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STRUCTURAL CONTROL ON DRAINAGE NETWORK OF THE SOUTH-WESTERN SIDE OF THE AGRI RIVER UPPER VALLEY (SOUTHERN APENNINES, ITALY)

ABSTRACT: CAPOLONGO D., CECARO G., GIANO S.I., LAZZARI M. & SCHIATTARELLA M., *Structural control on drainage network of the south-western side of the Agri River upper valley (Southern Apennines, Italy).* (IT ISSN 1724-4757, 2005).

Relationships between low order streams and fracture pattern of the upper part of the Agri Valley (Southern Italy) have been analysed by comparison of azimuthal diagrams to infer the existence of structural controls on recent evolution of drainage network. A computer-aided counting procedure based on DEM and GIS methods, greatly improved the quantitative analysis, allowing rapid treatment of a large number of orientation data.

The upper valley of the Agri River is an intermontane Quaternary basin located in the axial zone of the southern Apennines. Tectonics has strongly controlled shape, morphology, and sedimentary evolution of the basin up to the present. Pleistocene extensional tectonics is commonly envisaged as broadly responsible for the basin evolution, but many data suggest that the Agri valley is a more complex structure than a simple extensional graben or than a pull-apart basin.

The study area coincide with the south-western flank of the valley, which is prevalently made of Meso-Cenozoic shallow-water carbonates thrust on coeval pelagic successions and broadly affected by Plio-Quaternary high-angle faults. The basin floor is filled by middle Pleistocene faulted alluvial deposits. Evidences of deformation in younger sediments as well (i.e. upper Pleistocene to Holocene) have been recently documented by radiocarbon dating of faulted palaeosols.

The outcrop-scale fracture pattern of the south-western side of the Agri River upper valley is characterized by the presence of several sets of sub-vertical joints. Two of them are well-defined sub-orthogonal sets and correspond to N150°±10° and N60°±10° trends. Other sets show with N-S and N120°±10° trends, which represent the orientations of regional high-angle faults. In many areas of southern Apennines the N150°-striking minor faults and joints and associated orthogonal fractures represent the youngest structures of Quaternary brittle deformation, produced by NE-SW extension.

The basic elaboration of the hydrographic net map has been made on 1:25000 scale IGMI topographic maps, on which all streams have been recognized and digitized with Arcview GIS software. In this way, the fluvial net is geo-referenced and the related dataset is enriched with additional information. As a matter of fact, every single stream is linked to a table with sub-basin pertinence, hierarchic order and length. Further, for the I to III order streams also the orientation in azimuthal notation is reported.

In this study only the I and II orders have been considered because of their better susceptivity with regard to tectonic influence. The minor fluvial network of the south-western flank of the valley is arranged according to the same trends of the fracture systems. In particular, the rose diagram related to the first order streams shows a clear maximum corresponding to the N160°-170° orientation class, with a minor sub-orthogonal trend. The second order streams are arranged according to N160°-170°, N50°-60° and N80°-90° trends. Both diagrams do not show significant statistical dispersion or background noise.

The fracture pattern of the upper Agri Valley strongly controlled genesis and arrangement of minor streams, which traced the youngest sets of joints and minor faults (NW-SE and NE-SW trends). E-W-trending structures also exerted a structural control, but only on the II order streams: this fact may depend on the age of these features, which seem to pre-date the other trends.

KEY WORDS: Tectonic Geomorphology, Drainage Network Analysis, Southern Apennines (Italy).

RIASSUNTO: CAPOLONGO D., CECARO G., GIANO S.I., LAZZARI M. & SCHIATTARELLA M., *Controllo strutturale sul reticolo idrografico del bordo sud-occidentale dell'Alta Val d'Agri (Appennino meridionale, Italia).* (IT ISSN 1724-4757, 2005).

Sono state investigate le relazioni tra i corsi d'acqua di rango gerarchico inferiore e lo stato di fratturazione del bordo sud-occidentale dell'Alta Val d'Agri, una depressione di origine tettonica ed età quaternaria ubicata nella zona assiale dell'Appennino campano-lucano, lungo una fascia a forte pericolosità geomorfologica ed elevato rischio sismico. La comparazione tra le due popolazioni di dati è stata effettuata sia sulla ba-

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se del calcolo automatico, a partire da modelli digitali del terreno, che su quella dei rilievi diretti sul campo, che hanno consentito l'acquisizione delle misure relative all'orientazione di superfici di frattura ed i necessari controlli delle caratteristiche geomorfologiche del reticolo idrografico.

Il *pattern* delle fratture alla scala dell'affioramento, che interessa prevalentemente carbonati meso-cenozoici di mare basso (*Unità dei Monti della Maddalena*) e successioni pelagiche lapidee del Triassico e Giurassico (*Unità Lagonegresi*), è costituito da un ben definito sistema di *joints* tettonici sub-verticali, caratterizzato da due famiglie sub-ortogonali con orientazioni N150°±10° e N60°±10°, e da altri *set* con direzioni N-S e N120°±10° che ricalcano andamenti di faglie ad alto angolo di rilevanza regionale e genesi neotettonica. L'andamento N150° è peraltro rappresentativo delle strutture della deformazione fragile quaternaria più recente (Pleistocene medio - Attuale), prodotta da estensione in direzione NE-SO.

La comparazione dei diagrammi del campo di fratture e dei corsi di I e II ordine, maggiormente suscettibili di controllo strutturale, ha mostrato una generale corrispondenza degli andamenti. I corsi di I ordine, in particolare, ricoprono fedelmente le discontinuità tettoniche orientate N160°-170° e, in subordine, quelle sub-ortogonali a queste, mentre i corsi di II ordine sono distribuiti anche secondo il *trend* E-O, che sembra pertanto riferibile al controllo esercitato da elementi strutturali più antichi – in termini neotettonici – di quelli relativi agli altri due andamenti. In tempi altopleistocenici, le faglie minori ed i sistemi di diaclasi legati ai lineamenti bordieri dell'alta valle, con orientazione N120°, non hanno invece prodotto un apprezzabile effetto morfotettonico sul reticolo in destra orografica.

TERMINI CHIAVE: Geomorfologia tettonica, Analisi del reticolo idrografico, Appennino meridionale (Italia).

INTRODUCTION

Structural and geomorphological features of the southwestern flank of the upper valley of the Agri River, a Quaternary graben located in the axial zone of the southern Apennines (fig. 1), have been compared to outline the recent tectonic history of this depression, where giant-type oil reservoirs, discovered in the second half of the eighties, have been exploited since the beginnings of the last decade. Historical seismicity of that area, reaching the XII MCS degree, is well-known as well as the meaning of the relevant early and middle Pleistocene tectonic activity. Yet, the time span from the late Pleistocene to Present is surely the less known from a tectonic point of view, because of the paucity of good exposures of deformed stratigraphic markers younger than 100 ka.

