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AZIMUTHAL TRANSECTS OF STREAM ORIENTATIONS: AN ADVANCE IN UNDERSTANDING THE REGIONAL MORPHOTECTONIC SETTING OF EASTERN ABRUZZO (CENTRAL ITALY)

ABSTRACT: DELLA SETA M., *Azimuthal transects of stream orientations: an advance in understanding the regional morphotectonic setting of eastern Abruzzo (Central Italy)*. (IT ISSN 1724-4757, 2004).

The recently proposed *azimuthal transects method* was applied to the drainage network of the eastern Abruzzo area, in order to confirm the location and identify the kinematics of regional fault zones, supposed to characterise the boundaries between different morphotectonic sectors previously recognised in the area. This methodology consists of applying the azimuthal analysis of low order (younger) stream orientations along transects crossing inferred faults. Its usefulness in morphotectonic investigations is linked to the possibility of identify statistical progressive rotations of channels induced by strike-slip displacements, especially where the classical structural analysis is unlikely to be performed because of lacking pervasive deformations within outcropping rocks.

At the boundaries between the three different morphotectonic sectors formerly mentioned, strike-slip offsets were identified along E-W oriented fault zones, whose presence is also suggested by some macroscopic geomorphological evidence, such as the deflection of several main rivers towards the E-W direction. These results are consistent with those get by structural and geophysical studies, thus allowing to infer that these shallow crust plio-quaternary deformations could be the effect of the activity of the E-W lithospheric deformation zone which, according to many Authors, would divide the Adriatic plate into two different portions.

KEY WORDS: Quantitative Geomorphology, Neotectonics, Drainage network, Azimuthal transects, Abruzzo (Italy).

RIASSUNTO: DELLA SETA M., *Transetti azimutali delle aste fluviali: un passo avanti nella comprensione dell'assetto morfotettonico regionale dell'Abruzzo orientale (Italia Centrale)*. (IT ISSN 1724-4757, 2004).

Nell'area dell'Abruzzo orientale è stato applicato alla rete idrografica il metodo, recentemente proposto, dei *transetti azimutali*, con l'obiettivo di localizzare e caratterizzare alcune faglie regionali che, come era stato precedentemente ipotizzato, potrebbero rappresentare le zone di confine fra alcuni settori ad assetto morfotettonico differente, individuati in quest'area. Tale metodologia consiste nell'applicazione dell'analisi azimutale dell'orientazione delle aste di ordine più basso (più recenti), lungo transetti che attraversano faglie ipotetiche. La sua utilità nelle indagini di carattere morfotettonico consiste nella possibilità di identificare statisticamente eventuali rotazioni progressive delle aste indotte da rigetti trascorrenti, specialmente quando l'analisi strutturale classica è difficilmente applicabile per mancanza di deformazioni pervasive nelle rocce affioranti.

In corrispondenza dei limiti di tre differenti settori morfotettonici, sono state ipotizzate delle componenti cinematiche trascorrenti lungo zone di faglia ad andamento E-W, la cui presenza è suggerita anche da alcune evidenze morfologiche, come la deviazione di molti corsi d'acqua principali verso la direzione E-W. Questi risultati appaiono in accordo con quelli ricavati da lavori di carattere strutturale e geofisico, avvalorando l'ipotesi che queste deformazioni superficiali plio-quaternarie possano rappresentare l'effetto dell'attività della zona di deformazione litosferica ad andamento E-W che, secondo alcuni Autori, dividerebbe in due distinte porzioni la placca adriatica.

TERMINI CHIAVE: Geomorfologia quantitativa, Neotettonica, Reticolo idrografico, Transetti azimutali, Abruzzo.

