C. CURRADO* & C. D'AMBROGI**

COMPARISON BETWEEN GEOLOGICAL AND MORPHOMETRIC DATA IN THE PERIADRIATIC BASIN (CENTRAL ITALY)

INDEX

ABSTRACT

The existing morphotectonic setting of the *Periadriatic Basin* results not only from the interactions between syn-sedimentary tectonics, climatic changes and eustatism, but also from a generalized uplifting process. In particular, during the Plio-Pleistocene time, the activity of several transversal fault systems (N20°-35°E, N45°-60°E), corresponding to pre-existing tectonic elements cutting the pre-Pliocene basement, has given rise to the subdivision of the area into several sectors characterized by differential vertical movements.

Geological analysis has been used to define a preliminary morphostructural arrangement in the area between the Pescara River and the Sangro River; in addition, morphometric analyses have been used to verify their possible contribution in morphotectonic studies.

The morphotectonic parameters (Amplitude of relief, channel gradient, drainage density) have been measured for each of the identified sectors. The calculated values confirm the data obtained by field surveys. The results of this work underline the importance of the use of morphotectonic parameters as a neotectonic tool. These parameters are particularly useful in areas where, due to the mechanical characteristics of the outcropping rocks, classical structural analysis does not provide a clear definition of the tectonic activity.

RIASSUNTO

L'attuale assetto morfostrutturale del *Bacino periadriatico* è il risultato dell'interazione tra tettonica sinsedimentaria, variazioni climatiche, eustatismo nonché di un generalizzato fenomeno di sollevamento.

In particolare, durante il Plio-Pleistocene, l'attività di sistemi di dislocazioni trasversali (N20°-35°E, N45°-60°E), in corrrispondenza di elementi strutturali preesisenti nel basamento prepliocenico, ha determinato l'articolazione del settore in blocchi caratterizzati da movimenti verticali differenziati.

Gli studi condotti nell'area compresa tra il F. Pescara ed il F. Sangro sono stati volti alla definizione di un preliminare assetto morfostrutturale su basi geologiche e alla comparazione di dati morfometrici al fine di definire il possibile contributo dell'analisi morfometrica a studi di carattere morfotettonico.

I valori dell'Energia del rilievo, del gradiente delle aste di I e II ordine nonché la densità di drenaggio sono stati calcolati per i differenti blocchi morfostrutturali identificati e hanno evidenziato una buona corrispondenza tra dato geologico e dato morfometrico.

I risultati ottenuti incoraggiano a continuare in tale direzione soprattutto per quelle aree in cui, a causa delle caratteristiche litologiche delle unità affioranti, l'analisi strutturale classica non fornisce una esatta definizione dell'attività tettonica recente.

KEY WORDS: Neotectonic, Morphometric Parameters, Periadriatic Basin, Drainage network.

PAROLE CHIAVE: Neotettonica, Parametri morfometrici, Bacino periadriatico, Reticolo idrografico.

1. INTRODUCTION

The purpose of this work is to improve the definition of the morphostructural setting of the southern region of *Periadriatic Basin*, and to verify the possible contribution of morphometric analyses to the study of its tectonic evolution.

The chosen area is located between the Central Apennines and the Adriatic Sea and is bounded by the Pescara River to the North and the Sangro River to the South.

The geodynamic process of convergence between the Eurasian and African plates starts in the Late Cretaceous and is characterized by a continent-continent collision (ROYDEN, 1993). The direct result of the process is the structuring of two orogenic systems: the Alps - migrating toward the European foreland, and the Apennines - migrating toward the African foreland. The Apennine orogen is built up during the beginning phase of the continental collision, starting in the Oligocene time (OGNIBEN, 1985).

