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CHARACTERIZATION OF RECENT DEFORMATIONAL SEQUENCES IN SOME AREAS OF THE ABRUZZI APENNINES (CENTRAL ITALY): IMPLICATIONS AND PROBLEMS

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ABSTRACT - *Characterization of recent deformational sequences in some areas of the Abruzzi Apennines (Central Italy): implications and problems* - Il Quaternario, **4**(1a), 1991, p. 85-98 - Recent integrated studies of structural geology, geomorphology and stratigraphy have made it possible to reconstruct the Quaternary kinematic evolution of two key-areas for the study of the recent tectonics of the Abruzzi Apennines.

Pleistocene continental deposits were studied in the Upper Sangro River Valley. These deposits, conglomerate and boulder beds, were displaced by NW-SE faults which have a left-lateral behaviour, with an almost negligible vertical component. The left-lateral strike-slip deformation occurred after the deformation connected to extensional tectonics.

For the second area, between the little towns of Barisciano and Calascio, near the Gran Sasso chain, the structural analysis and, to a minor extent, observations made on Pleistocene continental deposits have made it possible to define the existence of a strike-slip deformation, of Pleistocene age, which occurred after the deformation related to the extensional tectonics. It is reasonable to believe that the change in deformational regime did not precede the Lower Pleistocene on the basis of geomorphological and stratigraphic considerations.

In addition this paper also provides bibliographic references of works presenting evidence of transcurrent movements on NW-SE faults in the Abruzzi Apennines.

The finding of recent transcurrent movements along NW-SE faults raises some interpretational problems. Such problems derive from the fact that the deformational event underway at the regional scale in the Abruzzi Apennines is generally believed to be related to extensional tectonics, which is responsible for the major vertical displacements assumed to have occurred mainly along NW-SE faults. Perhaps a single deformational mechanism can explain the co-existence of normal and strike-slip movements. Such a model is very difficult to infer, because the causes of the strike-slip movements at the NW-SE faults during the Quaternary are not clear. An alternative view is represented by a model according to which extensional and strike-slip deformations alternate.

The interpretational problems can be summarized into four basic points: 1) role of the transcurrent deformations; 2) possible influence of the movements of lower order structures; 3) relationship with the origin of intra-mountain basins; 4) relationship with seismic activity.

Beyond the problems themselves, the discussion on these four points shows how many difficulties can arise when seeking to work out neotectonic models for areas characterized by structurally and kinematically complex orogens, especially when passing from considerations at the regional scale to considerations at the local scale.

RIASSUNTO - *Caratterizzazione delle sequenze deformazionali recenti di alcune aree dell'Appennino abruzzese (Italia centrale): implicazioni e problematiche* - Il Quaternario, **4**(1a), 1991, p. 85-98 - Recenti studi integrati di geologia strutturale, geomorfologia e stratigrafia hanno consentito la ricostruzione dell'evoluzione cinematica quaternaria di due aree significative per lo studio della tettonica recente dell'Appennino abruzzese.

Nel caso dell'alta valle del F. Sangro sono stati studiati sedimenti continentali pleistocenici, essenzialmente un deposito conglomeratico e un deposito a blocchi, dislocati da faglie con direzione NW-SE. Tali faglie mostrano un comportamento trascorrente sinistro, con componenti verticali del movimento praticamente trascurabili. Le deformazioni trascorrenti sinistre sono successive a quelle legate alla tettonica distensiva.

L'analisi strutturale e in misura minore osservazioni sui depositi continentali pleistocenici nell'area compresa tra Barisciano e Calascio hanno permesso di definire l'esistenza di deformazioni trascorrenti pleistoceniche, successive a quelle caratteristiche della tettonica distensiva. Il cambiamento di regime deformativo dovrebbe non essere precedente al Pleistocene inferiore, in base a considerazioni di ordine geomorfologico e stratigrafico.

Vengono riportati inoltre dati bibliografici relativi ad evidenze di trascorrenze su faglie con direzione NW-SE nell'Appennino abruzzese.

Il ritrovamento di motivi trascorrenti recenti in corrispondenza di faglie NW-SE, pone una serie di problemi di ordine interpretativo, soprattutto perchè è generalmente ritenuto che la fase deformativa in atto a scala regionale nell'Appennino abruzzese sia legata alla tettonica distensiva e sia responsabile di importanti rigetti verticali, osservabili soprattutto in corrispondenza delle faglie NW-SE. Premessa la possibilità di una dipendenza tra i movimenti di tipo diretto e quelli di tipo trascorrente in funzione di un unico meccanismo deformativo, risulta comunque difficile la comprensione dei motivi per cui nel corso del Quaternario si sono verificati movimenti trascorrenti in corrispondenza di faglie con direzione NW-SE. I problemi interpretativi sono riassumibili essenzialmente in quattro punti: 1) importanza delle deformazioni trascorrenti; 2) possibili riflessi dell'attività di strutture principali; 3) relazione con la genesi dei bacini intramontani; 4) relazione con l'attività sismica.

La discussione sui quattro punti proposti evidenzia, al di là delle stesse problematiche, le difficoltà che possono nascere nel tentativo di proporre modelli neotettonici in aree caratterizzate da orogeni strutturalmente e cinematicamente complessi, soprattutto a seguito del confronto di indicazioni a scala regionale con dati a scala locale.

Key-words: Recent tectonics, strike-slip deformations, continental deposits, intramountain basins, seismotectonic setting, Upper Sangro River Valley, Barisciano-Calascio area

Parole chiave: Tettonica recente, deformazioni trascorrenti, depositi continentali, bacini intramontani, sismotettonica, alta valle del fiume Sangro, area Barisciano-Calascio