INTRODUCTION

A wide series of works outlined the usefulness of quantitative geomorphic methods in the study of tectonically active regions. This was evidenced through the application of statistical analysis and through the definition of unbiased parameters in order to quantify the neotectonic influence on morphogenetic processes (Keller & *alii*, 1982; Hare & Gardner, 1985; Ciccacci & *alii*, 1986, 1988; Mer-

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ritts & Vincent, 1989; Mayer, 1990; Cox, 1994; Merritts & *alii*, 1994; Gao & Xia, 1996; Jackson & *alii*, 1996; Keller & Pinter, 1996; Demoulin, 1998; Belisario & *alii*, 1999; Currado, 1999; Currado & Fredi, 2000).

Many Authors focused their investigations on the configuration of drainage networks, as they represent physiographic features particularly sensitive to rock weakness and surface slope changes, due to brittle and/or ductile tectonics (Ollier, 1981; Leeder & Jackson, 1993; Jackson & *alii*, 1996; Alvarez, 1999).

Following this kind of morphometric approach, Currado (1999) and Currado & Fredi (2000) delineated the morphotectonic setting of eastern Abruzzo (Central Italy; fig. 1), located between the Apennine chain and the Adriatic Sea, within the emerged Messinian-Early Pliocene foredeep domain. Here the foredeep deposits are finally overlain by a Plio-Pleistocene marine sequence. Examining the drainage patterns and the influence of tectonics on the development of basin landforms, the Authors recognised different morphotectonic sectors and suggested that they could be bounded by lithospheric discontinuities.

In this paper the analysis of stream channels orientations was performed by the *azimuthal transects method* (Belisario & *alii*, 1999); the aim is to identify the kinematics of regional fault zones, supposed to be major discontinuities within the morphotectonic setting of eastern Abruzzo (Currado, 1999; Currado & Fredi, 2000).

In fact, this method had previously provided good results in the detection of strike-slip displacements along faults, especially in areas, like the investigated one, where

