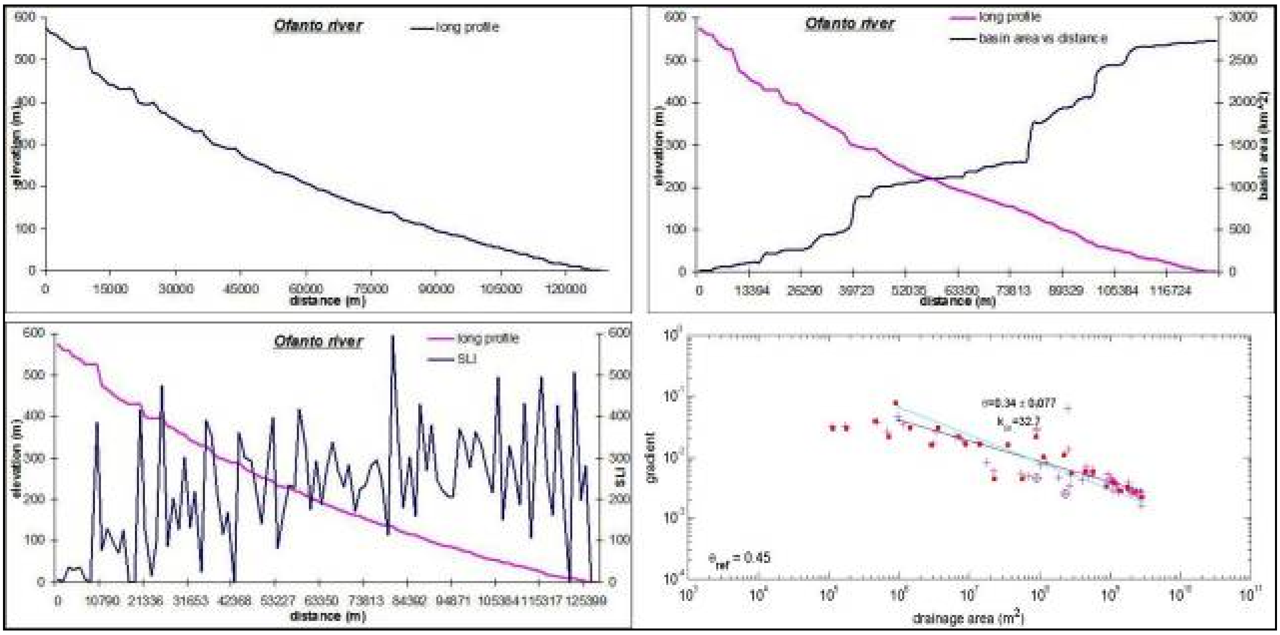


Fig. 4.37: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Ofanto river.

The Ofanto river springs on the outer flank of the Southern Apennines, in correspondence of the town of Nusco, it flows in the first 40km following a mean W-E direction, then it changes its direction following a S-N direction until the 60km, and it finally follows a SW-NE direction until its mouth.

The Ofanto long profile is very typical, it is in fact one of the most rectilinear profiles in the whole Southern Apennine, there are no knickpoints of relevance, the small knickpoint-like feature that is possible to see in the uppermost reach of the profile are not real knickpoints, but they are due to errors in the dem. The rectilinear shape could suggest a relative youth of this profile, in particular it could suggest that the area where the Ofanto valley is located has experienced recent uplift so that the river hasn't had enough time to incise its valley reaching a concave upward profile.

The lack of a knickpoint is not shown in the SLI graph, in fact the SLI curve is characterized by a continue alternation of positive and negative peaks, that seem to follow an increasing trend moving from the beginning of the profile until its end, and that don't correspond to some knickpoints in the Ofanto long profile: this data suggest that some important slope variation occurs along the Ofanto valley, slope variations that is not possible to recognize at this scale of analysis and that could be the base for more detailed researches.

The basin area graph is characterized by the occurrence of two major jumps, that are individuated at a distance of about 30km and 80km from the beginning of the profile, and that are due to the confluence of the Forra di Venosa river and the Locone river, two right tributaries of the Ofanto river.

The slope/area analysis shows a concavity value of 0.34, this is one of the lowest values in the whole chain testifying the rectilinear shape of the long profile, while the Ks index has a value of 32.70.

- Tappino river

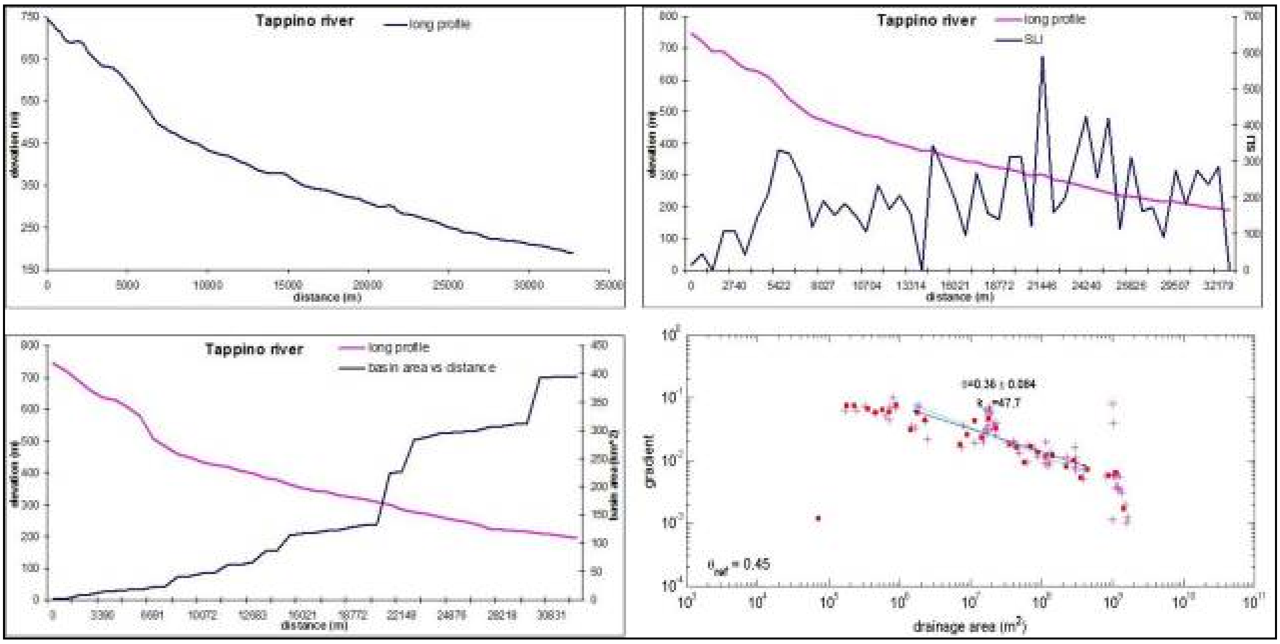


Fig. 4.38: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Tappino river.

The Tappino river springs on the south-eastern side of the Mt. Vairano, close to the town of Campobasso, it flows for about 35km until its confluence with the Fortore river following alternatively a SW-NE and a NW-SE direction along its entire course.

The Tappino long profile shows a slightly concave upward shape that is very close to a more rectilinear shape. It is possible to separate the long profile in two different sectors: the first one is individuated at an elevation comprises between 750m and 450m a.s.l., here the long profile is slightly convex upward with the occurrence of two small knickpoints at an elevation of about 700m and 650m a.s.l., in this area there is a normal fault that could be responsible of the individuation of these knickpoints, but the convex upward shape could suggest that a recent uplift has occurred in this portion of the long profile; the second sector moves from 450m a.s.l. until the end of the profile, here the long profile shows a more rectilinear shape with the lack of knickpoints of relevance, except that for two small knickpoints individuated at an elevation of about 350m and 300m a.s.l. and that are probably related to a lithological variation (in this area there is the stratigraphical contact between the terrigenous units cropping out on the outer flank of the chain and the Flysch Rosso Formation).

The SLI curve seems to reflect the difference between the two previously recognized sector: in particular, in the first sector the SLI values are very low and they are characterized by just one high peak individuated at the end of the convex upward sector; the second sector is instead characterized by higher values that are similar to the highest value of the first sector, with the highest peak that is recognized in correspondence of the first small knickpoint individuated in this area.

The basin area graph is characterized by two relevant jumps in the curve, which are individuated at a distance of about 20km and 30km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.36, which is very close to the lowest value among all the Adriatic rivers, and a steepness value of 47.70.

- Vulgano river

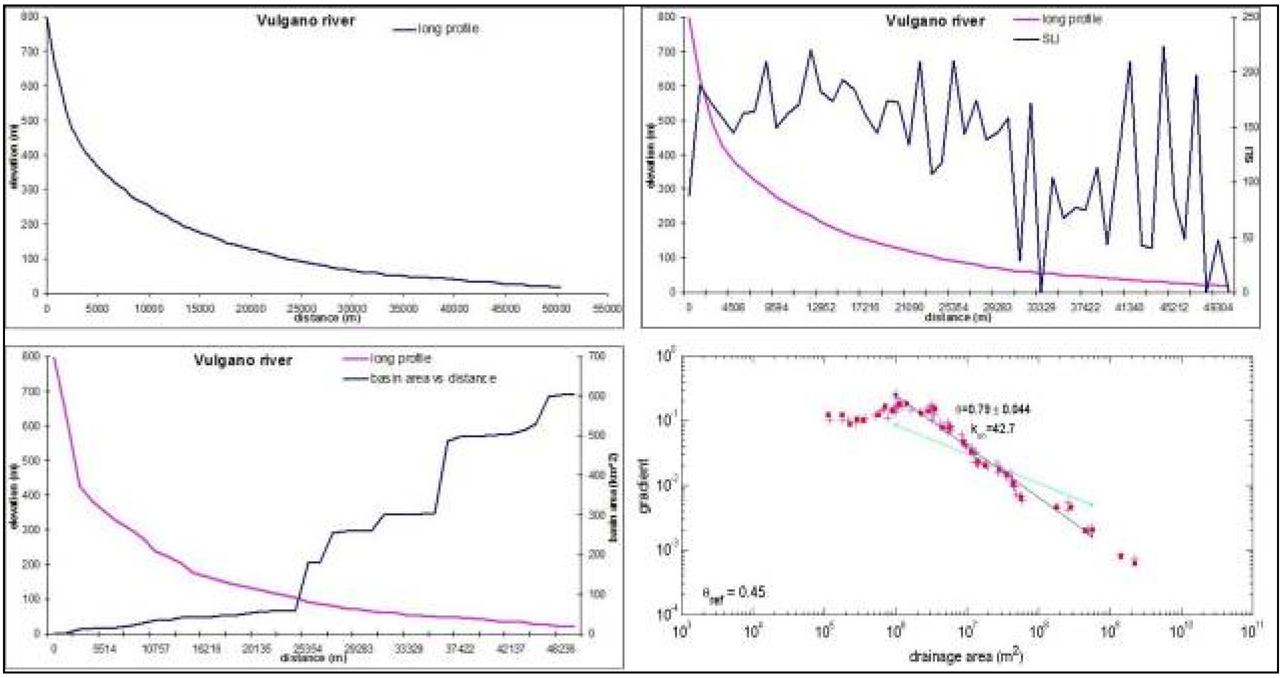


Fig. 4.39: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Vulgano river.

The Vulgano river springs on the north side of the Mt. Pagliarone, on the outer side of the Southern Apennines, and it flows for about 50km until its confluence with the Candelaro river following a mean SW-NE direction with little variations of direction.

The Vulgano long profile is characterized by a clear concave upward shape, the profile looks almost perfectly smoothed with the lack of knickpoints of relevance. This enhanced concave upward shape is probably due to the combination of the lack of important lithological variations (the profile moves in the foredeep deposits along its entire course) and the lack of tectonic elements.

The concave upward shape doesn't correspond with a SLI curve that tends to decrease as the profile moves downstream, but the SLI curve is characterized by the occurrence of several high peaks, in particular it is possible to separate two different sectors with the separation point that is about at 30km from the beginning of the profile: in the first sector the SLI values are high and the values of the highest and lowest peaks are not so different; in the second sector the SLI curve progressively tends to decrease, a trend that is anyway interrupted by the occurrence of three high and narrow peaks in the lowermost reach of the long profile suggesting that in this area some important slope variation occurs and that such variations deserve more detailed analysis to be investigated.

The basin area graph is characterized by the occurrence of two important jumps, that are individuated at a distance of about 25km and 37km respectively: the first jump is not real but it is due to some dem errors that occur in the flat coastal area (see the Carapelle and Cervaro analysis for a more detailed discussion about this problem), the second jump is due to the confluence of the Salsola river.

The slope/area analysis shows a concavity value of 0.79, that is the highest value among all the Adriatic rivers, and a steepness value of 42.70.

4.1.3 Ionian rivers

- Agri river

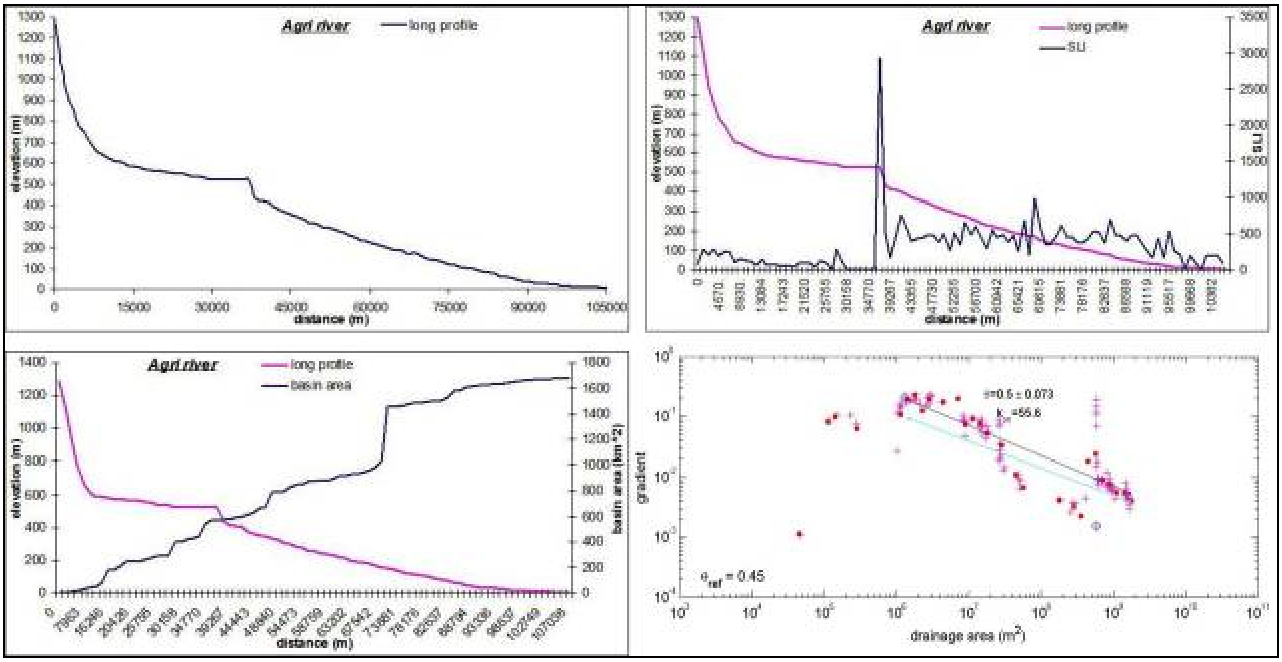


Fig. 4.40: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Agri river.

The Agri river springs north of the Mt. Volturino, it flows for about 110km with a mean WNW-ESE direction, with the occurrence of several variations of direction that bring the valley to follow a N-S and a W-E direction in the upper reach of the profile and into the Sant'Arcangelo basin respectively.

The Agri long profile shows a concave upward shape, also if it is possible to recognize two different sectors: the first one moves from the beginning of the profile until 35km and it has a clearer concave up shape, while the second one moves from 35km until the mouth and it shows a more rectilinear shape. The limit between the two sectors is marked by the occurrence of a knickpoint: this knickpoint is located in the low Agri valley, where the Agri river flows into a gorge it has cut into the substrate (Gorgoglione Flysch), but this is a false knickpoint because it is due to the presence of a dam. If we anyway try to eliminate this false knickpoint, we can see that the long profile is clearly convex in this area, so this is the only part of the Agri valley where the long profile shows some perturbation, with a convex shape that could be related to a recent uplift that this area has experienced: this data is in agreement with the elevation of the river terraces, that are at higher elevation in this part of the profile than in the portion of the long profile just upstream the knickpoint.

The lack of important variation of slope is also shown by the SLI graph, in particular the curve could be separated in two distinct portions, the first one located upstream the convex sector with very low values of the SLI, then there is the highest peak in correspondence of the false knickpoint, and the second sector is located downstream of the convex sector, with the SLI values that are higher than the previous sector, with a more enhanced alternation of high and low peaks, that could be related to slope variations that is not possible to recognize in the long profile and that should deserve more detailed analysis (in this sector the Agri flows into the Sant'Arcangelo basin, it then crosses the Nocara ridge to the north and it finally flows into the foredeep deposits until its mouth).

The basin area graph is characterized by two minor jumps immediately before and after the false knickpoint, that are due to the confluence of the Maglia and the Racanello rivers into the Agri river while, at about 75km, there is the biggest jump that is related to the confluence of the Sauro river.

The slope/area analysis shows a concavity value of 0.50, that is one of the highest among all the Ionian rivers, and a Ks value of 55.60.

- Basentello river

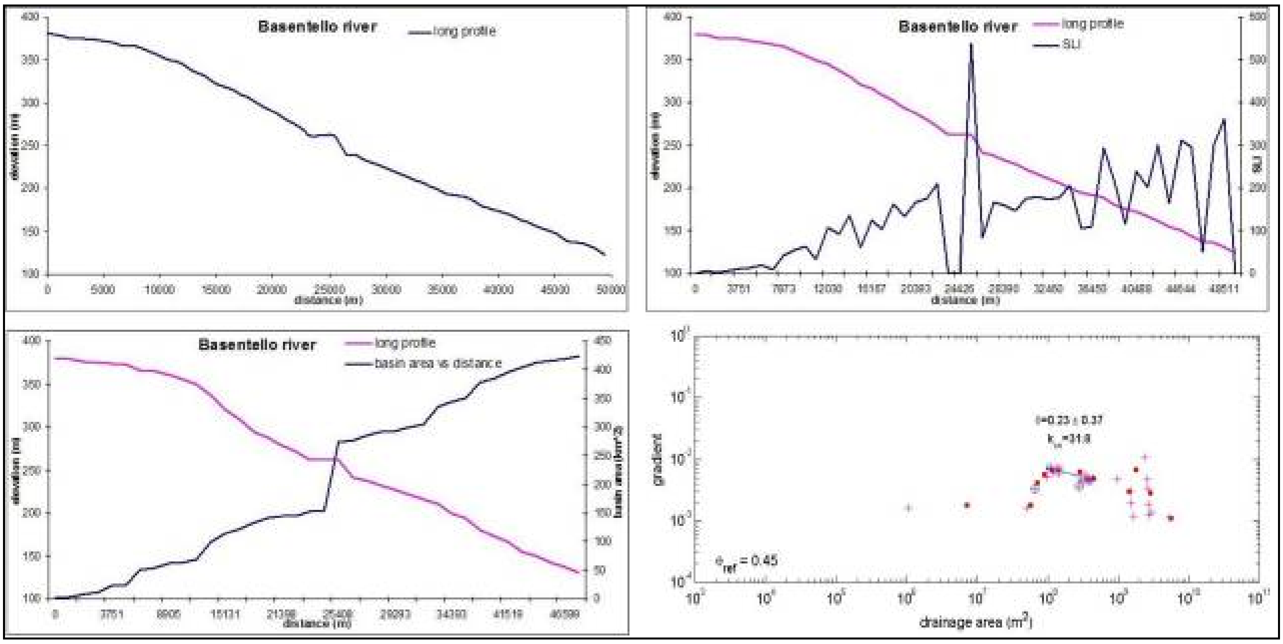


Fig. 4.41: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Basentello river.

The Basentello river springs about 10km north of the town of Banzi, in the area where the Lavello high is located (Balduzzi et al., 1982), it flows for about 50km until its confluence in the Bradano river and it follows a mean NW-SE direction, with local variations of direction.

The Basentello long profile shows a slightly convex upward shape, in particular it is possible to separate the long profile in two different sectors, a first one comprised between 400m and 300m a.s.l. and a second one that moves from 300m a.s.l. until the end of the profile: the first sector presents a clear convex upward shape while the second sector shows a more rectilinear shape, with the occurrence of a knickpoint at an elevation of about 250m a.s.l.: in this area there are no lithological variations of relevance and there are no tectonic elements, so the reason of this knickpoint should be investigated with more detailed analysis. It is interesting to notice that the convex upward sector is located in correspondence of the Lavello high, a morphostructural high separating the Puglia basin from the Lucanian basin (Balduzzi et al., 1982), so this convex upward sector suggest that a recent uplift has occurred in this area and it could be related with the uplift of the Lavello high.

The SLI curve is characterized by very low values in the uppermost reach of the long profile, values that then tend to arise as the profile moves towards the confluence with the Bradano river, an increasing trend that is locally interrupted by the highest peak in the curve that is individuated in correspondence of the knickpoint recognized in the rectilinear part of the long profile.

The basin area graph shows a progressive growth of the curve, with a relevant jump that is individuated at a distance of about 25km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.23, that is the lowest value among all the Ionian rivers, and a steepness value of 31.80.

- Basento river

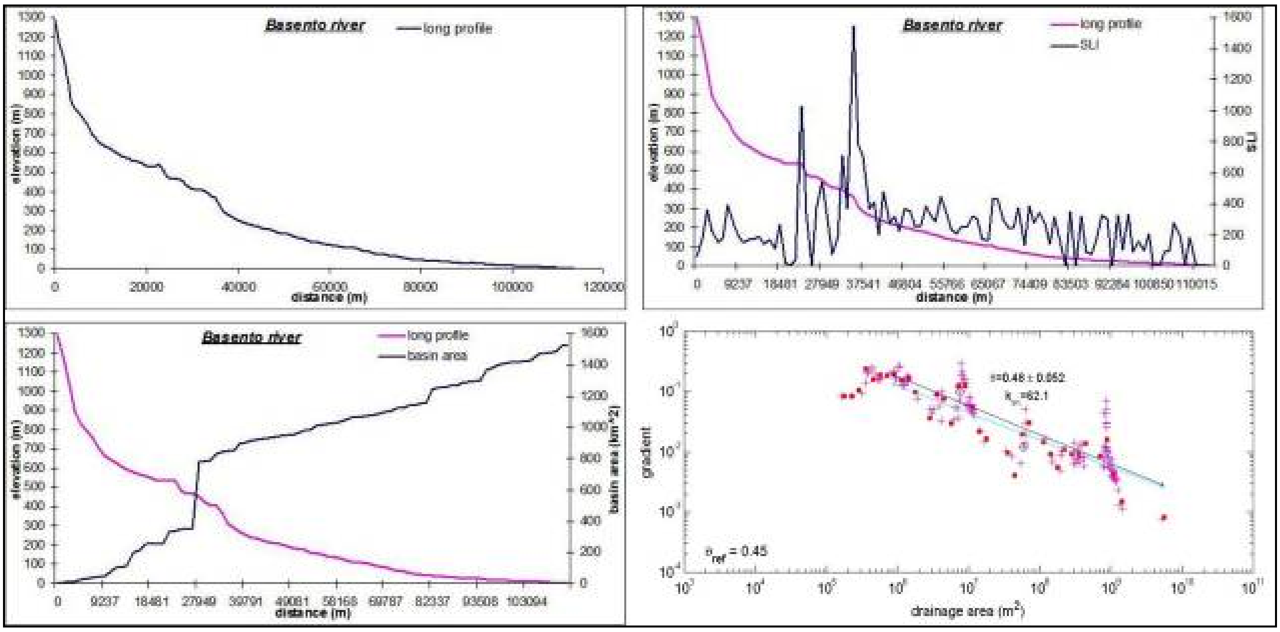


Fig. 4.42: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Basento river.

The Basento river springs on the Mt. Arioso, a relief located on the outer portion of the chain where the Lagonegro Units crop out. The Basento course is characterized by continue variations of direction, in particular it follows a SW-NE direction in the first 23km, to then move to a NW-SE direction for the next 20km, it then flows again following a SW-NE direction for the next 12km and it finally follows a NW-SE direction until its mouth.

The Basento long profile is concave upward, the concavity is interrupted by the occurrence of several knickpoints at an elevation comprises between 300m and 600m a.s.l., at a distance from the beginning of the profile comprised between 20km and 40km, so that it is possible to recognize a knickzone in this area. This area is characterized by the occurrence of different lithologies, in particular, as we move downstream in this area, we meet the Neogene terrigenous units (Ariano Unit), the Sicilidi Units, the Flysch Rosso and the Neogene terrigenous units (Gorgoglione Flysch): the first knickpoint, that is individuated at an elevation of about 500m a.s.l., is due to the passage from the Ariano Unit to the Sicilidi Unit, while the other two knickpoints, located at an elevation of about 400m and 350m, are due to the tectonic contact between the Sicilidi Units and the Numidian Flysch and to the stratigraphical contact between the Numidian Flysch and the Gorgoglione Flysch respectively.

The occurrence of this knickzone is well shown in the SLI graph: in fact, in the portion of the profile characterized by the occurrence of the knickpoints, the highest peaks of the SLI curve are individuated. In addiction to this, the SLI curve can be separated in two different portions, such as it has occurred for the Agri river, and in particular a first sector upstream the knickzone with lower SLI values and with a low variability, and a second sector with a greater variability of the SLI and with higher values: this second sector moves into the foredeep domain, so this suggest that there is some variation of slope that is not possible to recognize by the long profile and that should deserve more detailed analysis.

The basin area graph is characterized by one major jump, that is located at a distance of about 25km from the beginning of the profile in correspondence of the knickzone, and that is due to the confluence with the Camastra river.

The slope/area analysis shows a concavity value of 0.48, that is very close to the average value among all the Ionian rivers, and a steepness value of 62.10.

- Bradano river

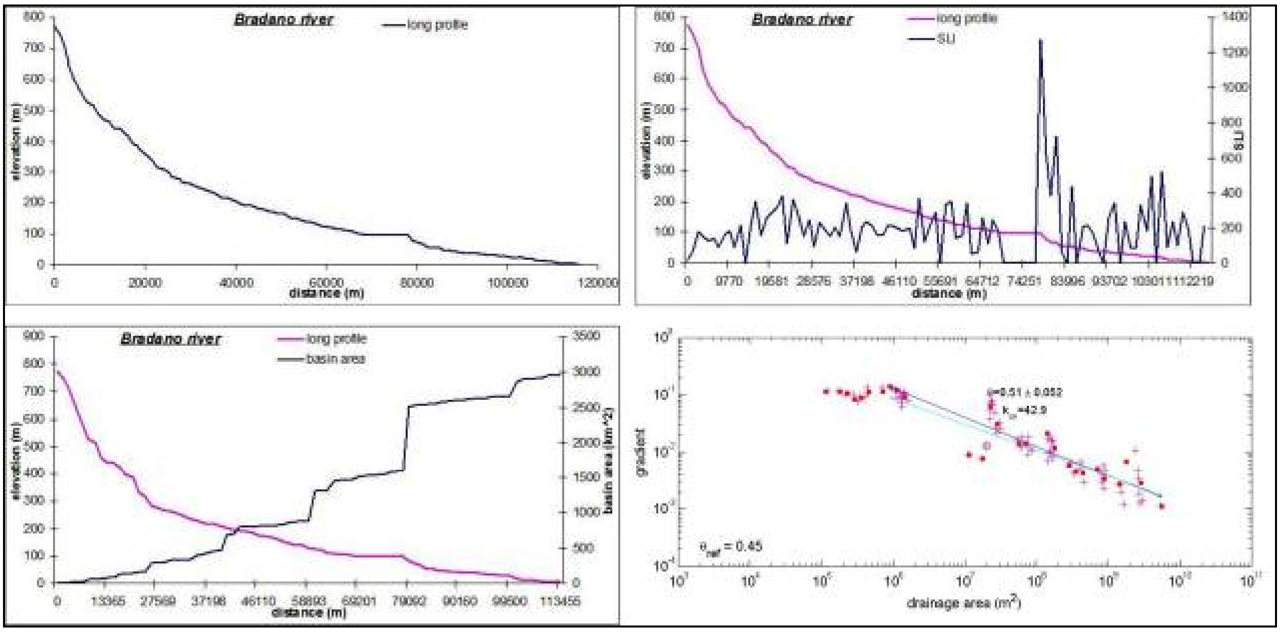


Fig. 4.43: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Bradano river.

The Bradano river springs on the outer flank of the Southern Apennines, south of the Vulture volcano. Its course is characterized by a general NW-SE direction, with several variations of direction in the first 25km, that bring the Bradano to follow alternatively an apenninic and antiapenninic direction (this occurs before the Bradano moves into the foredeep deposits), as the Bradano flows into the foredeep deposits it changes its orientation and the valley follows a NW-SE direction until the mouth, with little variations of direction.

The Bradano long profile shows a concave upward shape, with no knickpoints of relevance. The only knickpoint that is possible to recognize is located at an elevation of about 100m a.s.l. and it is due to the presence of a dam. It is anyway possible to recognize a slightly convex sector that is located at an elevation comprised between 300m and 500m a.s.l.: in this area the Bradano flows into the terrigenous units cropping out on the outer flank of the chain, with the occurrence of lithological variations because of the outcropping of terrigenous units (Serrapalazzo formation) and the Numidian Flysch whose contact is in same cases stratigraphical and in other case tectonic (thrust fault). The occurrence of this slightly convex sector could be related to a recent uplift that this area has experienced. It is also possible to notice that, as we move downstream this convex sector and the Bradano river flows into the foredeep domain, the long profile becomes almost perfectly rectilinear, recalling the shape of the Ionian rivers flowing into the foredeep deposits.

The lack of important slope variations is shown by the SLI graph: the curve is not characterized by important peaks, the highest of which is located in correspondence of the false knickpoint, but the SLI seems to range around an average value of about 200.

The basin area graph is characterized by three main jumps, which are located at a distance of about 45km, 60km and 80km from the beginning of the profile: these three jumps are due to the confluence with the Castagno creek, and with the Basentello and the Gravina di Picciano rivers.

The slope/area analysis shows a concavity value of 0.51, that is one of the highest among all the Ionian rivers, and a steepness value of 42.90.

- Camastra river

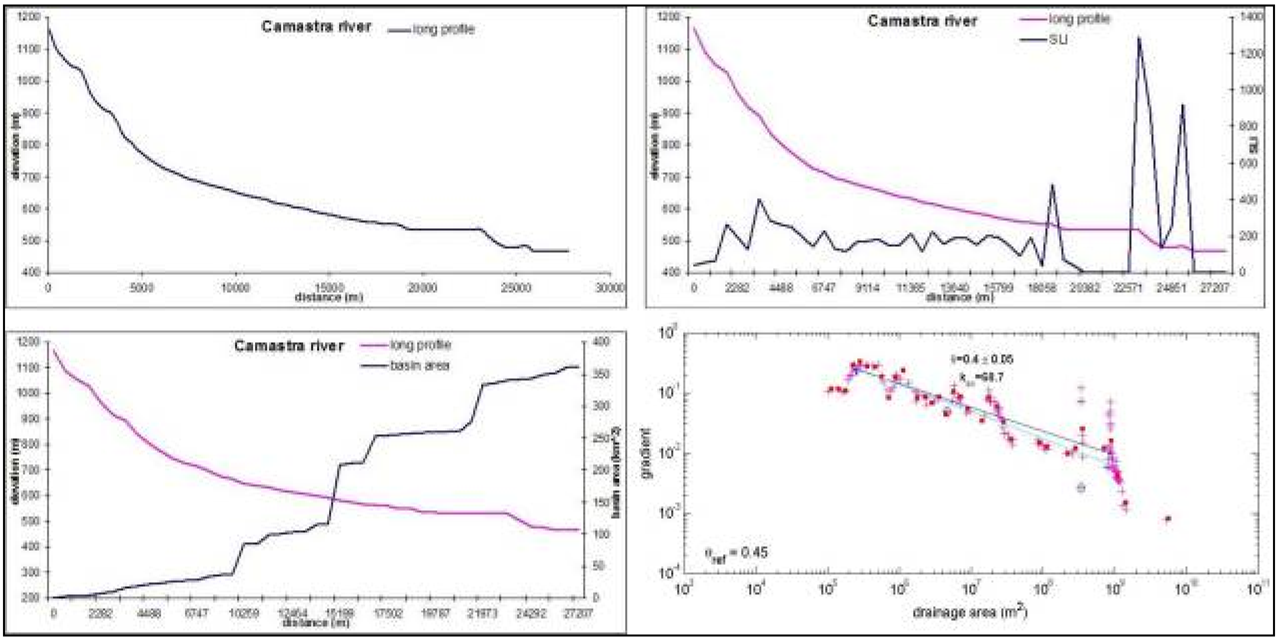


Fig. 4.44: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Camastra river.

The Camastra river springs on the north side of the Mt. Tempa di Calvello, that is located about 7km west of the Calvello basin, it flows for about 30km until its confluence with the Basento river following a SSW-NNE direction in the first 20km and it then changes its direction towards a SW-NE direction.

The Camastra long profile shows a concave upward shape that is characterized by the occurrence of four main knickpoints: the first knickpoint is individuated at an elevation of about 1050m a.s.l. in the uppermost reach of the long profile, in this area the Camastra valley moves into the Lagonegro Units, the knickpoint is due to the occurrence of a normal fault interesting the Lagonegro Units; the second knickpoint is individuated at an elevation of about 900m a.s.l., in this case in this area a thrust fault is individuated, it is responsible of the contact between the North-Calabrian Units and the Lagonegro Units, and it is the main reason of the individuation of this knickpoint, together with the lithological contrast between the two mentioned units; the third and the fourth knickpoints are located at an elevation of about 550m and 500m a.s.l., in the lowermost reach of the long profile, here other thrust faults are individuated, they are responsible of the tectonic contact between the Sicilidi Units and the Flysch Rosso Formation and between the Flysch Rosso Formation and the Gorgoglione Flysch, so in this case the knickpoint is due to the combination of the tectonic and the lithological contrast between the mentioned units.

The SLI graph is characterized by very low values in the upper part of the long profile, with high peaks that are individuated in correspondence of the first three knickpoints, while the highest peak of the whole curve is individuated in correspondence of the last knickpoint, and it is followed by another important peak that correspond to the location of another small knickpoint on the long profile.

The basin area graph is characterized by the occurrence of three main jumps that are individuated at about 10km, 16km and 22km from the beginning of the profile in correspondence of the confluence with the Piesco river, the Forra d'Anzi river and the Serrapotamo creek respectively.

The slope/analysis shows a concavity value of 0.40, which is very close to the average value among all the Ionian rivers, and a Ks value of 68.70.

- Cavone river

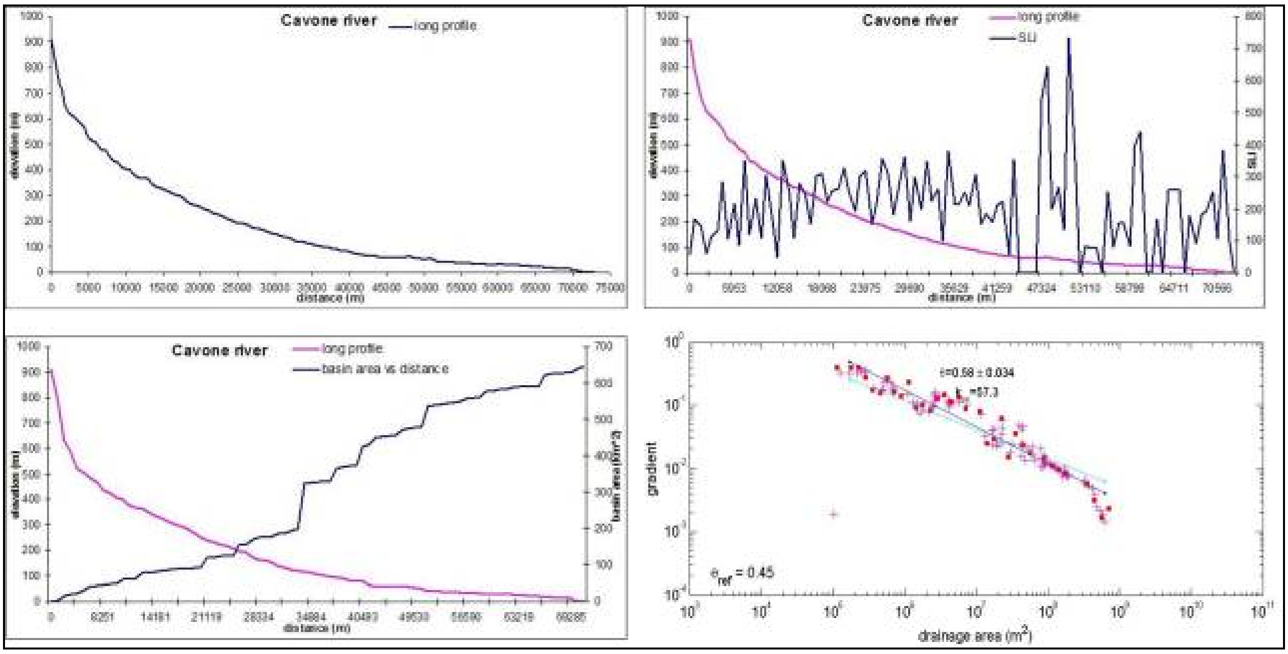


Fig. 4.45: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Cavone river.

The Cavone river springs on the east side of the Mt. dell'Impiso, on the outer flank of the Southern Apennines, it flows for about 75km until its mouth in the Ionian sea following a SW-NE direction in the first 13km of its course, and then following a NW-SE direction from this point until the mouth.

The Cavone long profile shows a clear concave upward shape, the profile is not characterized by the occurrence of some knickpoint of relevance, the only small knickpoint that is possible to recognize is individuated at about 600m a.s.l., in the uppermost reach of the long profile: in this area it is individuated one of the thrust faults that interest the terrigenous units cropping out on the outer flank of the chain, so this knickpoint is due to the presence of such thrust fault more than to a lithological variation, considering that the lithologies interested by the thrust are not so different (they have been all grouped into the "Pre- to Late Orogenic Neogene Units" in the map of fig. 3.1). Another small knickpoint is individuated at an elevation of about 50m a.s.l. in the lowermost reach of the long profile, in this case the profile moves into the foredeep deposits, there are no lithological variation or tectonic elements of relevance, so this small knickpoint should deserve more detailed analysis.

The SLI curve could be separated in two different sectors, that are separated almost in correspondence of the second knickpoint: in the area upstream this knickpoint the SLI curve is characterized by low values with the higher peaks that are very close spaced; in the portion of the profile downstream the knickpoint the SLI values are higher, with the highest peak that is individuated in correspondence of the knickpoint, and with the higher peaks that are more widely spaced if compared to the previous sector.

The basin area curve is characterized by a main jump that is individuated after about 35km from the beginning of the profile and that is due to the confluence with the Misegna creek.

The slope/area analysis shows a concavity value of 0.58, which is higher than the average value among all the Ionian rivers, and a steepness value of 57.30.

- Cogliandrino river

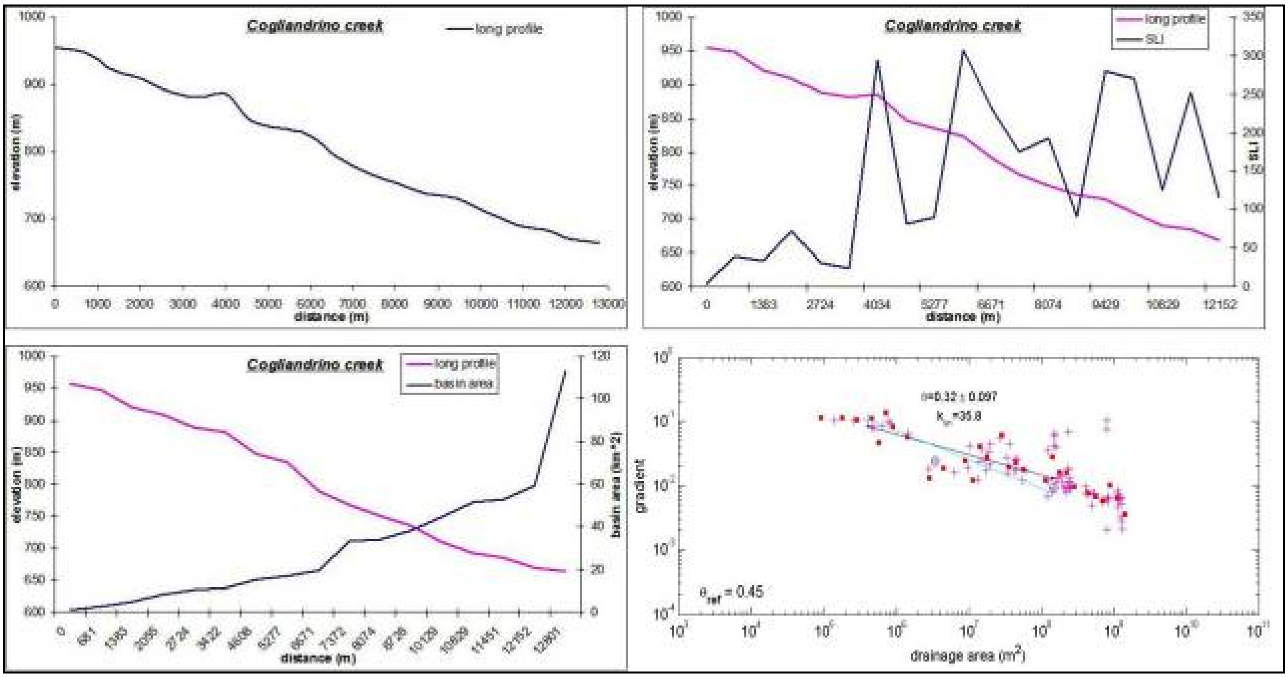


Fig. 4.46: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Cogliandrino river.