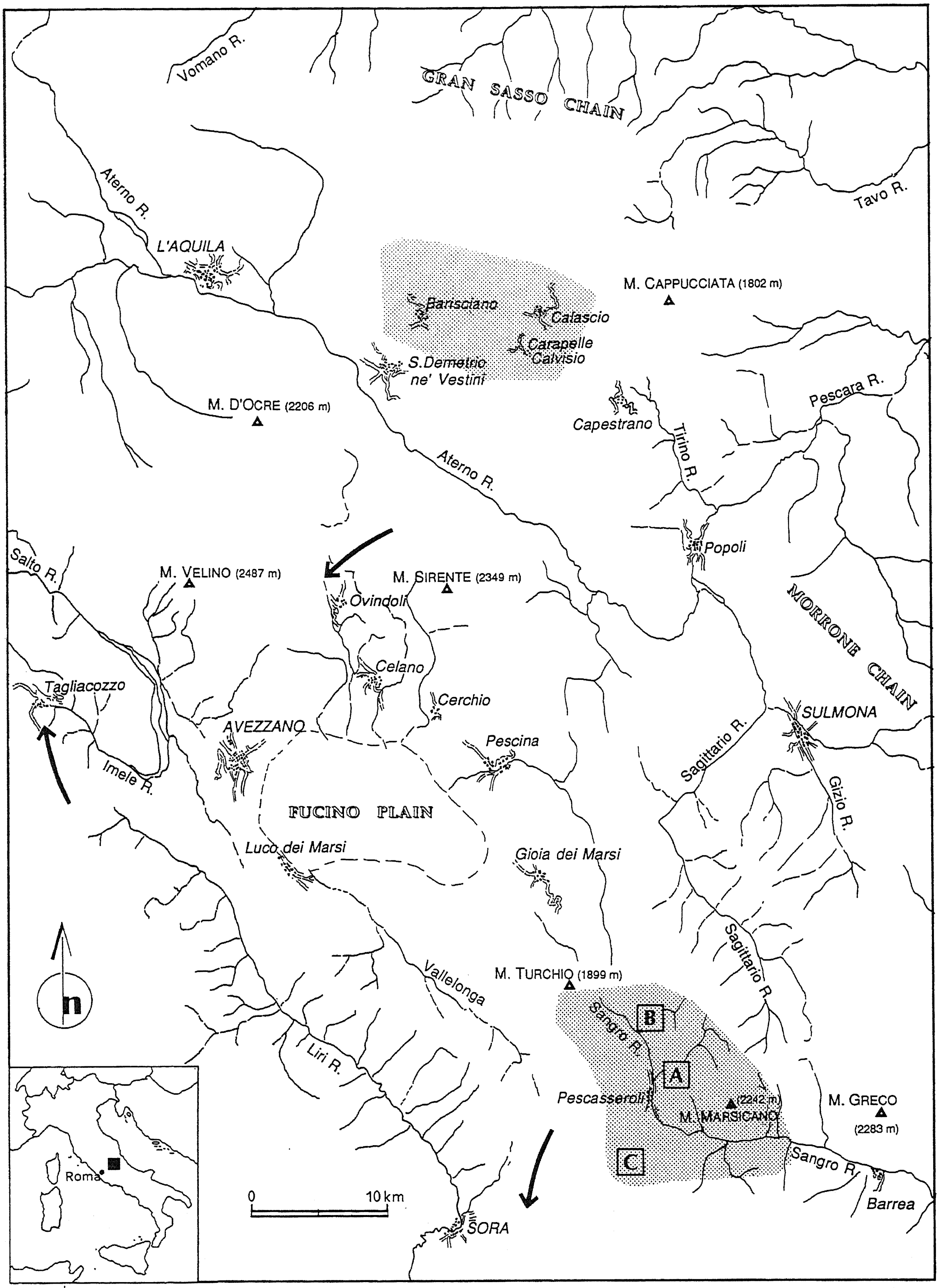

Fig. 1 - Location of the investigated areas. The grey areas are the subject matter of this paper. Ovindoli and Tagliacozzo, referred to in the citations, are indicated by two arrows. Letters A, B and C, in the Upper Sangro River Valley, respectively point to the location of Colli Alti, La Mandrella and Campo Rotondo.

Ubicazione delle aree studiate. In grisè sono riportate le due aree cui si riferiscono gli studi degli autori della presente nota. Con le due frecce sono evidenziate le aree di Ovindoli e di Tagliacozzo, cui si fa riferimento citando altri autori. Con le lettere A, B, C, nell'alta valle del F. Sangro, si intende l'ubicazione rispettivamente dell'area dei Colli Alti, de La Mandrella, di Campo Rotondo.

1. INTRODUCTION

The structural features of the Abruzzi Apennines, the central section of the Apenninic chain, are due to a complex succession of mainly compressional and extensional tectonic events (Accordi, 1966; Castellarin *et al.*, 1978; Ghisetti & Vezzani, 1988). In the study of recent tectonics an important role is attributed to the general extensional tectonic activity which is responsible for major vertical displacements along the master-faults of the area (Accordi, 1966; Colacicchi, 1967; C.N.R.-P.F.G., 1987).

This paper discusses detailed studies carried out in two areas (data about other areas are desumed from existing bibliography) of the Abruzzi Apennines aimed at defining the succession of Quaternary deformational events. The choice of significant areas for the study of Quaternary kinematics is usually made considering the presence of Quaternary continental deposits, typical morphologies indicating active tectonics, and knowledge, from the bibliography, of active structures. Particularly one of the chosen areas, the Upper Sangro River Valley, appears to be a key-area for the understanding of recent kinematics, because it is characterized by the presence of a 20 km long master-fault (Bigi *et al.*, 1986) and is located near the Ortona-Roccamonfina line, a N-S lineament with an important role in the geodynamic evolution of the Apenninic chain (Patacca *et al.*, 1990). The results suggest that the general assumption of an active and essentially extensional tectonics can at times be questioned by detailed observations. These observations highlight the difficulties that are usually encountered in working out neotectonic models for complex orogens.

2. GEOLOGICAL AND MORPHOLOGICAL SETTING

From the geo-morphological point of view the Abruzzi Apennines is characterized by NW-SE mountain ridges carved in the Meso-Cenozoic carbonatic sequence, adjacent to valley bottoms excavated in Miocene clayey-arenaceous flysch (Fig. 1). Extensional deformations account for the vertical movements noticeable along the NW-SE faults with throws of up to hundreds of metres (Accordi, 1966). The superimposition of an extensional event over compressional ones represents the general model based on the available data (Accordi, 1966; Castellarin *et al.*, 1978; C.N.R.-P.F.G., 1987), and is also demonstrated in works focusing on structural issues (Salvini & Vittori, 1982; Cavinato *et al.*, 1986).

The structural continuity of single carbonatic ridges is often interrupted by major transversal structural elements or by some depressions of large (*e.g.* Piana del Fucino, the Sulmona basin) and small (*e.g.* Piano di Pezza, the Pescasseroli basin) dimensions.

In terms of geodynamic evolution, the building of the Abruzzi Apennines, and of the whole of the Apennines, seems to be strongly influenced by the opening of the Thyrrenian basin, W of the mountain chain (Locardi, 1982 and 1988; Patacca & Scandone, 1987).

The Abruzzi Apennines, as shown in the Neotectonic Map of Italy (C.N.R.-P.F.G., 1987) is a tectonically active region, characterized in particular by "nearly continuous Pliocene and Quaternary uplifts with tectonic troughs developing during the Pliocene and Quaternary or during the Quaternary only". Several papers consider the problem of recent tectonics of the Abruzzi Apennines, from different points of view and sometimes reach different conclusions (for example: Bosi & Bertini, 1970; Demangeot, 1973; Bosi, 1975; Bertini & Bosi, 1976; Blumetti *et al.*, 1986; Bertini *et al.*, 1986; C.N.R.-E.N.E.A., 1989; Bosi & Messina, 1990; Galadini & Messina, 1990).