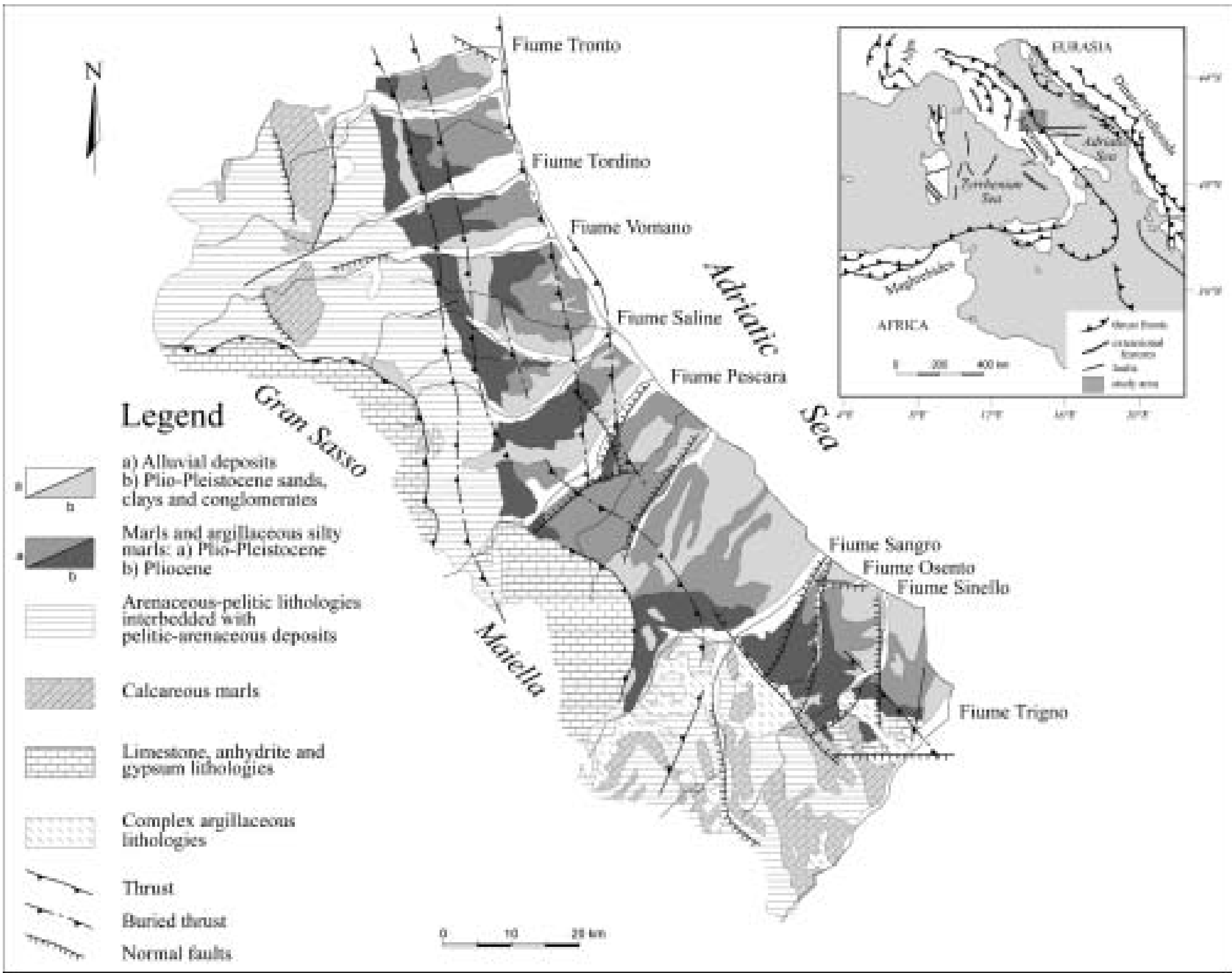

FIG. 1 - Geodynamic framework and geolithological sketch of eastern Abruzzo. In the geolithological sketch different facies have been grouped, even if heterochronous, following a criterion based on their erodibility. Nevertheless, because of their relatively simple monoclinal arrangement, Pliocene and Pleistocene deposits, which are widespread in the outcrops of the eastern (and most studied) portion of the area, have been distinguished chronologically as well.

the tectonic deformation cannot be clearly registered because of the mechanical properties of outcropping lithologies (Belisario & *alii*, 1999).

GEOLOGICAL OUTLINE OF THE EASTERN ABRUZZO

The study area is located within the geodynamic frame of the Mediterranean region, whose present setting was determined by the interaction between Eurasian and African plates, originally separated by the Tethys ocean (McKenzie, 1972). The convergence between these plates started during the Cretaceous and gave rise to the Apennine orogenic system, that was built up starting from Upper Miocene, and is characterised by a northeastward verging thrust-fold belt, with axis oriented from NW-SE to NNW-SSE (fig. 1). The system underwent an eastward migration along with the extension in its inner domains (Parotto & Praturlon, 1975; Faccenna & *alii*, 1997, 2001).

The study area corresponds to the eastern and most external sector of the orogenic system (Peri-Adriatic Foredeep Basin), where the «adriatic plate» (Adria) played a crucial role (Argnani & *alii*, 1991). This block, representing eastward the present foreland domain, was considered homogeneous and relatively undeformed by some Authors (Anderson & Jackson, 1987). Nevertheless, there are evidence of some differences in the lithospheric characters and in the current outline between its northern and southern portions (Console & *alii*, 1993; Favali & *alii*, 1993; Gambini & Tozzi, 1996).

In the eastern Abruzzo area gently folded sediments of Early-Middle Pliocene, Early Pleistocene overlie unconformably the strongly folded terrigenous units of Oligocene, Lower Pliocene (fig. 1) (Centamore & *alii*, 1990, 1993). In the upper part of the Pleistocene sequences, many transgressive-regressive phases are recorded which culminate with beach sediments passing landward to alluvial fan deposits (Casnedi, 1983).