The Cogliandrino river flows in the area comprised between the Sirino massif, the Mt. Alpi and the Mt. Raparo, which is a strategic area in the Southern Apennines because of the rock exhumation processes that are involved to explain the outcropping of the Lagonegro Units on the Sirino massif, and the outcropping of the Apulian carbonates on the Mt. Alpi. The river has a course of about 15km that follows a N-S direction, with no variations of direction.

The Cogliandrino long profile shows a slightly convex upward shape, and this feature make this river peculiar because this is the only Southern Apennines river whose profile is clearly convex from the beginning of the valley until its end. There is some little slope variation, but it is not possible to talk about the presence of knickpoints, also if anyway two small knickpoints seem to occur at an elevation of about 850m and 800m a.s.l.: the first one is not a real knickpoint but it is due to some error in the dem, while the second one is located at the stratigraphical contact between the Albidona Flysch and the North-Calabrian Units, so this one could be due to this lithological variation.

The convex shape of the long profile is also enhanced by the SLI graph: in the case of a convex profile, in fact, the slope of the long profile increase as the profile moves downstream and, consequently, the SLI curve should tends to increase too. This is what occurs in the case of the Cogliandrino river, with the SLI curve that clearly tends to arise as the profile moves downstream, as it can be easily recognized by the envelop of the minimum peaks.

The basin area graph doesn't show any relevant jump, so it means that the Cogliandrino tributaries are almost of the same sizes, in particular in terms of drainage area.

The slope/area analysis shows a concavity value of 0.32, that is very low and that testify the convex upward shape of the long profile, while the steepness index has a value of 35.80.

- Frida river

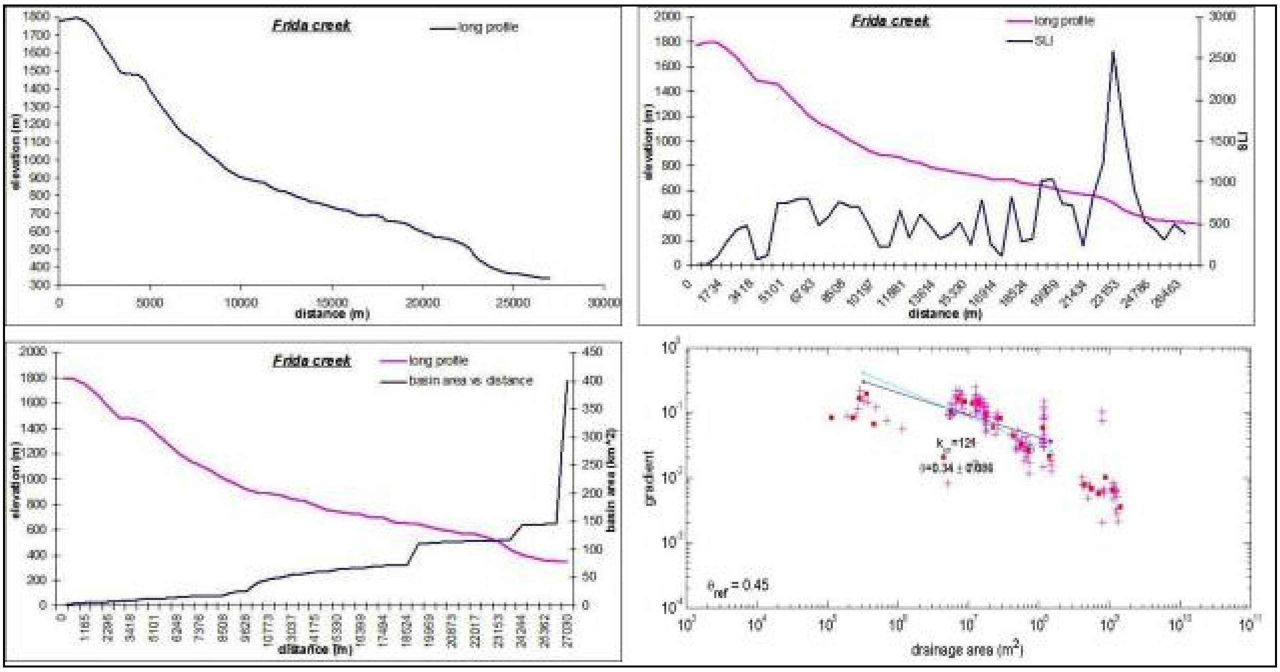


Fig. 4.47: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Frida river.

The Frida river starts on the northern side of the Pollino massif, it flows for about 30km before its confluence with the Sinni river following a mean N-S direction, with several variation of direction, and in particular it follows a SE-NW direction in the first 5km, it then changes its direction flowing S-N for the following 5km, it then follows a SE-NW direction for the next 9km and it finally follows a SW-NE direction until the junction with the Sinni river.

The Frida long profile shows a general concave upward shape, also if this concave upward shape tends to an almost rectilinear shape. The long profile is characterized by the occurrence of several knickpoints: the first one is individuated in the uppermost reach of the long profile, at an elevation of about 1800m a.s.l., but this is probably due to some error in the original dem, because the long profile seems to slightly arise in this area; the knickpoint located at an elevation of about 1500m is more relevant, it is individuated inside the Pollino massif, in an area where the Pollino massif is interested by several normal faults, so this knickpoint is related to the presence of some of these faults; the lowermost knickpoint is located at an elevation of about 500m a.s.l., in the lowermost reach of the long profile, this area is characterized by the stratigraphical contact between the Liguridi Units and the quaternary deposits of the Sant'Arcangelo basin, so this knickpoint is probably due to the lithological contrast between the two mentioned lithologies.

The SLI curve is characterized by a little variation of the SLI values, in particular it is interesting to notice that the peak related to the 1500m a.s.l. knickpoint is not so enhanced but, to the contrary, there are higher peaks that don't have a clear relation with the location of other knickpoints. The only knickpoint that is clearly recognizable in the SLI curve is the lowermost, which also corresponds with the highest peaks of the whole curve.

The basin area graph is not characterized by important jump: in the lowermost part of the curve, it abruptly increases but this is not related to the confluence with some tributary and it is probably due to some error in the dem. If we exclude this point, the only relevant jump is due to the confluence with the Peschiera river that occurs about 5km upstream the confluence of the Frida river into the Sinni river.

The slope/area analysis shows a concavity value of 0.34, which is one of the lowest among all the Ionian rivers, while the Ks index is of 121.

- Gravina di Picciano river

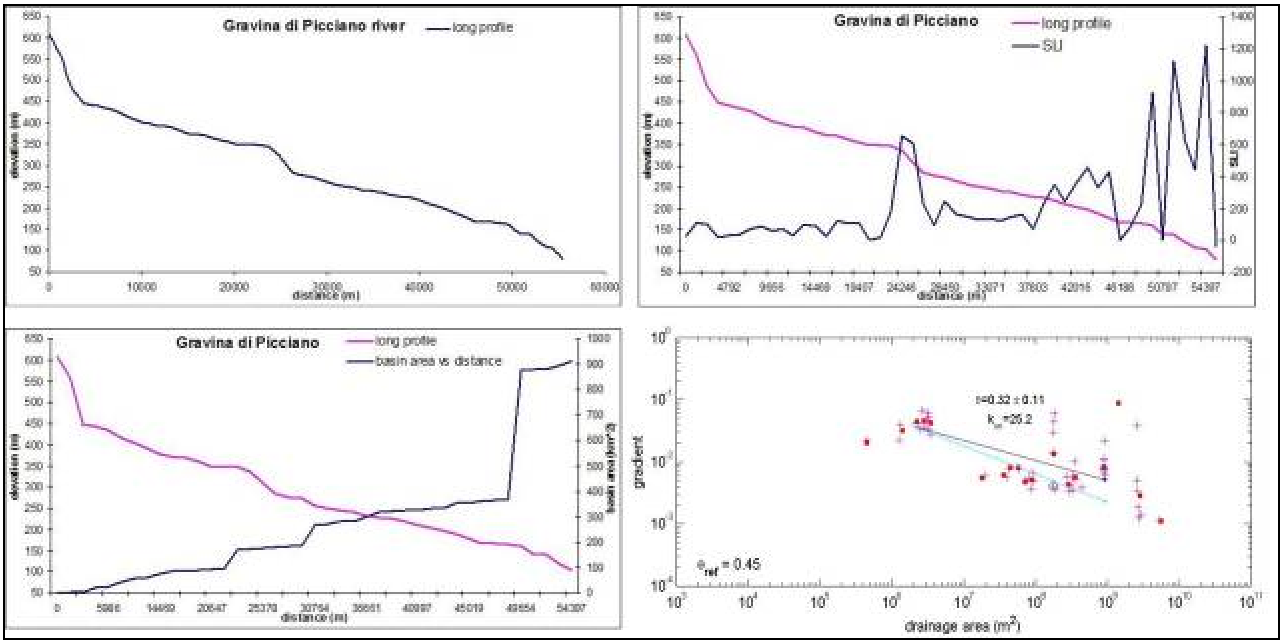


Fig. 4.48: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Gravina di Picciano river.

The Gravina di Picciano river springs on the west side of the Murge region, about 30km NW of the town of Altamura, it flows for about 60km until its confluence with the Bradano river following a mean NW-SE direction with a few local variations of direction.

The Gravina di Picciano long profile shows a slightly concave upward shape, that is close to a rectilinear shape. The long profile is characterized by an uppermost steep reach that corresponds to the part of the profile where the river moves into the carbonate of the Murge region, downstream this area the profile becomes gentler and two knickpoints are individuated: the first one is individuated at an elevation of about 350m a.s.l., the profile moves into the quaternary filling of the Bradanic foredeep, in this part of the profile there is a lithological variations with the passage from the Irsina Conglomerates to the Montemarano Sands, so this lithological variation could be the reason of the presence of this knickpoint; the second knickpoint is individuated at an elevation of about 150m a.s.l., in this case there are no lithological variations or tectonic elements that is possible to recognize at this scale of investigation, so it should deserves more detailed analysis.

The SLI curve is characterized by very low values along almost the entire profile, with high peaks that are individuated just in correspondence of the two mentioned knickpoints, and with the occurrence of higher peaks in the lowermost reach of the long profile.

The basin are graph is characterized by a slow arise of the curve, with the only high jump that is individuated in the lowermost reach of the long profile, at about 4km from the beginning of the profile and that is due to an error in the dem that determines the false confluence of the Gravina di Matera river into the Gravina di Picciano river.

The slope/area analysis shows a concavity of 0.32, that is one of the lowest among all the Ionian rivers, and a steepness value of 25.20.

- Maglia river

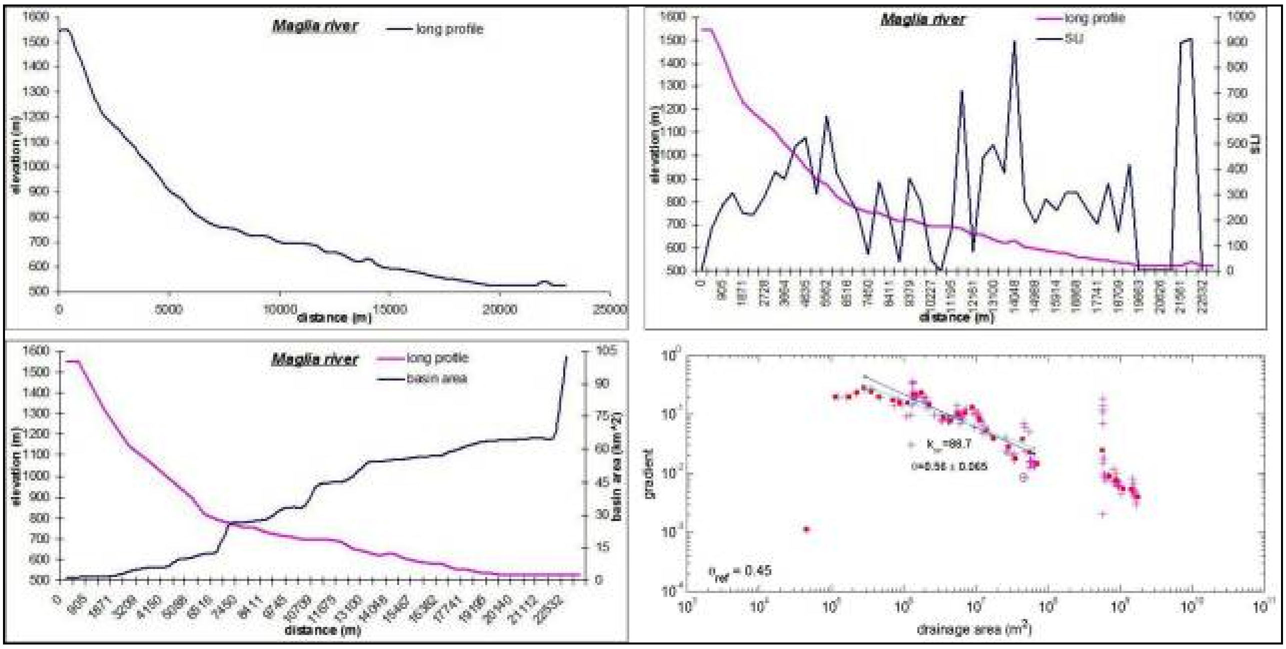


Fig. 4.49: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Maglia river.

The Maglia river springs on the Mt. Serra Grumenta, on the northeastern side of Sirino massif. It flows for about 25km before its confluence into the Agri river following a mean SW-NE direction, with little variations of direction, and in particular it follows a SSW-NNE direction in the first 15km and it then follows a SW-NE direction until its confluence with the Agri river.

The Maglia long profile has a concave upward shape, with the lack of knickpoints of relevance. It is anyway possible to recognize two slightly convex portion of the long profile: the first one is developed at an elevation comprises between 800m and 1200m a.s.l., in this area the Maglia river flows into the northern side of the Sirino massif, here there are several normal faults and thrust faults interesting the Lagonegro Units cropping out in this area, so this convex sector could be due either to the occurrence of the mentioned tectonic element or to a recent uplift that has interested the area; the second convex sector is developed at an elevation comprises between 700m and 600m a.s.l., this is a very complex area, with the occurrence of a tectonic contact between the Lagonegro Units and the North-Calabrian Units, and a stratigraphical contact of the Albidona Flysch with both the North-Calabrian Units and the Lagonegro Units, so probably this convex sector is due to the combination of a lithological and a tectonic control.

The SLI curve is characterized by the occurrence of several high peaks, which are mainly concentrated in the convex sector individuated on the long profile. There is an anomalous high peak in the lowermost reach of the profile, in correspondence of the confluence with the Agri river: this peak is probably due to an error in the dem because in this point the long profile seems to move towards higher elevations.

The basin area graph is characterized by a progressive growth of the curve, with the main jump that is individuated at about 7km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.56, that is one of the highest among all the Ionian rivers, and a Ks value of 88.70.

- Peschiera river

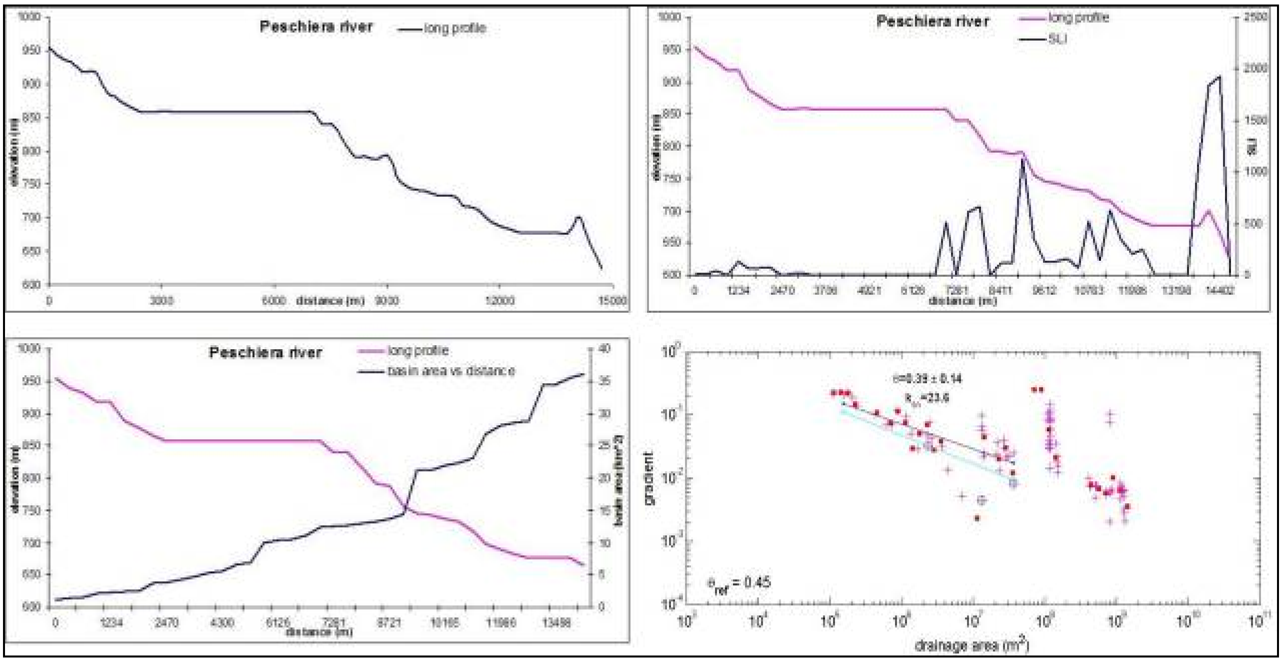


Fig. 4.50: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Peschiera river.

The Peschiera river springs about 3km east of the Mt. Zaccana, in the area close to the south-eastern portion of the Sant'Arcangelo basin, and it flows for about 15km until its confluence with the Frida river following a mean W-E direction, with several variations of direction along the entire course.

The Peschiera long profile shows a very articulated shape, it can be considered an almost rectilinear shape but it is characterized by the occurrence of several knickpoints: the first one, that is also the biggest knickpoint, is individuated at an elevation of about 850m a.s.l., in this area the river moves in a very lithologically heterogeneous context, with the passage from the quaternary sediments of the Sant'Arcangelo basin to the metamorphic Frida Units, so this knickpoint could be interpreted as due to this lithological variation; it is followed by the occurrence of other three smaller knickpoints that are individuated at an elevation of 840m , 800m and 730m a.s.l. and that are due to other lithological contrast between the local outcropping of the quaternary deposits of the Sant'Arcangelo basin and the metamorphic Frida Unit.

The SLI curve is characterized by very low values along most of the long profile, with the higher peaks that are individuated in the lowermost reach of the long profile: if we exclude the last peak that is located in the lowermost reach of the long profile and that is due to an error in the dem, the highest peaks are individuated in correspondence of the previously described knickpoints, it is interesting to notice that the biggest knickpoint don't correspond with the highest peak in the SLI curve.

The basin area curve is characterized by a progressive arise of the curve, that seems to proceeds almost in a constant way, with the main jumps that are individuated at about 9km and 12km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.39, which is lower than the average value among all the Ionian rivers, and a steepness value of 23.60.

- Racanello river

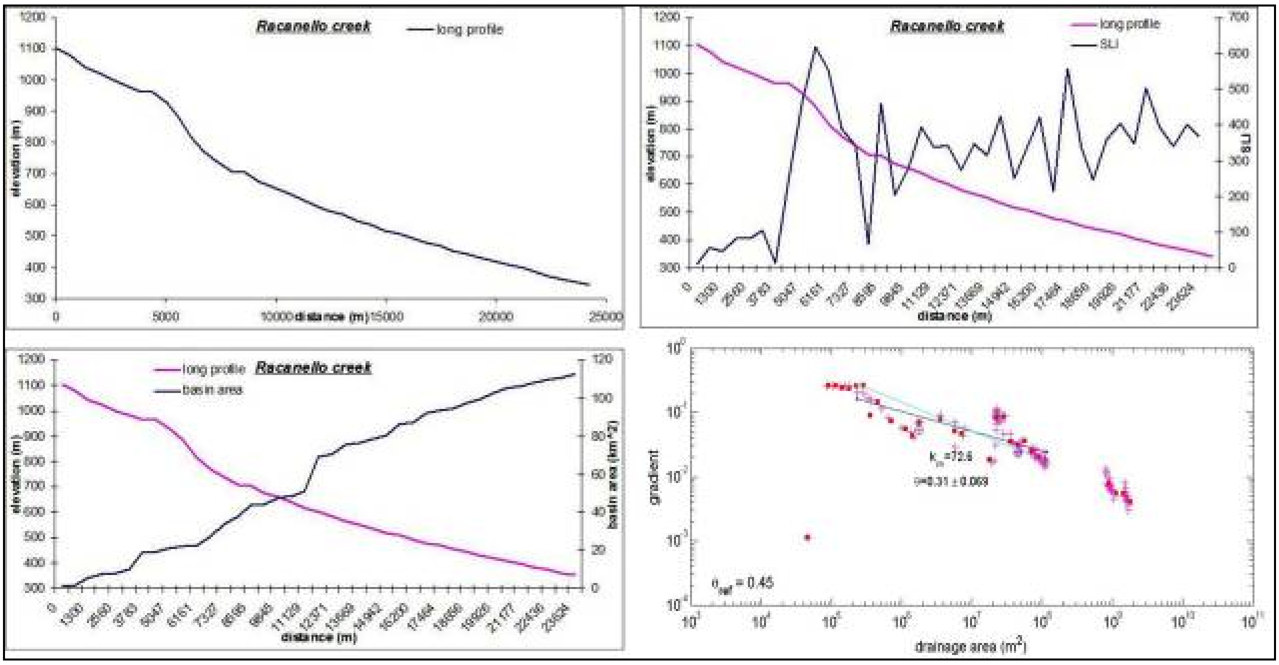


Fig. 4.51: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Racanello river.

The Racanello river springs east of the Mt. Raparo and it flows for about 25km before its confluence into the Agri river. Its course is characterized by several variations of direction, in particular in the first 4km the Racanello river follows a NNW-SSE direction, then it follows a W-E direction for the next 12km and it finally follows a S-N direction until its confluence with the Agri river.

The Racanello long profile shows a mean rectilinear shape, also if the profile can be separated in two different sectors, the first one comprised between 700m and 1100m a.s.l. and the second one that runs from the 700m a.s.l. until the confluence with the Agri river: in the first sector the long profile shows a slightly convex upward shape, this sector is individuated in a very complex portion of the Racanello valley because of the occurrence of Apennine carbonates and Lagonegro Units whose contact is tectonic, so the combination of the lithological control and the tectonic control results in this convex sector; in addiction to this, we have to consider that this sector is located on the north side of the Mt. Alpi, and that the thermochronological data suggest a recent uplift for this area (Mazzoli et al., 2006), that could have influenced also the Racanello long profile. In the second sector the Racanello long profile is clearly rectilinear, in this area the Racanello valley moves into the quaternary filling of the Sant'Arcangelo basin, recalling the shape that the Ionian rivers flowing into the foredeep show.

The SLI graph enhances the lack of a concave shape of the long profile, in particular in the uppermost reach of the curve the SLI values are very low, that then tend to progressively arise, with the highest peak that is reached in correspondence of the convex sector.

The basin area curve arises almost in a constant way, there is just one important jump that is located at a distance of about 12km from the beginning of the profile.

The slope/area analysis shows a concavity value of 0.31, that is one the lowest among all the Ionian rivers, and a steepness value of 72.60.

- Rubbio river

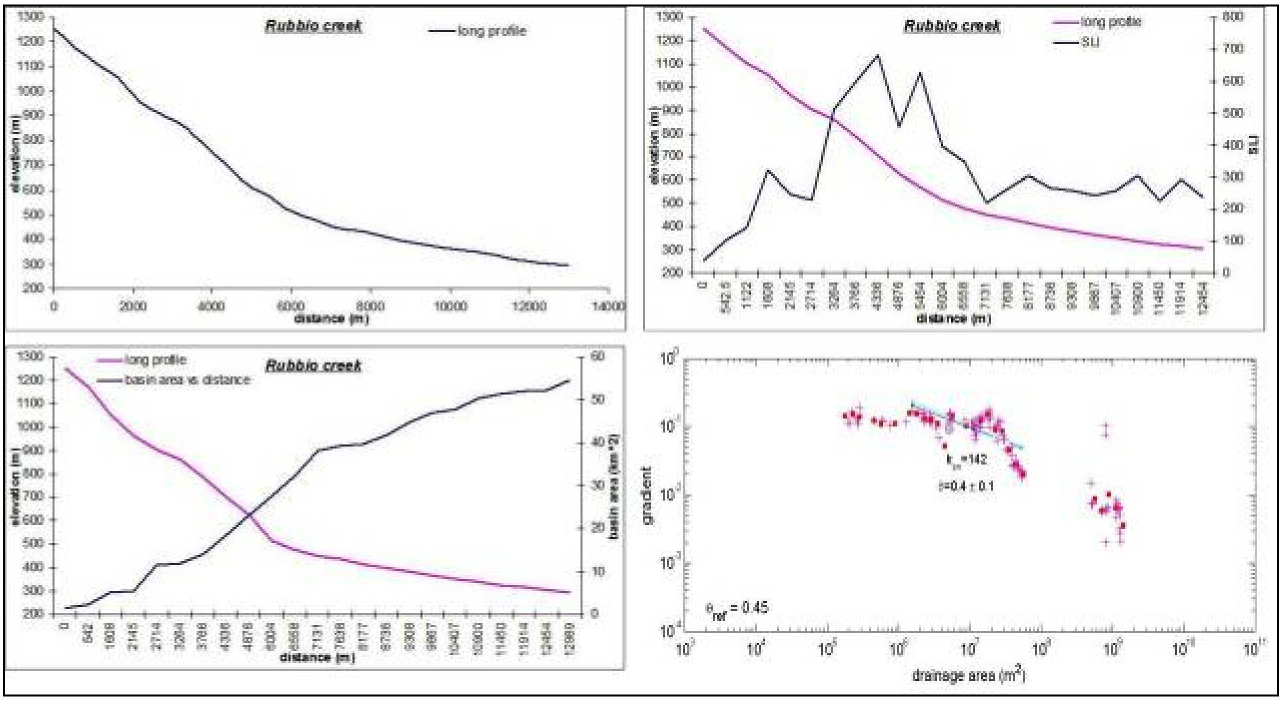


Fig. 4.52: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Racanello river.

The Rubbio river springs on the north side of the Pollino massif, it flows for about 15km before its confluence with the Sinni river. The Rubbio river follows a S-N direction along all its course, with no important variation of direction.

The Rubbio long profile shows a slightly concave upward shape. The long profile can be anyway separated in two different sectors: the first one is individuated at an elevation comprises between 800m and 1300m a.s.l., it has a rectilinear shape and it is located in an area characterized by the tectonic contact between the Liguridi Units and the North-Calabrian units, with the occurrence of two knickpoints at an elevation of 1050m and 850m a.s.l. that are due to the combination of both a lithological and tectonic control; the second sector is individuated at an elevation comprises between 800m and 300m a.s.l., this sector shows a slightly concave up shape, the Rubbio river flows on the North-Calabrian Units in the first 3km and it flows into the quaternary filling of the Sant'Arcangelo basin in the last 7km.

The SLI graph has a general increasing trend, which is typical of long profile that are convex or that looks rectilinear, with the highest peak that is located in correspondence of the second knickpoint at the end of uppermost reach.

The basin area curve looks almost straight, enhancing the lack of big tributaries.

The slope/area analysis shows a concavity value of 0.40, very close to the medium value of all the Ionian rivers, and a Ks index of 142 that is the highest value in all the Southern Apennines.

- Sarmento river

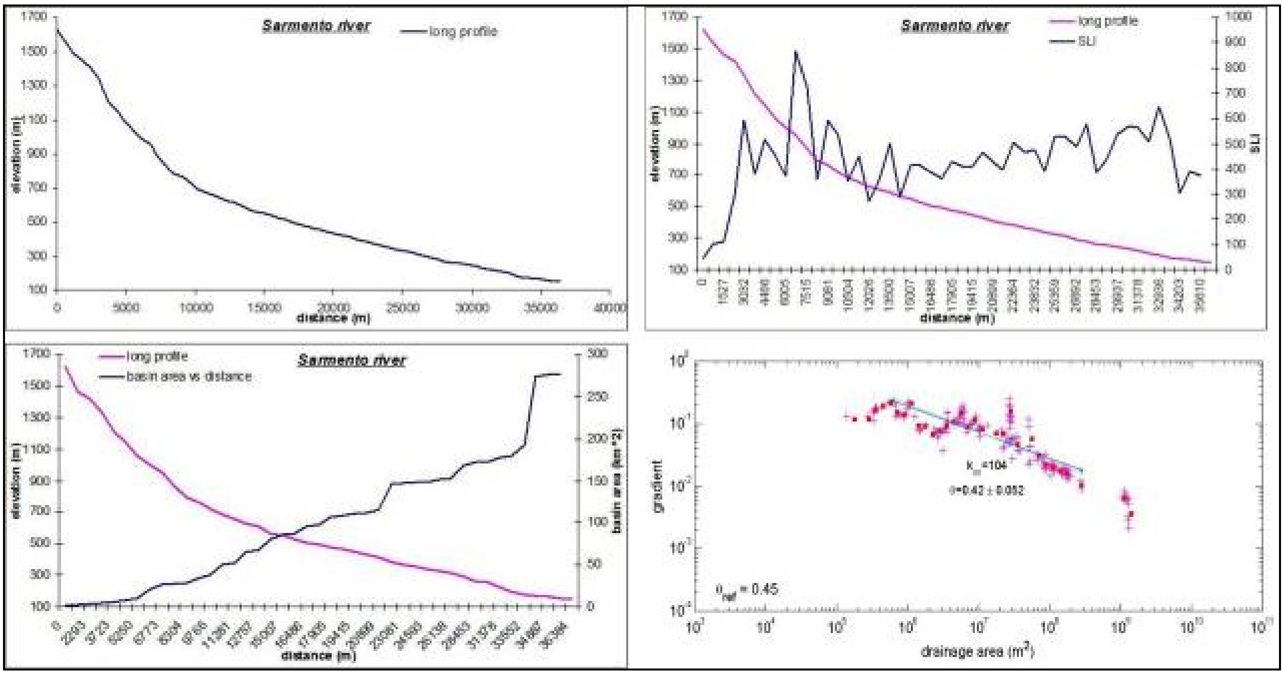


Fig. 4.53: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Sarmento river.

The Sarmento river springs on the NE side of the Pollino massif, it flows for about 40km before its confluence with the Sinni river. Its course is characterized by several variations of direction, in particular in the first 12km it follows a WSW-ENE direction, it then follows a S-N direction in the following 9km, and it finally follows a SW-NE direction until its confluence with the Sinni river.

The Sarmento long profile shows a concave upward shape, but it is possible to recognize two different sectors: the first one is individuated at an elevation comprises between 700m and 1500m a.s.l., it has a rectilinear shape that is close to a slightly convex upward shape, this sector is individuated in an very complex area from a tectonic and lithological point of view, with the occurrence of tectonic contact between the Liguridi Units and the North-Calabrian Units and between the North-Calabrian Units and the Albidona Flysch, and with the occurrence of several normal faults interesting the North-Calabrian Units too, so this slightly convex sector, where a few knickpoints could be individuated, is probably due to the combination of a tectonic and lithological control (this situation has also been recognized in the upper reach of the Rubbio profile, and we have to remember that the Sarmento and the Rubbio valleys are adjacent); the second sector is characterized by a more rectilinear shape, it is developed in the area where the Sarmento valley moves into the quaternary deposits of the Sant'Arcangelo basin, recalling the shape of the Racanello and the Rubbio rivers when they flow into the same deposits.

The SLI curve has a general increasing trend, with the highest peaks individuated in the lowermost portion of the slightly convex sector, in correspondence of one of the knickpoints that have been individuated in this area: the curve recall the increasing trend typical of the non concave upward long profiles.

The basin area curve arise almost in a constant way, with no important jumps, except that for one jump located at a distance of 22km from the beginning of the profile, in the lowermost portion of the long profile.

The slope/area analysis shows a concavity value of 0.42 that is very close to the medium value of all the Ionian rivers, and a steepness index of 104.

- Sauro river

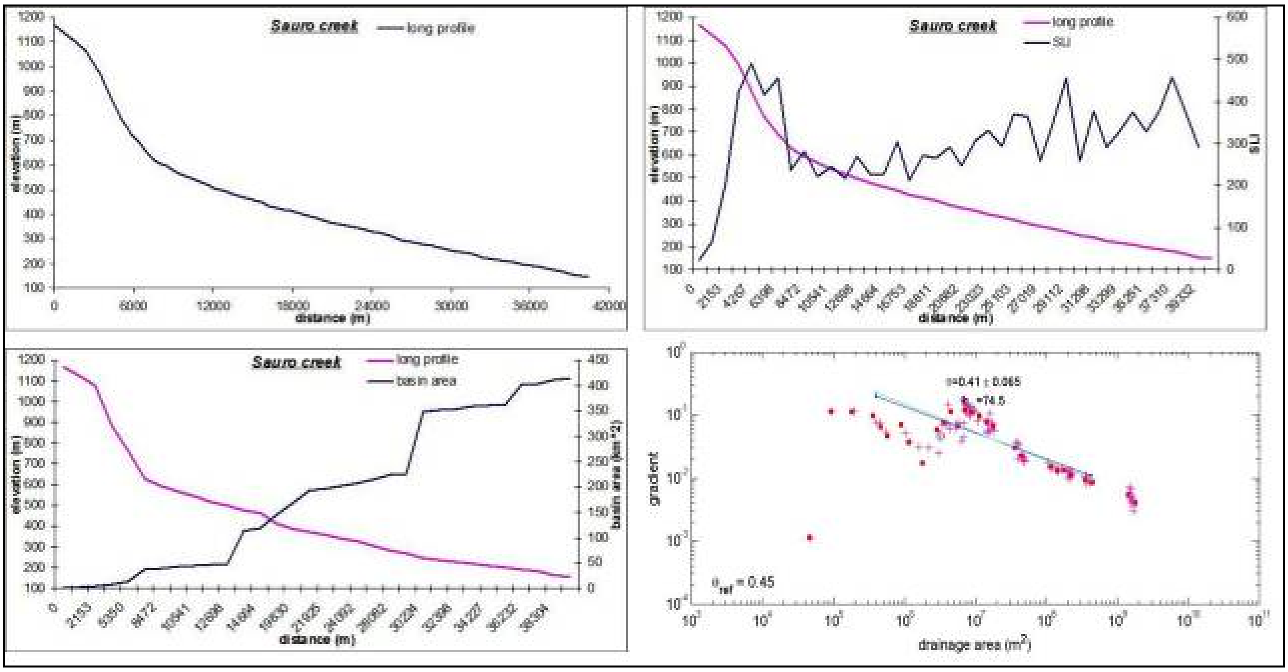


Fig. 4.54: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Sauro river.

The Sauro river springs on the Mt. Caldarosa, on the outer flank of the Southern Apennines, and it flows for about 40km before its confluence with the Agri river. The Sauro river follows a mean WNW-ESE direction, with no important variation of direction, except that for a W-E oriented sector located in the first 5km of the Sauro valley.

The Sauro long profile has a general concave upward shape, but it can be separated in two different sectors: the first one is comprised between 600m and 1200m a.s.l., in this sector the long profile shows a clear convex upward shape, here the Sauro long profile moves entirely into the Sicilidi Units, with the Lagonegro Units cropping out just in a narrow area, so this convex sector is probably related to a recent uplift that could have affected this area; the second sector moves from 500m a.s.l. to the confluence with the Agri river (150m a.s.l.) and it is characterized by a rectilinear shape, in the first 3km of this sector the Sauro valley moves into the Sicilidi Units while it flows into the quaternary filling of the Sant'Arcangelo basin for the remaining part of the profile, recalling the shape of the Racanello, Rubbio and Sarmento rivers when they flow into the same deposits.

The SLI curve shows a general increasing trend, with the highest peak that is located in correspondence of the convex sector, an increasing trend that is typical for the Ionian rivers with a rectilinear long profile.

The basin area graph is characterized by two main jumps, that are individuated at a distance of about 12km and 30km from the beginning of the profile, the second one of which is due to the confluence with the Gorgoglione river.

The slope/area analysis shows a concavity value of 0.41, very close to the average value of all the Ionian rivers, and a steepness value of 74.50.

- Serrapotamo river

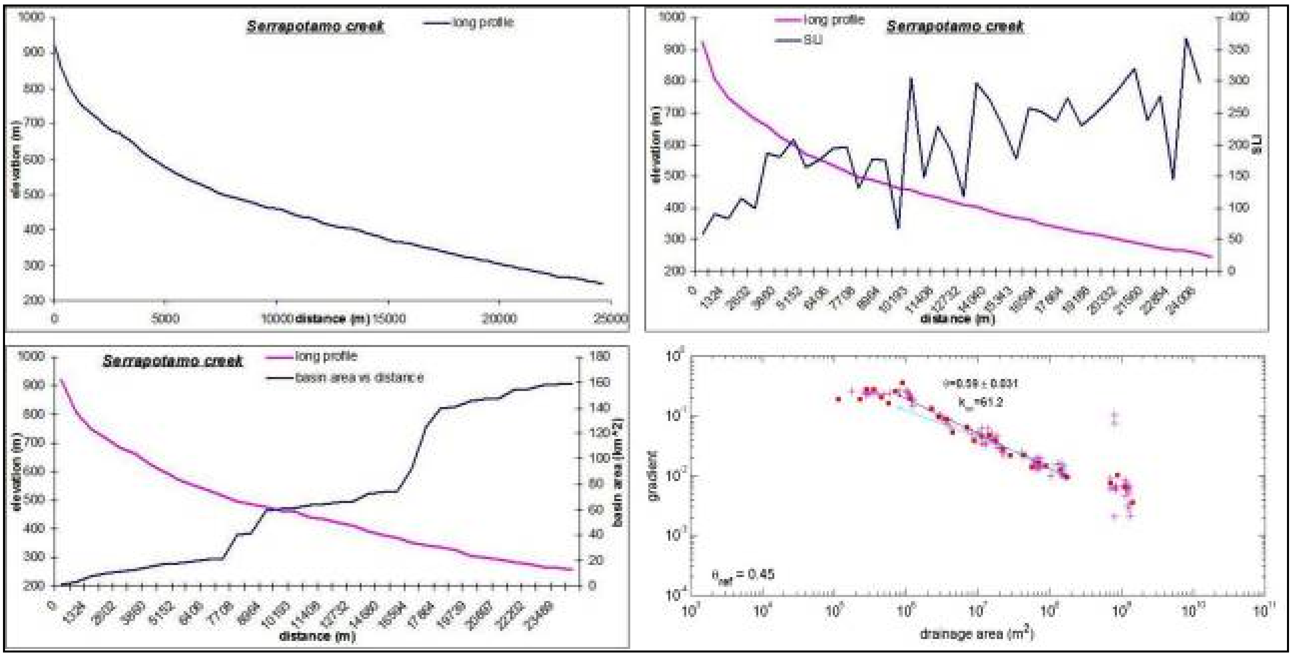


Fig. 4.55: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Serrapotamo river.

The Serrapotamo river springs on the Mt. Asprello, which is located west of the Mt. Alpi, it flows for about 25km before its confluence with the Sinni river (the Serrapotamo river is the main tributary on the idrographic right of the Sinni river), and its course follows a W-E direction with no relevant variations of direction.

The Serrapotamo long profile is almost perfectly rectilinear, with the lack of relevant knickpoints, it is anyway possible to recognize two different sectors: the first one moves from 650m and 900m a.s.l. and it has a slightly concave upward shape, in this sector the Serrapotamo moves into the Albidona flysch and there are no tectonic elements of relevance; the second sector moves from 650m a.s.l. until the confluence with the Sinni river (250m a.s.l.) and it is characterized by a rectilinear shape, in this sector the profile moves into the quaternary filling of the Sant'Arcangelo basin, recalling the rectilinear shape that all the Ionian rivers flowing into this deposits show.