Moreover this region is seismically active (C.N.R.-P.F.G., 1985), being characterized also by strong earthquakes, as the 1915 Avezzano earthquake (Basili & Valensise, 1986; Serva, 1989; Ward & Valensise, 1989). This seismic activity is further confirmed by paleoseismological data that are available for some areas of the Abruzzi Apennines (Giraudi, 1988; 1989a; 1989b; 1989c), and which are evidence of major seismic events responsible for surface faulting.

3. EXAMPLES OF RECENT TECTONIC EVOLUTION

3.1 The Upper Sangro River Valley

In the Geological Map of the Abruzzi National Park (Bigi *et al.*,1986) some sectors of the southwest flank of the Upper Sangro Valley are represented, from a structural viewpoint, as an overthrust of carbonatic units over the clayey-arenaceous Miocene flysch. At the foot of the northeast flank, the map shows a normal fault which virtually borders most of the Upper Sangro Valley and is responsible for the contact between the Mesozoic carbonatic sequence and the Miocene flysch.

Continental deposits have been observed in the upper sector of the valley, which are mainly poorly-to-strongly cemented calcareous conglomerates, with subhorizontal bedding ("Pescasseroli Formation" in Figs. 2, 3 and 4), outcropping extensively in the La Mandrella and Colli Alti areas ("A" and "B" in Fig. 1). At higher elevations, the conglomerates grade into calcareous breccias, with a dip-slope attitude. These deposits are attributed to the Middle-Pleistocene. A boulder deposit ("Campo Rotondo Formation" in Figs. 3 and 4, attributed by Galadini & Messina (1990) to a series of ancient landslides, outcrops in the Campo Rotondo area ("C" in

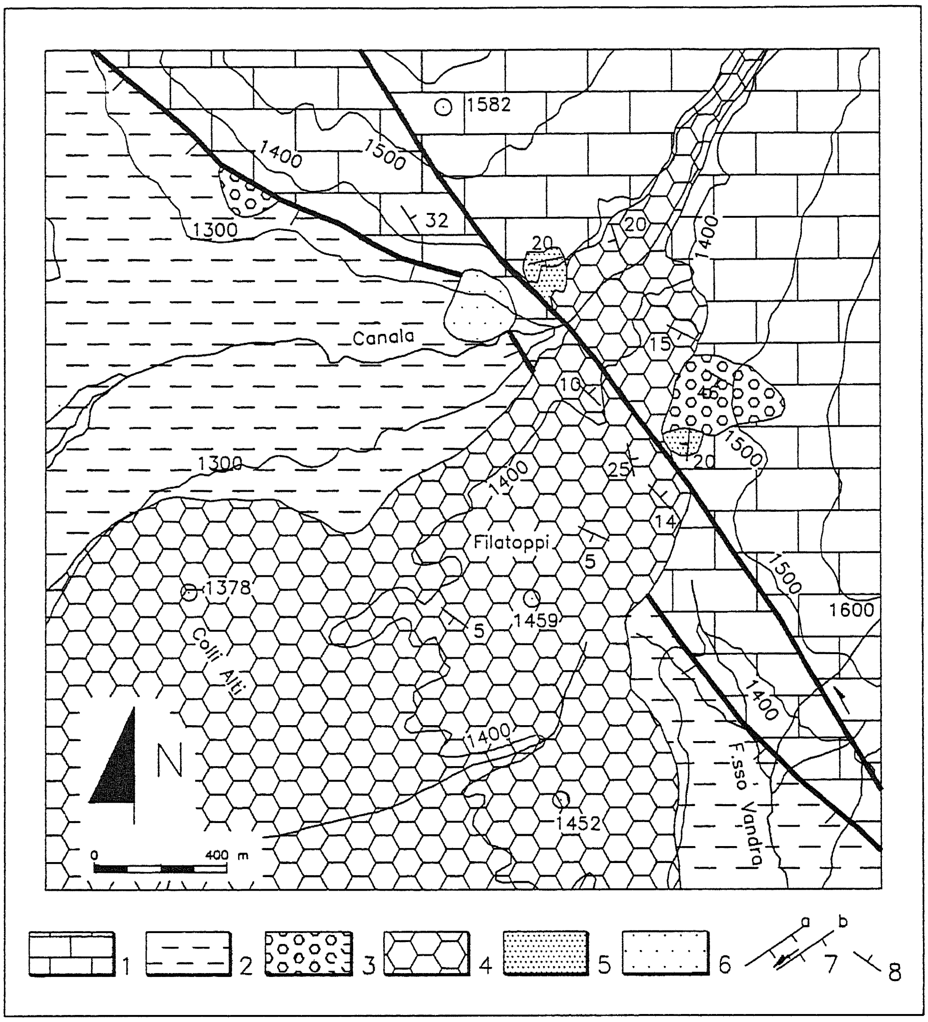

Fig. 2 - Schematic geological map of the Colli Alti area (A in Fig. 1). Legend: 1) calcareous rocks of the Mesozoic carbonatic sequence; 2) Miocene clayey-arenaceous flysch; 3) calcareous breccias; 4) conglomerates of the "Pescasseroli Formation"; 5) calcareous breccias; 6) non cemented talus debris; 7) faults (a, normal; b, left-lateral transcurrent); 8) layers attitude.

Carta geologica schematica dell'area dei Colli Alti (A in Fig. 1). Legenda: 1) calcari della successione carbonatica mesozoica; 2) flysch argilloso-arenaceo miocenico; 3) brecce calcaree; 4) conglomerati della "Formazione di Pescasseroli"; 5) brecce calcaree; 6) detrito di falda non cementato; 7) faglie (a, normali; b, trascorrenti sinistre); 8) giacitura degli strati.

Fig. 1). This deposit underlies the conglomerates.

The geological maps of the Colli Alti, La Mandrella and Campo Rotondo areas (Figs. 2, 3 and 4), show that the continental deposits have been displaced by a number of NW-SE faults. Two faults are visible in the Colli Alti area (Fig. 2). The southwesternmost fault is certainly the older one, and it puts the carbonatic sequence into contact with the flysch. This fault, as already shown in the Geological Map of the Abruzzi National Park (Bigi *et al.*, 1986), has not displaced the Quaternary continental deposits. But these deposits have been displaced by the other fault which is nearly parallel to the older one. The younger fault displays a left-lateral strike-slip behaviour with a horizontal component of the movement of over a hundred metres and an almost negligible vertical component.

The two faults meet at a point lying immediately to the NW of the area represented in the geological map (Fig. 2). Here, erosional processes have exposed fault planes and their kinematic indicators (Fig. 5). On the older master fault the striae are mainly of the dip-slip type, whereas on that responsible for more recent displacements the kinematic indicators are essentially left-lateral. Strike-slip striae are found also on the fault plane bordering the valley to the SE of the area represented in the geological map of Fig. 2.

