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# Integrated Morphometric Analysis in GIS Environment Applied to Active Tectonic Areas

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## 1. Introduction

This chapter describes a methodology for constraining the structural lineaments in active tectonic areas by integrating morphological and morphometrical data derived by DEMs (Digital Elevation Models) processing, with different geophysical data, as local seismicity and ground deformation data. Furthermore, validation of the lineaments extracted from DEM is carried out by looking over geological and geomorphological maps of literature, available aerial photo and field surveys reports (Fig.1).

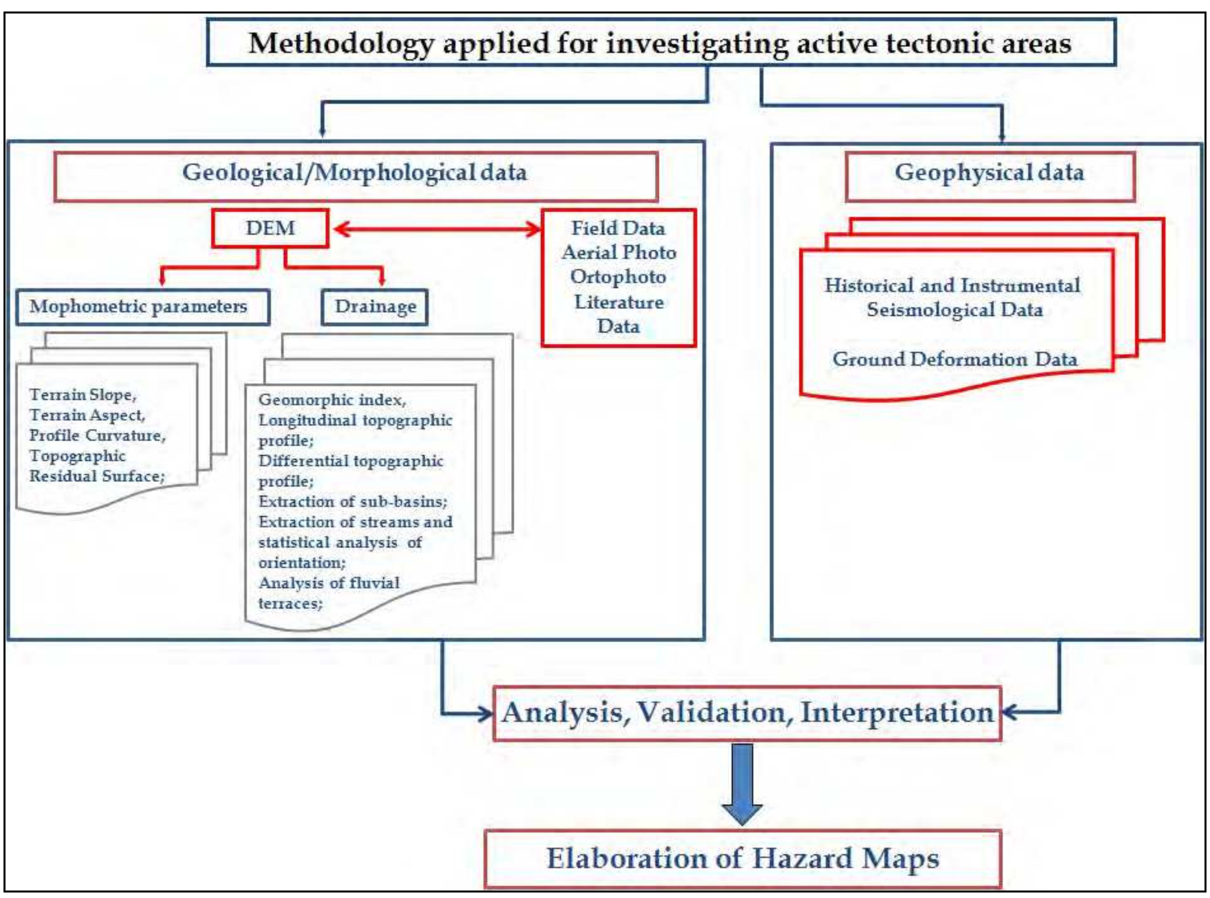


Fig. 1. Flow chart describing the methodology applied for investigating active tectonic areas.

The morphometric parameters of the terrain slope, terrain aspect, profile curvature, tangential curvature and topographic residual surface are chosen for identifying the linear continuity of the morphostructural features observed on the DEM. The criteria of lineament extraction is based on the identification of linear topographic surface features, such as valleys, ridges, breaks in slope, boundaries of elevated areas aligned in a rectilinear or slightly curvilinear shape and that distinctly differ from the patterns of adjacent features.

The geophysical data considered in this analysis include spatial distribution of local earthquakes, accurate locations of seismic sequences and relative focal mechanisms, which could confirm activity of local tectonic structures.

The areas selected for testing our methodology, located in Southern Italy, are the Agri Valley (Campania-Lucania regions), hit by the strong historical earthquake of December 26, 1857 ($I_{max}$=XI, $M_e$=7.0) and also by recent micro-seismicity; the Sannio area (Campania-Molise regions), affected in historical time by the strong earthquake of June 5, 1688 ($I_{max}$=XI, $M_e$=6.7) and in recent time by seismic sequences of moderate energy; the Campi Flegrei volcanic district (Campania region, Thyrrenian coast), characterized in the past decades by major bradyseismic crises with remarkable ground uplift and intense seismic activity, and recently by minor crises with lower deformation (Fig. 2).

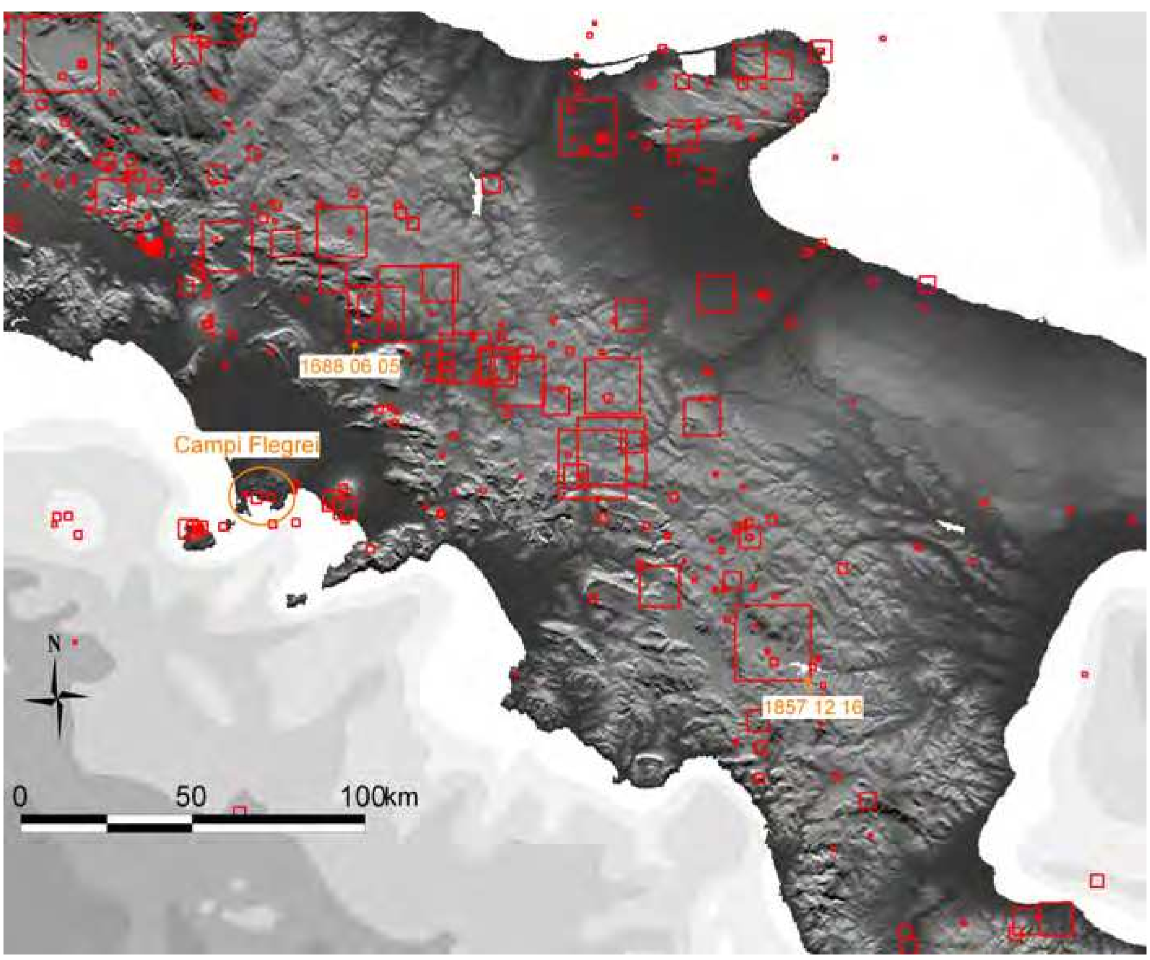



Fig. 2. Historical and recent earthquakes in the Southern Apennines of Italy (red squares) from CPTI04 catalogue; the epicenters of the 1688 Sannio earthquake ($I_{max}$=XI, $M_e$=6.7) and the 1857 Agri Valley earthquake ($I_{max}$=XI, $M_e$=7.0, CPTI, 1999) are pointed out; the Campi Flegrei volcanic area location is indicated by the orange circle.