The SLI graph is characterized by a general increasing trend, with the SLI values that are very low in the first concave upward sector, and that then becomes greater as the profile moves into the second sector, this type of curve is similar to all the other rivers with a rectilinear or convex upward shape.

The basin area graph is characterized by the occurrence of two major jumps, that are located at about 7km and 17km respectively and that are due to the confluence with the Il Vallone creek and the Fosso di Castronuovo river.

The slope/area analysis shows a concavity value of 0.59, that is the highest value among all the Ionian rivers, and a steepness value of 61.20.

- Sinni river

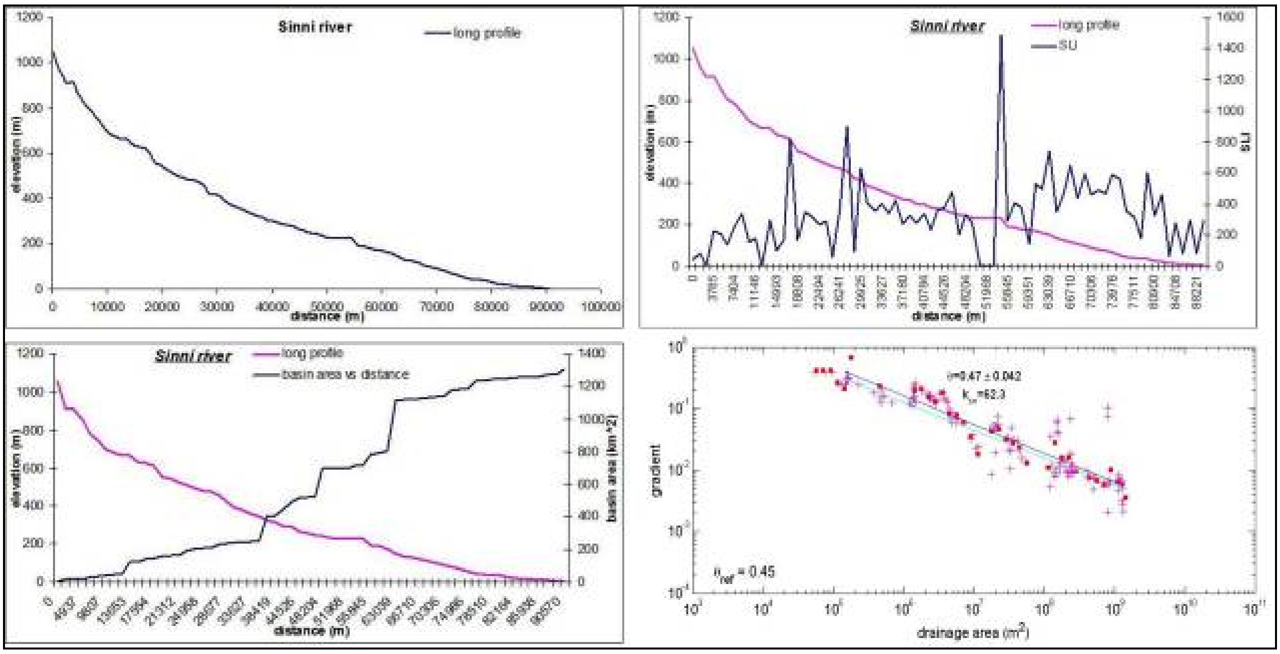


Fig. 4.56: longitudinal profile, SLI, drainage area vs distance and slope/area graphs of the Sinni river.

The Sinni river springs on the north side of the Sirino massif, it flows for about 100km before it reaches the Ionian sea; its course is characterized by several variation of direction, in particular the Sinni follows a N-S direction in the first 8km, it then follows a WSW-ENE direction for the following 50km until the Nocara ridge; as the Sinni crosses the Nocara ridge it follows a NW-SE direction in the first 5km and it then follows a SW-NE direction for the next 13km, while in the last 15km the Sinni follows a NW-SE direction.

The Sinni long profile shows a slightly concave upward shape, which is very close to a rectilinear shape. The long profile is characterized by the occurrence of 4 knickpoints: the first one is located at an elevation of about 900m a.s.l. and it is related to the presence of a normal fault, NW-SE oriented, that interests the Lagonegro Units; the second one is located at an elevation of about 600m a.s.l., this knickpoint is individuated in the portion of the Sinni valley immediately south of the Mt. Alpi, an Apulian carbonate relief bordered by normal faults, so this knickpoint could be related to the activity of this normal fault; the third knickpoint is individuated at an elevation of about 450-400m a.s.l., in this area there is the stratigraphical contact between the quaternary deposits of the Sant'Arcangelo basin and the Liguridi units, so this knickpoint is probably due to this lithological contrast between the two mentioned units; the fourth knickpoint is a false knickpoint because it is due to the presence of a dam.

The SLI graph shows the highest peaks in correspondence of the previously analyzed knickpoints; in particular it is interesting to notice that the first knickpoint doesn't correspond to a peak in the SLI curve, while the highest peak in the curve is individuated in correspondence of the false knickpoint. It is also interesting to notice that in the area downstream the false knickpoint, where the Sinni river crosses the Nocara ridge and it then flows into the foredeep deposits, the SLI values are higher than in the upstream portion of the profile (except that for the areas where the knickpoints are located).

The basin area curve is characterized by five major jumps that are due to the confluence of the Cogliandrino, Frida, Rubbio, Serrapotamo and Sarmento rivers as the profile moves downstream.

The slope/area analysis shows a concavity value of 0.47, that is pretty high considering the almost rectilinear shape of the long profile, and a Ks value of 62.30.

4.2 RESULTS

4.2.1 Morphological analysis of the river long profiles

River long profiles in the Southern Apennines are very different if we consider the Tyrrhenian, Adriatic and Ionian flank: the long profiles of the main rivers of the three different sectors are shown in fig. 4.57.

The Tyrrhenian rivers show a clear concave upward long profiles, in particular, if we just consider the main trunks, the concave upward shape is very clear for both the Volturno and the Sele rivers: in particular the Volturno river long profile doesn't present any evidence of knickpoints, while the Sele long profile presents a small convexity at an elevation comprises between 1000m a.s.l. and 500m a.s.l., in the upper part of its course, where it flows through the Picentini ridge, and another convex sector at an elevation comprises between 200m a.s.l. and 100m a.s.l.: this area corresponds with the high Sele valley, close to town of Contursi, that is an area characterized by active tectonic as testified by previous papers (Ascione et al., 2003), so this convex part of the Sele long profile is probably due the presence of an active fault in this area.

The Adriatic rivers long profiles are characterized by different shapes, that are anyway very different if compared to the Tyrrhenian rivers: in particular, there are long profiles with a clear rectilinear shape (Ofanto river), other long profiles with a less enhanced rectilinear shape (Carapelle river, in both cases there are no evident knickpoints along the whole profiles), and there are long profiles (Fortore river) with a shape that is close to those one of the Ionian rivers, with a concave upward shape that is less enhanced if compared to the Tyrrhenian rivers and with the presence of several knickpoints (in the case of the Fortore river such knickpoints are individuated at an elevation comprises between 300 and 500 meters).

The Ionian rivers (Agri, Bradano, Basento and Sinni) show longitudinal profiles with a shape that is in the middle between the two previously analyzed sectors, with a concave upward shape that is not so pronounced for the Sinni, whose shape is close to a rectilinear one, and with the presence of knickpoints that are in some cases due to lithological variations (such as in the case of the lowest knickpoint of the Basento river that is due to the contact of the Lagonegro Unit with the Numidian Flysch), while in other cases are due either to normal faults (such as in the case of the knickpoint individuated on the Sinni long profile and that is located in correspondence of the west side of the Mt. Alpi, that is a fault scarp with a high angle normal fault previously described in recent papers, Mazzoli et. al, 2006) or to thrust faults (knickpoint along the Basento river located in correspondence of a back-thrust of the Sicilidi Unit on the Lagonegro Unit).

It is also interesting to notice that all the Ionian rivers flowing into the quaternary filling of the Sant'Arcangelo basin (Sinni, Serrapotamo, Sauro, Sarmento, Racanello and Agri rivers) and flowing into the quaternary deposits of the Bradanic foredeep (Sinni, Racanello, Bradano, Basento, Basentello and Agri rivers) change their shape and their long profiles look almost perfectly rectilinear as they flow into these quaternary deposits. In addiction, we want to point the attention on the highest reach of the Basentello river: this reach is located in correspondence of the Lavello High (a morphostructural high separating the Puglia basin from the Lucanian basin, Balduzzi et al, 1982) and the Basentello long profile looks convex upward, so this convexity could be related to the uplift of this morphostructural high.

We also want to point the attention on the Agri long profile: in this case the only knickpoint is due to the presence of a dam but, if we don't consider the dam, we see that this part of the profile is clearly convex upward, this shape suggest that a recent uplift affected this part of the Agri basin, a data that is in agreement with the elevation of the river terraces, that are at higher elevation in this part of the profile than in the portion of the long profile immediately upstream the knickpoint.

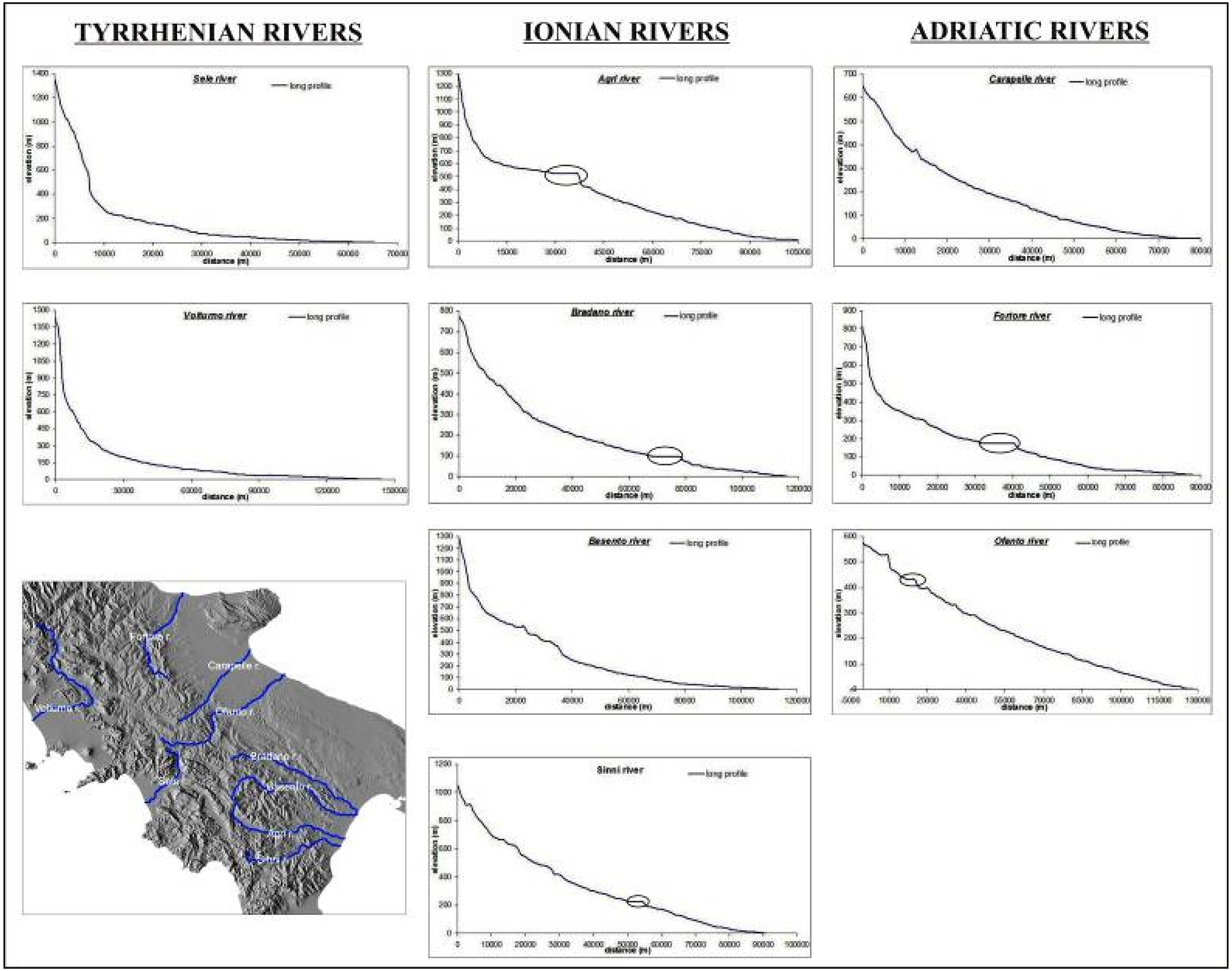


Fig. 4.57: long profile of the main rivers of the Southern Apennine, the knickpoints highlighted by the circle are due to the presence of a dam.

4.2.2 Analysis of the concavity and steepness indexes

We analyzed fifty-two rivers, both main trunks and tributaries, so distributed along all the Southern Apennines chain: 23 rivers are located on the Tyrrhenian side, 17 of them are located on the Ionian side and 12 of them are located on the Adriatic side (see fig. 4.1): the drainage areas range from a minimum of 37.55 km^2 for the Peschiera river (Ionian side) to a maximum of 6042.82 km^2 for the Volturno river (Tyrrhenian side), while the length of the analyzed rivers range from a minimum of 13.33 km for the Cogliandrino river (Ionian side) to a maximum of 168.34 km for the Volturno river (Tyrrhenian side).

The Θ and Ks values we obtained are shown in table 4.4. We separately analyzed the three sectors in which we subdivided the Southern Apennines, considering first the whole data we obtained and then analyzing separately the main trunks from the main channels. The concavity index shows little differences between the three sectors, with the Tyrrhenian rivers showing the highest mean value (with a value of 0.52) and the Ionian rivers showing the lowest mean values (with a value of 0.43), while the Adriatic rivers show a mean value that is in the middle between the two previous sectors (with a value of 0.48). The Ks index shows more relevant differences between the three sectors, with the Tyrrhenian rivers showing the highest value (with a mean value of 73.52), while the lowest values are reached by the Adriatic rivers (with a value of 42.53) and with the Ionian rivers lying between the two previous sectors(with a mean value of 66.43).

In table 4.5 we have analyzed the main trunks and their tributaries separately. In this case, if we just consider the main trunks, we have the highest concavity for the Tyrrhenian rivers (with a mean value of 0.58), the lowest concavity for the Adriatic rivers (with a mean value of 0.45), while the Ionian rivers show a mean value of 0.48 that is in between the two previous one. Considering the main tributaries, the concavity index is the highest for the Tyrrhenian channels (with a mean value of 0.48) and it is the lowest for the Ionian channels (with a mean value of 0.40), while the Adriatic channels show a mean value of 0.46 that is very close to the Tyrrhenian one. If we consider the steepness index of the main trunks we have the highest value for the Tyrrhenian rivers (with a mean value of 90.04), a lower value for the Ionian rivers (with a mean value of 50.9) and the lowest value for the Adriatic rivers (with a mean value of 41.36). The Ks index of the main channels is instead higher for the Ionian channels (with a mean value of 74.9) and lower for the Adriatic channels (with a mean value of 43.9), while the Tyrrhenian channels show a mean value of 57.74.

We have also created the map of the Ks index of the Southern Apennine rivers: it is shown in fig. 4.58. In this map (considering the range of values that have been automatically calculated by Arcmap) we have to point out the attention on the location of the red values along the rivers, which are the highest values and that correspond with the location of the knickpoints along every single river. A few consideration can be done about this map:

- if we consider the north side of the Southern Apennines, here the highest Ks values are reached just in the up-stream portion of the Volturno and Vandra rivers;
- in the area delimited by the Matese ridge and Roccamonfina volcano to the north-west, the Gargano peninsula to the north-east, the Murge to the south-east and the north side of the Picentini ridge to the south-west, there are no significant peaks in the Ks values, that seem to be almost constant, except that for some isolated high values along the Ufita and Tammaro rivers;
- the highest values of the Ks index are obtained in the southern portion of the chain, in particular there are several high values along the Sele and Tusciano river (and in particular when they flow through the Picentini ridge), along the Platano, Melandro and Tanagro rivers (in the sector where they flow through the southern side of the Marzano ridge, the northern side of the Maddalena mountains ridge and the medium Tanagro river valley), in the Cilento region (along the Mingardo, Lambro and Bussento rivers), in the middle part of the Noce river valley and the Mercure river valley, on the north side of the Pollino ridge (upper reaches of the Mercure

river valley, Frida, Peschiera, Rubbio and Sarmento rivers), in the upstream areas of the Sinni and Maglia rivers (north side of the Mt. Sirino), on the southern side of the Mt. Raparo (Racanello river) and the Mt. Alpi (Sinni river), along the medium Basento river valley (downstream the confluence with the Camastra river, on the east side of the Pliocene basin of Calvello) and along the Agri river in the area comprises between the high Agri river valley and the Sant'Arcaneglo basin, where the Agri river cuts a gorge into the bedrock, here represented by the Gorgoglione Flysch.

Tyrrhenian rivers					
Id	river	Θ	Ks	L (km)	Drainage area (km^2)
1	Alento	0.66	47.00	32.62	413.25
2	Bussento	0.39	127.00	34.04	347.22
3	Calore	0.54	61.00	25.59	99.12
4	Calore_beneventano	0.61	55.20	108.40	3073.77
5	Calore_salernitano	0.47	75.20	57.97	667.10
6	Forra_di_muro	0.38	56.40	18.01	104.04
7	Forra_di_tito	0.58	63.30	25.17	145.37
8	Lambro	0.66	122.00	21.24	75.99
9	Melandro	0.43	66.40	37.01	287.29
10	Mercure	0.58	111.00	50.70	587.59
11	Mingardo	0.60	101.00	39.82	231.97
12	Miscano	0.49	55.80	33.78	729.54
13	Noce	0.32	83.30	46.99	321.46
14	Platano	0.39	51.60	41.86	321.17
15	Sabato	0.49	46.30	54.28	403.07
16	Sarno	0.95	64.20	21.89	485.19
17	Sele	0.67	98.70	72.38	2756.86
18	Solofrana	0.73	61.10	38.49	299.72
19	Tammaro	0.43	41.00	65.46	672.77
20	Tusciano	0.29	83.20	33.42	195.31
21	Ufita	0.38	44.50	43.93	469.59
22	Vandra	0.31	72.80	32.11	371.00
23	Volturno	0.72	103.00	168.34	6042.89
	maximum	**0.95**	**127.00**		
	mean	**0.52**	**73.52**		
	minimum	**0.29**	**41.00**		

Ionian rivers					
id	river	Θ	Ks	L (km)	Drainage area (km^2)
36	Agri	0.50	55.60	118.22	1675.61
37	Basentello	0.23	31.80	52.68	433.62
38	Basento	0.48	62.10	139.21	1549.92
39	Bradano	0.51	42.90	130.64	3050.09
40	Camastra	0.40	68.70	29.38	361.42
41	Cavone	0.58	57.30	77.94	642.88
42	Cogliandrino	0.32	35.80	13.33	61.54
43	Frida	0.34	121.00	28.55	149.43
44	Gravina_di_picciano	0.32	25.20	61.94	913.87
45	Maglia	0.56	88.70	23.81	69.04
46	Peschiera	0.39	23.60	15.20	37.55
47	Racanello	0.31	72.60	24.53	114.13
48	Rubbio	0.40	142.00	13.90	53.46
49	Sarmento	0.42	104.00	38.67	282.99
50	Sauro	0.41	74.50	43.42	425.22
51	Serrapotamo	0.59	61.20	26.93	161.06
52	Sinni	0.47	62.30	101.35	1309.05
	maximum	**0.59**	**142.00**		
	mean	**0.43**	**66.43**		
	minimum	**0.23**	**23.60**		

Adriatic rivers					
id	river	Θ	Ks	L (km)	Drainage area (km^2)
24	Biferno	0.52	68.80	98.02	1313.06
25	Candelaro	0.52	8.83	69.96	2263.53
26	Carapelle	0.49	48.30	80.41	895.99
27	Celone	0.54	48.00	68.44	326.24
28	Cervaro	0.33	37.50	105.66	645.33
29	Forra_di_venosa	0.47	33.40	34.31	441.60
30	Fortore	0.48	52.00	101.19	1601.08
31	Fosso_di_stroppito	0.63	64.40	28.03	301.41
32	Locone	0.30	26.00	34.52	287.79
33	Ofanto	0.34	32.70	149.65	2773.96
34	Tappino	0.36	47.70	34.66	401.08
35	Vulgano	0.79	42.70	56.74	609.89
	maximum	**0.79**	**68.80**		
	mean	**0.48**	**42.53**		
	minimum	**0.30**	**8.83**		

Tab. 4.4: Θ and Ks values for all the analyzed rivers

MAIN TRUNKS

Tyrrhenian rivers

river	Θ	Ks	L (km)	Drainage area (km^2)	max Θ	max Ks
Alento	0.66	47.00	32.62	413.25	0.95	127.00
Bussento	0.39	127.00	34.04	347.22	**mean Θ**	**mean Ks**
Lambro	0.66	122.00	21.24	75.99	0.58	94.04
Mercure	0.58	111.00	50.70	587.59	**min Θ**	**min Ks**
Mingardo	0.60	101.00	39.82	231.97	0.29	47.00
Noce	0.32	83.30	46.99	321.46		
Sele	0.67	98.70	72.38	2756.86		
Sarno	0.95	64.20	21.89	485.19		
Tusciano	0.29	83.20	33.42	195.31		
Volturno	0.72	103.00	168.34	6042.89		

Ionian rivers

river	Θ	Ks	L (km)	Drainage area (km^2)	max Θ	max Ks
Agri	0.50	55.60	118.22	1675.61	0.58	62.30
Basento	0.48	62.10	139.21	1549.92	**mean Θ**	**mean Ks**
Bradano	0.51	42.90	130.64	3050.09	0.48	50.90
Cavone	0.58	57.30	77.94	642.88	**min Θ**	**min Ks**
Gravina_di_picciano	0.32	25.20	61.94	913.87	0.32	25.20
Sinni	0.47	62.30	101.35	1309.05		

Adriatic rivers

river	Θ	Ks	L (km)	Drainage area (km^2)	max Θ	max Ks
Biferno	0.52	68.80	98.02	1313.06	0.52	68.80
Candelaro	0.52	8.83	69.96	2263.53	**mean Θ**	**mean Ks**
Carapelle	0.49	48.30	80.41	895.99	0.45	41.36
Cervaro	0.33	37.50	105.66	645.33	**min Θ**	**min Ks**
Fortore	0.48	52.00	101.19	1601.08	0.33	8.83
Ofanto	0.34	32.70	149.65	2773.96		

MAIN TRIBUTARIES

Tyrrhenian rivers

river	Θ	Ks	L (km)	Drainage area (km^2)	max Θ	max Ks
Calore	0.54	61.00	25.59	99.12	0.73	75.20
Calore_beneventano	0.61	55.20	108.40	3073.77	**mean Θ**	**mean Ks**
Calore_salernitano	0.47	75.20	57.97	667.10	0.48	57.74
Forra_di_muro	0.38	56.40	18.01	104.04	**min Θ**	**min Ks**
Forra_di_tito	0.58	63.30	25.17	145.37	0.31	41.00
Melandro	0.43	66.40	37.01	287.29		
Miscano	0.49	55.80	33.78	729.54		
Platano	0.39	51.60	41.86	321.17		
Sabato	0.49	46.30	54.28	403.07		
Solofrana	0.73	61.10	38.49	299.72		
Tammaro	0.43	41.00	65.46	672.77		
Ufita	0.38	44.50	43.93	469.59		
Vandra	0.31	72.80	32.11	371.00		

Ionian rivers

river	Θ	Ks	L (km)	Drainage area (km^2)	max Θ	max Ks
Basentello	0.23	31.80	52.68	433.62	0.59	142.00
Camastra	0.40	68.70	29.38	361.42	**mean Θ**	**mean Ks**
Cogliandrino	0.32	35.80	13.33	61.54	0.40	74.90
Frida	0.34	121.00	28.55	149.43	**min Θ**	**min Ks**
Maglia	0.56	88.70	23.81	69.04	0.23	23.60
Peschiera	0.39	23.60	15.20	37.55		
Racanello	0.31	72.60	24.53	114.13		
Rubbio	0.40	142.00	13.90	53.46		
Sarmento	0.42	104.00	38.67	282.99		
Sauro	0.41	74.50	43.42	425.22		
Serrapotamo	0.59	61.20	26.93	161.06		

Adriatic rivers

river	Θ	Ks	L (km)	Drainage area (km^2)	max Θ	max Ks
Celone	0.54	48.00	68.44	326.24	0.63	64.40
Forra_di_venosa	0.47	33.40	34.31	441.60	**mean Θ**	**mean Ks**
Fosso_di_troppito	0.63	64.40	28.03	301.41	0.46	43.90
Locone	0.30	26.00	34.52	287.79	**min Θ**	**min Ks**
Tappino	0.36	47.70	34.66	401.08	0.30	26.00

tab. 4.5: Θ and Ks indexes for the main trunks and their tributaries.

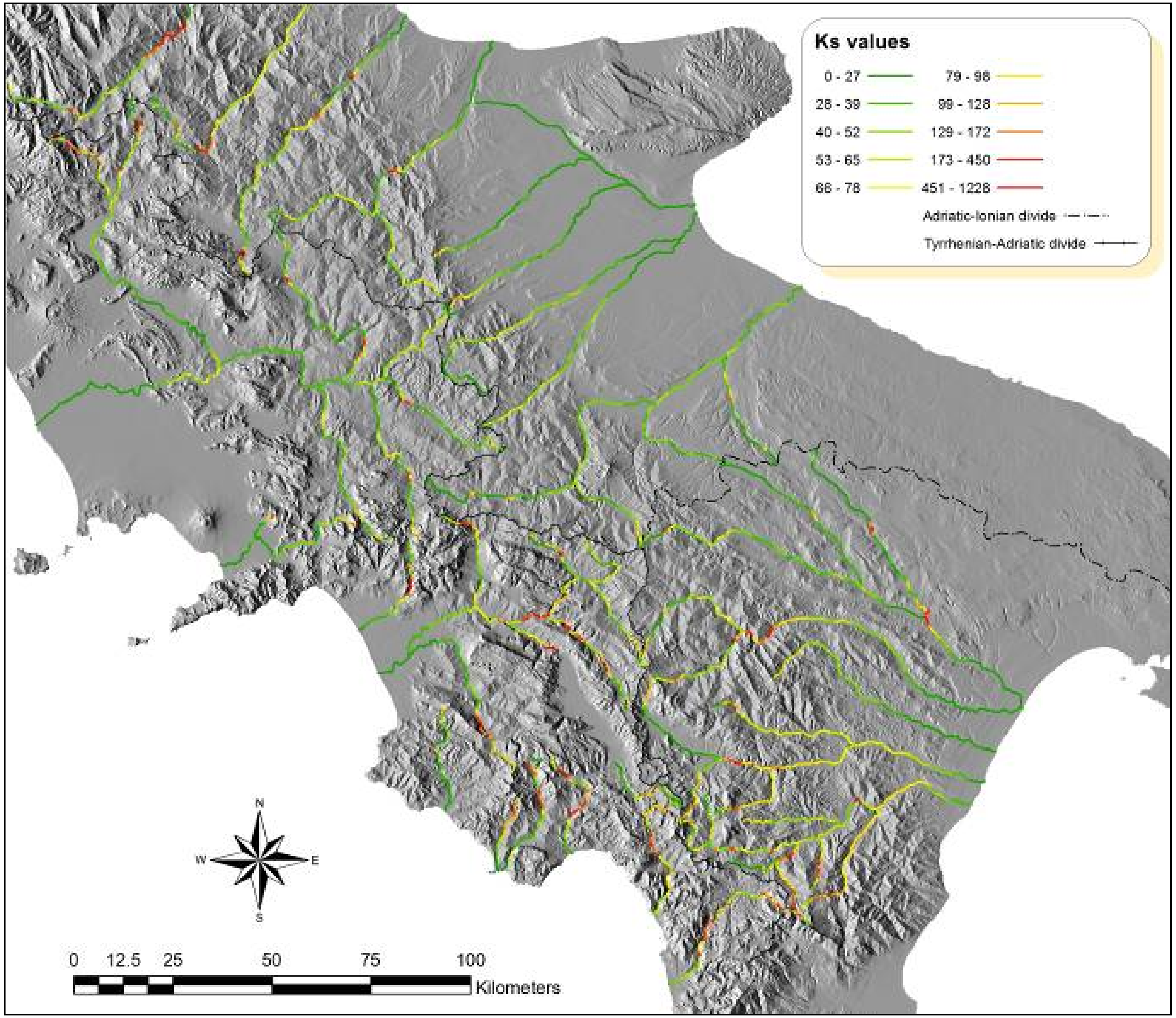


Fig. 4.58: "Ks Map of the Southern Apennines". The classes in which the Ks values have been subdivided have been automatically calculated by Arcgis 9.2: to read the map you just have to consider the location of the red classes that show the higher values and whose location corresponds in all the cases with the location of a knickpoint along the considered river.

4.3 DIVIDE AND MAXIMUM ELEVATION LINE LOCATION

The location of the divide and the maximum elevation line is shown in fig. 3.18, it is one of the most relevant feature to observe in the Southern Apennines: in fact the two lines don't run together, with the divide that is shifted towards the east in comparison to the maximum elevation line that, on other hand, is very close to the Tyrrhenian coast, giving the typical asymmetrical topographic profile to the chain.

If we compare the Southern Apennines chain with the Calabrian Arc and the Central Apennines chain, we notice how the location of the divide and the maximum elevation line is very different in the three sectors: in particular, in the Central Apennines the divide is located west of the maximum elevation line, in the Southern Apennine the divide is located east of the maximum elevation line, while in the Calabrian Arc the two lines are almost perfectly coincident (Amato et al., 1995).

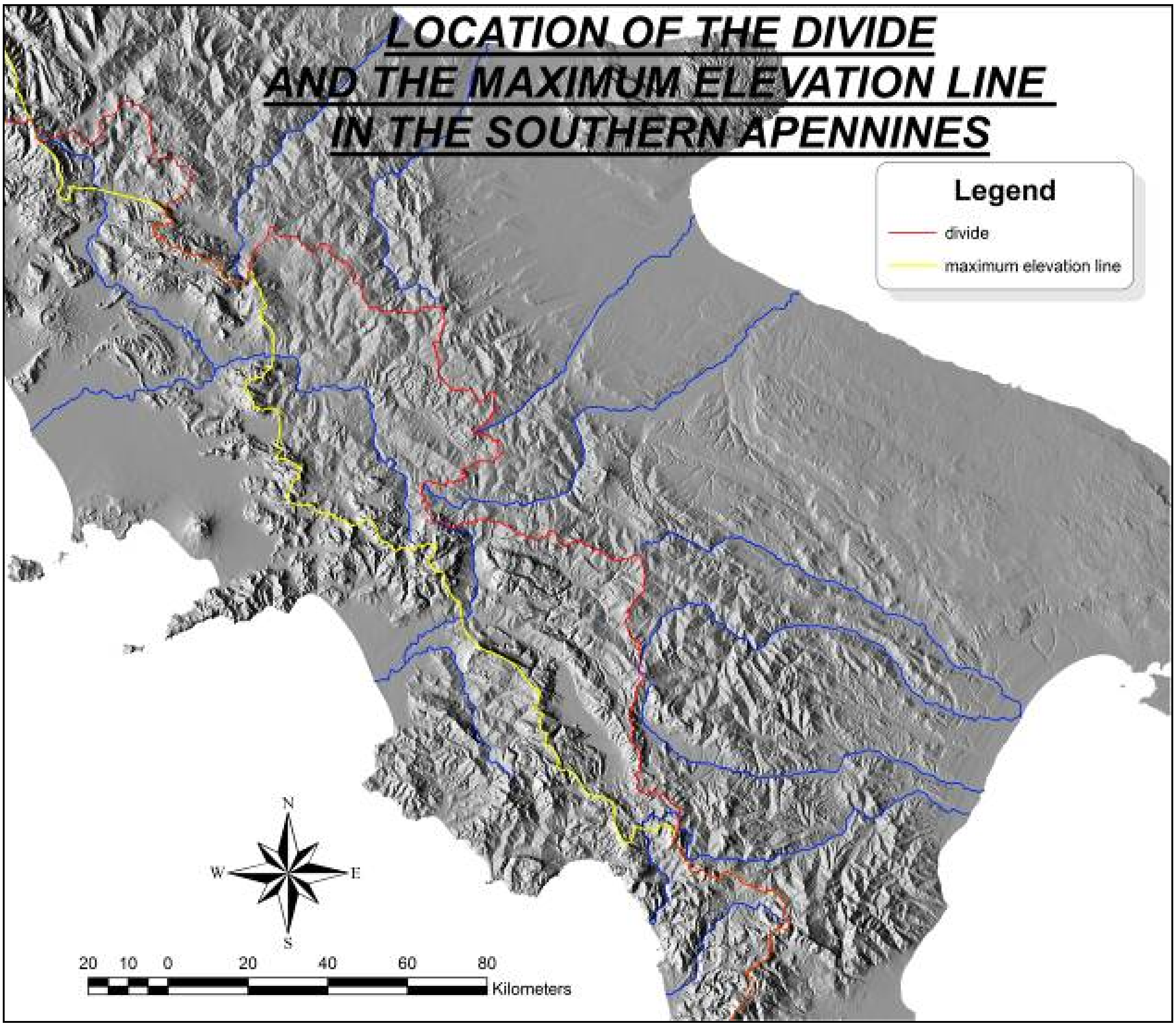


Fig. 3.18 : location of the divide and the maximum elevation line in the Southern Apennines.

The divide run between 600m a.s.l. and about 2000m a.s.l. (Matese massif and Mt. Sirino), there are no relationships between the location of the divide and the lithologies, in fact it moves both on the Apennine carbonate than on the external flysch and the Lagonegro units, while the maximum elevation line is located in correspondence of the more conservative lithologies, with the elevation ranging between 1300m and 2000m a.s.l., and in particular it is developed on the highest peaks of the carbonate massifs along all the chain, with the only exception that is represented by the Mt. Sirino (where the more resistant formations of the Lagonegro units crops out).

The first separation of the divide and the maximum elevation line is individuated in the northern sector of the Southern Apennines, in particular in the high Volturno valley. Here the maximum elevation line is located on the carbonates of the Mainarde massif, while the divide is located eastern of the highest peaks, and in particular on the terrigenous units cropping out around the town of Isernia. Moving from this point to the south, the two lines became coincident on the Matese massif while, from this point to the south until the Sirino massif, the two lines are strongly separated: in particular the maximum elevation line moves on the high calcareous massif cropping out on the inner side of the chain (Taburno-Camposauro massif, Monti di Avella ridge, Monti Picentini ridge, Alburno-Cervati ridge, Cocuzzo-Serralunga ridge), while the divide line moves on the outer side of the chain, showing an arch-like shape that is interrupted by the Ofanto valley, that represents the only area of this portion of the chain where the two lines are pretty close, and being developed on less conservative lithologies such as the terrigenous units of the External Flysch and, to the south, on the Lagonegro Units cropping out on the north side of the Agri valley and on the Apennine carbonate cropping out on the Maddalena ridge. From the Sirino massif to the Pollino massif, that could be considered the southern limit of the Southern Apennines, the two lines run together, moving both on the hardest lithologies represented here by the calcareous lithologies of the Lagonegro Units on the Sirino massif, and on the Apennine carbonates of the Pollino massif.

The non correspondence of the two lines in the area comprises between the Matese massif and the Sirino massif is due to the capture of the main Tyrrhenian rivers (the Volturno and the Sele rivers) of the trunks located in the axial portion of the chain, capture that has occurred once the Tyrrhenian rivers had overpassed by superimposition the obstacle represented by the calcareous ridges: once they had overpassed them, they drainage basin became greater by including areas located east of the considered calcareous ridges, a phenomena that was encouraged by the occurrence either of weaker terrigenous units (Calore Beneventano valley and high Volturno valley) or by the presence of morphostructural low where low competence lithlogies crop out (such as the Sicilidi units that crop out in the high Sele valley).

Amato et al. (1995) did a detailed analysis of the Southern Apennines divide-maximum elevation line relationships: they also pointed out that the non-coincidence of the two lines was encouraged by regressive erosion of the Tyrrhenian rivers, that had overpassed the narrow areas where the calcareous ridges are located, and that then enlarged their basins in the erodible terrigenous units cropping out on the outer side of the chain. The author also considered possible alternative solutions to this one, and in particular they try to explain the non-coincidence by involving a migration of the two lines toward the east and then an enhanced uplift on the inner side of the chain that was responsible of the individuation of the highest peaks in this area: this hypothesis is impossible to confirm because we have to suppose a recent uplift on the Tyrrhenian, that should proceeds as slow to allow the Tyrrhenian rivers to maintain their flow direction and to cut in antecedence the new created reliefs; in addiction to this, there are no geological data to confirm such a recent uplift on the Tyrrhenian flank while we know that the uplift rate are higher on the outer side of chain than on the inner side (Cinque, 1992; Romano, 1992; Amato, 1995). The only event that could agree with this hypotheses is the occurrence of lacustrian and alluvial deposition in some areas east of the maximum elevation line (Calore Beneventano and Tanagro valleys), but this events could be explained also if we consider local situations, with tectonic movements that could create an obstacle to the flowing of the rivers, determining the mentioned alluvial deposition and the lacustrian condition.

Another hypotheses Amato et al. (1995) considered to explain such a non coincidence was a non continuous uplift of the calcareous ridges where the maximum elevation line moves: this hypotheses is not verified again because of the occurrence of several fault-line scarps in these areas instead of fault scarp, so it means that most of the calcareous ridges are now emerged because of the morphoselection that has occurred during the erosion of paleolandscapes and not because of the uplift.

The non validation of these two alternative hypotheses let Amato et al. (1995) to confirm the first hypotheses, so the non-coincidence of the two lines is due to the regressive erosion of the Tyrrhenian rivers.

4.4 DISCUSSION

The analysis of the river system shows how there is a spatial variations of the morphological and morphometrical features of the Southern Apennine rivers.

If we consider the shape of the river long profiles we notice that the Tyrrhenian rivers have a clear concave-up shape with no important knickpoints, while the Adriatic rivers show a more rectilinear shape and the Ionian rivers show a less evident concave-up shape, in same cases close to the rectilinear, with evident knickpoints along the profiles.

The reason of such a difference could be explained if we consider that it has been proposed a rebound of the lithospheric Adriatic slab (Cinque et al., 1993) that has determined a recent uplift on the Adriatic and Ionian side of the Southern Apennine as it is testified by the elevation of the marine terraces along the Ionian coast (Amato et. al., 2000) and by the tilting of the Irsina Conglomerate (that represents the closure of the sedimentary filling of the Bradanic foredeep, Cinque et al., 1993) towards the NE. If this hypothesized rebound (with recent uplift on the outer side of the chain) really occurred, we expected it should influence the shape of the river long profile on the inner and the outer side of the chain, and in particular we expect Tyrrhenian rivers (inner side) clearly concave upward and Ionian and Adriatic (outer side) rivers with a less evident concave-up shape: this is what we obtained by the analysis of the river long profiles, so the different shape among the Tyrrhenian, Adriatic and Ionian long profiles can be related to surface uplift due to the rebound of the sinking lithospheric slab which has determined a more enhanced uplift of the Adriatic flank than the Tyrrhenian flank.

We also have to consider that the shape of the Volturno and the Sele longitudinal profiles on the Tyrrhenian flank, which are the most concave-upward long profiles among all the Southern Apennines rivers, could be affected by the fact that these rivers flow into the main extensional basins of the chain. These areas have experienced a continuous subsidence during the Quaternary, and this is probably the main process that determines this so-enhanced concave upward shape. If we try to exclude the Volturno and Sele long profiles by the analysis and we try to compare the shape of the other Tyrrhenian long profiles with the Ionian and the Adriatic long profiles, we notice that such a difference still exist, so the Tyrrhenian rivers have a clear concave upward shape and the Adriatic and Ionian long profiles have a less concave upward shape, in most cases very close to a rectilinear one, so the considerations previously discussed about the relationship between the long profiles and the rebound of the Adriatic slab are confirmed.

The proposed more enhanced uplift of the Adriatic flank has probably played a relevant role in the decoupling of the maximum elevation line and the divide, together with the regressive erosion of the Tyrrhenian rivers because of the extensional tectonics of the inner areas: the stronger post-orogenic uplift occurred on the outer side of the chain since the Middle Pleistocene has in fact determined a minor ability of the Adriatic and Ionian rivers (which experienced a continuous downcutting) to compete with the Tyrrhenian rivers. This fact is enhanced by the comparison of the valley bottoms, which are higher for the rivers flowing on the outer flank than for the rivers flowing on the inner flank of the chain. This has probably contributed, together with regressive river erosion due to the extensional tectonics on the Tyrrhenian margin (see sec. 3.5), in the decoupling between the maximum elevation line and the main divide, which is one of the peculiar features of the Southern Apennines chain.