The planimetric geometry of fluvial networks is an important morphostructural indicator in tectonically active regions or recent chains as Neogene orogenic belts and related foreland areas (Ollier, 1981). Quaternary tectonics normally has a strong influence on hydrographic patterns, controlling orientations and arrangements of fluvial streams. In particular, minor streams (i.e. from first to third order) generally reveal tectonic susceptivity, being often controlled by fracture pattern or, in some cases, by minor synclines or mesoscopic structures as joint or cleavage sets (see for example Schiattarella & Torrente, 1985). Many studies have been dedicated to these topics in different parts of the world. The methods used in several papers illustrating the relationships between fluvial net geometry and recent tectonics in different geodynamic settings are based on azimuthal comparison between main streams directions and fracture systems (Everette Bannister, 1980; Scheidegger, 1983; Ciccacci & *alii*, 1987; Perri & Schiattarella, 1997; Beavis, 2000; Beneduce & *alii*, 2004; among others), and/or morphometric calculations (Strahler, 1957; Avena & *alii*, 1967; Firpo & Spagnolo, 2001; among others). Other classical and modern works are based on geomorphological remarks (asymmetry of the valleys, shape of the net, angles of confluence between channels) as well as on regional morphotectonics (Ollier, 1993; Amato & *alii*, 1995; among others).

In the Agri upper valley (fig. 1), included in the «axial zone» of the southern Apennines (Ortolani & *alii*, 1992),

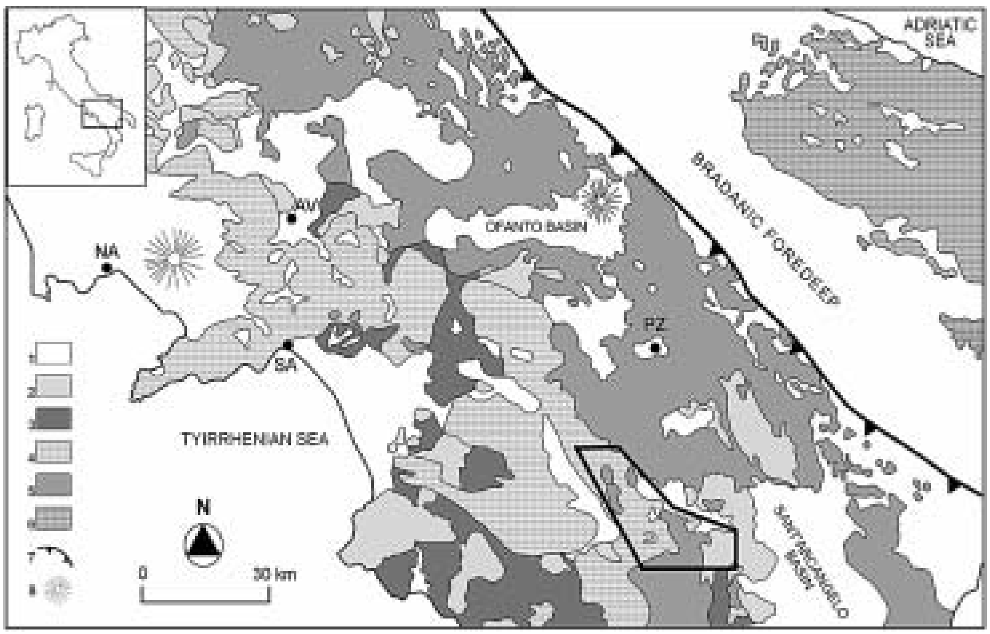


FIG. 1 - Geological sketch map of the Southern Apennines (study area in the bold frame). Legend: 1. Plio-Quaternary clastics and Quaternary volcanics; 2. Miocene syntectonic deposits; 3. Jurassic to Oligocene ophiolite-bearing internal units (*Liguride units*); 4. Meso-Cenozoic shallow-water carbonates of the Campania-Lucania platform; 5. Lower-Middle Triassic to upper Miocene shallow-water and deep-sea successions of the Lagonegro basin; 6. Meso-Cenozoic shallow-water carbonates of the Apulian platform; 7. Thrust front of the chain; 8. Volcanoes.

the fluvial network is represented by a major braided stream running on a wide and incised floodplain in which several sub-orthogonal tributaries converge from the right and left orographic side. Low order streams and several segments of major rivers appear to be structurally controlled, as suggested by comparison with the fracture system. The modalities of this control and its neotectonic meaning are the object of this note.

REGIONAL FRAMEWORK

The southern Apennines are a NE-verging orogenic wedge accreted from late Oligocene-early Miocene to Pleistocene. The chain is composed of Mesozoic-Cenozoic sedimentary cover from several palaeogeographic domains (i.e. the Ligurian oceanic crust and the western passive margin of the Adriatic plate) and of the Neogene-Pleistocene piggyback basin and foredeep deposits of the active margin. Recent shortening occurred at the belt front deforming Pleistocene sediments and volcanics (Pieri & *alii*, 1997; Beneduce & Schiattarella, 1997) whereas widely documented extension is still active along the Apennines axis (Ortolani & *alii*, 1992; Amato & Montone, 1997). The average direction of the chain axis is about N150°, corresponding to the strike of the main thrusts and coaxial normal faults. The belt is also affected by Plio-Quaternary strike-slip faults mainly oriented according to N120°±10° and N50-60° trends and by low-angle normal faults (Schiattarella, 1998; Schiattarella & *alii*, 2003, and references therein).

From the Tyrrhenian Sea to the Adriatic (Apulian) foreland (i.e. from the top to the bottom of the tectonic stack) the following huge structural units are observed (Pescatore & *alii*, 1999): (1) Jurassic to Oligocene polydeformed ophiolitic units, unconformably covered by syntectonic deposits, early Miocene in age (*Liguride units*); (2) a carbonate platform unit (Campania-Lucania platform), whose age ranges from late Triassic to early Miocene; (3) several units mainly composed by deep-sea sediments, ranging from early Triassic to lower-middle Miocene (*Lagonegro units*); (4) a frontal imbricate fan made up of Cretaceous to lower Miocene deep-sea marls, shales and sandstones covered by middle to upper Miocene flysch deposits; (5) Pliocene to Pleistocene foredeep clastic deposits; (6) the Apulian carbonate platform, which has been partly incorporated at the base of the accretionary wedge, forming toward east the less deformed foreland area.

GEOLOGICAL OUTLINE AND QUATERNARY EVOLUTION OF THE UPPER AGRI VALLEY

The upper valley of the Agri River is a NW-SE trending intermontane basin located in the Lucanian Apennine (fig. 1). This fault-bounded basin is about 30 km long and 12 km large and formed during Quaternary times in the hinterland of the fold-and-thrust belt after the major Miocene-Pliocene episodes of shortening. It coincides with the upper portion of a major valley of the Basilicata region and is about 540 km^2 large (a little more than 1/3 of the whole fluvial basin).