In the La Mandrella area (Fig. 3) the conglomerates of the "Pescasseroli Formation" and the underlying boulder deposit of the "Campo Rotondo Formation" are faulted too. Also in this case the left-lateral transcurrent displacement is clear, and the vertical component is insignificant. In fact the planar base of the Quaternary deposits on the carbonatic bedrock remains at the same elevation across the fault.

In the Campo Rotondo area a survey of the boulder deposit has shown that it has been displaced by at least

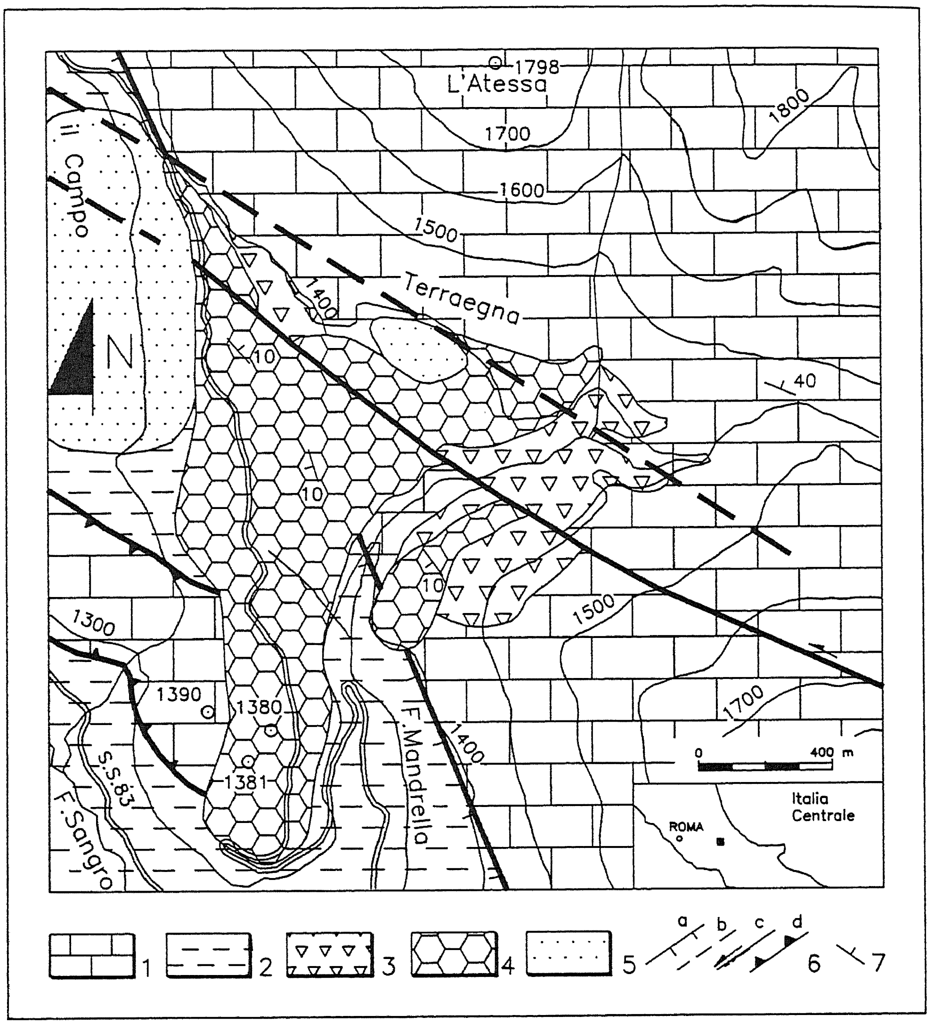

Fig. 3 - Schematic geological map of the La Mandrella area (B in Fig. 1). Legend: 1) calcareous rocks of the Mesozoic carbonatic sequence; 2) Miocene clayey-arenaceous flysch; 3) boulders of the "Campo Rotondo Formation"; 4) conglomerates of the "Pescasseroli Formation"; 5) colluvial-alluvial deposits; 6) faults (a, normal; b, presumed; c, left-lateral transcurrent; d, thrust); 7) layers attitude.

Carta geologica schematica dell'area de La Mandrella (B in Fig. 1). Legenda: 1) calcari della successione carbonatica mesozoica; 2) flysch argilloso-arenaceo miocenico; 3) blocchi calcarei della "Formazione di Campo Rotondo"; 4) conglomerati della "Formazione di Pescasseroli"; 5) depositi colluvio-alluviali; 6) faglie (a, normali; b, ipotizzate; c, trascorrenti sinistre; d, inverse); 7) giacitura degli strati.

two faults (F1 and F2 in Fig. 4). The left-lateral component, which is more than twice the vertical one, can be clearly identified for one of them (the northeasternmost one). For the other fault (the southwesternmost one) the kinematics is more difficult to infer because of the erosion of the boulder deposit in the Mancina Valley.

The observations discussed above suggest a succession of deformational events that are more complex than those generally considered for this region. Indeed, after compressional and extensional deformations, a recent left-lateral strike-slip deformation is recorded in the Upper Sangro Valley. This deformation may have characterized the area at least since the Middle Pleistocene. In fact the conglomerates of Middle Pleistocene age appear to have been displaced by essentially left-lateral transcurrent faults (except for the Colli Alti-Colli Bassi fault, discussed in the following). The existence of a previous extensional tectonic activity is not sufficient to set the time at which the strike-slip deformations began, because there is no evidence showing that extensional tectonics in the Upper Sangro Valley occurred also during the Quaternary.

The only exception to the transcurrent deformational regime is offered by the fault that separates the two areas of Colli Alti and Colli Bassi (Colacicchi, 1967), immediately to the SW of the area represented in the geological map in Fig. 2. This is a normal fault which displaced the erosional surface superimposed on the conglomerates by about 80 metres. This fault represents the terminal portion of a structure originating from the Vallelonga area (Fig. 1), for which a structural survey is currently being carried out. The kinematics of this fault needs to be evaluated within the kinematic framework of the Vallelonga structures (Fig. 1).