The Θ values show a difference among the three sectors, with the Tyrrhenian rivers showing the highest value (Θ=0.52), the Adriatic rivers showing a lower value (Θ=0.45) and with the Ionian rivers showing the lowest value (Θ=0.43). This data confirm what we noticed by the analysis of the river long profiles, in particular the Tyrrhenian rivers have a more evident concave-up shape and the Ionian rivers the less evident concave-up shape. If we then consider the Θ values we calculated for both the main trunks and main tributaries, we still have the Tyrrhenian rivers showing in both cases the highest values but, if we just consider the main trunks then we have that the Adriatic rivers show the lowest value while, if we just consider the main tributaries, then the Ionian rivers show the lowest value. If we also consider the spatial distribution of the main trunks and tributaries on the Tyrrhenian side, we notice that the first one are limited to the external flank of the chain (they are limited to the east by the Matese, the Picentini and the Alburno-Cervati ridges), while the second one are located in the axial portion of the chain: considering the Θ values obtained by the two categories, we notice how the concavity index is higher on the external side of the chain (Θ=58) and it is lower in the axial portion of the chain (Θ=48). If we add to this consideration the data about the Agri and Sinni rivers (which are the only two Ionian rivers that flow in the axial sector of the chain), their concavity values are similar to those one of the Tyrrhenian tributaries, while the rivers flowing on the outer side of the chain and on the Bradanic foredeep (here comprising the main trunks on the Adriatic flank and the main trunks and tributaries of the Ionian flank) show the lowermost values: we argue that a gradient of the concavity index exists in the Southern Apennine, and it moves from the west side of the chain (higher values, inner side of the orogen) to the east side of the chain (lower values, outer side of the orogen, Bradanic foredeep and Apulian foreland), in agreement with what we noticed for the shape of the river longitudinal profiles.

If we consider the Ks values, we noticed that in all the considered cases (whole data, main trunks and main tributaries) the Adriatic rivers show the lowest values, while the Tyrrhenian rivers always show the highest values, except that for the main channels, where the Ks value is higher for the Ionian tributaries. These data could suggest that the more recent uplift occurred on the Tyrrhenian flank of the chain, but we know by literature that this is not correct (Cinque, 1992; Cinque et al., 1993; Amato et al., 2000), because it is actually accepted the idea of a different uplift rate on the Southern Apennines, uplift rate that has been found to be higher on the outer side of the chain and that decreases moving towards the inner side of the Southern Apennines: we think that, in the case of the Southern Apennines, the Ks values extrapolated for the whole river long profile are not representative of recent rock uplift, as it has been suggested in literature. However, we think that some important considerations can be argued regarding the Ks variations along every single river: in fact, such variations show a correlation with areas tectonically active, with the high Ks values that correspond with the chain s.s., while in other cases the Ks values show a clear lithological control, in particular with high red values in fig. 4.58 that correspond with areas where the rivers flow into resistant rocks (mainly carbonate of the Apennine and Lagonegro units), while the lowest green values of fig. 4.58 correspond either with areas of active subsidence (intramontane basins, such as the Agri, Ufita and Volturno valleys) or with areas where low resistance rocks are exposed (Bradanic foredeep, peri-tyrrhenian coastal plain, external flysch units). Some of the highest values are located in correspondence of the thresholds of the intramontane basins, such as in the case of the Ufita, Agri and Mercure rivers. We then want to point the attention on the data we obtained for the Bradanic foredeep on the Adriatic flank and for the Sele plain on the Tyrrhenian flank: these areas have experienced recent rock uplift (Cinque, 1992; Cinque et al., 1993; Amato et al., 2000) but, nevertheless, we notice that rivers in this areas show very low Ks values (green values of fig. 4.58): in these cases the lithology probably play an important role in lowering the Ks values.

We suggest that in a geological setting such as the Southern Apennines, that is characterized by important lithological variations also in very close areas, the Ks index seems to reflect such variations more than recent rock uplift. We also noticed that the peaks in the Ks values correspond with the location of a knickpoint along a river, and this is the only information we can extrapolated from this type of analysis, identifying if there is an either lithological or tectonic influence on the occurrence of such a knickpoint: from this point of view the Ks index seems to assume the same meaning of the SLI of Hack (1957) as it can be shown by the comparison of two graphs relative to the considered parameters for the same river (fig. 4.59): of course, we know that mathematically the two parameters have a different significance, with the Ks index representing the Y-intercept of the regression line of the slope/area graph, and the SLI index that is calculated as SLI = ($\Delta Z/\Delta X$) L (with ΔZ = variation of elevation of every reach in which the profile has been subdivided, ΔX = length of the considered reach, L = distance from the beginning of the profile to the mid-point of the considered reach), but nevertheless they seem to give the same information in our study.

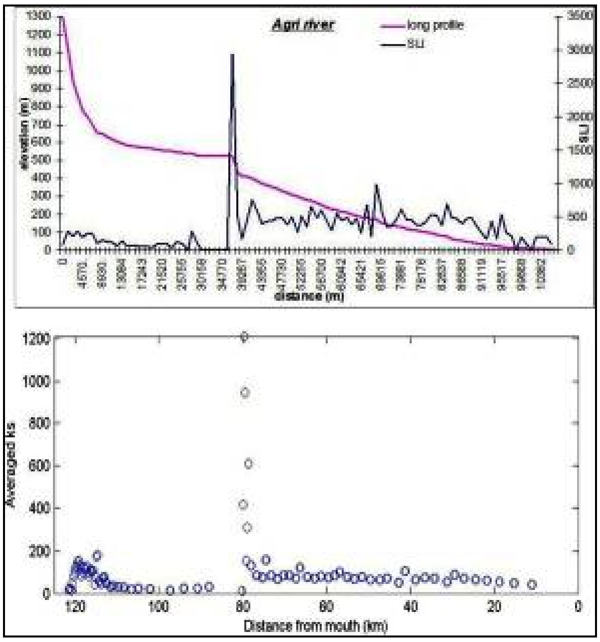


Fig. 4.59: comparison of the SLI (upper graph) and Ks (lower graph) variations for the Agri river: as we can see the two graphs look almost perfectly the same, with the highest peak in correspondence of the Agri knickpoint.

To conclude we want to show one of the cases that allowed us to think that the Ks index is not a good indicator of recent rock uplift in the case of the Southern Apennines, by discussing the Ks value obtained for the Ionian rivers: several orders of marine terraces have been recognized along all the Ionian coast (Amato et al., 2000), testifying a recent uplift that has occurred mainly on the west side of the Ionian coast (close to the Apennine front) than on the east side. If the Ks index was only sensitive to the rock uplift rate then we expected a gradient of the Ks values, that should progressively decrease moving from the west side of the Ionian coast (Sinni river) towards the east side (Bradano river), and passing through the Agri, Cavone and Basento rivers too (in order moving from the west to the east): our data suggest that the Ks index is pretty high for the Sinni river (62.30), it slightly decreases passing to the Agri river (55.60), and it then tend to increase again moving to Cavone river (57.30) and the Basento river (62.10, a value that is similar to that one of the Sinni river), and the Ks index is then minimum for the Bradano river(42.90), highlighting that the supposed decreasing trend doesn't exit and that the Ks index is strongly influenced by some other factor (such ad the lithology) more than the rock uplift rate in the case of the Southern Apennines.

CHAPTER 5

FOCUSING ON AN AREA OF HIGH RELEVANCE: THE NOCE-SIRINO-ALPI-SANT'ARCANGELO TRANSECT

5.1 INTRODUCTION

In this chapter we move from the large scale analysis of the previous chapters, to the small scale analysis of the Noce-Sirino-Alpi-Sant'Arcangelo transect. This transect develops from the Noce river coastal plain on the Tyrrhenian coast and crosses the Mt. Sirino, the Mt. Alpi, the Plio-Pleistocene Sant'Arcangelo basin and reaches the Ionian coast in the area comprised between the Sinni and the Agri rivers mouths. The study of this transect has been based on morphological and morphometrical analysis with the aim to produce new constraints to the rock exhumation processes highlighted by recent thermochronological studies (Aldega et al., 2003; Mazzoli et al., 2006; Mazzoli et al., 2008).

The selection of this transect was based onto:

- presence, on both the Tyrrhenian and the Adriatic coastal sectors, of marine terraces which allow constraining the timing and amount of absolute vertical motions;
- presence of a stratigraphical record (from the Sant'Arcangelo basin to the Pleistocene lasustrine Noce river basin) almost continuous over the Middle Pliocene-Quaternary time span, which allows the chronological reordering of the coeval erosional/depositional events;
- presence of structures related to the shortening and to the Quaternary Tyrrhenian and intramontane extension;
- structural and thermochronometric evidence for exhumation processes.

Along the transect, all the main structural units of the Southern Apennines are exposed. These are represented by the carbonates of the Campano-Lucana platform (i.e., the Coccovello, Serralunga and Serra Rotonda mounts), that sometimes crops out in a unusual external position (Raparo mount); the Lagonegro units cropping out in the western portion of the transect, and that corresponds with the highest peak of this portion of the Campano-Lucano Apennine (Sirino mount, 2009m a.s.l.); the carbonates of the Apulian platform (Mt. Alpi); the Liguridi Units crop out in some important valley (Noce and Cogliandrino valleys); metamorphic rocks of the Frido Unit (cropping out in the southern portion of the area); terrigenous units of the Albidona Flysch and the Gorgoglione Flysch.

The chapter is so organized: in the first six sections the stratigraphical and structural features of the main morphostructural elements are described (Noce basin, Mt. Sirino and Mt. Alpi, and Sant'Arcangelo basin); then the morphometrical parameters of the area are reported. In the subsequent sections the results of the field analysis of the Sant'Arcangelo basin are exposed. The last two sections are dedicated to the results of the detailed analysis of the Sinni and Noce valleys, which was carried out with the aim of reconstructing the geomorphological evolution of such valleys. In the last chapter the discussion of the previous data is presented.

5.2 THE NOCE RIVER BASIN

The Noce river basin is bounded to the west by the carbonatic elevation of the Mt. Coccovello, to the south by the Trecchina and Messina Mts., to the east by the Sirino massif and to the north by the Mt. Tempa Pertusata, which represents the divide between the Noce river and the Calore river basins (the Calore river is the main tributary of the Tanagro river, which flows from south to the north into the intramontane depression of the Vallo di Diano) (fig. 5.1). The Noce river valley has been characterized by the development of an intramontane basin, characterized by fluvio-lacustrine sedimentation, during the Quaternary, and more correctly during the Lower Pleistocene (Santangelo, 1991).

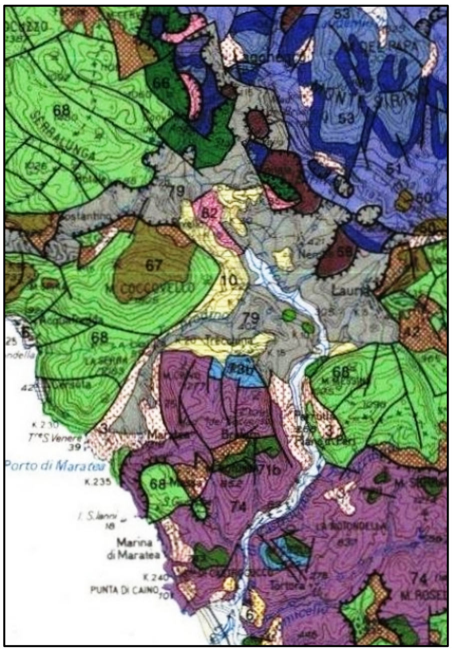


fig. 5.1 = geological setting of the Noce basin. 10) lacustrine deposits; 42) Cerchiara formation; 50-53) Lagonegro basin succession; 62) Monti della Maddalena formation; 66) Monte Foraporta unit; 67) Trentinara formation; 68) Alburno – Cervati – Pollino Unit; 74) Verbicaro formation ; 79) North-Calabrian Units (from Geological Map of the Southern Apennine, scale 1:250000).

The Noce river basin is characterized by a Meso-Cenozoic bedrock covered by quaternary continental deposits. The Meso-Cenozoic sequence is characterized by the following units (from Santangelo, 1991):

- North-Calabrian Units (Crete Nere formation), made up by marls, cherty marls, blackish, yellowish and greenish clays, cherty limestones, silts and greyish quartzite (Eocene);
- Monti di Trecchina Unit, made up by limestone with carbonatic platform slope facies, passing upward to limestone with chert of basinal facies (Late Triassic to Early Miocene);
- Carbonatic Units of the Silentino-Lucani massifs (Messina, Serra San Filippo, Coccovello, Serralunga and Lauria Mts.) made up by neritic limestones (Lower Jurassic to Miocene);
- Monte Foraporta Unit, made up by dolostones and limestones with basinal facies (Jurassic);
- Monti della Maddalena Unit, made up by white and grey stratified dolostones, intensely tectonized, cropping out in the areas of Rivello, Nemoli and Lagonegro (lower Triassic);
- Lagonegro Units, the succession starts with reef limestones (Monte Facito formation) that passes upward to deeper sediments represented by limestone with chert (Calcari con Selce formation) and chert (Scisti Silicei formation), with the top of the succession that signs the return to a less deep environment (Flysch Galestrino formation), and ending with the continental Numidian Flysch (it is interpreted as an aeolian deposit), (Middle Trias to Lower Miocene).

The Quaternary deposits of the basin consist of conglomerate and silty sediments that are interpreted as the evidence of a fluvio-lacustrine basin formed during the Pleistocene (Santangelo, 1991). The continental deposits crop out in the southern and western portion of the Noce basin, in the area from Mt. Serra Luceta to the north, Rivello, Nemoli and Trecchina towns to the south and the Prodino valley to the west. The Pleistocene lake was first recognized by De Lorenzo (1896, 1898).

Santangelo (1991) identified as the most representative sections of the Quaternary continental deposits those of “Le Cuini” and “I Puoi” (fig. 5.2).

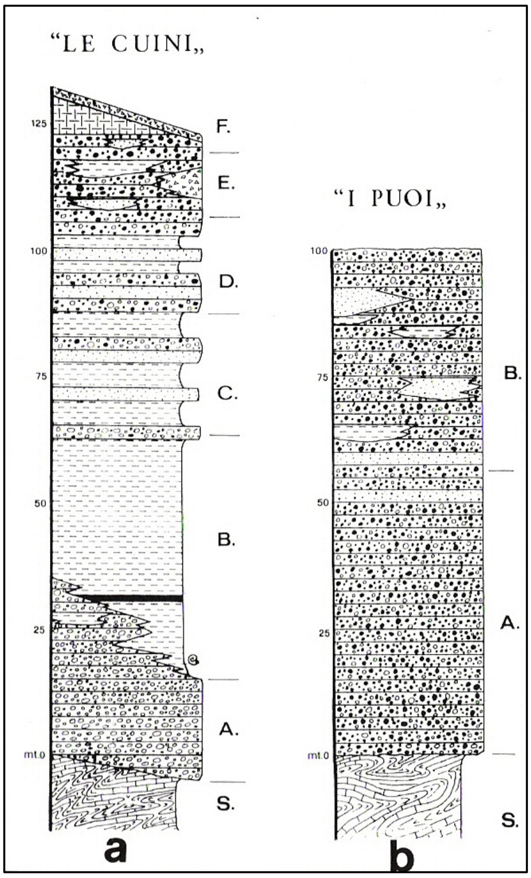


Fig. 5.2 = “Le Cuini” and “I Puoi” sections. **a)** S) substrate, A) calacareous conglomerate, B) greyish clays and silts, C) alternance of clay, silts and conglomerates, D) sands and conglomerates in a silty reddish matrix, E) polygenic conglomerates, F) reddish clay and slope breccias; **b)** S) substrate, A) polygenic conglomerates in sandy-silty matrix, B) polygenic conglomerate with lenses of sands and clays (from Santangelo, 1991).

The “Le Cuini” section is located at the toe of the eastern scarp of the Mt. Coccovello, on the left side of the Prodino valley, and has a maximum thickness of 150 meters. It is characterized at the base by a conglomeratic succession composed of rounded and sorted carbonate pebbles horizontally bedded with intercalations, in the upper part, of clayey lenses rich in gasterophods, ostrachods and bivalves, for a total thickness of about 30 meters. It passes upwards to a clayey and clayey-sandy unit, 30 m thick, the clays are greyish and blueish and contain pyroxene rich volcanoclastic layer at the base of the unit, and a lignite rich layer, some decimetre thick, horizontally bedded. This mainly clayey unit passes upwards to a sandy and sandy clayey unit, 35 m thick. The “Le Cuini” section ends with a conglomeratic unit, 20 m thick, characterized by rounded pebbles in a clayey matrix, alternated with sands and clayey sands: the pebbles are derived from different units, including the Lagonegro Unit (Scisti Silicei and Flysch Galestrino formations) and the carbonates of the Apennine platform. The conglomeratic sequence locally contains angular calcareous breccias, that is interpreted as the debris slope of the Mt. Coccovello. The top of this conglomeratic unit is characterized by the occurrence of a pedogenized reddish clayey unit covered by debris slope.

The “I Puoi” section is located in the centre of the basin, south of Nemoli settlement. The section is entirely conglomeratic. The total thickness is about 100 m, and is characterized from the base to the top by conglomerates derived from different stratigraphical units in a sandy-clayey yellowish matrix, with local intercalations of sandy and silty lenses, horizontally bedding. This conglomerate body is characterized by an upward decrease in the pebble size and by an increase in the amount of pebbles derived from the Lagonegro Units.

Other outcrops occurs in the area of Nemoli and Rivello (polygenic conglomeratic units), on the western slope of the Mt. Coccovello (clayey units), in Serra Luceta and I Murgi areas (polygenic rounded conglomerate in a yellowish-reddish sandy matrix) (Santangelo, 1991).

Santangelo (1991), as De Lorenzo (1898), noticed, that there is an inverse distribution of the facies in the Noce basin, with the conglomeratic units located in the present centre of the basin and the clayey lacustrine units outcropping close to the western margin of the basin.

Regarding the age, the results of the K/Ar analysis on a pyroclastic level assigned a Miocene age to the lacustrine deposits, inconsistent with geological evidences. Santangelo (1991) proposed a late Lower Pleistocene - early Middle Pleistocene age by the relationships of the lacustrine deposits with marine terraces occurring in the Noce river coastal plain.

In the geomorphological evolution of the Noce river basin Santangelo (1991) recognized the following steps: in the late Lower Pleistocene, the southern portion of the basin experienced an uplift stronger than the northern portion, determining the onset of the lacustrine phase. In the late Lower Pleistocene – early Middle Pleistocene the lake was filled up, the Noce river passed over the Parrutta gorge. In the Middle Pleistocene – Late Pleistocene a large scale uplift affected the whole area triggering a regressive erosion and consequent incision of the Noce deposits.

5.3 THE MT. SIRINO

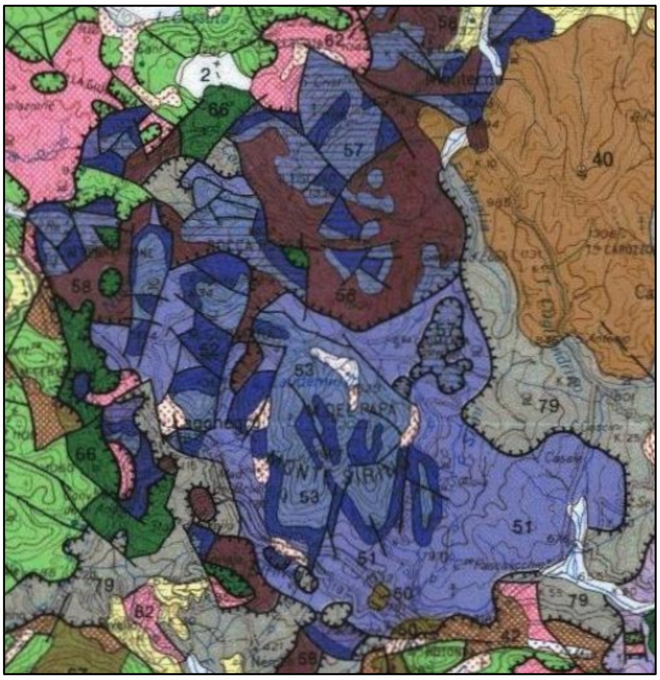


fig. 5.3 = geological setting of the Sirino massif. 10) lacustrine deposits; 40) Albidona – San Mauro – Pollica Flysch; 42) Cerchiara formation; 50-51-52-53-58) Lagonegro basin succession; 62) Monti della Maddalena formation; 66) Monte Foraporta unit; 67) Trentinara formation; 79) North-Calabrian Units (from Geological Map of the Southern Apennine, scale 1:250000).

Mt. Sirino has been the object of several studies because in this area the entire Lagonegro Basin succession is exposed: in the paleogeographical reconstruction of the Southern Apennines the Lagonegro Basin separated the Apennine and the Apulian carbonatic platforms (Scandone, 1967, 1972; Laubscher and Bernoulli, 1977; Channell et al., 1979; Mostardini and Merlini, 1986; Roure et al., 1991; Marsella et al., 1995; Cinque et al., 1993; Mazzoli, 1992, 1993).

The Lagonegro basin succession outcrops in a tectonic window formed in correspondence of a culmination which developed as an antiformal stack of the buried carbonate thrust sheets (Mazzoli, 1992; Cinque et al., 1993).

The Lagonegro succession in the Mt. Sirino area is characterized by two superposed nappes consisting of Mesozoic Lagonegro basin sediments (Scandone 1967, 1972). The two nappes are characterized by well defined, different but clearly correlatable, Upper Triassic to Middle Cretaceous stratigraphies: the oldest deposit of the basin, represented by the Middle Triassic Monte Facito Formation, only outcrop at the base of the upper nappe. There are sedimentological differences among the two nappes: the upper nappe (Lagonegro Unit II) displays more proximal basin facies, while the lower nappe (Lagonegro Unit I) shows more distal, deep basin facies (fig. 5.4 and 5.5) (Mazzoli, 1992).

Several formations have been distinguished in the two structural units, and in particular (from Torrente, 1990);

- "*Monte Facito Formation*": calcarenites, marls, sandstones with interbedded organogenic limestones of shallow marine to basinal facies, Middle Triassic age;
- "*Calcari con Selce Formation*": cherty limestone of basinal facies, pelagic and risedimented beds, Upper Triassic in age;
- "*Scisti Silicei Formation*": siliceous shales, radiolarites and calcarenites of basinal facies, Jurassic in age;
- "*Flysch Galestrino Formation*": marls, argillites and siliceous limestones rich in iron and manganese of basinal facies, Lower Createaceous in age.

According to Scandone (1972, 1975) a possible upward prosecution of the Lagonegro sequence is represented by the "*Flysch Rosso Formation*" (siliceous argillites, calcareous breccias and calcarenites of Upper Cretaceous-Tertiary age) and by the "*Numidian Flysch Formation*" (graded yellowish quartz sandstones of Lower Miocene age).

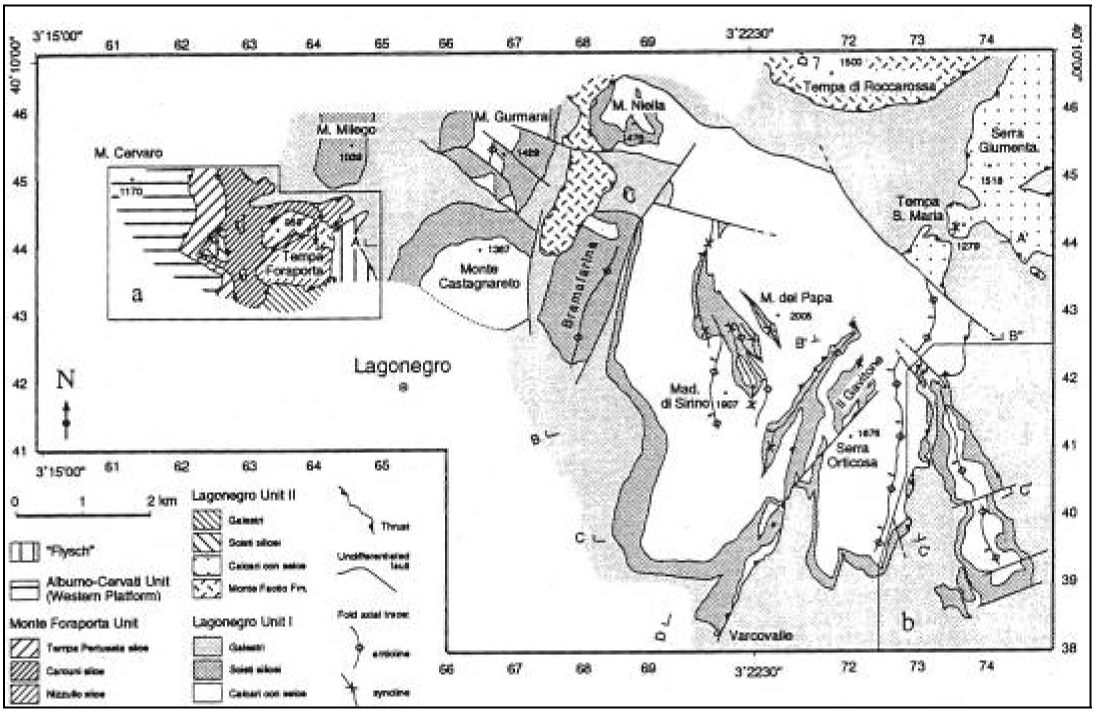


Fig. 5.4: geological map of the Sirino Massif (from Mazzoli et al., 1992).

The onset of thrusting leading to the emplacement of the Lagonegro Unit II onto the Lagonegro Unit I cannot be directly dated, as the youngest sediments on top of the lower nappe are Lower Createaceous in age and thrusting is certainly much younger (Mazzoli, 1992). Scandone (1972, 1975) proposed a Langhian age for the thrusting of Lagonegro Unit II onto Lagonegro Unit I, which was based on observation of the Numidian Flysch on top of Lagonegro Unit II; this age was confirmed by Mostardini and Merlini (1986) and by Hill and Hayward (1988) based on section balancing of seismic reflection profiles across the whole chain and of geological cross sections calibrated by well data. However, Mazzoli (1992) suggest a more recent age (Upper Tortonian) for the onset of deformation within the Mesozoic Lagonegro units, on the base of tectonic reconstruction; the author also suggest that the thrusting event was preceded by the detachment of the Tertiary sediments covers from their Mesozoic substratum (Lentini et al., 1990; Roure et al., 1991).

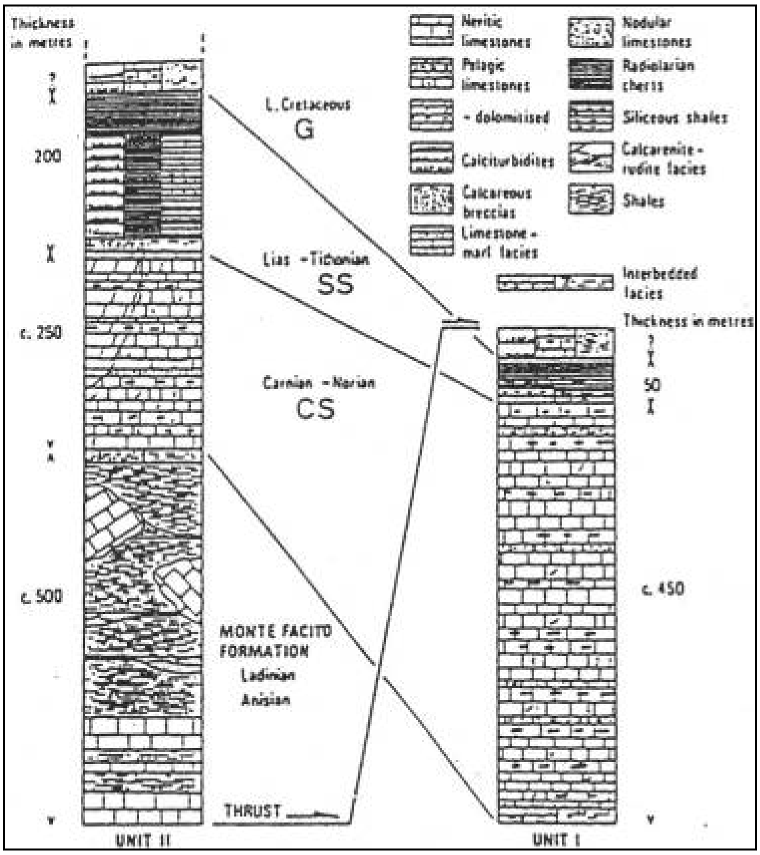


Fig. 5.5: stratigraphical correlation among the Lagonegro Unit I and II (from Mazzoli, 1992).

The tectonic evolution of the Lagonegro Units cropping out in the Mt. Sirino area are summarized in Mazzoli (1992), which proposes the following points:

1- the earliest deformation recorded by the Mesozoic Lagonegro sediments is that related to diagenetic compaction, which is very important particularly in the less competence lithologies (mudstones and argillites);
2- folding in the upper Lagonegro unit (II) appears to have been essentially coeval with nappe emplacement;
3- the main nappe contact is itself gently bowed, but is discordant to the structures in the footwall, locally it also cut down-section in the direction of transport into the underlying Lagonegro Unit I;
4- further thrusting occurred within the Lagonegro Unit I, involving faulting of already folded rocks with only limited displacements compared to the main nappe transport;
5- kinematic analysis of the Lagonegro and adjacent nappes indicates E- to NE- directed overthrusting throughout the whole deformation sequence (D1 tectonic phase);
6- refolding of the whole tectonic pile occurred as a consequence of N-S to NNE-SSW shortening (D2 tectonic phase); this event produced different types of interference structures at various scale, the most commonly observed are transitional forms between Type-1 and Type-2 interference patterns of Ramsay (1967); although these are complex structures that never represent end-members, at a first approximation a pattern can be recognized consisting of (dominant Type-1) dome-like structure developed on early broad anticlines and of (dominant Type-2) tight synclinal structures with folded axial surfaces developed on early pinched synclines;
7- folding of the axial surfaces of early structures is at least partly responsible for the markedly arcuate F1 structural trends; it not anyway possible to determine how much of this curvature was preexisting (related to D1 thrusting) and how much was accentuated or newly formed by D2 related strains.

5.4 THE MT. ALPI

Mt. Alpi is a morphostructural high located E of the Mt. Sirino. The main feature of this elevation is that it is made up of carbonates of the Apulian Platform, and this is the only area of the Southern Apennines chain s.s. where the Apulian platform crops out (fig. 5.9).

Mt. Alpi has been the object of studies, e.g. Sgrosso (1988b) and Taddei and Siano (1992), where a detailed stratigraphic study is reported, and Corrado et al. (2002), Mazzoli et al. (2006) and Mazzoli et al. (2008) where the structural setting and the thermochronological analysis applied on the Mt. Alpi are reported.

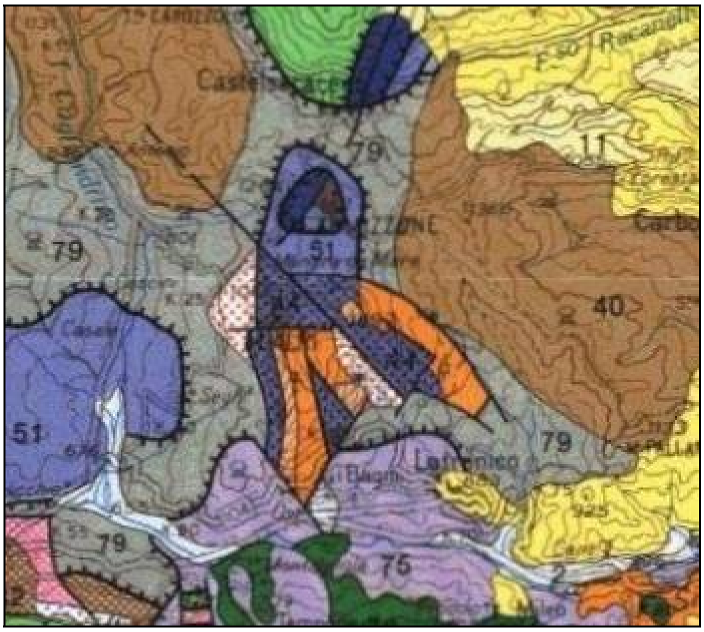


Fig. 5.9 = geological setting of the Noce basin. 11) Alluvial Conglomerates; 40) Albidona – San Mauro - Pollica Flysch; 44) Mt. Alpi Unit; 51) Lagonegro Unit; 75) Liguridi Units; 79) Crete Nere formation (from Geological Map of the Southern Apennine, scale 1:250000).

Mt. Alpi Unit consists of Mesozoic peritidal carbonates unconformably overlain by Miocene deposits, which includes two different transgressive stratigraphic units (Mazzoli et al., 2006). The stratigraphic succession starts with about 1000m of Mesozoic carbonates, mainly greyish calcilutite with the intercalation of dolomitic and oolitic layers (Sartori and Crescenti, 1962). Two Neogene transgressive cycles lie on top of the Mesozoic sediments. The first cycle is about 30m thick, it is transgressive concordant on the substratum and it is made by (moving from the base to the top) biodetritical calcarenites passing laterally into fine calcarenites with chert, biodetritical calcarenites with bivalves and algae, bituminous calcarenites, bituminous calcilutites, marls and polygenic breccias. The second cycle is about 200m thick, it unconformably overlies the deposits of the first cycle and locally the Mesozoic substratum, it is characterized by polygenic conglomerates, sandstone and siltstone, the conglomerates are organized in beds 0.1 to several meters thick, with most of the clasts that are carbonates, and with the presence of argillite, chert, micritic limestone and sandstone derived from the erosion of the allochthonous units (Taddei and Siano, 1992; Alberti et al., 2001).

Mt. Alpi Unit is tectonically overlain (with low angle contacts) and also surrounded (along recent high-angle faults) by various allochthonous elements: the geology of these elements is complex, as they include highly disrupted and discontinuous remnants of the Liguride Units, as well as of Mesozoic-Paleogene carbonate slope and pelagic basin succession. The allochthonous elements also include a tectonic mélange made up of a highly deformed argillaceous silty matrix including black-brown, red and green pelites with blocks of calcareous sandstones, micritic limestones, radiolarian cherts, laminated black algal limestones and calcarenites (Mazzoli et al., 2006 and reference therin) (fig. 5.10). The geology of the area is complicated by the occurrence of low-angle extensional faults rooted within the allochthonous units tectonically overlying the Monte Alpi Unit. An important low-angle detachment fault occurs west of the Monte Alpi area: it is named Cogliandrino fault and it downthrows the allochthonous units to the NE, producing significant tectonic omission revealed by the anomalous contact between the Liguride units and the Lagonegro Units (fig. 5.11).

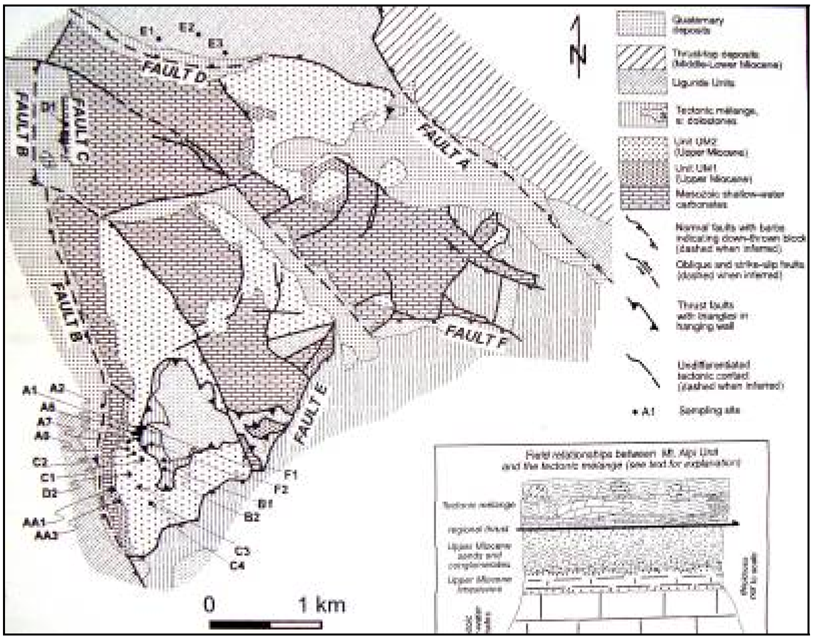


Fig. 5.10: geological map of the Mt. Alpi area (from Mazzoli et al., 2006).

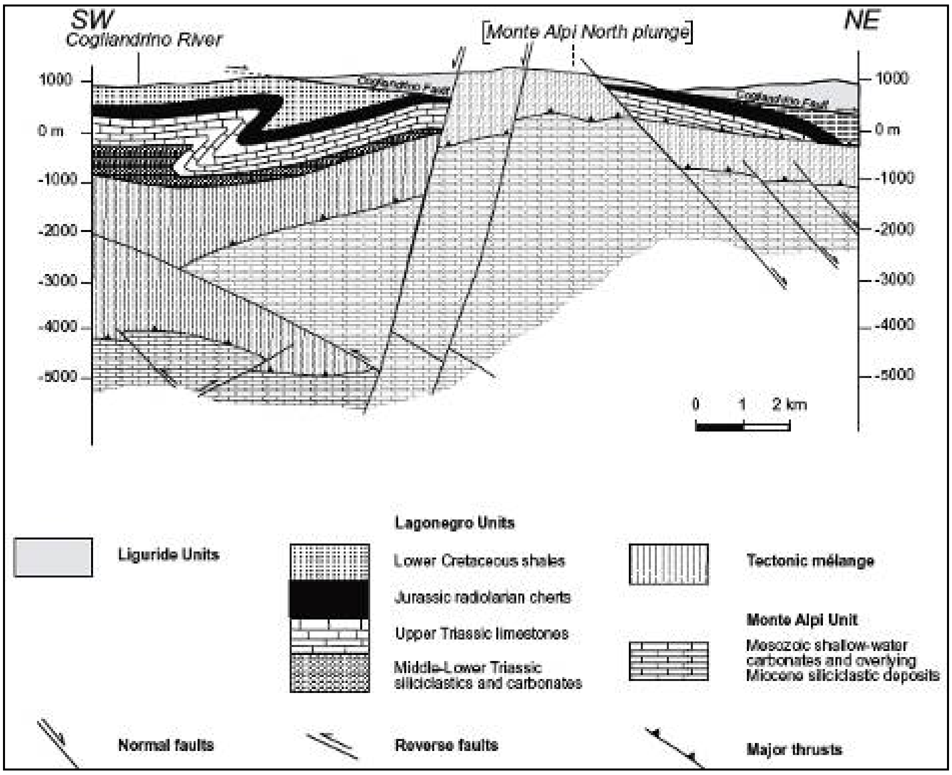


Fig. 5.11: geological cross section based on surface geology, seismic reflection profiles and well logs (from Mazzoli et al., 2006).

The Mt. Alpi is characterized by the presence of several high angle faults, named from A to F in fig. 5.10: there are no kinematic data for the faults A, D and E, but the normal component of motion is indicated by the significantly downthrown units occurring in the hanging walls. The E-W trending fault F shows a pure normal sense of slip. Fault C is a N-S striking fault located in the northern portion of the Mt. Alpi area. Faults within the Monte Alpi carbonate block may be characterized by more complex kinematics, possibly resulting from multiple reactivation of inherited structures (e.g. fault C) and/or transtension. Available subsurface data (Cello et al., 1990; Corrado et al., 2002) indicate that the Mt. Alpi block is part of a much larger antiformal structure made of Apulian platform carbonates that have been significantly uplifted above their regional level by major reverse fault (fig. 5.11). Therefore, the Mt. Alpi outcrop owes its peculiar present day position within the thrust belt to a series of structural features: it forms part of the crestal zone of a large reverse fault-related antiform of the Apulian Unit, it lies in the footwall to the low-angle Cogliandrio fault and it has been reworked by recent high angle faults (fig. 5.12).