Particulary, the Agri Valley and the Sannio area are active tectonic areas of the Southern Apennines chain and are characterized by a complex inherited tectonic setting, low-tectonic deformation rates that hide the seismogenic sources geometry, and youthfulness of the sources. Whereas the morphotectonic features of the Campi Flegrei caldera resulted from the combined action of both volcanism and regional tectonics, mainly correlated with a circular geometry of deformation (volcanism), and NW-SE, NE-SW normal faults (regional tectonics).
As regards all the above studied areas, due to the difficulty or not straightforward recognition of the induced surface deformation, besides the lack of recent surveyed structural data, the operation of the GIS system has enabled us to process and generate original informative layers, through image analysis, such as new structural lineaments.
The synthesis of our main findings has consisted in structural thematic maps of the new lineaments, which are the final results of our application, representing a contribution to understanding the potential active faults of the investigated areas, for the assessment of local geological-environmental hazard parameters.

## 2. Methodology

Although the interpretation of land morphology applied to tectonic deformation has been broadly studied, there are few examples of integration of digital methods for tectonic geomorphology with the classical approach (Burbank and Anderson, 2001, Keller and Pinter, 2002, Jordan et al., 2005; Nappi et. al., 2009). Quantitative analysis of the topographic features contributes to study the interaction between tectonics and surface processes, providing a basis for modelling landscape evolution. Particularly, geo-morphometrical analysis of DEMs represents a methodology for studying the morphotectonics of an area quantitatively, recognizing the main tectonic structures (e.g., Jordan et al. 2005). Geologic structures may produce linearly aligned features not typically common in nature, therefore, recognizing, measuring, and interpreting all the linear and areal surface features is of great importance in geodynamics. Intersection of bedding with the topographic surface can appear as linear features or planar features in DEMs. Linear morphological expressions of fractures include: linear valleys, linear ridgelines, and linear slope breaks.
The methodology applied consists of geo-morphometrical analysis of high resolution DEMs (20x20, 5x5 m pixel), integrated with the geological and geomorphological data derived from literature, photo-interpretation and field surveys, besides seimic data and ground deformation data analysis (Fig.1).
In particular, geomorphic analysis of topography consists of different steps: a) generation of high resolution DEMs derived from interpolation of altimetrical data in vector format; b) extraction and analysis of topographic parameters derived from DEM to identify their linear continuity associable to fault lineaments; c) statistical analysis of the azimuthal distribution of the morphostructural lineaments extracted. The morphometric parameters analyzed in our work are have been extracted following the methods of Moore et al., 1993 (*terrain aspect, terrain slope, tangential curvature, profile curvature, shaded relief, topographic residual surface*). The *terrain aspect* (At=arctan[(−dH/dy)/(dH/dx)]) measures the downhill direction of the steepest slope (i.e., dip direction) at each grid node, and identifies the linear geomorphic features (crest lines) that can be associated with footwalls of normal faults.
The *terrain slope* (S=[(dH/dx)(2)+(dH/dy)(2)](1/2)) measures the slope at any grid node on the surface and, for a particular point on the surface, is based on the direction of the steepest descent or ascent at that point, highlighting the presence of scarps and slope-breaks.

The *tangential curvature* $K_T$ measures the topographic surface curvature in the direction perpendicular to the maximum gradient direction, or tangential to the contour lines:

$$K_T = \frac{\left(\frac{\partial^2 z}{\partial x^2}\right)\left(\frac{\partial z}{\partial y}\right)^2 - 2\left(\frac{\partial^2 z}{\partial x \partial y}\right)\left(\frac{\partial z}{\partial x}\right)\left(\frac{\partial z}{\partial y}\right) + \left(\frac{\partial^2 z}{\partial y^2}\right)\left(\frac{\partial z}{\partial x}\right)^2}{pq^{1/2}} \tag{1}$$

$$p = \left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2$$

$$q = 1 + p$$

The *profile curvature* $K_p$ quantifies the rate of change in slope along the direction of maximum slope:

$$Kp = \frac{\left(\frac{\partial^2 z}{\partial x^2}\right)\left(\frac{\partial z}{\partial x}\right)^2 + 2\left(\frac{\partial^2 z}{\partial x \partial y}\right)\left(\frac{\partial z}{\partial x}\right)\left(\frac{\partial z}{\partial y}\right) + \left(\frac{\partial^2 z}{\partial y^2}\right)\left(\frac{\partial z}{\partial y}\right)^2}{pq^{3/2}} \tag{2}$$

$$p = \left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2$$

$$q = 1 + p$$

Negative values of both tangential curvature and profile curvature indicate that the surface is upwardly convex; positive values show that the surface is upwardly concave. A curvature value of zero indicates that the surface is flat. In our procedure, we have low-pass filtered and classified the DEM, and have identified the highest values of tangential and profile curvature for outlining basins/ridges.

The *topographic residual surface* represents a measure of relief within the landscape. This parameter indicates how suddenly channels are incised into the landforms (Hilley and Arrosmith, 2000). In areas undergoing rapid uplift, as active tectonic areas, channels will incise steeply into the surrounding soil. Therefore, high values of residual surface should correlate with rapidly uplifting areas.

The residual surface is calculated by subtracting two derived surfaces: the envelope and the subenvelope surfaces. The envelope is a surface interpolated from the stream bottoms in a landscape and the subenvelope is a surface interpolated from the ridge lines in a landscape. The final distribution of the topographic residual values depends on the points selected for the envelope and subenvelope surfaces.

The topographic residual surface for the study areas has been calculated using the algorithm of Hilley and Arrosmith, 2000, (modified). We have removed all pits from DEM using Arc/INFO "fill" command before applying the algorithm, since the reliability of the topographic residual map depends fairly strongly on data quality (Nappi et al., 2009).

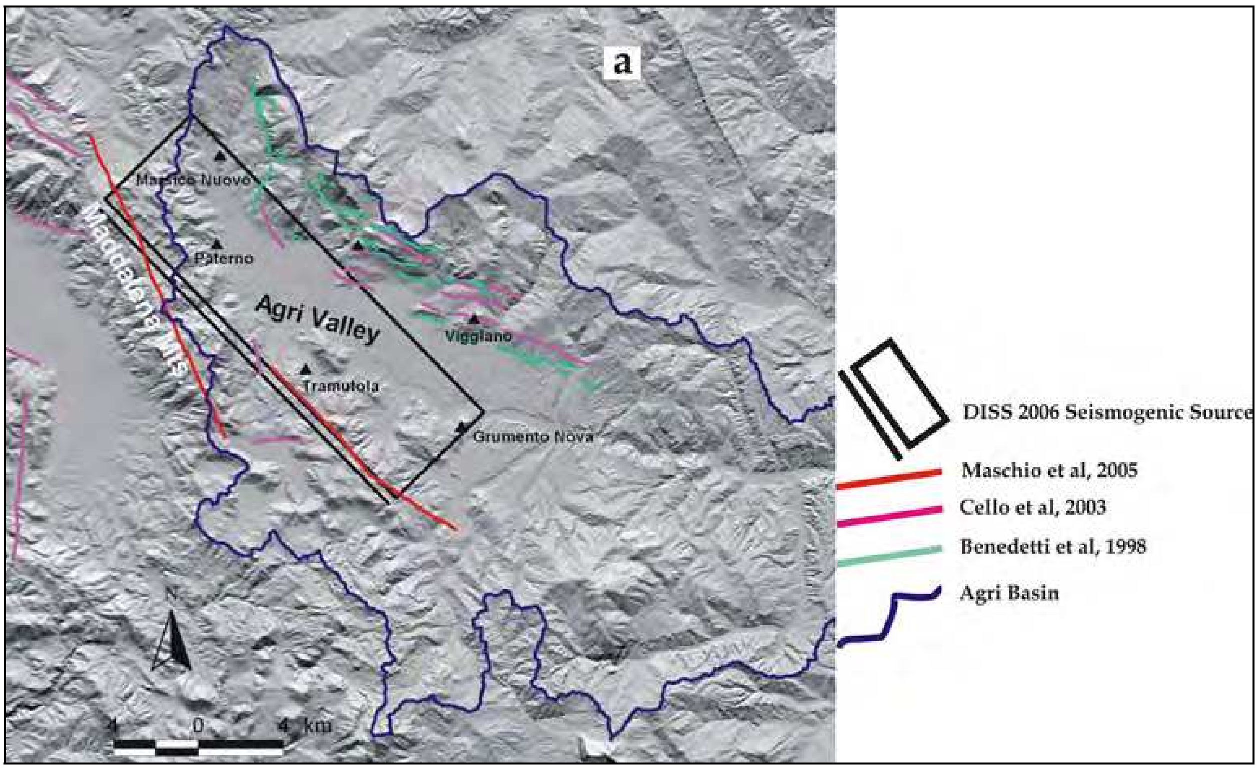
The followed methodology recommends the integration of data derived from digital parameters with those extracted through classical approach. In particular, the drainage