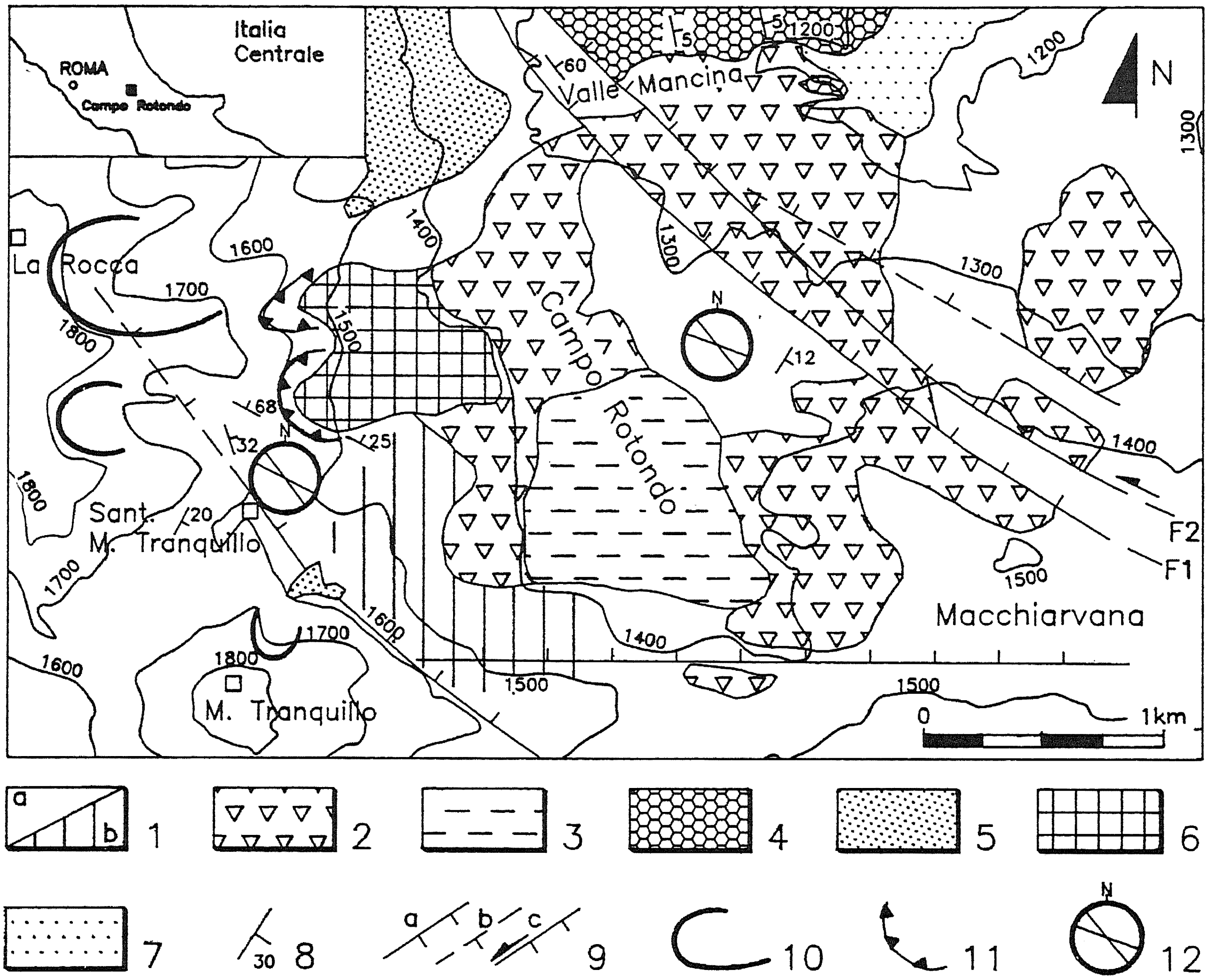

Fig. 4 - Schematic geological map of the Campo Rotondo area (C in Fig. 1). Legend: 1a) calcareous rocks of the Mesozoic carbonatic sequence; 1b) calcareous bedrock with evidence of gravitational deformations; 2) boulders of the "Campo Rotondo formation"; 3) probably pre-Würmian glacial deposits; 4) conglomerates of the "Pescasseroli formation"; 5) Würmian glacial deposits; 6) present landslide deposits; 7) alluvial deposits; 8) layers attitude; 9) faults (a, normal; b, presumed; c, left-lateral transcurrent); 10) glacial cirques; 11) landslide scarp; 12) pattern of the main sets of fracture.

Carta geologica schematica dell'area di Campo Rotondo (C in Fig. 1). Legenda: 1a) calcari della successione carbonatica mesozoica; 1b) substrato calcareo con evidenze di deformazioni gravitative; 2) blocchi calcarei della "Formazione di Campo Rotondo"; 3) probabili depositi glaciali pre-würmiani; 4) conglomerati della "Formazione di Pescasseroli"; 5) depositi glaciali würmiani; 6) depositi di frana attuali; 7) depositi alluvionali; 8) giacitura degli strati; 9) faglie (a, normali; b, ipotizzate; c, trascorrenti sinistre); 10) circhi glaciali; 11) nicchie di frana; 12) pattern *dei principali* set *di fratture.*

3.2 Barisciano-Calascio Area

In the area between the little towns of Barisciano and Calascio, South of the Gran Sasso chain, a large amount of structural data were required to define the Quaternary deformational sequence. This area is characterized by systems of closed elongated depressions trending generally NW-SE, bordered by prevalently normal and oblique-slip faults (Fig. 6). Galadini & Salvi (1990), in a study conducted on a Landsat image of the area, observed that the depression systems have an arcuated, sometimes sigmoidal shape. The area where this unusual pattern is observed is bounded by two NE-SW lineaments which partially correspond to mapped faults. Extensive outcrops of Pleistocene calcareous breccias with a pinkish matrix can be found on the slopes of the small depressions, especially the south-west facing slopes.

At times, the observed faults (Fig. 7) displaced the breccias, and often the fault planes outcrop in the Mesozoic carbonatic sequence, creating fault scarps. The faults clearly have irregular trends, sigmoidal in some cases and are not very long (1÷2 km); sometimes they are arranged according to an en-echelon pattern. Structural analysis of these faults was based on measurements on more than 900 fault planes at the mesoscopic scale and of their kinematic indicators. The Schmidt diagrams and the histogram reported as an example in Fig. 8 and in Fig. 9, relative to data from the