The migration eastward and outward of the belt-foredeep system gives rise to the structuring of several foredeep basins. The age of these basins decreases from West to East, from the *Macigno* to the *Cellino Basin*. In the study area, outcropping rocks belonging to the most recent and external basin (*Cellino Formation*) are located between Guadiagrele and Casoli. By the end of the Middle Pliocene time, the whole area represents a single piggy-back basin (*Periadriatic Basin*) (ORI *et al.*, 1991; PATACCA *et al.*, 1990).

The evolution of the *Periadriatic Basin* is strongly influenced by Plio-Pliestocenic syn-sedimentary tectonics.

(*) 5936 Hickory st.#4, Carpinteria California
c_currado@yahoo.com
(**) Servizio Geologico Nazionale – Roma chiara.dambrogi@dstn.it

In particular, the activity of several transversal fault systems controls the physiography of the basin as well as its depositional environments and the geometry of the depositional systems (BIGI *et al.*, 1995b; 1997a).

During the Upper Pliocene/Lower Pleistocene, a generalized uplift takes place. This uplif, which is greatest along the Apennine chain, gives rise to an eastward progressive tilting (COLTORTI *et al.*, 1991; DRAMIS, 1992, RASSE, 1993). In the early Pleistocene the study area, along with much of Central Italy, begins to emerge. Climatic changes and eustatic fluctuations contribute to the evolution of the area (DEMANGEOT, 1965; DUFAURE *et al.*, 1988; AMBROSETTI *et al.*, 1982). A drainage network develops as a result of the slope caused by the tilting process and to the influences of several tectonic elements (BIGI *et al.*, 1997b).

This research progresses through two different phases: a geological field survey, and several morphometric analyses obtained from topographic maps (scale 1:25.000) related to both the orographic configuration and the drainage network of the area under investigation.

Quantitative analysis is possible because of the particular morphotectonic arrangement of the area and the homogeneous lithologies of the outcropping rocks (mostly clays, sands and pebbles) that give rise to similar erosional processes throughout the area. For this reason, the comparison of parameters related to morphological features emphasizes the importance of recent tectonics.

It is important to note that the Maiella Unit as well as the "*Colata Aventino-Sangro*" deposits are not included into the morhometric analyses.

2. GEOLOGICAL AND STRUCTURAL SETTING

2.1. Geological setting

The area under investigation corresponds to the *Chieti sector* of *the Periadriatic Basin*, according to BIGI *et al.* (1995b).

The Maiella massif bounds the study area to the West. Cretaceous-Miocene carbonate sediments, characteristic of platform and slope sequences, make up this massif (BERNOULLI *et al.*, 1992).

In the late Messinian-early Pliocene marine sediments formed by the *Argille del Cigno* are deposited in the foreland located to the East of the Apennine chain.

The *Cellino Formation* deposits, made up mostly by clay and fine sand and corresponding to the *M* and *LP sequences* (CASNEDI, 1991; ORI *et al.*, 1991), are related to the external and distal part of the Early Pliocene foredeep. Also interbedded within these sediments are the chaotic gravity deposits belonging to the "*Colata Aventino–Sangro*" (Fig. 1). The deposition of the "*Colata Aventino–Sangro*" takes place in several phases throughout the Pliocene time. The first phase takes place during the Lower Pliocene (*G. puncticulata-G. margaritae* concurrent-range Zone), within the *Cellino Formation.* The second and third phases occur within the silty sediments of the Plio-Pleistocene piggy-back sequence (between *G. puncticulata* Zone and *G. crassaformis* Zone and in the Upper Pliocene) (BIGI *et al.*, 1995b; 1997a).

The Plio-Pleistocene sedimentary succession of the *Periadriatic Basin* overlays the Pliocene *Cellino Formation* deposits unconformably.

This succession, characterized by a general regressive trend, shows a shallowing in the depositional environments; in the area under investigation (Fig. 1) it starts with neritic clays (*Mutignano Formation* or P_2-Q_m *sequences*) and goes on with unconformable sandy beach deposits (Q_{m1} *sequence*) (BIGI *et al.*, 1995b).