Tectonics has strongly controlled shape, morphology and sedimentary evolution of the basin up to the present. As a matter of fact, historical seismicity shows that the Agri upper valley has been hit by recurrent and large earthquakes such as the 1857 Basilicata («Neapolitan» *Auct.*) earthquake. Early Pleistocene displacement along the boundary faults is dramatically evidenced by coeval slope deposits which are tilted and uplifted at various elevations along the basin flanks. The basin floor is filled by middle Pleistocene alluvial deposits which are faulted as well. Extensional tectonics is commonly envisaged as responsible for the basin evolution. Evidences of deformation also in younger sediments have been recently documented (Giano & *alii*, 2000). Radiocarbon dating of faulted palaeosols supports in fact the field evidence of very recent deformation associated to relevant displacements, yielding ages between 40 and 20 ka.

The pre-Quaternary bedrock (fig. 2) is constituted of Mesozoic-Cenozoic shallow-water and slope carbonates (*Monte Marzano - Monti della Maddalena Unit*), prevalently outcropping along the western side of the basin, thrust on coeval pelagic successions (*Lagonegro units*) which crop out mainly along the eastern flank of the valley. Toward the east and south-east the bedrock is formed by Tertiary siliciclastic sediments (Albidona and Gorgoglione Fms) which occupy the southern part of the upper valley. In Quaternary times, the neogene contractional structures have been truncated by high-angle faults with different kinematics, which led to the genesis of the valley and controlled depositional architecture and landscape evolution (Boenzi & *alii*, 2004).

The Quaternary sediments are entirely constituted of continental clastics, represented by lower to upper Pleistocene slope coarse-grained deposits, which form coalescent fans along the flanks of the basin, and by middle Pleistocene alluvial deposits («Complesso Val d'Agri», Di Niro & *alii*, 1992) in the plain. The age of the Quaternary sediments have been deduced by correlating some morphostratigraphic features of the Agri upper valley with the post-Sicilian ones from the nearby Sant'Arcangelo Pliocene-Pleistocene basin (Di Niro & *alii*, 1992). The entire Pleistocene succession reaches a thickness of about 250 m.

On the grounds of recent geomorphological and structural studies (Di Niro & Giano, 1995; Giano & *alii*, 1997; Schiattarella & *alii*, 1998; Giano & *alii*, 2000; Cello & *alii*, 2000) the valley appears to be a more complex structure than an extensional graben, as traditionally assumed in the literature, or than a simple pull-apart basin. In any case, the last generation of lineations on fault planes documents an extensional regime with a NE-SW tensile axis. Such a tectonic regime persists until now as inferred by the regional seismicity and *in situ* stress measurements (Amato & Selvaggi, 1993; Amato & Montone, 1997) and as proved by the occurrence of palaeosols involved in normal faulting (Giano & *alii*, 2000).

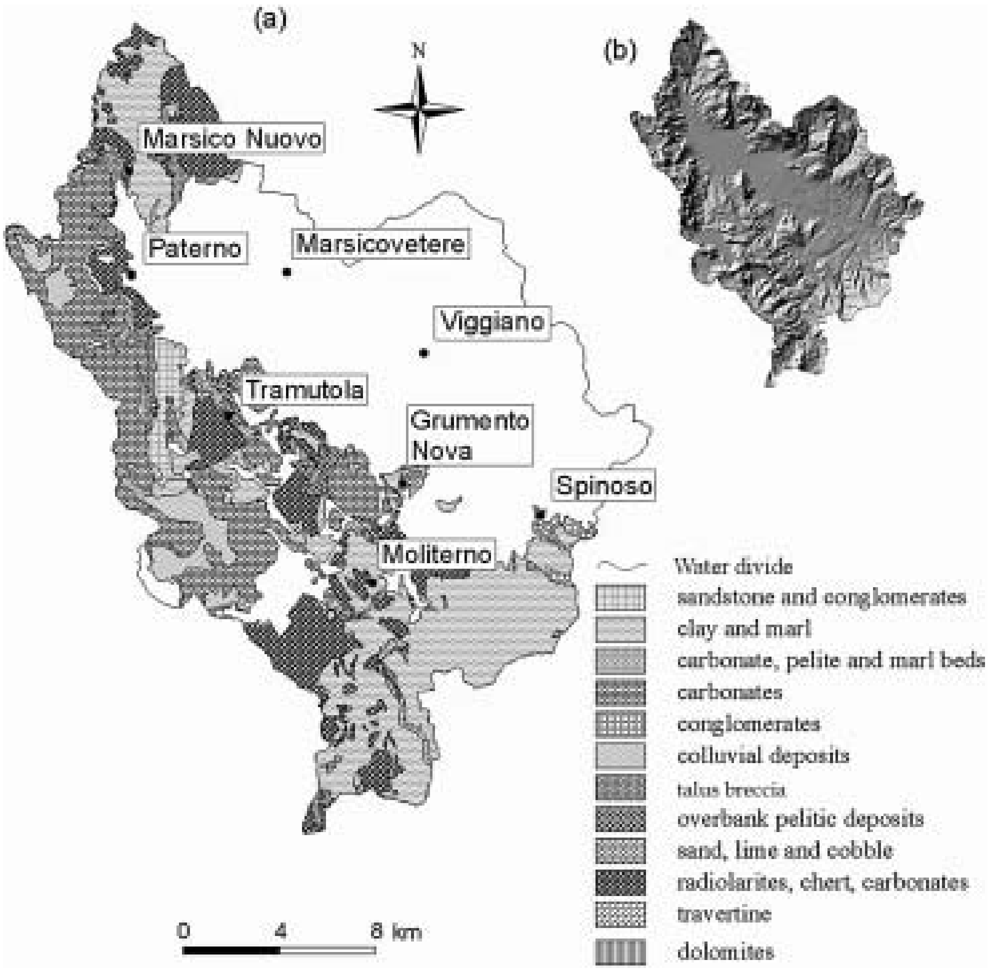


FIG. 2 - Lithological sketch map of the upper part of the Agri River valley. Spatial distribution of the main lithological groups (a); hill-shaded view of the study area (b). Blank indicates the alluvial plain, the endoreic suspended basins and the north-eastern side of the valley.

The genesis and the early Pleistocene evolution of the Agri basin were controlled by left-lateral strike-slip N120° trending master faults, reactivated as normal faults since middle Pleistocene times (Giano & *alii*, 1997; Schiattarella & *alii*, 1998). Indeed, N120° striking faults are regional tectonic structures responsible for the genesis of many Quaternary intermontane basins of the southern Apennines and their kinematic history is quite similar all along the chain (Schiattarella, 1998).