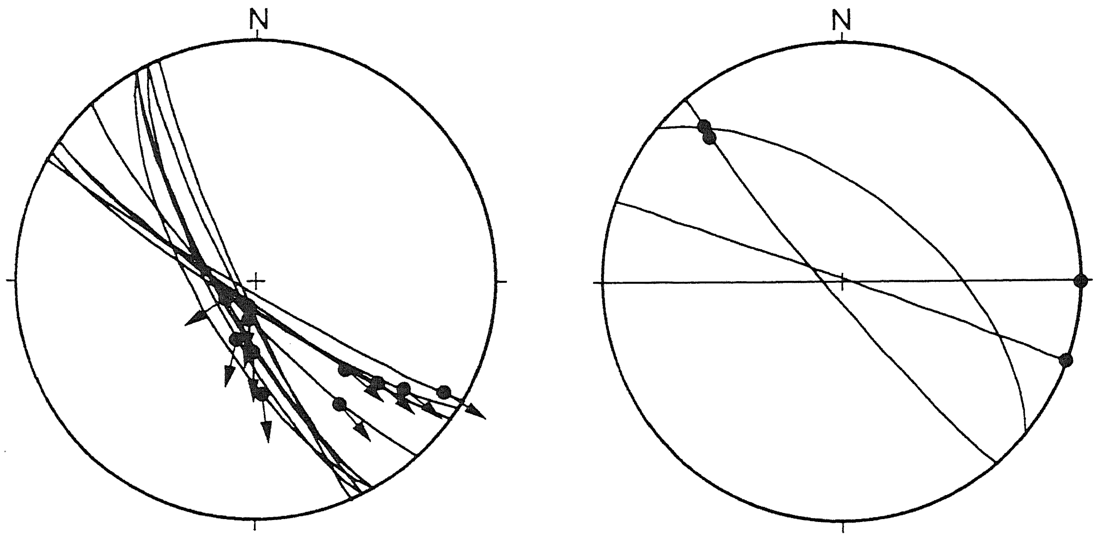

Fig. 5 - Schmidt diagrams (lower hemisphere projection) relative to fault planes and kinematic indicators sampled on the lefthand slope of the Upper Sangro River Valley. The diagram on the left refers to the intersection zone of the structures of Fig. 2, in the northwestern area of the geological map. The diagram on the right refers to the same structure bordering the Sangro valley in an area lying to the SE of the area included in the geological map in Fig. 2.

Diagrammi di Schmidt (proiezione emisfero inferiore) relativi a piani di faglia e indicatori cinematici campionati sul versante sinistro dell'alta valle del F. Sangro. Il diagramma a sinistra si riferisce al punto di intersezione delle strutture riportate in Fig. 2, nell'area a NW della carta geologica. Il diagramma a destra si riferisce ad un'area a SE di quella compresa nella carta geologica di Fig. 2, sempre in corrispondenza della struttura bordiera della valle del F. Sangro.

Mesozoic carbonatic sequence of the central and south-eastern sectors of the Barisciano-Calascio area, show a polyphased deformation, evidenced by dip-slip, oblique-slip and strike-slip kinematic indicators. Wherever the sequence of the kinematic events could be resolved on the mesoscopic fault planes, the horizontal movements occurred after the normal ones.

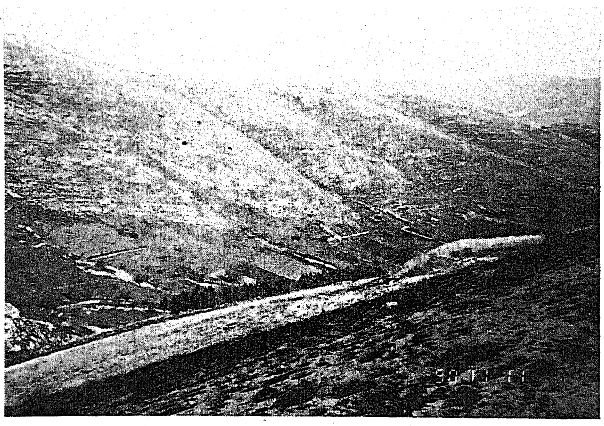

Fig. 6 - View of the northern flank and part of the bottom of the il Tagno depression, in the eastern sector of the Barisciano-Calascio area.

Panoramica del versante settentrionale e del fondo della depressione de il Tagno, nel settore orientale dell'area compresa tra i paesi di Barisciano e Calascio.

Strike-slip movements have been observed offsetting Pleistocene continental deposits along a N-S fault in the breccias of Valle Valiano (NW sector of the Barisciano-Calascio area). On the northern slope of the Carapelle basin (to the SE of the area under investigation), a NW-SE transcurrent fault caused a horizontal displacement of the boundary between two generations of breccias. The anomalous trend of the boundary across the fault is not referable to depositional factors. Moreover, on the fault plane, strike-slip striae can be directly observed on the breccias. In the Calascio area a red colluvium overlying Pleistocene breccia was displaced by a WNW-ESE transcurrent fault. On the colluvium the striae are not preserved, but we can infer the strike-slip kinematics from stratigraphic considerations on the colluvium and on the other continental deposits observable across the fault.

On the basis of all the data discussed above also in the case of the Barisciano-Calascio area it seems quite likely that deformations with exclusively vertical movements, which caused the nucleation and deepening of the depressions, were followed by a deformation using the pre-existing structures and consisting mainly of strike-slip movements. A possible explanation for the data presented above could be that left-lateral strike-slip movements along NE-SW deep-seated faults induce right-lateral strike-slip movements on the NW-SE and E-W faults in the overburden (Anàdon *et al.*, 1985; Mandl, 1988). In this context the faults bordering the mentioned depressions have had, first of all, an important normal and oblique behaviour and then a short, recent history of strike-slip movements. From a structural point of view, strike-slip movements are not so evident on the faults that border the depressions (Galadini & Giuliani, in preparation). These movements are connected to the intense faulting internal to the ridges that separates the depressions, suggesting a semi-brittle kind of general