In addition, in the area between the Foro River and the Moro Torrent, it is possible to find – within the Q_{m1} sands, at different stratigraphic positions – gravel deposits characteristic of delta and shoreface, having a lenticular geometry (BIGI *et al.*, 1995b; D'AMBROGI, 1999), related to a paleo-drainage network.

Between the upper part of the Lower Pleistocene and the Middle Pleistocene p.p. the sedimentation of continental deposits (Q_c *sequence,* according to BIGI *et al.*, 1995b) occurs (Fig. 1).

Starting from the Lower Pleistocene, a generalized uplift occurs. Since this phenomenon is greater along the Apennines, it causes a tilting towards East during the emersion of the area (AMBROSETTI *et al.*, 1982; DEMANGEOT, 1965; DRAMIS, 1992; DUFAURE *et al.*, 1988, RASSE, 1993). An early drainage network emplaces and, affected by Quaternary climatic changes and eustatic fluctuations, leads to the formation of four different orders of fluvial terraces (BIONDI & COLTORTI, 1982; CONTI *et al.*, 1983).

2.2. Structural setting

The morphotectonic setting of the *Periadriatic Basin* is due to a polyphasic tectonics that has been occurring since the Pliocene and throughout the Quaternary time. The many tectonic phases are characterized by different kinematics: compressive in the beginning and extensional later with uplifting and tilting process occurring at the same time.

The compressive phase (Upper Miocene-Lower Pliocene) produces several thrusts in the Apennines, causing their eastward migration and affecting the foredeep deposits (MOSTARDINI & MERLINI, 1986; GHISETTI *et al.*, 1994; BIGI *et al.*, 1995a).

In the study area, according to the field data, it is possible to underline extensional tectonic activity as well as uplifting and tilting processes that started in the Upper Pliocene/Lower Pleistocene.

Within the area, the most important fault systems are N±20°, N20°-35°E, N45°-60°E, N40°-60°W oriented (Fig. 1). Of importance, are the anti-Apennine systems that cause not only the subdivision of the basin during the sedimentation processes, but also the variation of the depositional environments, and later, affect the emplacement of the drainage network.

The N20°-35°E and N45°-60°E trending faults, that usually show vertical movement and are often connected to preexisting tectonic elements (BIGI *et al.*, 1995b; BIGI *et al.*, 1997b), bound different sectors characterized by differential subsidence during the Pliocene and tilting and differential uplifting during the Pleistocene.

The differences in thickness and in facies of the Plio-Pleistocene sediments revealed by field and well data show the tectonic activity of these fault systems and the structuring of the various sectors. In addition, the direction (N20°-35°E) of the main channels (Alento River, Foro River, Dendalo Torrent and Moro Torrent) suggests a tectonic control of this fault system on the development of mainstreams themselves.

The N40°-60°W fault system acts during the Pliocene time and restarts its activity after the deposition and down-cutting of the second order fluvial terraces (end of Middle Pleistocene). In the Upper Pleistocene this fault system controls the deposition of a system of alluvial fans near Pretoro-Rapino (third order of fluvial terraces). In addition, its activity is clearly shown by the presence of stream elbows close to the Maiella massif and along the coast, where the influence of the uplifting of the *"dorsale*