More recently, geomorphic and tectonic features from the western flank of the Agri River upper valley in the southern Apennines have been examined to determine regional and local uplift rates in the geodynamic frame of southern Italy (Schiattarella & *alii*, 2003, Boenzi & *alii*, 2004). Four orders of polygenic surfaces, which relics are well preserved along the water divide and suspended on the present valley floor, are recognizable in the high valley (fig. 3). Two of them are erosional (S1 and S2) whereas the lower ones (S3 and S4) are both depositional and erosional. According to the regional-scale interpretations (Brancaccio & *alii*, 1991; Amato & Cinque, 1999; Schiattarella & *alii*, 2003), the ages of these surfaces are included in a time span ranging from 1.8 to 0.125 Ma. A more ancient surface, probably sculptured during late Pliocene times, can be also recognized in the neighbouring areas of the Campania-Lucania Apennines. Using this kind of geomorphic features and Pleistocene deposits involved in the genesis of erosional and depositional landsurfaces, a set of uplift rates has been calculated for the south-western flank of the valley. The values of the Quaternary local uplift rates may vary from a minimum of 0.3 mm/yr to a maximum of about 1 mm/yr whereas the values of the regional uplift rate are always equal or higher than 1 mm/yr in the last 1.2 Ma. All these data are in good agreement with those from other areas of southern Apennines (Schiattarella & *alii*, 2003, and references therein). Due to high slip rates on fault planes (0,5 to 0.8 mm/yr in the 1.2-0.73 Ma time span) the major part of the amplitude of relief can be ascribed to the activity of basin-border faults. Yet, the local morphostructural offsets have to be coupled with regional raising of the orogen to reach the total amount of Quaternary uplift. An acceleration of the local component of vertical motion starting from the early-middle Pleistocene can be also deduced. It is worthy to note that during late Pleistocene to Holocene times the same fault system was characterized by a slip rate strongly decreased up to 0.1 mm/yr (Schiattarella & *alii*, 2003, Boenzi & *alii*, 2004).

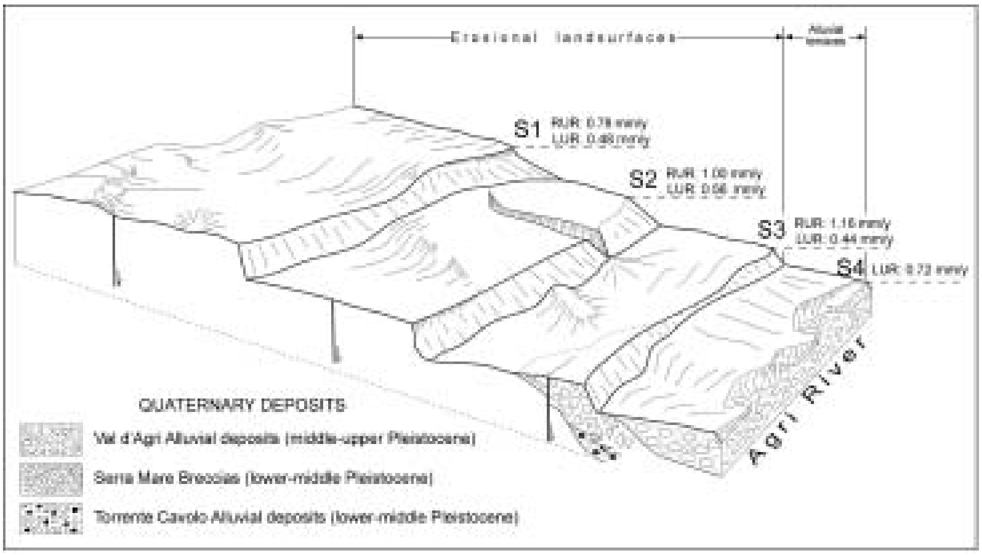


FIG. 3 - Block-diagram showing type, arrangement, and age of the landsurfaces. Acronyms: **S1**: Upper Pliocene to Lower Pleistocene erosional surface cutting the pre-Quaternary bedrock, located at more than 1300 m a.s.l.; **S2**: Lower Pleistocene erosional surface cutting the pre-Quaternary bedrock located between 1000 and 1300 m a.s.l.; **S3**: Lower-Middle Pleistocene erosional surfaces developed both in the pre-Quaternary rocks and slope breccias, located between 750 and 1000 m a.s.l.; **S4**: Middle-Upper Pleistocene erosional surfaces and alluvial terraces located between 570 and 650 m a.s.l.; **RUR**: regional uplift rate; **LUR**: local uplift rate.

DATA AND METHODS

Hydrography

Analysis of hydrography has been carried out following the classical approach of the quantitative geomorphology (Horton, 1945; Strahler, 1957), applied and widened by some Italian authors (Avena & *alii*, 1967; Ciccacci & *alii*, 1980). The morphometric parameters, gathered from this type of analysis, express the developing and geometry of the drainage basins, that are expression of the erosion, transport and sedimentation processes linked to the river dynamics. Assuming that the morphological dynamics of a hydrographic basin shows traces of the structural conditioning and geodynamic activity, that characterizes the actual landscape, the quantitative studies have shown that some parameters may assume determinate values in conditions of tectonic activity (Horton, 1945; Strahler, 1957; Melton, 1958; Avena & *alii*, 1967; Ciccacci & *alii*, 1980; Forni & Forno, 1988; Dramis & Gentili, 1977). This quantitative approach has been successfully applied in a lot of neotectonic studies carried out on the hydrographic basins (Centamore & *alii*, 1996; Delcaillau, 2001; among others).

To perform this analysis, an hydrographic map has been elaborated on a 1:25000 scale, on which the main morphometric elements and the relative parameters have been evaluated. Moreover, starting from the contour lines and quoted points, a DEM of the studied area, with a pixel of 30 m, has been built (fig. 2b). Successively, a slope and relief map has been extracted from the DEM. A lithological map of the examined sector, merging the different geological units or part of them, has been produced (fig. 2a). The quantitative analysis of the hydrographic network has been subdivided in partial sub-basins, to be studied as individual geomorphological units (fig. 4).

The fluvial net has been organized according to the Strahler method and digitized with the software Arcview GIS on geo-referred topographic maps. Starting from the topography and using the software GIS, the main morphometric elements have been calculated for each basin; those are: length and frequency of fluvial streams for each order, computation of the anomalous streams in relation to their affiliation order (streams that do not feed the collectors of the immediately upper rank), area and perimeter of every basins.

On the base of these data the main quantitative parameters (tabs. 1 and 2) have been calculated. An hypsometric analysis, as expression of the basin evolution and therefore useful to furnish elements on the rejuvenation phenomena that have interested the study area, has been carried out. Besides the quantitative analysis, a series of topographic profiles, both longitudinal and transversal to the main channels that drain the sector, have been built. The presence of knickpoints along the fluvial profiles as well as slope break-points along the valley flanks and their V shape with convex slopes can be considered as possible landscape rejuvenation evidences, often controlled by active tectonics (fig. 5). A study on the I and II order stream orientation has been carried out to examine the presence of possible preferential directions controlled by tectonics. The measure of the stream directions has been computed through a computer-based procedure implemented with ARC-INFO, extrapolating from the drainage map only the streams of I and II order. These data have been statistically processed and compared with the field orientation data of the fracturing state of the rocks (fig. 6). All the second order streams have been taken into account for the statistical analysis, whereas only a representative sample of the first order streams, more or less comparable in number with the second order stream sample, has been here considered because of the large number of segments which form the entire population of those data. Such a sample has been selected according to the stream length. The re-