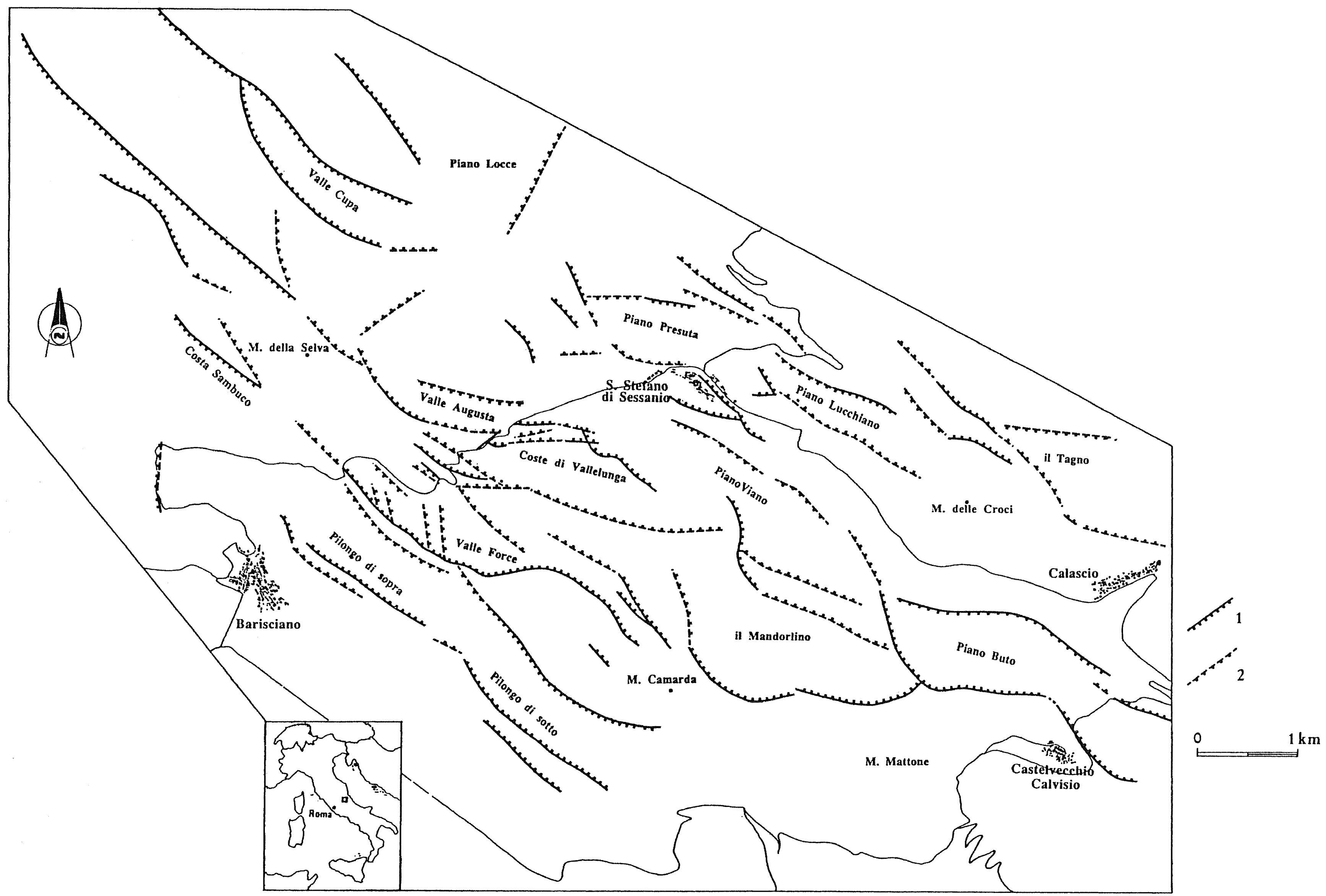

Fig. 7 - Scheme of the faults in the Barisciano-Calascio area. Legend: 1) normal and oblique faults; 2) presumed faults (see text for further explanations about the kinematics of the faults).

Schema delle faglie dell'area Barisciano-Calascio. Legenda: 1) faglie normali ed oblique; 2) faglie ipotizzate (ulteriori spiegazioni circa la cinematica delle faglie sono riportate nel testo).

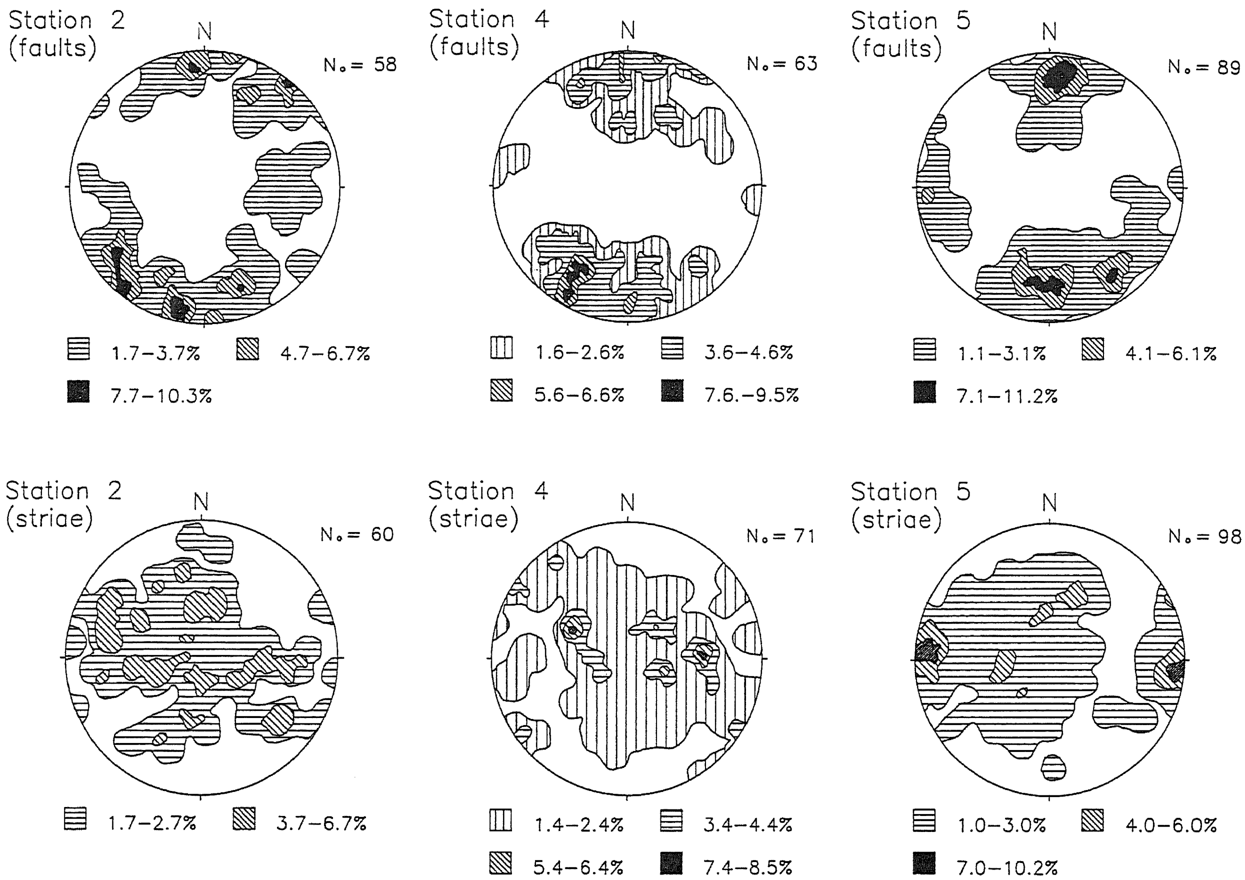

Fig. 8 - Contouring of the fault plane poles and striae in Schmidt diagrams (lower hemisphere projection). The data refer to some of the stations for the measurement of structural elements in the Barisciano-Calascio area, in the Mesozoic carbonatic sequence.

Contouring *dei poli dei piani di faglia e relative strie su diagrammi di Schmidt (proiezione emisfero inferiore). I dati si riferiscono ad alcune delle stazioni di misura di elementi strutturali dell'area Barisciano-Calascio, effettuate in corrispondenza di affioramenti della successione carbonatica mesozoica.*

deformation.

The time at which the deformational regime changed can be approximately inferred and probably did not precede the Lower Pleistocene. Indeed extensional deformation has been interpreted to be at the origin of small ridges in breccias attributed to the Lower Pleistocene by Bosi & Bertini (1970) and strike-slip deformations are successive to the building of these breccia ridges.