From the neoctectonic point of view, in this area NW-SE to N-S buried thrusts of Pliocene age were recognized, along with Quaternary normal faults mainly oriented NW-SE, SW-NE and N-S (fig. 1) (Ambrosetti & *alii*, 1986; Aucelli & *alii*, 1996).

MORPHOLOGICAL AND MORPHOTECTONIC SETTING OF THE STUDY AREA

The eastern Abruzzo area, located between the Fiume Tronto to the North and the Fiume Trigno to the South, is clearly marked by the presence of three different morphological domains.

Starting from the West, the Laga Mountains, the Gran Sasso Range and the Maiella Mountain offer a typical mountain landscape. Glacial and peri-glacial lanforms are widespread, along with the typical non-alignment between maximum heights and watersheds (Mazzanti & Trevisan, 1978).

Toward the East the hilly landscape is somewhere interrupted by calcareous ridges, such as the Montagna dei Fiori – Montagnone N-S trending structure. Here the morphogenesis is mainly due to sheet and rill erosion, accompanied by mass movements.

Finally, a very low relief characterizes the easternmost portion of the area, near to the coast of the Adriatic Sea. The main valleys are broad and show different orders of terraces; large alluvial plains are present.

On the whole, the drainage system underwent the strong influence of tectonic, and especially neotectonic, events. The original network exploited the presence of some regional tectonic lines transversal to the apenninic trends, active since the Miocene (Guerricchio, 1990). Then the main streams maintained their direction, even during the formation of compressional structures (Middle Pliocene). Successively, a general uplift, migrating from East to West, caused the complete emersion of the area during the Early Pleistocene (Dramis, 1992). The erosional processes in subaerial environment produced a series of paleosurfaces, presently dislocated by quaternary tectonics.

Besides the general uplift process that involved the whole Central Italy starting from Early Pleistocene (Demangeot, 1965, Ambrosetti & *alii*, 1982; Dufaure & *alii*, 1988), a wet climatic phase also contributed to an increasing of fluvial deepening, that caused the dissection of the ancient paleosurfaces into isolated remnants.

The spatial variations of amplitude of relief, the morphological field evidence of tectonics, the statistical distribution of stream orientations and the values of the geomorphic indices by Keller & Pinter (1996; and references therein) related to the asymmetry of valley, led Currado (1999) and Currado & Fredi (2000) to subdivide the eastern Abruzzo area into three different morphotectonic sectors.

The *northern sector*, bounded by the Fiume Tronto and the Fiume Saline, is marked by N-S alignments of morphotectonic field evidence, accompanied by N-S and NE-SW preferential stream orientations (especially for channels of lower orders in Strahler's hierarchy); here a general tilting toward WSW was also inferred.

The *central sector* shows E-W alignments of morphotectonic field evidence, NE-SW and E-W preferential stream orientations and southeastward tilting.

The *southern sector* is characterised by N-S alignments of morphotectonic field evidence and by N-S, E-W and NW-SE preferential stream orientations; the high variability of data indicates that the tectonic arrangement of this sector is very complex.

Moreover the boundaries between these sectors were tentatively located. The Authors also supposed that some of these boundaries could be represented by E-W oriented tectonic discontinuities.

This work focuses on the morphotectonic aspects of the eastern Abruzzo area that can help the more precise characterisation of the previously mentioned boundaries. In particular, the possible existence of plio-quaternary strike-slip fault zones, in correspondence of sector boundaries, was verified and their kinematics was inferred, applying the methodology proposed by Belisario & *alii* (1999).

AZIMUTHAL TRANSECTS METHOD

As known the activity of strike-slip faults may be outlined by offset and/or deflection of stream channels crossing the fault zones, often associated to other typical landforms (Allen & *alii*, 1984; Keller & Pinter, 1996).