TABLE 1 - Quantitative hydrographical parameters for each sub-basin

Basin	A (km^2)	P (km)	Nu	L (km)	D	F	Rb_{mean}	Rbd	R	Re	Rc	Rh
Maglia	63,9	45,9	1388	380,2	6	21,7	5.93	4.78	1.15	0.5	0.4	0.08
Vella	29,5	23,6	689	202,3	6,8	23	3.62	3.01	0.61	0.7	0.7	0.1
Sciaura	46,5	34	704	180,6	3,9	15	4.98	4.31	0.67	0.6	0.5	0.06
Rio Cavolo	28,7	29,2	256	89,4	3,1	8,9	6.9	6.14	0.77	0.8	0.4	0.11
Gilberti	12,7	19,5	125	43,3	3,4	9,8	3.2	2.76	0.44	0.6	0.4	0.08
Romanella	4,7	10,9	34	14,1	3,1	7,4	2.98	2.38	0.6	0.5	0.5	0.1
Romana	10.7	17.1	25	18.2	1.7	2.3	2.6	2.3	0.3	0.6	0.5	0.1
Chiuscenne	8,4	14,6	77	30,1	3,6	9,3	3.98	3.54	0.44	1.2	0.5	0.3

A area
P perimeter
Nu total number of streams
L total length of the streams
D drainage density (SLu/A) (Horton, 1945)
F stream frequency (SNu/A) (Horton, 1945)
Rb_{mean} mean bifurcation ratio (Horton, 1945)
Rbd_{mean} mean direct bifurcation ratio (Avena & *alii*, 1967)
R_{mean} mean bifurcation index (Avena & *alii*, 1967)
Re elongation ratio (Schumm, 1956)
Rc circularity ratio (Schumm, 1956)
Rh relief ratio (Schumm, 1956)

TABLE 2 - Bifurcation ratios for each sub-basin

Basin	Rb I/II	Rb II/III	Rb III/IV	Rb IV/V	Rb V/VI	Rbd I/II	Rbd II/III	Rbd III/IV	Rbd IV/V	Rbd V/VI	R I/II	R II/III	R III/IV	R IV/V	R V/VI
Maglia	4.1	4.6	7	8	_	2.9	3.2	5	8	_	1.2	1.4	2	0	_
Vella	4	3.9	3.6	4.5	2	2.9	2.9	2.6	4.5	2	1.1	1	1	0	0
Sciaura	4.4	4.2	7.2	4	_	3.3	3.2	6.7	4	_	1.1	1	0.5	0	_
Rio Cavolo	4	3.7	13	_	_	2.7	2.7	13	_	_	1.3	1	0	_	_
Gilberti	4	3.8	2	3	_	2.9	3.2	2	3	_	1.1	0.6	0	0	_
Romanella	3.4	3.5	2	_	_	3.1	2	2	_	_	0.4	1.5	0	_	_
Romana	3.4	2.5	2	_	_	2.4	2.5	2	_	_	1	0	0	_	_
Chiuscenne	4.6	4.3	3	_	_	3.3	4.3	3	_	_	1.3	0	0	_	_

Rb bifurcation ratio (Nu/Nu+1) (Horton 1945)
Rbd direct bifurcation ratio (Nud/Nu+1; Nud represent the number of streams of u order that drain in a stream of u+1 order) (Avena & *alii*, 1967)
R bifurcation index (Rb - Rbd) (Avena & *alii*, 1967)

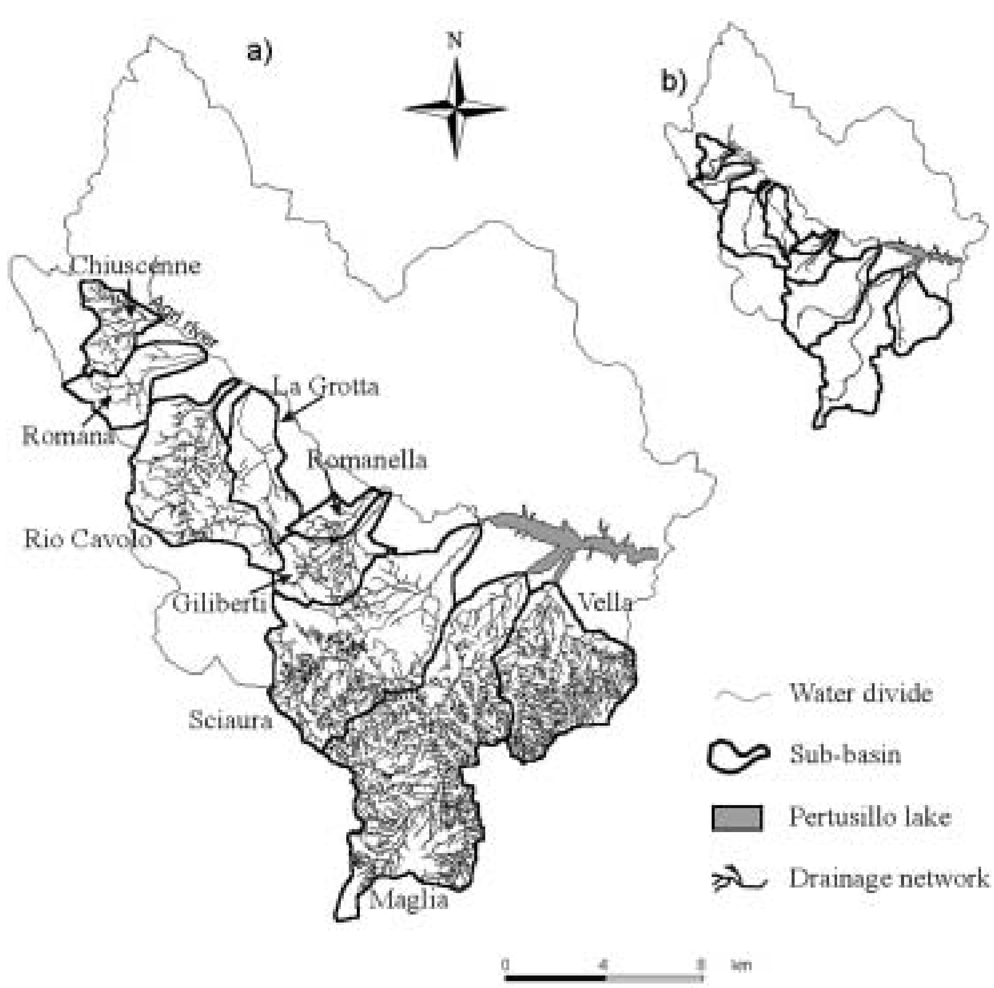
sulting dataset is constituted by 4725 segments, with a balanced proportion between first and second order orientation data. The choice of streams with lower hierarchical orders has been suggested by their relative chronology: in fact, these segments are the youngest of the whole network, so their orientation can show the most recent tectonic influences.

The creation of a geo-referred database of the studied area allowed the comparison among geomorphological features, structural data, and the other characteristics of the basin, such as lithology, dip, slope, so that it has been possible to integrate the results with the necessary data for a correct interpretation.