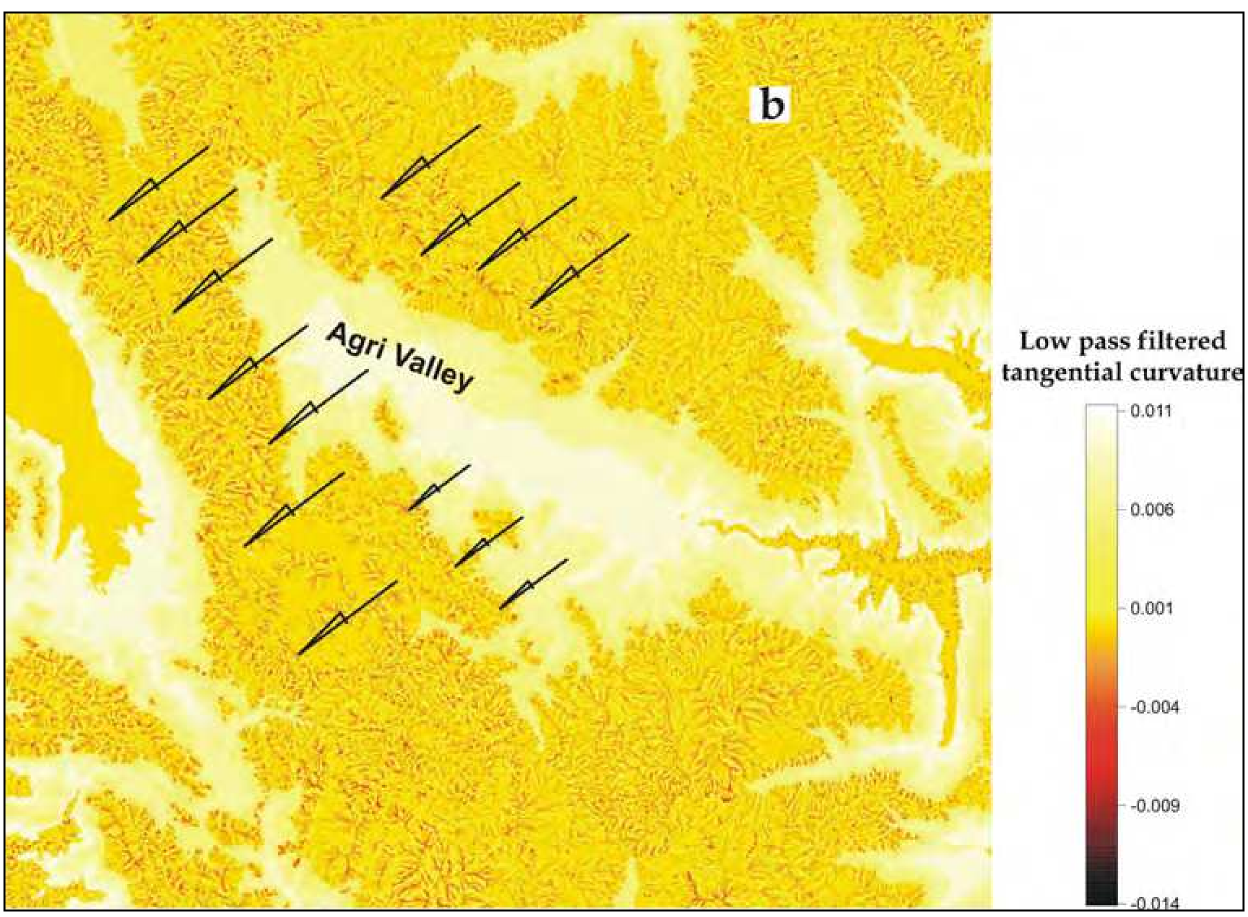
networks have been performed since they represent young features of landform and they have possibly registered the recent tectonic deformation; indeed, the drainage pattern is one of the most significant features that could be influenced by tectonic activity. Phenomena of antecedence, rivers diversions, shifts in channel pattern and longitudinal change of the channel behaviour reveal tectonic modifications. Therefore the quantitative geomorphic analysis of the drainage networks has consisted of evaluation of the following: 1) geomorphic indexes (Keller & Pinter, 2002) such as Asymmetry Factor (AF=100(Ar/At)), Transverse Topographic Symmetry Factor (T=Da/Dd), Stream Length gradient (SL=(DH/DL)L) and mountain front Sinuosity (Smf=Lmf/Ls); 2) the longitudinal topographic profile, the topographic profiles adjacent to the stream and the relative differential profile; 3) extraction of sub-basins; 4) extraction and statistical analysis of the stream orientation; 4) analysis of the river terraces.
The analysis of the geological data found in literature and field survey reports has consisted in collecting and cataloging the whole cartographic available dataset, in addition to recent publications and scientific papers, relative to the case study areas. Moreover, seismological data as ipocenters and focal mechanisms of hystorical and recent earthquakes extracted from the available seismic catalogues have been used in this study with the aim of constraining the activity of the investigated structural lineaments.

## 3. The case study areas

### 3.1 The Agri Valley basin

The Agri Valley is a NW-SE oriented Quaternary intermountain basin associated to the last stages of the Lucanian Apennines fold-and-thrust belt building, with inherited topographic setting that still represents the most striking feature (Fig.3a). It represented the epicentral area of the 1857 destructive earthquake ($M_e$=7.0; Imax=XI; MALLET, 1862; Gruppo di lavoro CPTI, 1999, 2004). This earthquake has been localized along the narrow topographic culmination of the chain where the historical destructive seismicity, characterized by extensional focal mechanisms, is concentrated together with the active faults of this portion of the Southern Appenines.
Different models have been suggested for the 1857 seismogenetic structure, based on: geological and structural surveys (Borraccini et al., 2002; Cello et al., 2003; Giano et al.,1997, 2000); geomorphological analysis (Di Niro et al., 1992, Di Niro and Giano, 1995; Giano, 2011); seismotectonic analysis (Benedetti et al., 1998; Burrato & Valensise, 2008; Improta et al., 2010; Maschio et al. 2005; Pantosti and Valensise, 1988; Valensise & Pantosti, 2001a), but there are still some open questions. Indeed in this region, contrasting with the events size, several tectonic and geomorphic factors concur to hide the active extensional seismogenetic faults. The inherited tectonic history of the peninsula with strong deformation readable on the topographic configuration, the low rates of present tectonic deformation, the youthfulness of the latest major change in the tectonic regime, the lithologies with strong erosional contrast (Valensise and Pantosti, 2001b), represent the reasons for the questionable recognition of the seismogenic source position. In this complex seismotectonic setting our integrated methodology turns out to be necessary for acquiring basic knowledge of new geomorphological features which could substantiate the different suggested hypotheses. Quantitative geomorphic analysis, which has been performed using a medium-resolution DEM (20x20 m), has allowed the identification of a series of NW-SE oriented features along the western side of the valley, spatially continuous and evenly distributed, even outside the


a
Marsico Nuovo
Paterno
Agri Valley
Viggiano
Tramutola
Grumento Nova
N
4 0 4 km
DISS 2006 Seismogenic Source
Maschio et al, 2005
Cello et al, 2003
Benedetti et al, 1998
Agri Basin


b
Agri Valley
Low pass filtered tangential curvature
0.011
0.006
0.001
-0.004
-0.009
-0.014