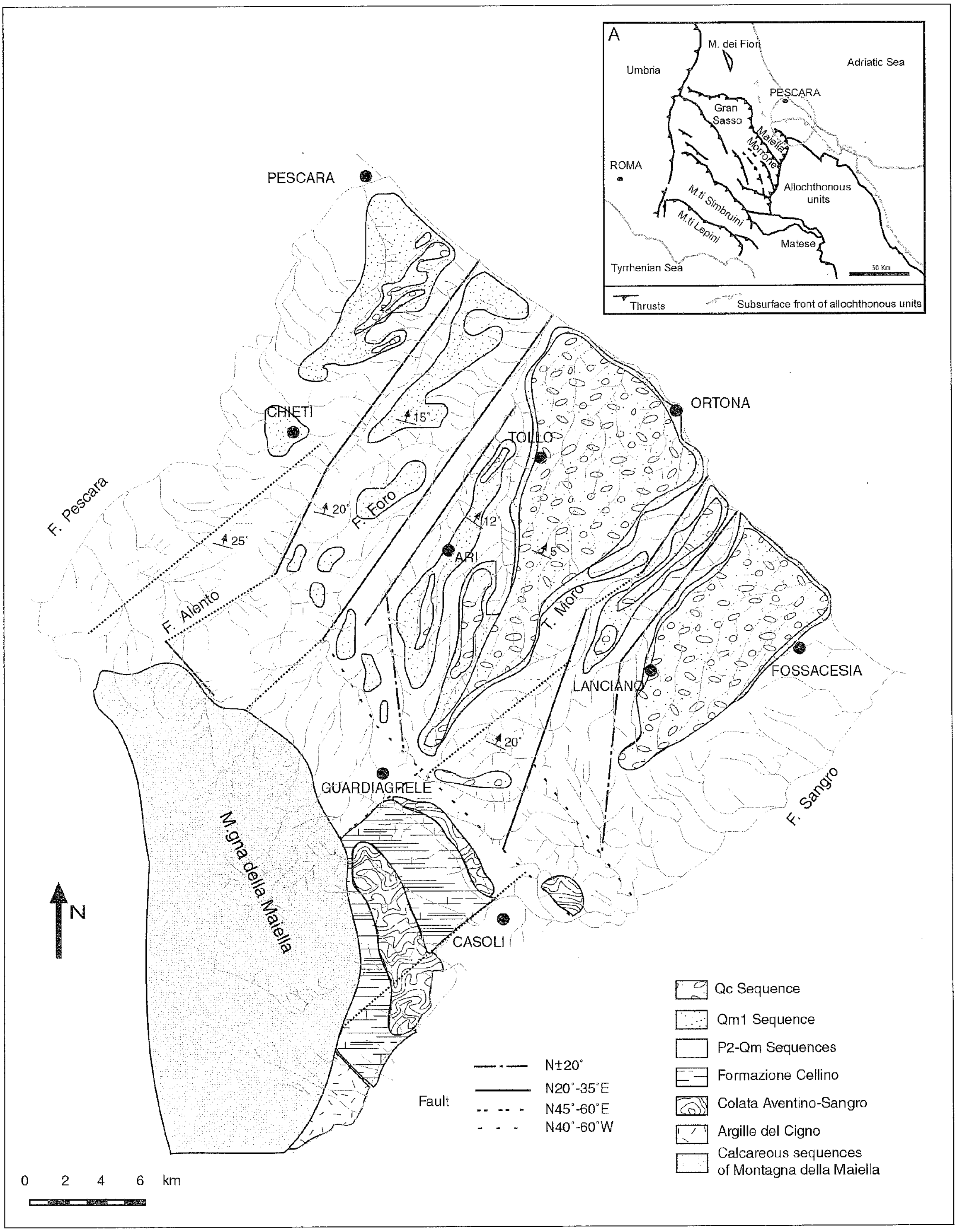

Fig. 1 – Geological map (after D'AMBROGI, 1999; modified). A) Location of the investigated area (map from EBERLI *et al.*, 1992; simplified).

costiera" ridge is evident (Ori *et al.*, 1991; Bigi *et al.*, 1995b).

During the Lower Pleistocene, the area starts to emerge and to tilt eastward. Presently, several marine deposits (Sicilian) of the Q_{m1} *sequence* are located at 50 m on the sea level along the coast (Ortona) and at 500 m close to the Maiella massif (Guardiagrele).