Fracture system

Data on tectonic joints and cleavages come from 20 measurement stations scattered along the south-western side of the upper valley, for a total number of 2732 measures. For each fracture plane, a complete attitude set has been collected, but only the azimuthal data related to high-angle fractures have been used in this study, because

FIG. 4 - Drainage network of the south-western side of the upper valley of the Agri River. Hydrographic pattern for each sub-basin (a); sub-basin arrangement (b).



of their large diffusion, neotectonic origin, and capability of structural control on low-order streams. All data have been re-organized in three different sectors, distinguished on the basis of their main lithological nature and structural features (from north: Marsico Nuovo - Tramutola sector, Magorno plain - Grumento Nova sector, and Moliterno sector). In the southernmost sector (i.e. Moliterno village and its surroundings), the *Lagonegro*-type pelagic units largely crop out, whereas Meso-Cenozoic shallow-water carbonate rocks constitute the geological backbone of the other two sectors. Rose diagrams (fig. 6b) have been done for every sector, thus grouping thousands of fractures coming from the single different structural stations.

RESULTS AND DISCUSSION

The study area has an extension of about 300 square kilometres, and is drained by more than 3000 stream segments. The outcrop of different rocks reflect the different drainage density and geometry. The drainage network is more developed in the southern sector mostly in presence of lithologies with higher erodibility; here the drainage basins have a greater extent and are characterized by higher values of drainage density and frequency. On the calcareous formations, largely outcropping in the northern sector, sub-basins have a smaller drainage area and its hydrographic network is characterized by several holes, so often a fluvial segment, does not reach a collector of superior order. Thus, the drainage network in this area result fragmentaded. In the karst depressions, where the runoff is lacking, there is not a surface drainage systems.

From a morphotectonic point of view, the values which stress the evolutionary state of a catchment basin - such as bifurcation ratio and index (*Rb*, *Rbd* and *R*), elongation and circularity ratios (*Re*, *Rc*), and the relief ratio (*Rh*) - give useful elements to point out landscape rejuvenation phenomena. The parameters *Rb*, *Rbd* and *R* express the state of hierarchical organization of the drainage network, that is related to the maturity of the basin and to its geomorphological processes. The parameters *Re* and *Rc* describe shape and geometry of the basins and depend on the evolutionary stage of the landforms. The plano-altimetric offsets of the water-divides and the elongated forms

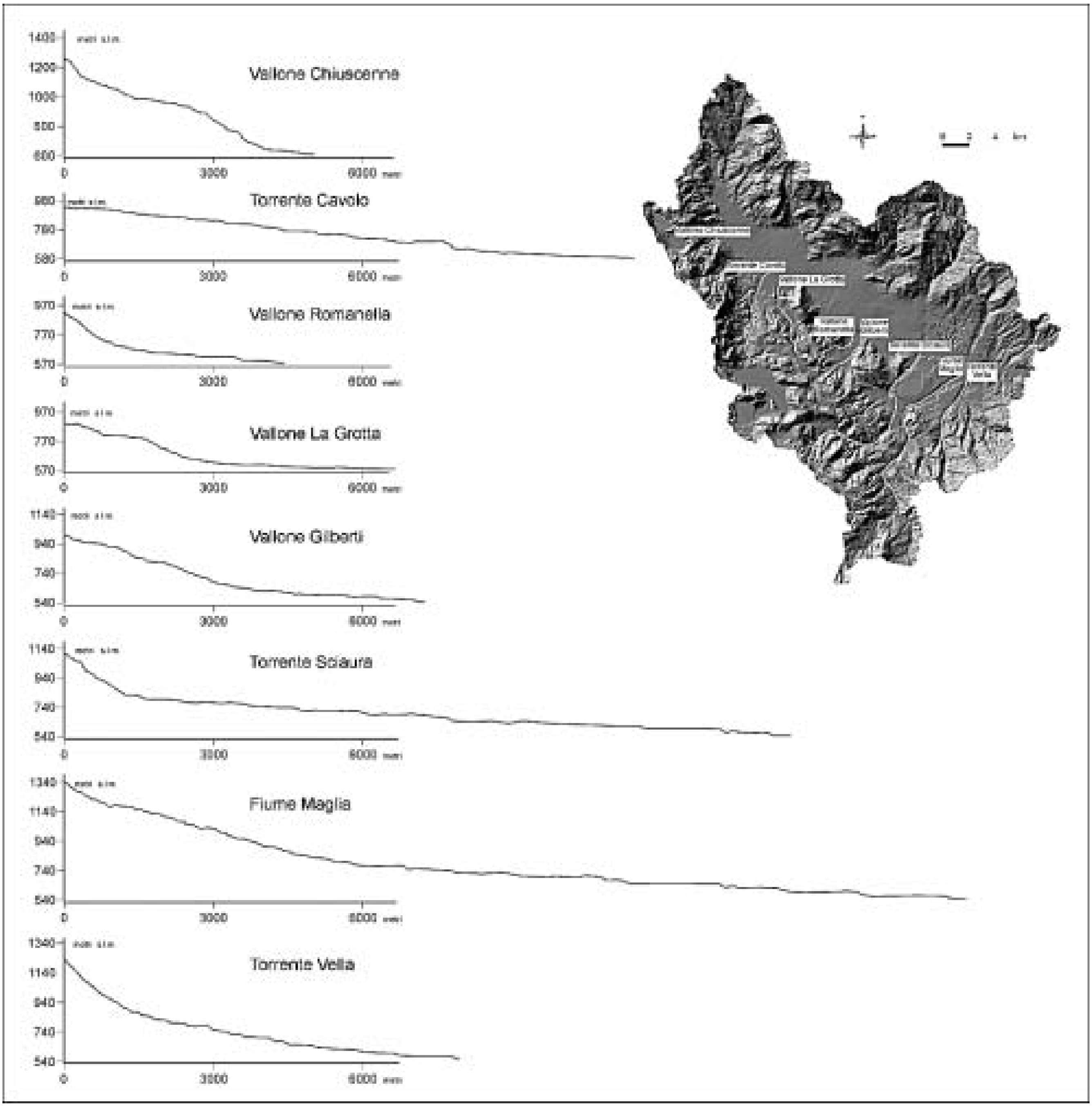


FIG. 5 - Longitudinal profiles of the main streams flowing in the south-western side of the Agri upper valley, computed from the Digital Elevation Model (see text for details).