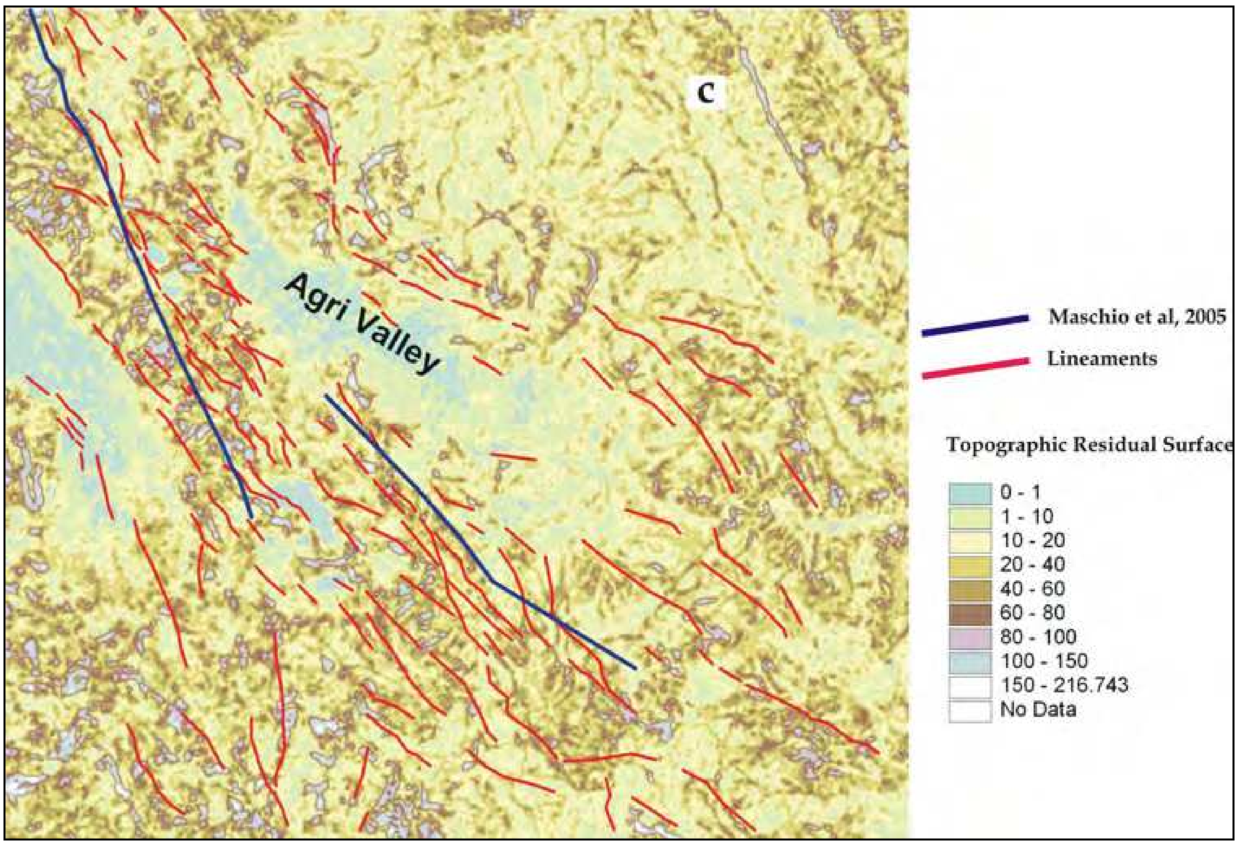



Fig. 3. a) Hypothesis from literature for the 1857 seismogenic source: black box from Valensise e Pantosti, 2001a; green line from Benedetti et al., 1998; red line from Maschio et al., 2005. Morphometric parameters extracted from DEM: b) Low pass tangential curvature with the arrows indicating the linear continuity of the parameter; c) morphostructural lineaments extracted from topographic residual surface (red lines) and the recent active lineaments derived from Maschio et al., 2005 (blue line).

basin, and coinciding with recent scarps. Whereas, on the eastern side of the valley, the lineaments coincide with the west-dipping fault system identified in the ground (Figs. 3b, 3c). It was performed also a study on the paleosurfaces of the basin (Nappi et al., 2002) wich represent relict surfaces of ancient periods of the local base-level, in geomorphic situation that was probably very different from the current conditions (Ollier, 1991). On this basis these studies point out the possible presence of zones affected by differential vertical movements and assess the geometry and kinematics of the relative structural elements. Previous studies on the paleosurfaces of the Agry Valley had been carried out (Amato e Cinque, 1999; Giano et al., 1997, 2000; Giano, 2011; Schiattarella et al., 2003) with the aim of estimating the regional tectonic uplift. On the other hand, in order to acquire information on the deformation of the topography due to active faults, further analysis and correlations based on morphological criteria have been carried out.

The spatial continuity of the paleosurfaces, the correspondence of elevation and the change of slope have been examined respect to the present topography for taking into account the probable original gradient of each surface. We have identified eight groups of remnant surfaces at different elevation of the basin, but the distribution of various orders with respect to the current topography is not the same on both sides of the basin (Fig.4).

The surfaces at highest elevations (1700-1500m a.s.l; 1400-1200m a.s.l), according to the authors (Amato e Cinque, 1999; Giano et al., 1997, 2000) are considered the most ancient and are clearly visible on the landscape. The paleosurfaces at elevation of 1700-1500 m a.s.l are only visible on the eastern side of the Agri Valley; the paleosurfaces at elevation 1400-1200 m a.s.l are well rapresented on both sides of the valley, although the distribution of several patches shows a linear continuity on the western side with lacks on the eastern side. The remnant surfaces at elevation of 1200-1100 m a.s.l are rather fragmented on both sides of the valley and are not much representative. The paleosurfaces at elevation of 1100-1000 m a.s.l. are rather fragmented on both sides of the valley and are better represented on the western side, compared to the eastern side. The remnant surfaces, of more recent age, are fragmented in small edges on the western side of the valley with evidence of faulting of paleosurfaces at elevation of 930-880 m a.s.l..Therefore, the study of paleosurfaces of the Agri Valley has evidenced that their spatial distribution is not symmetrical on both flanks of the basin. The eastern side of the valley is characterized by paleosurfaces of high elevation with uniform morphologic characteristics while the paleosurfaces of low elevation are lacking; the western side is characterized by different and fragmented high elevation paleosurfaces with constant NW-SE trend, and also by low elevation paleosurfaces. This geomorphological observation supports the landscape deformation modeled by the authors Maschio et al., (2005), Valensise & Pantosti, (2001a), DISS (2007) for the 1857 seimogenic source.

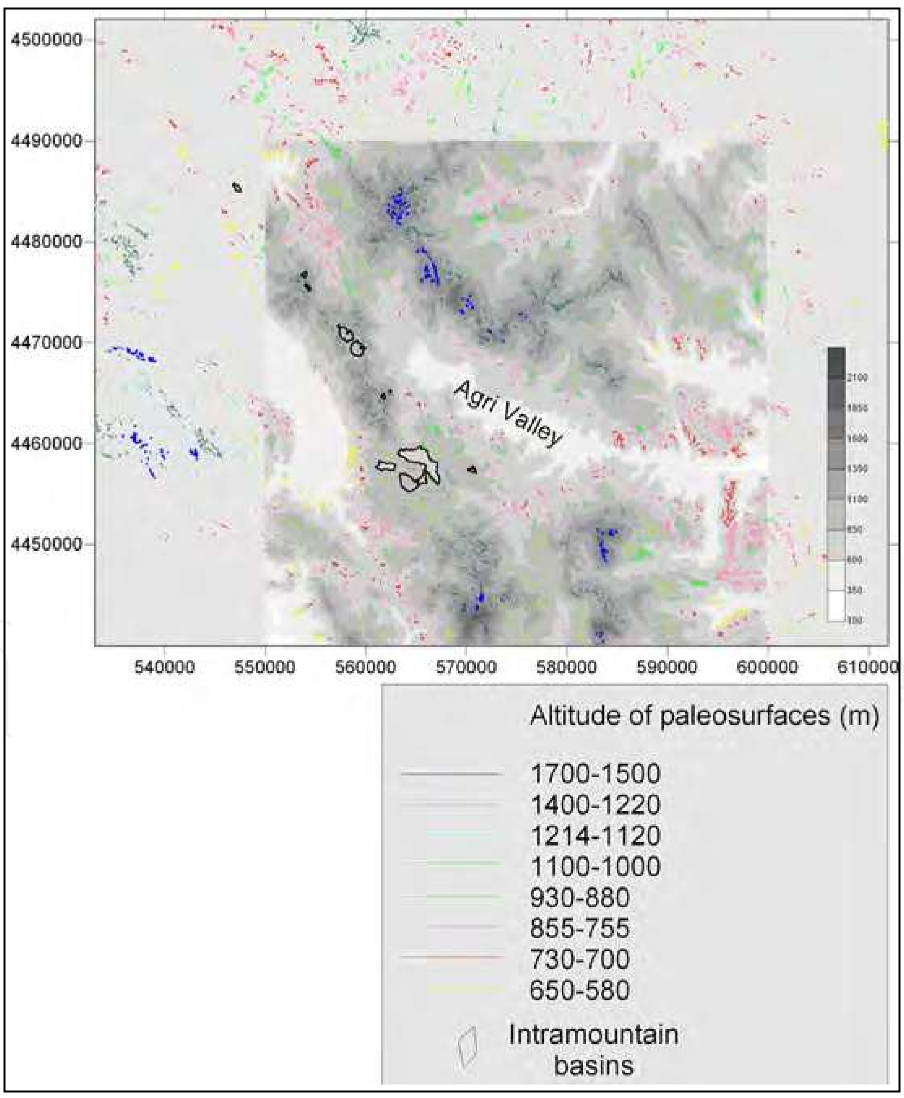



Fig. 4. Spatial distribution of the paleosurfaces and basins extracted from DEM analysis.