The uplifting process increases during the Lower Pleistocene and gives rise to a marked unconformity between the P_2-Q_m *sequences* deposits (clays) and the Q_{m1} *sequence* (sands). The present inclination of the clay strata (20°-25°), deposited on a slightly sloped surface in a platform environment, indicates that the tilting occurred after their deposition (Lower Pleistocene p.p.).

The slope of the conglomeratic deposits (*Qml sequence*) is usually about 10°-15°, but it decreases toward the coast; meaning that the uplift process acted not only during the deposition of the P_2-Q_m *sequence*, but also throughout the deposition of the Q_{m1} *sequence*.

The uplift process is characterized by an increase of its rates at the end of Lower Pleistocene. This is a likely result of a post-compressive isostatic upheaval, combined with vertical movements linked to the extensional tectonics (Dramis, 1992).

3. TECTONIC-SEDIMENTARY EVOLUTION

The tectonic-sedimentary evolution of the investigated area is strongly linked to the gradual belt-foredeep system migration of the Central Apennines. This migration gives rise to the development of several basins, from West to East, filled by torbiditic deposits and of piggy-back basin.

In the area under investigation the outcropping rocks belong to the most recent and external foredeep (*Cellino Formation*) and to the piggy-back *Periadriatic Basin*.

During Pliocene time and Lower Pleistocene p.p., as shown by the examination of the outcropping rocks and well data, the study area (*Chieti sector* according to Bigi *et al.*, 1995b) is subdivided into several sub-sectors that are characterized by differential subsidence. The *Colata Aventino-Sangro* emplaces within the lowest sector, which is located in the Southern region of the study area. The different sectors are bounded by N35°E oriented faults, likely preexisting tectonic elements.

During the Upper Pliocene coarse layers (Turrivalignani conglomeratic deposits and storm layers) form at different stratigraphic positions inside the P_2-Q_m *sequence*.

In the Lower Pleistocene, the activity of several fault systems together with the generalized uplifting, greater along the mountain range, cause a longitudinal subdivision of the *Chieti Sector* (Centamore *et al.*, 1996; Bigi *et al.*, 1995b; Bigi *et al.*, 1997b). The new structural arrangement often shows a reversal of tectonic behavior, which is in contrast with the Pliocenic setting. This arrangement reflects a common situation throughout the entire *Periadriatic Basin*.

During the emersion process, the early hydrographic network emplacement is controlled by the physiography of the basin, and drains toward the lowest areas. Between the Foro River and the Moro Torrent, a paleo-drainage network has been found, in which, the thickness of its deposit decreases towards SE and NW, suggesting a lowered SW-NE oriented area bounded by N30°-35°E oriented faults. This paleo-drainage network deposits gravel sediment, at different stratigraphic positions, within the Q_{m1} *sequence* (Bigi *et al.*, 1995b; D'Ambrogi, 1999).

Finally, with the complete emersion of the area, erosional processes influenced by a dry climate take place (Suc, 1984). At the end of Lower Pleistocene there is an increase in the uplift rates. Also, climatic changes and eustatic fluctuations give rise to riverbed deepening.

N20°-35°E, N40°-60°W, N±20°, and N40°-60°E dip-slip trending fault systems bind many sectors characterized by differential uplift. This characteristic is suggested by the presence of Q_c *sequence* (fluvial-deltaic and coastal plain deposits) at different altitudes within the various sectors, and by the displacement of limits between P_2-Q_m/ Q_{m1} and Q_{m1}/Q_c *sequences*.

The obtained results suggest the complex morphostuctural setting shown in Fig. 2. The arrangement has been simplified to allow the use of morphometric parameters.

Fig. 2 shows the four sectors, each made up of subsectors with similar uplift and characterized by different amounts of uplift: the A sector is the highest; B and D sectors experience about the same uplift; and the C sector that is downthrown.

4. MORPHOMETRIC PARAMETERS

Several geomorphic parameters are measured and then used to identify, quantify, and evaluate the zones that are subject to differential uplift (previously described by field surveys). Such parameters are: the amplitude of relief, the channel gradient, the drainage density.