In this context the azimuthal analysis of stream orientations provides a significant contribution, as it can evidence the statistical progressive rotations of channels. For this reason Belisario & *alii* (1999) applied the azimuthal analysis along transects crossing a known strike-slip fault zone; the statistical behaviour of lower order stream channels near the fault was studied in particular. In fact stream channels of 1st and 2nd order (Strahler's method), because of their recent emplacement, are generally more sensitive than higher order ones to the tectonic influence; moreover, they often represent 60÷70% of the cumulative length of the whole drainage network, thus providing interesting and statistically significant results.

In fig. 2 the steps followed by Belisario & *alii* (1999) for the computing of azimuthal transects are shown. In order to prepare a suitable data base the drainage network, traced from topographic maps (scale 1:25,000), is hierarchically ordered after Strahler (1957), digitised with a graphic table (100 lines/mm) and rectified by an automatic process. In this way, for each rectilinear segment of 1st and 2nd order channels, geographical coordinates of the extremes, azimuth and length were elaborated.

Using the software DAISY 2.16b (Salvini, 1998) the extremes, length and width of each transect are chosen. Thus, with a totally automated processing, a series of azimuthal spectra, regularly spaced along the trace, are elaborated along each transect.

At the end of processing an output diagram for each transect is obtained (fig. 3), where the X-axis represents the along transect distance, while the Y-axis indicates azimuthal values from 90°E to 90°W. Upon this X-Y plane azimuthal spectra peaks are projected, thus giving rise to a variety of «geometries».

The interpretative models for fault kinematics introduced by Belisario & *alii* (1999) indicate that the progressive rotations of stream channels, in crossing a strike-slip fault zone, determine «bell-shaped» azimuthal spectra in case of left-lateral components, while right-lateral kinematics induce a typical «valley-shaped» geometry (fig. 3).

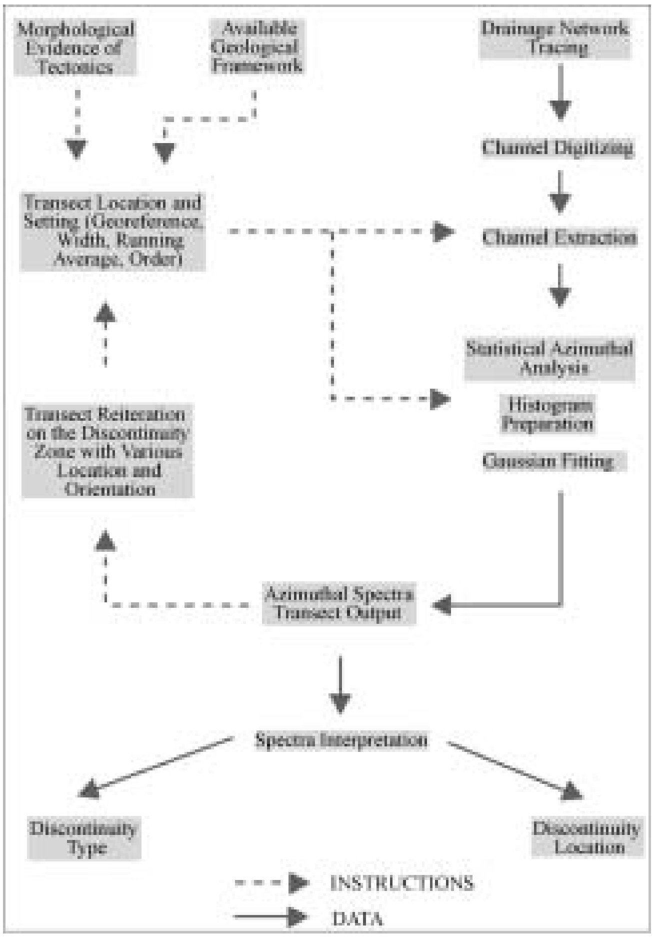

FIG. 2 - Flow diagram illustrating the schematic sequence of the performed *azimuthal transects method* phases.