### 3.2 The Tammaro river basin

The Sannio area is located inside the Southern Apennines fold and thrust belt that has been affected by extensional deformation since middle-late Pleistocene (Cinque et al. 1993; Hippolyte et al. 1994; Westaway, 1993). The most important historical seismic event occurred in the Sannio on June 5, 1688 ($M_w$ = 6.7, CPTI 1999); this strong earthquake destroyed many towns of the area, while in recent times low-and moderate-energy seismic sequences ($M_d$ max = 4.1) occurred in 1990–1992 near the town of Benevento, in 1997 along the border between Campania and Molise near the Tammaro river, and in 2001 near Isernia, (Milano et al. 1999, 2005; Vilardo et al. 2003). Among the recent earthquakes, the event with maximum magnitude $M_l$ = 4.5 occurred on March 19, 1997, and the relative motion from its focal mechanism was a dip-slip on a NW-SE trending fault (Pondrelli et al. 2006).

As regards the 1688 seismogenic fault a NW-SE trending normal fault has also been hypothesized in the DISS by Valensise & Pantosti, 2001a (Fig.5a), on the basis of the similarity among the strongest earthquakes sources occurred along the Southern Apennines chain. However, the location and geometry of the seismogenetic source of the $M_w$ = 6.7, 1688 Sannio normal faulting earthquake is still a subject of scientific debate. This is due to several reasons: a) the possible incompleteness of the damage pattern data b) the difficult or not straightforward recognition of the induced surface deformation, c) the possible occurrence of blind or hidden faulting, and d) the low tectonic deformation rates and youthfulness of the source. The most important literature hypotheses for the 1688 source position are the following:

1. a NW-SE trending, NE-dipping, 25 km-long normal fault running along the SW margin of the Tammaro river basin (Valensise & Pantosti, 2001a; DISS Working Group, 2007);
2. a WNW-ESE trending, NE-dipping, 32 km-long normal fault located along the Calore River Valley (Di Bucci et al., 2006).

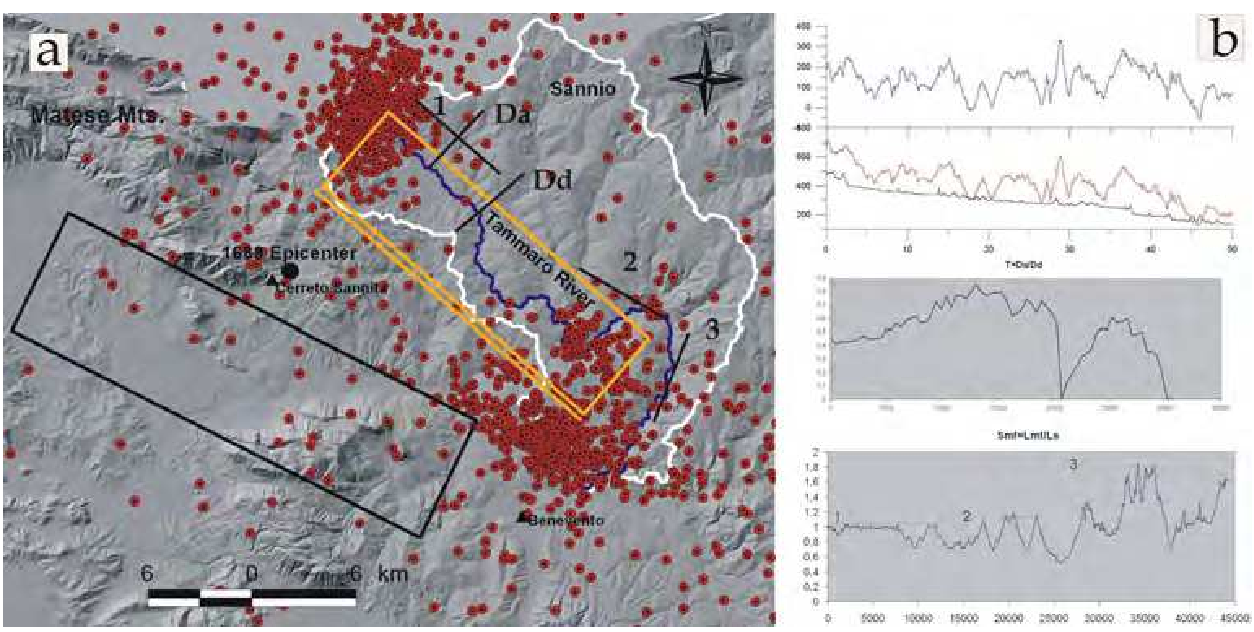



Fig. 5. a) Epicentral distribution of the instrumental seismicity from 1980 to 2006 in the Sannio area (red circles) and supposed 1688 seismogenic source positions (literature hypotheses): in orange the box of Valensise & Pantosti, 2001a, in black that of Di Bucci et al., 2006; b) from top to bottom: differential profile, elevation profile and longitudinal profile along the Tammaro river; T asimmetry factor; Smf mountain front Sinuosity evaluated along the segments 1, 2, 3 of the river, indicated on the left map.

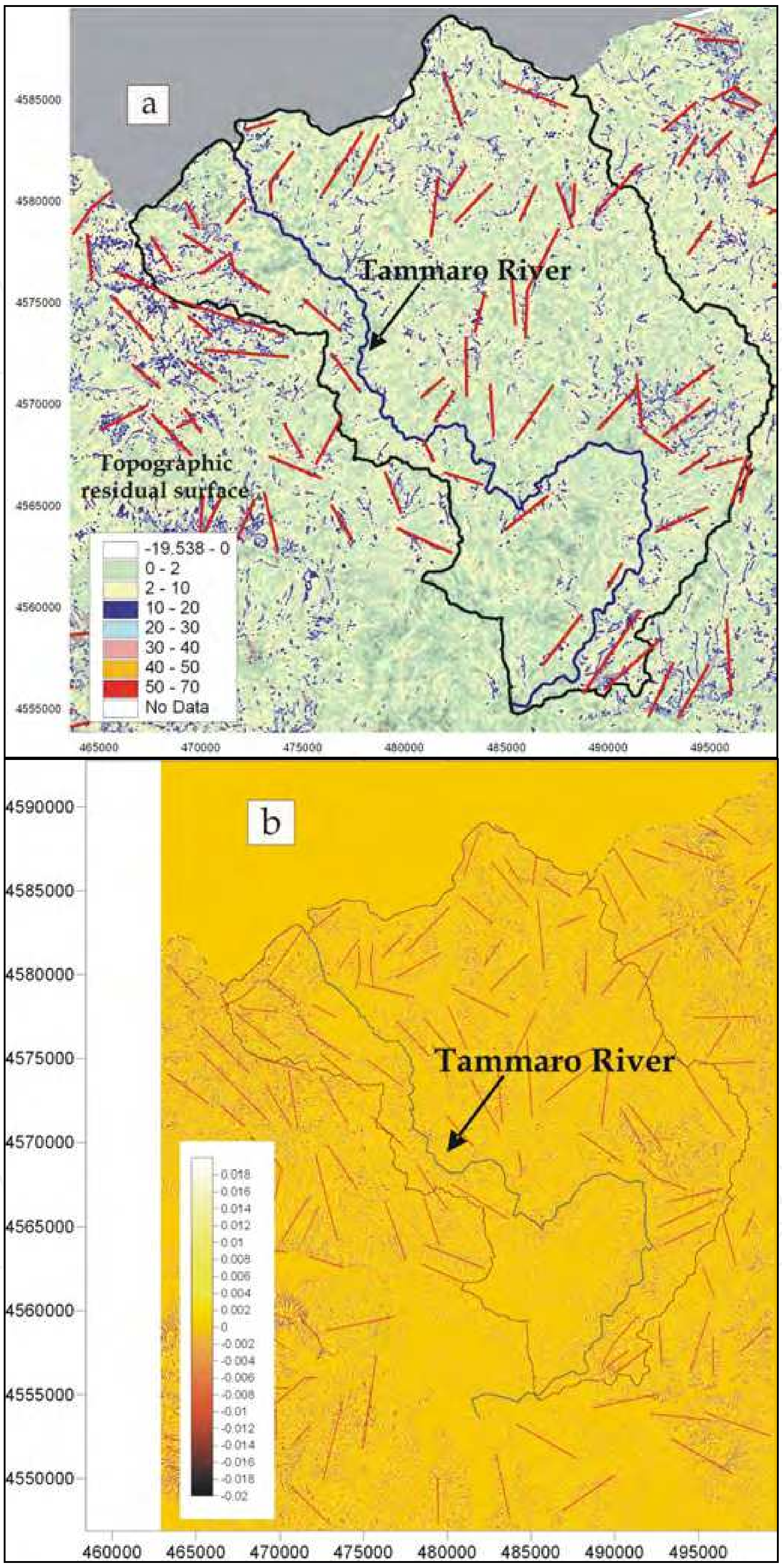



Fig. 6. The lineaments (red lines) extracted from the DEM analysis of the Tammaro basin: morphometric parameters of a) topographic residual surface; b) tangential curvature.