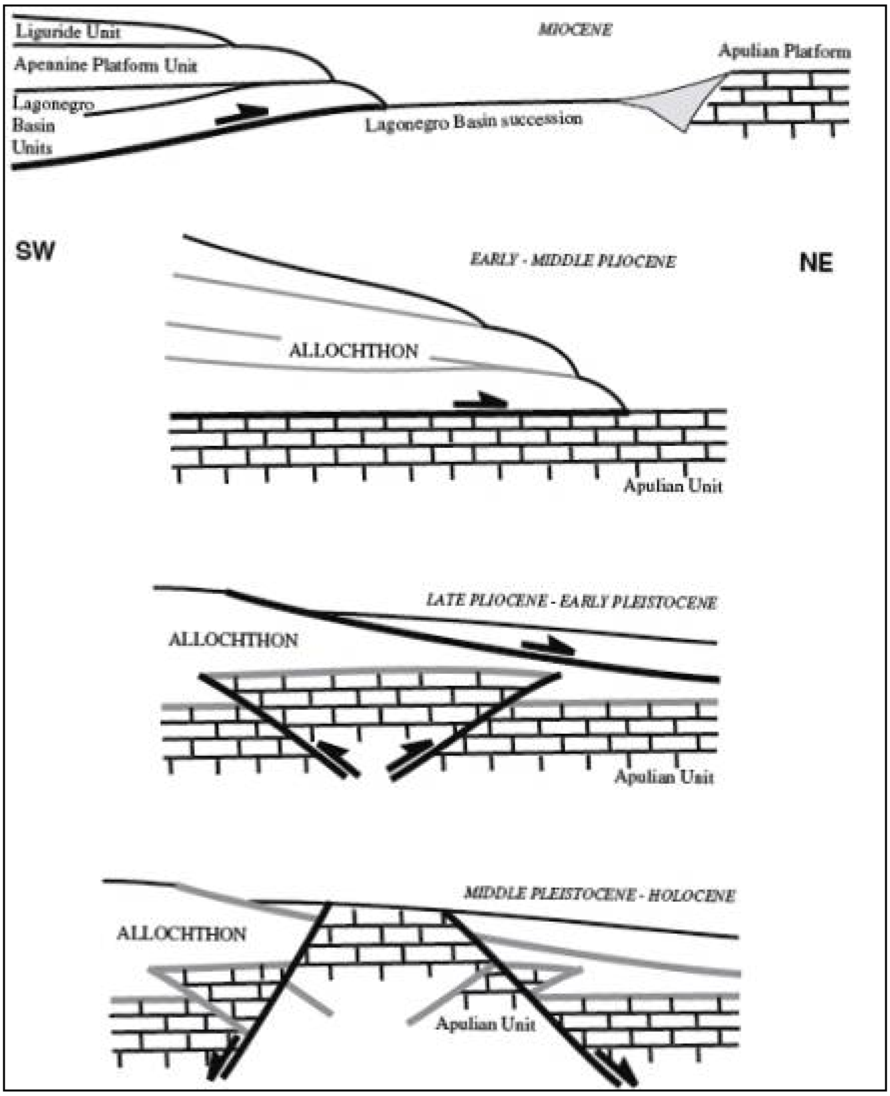


Fig. 5.12: tectonic evolution proposed for the Monte Alpi area (from Mazzoli et al., 2006).

5.5 THE SANT'ARCANGELO BASIN

The Sant'Arcangelo basin is one of the largest thrust-top Plio-Quaternary basins in the Southern Apennines, which shows a marine to continental facies as we move from the oldest to the youngest units. This basin is located in Lucania region, and it is bounded by the Val d'Agri – Mt.

Raparo – Mt. Alpi system to the west, by the External Flysch to the north, by the Nocara ridge to the east and by the Pollino massif to the south (fig. 5.6).

The Sant' Arcangelo basin has been the object of numerous studies, we can remember the papers by Vezzani (1967a,b), Caldara et al. (1988), Turco (1990), Hyppolite (1991, 1994a,b), Pieri et al. (1994), Zavala (2000), Patacca and Scandone (2001), Benvenuti et al. (2006).

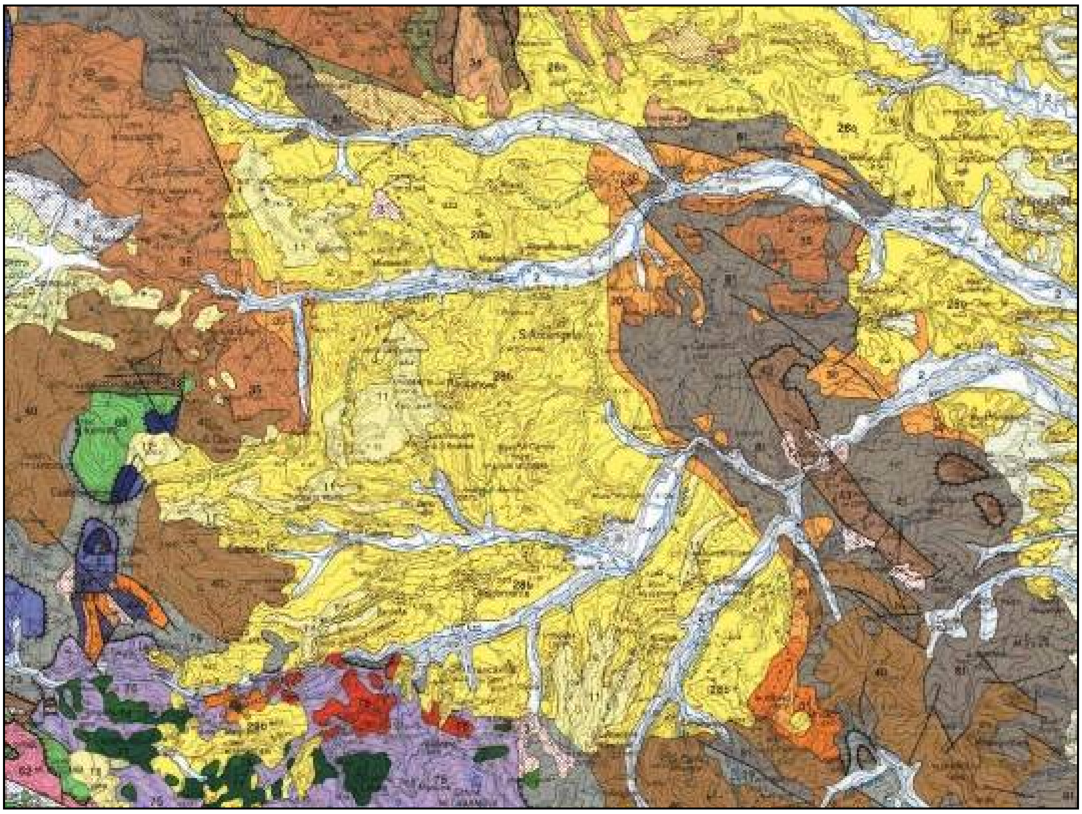


Fig. 5.6 = geological setting of the Sant'Arcangelo basin. 10) terraced lacustrine deposits; 11-28-30) quaternary filling of the Sant'Arcangelo basin; 35) Gorgoglione Flysch; 40) Albidona – San Mauro – Pollica Flysch; 43) Numidian Flysch; 44) M.te Alpi Unit; 50-51-52-53-58) Lagonegro basin succession; 62) Monti della Maddalena Unit; 68) Alburno – Cervati – Pollino Unit; 75-76-77-78) Liguridi Units; 79) North-Calabrian Units; 81) Sicilidi Units (from Geological Map of the Southern Apennine, scale 1:250000).

The tectono-stratigraphical architecture of the basin is strongly debated. One of the main problem in the reconstruction of the tectonic evolution of the basin is linked to the migration of the depocentre. Some authors recognize a progressive forward (northeastward) migration of the depocentre (Caldara et al., 1988; Pieri et al., 1994), while other authors recognize a southwestward migration of the depocentre linked to the sindepositional tilt caused by the growth of the Nocara ridge (Hippolyte et al, 1991; Hippolyte, 1992; Camarlinghi et al. 1994; Hippolyte et al., 1994).

Patacca and Scandone (2001) proposed a detailed reconstruction of the Sant'Arcangelo basin stratigraphy, based on biostratigraphic data and they figured out a correlation between the Sant'Arcangelo units and the foredeep units. The sedimentary units recognized by the Authors are the following (fig. 5.7):

- "*Caliandro cycle*" (3.30-1.83Ma): it is well exposed on the northwestern, northern and eastern portions of the basin. It consists of a transgressive-regressive cycle which testifies a sedimentation on a wide passive shelf open towards the foredeep basin. It is correlated in the foredeep to a few metres of condensed foraminiferal limestones and marls (3.70-2.13Ma) which drape the Apulia carbonates;
- "*Craco clay – Sant'Arcangelo sandstone*" (1.83-1.50Ma): this unit crops out in the east side of the Sant'Arcangelo basin, west of the Nocara ridge. This unit disconformably overlains the Caliandro cycle, and consists of inner-shelf clays and

silty clays eastward grading into open-shelf foraminiferal mudstones, which contain two volcanoclastic layers (Craco clay), grading upwards into bioturbated shell-rich sandstones with wavy bedding and internal cross-lamination (Sant'Arcangelo sandstone). The transition from the Craco clays to the Sant'Arcangelo sandstones is observable in the Sant'Arcangelo synform area, while the sandstone unit is not present east of the Nocara ridge where it is substituted by a more distal muddy deposit drapping the Apenninic thrusts sheets as far as the nappe front;

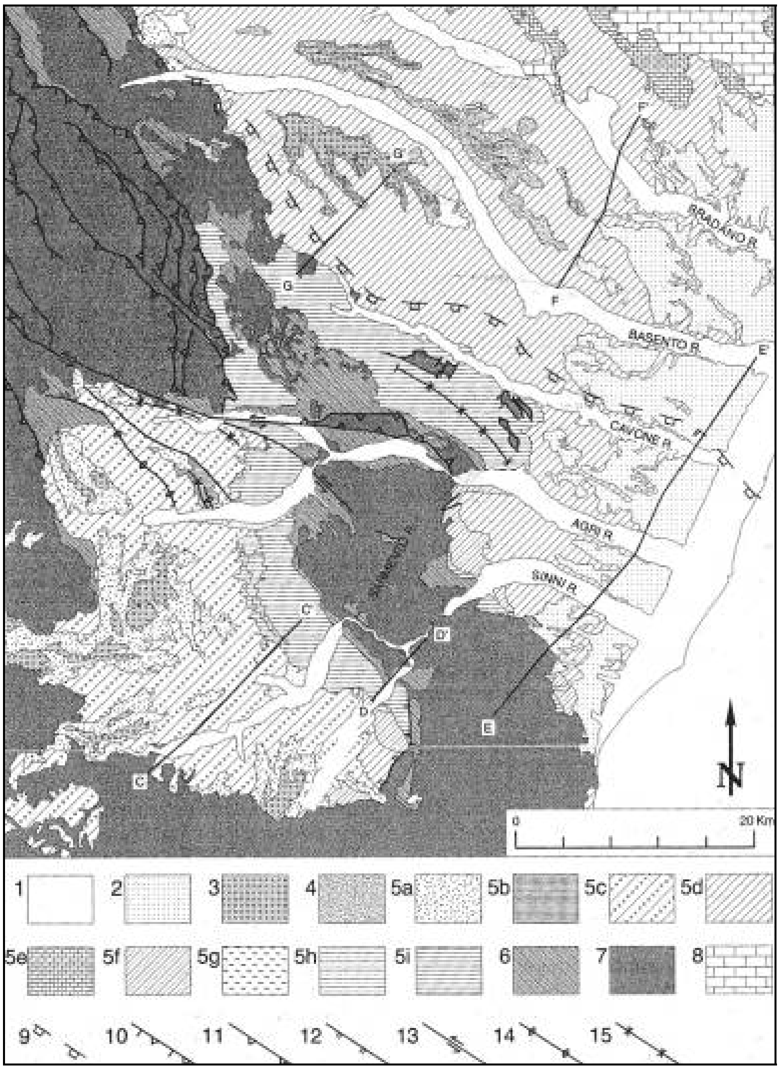


Fig. 5.7: geological map of the Sant'Arcangelo basin: 1)alluvial and shore deposits (Holocene); 2) terraced continental and shallow marine deposits (Middle – Upper Pleistocene); 3) Serracorneta Conglomerate (Middle Pleistocene); 4) Monte Marano and Staturo sandstone (Middle Pleistocene); 5a) Castronuovo Conglomerate (Middle Pleistocene); 5b) San Lorenzo clay (Middle Pleistocene); 5c) Sinni Synthem (Lower – Middle Pleistocene); 5d) upper portion of the Sarmento Synthem -Montalbano sandstone – Gravina clays and Sub Apenninic Clays (Lower – Middle Pleistocene); 5e) Gravina Calcarenite (Lower – Middle Pleistocene); 5f) lower portion of the Sarmento synthem and Tursi sandstone (Lower Pleistocene); 5g) chaotic slope deposits in the footwall of the nappe frontal ramp (Basento valley, Lower Pleistocene); 5h) Sant'Arcangelo and Garaguso sandstone (Lower Pleistocene); 5i) Craco clay (Lower Pleistocene); 6) Upper Pliocene sequence; 7) Apenninic nappes and thrust-sheet-top deposits older than 3.70Ma; 8) Apulia carbonates; 9) fron of the Apenninic nappes; 10-11) Pliocene and Lower-Middle Pleistocene thrusts; 12) normal fault; 13) strike-slip fault; 14) anticline axis; 15) syncline axis (from Patacca and Scandone, 2001).

- "*Sarmento Synthem*" (1.5-0.92Ma): this unit disconformably overlains the formerly described deposits. It consists of a backsteepening, deepening upward, clastic deposits capped by lagoon/prodelta mudstones which belong to a retrograding coarse-grained fan-delta system. This unit was deposited on top of the allochthonous sheets when the latter formed a passive shelf open toward the foredeep basin and extended without interruptions from the present day Sant'Arcangelo synform to the buried nappe front. This unit has been correlated to the Tursi Sandstone plus the lower interval of the Sub Apenninic Clays in the foredeep;

- "*Sinni Synthem*" (0.92-0.7Ma): this unit overlains, with progressive angular unconformity, all the above described deposits. It consists of coarse-grained fan delta deposits showing backsteepening geometry and an overall progradational facies architecture; it is correlated with the Sub-Apenninic Clays in the foredeep;
- "*Castronuovo Conglomerate and San Lorenzo Unit*" (0.7-0.66Ma): this unit unconformably overlains the Sinni Synthem. The Castronuono Conglomerate is well exposed on the western and northern portions of the Sant'Arcangelo basin, while the lacustrine San Lorenzo Unit is only exposed in the northern portion of the synform. It consists of braided plain deposits interfingering with lacustrine deposits. These units are correlated with the upper portion of the Sub-Apenninic Clays and the Montalbano Sandstones in the foredeep;
- "*Serracorneta Conglomerate*" (0.6Ma): it crops out on top of the hills along the northwestern, western and southern portion of the Sant'Arcangelo synform. This unit consists of reddish, weathered alluvial conglomerates overlying a meter-thick horizon of reddish paleosoil; the paleosoil at the base of the Serracorneta Conglomerate is correlated with the Monte Marano sandstones in the foredeep, while the Serracorneta Conglomerates have been correlated with the Irsina Conglomerate in the foredeep.

Benvenuti et al. (2006) been based on analysis of lithofacies and unconformities have distinguished five major synthems. These are (fig. 5.8):

- "*Caliandro Synthem*" (3.2-2Ma): it unconformably rests on the pre-Pliocene substratum, it consists of terrestrial or shallow marine deposits (C1 sub-synthem = gravels, sands, silts and diatomaceous clays exposed on the northern, western and eastern margin of the basin; C2 sub-synthem = sands and massive muds exposed on the western margin of the basin; C3 sub-synthem = gravels and sands cropping out on the western margin of the basin), and shelfal terrigenous and siliceous deposits (Cd sub-synthem = massive silty clays and marls rich in microfossils; Ce sub-synthem = massive and subordinated planar laminated whitish diatomaceous silts exposed in a few locations on the north-eastern margin of the basin), for a total thickness of about 1000m;
- "*Aliano Synthem*" (2-0.9Ma): it unconformably overlain the Caliandro synthem, it is separated in four subsynthems showing a continental environment chracterized by gravels, sands and muds deposits up to about 1500m thick;
- "*Missanello-Noepoli Synthem*" (0.9-0.6Ma): it is separated by a basin-wide unconformities from the lower Aliano Synthem, it is separated in four sub-synthems showing a continental facies (they are made by gravels, sub-synthems MN1 and MN2, greyish-whitish silty clays, sub-synthem MN3, and gravels alternated to floodplain sandy-clayey silts, sub-synthem MN4) that is at least 200m thick;
- "*Serracorneta Synthem*" (0.6-0.2Ma): it unconformably rests on the Missanello-Noepoli Synthem and is bounded at the top by an erosional surface and locally by remains of reddish paleosoil, three sub-synthems have been distinguished in this synthem, all showing continental facies (sub-synthem CSC1 = gravels and subordinate sands; sub-synthem CSC2 = breccia of angular and sub-angular boulder- to pebble-size cemented gravels; sub-synthem CSC3 = deeply weathered

angular to sub-rounded gravel and sandy silt in centimetre- to metre-thick lenticular beds), with an estimated thickness of about 100m.

- "*Valdagri Synthem*" (0.2Ma-present): it consists of terraced alluvial gravels and sands developed throughout the progressive incision of the drainage system within the older Sant'Arcangelo basin deposits to the present hidrography.

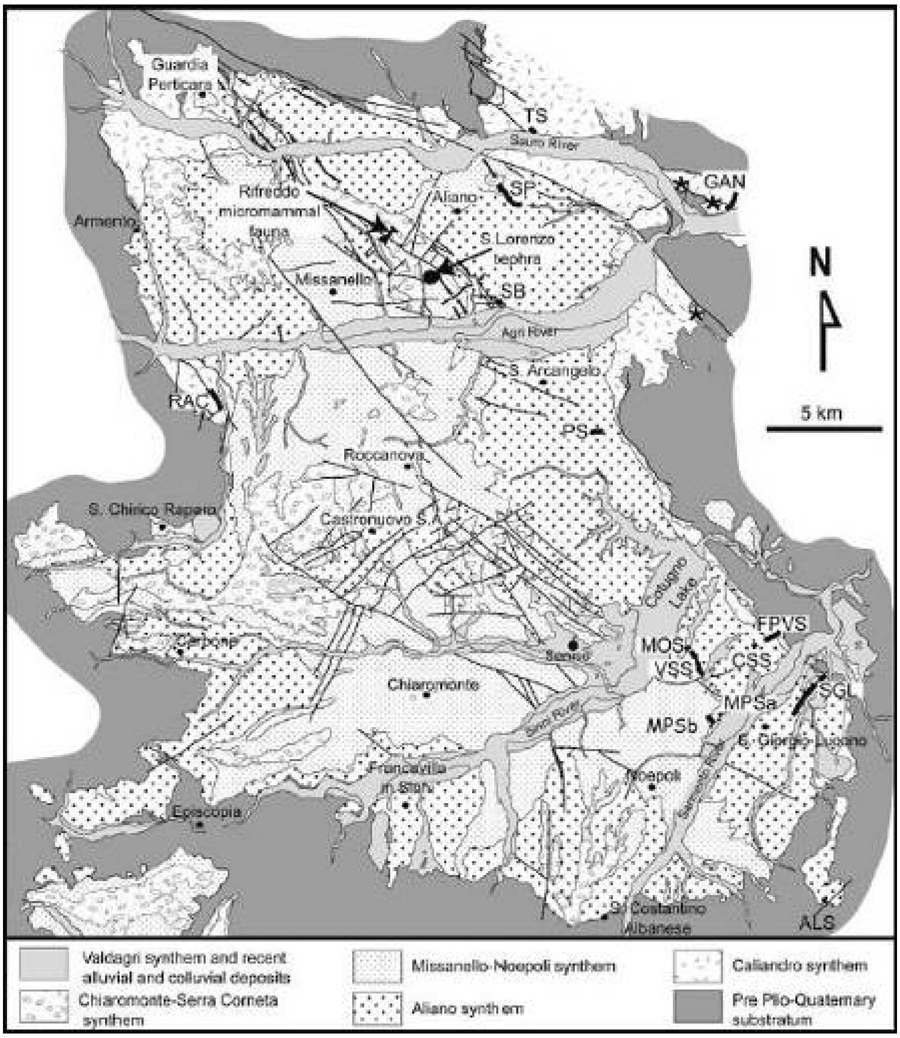


Fig. 5.8: geological map of the Sant'Arcangelo basin (from Benvenuti et al., 20069.

5.6 THERMOCHRONOLOGICAL DATA IN THE AREA

Thermochronometric data from the Mt. Sirino and the Mt. Alpi areas (which correspond to the outcropping of the deepest tectonic units of the Southern Apennines orogenic system, and in particular the whole Lagonegro Basin succession crop out on the Mt. Sirino while the carbonates of the Apulian Platform crop out on the Mt. Alpi) are summarized in Mazzoli et al. (2008), Corrado et al. (2002) and in Mazzoli et al. (2006).

In both areas, the thermochronometric method applied to reconstruct the thermal history of the outcropping lithologies is the Apatite Fission Track (see sect. 1.5). The thermochronometric data are reported in fig. 1.19, here a zoom of that map is reported, enhancing the Mt. Sirino and Mt. Alpi areas (fig. 5.13).

The Apatite Fission Tracks determined on the Mt. Sirino show an age of 2.5±0.9Ma, so this means that the Lagonegro Units where covered by about 4km of rocks at that time, and that since that moment the rock exhumation took place: we can try to determine an average rock exhumation rate but we cannot determine if there has been an acceleration in the process or not, anyway the mean rock exhumation rate is of about 1.6mm/yr.

In the Mt. Alpi area the Apatite Fission Tracks show an age ranging between 2.0±0.7Ma and 3.2±1.2Ma. This means that the medium rock exhumation rate between 3.2 and the Present was of about 1.81mm/yr.

We have finally to say that such exhumation processes are related to the activation of low angle normal faults (detachment faults): an example of the detachment faults is the Cogliandrino fault (fig. 5.11) , an east dipping low angle normal fault located on the west side of the Mt. Alpi (Mazzoli et al. (2006) suggested that the related extensional process was thin-skinned, being kinematically linked with shallow thrusting farther east) that is cut by high angle normal faults on both flanks of the Mt. Alpi and that is considered the main responsible of the exhumation of the Apulian carbonates in the Mt. Alpi area (Mazzoli et al., 2006).

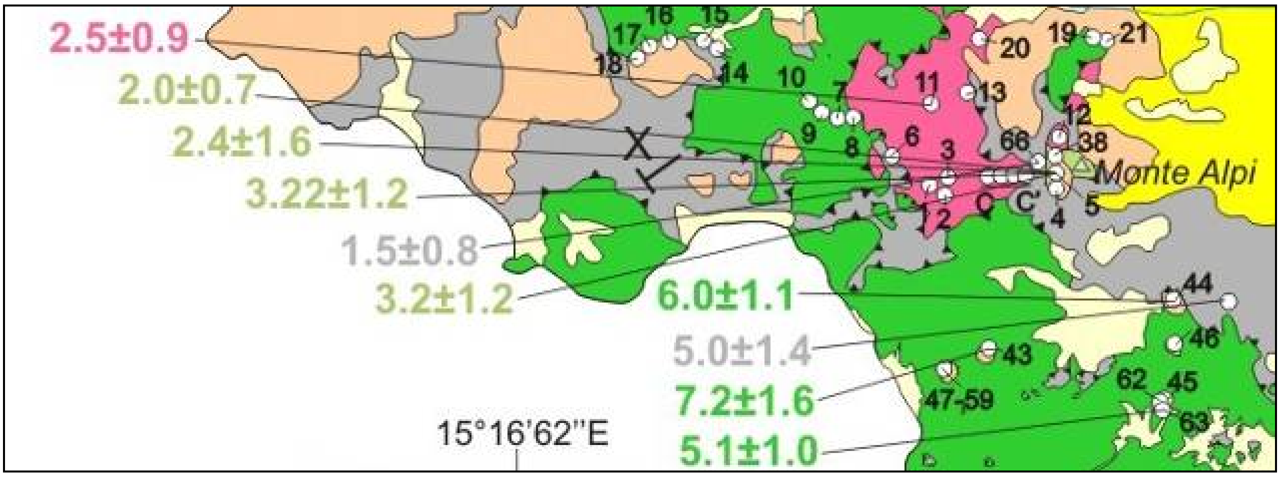


Fig. 5.13: the thermochronological data produced in the study area are shown in this map, that is a zoom of the map of fig. 1.19: the thermochronological data regarding the Mt. Sirino are shown with the pink colour (Apatite Fission Tracks), the thermochronological data regarding the Mt. Alpi are shown with the light brown (Apatite Fission Tracks) and the light grey (Ur/Th/He), the green and light grey data in the lowermost portion of the map are related to the Pollino massif and they have not been considered in this study (map from Mazzoli et al., 2008, modified).

5.7 FIELD ANALYSIS OF THE SEDIMENTOLOGICAL RECORD OF THE SANT'ARCANGELO BASIN

The Sant'Arcangelo basin is characterized by a continue marine to continental deposition that is ranges from the Middle Pliocene to the Quaternary, and that has been studied in detail by various authors (see sec. 5.5), studies that have allowed the individuation of several stratigraphical units inside the Quaternary filling.

In addiction we have to consider that:

- exhumation of the tectonic units outcropping in the Mt. Sirino and the Mt. Alpi areas, which took place during the Plio-Quaternary times, was coeval to the sedimentation in the Sant'Arcangelo basin;
- the materials eroded in Mt. Sirino and Mt. Alpi areas (which fall within the hydrographic basins draining towards the Sant'Arcangelo basin) were eventually deposited within the Sant'Arcangelo basin.

Based on these hypotheses, the compositional analysis of the Plio-Quaternary succession of the Sant'Arcangelo basin was carried out. This was done with the aim of providing age constraints to the exhumation processes and, in particular, to the exposure on the surface of the exhumed tectonic units, through the search for clasts derived from these units in the different stratigraphical units of the Sant'Arcangelo sequence. The search was focused on clasts derived from the Lagonegro units, the lithological signature of which is more easily recognizable. Conversely, Mt.

Alpi succession rock-types are not distinctive in relation to carbonates of the Apennine platform, which are more largely exposed.

Portions of the Sant'Arcangelo basin more prone to receive sedimentary inputs from the Mt. Sirino are represented by the area including the Racanello, the Serrapotamo, the Sinni, the Frida and the Rubbio valleys, which are located in the southern portion of the Sant'Arcangelo basin. The northern portion of the basin (which includes the present Agri valley) was excluded by the analysis based on the consideration that the Lagonegro derived clasts, in this area, can be related to sedimentary inputs by the Mt. Volturino area where, based on thermochronometric data (Mazzoli et al., 2008), rock exhumation processes took place earlier than Plio-Quaternary times (fig. 1.19).

The compositional analysis was framed within the reference stratigraphy provided by Benvenuti et al. (2006). The entire stratigraphical sequence represents a regressive cycle, which starts with the marine sediments of the Caliandro synthem, and that moves to the deltaic facies of the Aliano synthem, to the alluvial plain facies of the Missanello-Noepoli synthem and that ends with the alluvial fan facies of the Serraconrneta synthem. The analysis is described as it follows.

- Caliandro synthem (3.6-2Ma)

The Caliandro synthem crops out on the easternmost portion of the Sant'Arcangelo basin (along all the west side of the Nocara ridge), on the western portion of the basin in correspondence of the Agri-Racanello confluence and in the north-western portion of the Sant'Arcangelo basin along the Sauro valley. It has been analyzed in detail in the area of the Monte Cotugno dam (fig. 5.14).

Fig. 5.14: the Caliandro synthem cropping out in the area close to the Monte Cotugno dam.

The deposit is characterized, from the base, by clast-supported well cemented conglomerates, with medium rounded to rounded clasts, ranging from a few centimetres to a maximum size of about 50cm. The deposit is locally interrupted in its upper portion by the presence of well cemented sand lenses (fig. 5.14.A-B). Moving to the top of the succession, the deposit is characterized by a yellowish well cemented sand, very rich in pectinids, ostreids and bivalves, with local cross bedding and with the presence of more cemented sand lenses (fig. 5.14.C-D). The clasts characterizing the conglomerate body are made up of sandstones (very rich in muscovite, and with abundant quartz and pyroxene), and with the presence of limestones (calcilutites with piano-parallel lamination), marls, and metamorphic clasts and granite which suggest an alimentation from the south, from the area where the Albidona Flysch and the Liguridi units crops out. No clasts from the Lagonegro units rock-types were found in this synthem. This data suggest that the topographic surface at the time was builds up on the highest tectono/stratigraphical units of the orogenic pile.

- Aliano synthem (2-0.9Ma)

The Aliano synthem extensively crops out in the eastern and the northern portion of the Sant'Arcangelo basin (in the areas around the towns of San Chirico Raparo, Castronuovo di Sant'Andrea, Calvera, Carbone, Teana, Latronico and Episcopia). The analysis has been carried out in the last areas, excluding the northernmost portion of the Sant'Arcangelo basin (fig. 5.15).

Fig. 5.15: the Aliano synthem. A) clay facies cropping out in the eastern portion of the basin; B) conglomerate facies cropping out about 0.5km north of the town of Teana; C) conglomerate facies cropping out close to the cemetery of Episcopia; D) conglomerate facies cropping out about 5km east of the town of Latronico.

The Aliano synthem shows facies variation moving from the eastern to the western areas: close to the Nocara ridge, the succession consists of greyish massive silty clays (fig. 5.15.A). In the area close the town of Teana the succession is made up of matrix supported conglomerate, with brownish sandy matrix, with sub-rounded clasts ranging from cm to 1-2dm in size, they are made up of limestones, sandstones, marls and chert (green and red), there are local lenses of well cemented sands (fig. 5.15.B). Around Episcopia the succession is made up of, from the base, 10m of matrix supported conglomerates, with sandy matrix and presence of sandy lenses, the clasts are sub-rounded and cm to 1-2dm in size, they are made up of limestones, sandstones, marl and chert, this unit is followed by a brownish clayey level 0.5m thick and by 2m of polygenic matrix supported conglomerates (fig. 5.15.C). In the area east of the town of Latronico the succession is made by a matrix supported conglomerate, with sandy matrix, with clast ranging from few cm to 1-2dm in size, with rare blocks of about 5dm, they are made by limestone, marls, sandstones and chert, the deposit is characterized by the presence of local sandy lenses (fig. 5.15.D). The compositional analysis of the Aliano synthem let us to recognize clasts derived from the Lagonegro Units rock-types, in particular in the areas of Teana, Episcopia and Latronico it has been recognized chert clasts derived from the shales of the Scisti Silicei formations of the Lagonegro succession.

- Missanello-Noepoli synthem (0.9-0.6Ma)

The Missanello-Noepoli synthem crops out in the central portion of the Sant'Arcangelo basin, in the area of San Chirico Raparo, in the Racanello valley (southeast of the Mt. Raparo) and in the southwestern portion of the basin (in the area south of the towns of Magnano and Preti) (fig. 5.16).

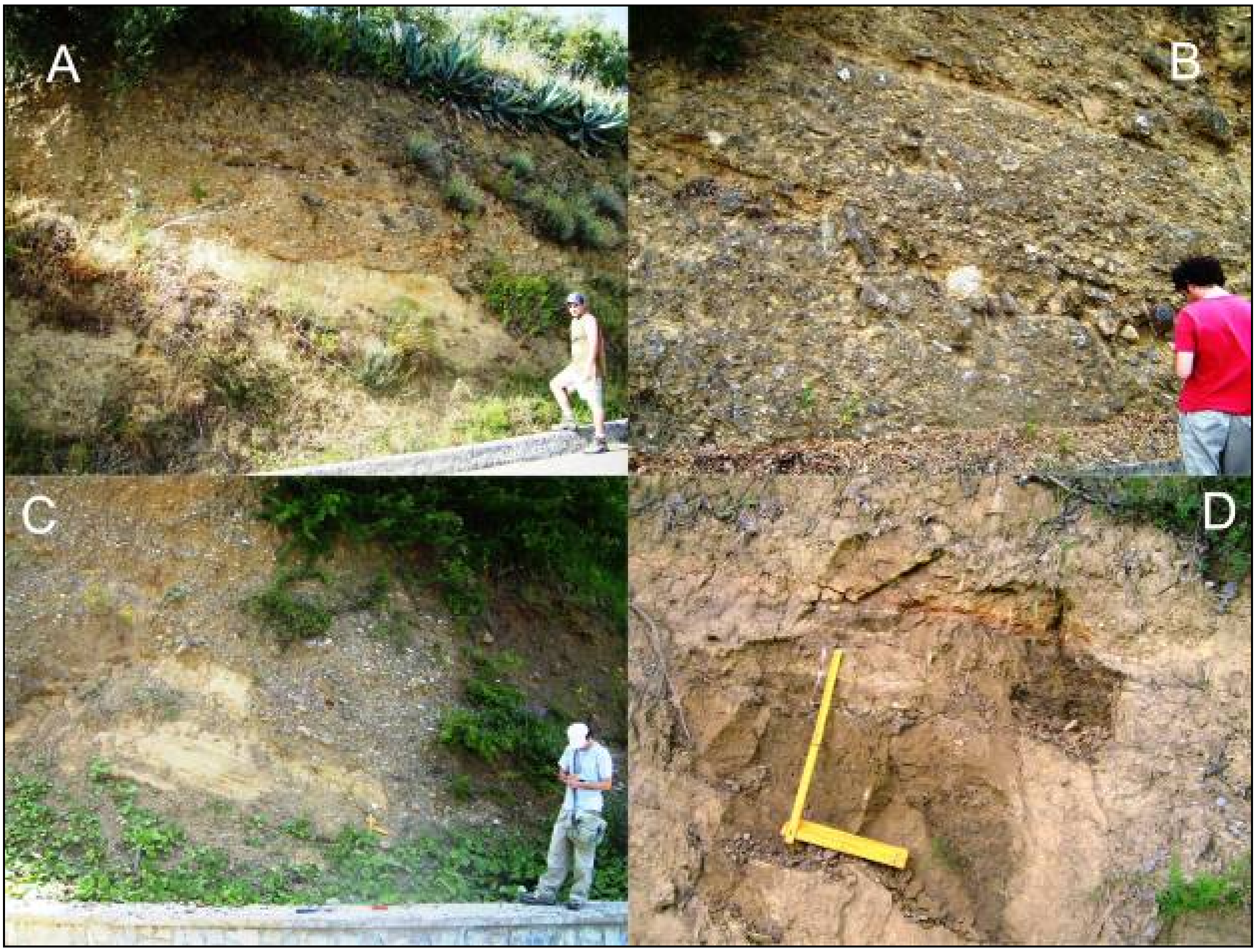


Fig. 5.16: the Missanello-Noepoli synthem cropping out in the area close to the town of Calvera (A), the town of San Chirico Raparo (B), and in the area close the town of Preti (C-D).

The Missanello-Noepoli synthem shows little facies variations in the whole basin. In the area close to the town of Calvera (central part of the Sant'Arcangelo basin) the deposit is made up of a conglomerate to sandy unit interrupted by a conglomerate lens, a few meter thick, the clasts inside the conglomerate lens range from a few cm to 1-2dm in size, they are subrounded and lithologically they are made by limestone, sandstone and chert, it is evident the erosional contact between the two units (fig. 5.16.A). In the area of San Chirico Raparo the deposit is made up of a well cemented matrix supported conglomerate, with a silty-sandy matrix, the clasts size range from a few cm to rare blocks of also 50cm, they are made up of sandstones (rich in plagioclase and with a few quartz), marls and shales (fig. 5.16.B). In the area close the town of Preti the synthem is represented by a silty-sandy deposit, with presence of conglomerate lenses 2-3dm thick, and with the presence of a pyroclastic level 2-3cm. This unit is passes towards the top to a conglomerate lenses 4-5m thick, with clasts ranging from a few cm to 2-3dm in size, the clasts are subrounded to rounded and they are made up of limestones, sandstones, marls, chert and cherty limestone (fig. 5.16.C-D). In this synthem, clasts derived from the Lagonegro units have been recognized in the areas Calvera and Preti, they are represented by chert from the Scista Silicei formation and cherty limestones from the Calcari con Selce formation.

- Serracorneta synthem (0.6-0.2Ma)

The Serracorneta synthem crops out on top of the hills that are present in the northern, western and southern portion of the Sant'Arcangelo basin, and it represents the closing cycle of the sedimentary filling of this basin (fig. 5.17).

Fig. 5.17: the Serracorneta synthem cropping out about 5km west of the town of Fardella (A), on the western portion of Serra della Cerrosa ridge (B) and on the suotheastern side of the Mt. Raparo (C-D).

In the western portion of Serra della Cerrosa ridge the deposit is made up of a matrix supported conglomerate, with sandy reddish matrix, the clasts vary from rounded to well rounded, they range from a few cm to 1-2dm in size, they are made by sandstones, marls, limestones and metamorphic rocks (fig. 5.17.A). In the area west of the town of Fardella the deposit consist of a matrix supported conglomerate, with sandy reddish matrix, the clasts range from a few cm to rare blocks of about 50cm, they are poorly rounded to sub-rounded and they are made by limestones, marls, sandstones, metamorphic rocks, cherty pelites, with the presence of sandy lenses a few decimetres thick (fig. 5.17.B). In the area close to the Mt. Raparo the Serracorneta synthem is made by a matrix supported conglomerate, with sandy reddish matrix, the clasts range from a few cm to 1-2cm, they are angular to sub-rounded, they are made by abundant limestones, with a few sandstone (very rich in muscovite, such as it occur for the sandstones inside the Caliandro synthem cropping out close to the Monte Cotugno dam, this data suggest that they probably derive from the Albidona Flysch, prof. G. Bonardi, personal communications), there is no chert, the abundance of the limestones, the lack of chert and the presence of the Albidona Flysch in the area north of the Mt. Raparo suggest a local provenience of this deposit (fig. 5.17.C-D).

5.8 MORPHOMETRICAL ANALYSIS OF THE AREA

5.8.1 ELEVATION MAP

The elevation map of the Noce-Sirino-Alpi-Sant'Arcangelo transect is shown in fig. 5.18.

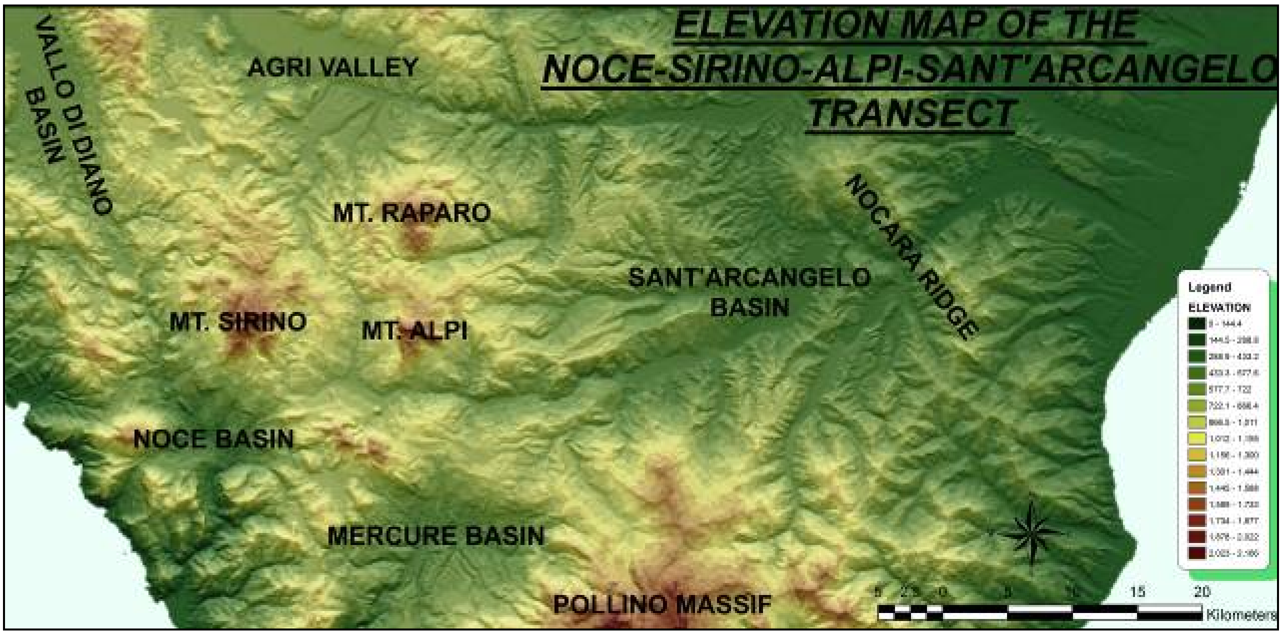


Fig. 5.18: "Elevation map of the Noce-Sirino-Alpi-Sant'Arcangelo transect".

The elevation in the study area ranges from the sea level to a maximum of 2166m a.s.l. (that is reached in the northern Pollino massif).