RESULTS

Taking into account the results obtained by Currado & Fredi (2000), several azimuthal transects were performed across areas that constitute probable sector boundaries, using an updated version of the software DAISY (DAISY 3; Salvini, 2002). Transect locations and orientations were chosen considering that these boundaries might be represented by nearly E-W oriented fault zones. This assumption is strengthened by the macroscopically evident E-W deflection of main rivers at probable boundary zones (fig. 4). In particular, this is evident for the Fiume Tronto (northern limit of first sector), for the Fiume Fino and Fiume Saline (limit between first and second sectors) and for the Fiume Aventino and Fiume Osento (limit between second and third sectors).

In fig. 4 the location of most significant transects is shown, along with the corresponding diagrams.

Transects A and B show the azimuthal distribution of 1st order channels within the Fiume Tronto drainage basin. Two «bell-shaped» spectra are clearly present, showing the progressive counter clockwise rotation of streams approaching the inferred fault zone of the Fiume Tronto, and the clockwise one while going away from it. Thus, according to Belisario & *alii* (1999), the presence of the fault zone is confirmed, which shows a left-lateral strike-slip kinematic component. Both the diagrams indicate that the left slope of the valley is characterised by a quite constant orientation of channels, while they progressively rotate and reach the maximum deflection (value of 50-60°W) just near the inferred tectonic feature. This is consistent with the presence of a deformation zone associated to the left-lateral offset along the fault.

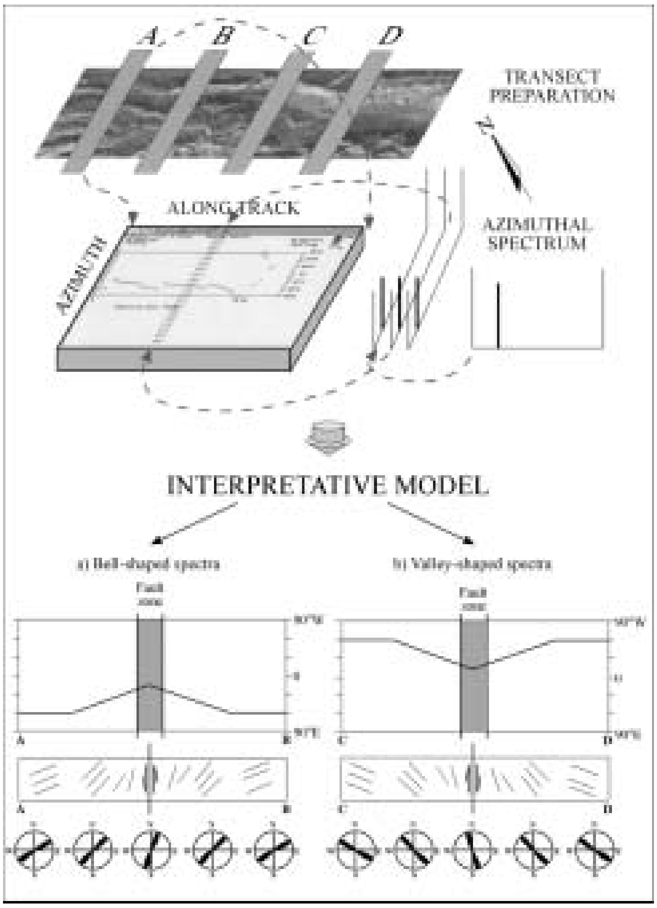

FIG. 3 - Scheme of the main processing steps, showing the transect preparation and an example of output diagram. In the lower part of the figure the interpretative model for obtained output diagrams is shown, according to Belisario & *alii* (1999).

Different kinematics seems to characterise the other two inferred sector boundaries.