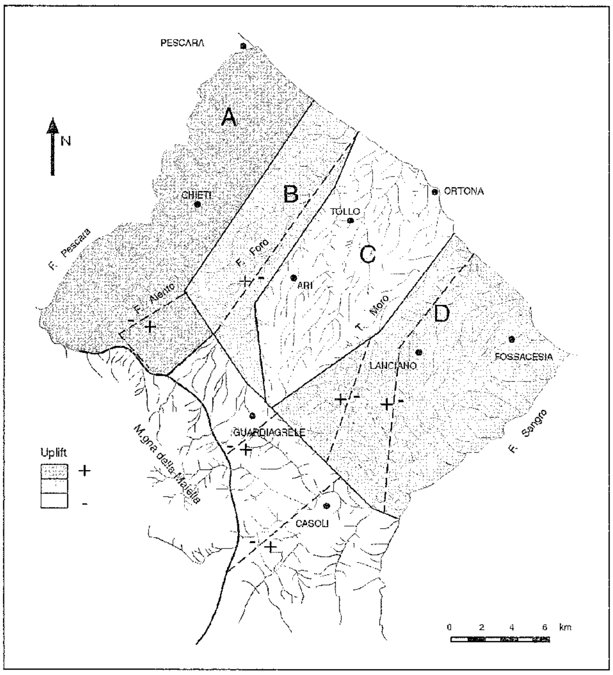

Fig. 2 – Morphostructural map. Each sector is divided into subsectors, characterized by similar uplift (after D'Ambrogi, 1999; modified).

4.1. Amplitude of relief

The *Amplitude of relief* (Ar) is a geomorphic parameter that allows careful examination of the orographic configuration in a given area. This parameter is defined as the maximum difference in elevation measured in unit cells (1 km^2). The neotectonic meaning of Ar has been tested by several previous studies (CENTAMORE *et al.*, 1996; DEL MONTE *et al.*, 1996; LUPIA PALMIERI *et al.*, 1996; LUPIA PALMIERI *et al.*, 1998).

The *Amplitude of relief* highlights zones characterized by more or less deep fluvial erosional processes that can be caused by differential uplift or subsidence phenomena.

The obtained values, divided into six classes, are shown in the mosaic map (Fig. 3). In this map, each class is symbolized by different colors. This allows an easy evaluation of the spatial distribution of the *Amplitude of relief* within the area. The map indicates that the highest values (corresponding to the V and the VI class) are in the southwestern part and are distributed in an arch shaped area corresponding to the calcareous rocks of the Maiella Units. In addition, the decrease of Ar values eastward (i.e. from the mountain chain toward the Adriatic Sea) is less evident, as might be expected.

Actually, the spatial distribution of Ar parameter suggests a strong relation between the alignments of cells with similar Ar values and the main structural directions. A close examination of the map reveals different alignments of similar values: the most important ones, NE-SW oriented, emphasize the main structural directions; the secondary alignments, N-S trending, are mostly located at the foot of the Maiella Mount, close to Pretoro and Casalincontrada.

Furthermore, the areal distribution of Ar values indicates a downthrown zone (sector C) when compared with adjacent zones. To quantify this characteristic, the percentage values relevant to each sector, and to the whole area, have been calculated. In the table 1 and Fig. 4, the obtained data are shown: in sector C, 62.6% of the values correspond to the lowest classes (I and II class). On the other hand, the Ar values relevant to the whole area correspond to higher classes (>II class: 50.5%).