The highest peaks correspond with outcrops of the hardest lithologies, e.g. calcareous-siliceous rocks of the Lagonegro Units (Mt. Sirino, 2005m a.s.l.), carbonates of the Apennine Platform (Pollino massif, highest peak 2267m a.s.l.; Mt. Raparo, 1764m; Mt. La Spina, 1652m) and carbonates of the Apulian Platform (Mt. Alpi, 1900m a.s.l.). Other areas inside the transect where this type of hard lithologies crop out, but the elevation reached here is lower, are highlighted by the light brown colours and the correspond to the M.ti della Maddalena ridge (Mt. Serra Longa, 1503m a.s.l.), Mt. Cervaro (1170m a.s.l.), Serralunga ridge (1480m a.s.l.), Mt. Coccovello (1512m a.s.l), Mt. Crivo (1277m a.s.l) and Mt. Messina (1025m a.s.l): all these relief are limited to the western portion of the transect, very close to the Tyrrhenian coast, and they all correspond to the outcropping of the carbonates of the Apennine Platform.

The central-eastern portion of the transect is the lowest in the whole transect and corresponds to outcrops of the weaker lithologies, such as the Liguridi Units, the North-Calabrian Units, the Sicilidi Units and the fillings of the Sant'Arcangelo basin and of the Bradanic foredeep.

The main valleys and intramontane basin are characterized by different elevations west and east of the Apennine divide. In particular, if we consider the intramontane basin of the Vallo di Diano and the high Agri valley, we have that, despite they are characterized by the outcrops of the same lithologies (e.g. quaternary continental deposits), the Vallo di Diano basin is located west of the Apennine divide and it reaches a medium elevation of about 450m a.s.l. while the Agri valley is located east of the Apennine divide and it reaches a medium elevation of about 550m a.s.l.. This situation occurs also in the southern portion of the transect: here there are the Noce valley and the Cogliandrino valley, which both cut the North-Calabrian Units, but the Noce valley is located west of the Apennine divide and it reaches a medium elevation of about 300m a.s.l., while the Cogliandrino valley is located east of the Apennine divide and it reaches a medium elevation of about 800m a.s.l.. This data suggest that the valleys on the Ionian flank are located at higher elevations than the Tyrrhenian valleys, as it has been discussed in the previous chapter (see sect. 3.2 and 3.3).

Another interesting feature is the presence of wide areas with an almost constant elevation. Such areas are located respectively east of Mt. Raparo and Mt. Alpi highs and in the area comprised between Mt. Alpi, Mt. Raparo and the north side of the Mt. Sirino. In the first area the elevation ranges from 700m and 900m a.s.l.. In the second area the elevation ranges from 1200m and 1400m a.s.l.. These two almost flat areas, that seem to assume the meaning of a paleosurface, are shown in fig. 5.19.

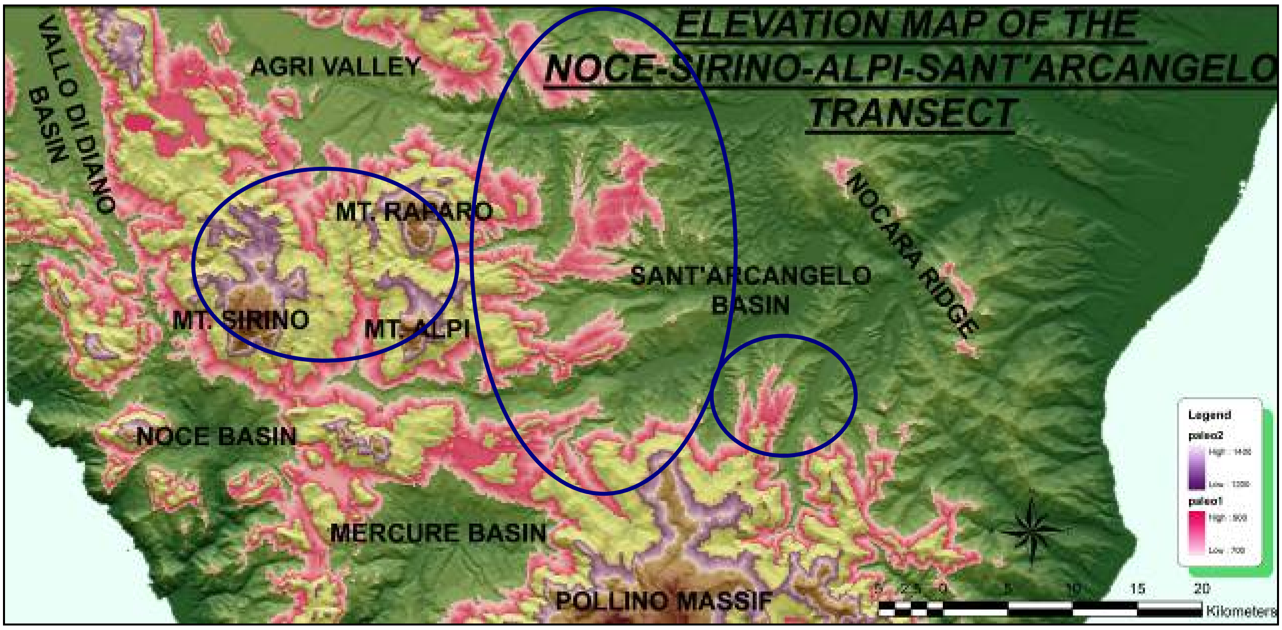


Fig 5.19 : location of the wide areas that seem to assume the meaning of a palesurface inside the transect, the areas of interest are marked by the blue circles.

It is interesting to notice that the area with the elevation ranging from 700m and 900m a.s.l. corresponds to the top of the Serracorneta Conglomerate, which represents the top of the sedimentary sequence of the Sant'Arcangelo basin, and that is 0.6Ma in age (Benvenuti et al., 2006). This *paleosurface* so coincides with the top eroded surface of the Serracorneta Conglomerate and so it is about 0.6Ma in age too (we'll see in the next sections that this data will be very useful to the analysis).

The highest *paleosurface* (1200-1400m a.s.l.) cuts different lithologies (e.g. Lagonegro units of the Mt. Sirino, Apennine carbonate of the Mt. Raparo and Apulian carbonates of the Mt. Alpi), so its formation took place after the exhumation of the Mt. Alpi and the Mt. Sirino ended, and the landscape looked almost like the present one.

5.8.2 MEDIUM ELEVATION MAP

The medium elevation map has been calculated by using a 5*5km moving window, the map is shown in fig. 5.20.

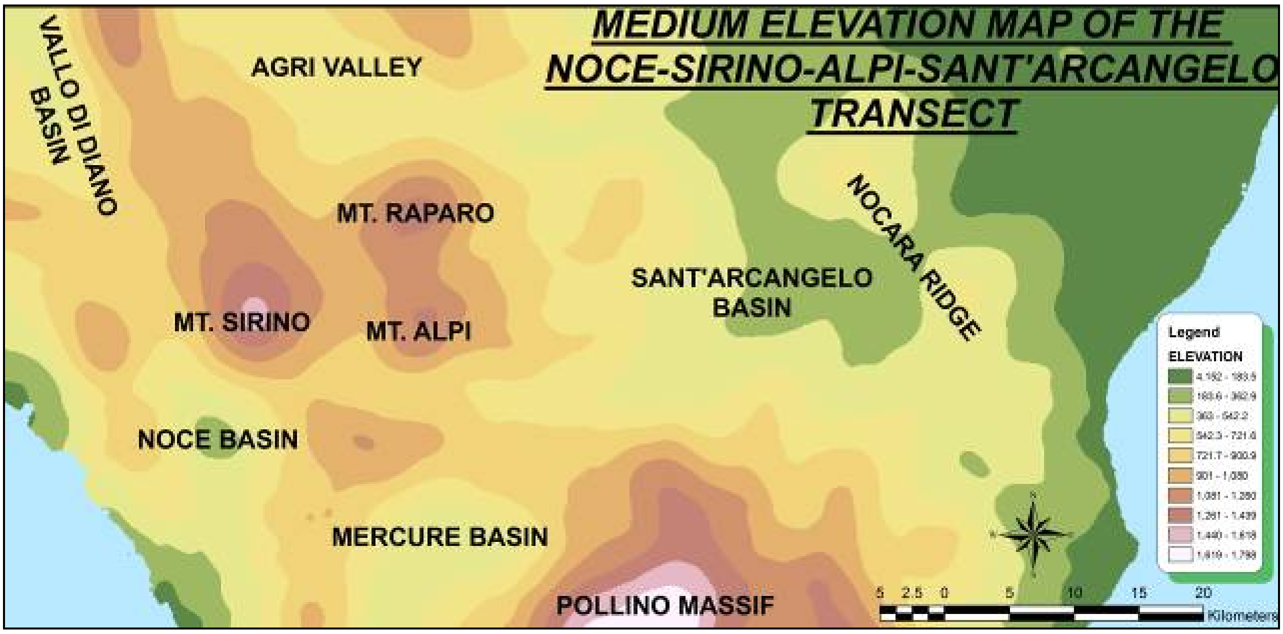


Fig. 5.20: "Medium Elevation Map of the Noce-Sirino-Alpi-Sant'Arcangelo transect"

By the medium elevation map we can observe that:

- the highest portions of the transect are the central and western one, which include the highest peaks in fig. 5.18;
- the medium elevation on the west side of the transect is relatively high in relation to the eastern side;
- the hypothesized paleosurfaces of fig. 5.18 are more evident in this map, where they are shown by the light brown (700-900m a.s.l.) and by the dark brown (1200-1400m a.s.l.) colours;
- some river valleys disappears in comparison to the map of fig. 5.18, and in particular this is the case of the Peschiera, Cogliandrino, high Noce, high Calore and Frido rivers valleys;
- some river valleys enlarged if compared to the map of fig. 5.18, this is the case of the Agri valley in the area where it cuts a gorge into the Gorgoglione Flysch, and the Sinni river in the area where it crosses over the Nocara ridge (here, the Sinni valley seems to merge with the Sarmento valley);
- the Noce valley is closed to the south by the Mt. Messina-M.ti di Trecchina reliefs, and it looks like an endoreic basin.

5.8.3 ENVELOPE MAP

The envelope map is shown in fig. 5.21.

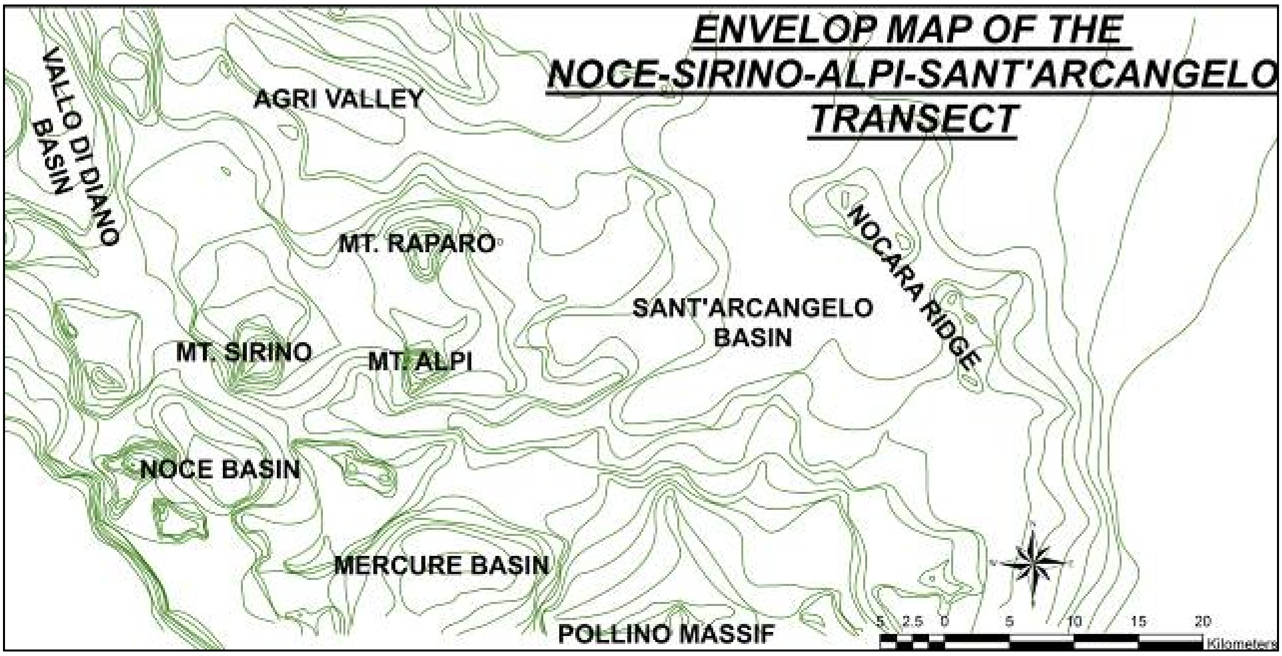


Fig. 5.21: “Envelope Map of the Southern Apennines”, the contour lines are 100m spaced.

The “Envelope Map” approximate the shape of the landscape in the absence of the more recent fluvial dissection (which is the dissection due to the low order trunks). The transect can be separated in different areas showing peculiar features:

- the westernmost and the central portions of the transect are characterized by several highs separated by wide, almost flat, areas; these highs correspond with the highest peaks of the map of fig. 5.18;
- particularly evident appear the Vallo di Diano and the high Agri intramontane grabens, which are separated by a wide divide (that corresponds with the M.ti della Maddalena ridge);
- the central-eastern sides of the transect show a much gentler relief. Here the topography is characterized by a low slope landscape dissected by two main river valleys (i.e. the Sinni and the Agri valleys);
- the map enhances the different shape of the Tyrrhenian and Ionian coasts; the first one is much steeper, assuming the features of a tectonic sea-cliff;
- both the Noce and the Mercure river valleys assume the feature of an endoreic basin;
- the smooth surfaces shown in fig. 5.18 are more evident, in particular the *paleosurface* at 700-900m a.s.l. extents more towards the south, widening in correspondence of the Sinni-Mercure divide, while the *paleosurface* at 1200-1400m a.s.l. extents more towards the north, involving all the area between the M.ti della Maddalena ridge and the Mt. Sirino and comprising all the area between the Mt. Sirino, Mt. Alpi and the Mt. Raparo (in this case the high Cogliandrino and the high Maglia valleys are completely deleted by the presence of such paleosurface);
- for the reasons previously discussed (see sect. 5.8.1) these two *paleosurfaces* seem to identify a syn-Serraconrneta landscape which is trapped into a pre-Serracorneta landscape;

- by the smoothed topography, a more striking distinction between sectors with different elevation can be done. This allows hypothesizing the presence of major tectonic lineaments which are sketched in fig. 5.22.

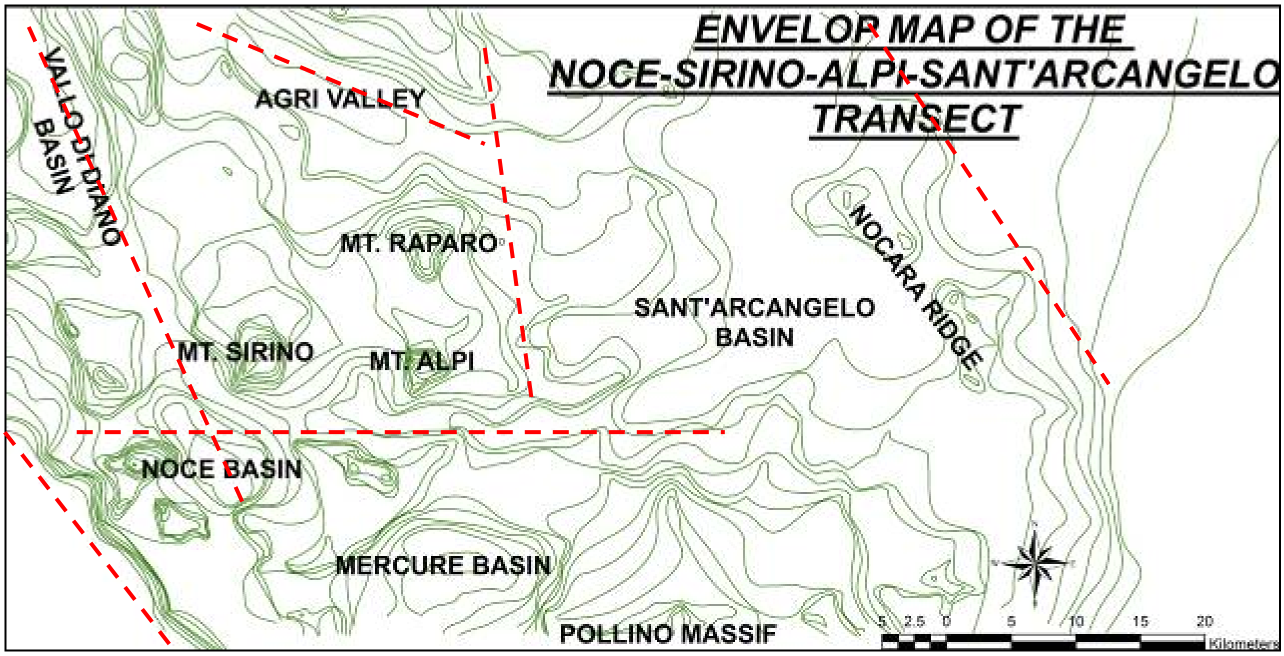


fig. 5.22: "Envelope Map of the Sirino-Noce-Alpi-Sant'Arcangelo transect" with the location of the supposed tectonic elements that seem to have played a relevant role separating areas with different morphological features.

5.8.4 SLOPE MAP

The slope map of the transect (fig. 5.23) has been created with the aim to determine another morphometrical parameter to characterize the study area, considering that the slope is one of the most relevant features of the landscape because it allows us, for example, a better individuation of some flat area that is not clear by the elevation map: one of the main aim that allowed us to the creation of this map is so to verify the real flat features of the proposed paleosurfaces of fig. 5.19.

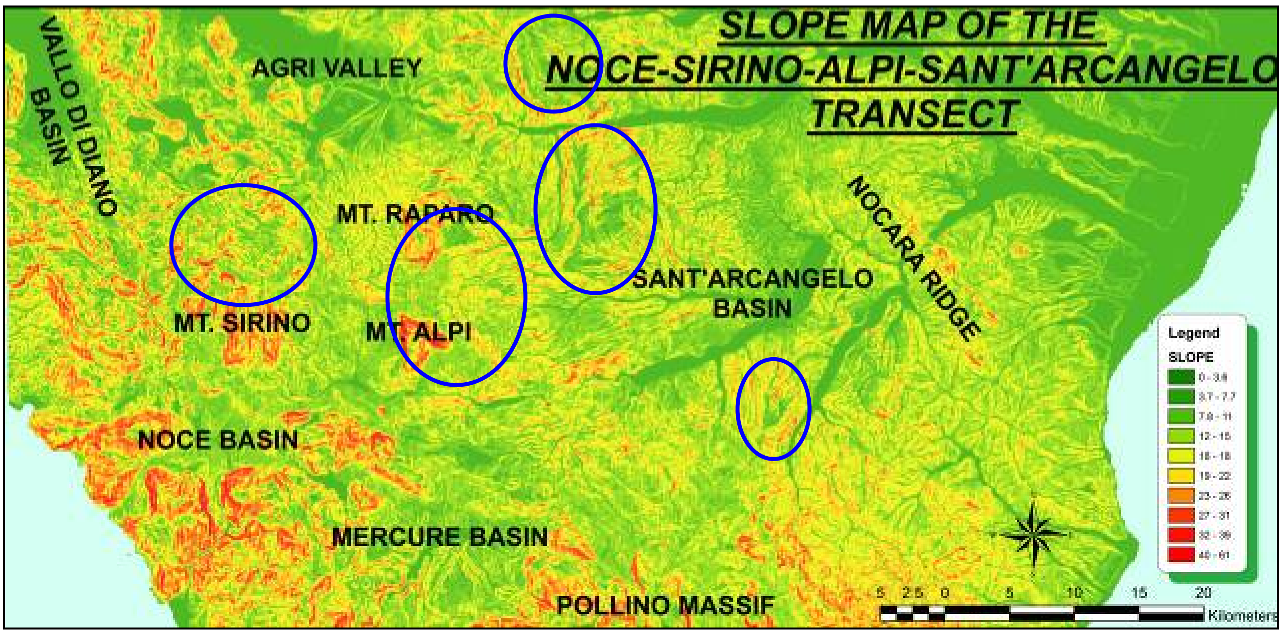


Fig. 5.23: "Slope Map of the Sirino-Noce-Alpi-Sant'Arcangelo transect".

As we can see from the map, the red colours indicates the steeper areas, whereas the green colours indicate the gentler areas.

We can see that the steepest portions of the transect are limited to the western side of the study area and they correspond with the hillslopes formed in the hardest lithologies, and in particular the carbonate of both the Apulian and Apennine Platforms and the calcareous-siliceous units of the Lagonegro Units.

It is interesting to notice that the only area on the eastern side of the transect that shows red colours is individuated on the Nocara ridge. In this case this steep area corresponds with the outcrops of the relatively hard Albidona Flysch in an area dominated by the weak Sicilidi Units.

The gentler portion of the chain is individuated east of Mt. Raparo-Mt. Alpi, enhancing a difference between the central-western and the eastern side of the transect that was previously noticed by the analysis of the “Envelop Map” (fig. 5.20). Here there is a dominance of the yellowish to dark greenish colours, in particular the gentler areas are located in correspondence of the main valleys (the Sinni, the Agri and the Sarmento valley), and in the area east of the Nocara ridge.

If we look at the map, we see how there are wide greenish areas east of the Mt. Raparo-Mt. Alpi and in the area between the Rubbio and the Sarmento valleys. These areas are located on the divides and they correspond with the individuation of the proposed paleosurface of 700-900m a.s.l.. The second proposed paleosurface (1200-1400m a.s.l.) is not well represented in this map: the area between the Mt. Sirino, the Mt. Raparo and the Mt. Alpi is characterized by several green sectors, but they seem to be widespread in the area between the Mt. Raparo and the Mt. Alpi, while they seem to be more concentrated in the area north of the Mt. Sirino, so in this case it’s just the area north of the Mt. Sirino that assumes the features of a paleosurface, while the same consideration cannot be argued for the area between the Mt. Raparo and the Mt. Alpi.

5.8.5 SLOPE OF THE FIRST ORDER CHANNELS

The “Slope of the First Order Trunks Map” has been created for the area of the Sant’Arcangelo basin. This was done in order to apply this method of investigation to a lithologically homogeneous area, and rule out the control exerted by rock erodibility on channel slope. The Sant’Arcangelo basin is the only area that can be considered homogeneous in term of erodibility, allowing the application of this technique of analysis. The map is shown in fig. 5.24.

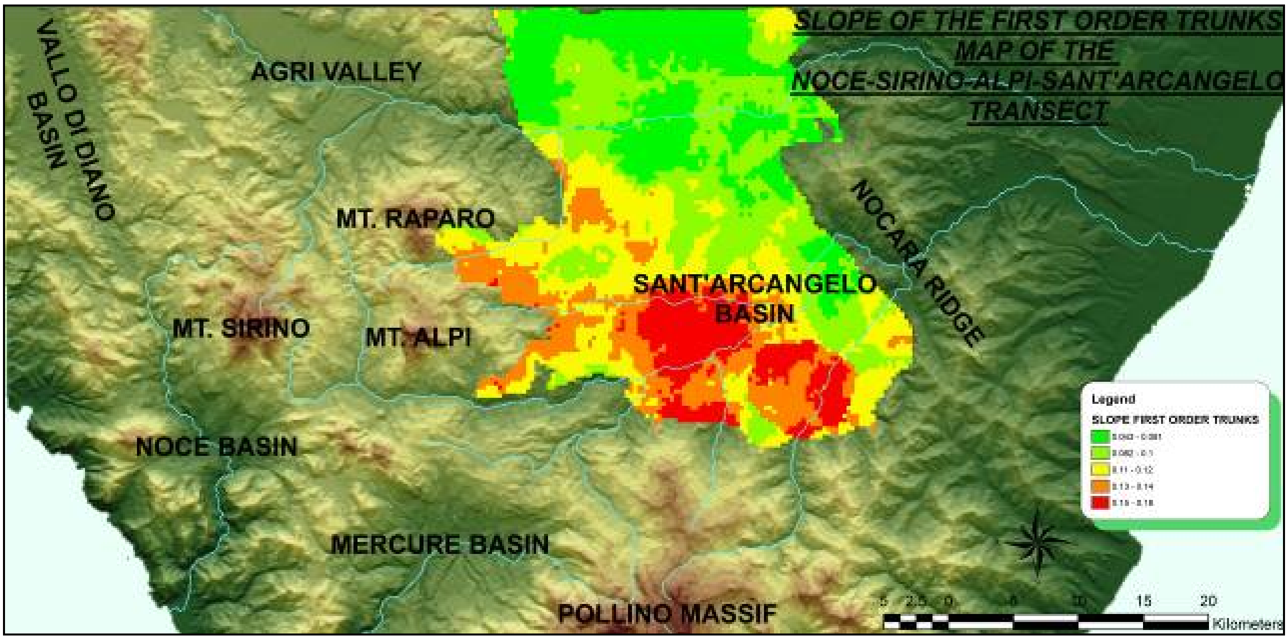


Fig. 5.24: “Slope of the First Order Trunks Map of the Noce-Sirino-Alpi-Sant’Arcangelo transect”.

As we can see from the map, the Sant'Arcangelo basin can be distinguished in two different sectors, that are separated by a NW-SE trending lineament extending from the Agri-Racanello confluence to the lowermost reach of the Sarmento valley.

The area located north-east of this lineament is characterized by very low values of the slope of the first order channels, as it can be easily recognized by the dominance of the greenish colours.

The area located south-west of this line is characterized by the higher values of the slope of the first order channels, that are identified by the orange to red colours in the map: in particular, the highest values in the whole Sant'Arcangelo basin are reached in the middle part of the Sinni valley (and in particular in the area comprised between the confluences with the Frida, the Rubbio and the Serrapotamo rivers), in the middle reach of the Sarmento river, in the area between the Sarmento valley and the Sinni valley, and in the easternmost portion of the basin (in the area between the Mt. Raparo and the Mt. Alpi).

This data suggest that the areas highlighted by the orange and the red colours have experienced more faster uplift than the areas in the greenish colours. There is an independent data that could confirm this hypothesis: the Serracorneta Conglomerate, which are located at an elevation ranging from 700 to 900 m a.s.l. in the south-western portion of the Sant'Arcangelo basin, reach elevations higher than 1000m a.s.l. in these areas.

5.8.6 DRAINAGE BASINS

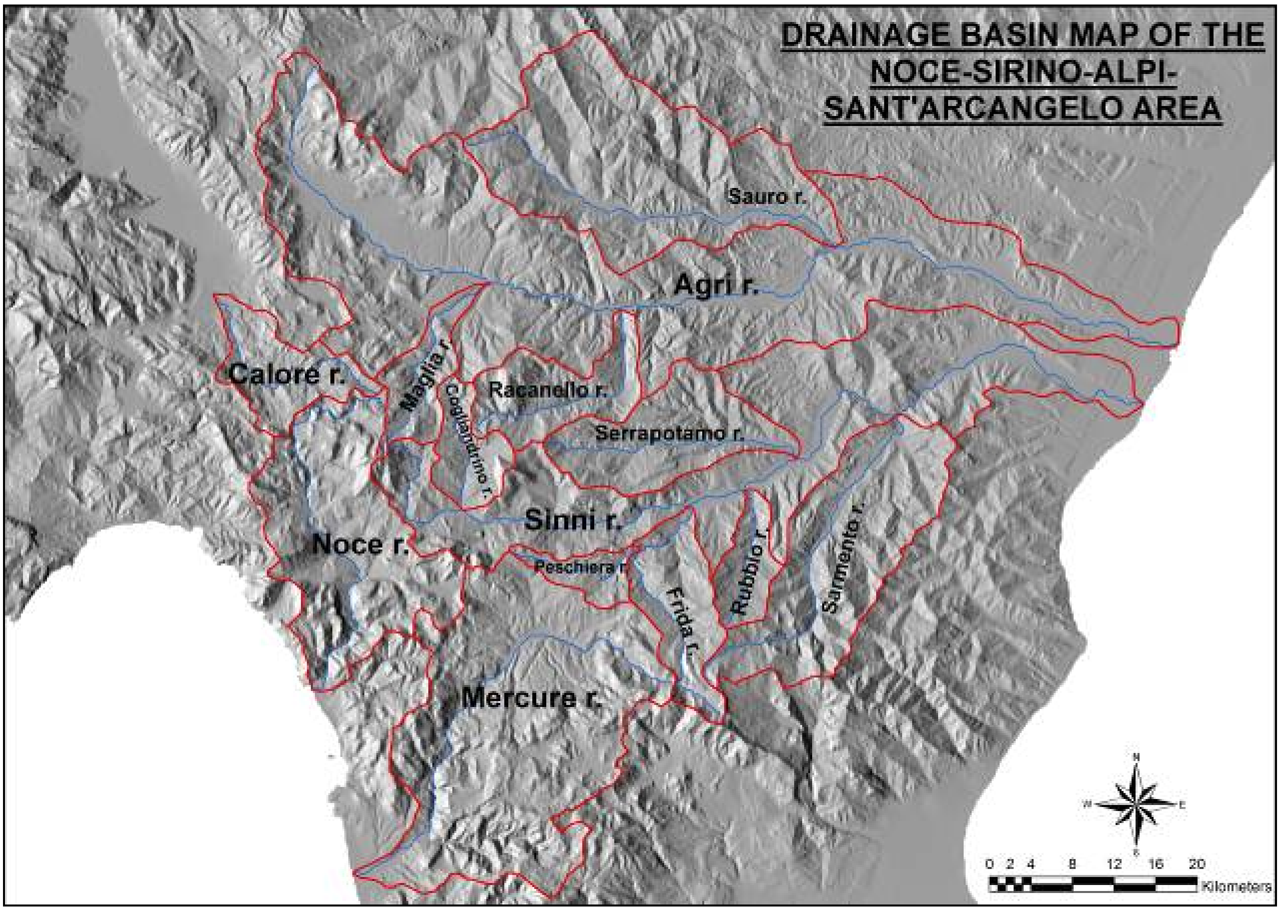


Fig. 5.24 = drainage basins map of the Noce-Sirino-Alpi-Sant'Arcangelo area.

One of the first considerations to do about the Drainage Basins Map (fig. 5.25) is the clear difference that occurs between the size and shape of the watersheds on the Tyrrhenian and the Ionian flanks: the Tyrrhenian watersheds are smaller than the Ionian ones which, in turn, show an elongated shape with an average apenninic trend, different from the more circular shape of the Tyrrhenian drainage basins.

It is possible to recognize in this area five major watersheds: the Calore, Noce and Mercure basins on the Tyrrhenian flank, and the Sinni and the Agri basins on the Ionian flank. Several sub-basins have been also mapped for the Ionian rivers, whose dimensions are comparable with those one of the Tyrrhenian drainage basins. The considerations regarding the shape of these sub-basins are included into the discussion of their main trunks drainage basin.

In the high Sinni river, in the area comprised from the headwater to Mt. Alpi, the watershed is wider on the idrographic left than on the idrographic right. From Mt. Alpi to the Nocara ridge the right flank is wider than the left flank. This switch can be interpreted as the result of the competition between the Sinni and the Mercure basin, with the Sinni basin that, in this area,, has been truncated because of the formation of the Mercure lacustrine basin. This has also determined the lack of important right tributaries upstream of Mt. Alpi area, right tributaries that start to appear immediately downstream the Mt. Alpi with the Peschiera, Frido, Rubbio and Sarmento rivers. Another consideration to do about the Sinni drainage basin is the convex shape of the watershed in the area between the Mercure and the Sinni valleys: this particular concave shape can be interpreted as due to a widening of the Mercure basin respect to the Sinni basin, so that we can say that the Mercure basin is “eating” part of the Sinni basin. In its southern portion the Sinni watershed crosses the carbonate Pollino massif. In this area, that corresponds with the high Frida and the high Sarmento river valleys, the watershed is characterized by an abrupt change of direction, that varies from NW-SE to N-S, and it then vary again from N-S to about W-E, with a general concave shape. From this point the Sinni watershed proceeds with a mean SW-NE orientation to the Nocara ridge. Downstream the Nocara ridge the divide changes its orientation, with a mean W-E direction that is constant until the river mouth. The north side of the Sinni watershed is characterized by a mean WNW-ESE orientation in the area from the Sinni mouth to the Nocara ridge. From this point until the area east of the Sirino massif, the Sinni watershed is characterized by two important convex sector, the first one comprised between the Nocara ridge and the north side of the Serrapotamo valley, while the second one is individuated in the area between the north side of the Serrapotamo valley and the Sirino massif. Those two concave portions of the Sinni watershed testify the widening of the Agri basin respect to the Sinni basin. It is important to notice that the second concave sector is interrupted by the Cogliandrino valley. The Cogliandrino river is a N-S oriented left tributary of the Sinni river which valley can be separated in two distinct portions, a lower one with a more circular shape and un upper one with a more elongated shape: in particular the upper reach interrupt the general concave shape of the Sinni watershed, determining an inversion of the “eating” relationship between the Sinni and the Agri rivers, with the Sinni basin that in this area is widening respect to the Agri basin. In addiction to this feature, we have to notice that on the extreme west side of the Sinni watershed, in correspondence of the Sirino massif, there is a narrow and long upper reach of the Maglia valley (a right tributary of the Agri river) that seems to cut the Sinni watershed, and that has a correspondence with the southern limit between the Racanello (right tributary of the Agri river) and the Sinni divide: in this area the Agri river was probably much larger towards the south, and this southern portion of the paleo-Agri basin has been then captured by the Sinni basin, in particular in the area of the Cogliandrino valley where the presence of weak lithologies (Albidona Flysch and North-Calabrian units) encouraged the regressive erosion responsible of the capture of this part of the paleo-Agri basin.

The Noce watershed is characterized by a few anomalies. In the area between the north side of Mt. Sirino and its west slope, the Noce watershed follows a NNE-SSW direction, while it changes its direction as it moves south of Mt. Sirino, following a NNW-SSE direction. This change of direction occurs in correspondence of a lithological variation, in particular there is the passage from the Lagonegro Units cropping out on the Mt. Sirino to the North-Calabrian Units cropping out in the area south of the Mt. Sirino. The widening of the Noce basin is also clear in the area between the town of Lauria and the Mt. Messina: here the Noce watershed presents a clear concave shape that testifies the enlargement of the Noce basin respect the Sinni and the Mercure basins. Moving from this enhanced concave portion of the watershed to the south, the Noce watershed proceeds almost constantly following a NE-SW direction, with a few convex sectors that indicate a widening of the drainage basin adjacent to the southern portion of the Noce valley respect the same Noce basin. The west side of the Noce watershed follows an almost constant NNW-SSE direction, with an enhanced convexity in correspondence of the Fiumitello creek, a small river flowing from the Mt. Coccovello to the Tyrrhenian coast: the outcropping of "weak" North-Calabrian Unit in the Fiumitello valley has encouraged the widening of this basin respect to the Noce basin, determining the occurrence of such a convex sector. In the upper part of the Noce valley, the watershed follows an almost constant SW-NE direction, with a slightly concave shape of the whole area: this feature, together with the occurrence of several oro-idrographic anomalies (hanging valleys, gorges) seem to indicate that in this area the Noce basin has enlarged respect to the Calore basin. One of the most relevant features to notice about the Noce watershed is that its western sector is very close to the Tyrrhenian coastline. This is an important feature if we consider that the rivers flowing close to the Tyrrhenian coast, west of the Noce basin, are very steep low order trunks with very small drainage basins. This data testify that, despite their steepness, these trunks have not yet captured the Noce basin, which can be justified considering that the Tyrrhenian coast is very young (the youth of the Tyrrhenian coast is also testified by the fact that the oldest marine terraces recognized in this area are Middle Pleistocene in age, Filocamao, 2006).

The west side of the Calore watershed looks almost perfectly rectilinear, with a SSE-NNW direction, a rectilinear shape that is interrupted by a concave sector where the Calore river seems to be enlarged respect to its adjacent basin. The northwestern side of the Calore drainage basin is characterized by a general NW-SE direction, with the Calore watershed turning around the active polje of the Magorno plain.

If we consider the western portion of the Agri basin, south of the Magorno plain the Agri watershed proceeds following a NW-SE direction along the Calore-Agri divide, while it changes its direction following a N-S direction along the Noce-Agri divide. Regarding the northern side of the Agri basin, north of the Magorno plain, the Agri watershed changes its orientation, passing from a SSE-NNW direction to a SSW-NNE direction. In this area the watershed presents the continue alternation of concave and convex sectors, that enhance the "eating" relationships between the Agri basin and its adjacent basins. In the northern-eastern portion of the Agri basin, the watershed is characterized by an abrupt change of direction, that varies from NNW-SSE to NE-SW, and that give a clear convex shape to this portion of the basin: this convex sector occurs in correspondence of a tectonic contact between the Lagonegro Units (cropping out in the Agri basin) and the Sicilidi Units (cropping out north of the Agri basin, in the Basento valley), and it is probably the main responsible of this convex sector, because the outcropping of the weak Sicilidi Units north of the Agri basin has encouraged a widening of the Basento basin respect to the Agri basin. From this point until the mouth, the Agri watershed shows an almost rectilinear shape, with small concave and convex sectors, and following a general NW-SE direction.

5.9 GEOMORPHOLOGICAL ANALYSIS OF THE TRANSECT

The Geomorphoogical analysis of the transect has been focused on the individuation of the main morphostructural elements (e.g., fault scarps and fault line scarps, low passes, subsequent rivers, hanging valleys, gorges), and basically it consists in a morphostructural analysis.

The recognized elements have been mapped in the Autocad environment on a contour map, with the contour lines that are 50m spaced. The main morphostructural features of the transect are described as it follows by showing several sketches of the morphostructural map of the transect, that are relative to the more interesting areas, and in particular Mt. Raparo, Mt. Alpi and Mt. Sirino areas and the high Noce valley.

5.9.1 MT. RAPARO AREA

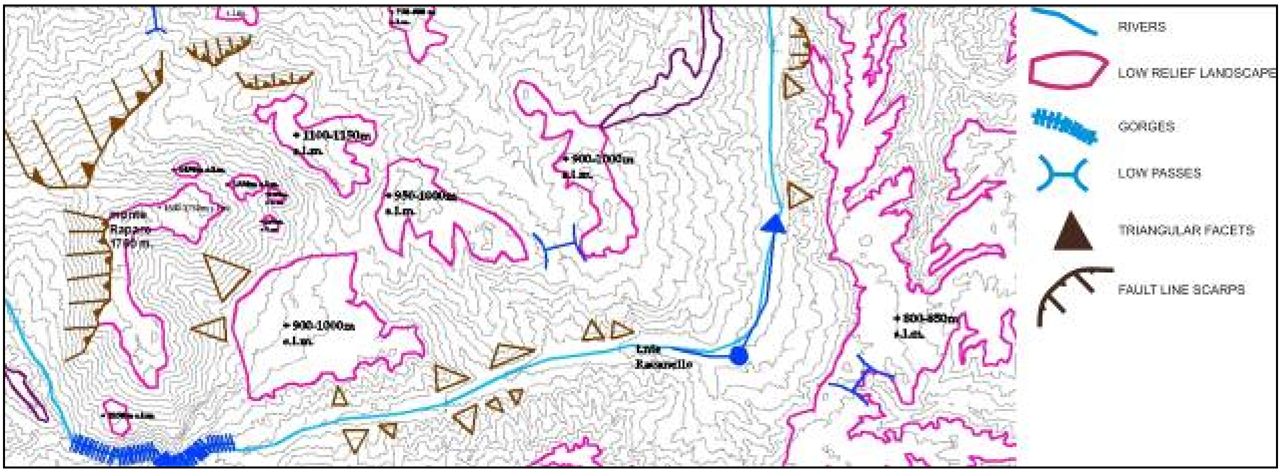


Fig. 5.26: sketch of the "Morphostructural Map of the Noce-Sirino-Alpi-Sant'Arcangelo transect" relative to the Mt. Raparo-Racanello creek area.

The area around Mt. Raparo (fig. 5.26-5.27) is characterized by a gentle landscape that is marked by the presence of several "low relief landscapes", which are wider on the central and eastern portion of the area where they correspond to the eroded depositional surface of the Serracorneta Conglomerate (see sect. 5.5-5.7), and are found at an elevation of about 800-1000m a.s.l (this morphostructural elements play an important role in the morphotectonic evolution of the area, as it has been discussed in the previous 5.8.1 to 5.8.4 sections). Some small flat landforms occur also around Mt. Raparo, they are smaller than the previous one because they cut the hard Apennine carbonates of Mt. Raparo, and they reach an elevation of about 1200-1300m a.s.l. on the north side of Mt. Raparo, an elevation of about 1250m a.s.l. on its south side, and an elevation of about 1700m a.s.l. on top of the Mt. Raparo.

Another important feature of this area is due to the presence of several fault line scarps and triangular facets: this elements show different orientation that vary from W-E to SW-NE until N-S, and, together with the marked straight shape of the Racanello valley, give to the Racanello river the feature of a subsequent valley along most of its course.