The methodology suggested in this chapter for investigating the seismogenetic source position has been completely applied due to the availability of high quality data. In particular it has been carried out a) detailed analysis of space-time features of the low energy seismic sequences by sub-setting each different seismic sequence in a number of events grouped on the basis of the events space clustering (Nappi et al., 2008); b) quantitative geomorphological analysis of the Tammaro river basin area for identifying the long term surface deformation possibly induced by the seismogenetic fault of the 1688 earthquake; c) integration in GIS environment of the geological and geomorphological data derived from photo-interpretation and field surveys with the morphometrical data derived by processing of a very high resolution DTM (5x5 m pixel), generated through the vectorial data of the Carta Tecnica Regionale of Campania.

The geomorphic indexes of drainage network as the mountain front Sinuosity ($1.2 < Smf < 2.5$) and Transverse Topographic Symmetry Factor (T=1 asymmetric basin) (Keller & Pinter, 2002) can be consistent with a possible recent tectonic control along the course of Tammaro river (Fig.5b), with a remarkable asymmetry of the basin towards SW. Furthermore, the longitudinal topographic profile, the topographic profile adjacent to the stream and the relative differential profile have evidenced the prevalent depositional behaviour of the early portion (20 km) of the Tammaro river (Fig. 5b).

A significant swarm of NW-SE contiguous lineaments on the SW side of the Tammaro river valley have been identified through the analysis of topographic parameters extracted by DTM (Fig 6a, b). The morphological analysis of the Ortophoto (1x1 pixel m) and the field observations have suggested a young morphological expression of such lineaments, also inferred by the existence of recent small basins along their trace, and by the identification of a structural mountain front corresponding to the above lineaments, the whole features suggesting a recent deformation activity.

### 3.3 The Campi Flegrei volcanic district

The Campi Flegrei volcanic district formed as a consequence of the lithospheric stretching in the central Tyrrhenian sea and Apennines belt parallel extension, since the Plio-Quaternary times (Scandone et al., 1991). The Campi Flegrei caldera is an active volcanic area located westerly of the town of Naples, characterized by high volcanic risk due to its very intense urbanization (Orsi et al., 1999).

The morphological features of this caldera resulted from the combined action of both volcanism and regional tectonics; in fact the caldera is a nested structure (Fig. 7) which originated through two major collapses related to the major eruptions of the Campanian Ignimbrite (39 ky) and the Neapolitan Yellow Tuff (15 ky) (De Vivo et al., 2001). After the Yellow Tuff eruption, volcanic activity and ground deformation have been very intense, with many different eruptive episodes. The last eruption took place in 1538 and formed the Mt. Nuovo cone (Di Vito et al., 1987). The magmatic system of the caldera is still active with intense hydrothermal activity (Chiodini et al., 2010), seismicity and ground deformation.

As regards the geodynamic history of the Campi Flegrei, the major bradyseismic crises occurred in 1969-1972 and 1982-1984, which were characterized by remarkable ground uplift and intense seismic activity; minor crises were observed in 1989, 1994, March-August 2000 and from June 2004 to October 2006, with low seismicity and moderate ground deformation (Del Gaudio et al., 2010).

Our study for the Campi Flegrei area has consisted in extraction of morphostructural lineaments based on the identification of linear topographic surface features derived from geomorphic analysis of high resolution DTM (5x5 m pixel); analysis and comparison of the lineaments spatial and statistical coherence with the structural lineaments already known from literature; correlation of the recent seismicity spatial distribution (crises of 1982-1984 and 2004-2006) with the obtained structural lineaments. Moreover, the results of the analysis have also been correlated to the local ground deformation data acquired through high precision levelling surveys over the last 20 years, and to the tiltmetric data continuously recorded locally over the last 10 years (Del Gaudio et al., 2009) with the aim of constraining the activity of the lineaments with local ground deformation data as well (Nappi et al., 2010b). In fig. 8 the morphometric parameters and the statistical analysis of the spatial distribution of the lineaments extracted are plotted. Two preferred NW-SE and NE-SW orientations are evident from the rose diagrams, in particular, from the terrain slope, terrain aspect and the topographic residual surface the lineaments with NW-SE orientation are prevalent.

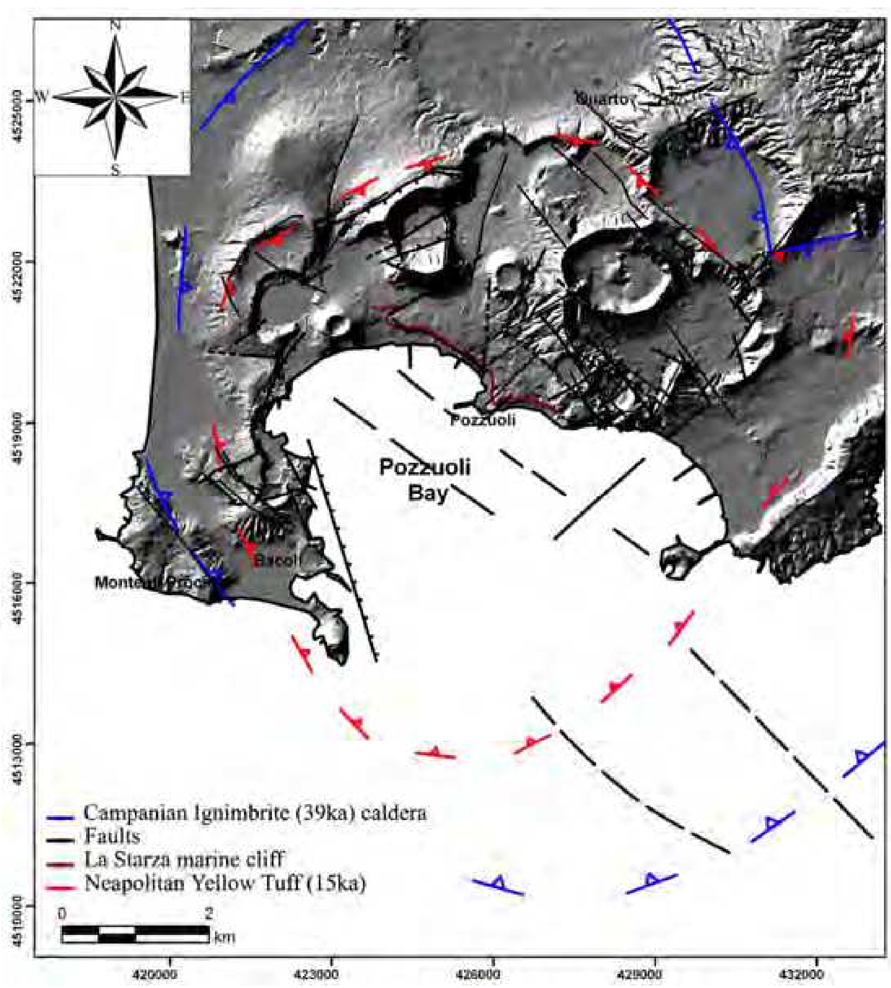



Fig. 7. Structural setting modified from Orsi et al., 1999. DTM (Digital Terrain Model) and structural data extracted from Bechtold et al., 2005.

Epicentres of the best located 1982-1984 seismic events appear clustered mostly in the central area of the maximum deformation observed (Fig. 9 left). A selection of events with $M_D \geq 2.5$ showes epicentres concentrated to the East of the Solfatara crater and hypocentres clustered above the STH and SFT (Solfatara) seismic stations with depths between 0.5 and 4 km. Epicentres of the best located 2005-2006 Volcano-Tectonic (VT) seismic events are concentrated on the eastern border of the Solfatara crater (Fig.9 right); the relative hypocenters are confined between 0.5 and 4 km and also clustered above the SFT (Solfatara) seismic station.