«Valley-shaped» azimuthal spectra along transects C and D suggest the presence of a fault zone with right-lateral offsets along E-W oriented segments of Fiume Fino and their ideal prolongation toward the East. In this case, especially for transect D, where the «valley-shaped» spectra is more evident, starting from a quite constant preferred orientation, the progressive rotation of channels rise a maximum, near the fault zone, at the azimuth of more or less 50°E. Considering that, with respect to the previous boundary, the orientation of the inferred fault zone is approximately the same (E-W), the azimuth value corresponding to maximum deflection of channels is clearly consistent with the presence of a synthetic deformation pattern induced by right-lateral kinematics. Analogous results were obtained for the third sector boundary, where two «valley-shaped» geometries are evident along the E-W segments of Fiume Aventino and Fiume Osento. Even in these cases the maximum deflection, observed in correspondence to the rivers, rise the 50°E azimuth value, thus confirming the above hypothesis.

CONCLUSIONS

The results obtained by the application of the azimuthal transects method improved the definition of the morphotectonic frame of eastern Abruzzo, issued from the quantitative geomorphic analyses performed by Currado (1999) and Currado & Fredi (2000). In fact, kinematic constraints are provided to the inferred deformation zones supposed to define three boundaries between the different morphotectonic sectors recognised by these Authors.

In fig. 4 a summarising sketch of the outcomes of Currado (1999) and Currado & Fredi (2000) is shown, along with those of this works.

The orientations of morphotectonic features and the directions of tilting within each of the three distinguished sector seem to be consistent with the results of several geological studies. In fact, the tilting direction of northern sector could be according to the presence of buried thrusts backlimbs (Ambrosetti & *alii*, 1986; Casnedi & Serafini, 1994) and/or could be due to the activity of E-verging normal faults (Cinque & *alii*, 1993). Moreover, the E-W morphotectonic features of central sector were correlated to the activity of the lithospheric E-W oriented deformation zone, interpreted by many Authors as an intraplate margin that divides the adriatic block in two different portions (Console & *alii*, 1993; Favali & *alii*, 1993; Gambini & Tozzi, 1996).

As a further outcome, the application of the azimuthal transects method allowed the more precise individuation of the tectonic discontinuities that mark the sector boundaries, as it has provided information about their eventual location and kinematics.

The three morphotectonic sectors distinguished by Currado (1999) and Currado & Fredi (2000) seems, in fact, to be bounded by E-W oriented fault zones, with plio-quaternary strike-slip activity whose presence is also suggested by some macroscopic geomorphological evidence, such as the deflection of several main rivers toward the E-W direction:

a) the northern boundary of the first sector was identified with a discontinuity along which the Fiume Tronto emplaced, where left-lateral strike-slip offset was inferred;
b) the boundary separating the first from the second sector was located between the Fiume Fino and the Fiume Pescara, along a fault zone characterised by right-lateral strike-slip kinematics. This tectonic feature might be identified with the right-lateral «Pescara-Dubrovnik line» indicated by Gambini & Tozzi (1996);
c) the boundary between second and third sector appears quite similar to the previous one, thus confirming the presence of right-lateral components along a tectonic discontinuity located in correspondence to E-W segments of Fiume Aventino and Fiume Osento.