(i.e. low values of these indexes) are typical of systems in youthful phase. The relief ratio *Rh* expresses finally the average slope of the basins whose value tends to zero toward the phase of maturity. The hypsometric analysis can provide other information on plano-altimetric configuration of whichever area, also on a regional scale (see for example D'Alessandro & *alii*, 1999, and references therein). Since in a maturity stage the surface running water tends to smooth the landscape depending on the base level, then a large area with lower elevation will indicate a more mature basin. The geometric expression of that evolution stage is a concave hypsometric curve with a very low value of the hypsometric integral («monadnock» phase). Tables 1 and 2 show numerous critical values of the quantitative para-

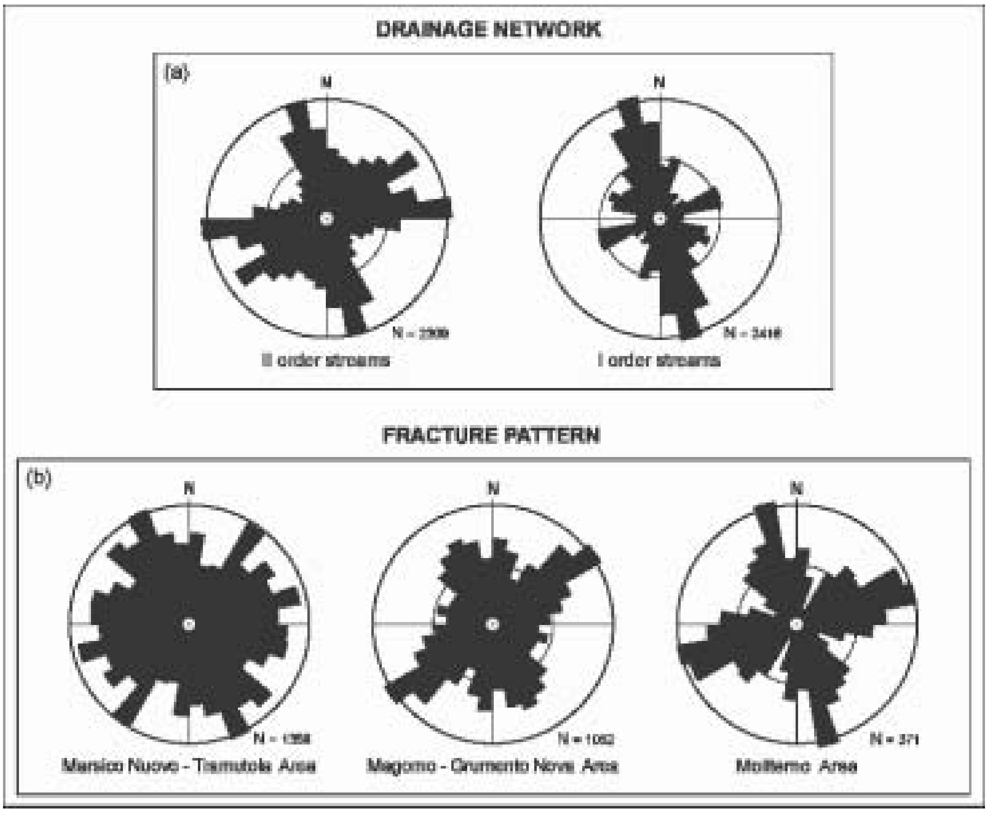


FIG. 6 - Azimuthal diagrams (10° intervals) representing I and II order streams from the Agri River orographic right (a) and fracture pattern from the same area (b).

meters for the basins of the study area. The bifurcation ratio and the direct bifurcation ratio assume, in basins as that of the *Fiume Maglia* and of the *Torrente Cavolo*, values grater than 5, that are expression of a strong structural control on the organization of the drainage network. In the other basins, however, these parameters assume values grater than 2, pointing out complex geological settings. This is also confirmed by the parameters *Re, Rc* e *Rh* whose values describe elongated basins with indented divides and slope gradients that increase, locally, the relief energy. Figure 7 illustrates the results of hypsometric analysis for the investigated basins. The curves show several profiles, in some cases with flexes that separate a rectilinear from concave and/or convex shape. This could be justified with lithological variations within the same basin, but in some cases only admitting that there are portions of the basin interested by rejuvenation phenomena nearby others already in condition of morphological stability. In active chains, in fact, the propagation of regressive erosion toward the catchment headwater normally occurs in a time span sufficiently long (i.e. 10^4-10^5 years) to allow the coexistence of different evolutionary stages in a narrow space. This seems to be also confirmed by the observation of the topographic profiles that show sinuous shape and numerous slope breaks of the curve (fig. 5). Another support comes from the longitudinal profiles of the main stream for each single sub-basin. In figure 5 all the profiles show a series of stairs (*knickpoints*), that do not always correspond to lithological variations along the river bed, and therefore can confidently represent the effect of the tectonic activity (Merrits & Vincent, 1989; Boenzi & *alii*, 2004; Molin & *alii*, 2004).

Tectonics influenced the organization of the upper Agri Valley fluvial network, that shows long rectilinear channel, stream elbows and rectangular patterns (fig. 8). Stream directions follow the trends of the main tectonic lines, as suggested by the overlay of the drainage map with the high-angle faults map.

The statistic treatment of fractures orientation field data shows the presence of several sets of joints. In particular, the outcrop-scale fracture pattern of the southwestern side of the Agri River upper valley is characterized by the presence of four sets of sub-vertical joints at least. Two of these are well-known in the southern Apennines and correspond to the N150°±10° set and its N60°±10°-trending orthogonal set. In many areas of the southern Apennines the N150°-striking minor faults and joints and associated orthogonal fractures represent the youngest structures of Quaternary brittle deformation (see for example Russo & Schiattarella, 1992, Schiattarella & *alii*, 1994, Perri & Schiattarella, 1997), produced by NE-SW extension. Other relevant joint sets are consistent with the N-S and N120°±10° trends of the rose diagrams (fig. 6b), which represent the regional orientations of major Plio-Quaternary high-angle faults (Schiattarella, 1998).