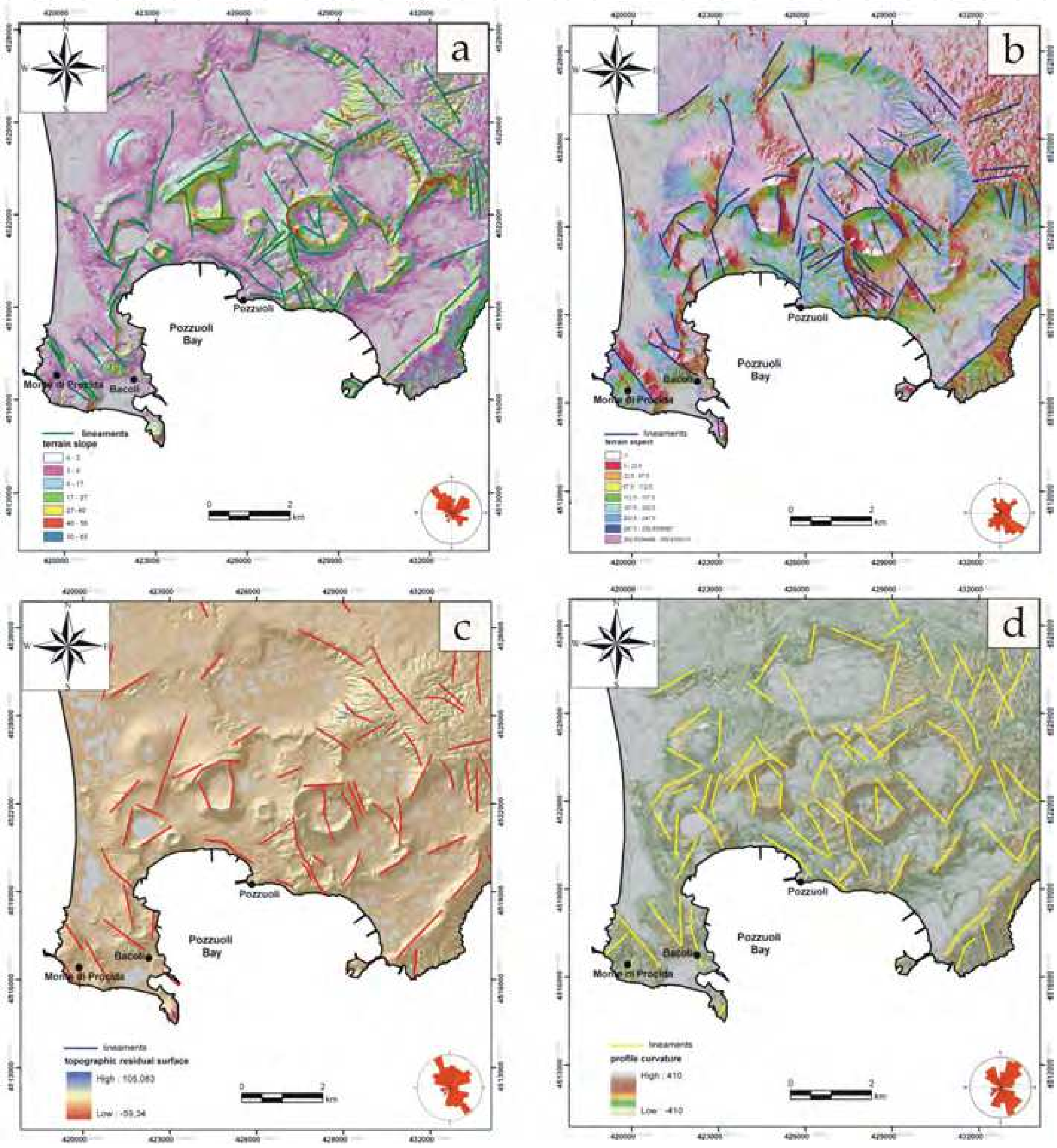



Fig. 8. The lineaments extracted from the morphometric parameters analysis; the rose diagrams represent the frequency distribution of the lineaments directions. a) the terrain slope map (lineaments in green); b) the terrain aspect map (lineaments in blue); c) the topographic residual surfaces map (lineaments in red); d) the profile curvature map (lineaments in yellow).

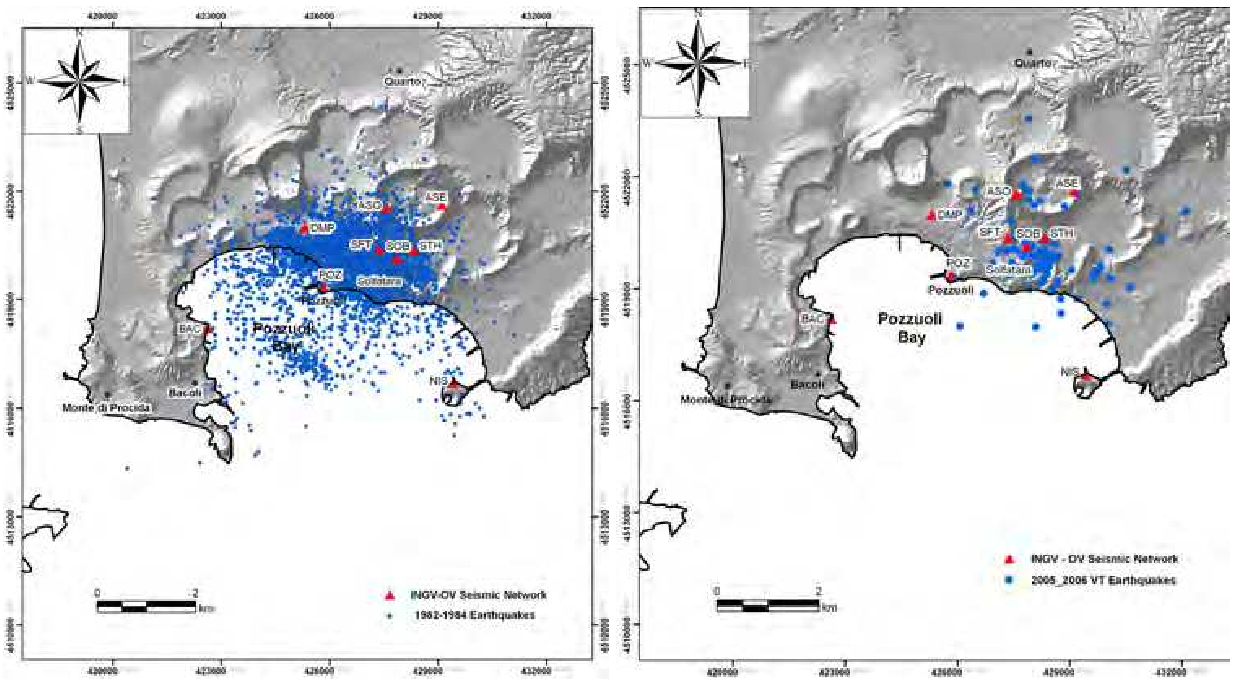



Fig. 9. The 1982-1984 seismic crises epicentres (blue circles) of the Campi Flegrei volcanic area (left map) and the epicentres of the best located 2005-2006 Volcano-Tectonic (VT) seismic events (right map).

## 4. Conclusions

The final step of the analysis and methodology proposed in this chapter has consisted in testing the congruence and consistency of the obtained results and of the possible interpretations, in the context of a coherent pattern of deformation taking place inside the studied areas.

The methodology applied to the Agri Valley has highlighted the agreement of the morphostructural lineaments identified on the SW side of the valley with the surface trace of faults system quoted in literature (Maschio et al., 2005). Moreover, these lineaments, jointing several intermountain sub-basins located only on the western side of the valley, are coincident with scarplets in recent deposits, in turn aligned with the main trend of the Maddalena Mts. Faults system, confirming their recent tectonic activity (Fig.3c). Throughout the study of the paleosurfaces from DEM analysis, the ancient erosional surface at 930-880 m a.s.l., on the western flank of the basin, is dislocated with throw of 25 m. The age of the paleosurfaces evaluated by Amato e Cinque, 1999; Schiattarella et al., 2003, as about 0.75 My (middle Pleistocene), suggested the recent tectonic activity of the western mountainside affected by post-middle Pleistocene deformation. The morphostructural data extracted following our methodology, relatively to the Agri Valley, accordingly support the recognized literature hypothesis of a NW-SE oriented seismogenic source, NE dipping, for the active faults system of the Agri Valley.