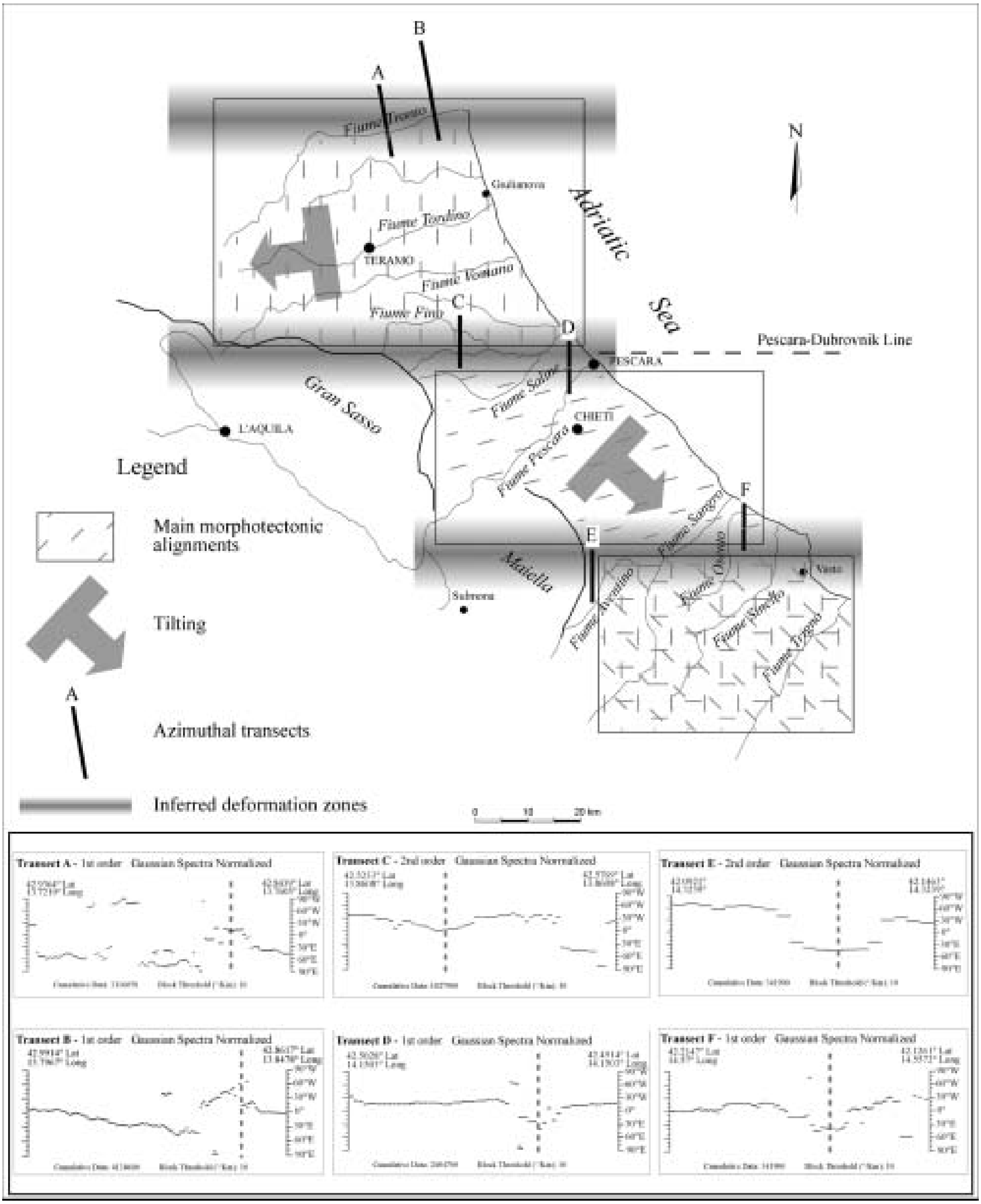

FIG. 4 - Scheme of the morphotectonic setting of eastern Abruzzo. The different morphotectonic sectors are shown, along with the location of boundary zones between them. Moreover, the diagrams for transects A, B, C, D, E, and F show typical «bell-shape» and «valley-shape» geometries suggesting the presence of E-W oriented fault zones with strike-slip kinematical components.

The relationship between these shallow crust deformations and the presence of lithospheric discontinuities is obviously not demonstrated, on the basis of the unique morphotectonic investigation. Nevertheless, the good agreement of the obtained results with those get by structural and geophysical works seems to be comforting. This means that the sector boundary discontinuities could have been generated as an effect of the deformation at the active E-W margin within the «adriatic plate» (Console & *alii*, 1993; Favali & *alii*, 1993; Gambini & Tozzi, 1996).

Finally, results obtained confirmed that the azimuthal transects analysis is a valid tool in the identification of regional strike-slip faults. Besides, the outcomes of this work encourage to extend the application of this method, in order to improve its potentiality to recognise dip-slip offsets as well.

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