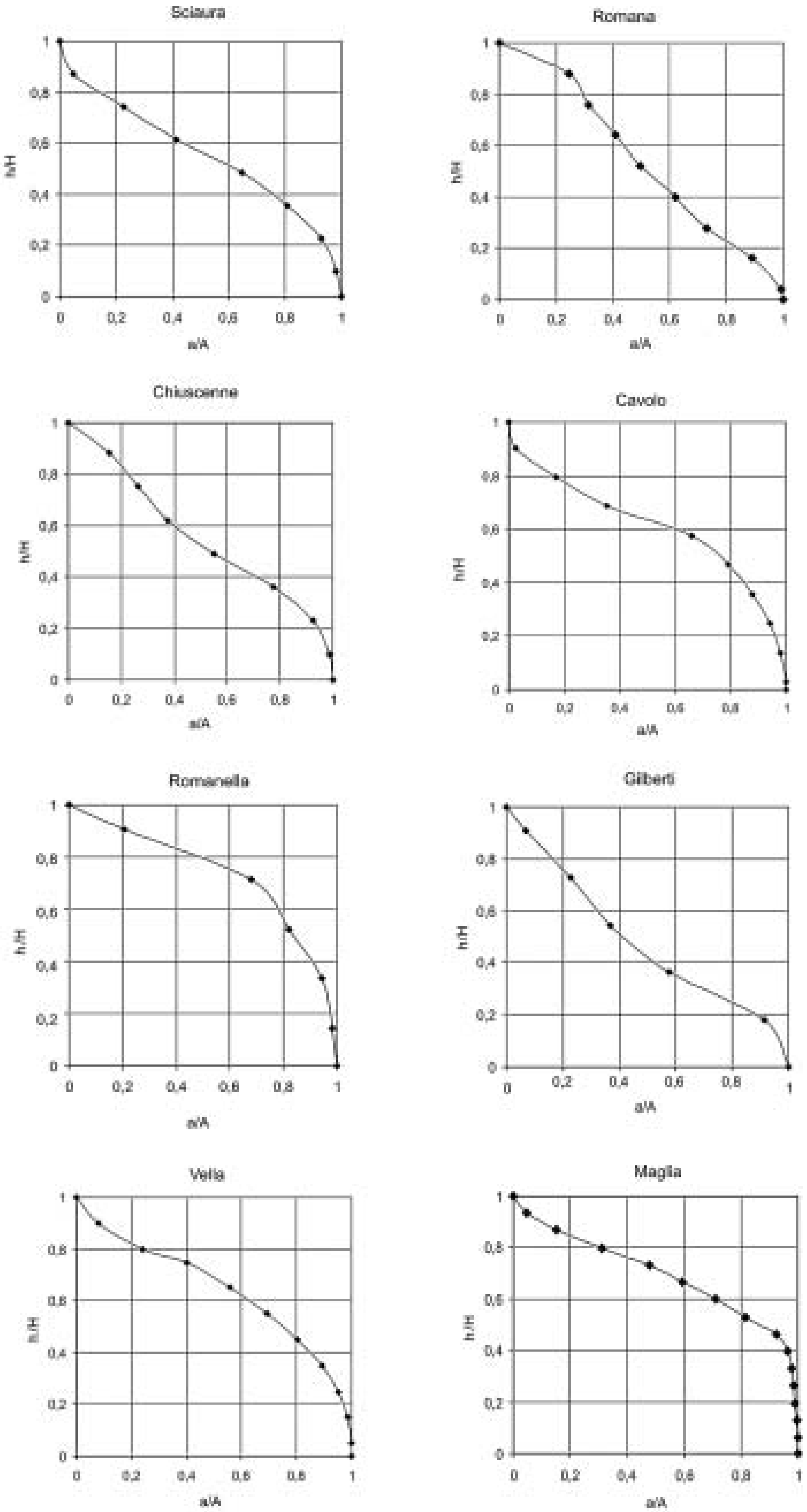
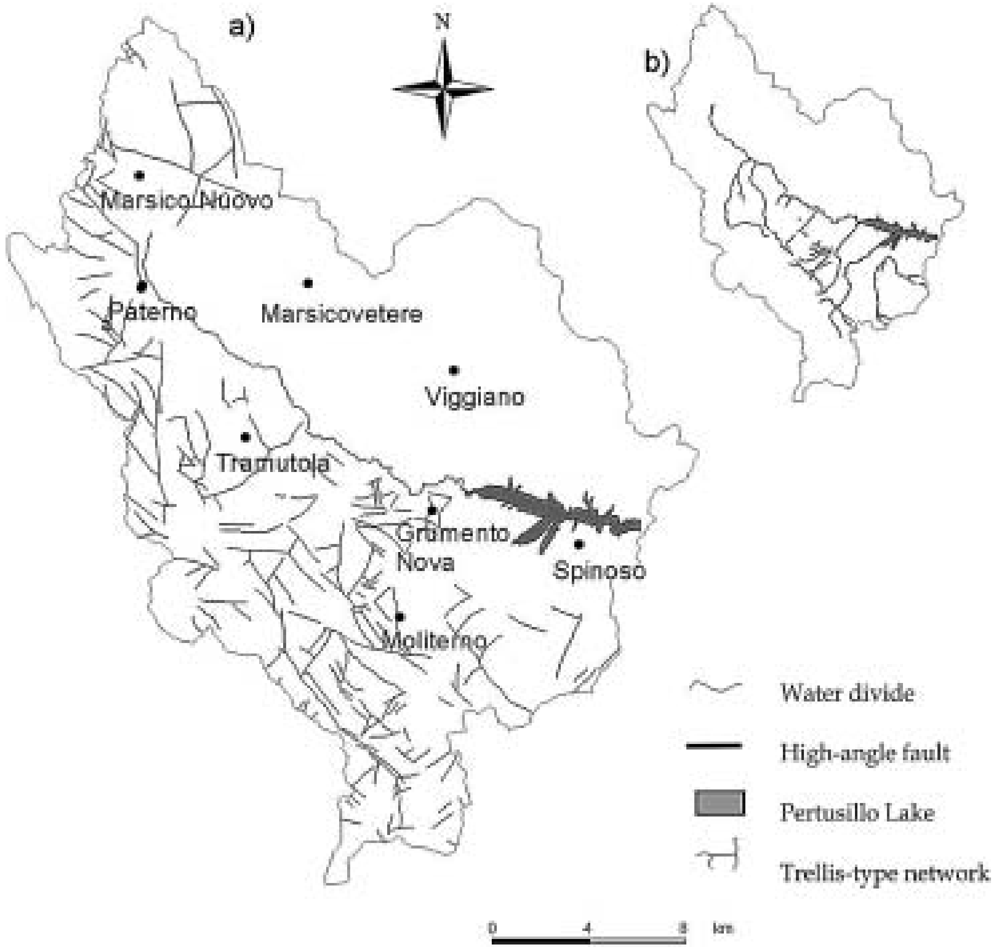


FIG. 7 - Hypsometric analysis of the sub-basins from the Agri River orographic right.

FIG. 8 - Morphotectonic features of the south-western side of the Agri upper valley. High-angle faults (a); trellis-type drainage network (b).



Crossing these data with those deriving from the measure of orientation of first and second stream order has given good results. The statistical analysis shows few and well defined preferential directions for the analysed streams. The rose diagram plot of the second stream order is characterized by a low statistical dispersion and absence of «background noise» (fig. 6a). It shows three peaks in correspondence of the N160°-170° class, a sub-orthogonal N60°-70° class and the E-W trend, whereas the first order streams just follow two of the three main trends, lacking the E-W-direction. Thus, the minor fluvial segments of the south-western flank of the valley (I and II order) are arranged according to the same trends of the fracture systems. This results suggest that the fracture pattern and minor faults (NW-SE and NE-SW trends)of the upper Agri Valley has strongly controlled the genesis and the arrangement of minor streams. E-W-trending structures also exerted a structural control, but only on the II order streams: this fact may depend on the age of these features, which seem to predate the other trends (see the paragraph on the Quaternary structural evolution). In other words, the E-W trend of the minor drainage channels may be interpreted as the inherited effect of the first neotectonic stage (pre-middle Pleistocene in age), characterized by strike-slip faulting, which caused a pervasive rocks fracturing responsible for the genesis of E-W-striking joint sets, then destined to control the geometry of the embryonic hydrographic pattern of the study area. In more recent times, the structural control has been mainly exerted by N150-160°-striking faults and fractures, parallel to the «Monti della Maddalena - Vallo di Diano» morphostructural trend. In the Late Pleistocene, faults and fractures linked to the N120°-striking master faults bordering the Agri River upper valley did not control meaningfully the youngest direction development.

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