For the Tammaro basin area, the results obtained by applying our methodology have indicated that the strong asymmetry of the basin, not influenced by geological factors, could have been conditioned by tectonics, oriented along SW direction. The presence of NW-SE topographic lineaments extracted from DEM, on the right hand side of the valley of the Tammaro river, further constrained by morphological analyses, confirms the existence of a

structural mountainside corresponding to the above lineaments. Moreover, also the presence of recent small basins along the trace of some morphostructural features extracted can be associated with recent tectonic activity.
As regards the analysis of seismological data relative to the Tammaro basin area, some recent seismic sequences of low energy, progressively activated, would concentrate particularly on some structural features exposed at surface (Fig. 10). In addition, some clusters of events (N. 5 and N. 3) concerning the same sequences are concentrated at the edge of the seismogenic source of the 1688 earthquake proposed by Valensise and Pantosti (2001a) (Fig. 5a), therefore it is possible to hypothesize that such clusters act as segment boundaries relatively to the master fault source (Nappi et al., 2008), constraining the linear dimension of the 1688 seismogenetic source.
The methodology applied to the Campi Flegrei volcanic area has allowed to identify significant structural lineaments from quantitative analysis of high resolution DEM (5x5 pixel m), extracting morphostructural features, based on their linear continuity. The statistical analysis of the spatial distribution of the lineaments extracted showes NW-SE and NE-SW preferred orientations; in particular, from the terrain slope, terrain aspect and the topographic residual surface the lineaments with NW-SE orientation are prevalent.

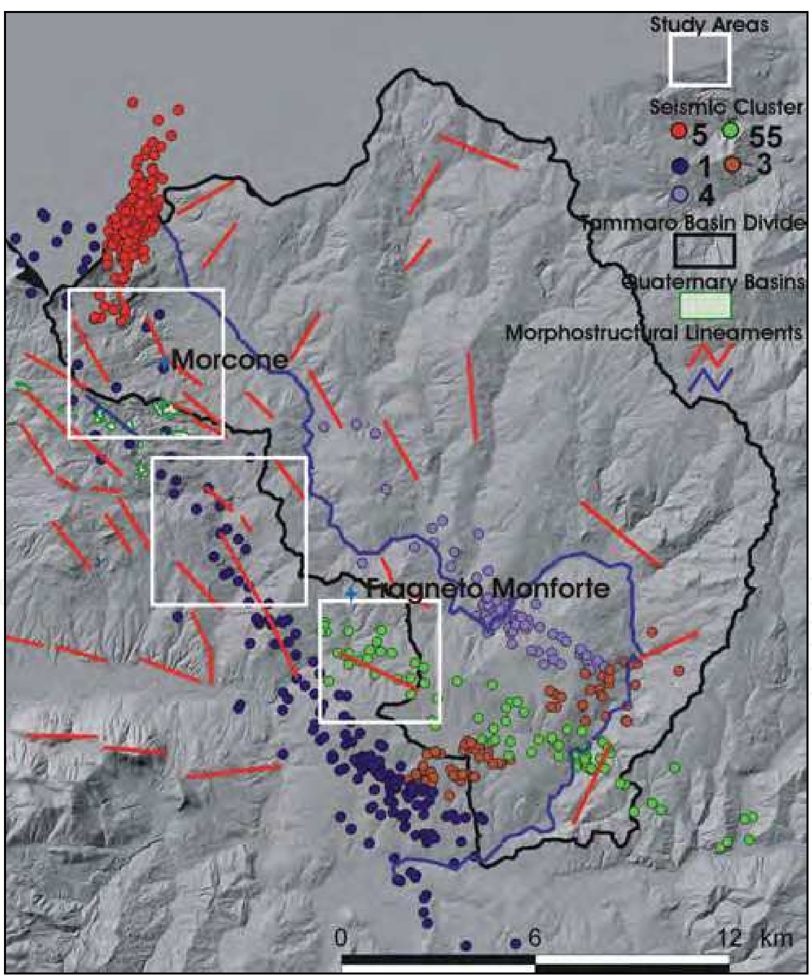



Fig. 10. Morphostructural lineaments (red and blue lines) extracted from DEM analysis; the main clusters of seismic events are mapped in group of different colors, and areas to be furtherly investigated in white boxes.

The analysis of seismological data pointed out that the epicentres of the best located 1982-1984 seismic events clustered mostly in the central area of maximum deformation but a selection of events with $M_D \geq 2.5$ have been located to the east of the Solfatara crater, with depths between 0.5 and 4 km, clustered above the STH and SFT (Solfatara) seismic stations. The S-N cross section of the 1982-84 epicentres, the S-N and W-E section of the 2005-2006 VT epicenters highlight a subvertical plane above the Solfatara crater that would suggest the activation of a seismogenic fault comparable with significant structural discontinuities NNW-SSE oriented, also identified through image analysis, located in the M. Olibano dome area (near OLB tilt station).

Moreover, the high precision levelling and tiltmetric data relative to the 2005-2006 years have clearly demonstrated asymmetrical deformation in the same area (OLB station) (Del Gaudio et al., 2009), meaning uplift of the rock volume to the SW of the fault zone and lowering to the NE fault zone side. For this reason we hypothesize a significant seismotectonic role of the fault zone located E-SE of the Solfatara crater (Fig.11), capable to accommodate the strain built up in these last unrest periods (2005-2006).

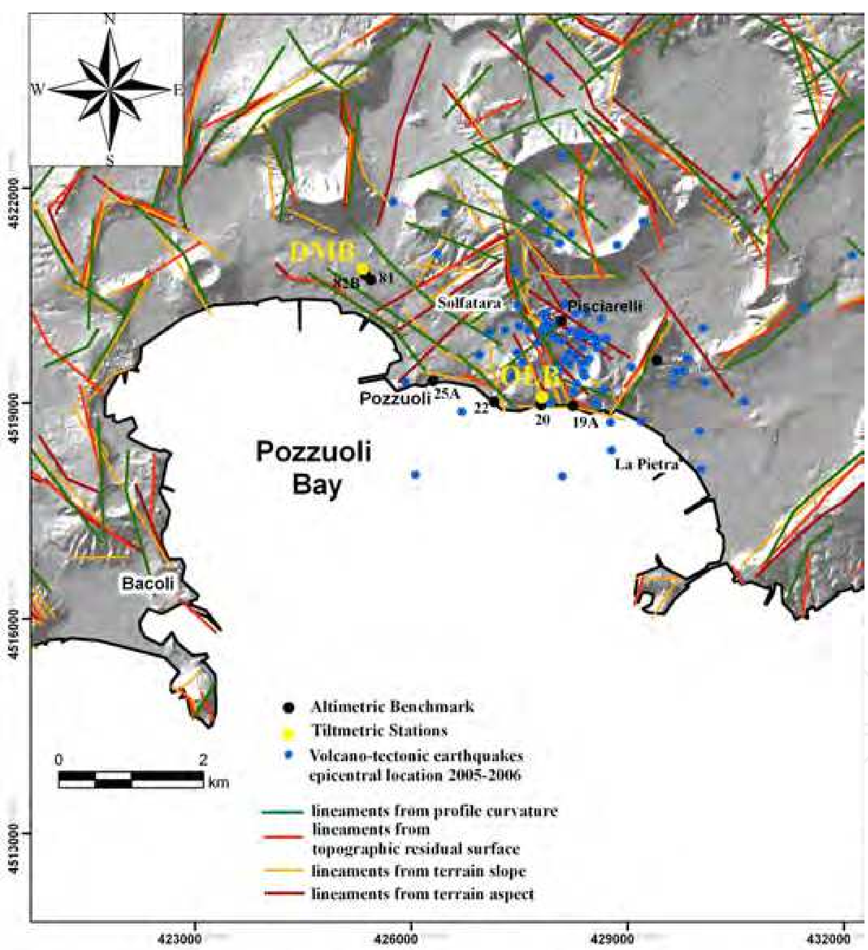



Fig. 11. The map shows different thematic layers overlapped: instrumental seismic events (VT 2005-2006) with blue circles and structural lineaments from morphometric analysis.

In conclusion, the areas selected as case study have revealed the efficiency of the methodology for investigating their complex tectonic setting, and the usefulness of generating original morphostructural data for improving scientific knowledge about active tectonic areas and associated hazards. Moreover, validation of new data with widely accepted literature data, has provided added value to the interpretations and future analysis. Accordingly, the results demonstrate the applicability of the method used so far only for active tectonic areas, even in active volcanic areas (Nappi et al., 2010a), confirming the usefulness and the need for a methodological approach of this kind.

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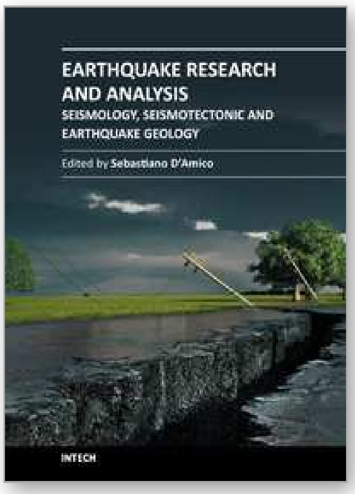

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This book is devoted to different aspects of earthquake research. Depending on their magnitude and the placement of the hypocenter, earthquakes have the potential to be very destructive. Given that they can cause significant losses and deaths, it is really important to understand the process and the physics of this phenomenon. This book does not focus on a unique problem in earthquake processes, but spans studies on historical earthquakes and seismology in different tectonic environments, to more applied studies on earthquake geology.