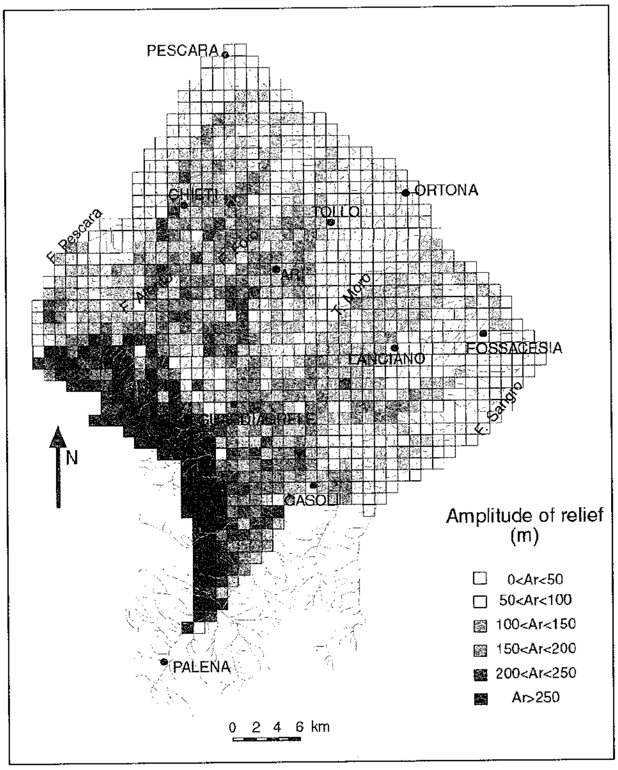

Fig. 3 – Amplitude of relief map (after CURRADO, 1999; modified).

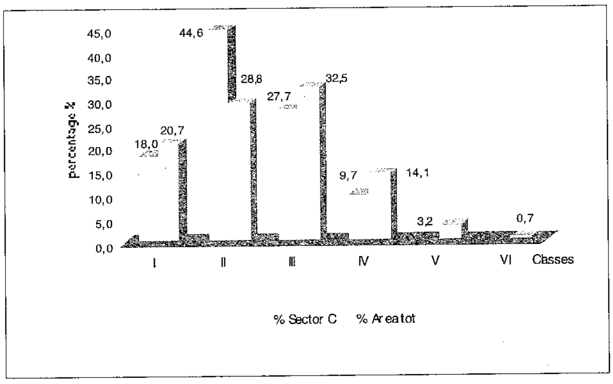

Fig. 4 – Amplitude of relief for sector C and total area.

4.2. Drainage network parameters

The *channel gradient* (g) and the *drainage density* are measured to show the responses of fluvial systems to localize uplifting and to identify the drainage network morphologies that accompany different amounts of uplift in the study area. Since the lower stream orders are more likely to be controlled by neotectonic activity, these parameters have been calculated only for the first and the second hierarchic stream orders (STRAHLER, 1957).

The channel gradient of the lower tributaries is one of the best indicators of recent uplifting. In fact, lower order streams tend to have steepest profiles in areas that are affected by uplifting, whereas larger streams can easily adjust their longitudinal profile to base-level changes (MERRITS & VINCENT, 1989).

The average of the channel gradients, related to the first and second stream orders, is calculated for each of the identified sectors. Table 2 and Fig. 5 show the obtained val-

Amplitude of relief (m)	0/50	51/100	101/150	151/250	251/350	>351
Classes	I	II	III	IV	V	VI
% Sector C	18.0	44.6	27.7	9.7		
% Area tot	20.7	28.8	32.5	14.1	3.2	0.7

Table 1 – Amplitude of relief.

	SECTOR A		SECTOR B		SECTOR C		SECTOR D	
	1st stream order	*2nd stream order*	*1st stream order*	*2nd stream order*	*1st stream order*	*2nd stream order*	*1st stream order*	*2nd stream order*
Number of segment	919	147	433	89	549	74	823	164
Total length (km)	244.25	112.66	154.90	56.91	237.62	114.42	284.46	140.38
Total area (km2)	234	234	128	128	218	218	283	283
Channel gradient (mean)	0.27	0.11	0.22	0.13	0.15	0.10	0.19	0.12
Drainage density (mean)	1.04	0.48	1.21	0.44	1.09	0.52	1.01	0.5

Table 2 – Morphometric properties.

ues. The variations in the steepness of first order channels indicate the greatest amount of uplift for sector A (g = 0.27). On the other hand, sector C is characterized by the lowest values (g = 0.15), which suggests that this sector is being downthrown. Sectors B and D have similar g-values (falling between A and C), which signify an intermediate uplift. Moreover, the slight difference in the values related to these sectors (B = 0.22; D = 0.19) suggests greater uplifting in sector B.