The area is also characterized by the occurrence of several low passes interrupting the continuity of some of the "low relief landscapes", there is a gorge along the Racanello river in the area where it flows south of the Mt. Raparo, and the Racanello river presents an L-shape in the middle part of its course that is due to a capture of the Agri river. It is interesting to notice that such L-shape is located in correspondence of a low pass in the westernmost "low relief landscape", so it is possible to hypothesize that the Racanello river used to flow following a W-E direction before the Agri river captured it.

Fig. 5.27: some pictures from the Mt. Raparo area; A) the erosional terrace on the southern side of the Mt. Raparo located at 1250m a.s.l. B) the gorge that the Racanello river cuts on the southern side of the Mt. Raparo.

5.9.2 MT. ALPI AREA

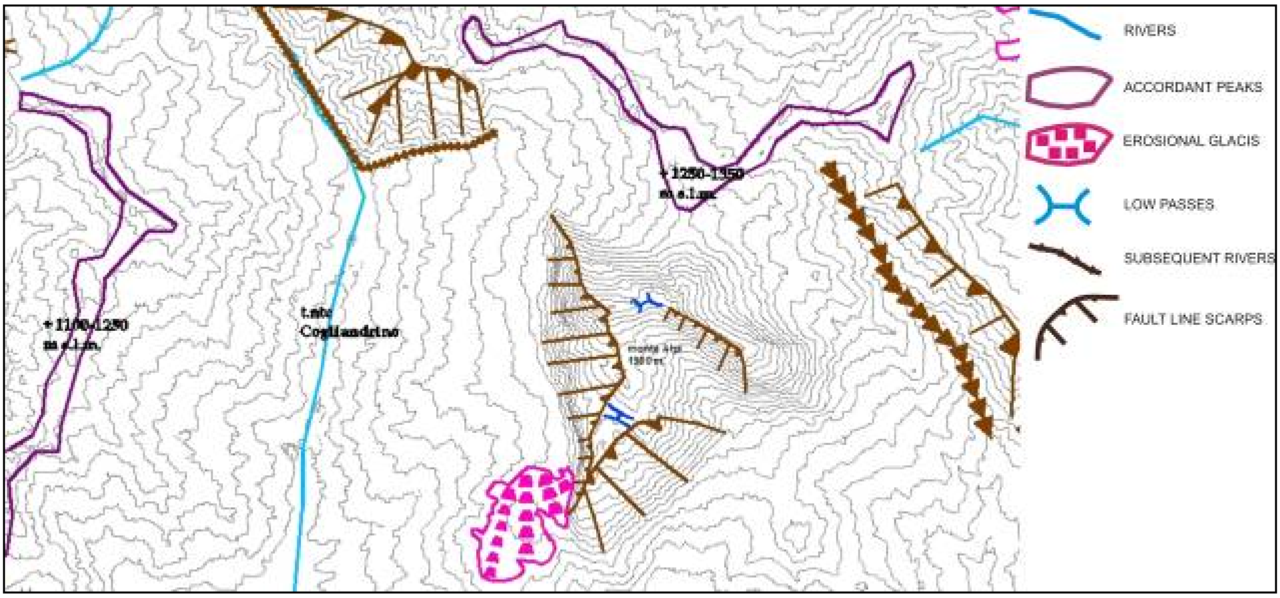


Fig. 5.28: sketch of the "Morphostructural Map of the Noce-Sirino-Alpi-Sant'Arcangelo transect" relative to the Mt. Alpi area.

In Mt. Alpi area (fig. 5.28-5.29) landforms that are interpreted as low relief landscapes are represented by gentle ridges (such as the divide between the Sinni and the Cogliandrino rivers) or to accordant peaks (such as in the area north of the Mt. Alpi) or to erosional glacis (such as on the southwestern side of the Mt. Alpi). All these flat features are at an elevation a.s.l. of about 1100-1300m, and they correspond with the highest almost flat area recognized in the elevation map (see sect. 5.8.1 to 5.8.4).

Mt. Alpi presents on its top two low-passes (which are intended as morphological lows comprised between two morphological highs, not correlated to the local base level) that are individuated at an elevation of about 1400m a.s.l. and 1800m a.s.l. respectively

The morphostructural map is then completed by the presence of several fault line scarps (they are individuated on the western and southern side of the Mt. Alpi) showing different orientation, that vary from N-S to NW-SE, W-E and SW-NE, and by the presence of some subsequent rivers such as the Cogliandrino creek (in the uppermost reach of its course) and the Fiumitello creek (east of the Mt. Alpi).

Fig. 5.29: some pictures from the Mt. Alpi area; A) the west slope of the Mt. Alpi and the low pass located at 1400m a.s.l.; B) particular of the low relief individuated in the area north of the Mt. Alpi.

5.9.3 MT. SIRINO AREA

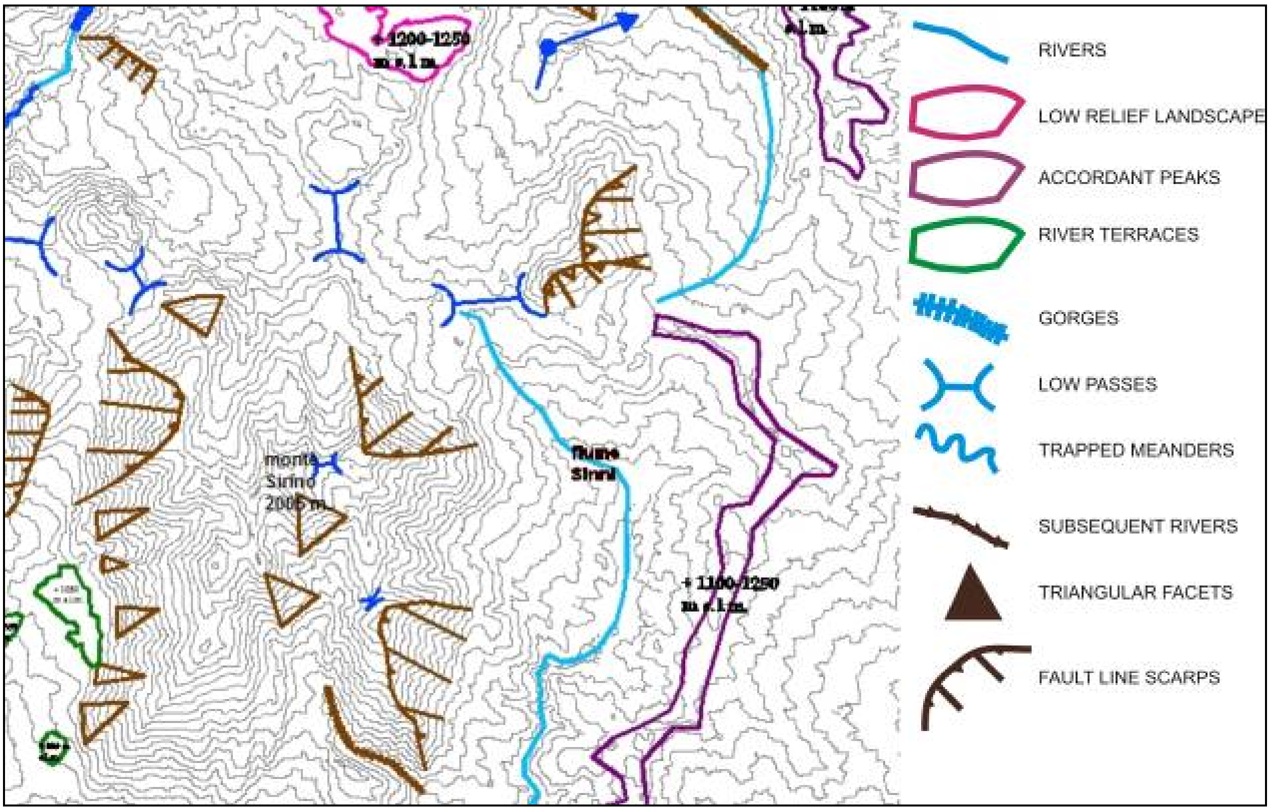


Fig. 5.30: sketch of the “Morphostructural Map of the Noce-Sirino-Alpi-Sant’Arcangelo transect” relative to the Mt. Sirino area.

Mt. Sirino area (fig. 5.30-5.31) is dominated by the presence of tectonic and idrographic landforms. Mt. Sirino is bounded by several fault line scarps and triangular facets, which show a prevalent N-S orientation, with some isolated fault line scarps NW-SE oriented and W-E oriented. Fault line scarps occur also NE of Mt. Sirino, on the Sinni-Maglia divide, with a W-E and a N-S orientation.

There are some flat elements that are represented by gentle ridges and by low relief landforms, located east and north of Mt. Sirino at an elevation a.s.l. of about 1100-1250m.

The area is characterized by the occurrence of several low passes, some of which are very small and occur on top of the Mt. Sirino, while most of them are wider and are found in the area north of the Mt. Sirino, around 1200-1300m a.s.l. that is similar to the elevation of the flat elements previously discussed.

Fig. 5.31: some pictures from the Mt. Sirino area; A) the Mt. Sirino seen from the north, it is possible to recognize the glacial circle that is present on the north side of the Mt. Sirino; B) the Sinni-Cogliandrino divide.

5.9.4 THE HIGH NOCE VALLEY

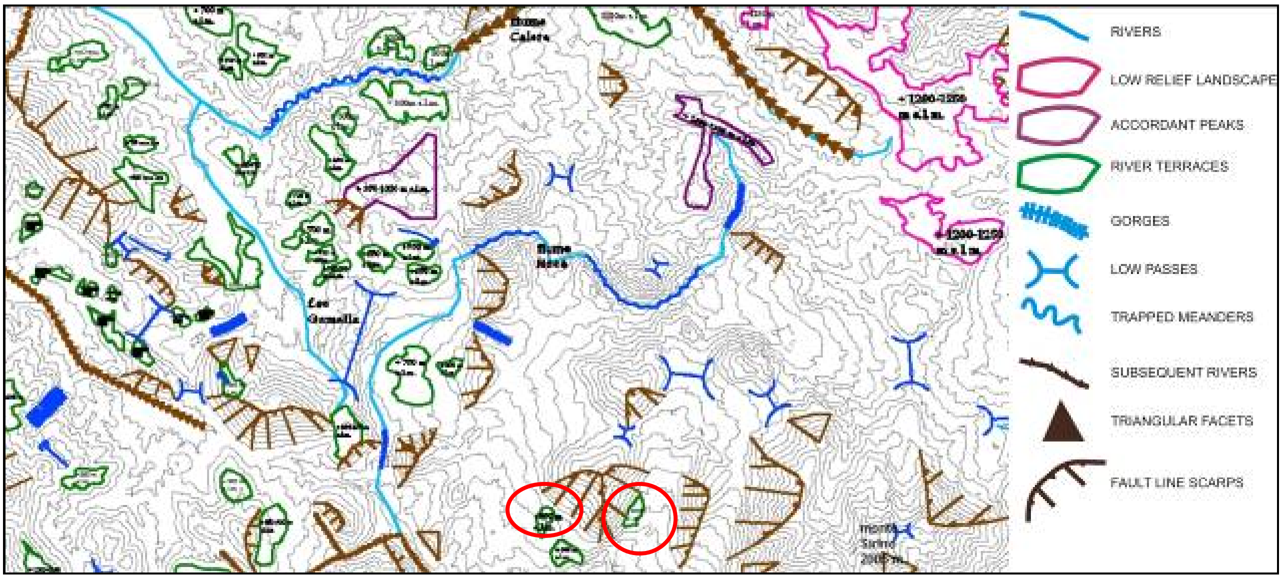


Fig. 5.32: sketch of the "Morphostructural Map of the Noce-Sirino-Alpi-Sant'Arcangelo transect" relative to the high Noce valley area, the circled river terraces are shown in fig. 5.32.B.

The high Noce valley is characterized by the presence of some remnants of the low relief landforms in the eastern portion of the area at elevation a.s.l. of about 1200-1300m.

In the area are recognized several fault line scarps with orientation varying from N-S to NW-SE, W-E, NE-SW. These landforms are found at tectonic contacts between the "hard" Apennine carbonates and the "weak" North-Calabrian Units.

The area is characterized by the presence of a large number of low passes and by the presence of several gorges and trapped meanders along both the high Noce than the high Calore valleys which are the effect of a lowering of the local base level.

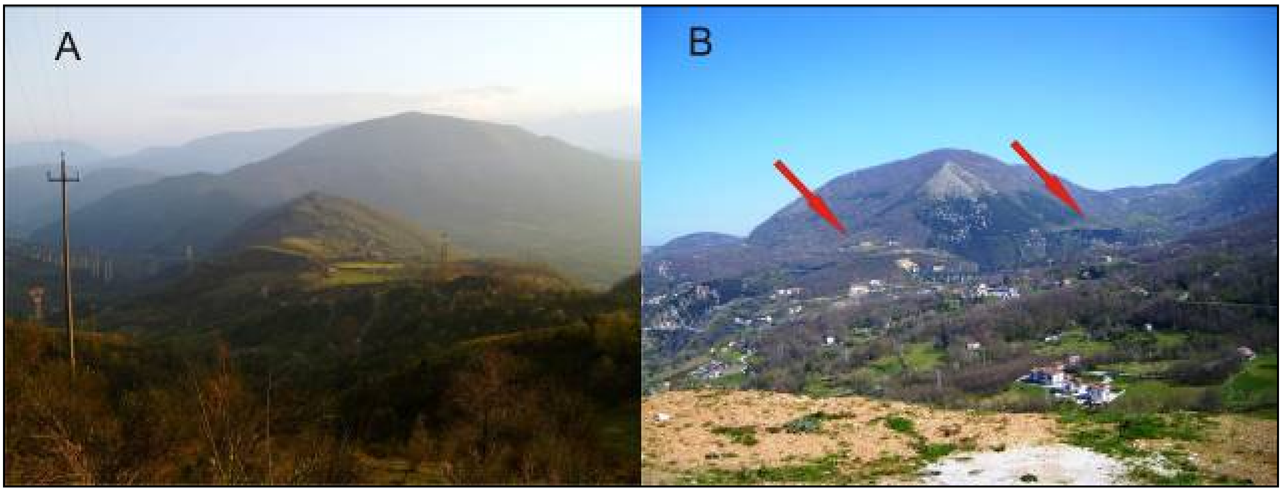


Fig. 5..33: some pictures from the High Noce valley area; A) Noce-Gamella divide; B) river terraces circled in fig. 5.x

5.10 THE ANALYSIS OF THE RIVER TERRACES AS A MEAN TO CONSTRAINT THE ROCK EXHUMATION PROCESSES

The river terraces are one of the most powerful geomorphological elements of the landscape, because they can help us to determine how the landscape has changed and at what rate.

The analysis of the river terraces have been carried out on both the Sinni and the Noce valleys. It has been carried out with the aim to reconstruct the history of the vertical motions (both absolute and relative) of these areas by the recognition of the local base level variations, and the individuation of the alluvial/lacustrine depocentre which could enhance differential vertical motions.

5.10.1 THE SINNI VALLEY

5.10.1.1 MAP OF THE RIVER TERRACES

The Sinni river represents a very interesting case to study for what regards the formation of river terraces and their location, because of the occurrence of a couple of features that make this river unique.

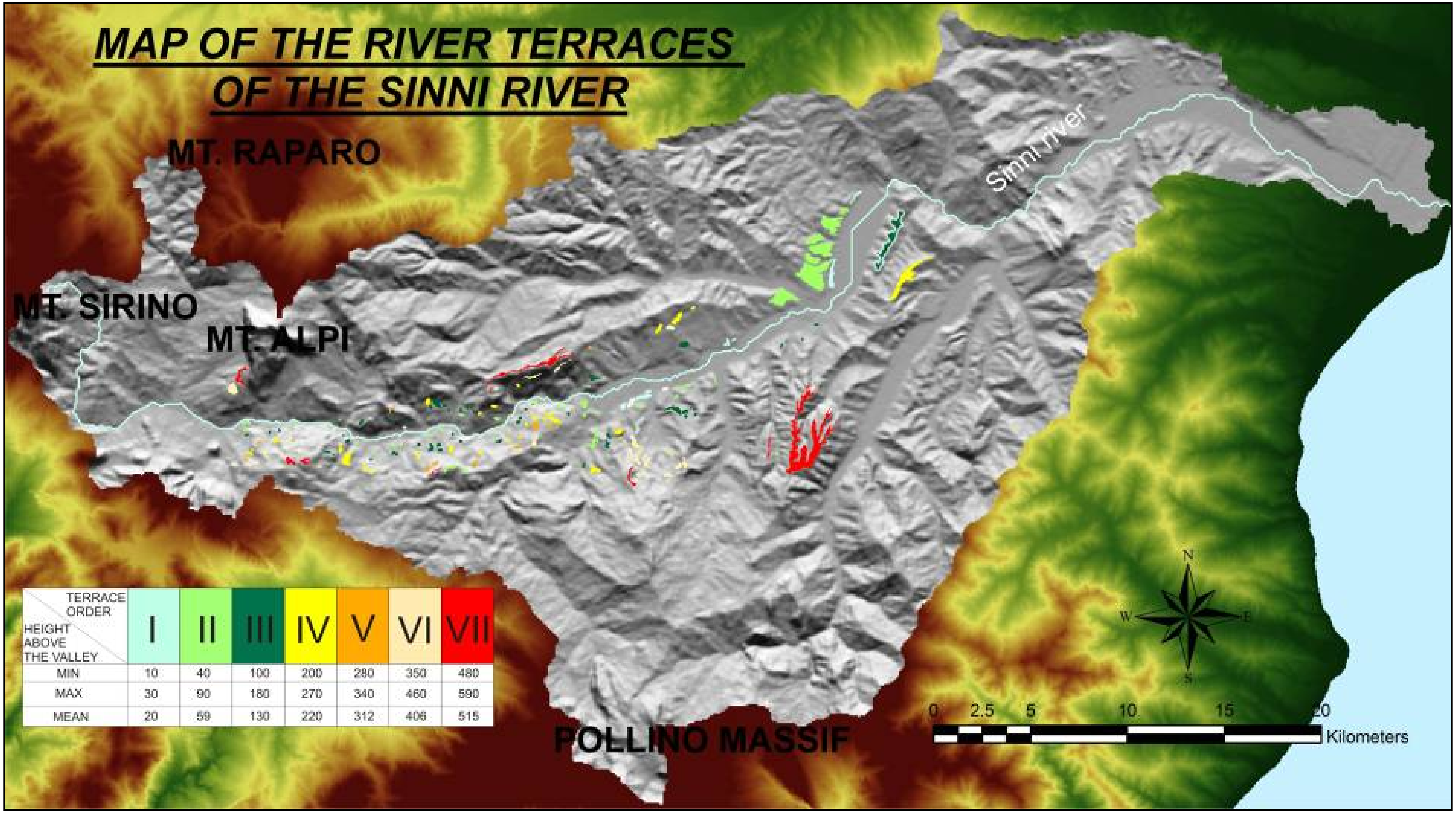
The map of the river terraces has been created by a detailed geomorphic analysis carried out on a 1:10000 scale topographic map. The single maps have been attached by the software Autocad, then the contour line and toponomastic layers have been extrapolated and printed in a new map; on the so-obtained map the river terraces have been recognized, mapped and grouped in different orders. This first step has been followed by field surveys and mapping. The terraces have been then mapped by using Arcgis, and the final map has been created by using Arcgis, importing the mapped terraces, extrapolating the dem of the Sinni basin from the Nasa 90m resolution dem and creating its hillshade (illumination from North, with an inclination of 45°) (fig. 5.34).

The river terrace are basically located in the area from Mt. Alpi to the Nocara ridge. Another particular feature is the uneven number of terrace orders on the two valley flanks. In particular there are more river terraces on the right flank than on the left flank, for instance downstream of Mt. Alpi there is the complete lack of river terraces on the left flank for about 6 km. This is due to a lithological control: in fact, the bedrock on the right flank of the Sinni valley, from Mt. Alpi to Francavilla in Sinni (where most of the terrace orders are preserved), is made of the Frido Unit (serpentinites, quartzite, phyllites, low grade metamorphic limestone, ophiolitic metabasalts, garnet gneiss, anphibolites), whereas from Francavilla in Sinni to the Nocara ridge, the bedrock on the right flank is made of more erodible Quaternary deposits of the Sant'Arcangelo basin and both the number and the order of river terraces decrease. On the left flank, the bedrock is made of North Calabria Units in the area around Mt. Alpi and there are no river terraces, except that for two strath terraces cut on Mt. Alpi Apulian carbonates while, from Mt. Alpi to the Nocara ridge the bedrock is made by the Quaternary deposits of the Sant'Arcangelo basin. Here several terraces have been recognized, often very small, the different orders are represented by a small number of terraces and often a determined order is limited to a very narrow area.

The grouping of the several terraces has not been easy, and in order to discern among the different orders, the data obtained from each terrace (in particular, absolute elevation and elevation from the valley floor) have been organized in a Microsoft Excel table: this table has allowed two different method of grouping by using both the absolute elevation than the elevation from the valley floor. In the first case, 10 order of river terraces have been recognized, but we had the problem that some order was often represented by only few terraces, often located in a very narrow area. By using the elevation of the valley floor as grouping parameter, we have recognized 6 order of river terraces: in this case, the correlation seemed to be more confident, because the several orders were almost continuously recognized along all the Sinni valley. The second grouping method has been so preferred.

The river terraces have been so grouped in 6 orders: they are individuated at elevations a.s.l. lower than the elevation of the depositional surface of the Serracorneta Conglomerates (for simplification, it is shown in the map as the 7th terrace order, also if we know that this is not a real terrace) which is recognized on the divide of the Sinni river and is dated at about 0.6Ma (see the discussion in sec. 5.11). The altimetrical range of all the 6 orders are shown in the table of fig. 5.34. If we consider that the incision history of the Sinni river started about 0.6Ma, we can then establish the incision rate of the Sinni river in this time span, by considering the elevation above the valley floor of the depositional surface of the Serracorneta Conglomerate: its height above the valley bottom range from 480m and 590m, so we have an incision of about 540m in the last 0.6Ma, which means that the Sinni river incision rate is about 1mm/yr.

Another important feature of the Sinni basin is that most of the river terraces are erosional terraces. there are just 9 depositional terraces: 2 of these terraces are located on the left flank of the Sinni valley, one is located about 10 km east of the Mt. Alpi (locality Demanio) and the second one about 1km SE of Chiaromonte. The remaining terraces are located on the right flank of the Sinni valley, one close to Agromonte Magnano, five located in the central portion of the basin (close to Francavilla in Sinni), and the last one, which is also the largest one, located on the right flank of the valley close to the Monte Cotugno dam (site Masseria della Ratta). The depositional terraces are marked on fig. 5.33 by a white continuous line. It is important to notice that most of the recognized deposits are alluvial fan derived from tributaries of the Sinni river and that have been deposited on the terraces cuts by the Sinni river. This consideration is made consistent by the plan form of some of the considered terraces and by the compositional analysis of the clasts recognized inside the deposit, which are often represented by lithologies (e.g. metamorphic rocks coming from the southern portion of the Sinni basin) not drained by the Sinni river.



TERRACE ORDER / HEIGHT ABOVE THE VALLEY	I	II	III	IV	V	VI	VII
MIN	10	40	100	200	280	350	480
MAX	30	90	180	270	340	460	590
MEAN	20	59	130	220	312	406	515

Fig. 5.34: map of the river terraces of the Sinni river. The 7 orders of river terraces are shown with different colours and they are specified in the table, notice that the river terraces are limited to the area comprises between the Mt. Alpi and the Nocara ridge. It is important to notice that the 7th order doesn't correspond to a real river terrace, but it correspond to the depositional surface of the Serracorneta Conglomerates (see text). The river terraces marked by a white continuous line are depositional terraces, otherwise they are erosional terraces: notice that there are very few depositional terraces, and that they are concentrated in the central portion of the basin (in the area around the town of Francavilla in Sinni), there is just one small depositional terrace in the upper portion of the basin (about 10 km east of the Mt. Alpi, locality Demanio), and the biggest depositional terraces are in the lower portion of the Sinni basin (close to the Monte Cotugno dam, on the idrographic right, locality Masseria della Ratta).

5.10.1.2 THE DEPOSITIONAL TERRACES

Site 1 : site Demanio, 10km east of the Mt. Alpi

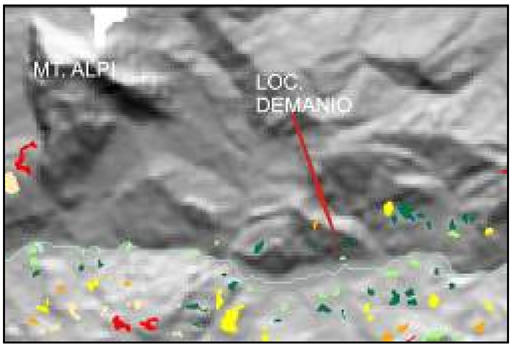


Fig. 5.35: depositional terrace in Demanio and its location in the map of fig. 5.34.

The deposit, with alluvial plain facies and thickness of about 1.5 m thick, is composed of about 60cm thick and it is a matrix supported massive gravel deposit, with a brownich-greyish sandy-silty matrix. Pebbles are sub-angular to sub-rounded, ranging from a 2-3 cm to 1-2 dm in size and composed of limestones, argillites, quartz and sandstones. These gravels passes upwards to 30cm of greyish silty-clayey deposits, with sparse sub-rounded gravels and to about 50-60cm thick and it is a matrix supported massive gravel deposit. Pebbles are sub-angular to sub-rounded, ranging from 1-2 cm to 1-2 dm in size and composed of limestones, argillites, sandstones and cherts.

The terrace belongs to the 2nd order on the left flank of the valley. The terrace root is at an elevation of 540m, while the rim is at an elevation of 530m, and the height on the local base level is 40 m.

Site 2 : about 0.5km NE of the town of Agromonte Magnano, site Maturo

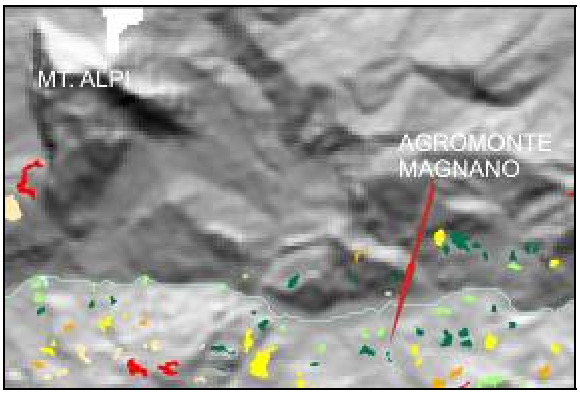


Fig. 5.36: depositional terrace in Maturo and its location on the map of fig. 5.34.

Massive matrix supported gravels, with yellowish sandy-silty matrix. The pebbles are sub-angular to sub-rounded, ranging from 3-4 cm to rare pebble of about 2 dm in size and composed of limestones (abundant calcarenites), and metamorphic rocks (metabasalts and serpentinites). The facies is alluvial fan.

The terrace is related to the 3rd order to the right valley flank. The terrace root is at an elevation of 660m, the rim is at an elevation of 640m, and the height from the local base level is 150 m.

Site 3 : about 1km SE of the town of Chiaromonte, site Savino

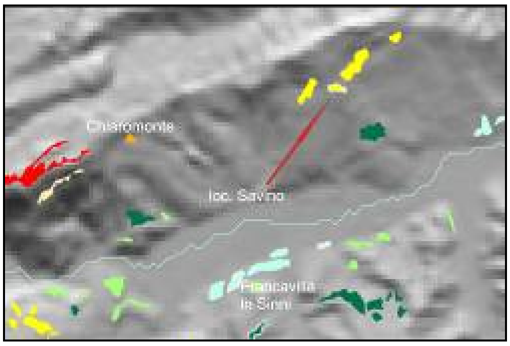


Fig. 5.37: depositional terrace in Savino and its location on the map of fig. 5.34.

Massive matrix supported gravels, with a sandy-silty yellowish to brownish matrix. Pebbles are rounded to sub-rounded gravels, cm to dm in size, and composed of limestones (mainly calcarenites), sandstones (including some michae rich sandstones dm in size), and cherty green, red and brown argillites. The facies is alluvial fan.

The terrace is related to the 3rd order on the left flank of the valley: the terrace root is at an elevation of 560m, the rim is at an elevation of 550m, and the height from the local base level is of 150 m.

Site 4 : about 1,5km NE of the town of Francavilla in Sinni, site S. Domenico

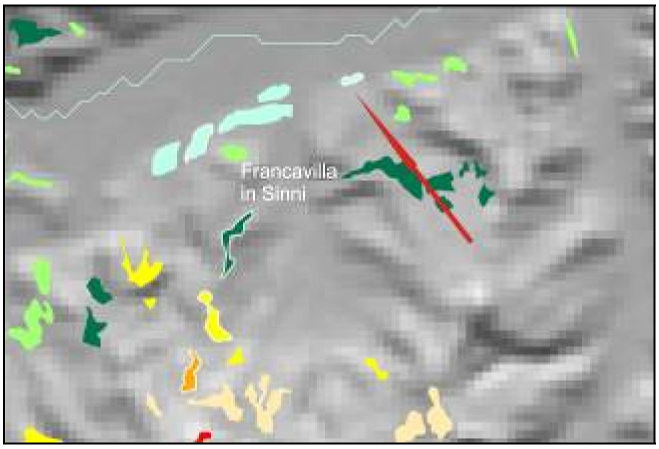


Fig. 5.38: depositional terrace in S. Domenico and its location on the map of fig. 5.34.

This depositional terrace is several (more than 4m) thick. At the base of the outcrop is exposed a 1m thick alternation of silty, massive gravel (clasts are angular, limestone rich, and there is no organization of the deposit), and sandy layers. It passes upwards to about 3m thick massive gravels deposit, with angular to sub-angular gravels, very poor in limestones, with a brownish to reddish silty to clayey matrix, and local intercalation of silty layers.

This terrace is located at the confluence of the Fosso San Nicola river (that incises a bedrock composed of the metamorphic Frido Unit) with the Sinni river: the lower unit is interpreted as an alluvial plain facies related to the Sinni river, while the upper unit is interpreted as the alluvial fan facies related to the Fosso San Nicola river.

This terrace is related to belongs to the 1st order on the right flank of the Sinni valley: the terrace root is at an elevation of 340m, while the rim is at an elevation of 330m, and the height from the local base level is of 20 m.

Site 5 : about 0,7km NW of the town of Francavilla in Sinni, site S. Eliana

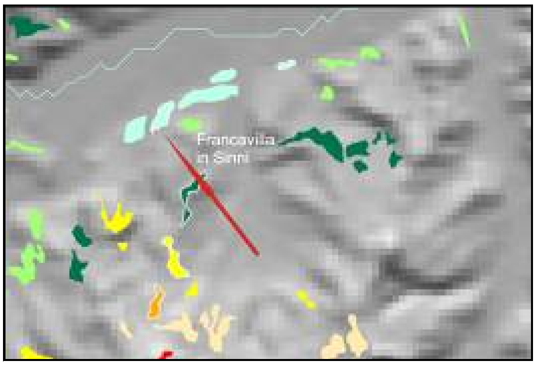


Fig. 5.39: depositional terrace in S. Eliana and its location on the map of fig. 5.34.

Clast supported deposit, thickness greater of 4 meters, with a sandy-silty yellowish matrix, local sandy lenses. Clasts are sub-rounded to angular, ranging from 1-2 cm to rare dm in size, and composed of limestones (calcarenites), few sandstones and argillites and abundant metamorphic rocks of the Frido Unit. The facies is interpreted as an alluvial fan facies.

This terrace is related to the 1st order on the right flank of the Sinni valley: the terrace root is at an elevation of 350m, the rim is at an elevation of 340m, and the height from the local base level is of 25 m.

Site 6 : cemetery of Francavilla in Sinni

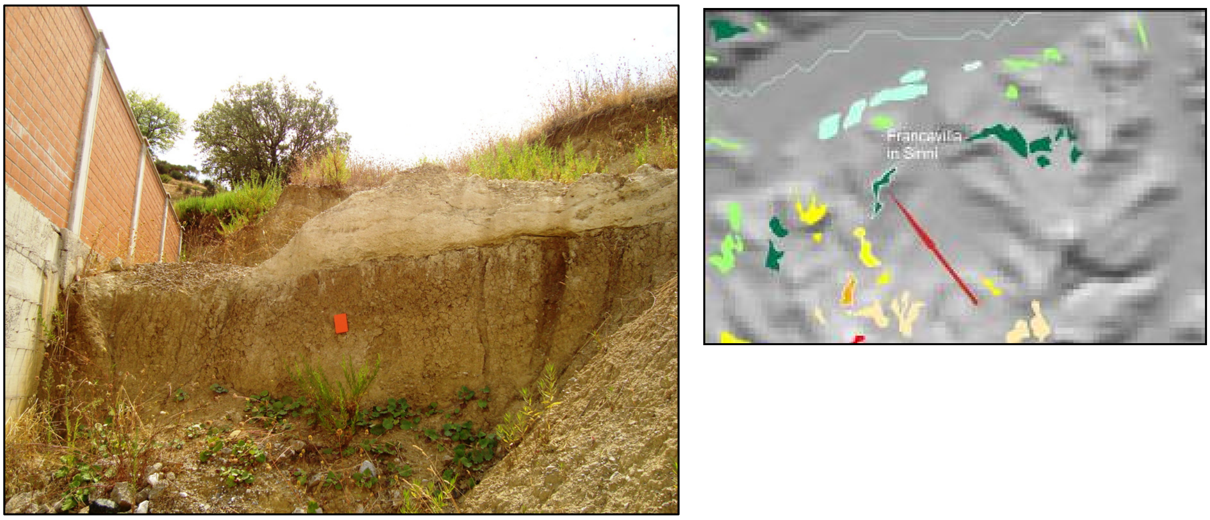


Fig. 5.40: depositional terrace in correspondence of the cemetery of Francavilla in Sinni and its location on the map of fig. 5.34.

The deposit is constituted at the base by about a 50cm thick deposit, it is a massive matrix supported deposit, with brownish sandy-silty matrix, pebbles are rounded to sub-rounded, centimetric in size, and composed of limestones with a few argillites and metamorphic rocks. It passes upwards to 1.5-2m thick deposit, it is a brownish sandy paleosoil, with the presence of a 30cm thick layer with abundant sub-rounded gravels (limestones and sandstones), which is recognized about 40cm down the top of the paleosoil. It passes upward to a greyish-whitish clay deposit, it is about 70cm thick, with rare centimetric not so rounded gravels (limestones) and to a massive matrix supported deposit, with yellowish sandy matrix, pebbles are not so rounded to sub-rounded, and composed of limestones and a few argillites, with the presence of a sandy layer about 50cm down the top of the deposit, which includes rare calcareous angular gravels.

The terrace is related to the 3rd order on the right flank of the Sinni valley. The terrace root is at an elevation of 480m, the rim is at an elevation of 460m, and the height from the local base level is of 140 m.

Site 7 : about 1.5km S of the town of Francavilla in Sinni, site Case S. Angelo

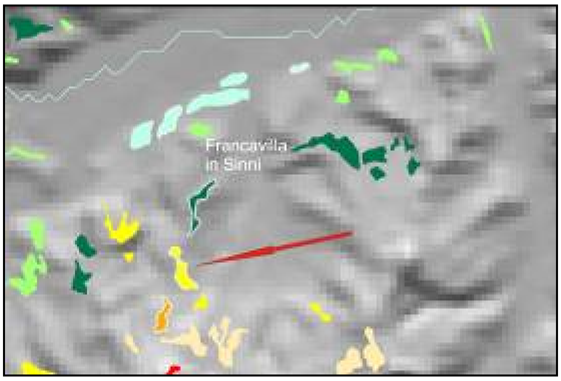
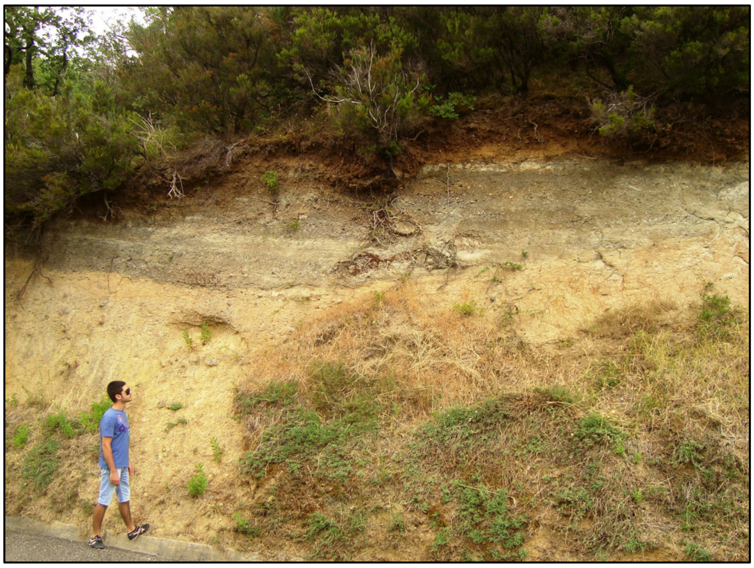


Fig. 5.41 : depositional terrace in Case S. Angelo and its location on the map of fig. 5.34.

The deposit is constituted at the base by about 2m thick massive matrix supported deposit, with brownish matrix, clasts are sub-rounded to rounded, a few cm in size, and composed of abundant metamorphic rocks (Frido Unit), few argillites. It passes upward to a greyish-yellowish clay deposit, which is about 1m thick, with no gravels, covered by 20cm of the actual soil.

The terrace is related to the 4th order on the right flank of the Sinni valley. The terrace root is at an elevation of 550m, the rim is at an elevation of 520m, and the height from the local base level is of 200 m.

Site 8 : about 2km S of the town of Francavilla in Sinni, in the area comprises between Case S. Angelo and Timpa del Tufo mount.



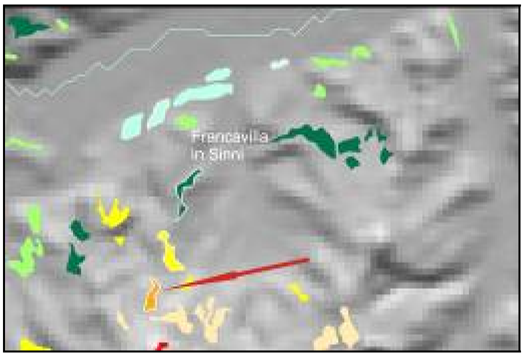


Fig. 5.42 : depositional terrace south of Francavilla in Sinni and its location on the map of fig. 5.34.

The deposit is about 2m thick, it is a massive matrix supported deposit with the intercalation of sandy lenses, clasts are sub-rounded, centimetric in size, and composed of limestones and a few metamorphic rocks. It passes upward to a greyish clayey layer about 20cm thick and to the present soil. The facies is alluvial plain.

The terrace is related to the 5th order on the right flank of the Sinni valley. The terrace root is at an elevation of 690m, the rim is at an elevation of 620m, and the height from the local base level is of 300 m.

Site 9 : about 1km SE of the Monte Cotugno dam, site Masseria della Ratta

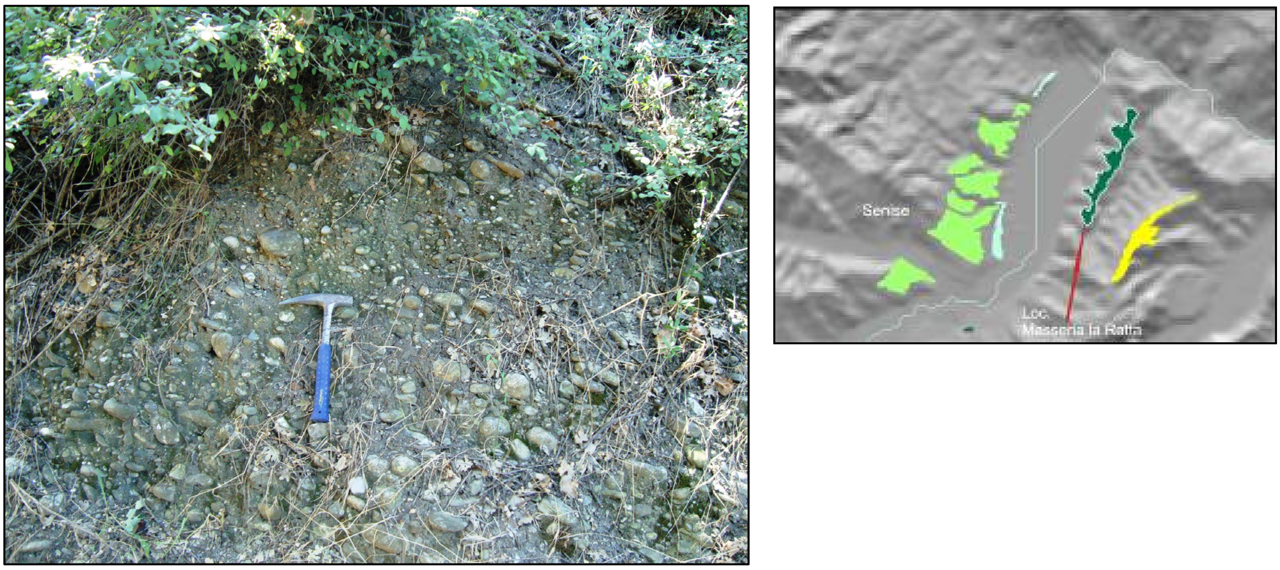


Fig. 5.43 : depositional terrace in Masseria della Ratta and its location on the map of fig. 5.34.

Massive matrix supported deposit, with brownish sandy-silty matrix, pebbles are sub-rounded to rounded, ranging from 1-2 cm to 2-3 dm in size, and composed of limestones, few sandstones and argillites**.** The facies is alluvial fan.

The terrace is related to the 3rd order on the right flank of the Sinni valley. The terrace root is at an elevation of 360m, the rim is at an elevation of 310m, and the height from the local base level is of 100 m.

5.10.2 THE NOCE VALLEY

5.10.2.1 MAP OF THE RIVER TERRACES

The map of the river terraces of the Noce basin has been obtained by the analysis of topographic maps in scale 1:5000. The single maps have been attached by using the software Autocad, then the contour line and toponomastic layers have been extrapolated by the map and have been printed in a new map. The so-obtained map has allowed a better analysis of the topography because of the lack of extra levels (roads, buildings, and so on) and it has allowed to individuation of several river terraces, which have been then grouped into three main order (pre-lake, syn-lake and post-lake terraces). The mapped terraces have been then studied in detail in the field to distinguish between strath terraces and depositional terraces. All the terraces have been then mapped by using Arcgis and the final map has been obtained by plotting these terraces on an hillshade (illumination from North, with an inclination of 45°) of the Noce basin (fig. 5.44).

The river terraces recognized in the Noce valley have been grouped into three main groups, that have been named respectively “pre-lake”, “syn-lake” and “post-lake” terraces. The distinction among these three groups has been based on elevation a.s.l. of the mapped terraces. To discern among the different groups, the altimetrical range of the lacustrine deposits as described by Santangelo (1991) has been used. The reference section is “Le Cuini” section: this is characterized by a 150m thick deposit, the base is at 350m a.s.l. while the top of the deposit is at 500m a.s.l.. By using this criteria, all the mapped terraces that were recognized in this altimetrical range in the area around Le Cuini (central portion of the Noce basin) were ascribed to the syn-lake terraces. The syn-lake terraces have been then recognized in the northern and southern portion of the basin by imaging that the Noce river has not changed its gradient in a relevant way, so that it can be applied to the syn-lake terraces in the central portion of the Noce valley to recognize other syn-lake terraces in the northern and southern portion of the Noce valley. In this way, it has been possible to recognized all the syn-lake terraces and to define the limit of the paleo-Noce lake. All the terraces there were then recognized at elevation higher than the syn-lake terraces have been ascribed to the pre-lake group: these are mainly represented by erosional glacis and strath terraces, in some case recognized on the carbonatic slope bordering the Noce valley (e.g. east slope of Mt. Coccovello). On the other hand, all the terraces recognized at elevation lower than the syn-lake terraces have been ascribed to the post-lake terraces: this have been recognized mainly in the southern portion of the Noce basin and along the Parrutta gorge.

The mapped terraces are reported in fig. 5.43. There are some observations that can be done about this map:

- the pre-lake terraces are all erosional terraces and are mainly located in the northern portion of the Noce valley. In the central and southern portion of the Noce basin they are just located on the eastern flank of the basin and on the northern slope of Mt. Messina;
- there are just two pre-lake terraces in the central portion of the Noce basin, they are located on the eastern side of the Mt. Coccovello, in sites Russignano and Elcitelli, at an elevation of about 650-700m a.s.l.;
- the syn-lake terraces are located in the central and southern portion of the Noce basin, and just a few of them are individuated in the northern portion of the basin;
- such syn-lake terraces are both erosional and depositional terraces, in particular the depositional terraces are located on the north side of the Monti di Trecchina ridge, on the south side of the Mt. Coccovello, in the area close to the town of Nemoli and Rivello, on the north side of Mt. Messina;
- in the north side of the basin it has been recognized one depositional syn-lake terrace on the south side of Mt. Serra Luceta: this deposit is located at an elevation of about 600m a.s.l. and the different elevation respect the other syn-lake terraces individuated in the central portion of the Noce basin is interpreted as due to the paleogradient of the Noce river;
- only one depositional terrace can be related to the syn-lake phase in the area south of the Parrutta gorge, it is individuated in site San Quaranto, at about 500m a.s.l., but its facies let us to interpret it as due to a local transport by some low order trunk;
- the post-lake terraces occur in the central and southern portion of the Noce basin: they are all erosional terraces and the biggest terraces referable to this group are individuated in sites Feliceta (200m a.s.l.) and S. Sago (150m a.s.l.).

The analysis of the river terraces has been carried out together with the study of the marine terraces individuated in correspondence of the mouth of the Noce river, and that have been previously studied by several authors (Damiani & Pannuzi, 1978; Carobene & Dai Pra, 1990; Filocamo, 2006), with the aim to establish the age of the Noce lake by using methods of relative chronology. There are several considerations that can be done about the marine terraces:

- the oldest marine terrace (140m a.s.l.) is Lower Pleistocene in age (Filocamo, 2006), it is recognized partly inside the Noce valley, so it means that when it was modelled a fluvial morphology already existed;
- this hypothesis is also confirmed by the compositional analysis of the marine deposit of the oldest marine terrace: the presence of clasts of the Lagonegro Units inside this deposit indicate that, at that time, there was an active drainage from Mt. Sirino to the south, and so Mt. Sirino was already a morphological high subject to the erosional processes and able to produce debris, and the Noce lake was so extincted;
- this oldest marine terrace is correlable with the post-lake terrace in locality Feliceta (200m a.s.l) and with a series of slope brakes that have been recognized on the slopes of the main valleys draining this area. It means that the syn-lake terrace, and consequently the individuation of the lacustrine basin, are older than this marine

terrace (which has a late Lower Pleistocene age) and they are tentatively attributable to the middle Lower Pleistocene.

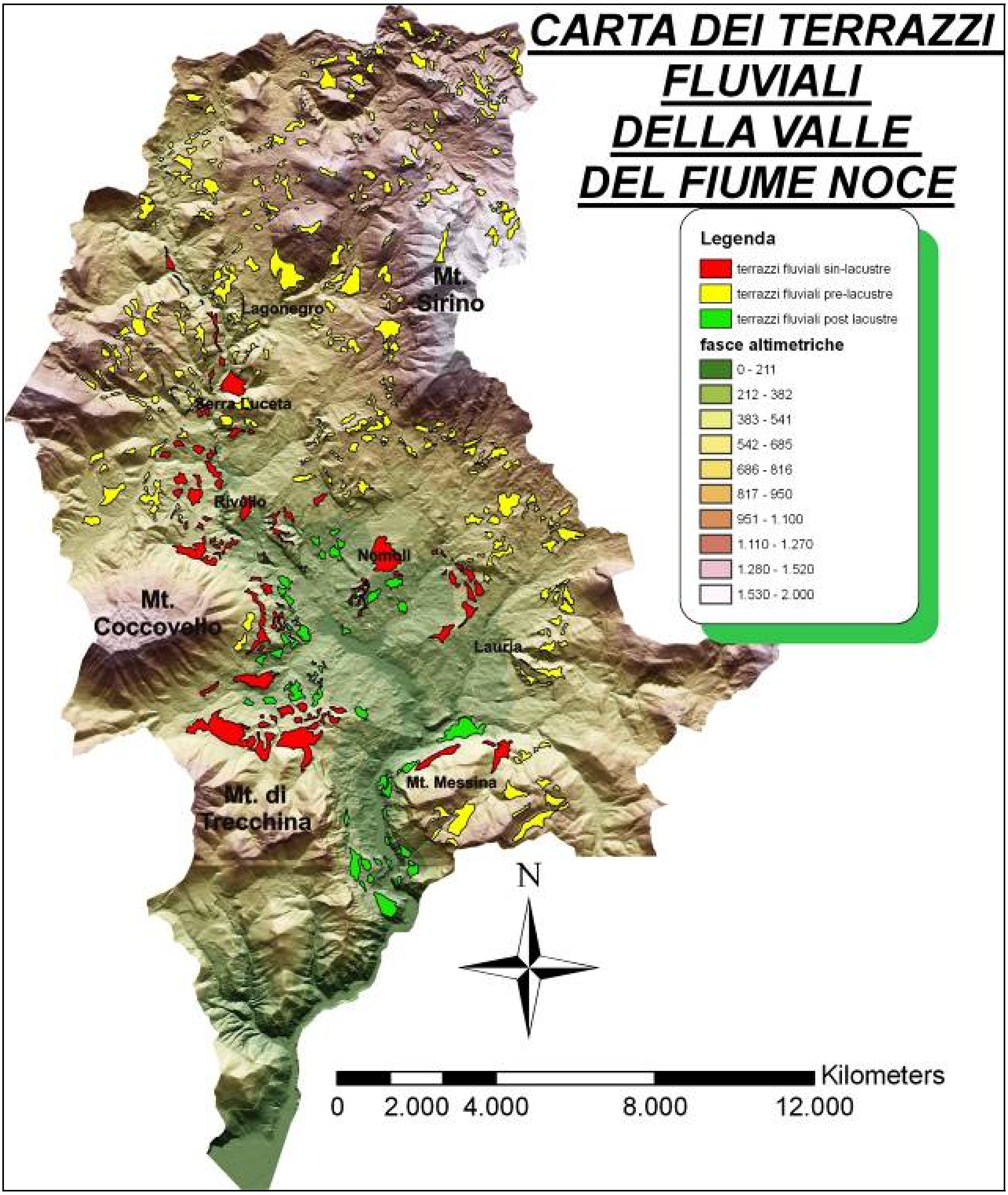


Fig. 5.44: map of the river terraces of the Noce basin, the river terraces have plotted on a 5m dem of the entire valley.

5.10.2.2 DEPOSITIONAL TERRACES

Site 1: about 0.5km northeast of the town of Trecchina

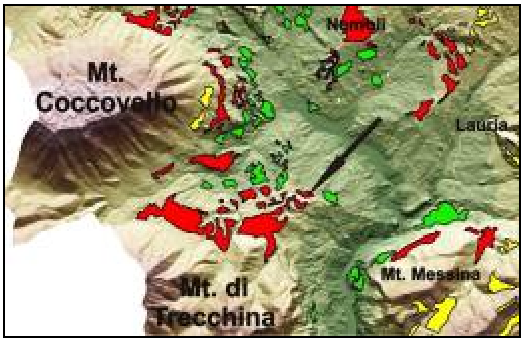


fig. 5.45: depositional terrace about 0.5km NE of the town of Trecchina and its location in the map of fig. 5.44.

Deposit about 7-8m thick made by the alternance of conglomerate (about 60-100cm thick) and sandy layers (about 30-50cm thick). The conglomerate layers are composed of sub-rounded clasts, ranging from a few cm to 1-1.5dm, and composed of cherts (green, red, grey and black), few argillites and sandstones and very few carbonatic clasts.

This terrace is related to the syn-lake terraces. The terrace root is at an elevation of 460m, the rim is at an elevation of 450m, and the height above the valley floor is of 275m.

Site 2: about 2km west of the town of Trecchina

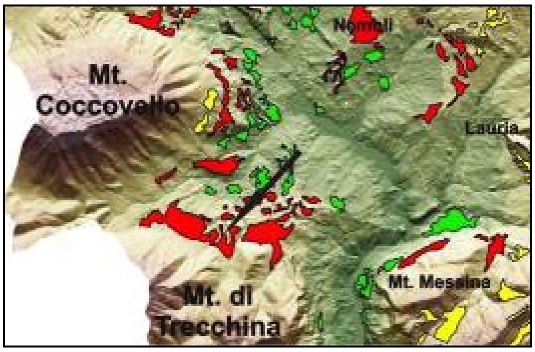


Fig. 5.46: colluvial deposit on top of the terrace located on the north side of Mt. Crivo and its location in the map of fig. 5.44.

This terrace doesn’t present a clear alluvial deposit, but it is anyway reported because of a particular feature of the quaternary deposit here present.

This is a brownish to dark brownish sandy-silty deposit, with rare angular carbonatic clasts in its upper portion, while there are no clasts in its lower portion. The limit between the uppermost and the lowermost portions is marked by a pyroclastic level, yellowish, about 15cm thick, which has been sampled with the idea to trying to date it, but the result are not yet available.

This terrace is related to the syn-lake terraces. The terrace root is at an elevation of 520m, the rim is at an elevation of 480m, and the height above the valley floor is of 150m.

Site 3: terrace in site Le Cuini, about 2km NW of the town of Trecchina

Fig. 5.47: depositional terrace in site Le Cuini and its location in the map of fig. 5.44.

Massive matrix supported deposit, with yellowish sandy-silty matrix. Pebbles are rounded, ranging from a few cm to 1dm in size, and composed of limestones.

This deposit represents the lowermost portion of the Le Cuini section of Santangelo (1991), the highest part of the succession has not be recognized in the field because of the large number of landslides that didn't allow to reach all the areas of interest.

This terrace is related to the syn-lake terraces. The terrace root is at an elevation of 425m, the rim is at an elevation of 325m, and the height above the valley floor is of 75m.

Site 4: site I Puoi, about 1km south of the town of Nemoli.

Fig. 5.48: depositional terrace in site I Puoi, about 1km south of the town of Nemoli and its location in the map of fig. 5.44.

Massive matrix supported deposit, with a silty-sandy yellowish matrix. Pebbles are sub-rounded to rounded, ranging from a few cm to 3-4dm in size, and composed of argillites, limestones and marly limestones, sandstones and cherts (green, red and black). The deposit, which is about 30m thick, is locally interrupted by metrical sandy layers.

This terrace is related to the syn-lake terraces. The terrace root is at an elevation of 410m, the rim is at an elevation of 370m, and the height above the valley floor is of 170m.

Site 5: about 1km east of the town of Rivello.

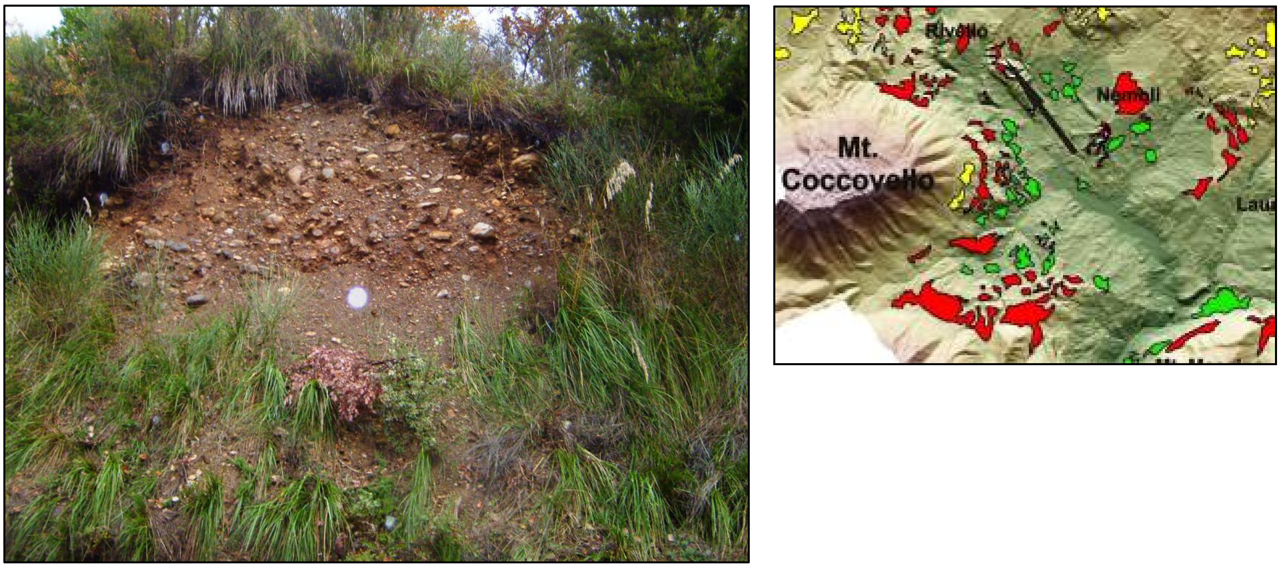


Fig. 5.49: depositional terrace located about 1km east of the town of Rivello and its location in the map of fig. 5.44.

Massive Matrix supported deposit, with a sandy-silty matrix. Pebbles are sub-rounded, ranging from a few cm to abundant decimetric clasts, and composed of sandstones, limestones, argillites, marls and cherts.

This terrace is related to the syn-lake terraces. The terrace root is at an elevation of 430m, the rim is at an elevation of 405m, and the height above the valley floor is of 125m.

Site 6: about 2km north of the town of Rivello

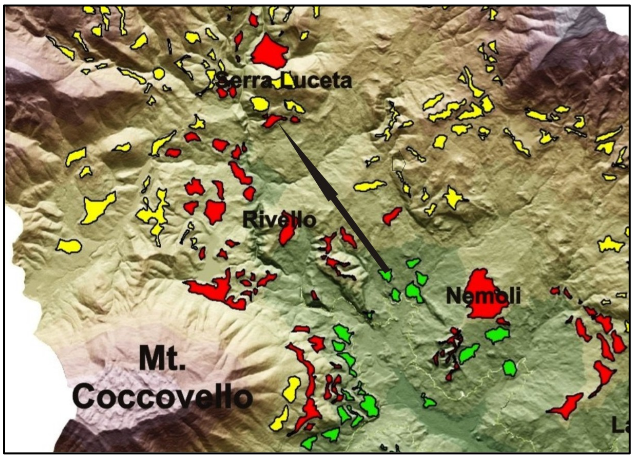


Fig. 5.50: depositional terrace located at about 2km north of the town of Rivello, on the southern slope of Mt. Serra Luceta and its location in the map of fig. 5.44.

Yellowish sandy-silty deposit, about 2.5-3m thick, with rare angular clasts of limestones, argillites and sandstones of centimetric size. The deposit is covered by 50cm of carbonatic breccias which represent the debris slope of the southern slope of Mt. Serra Luceta.

This terrace is related to the syn-lake terraces. The terrace root is at an elevation of 590m, the rim is at an elevation of 575m, and the height above the valley floor is of 225m.

5.11 DISCUSSION

The geomorphological, morphometrical and sedimentological analysis presented in this chapter has allowed a reconstruction of the morphotectonic evolution of this portion of the Southern Apennines.

The morphotectonic analysis allowed the recognition of two low relief landforms which are located in the western sector of the Sant'Arcangelo basin (700-900m a.s.l.) and in the area between the northern hillslope of Mt. Sirino, Mt. Raparo and Mt. Alpi (1200-1400m a.s.l.). These two "*paleosurfaces*" are very clear on the elevation map (sec. 5.8.1) and on the envelope map (sec. 5.8.3), and their flat feature is evident in the slope map (sec. 5.8.4). The lowest surface (700-900m a.s.l.) corresponds to the depositional surface of the Serracorneta Conglomerate, so it could be temporally constrained at about 0.6Ma. The morphological relationships between this lower paleosurface and the highest one are not clear, in particular the 1200-1400m a.s.l. paleosurface could be either the erosional surface linked to the depositional lower paleosurface or be older. What we can surely say is that the highest low relief landform is recognized in the area north of Mt. Sirino and it cuts both carbonates units than Lagonegro Units, so its formation took place after the exhumation of the Mt. Sirino ended and so, considering the data we are going to talk about soon, it could temporally constrained in the middle-late Lower Pleistocene, and in particular between 1.5-0.6Ma. The same consideration cannot be argued for Mt. Alpi because the remnants of such low relief landform, in this area, consist of narrow ridges and accordant peaks which don't involve the carbonate of the Mt. Alpi.

The lower temporal limit to the formation of the highest low relief landform (1200-1400m a.s.l.) has been provided by the compositional analysis of the Quaternary deposits of the Sant'Arcangelo basin. This analysis let us to recognize the oldest units of the Quaternary filling of the Sant'Arcangelo basin that contains clasts of the Lagonegro Units coming from the Mt. Sirino area: this unit is the subsynthem A2a (a subsynthem of the Aliano synthem by Benvenuti et al., 2006) which should be not older than 1.5Ma. This indicates that at this time the Lagonegro Units of Mt. Sirino had been exhumed and were affected by erosion, providing debris to the Sant'Arcangelo basin.

If we consider the Sinni river basin, which is located inside the Sant'Arcangelo basin, the study of the river terraces of such valley could produce interesting data about the incision history of the Sinni river. This analysis has allowed the identification of 6 orders of river terraces. Most of the Sinni river terraces are erosional (strath) terraces, only in a few places terraces are covered by thin deposit, with the identification of just 9 depositional terraces. This data suggests an overall tendency to bedrock incision of the Sinni river. In addiction, we have that the divide of the Sinni basin corresponds to the depositional surface of the Serracorneta Conglomerates (which are mapped as 7th order terrace in the map of the river terrace of the Sinni river in fig. 5.34), whose age is of about 0.6-0.2Ma (Benvenuti et al., 2006), while Patacca and Scandone (2001) suggest an age of 0.64Ma. The well developed paleosoils recognized inside the formation and the decalcification of the Formation let us to suppose that it has experienced several glacial-interglacial cycles, so that the age of 0.2 cannot be considerate appropriate, while it is considered more acceptable the age of 0.6Ma. So the incision history of the Sinni started about 0.6Ma: since that moment the Sinni river has experienced incision, a process that has been characterized by several stops which correspond to the formation of the lowest terraces. To date the lowest terraces we can try to correlate them with dated marine terraces on the Ionian coast (Amato, 2000). Here 9 order of marine terraces have been recognized and, considering their age, the highest marine terrace corresponds to the 6th order river terraces. To correlate the lowest order river terraces we can use the absolute elevations of the marine terraces and trying to project them into the Sinni valley by imaging that the paleogradient of the Sinni valley didn't change in a relevant way. By using this correlation, if we consider the 6th and the 7th order of marine terraces, we have that they are at an elevation ranging between 200-230m a.s.l. (they are dated at 0.331Ma, OIS 9 and 0.405Ma, OIS 11 respectively): the Sinni valley is at about 30-50m a.s.l. in this area, while it reaches an elevation of about 320m a.s.l. in the area of Francavilla in Sinni, with a lost of elevation of about 300m in 42km which determines a gradient of the Sinni valley of 0.7%. If we consider this gradient the same gradient that the Sinni valley had when the 6th-7th order of marine terraces were formed, and we project their absolute elevations upstream the Sinni valley, until the area of Francavilla in Sinni, we have that the 6th and the 7th order marine terraces correspond with 4th order river terraces, that are located at about 500m a.s.l. in the area of Francavilla in Sinni. In the same way, the lowest marine terraces (1st order, 0.053Ma) is at about 30m a.s.l. and it can be correlated with the 1st order river terraces recognized in the area of Francavilla in Sinni, which can be so temporally constrained to the late Upper Pleistocene.

Considering the age of the Serracorneta Conglomerate (0.6Ma) and its height above the Sinni valley (about 540m), it is possible to determine the incision rate of the Sinni river in the last 0.6Ma: such incision rate results of about 1mm/yr. The observed tendency of the Sinni river to incise the bedrock can be considered as the response to coeval uplift of both the chain and the foredeep. Although the incision rate is not a measure of the uplift rate (it can be either larger or equal to uplift rate), if we consider that the present day Sinni long profile is far from a theoretical equilibrium profile (see sect. 4.1.3), we can hypothesize that the estimated incision rate is probably close to the uplift rate. The latter can be reliably be considered not smaller than the half of the incision rate.

Terraces in the Noce valley have been grouped in three main orders: pre-lake, syn-lake and post-lake terraces. The lacustrine environment has been temporally constrained to the Lower Pleistocene, probably related to the late part of this period. The lacustrine condition were established in response to the formation of a threshold in the Trecchina Mts. – Mt. Messina area. The filling up of the lake is correlated with the combination of the progradation towards the south of the depositional activity of the main tributaries, and to the regressive erosion determined by the downcutting of the Tyrrhenian coastal sectors. The syn-lake terraces may be dated by relative chronology criteria, e.g. by a correlation of such terraces with the marine terraces located at the mouth of the Noce river, in the area around Praia a Mare. An Emilian-Sicilian age is proposed for the highest marine terraces at 170m and 140m a.s.l., while a Middle Pleistocene age is proposed for the 80m a.s.l. marine terrace, ages that are obtained by correlation with dated marine terraces individuated on the Tyrrhenian coast south of Praia a Mare, in the area between Scalea and the mouth of the Lao river (Filocamo, 2006). The oldest marine terraces are inset into the Noce valley, indicating that by that time the Noce valley had already been incised. In addiction, based on morphometrical evidences, such marine terraces can be correlated with the fluvial terraces at about 200m a.s.l. in site Feliceta, within the Noce valley, which belongs to the post-lake river terraces group. Another important issue is the presence into this marine deposits of Lagonegro clasts. The only area which supply these clasts is Mt. Sirino.

If we think in terms of rock exhumation of the Mt. Sirino, this means that at that time of the deposition of the oldest marine terraces on the Tyrrhenian coast at the mouth of the Noce river (about 1Ma) the Mt. Sirino was already experiencing erosion, so it was very close to the actual morphostructural setting.

The analysis of the "map of the slope of the 1st order channels" suggests that the area comprised between the Serrapotamo and the Sarmento river shows the highest values: these high slope values could be related to a more enhanced uplift that this area has experienced respect to the rest of the Sant'Arcangelo basin. This data is not easy to explain, it is anyway interesting to notice the huge difference that exist among the south-western and the northern portion of the Sant'Arcangelo basin, considering that both areas show very similar lithologies (conglomerate facies of the Sant'Arcangelo filling), while the low values obtained in the eastern portion of the basin, on the west side of the Nocara ridge, seem to be influenced by the presence of the clayey facies of the Sant'Arcangelo filling. However, if we combine these data with the uplift data obtained by the marine terraces on the Ionian coast (Amato, 2000), we have that the southwestern portion of the Sant'Arcangelo basin seems to be aligned with the southernmost Ionian coast, that is the portion of the Ionian coast which has experienced a more enhanced uplift: this data could suggest a connection between these two sectors, highlighting the presence of this NW-SE oriented portion of the Southern Apennines that has been strongly uplifted.

In conclusion, the study of the transect has provided new informations and constraints on the Quaternary evolution of the area.

The compositional analysis of the deposits of the Sant'Arcangelo and Noce basins and of the marine terraces of the Noce river coastal plain indicates that the Lagonegro Units which crop out in Mt. Sirino area were exposed and affected by erosional processes since the late part of the Early Pleistocene. Further evidence is given by the erosional surface which cuts the Lagonegro Units and the Apennine carbonates at an elevation a.s.l. of 1200-1400m, and that is individuated in the area north of Mt.Sirino, that can be related to the late Early Pleistocene – early Middle Pleistocene. These evidences constrain the exhumation of the Lagonegro Units which, based on the Apatite Fission Tracks (Mazzoli et al., 2008), are still deeply buried only 2.5Ma ago, and represents an undirect evidence of the large contribution providing by tectonic unroofing to the rock uplift. Since the late Early Pleistocene, Mt. Sirino was a morphostructural high separating the Sant'Arcangelo basin to the east from the Noce river valley to the west. However, while the former basin was subject to deposition until the first part of the Middle Pleistocene (0.6Ma, age of the Serracorneta Conglomerate), the Noce valley was subject to incision. Incision in the Noce valley was driven by regressive erosion related to downcutting of coastal sectors located in the Tyrrhenian margin. A temporal doming of the Noce valley caused formation of the Noce fluvio-lacustrine basin, which was subsequently filled up and incised. Formation of the Noce basin was probably related to the activity of a fault located in the eastern flank of the valley. This is suggested by the NNW-SSE alignment of triangular facets in the northern-central part of the basin. The coastline reached a position close to the present one in the late part of the Early Pleistocene, as it is demonstrated by the marine terraces which occur in the Noce river coastal plain.

In the area to the east of Mt. Sirino, the filling up of the Sant'Arcangelo basin was followed by a generalized large scale post-orogenic uplift. Fast uplift in the Bradanic area is testified by the flight of marine terrace in the Ionian coastal sector (Amato, 1999), By elevation of such marine terraces (see Amato, 1999), an average rate around 0.6-0.8 mm/yr can be inferred; furthermore, the coastal uplift rate tends to increase moving from the foredeep to the chain. Evidence from the Sant'Arcangelo area suggest that this tendency is maintained. Both the Sinni river incision rate and the analysis of long-river profiles suggest that the Sant'Arcangelo area has suffered fast and recent uplift. Moreover, evidences from the 1st order channels suggest that uplift was stronger in the western portion of the Sant'Arcangelo basin than in the eastern portion of the basin. The absence of any significant surface evidence of differential vertical motions across the Sant'Arcangelo – Mt-Sirino portion of the transect suggests that a significant post-orogenic uplift affected Mt. Sirino area too. In contrast, evidences from the western portion of the transect suggests an uneven distribution of the Middle Pleistocene p.p. – Present uplift across the chain. Marine terraces in the Noce coastal plain, in fact, occur at a maximum elevation around 140-160m a.s.l.. Based onto local evidences from the Noce valley (e.g., elevation of the Noce basin terraces) and by large scale morphometric features (e.g. swath profile, minimum and maximum elevation maps, long river profiles), we can argue that the boundary between the two sectors which experienced different amount and rate of uplift is located on the eastern side of the Noce river valley.

CHAPTER 6

DISCUSSION AND CONCLUSION

This study has highlighted the importance of the morphotectonic approach in the reconstruction of the tectonic events occurred either at a regional scale or at a local scale. In particular, the numerical analysis of digital topographic data has been very useful to the large scale characterization of the Southern Apennines chain landscape. Furthermore, the integration of data provided by the digital analysis technique (e.g. swath profiles, river long profiles and the derived metrics), with the data obtained through the "classical" geomorphological approach, based on morphostructural and morphostratigraphical analyses, has provided new constraints to the reconstruction of the vertical motions which affected the entire chain during the Quaternary.

The main results of this study can be summarized as follows:

- the analysis of the river network (long profiles, elevation of the valley bottom, and derived metrics such as the SLI and the concavity and steepness index) shows that there are several differences among the Tyrrhenian, Adriatic and Ionian slopes. In particular, the long profile of the Tyrrhenian rivers is close to a graded profile (concave up), whereas this doesn't occur for both the Adriatic and the Ionian long profiles (which are less concave up or also rectilinear). However, we have to consider that the enhanced concave up shape of the Tyrrhenian rivers is strongly influenced by the Quaternary normal faulting, with the Tyrrhenian rivers flowing into intramontane basins which suffered a marked subsidence during the Quaternary. In these cases the low gradient either of the lower reach of the long profiles or of the entire long profiles is strongly controlled by tectonic lowering (this is true also for the markedly concave up upper reach of the Agri river, where it flows into an intramontane basin);
- all the mentioned parameters, i.e. long profiles, derived metrics, elevation of the valley bottoms, show that the outer portion of the Southern Apennines (Adriatic and Ionian slopes) has been uplifted more recently and with higher rates than its inner side (Tyrrhenian slope). These data agree with data provided by the analysis of the shorelines, marine terraces and coastal deposits observed on the Ionian belt (Amato, 2000) and the Tyrrhenian margin (Romano, 1992; Caiazzo et al., 2006), which indicate that the Ionian flank has experienced larger uplift, since the Middle Pleistocene, than the Tyrrhenian flank;
- the analysis of the long-profiles has also shown differences between the Adriatic (more rectilinear) and the Ionian (less rectilinear) rivers. These differences may be related to the post-orogenic uplift trend that has been recognized by the depositional surface of the Irsina Conglomerate which gently dip towards the NE (a feature that has been related to the tilting of the foredeep and foreland domains in response to the isostatic rebound of the flexured Apulian slab, Cinque et al., 1993) and by the marine terraces in the Ionian belt, which suggest that the uplift tends to increase towards the west (Amato, 2000). The more rectilinear shape of the Adriatic rivers may be interpreted as resulting from the fact that these rivers flow transversal to the maximum uplift trend (or they follow the tilting direction), whereas the Ionian rivers into the foredeep flow parallel to the maximum uplift trend (or transversal to the tilting direction);
- the Ionian rivers show a very steep long profile when they flow into the Sant'Arcangelo basin. This suggests that the post-orogenic uplift recognized by the marine terraces in the foredeep affected also the outer portion of the chain,

involving at least the Sant'Arcangelo area. This is also suggested, to the north, by the steep upper reaches of the Ofanto and the Basento river, where they flow into the chain;

- by the comparison of the Agri and the Sinni long profile, by the map of the gradient of the first order channel, and by the Ks values (which are higher on the southern portion of the Sant'Arcangelo basin and that decrease moving towards its northern portion) it appears that the uplift in the Sant'Arcangelo area follows a N-S trend. However, further studies are necessary to discern about the reason of such different uplift;
- the detailed analysis of the Sinni valley has highlighted the presence of 7 orders of river terraces, the oldest of which is represented by the depositional surface of the Serracorneta conglomerate, so it is temporally constrained at about 0.6Ma (Patacca and Scandone, 2001; Benvenuti et al., 2006). The correlation proposed with this study of the lower terrace orders with dated marine terraces on the Ionian coast, has allowed the evaluation of an incision rate of about 1mm/yr. By the estimated incision rate (which can be considered an upper limit for the uplift rate), an uplift rate lower than 1mm/yr averaged over the 0.6Ma to Present time span can be estimated. This value is consistent with the average uplift rate of 0.67mm/yr estimated by Amato (2000) in the outer portion of the chain;
- as regards to the Middle Pleistocene to Present uplift trend, the above observations indicate that the uplift increases towards the west, probably reaching the chain axis. Coeval uplift in the Tyrrhenian margin (as estimated by elevation of Middle to Late Pleistocene marine terraces shorelines; Romano, 1992; Caiazzo et al., 2006; Filocamo, 2006) was much lower, not exceeding about 100 m. These evidences suggest that the uplift trend of the outer flank of the chain is not recognizable in the whole orogen. The western boundary of the more rapidly uplifting belt can be tentatively located in correspondence to the deep-seated normal faults that have formed the several Quaternary intramontane basins;
- the stronger post-orogenic uplift occurred on the outer side of the chain since the Middle Pleistocene has determined a minor ability of the Adriatic and Ionian rivers (which experienced a continuous downcutting) to compete with the Tyrrhenian rivers. This fact is enhanced by the comparison of the valley bottoms, which are higher for the rivers flowing on the outer flank than for the rivers flowing on the inner flank of the chain. This has probably contributed, together with regressive river erosion due to the extensional tectonics on the Tyrrhenian margin (see sec. 3.5), in the decoupling between the maximum elevation line and the main divide, which is one of the peculiar features of the Southern Apennines chain;
- regarding the large scale topographic features of the Southern Apennines, it is interesting to note that, notwithstanding the remarkable recent uplift on the outer flank of the chain, the Southern Apennines display an asymmetrical profile, with the outer (Adriatic-Ionian) flank smoother and less inclined than the inner (Tyrrhenian) flank. The differences between the Tyrrhenian and the Adriatic flanks are highlighted by the five swath profiles, which clearly show that the Tyrrhenian flank is much steeper than the Adriatic side;
- in addiction, the morphometrical data clearly show, and allow to quantify, what has been suggested by previous studies regarding the relief features within both the inner and the outer portion of the chain. In fact, the morphological and morphometrical features of the Tyrrhenian (inner) and the Adriatic-Ionian (outer) flanks of the Southern Apennines chain are markedly different. In particular, as shown by the local relief curves (Fig. 3.8-3.10-3.12-3.14-3.16), the Tyrrhenian side features a more fragmented landscape, with the presence of the highest peaks of the

chain which are separated by deep valleys, whereas the Adriatic side is characterized by a much smoother topography, which displays a gentle dip towards the NE;

- the mentioned features of the Southern Apennines topography had been formerly (e.g. Amato et al., 1995; Ascione & Cinque, 1999) related to the control exerted: i) on the asymmetrical orogen shape by hard/weak lithologies; and ii) on the higher local relief of the western-axial belt by both the juxtaposition of hard/weak lithologies and the Quaternary extensional tectonics (i.e. formation of periTyrrhenian and intramontane basins and related valley downcutting). However, this study has shown that the orogen maintains an overall asymmetrical shape regardless of lithology (e.g. Fig. 3.11-3.13, the morphological highs on the western and axial part of the Southern Apennines correspond to the outcropping of the Apennine carbonates and the Lagonegro Units, while the morphological highs individuated in the Cilento region correspond to the outcropping of the Cilento Units which can be considered just as "relatively hard lithologies") as well as the higher local relief of the western-axial belt is only partly related to erodibility contrasts and/or to the formation of intramontane basins (e.g. Fig. 3.9);
- all the above mentioned evidences suggest that the asymmetrical profile is a feature inherited from the syn-orogenic evolution. In other words, the outer portion of the Southern Apennines chain was characterised by a low topography before the last uplift events, and the current topography is inherited by a relatively older tectonics. The reason of such a low topography can be understood by the analysis of the studied transect: this transect suggests that the signature of this older tectonics is represented by the low angle normal faulting linked to exhumation processes and gravitational collapses towards the outer flank of the chain, which has lowered the topography of the entire chain. This consideration is confirmed by the comparison of the swath profiles of the Northern and Southern Apennines;
- the combination of the field analysis together with the morphological and morphometrical analysis of the Noce-Sirino-Alpi-Sant'Arcangelo transect allowed us to affirm that during the late Lower Pleistocene Mt. Sirino was already a morphological high which was experiencing erosion, so it means that the rock exhumation processes was finished. The comparison of these data with the thermochronological data suggest that in the period between 2.5Ma and the late Lower Pleistocene, the Mt. Sirino has experienced an enhanced rock exhumation that has brought it from an initial situation where it was covered by about 4km of rocks (2.5Ma) to a final situation where it outcrops on the Earth surface and it is subject to the exogenic processes;
- this data is confirmed by the analysis of the river terraces of the Noce valley: as it has been described in the section 5.10.2, the lacustrine conditions have been dated (by methods of relative chronology on the basis of the morphological relationships among the fluvial terraces of the Noce valley and dated marine terraces on the Tyrrhenian coast close to the Noce mouth) to the middle Lower Pleistocene, and the recognition of Lagonegro clasts inside the oldest marine deposits (Lower Pleistocene) suggests that at that time there was an active drainage from the Mt. Sirino to the south, and so the Mt. Sirino was already a morphological high subject to the erosional processes and able to produce debris, and the lake didn't exist anymore;
- in addiction to this, we have to consider that since its exhumation, the Mt. Sirino corresponds to the location of the Apennine divide, representing one of the few portion of the Southern Apennines where there is a coincidence between the maximum elevation line and the divide location. This situation is partly recognized

also in the Monti Picentini area, where the two lines (divide and maximum elevation lines) are very close. The Sirino and the Picentini ridge are two areas that have experienced enhanced uplift in recent times: this data suggest that such uplift has locally not allowed the retreat of the divide towards the outer portion of the chain;

- some final considerations concern the concavity and the steepness indexes, which have been calculated with the slope/area analysis. The concavity index, at a regional scale of investigation, is a useful tool in the comparison of rivers of the same hierarchic order, we cannot compare the concavity of the main trunks (such as it could be the Voltunro river) with that one of a small tributary (such as it could be the Vandra river), because there are other local parameters (drainage areas, discharge, climate, lithology) that have a strong influence on the concavity too. The Ks index is, in the same way, not very useful to discern among a lithological and tectonic control at a regional scale: anyway, if we use it for detailed analysis, we can see how the Ks peaks correspond with the location of the knickpoints, so, once we are sure that such knickpoint doesn't show a lithological control, we can interpret it in term of active tectonics (this is the case of the knickpoint in the upper reaches of the Sele and Platano rivers, which are linked to the San Gregorio Magno fault-line, which is a clear active fault). The Ks index, from this point of view, seem to assume the same meaning of the SLI, but the rapidity of the determination of the Ks index and its easy representation on thematic map, let us to prefer it to the SLI;
- a final consideration regards the long profile shape again: we can see that all the Southern Apennines rivers are far from the graded profile (we have "false graded profiles" for the Tyrrhenian rivers, and steep long profiles for the Adriatic-Ionian rivers), and this data give us an idea about the time necessary to reach a steady-state condition in the landscape: evidently, time in the order of 10^5 years are not enough long for the river system to reach a dynamic equilibrium among the uplift and the erosion in high erodibility areas. This is also confirmed by the landforms in the Sant'Arcangelo basin and in the foredeep, where it has not yet been reached a landscape with the alternance of crests and valleys (see the presence of several depositional plateau on the regressive conglomerates of Irsina, in the foredeep, and of Serracorneta, in the Sant'Arcangelo basin), which is the pre-condition to have an equilibrium among uplift and the lowering of the crests.

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