The obtained data regarding the second order streams do not show a great variability within the study area (table 2). This could be due to a very recent differential uplift phenomenon, which occurred after the emplacement of the second order streams (and before first order), or because the second order channels have already adjusted their longitudinal profiles, degrading the usefulness of their data in evaluating neotectonic events. These data suggest that a careful assessment of the channel gradient can contribute to a better understanding of the morphotectonic setting than can be achieved by geological survey alone.

The other drainage network parameter calculated to complete this analysis, is the *drainage density*. As mentioned above, the *drainage density* is measured for the first and the second hierarchic order. Unfortunately, the obtained data do not show any significant variation among the four sectors, nor does it show any significant correlation with geological data. This means that they do not satisfy (Table 2). It is probable that because this planimetric network feature is more deeply related to lithologic and climatic conditions, as MERRITS & VINCENT (1989) suggest, it is not a useful tectonic tool in the study area, which is characterized by a mostly homogeneous lithology.

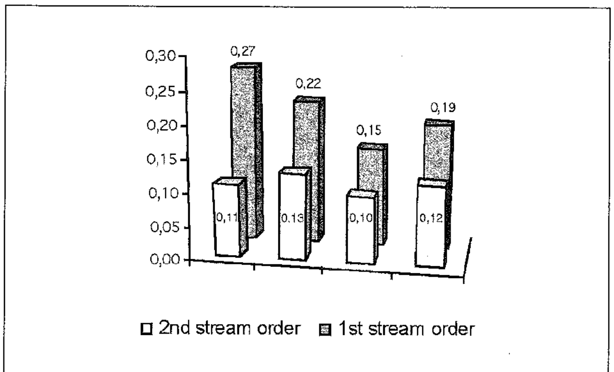

Fig. 5 – Channel gradient (mean) for 1st and 2nd stream order.

5. DISCUSSION AND CONCLUSION

In the study area, the geological survey and the morphometric analysis allow the reconstruction of the evolution of the *Periadriatic Basin* throughout the Pliocene and the Pleistocene.

During the Pleistocene, a generalized uplift process characterizes the basin. Between Pescara River and Sangro River, the activity of several fault systems gives rise to the subdivision of the area into several parts, sometimes with reversal tectonic behaviors compared to the Pliocenic arrangement. In particular, the field data suggest the presence of four sectors made up by various sub-sectors and characterized by differential uplift (see Fig. 2).

It is possible to use morphometric analyses to emphasize the uplift phenomena for the particular morphotectonic settings of the identified sectors, and for the homogeneity of the outcropping rocks. The Ar spatial distribution shows the strong relation between main structural directions and morphological features (Fig. 3). Moreover, the variability of the obtained geomorphic data within the study area (Tab. 2) confirms its subdivision into four sectors, as previously known by field data.

In summary, the identified sectors are:

- A sector, the most uplifted, with a channel gradient (*g*) for the first stream order of 0.27, bounded to the north by the Pescara River and to the South by the Alento River;

- B sector, situated between the Alento River and the Foro River, and characterized by an intermediate amount of uplift (g = 0.22);

- C sector, downthrown, located between the Foro River and the Moro Torrent (g = 0.15) and characterized by the presence of gravel from delta and beachface within the Q_{m1} *sequence*;

- D sector, the southern-most, equivalent to the B sector's intermediate upheaval process (g = 0.19).

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