3.3 Other evidence of transcurrent movements

Giraudi (1989a) observed that near Ovindoli (Fig. 1) an important NNW-SSE fault was responsible for the displacement of a moraine of the last Würmian pleniglacial with a vertical component of about 17 m and a horizontal left-lateral one of 65÷70 m and also for the displacement of a small gully in an adjacent fluvio-glacial fan with a vertical component of 7÷8 m and a horizontal left-lateral one of 12÷15 m. The left-lateral transcurrent component is about twice the vertical one.

In the Tagliacozzo area, W of the Fucino basin (Fig. 1), on the basis of structural data, left-lateral strike-slip deformations are believed to have preceded the extensional deformation (Montone & Salvini, 1989).

Corrado *et al.* (1990) emphasize the likely impor-

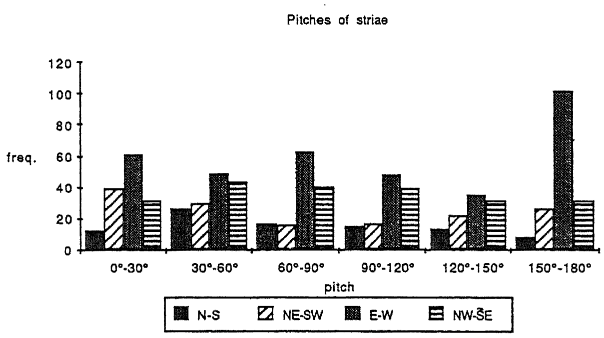

Fig. 9 - Frequency histogram of the pitch values of the striae, referring to the various direction fields of the faults. The histogram refers to all of the data sampled in the Mesozoic carbonatic sequence of the Barisciano-Calascio area.

Istogramma di frequenza relativo ai valori di pitches delle strie, in riferimento ai vari campi di direzione di faglie. L'istogramma si riferisce al totale dei dati campionati nella successione carbonatica mesozoica dell'area Barisciano-Calascio.

tance of strike-slip movements along NW-SE faults in the genesis of back-thrust systems in the Upper Sangro River Valley and in the adjacent Giovenco River Valley. Also in this case the strike-slip movements may have preceded the extensional tectonics.

Recent strike-slip deformations are reported by Serafini & Vittori (1986) in a structural paper on the Sora area (southern sector of Fig. 1). These Authors discuss the presence of strike-slip striae on an important fault responsible for the displacement of Quaternary continental deposits.

Patacca *et al.* (1990) observe that the Ortona-Roccamonfina line, an important tectonic lineament with a general N-S trend, bordering the Abruzzi Apennines to the SE, may have acted as a right-lateral transcurrent fault during the Pleistocene as an effect of the separation between the northern and southern Apenninic arcs. These observations are supported to some extent by the data presented by Naso *et al.* (1989) referring to a sector adjacent to the mentioned tectonic lineament.

4. DISCUSSION

Four points emerge from the foregoing data:

1) role of strike-slip deformations;
2) their possible relationship with the activity of main structures;
3) their relationship with the genesis of intra-mountain basins;
4) their relationship with seismic activity.

As regards the first point, it is necessary to understand whether the strike-slip deformations discussed above are of regional or only local importance. Ultimately, the role of transcurrent faults in recent and active geodynamics needs to be defined. Even though more data are clearly needed, some arguments can be developed now. While for the area between Barisciano and Calascio the recent structural and kinematic conditions in the neighbouring areas are unknown and hence general considerations cannot be made, these considerations can be made for the Sangro Valley and the Ovindoli area. The presence of strike-slip deformations before the extensional ones (Montone & Salvini, 1989; Corrado *et al.*, 1990) and also the evidence discussed above of recent strike-slip movements in the Sangro Valley and in the Ovindoli area may only justify the formulation of two hypotheses: a. alternation of at least two strike-slip deformational events (one of which Quaternary in age) with at least one important extensional deformational event between them; b. co-existence, during the Quaternary, of normal and strike-slip deformations along the NW-SE faults.

The second point of the discussion refers to the relationship between the cited right-lateral strike-slip movements along the important Ortona-Roccamonfina line (Ghisetti & Vezzani, 1988; Patacca *et al.*,1990) and the left-lateral deformations along the adjacent Sangro Valley. Such deformations could be related to differential movements of the northern Apenninic arc with respect to the southern Apennines (Patacca *et al.*, 1990). In this context a structural relationship of the type shown in Fig. 10 could be hypothesized, where the NW-SE faults are represented as being antithetic to the Ortona-Roccamonfina line. In this model the Upper Sangro Valley has a left-lateral transcurrent behaviour produced by the rotation of this Apenninic sector at the Ortona-Roccamonfina line. A model which envisages relationships between an important right-lateral transcurrent fault and antithetic left-lateral transcurrent faults (with different trends of the faults from those presented in Fig. 10) is proposed also by Mattei and Miccadei (1989) for the area of Mt. Greco, to the E of the sector of the Sangro Valley discussed in the present paper.

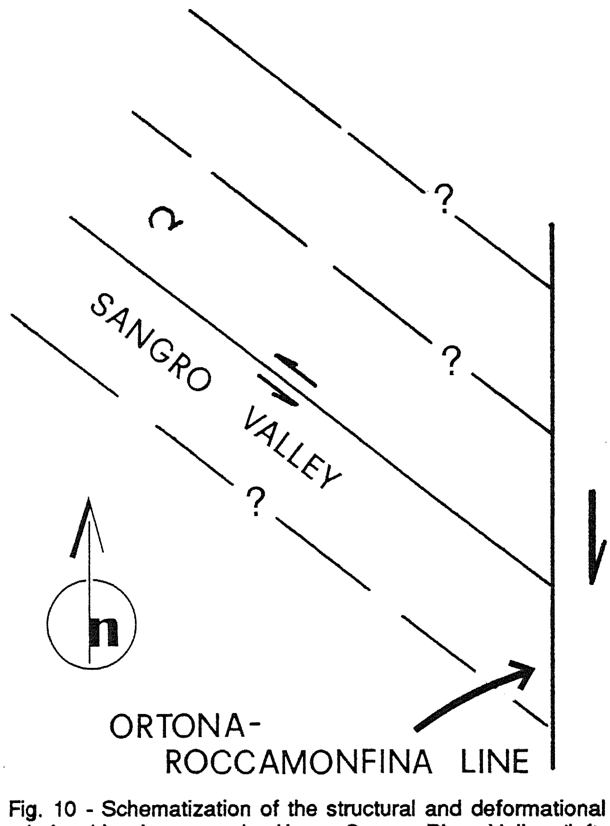

Fig. 10 - Schematization of the structural and deformational relationships between the Upper Sangro River Valley (left-lateral transcurrent movements) and the Ortona-Roccamonfina line (right-lateral transcurrent movements).

Schematizzazione delle relazioni strutturali e deformative esistenti tra l'alta valle del F. Sangro, caratterizzata da movimenti trascorrenti sinistri, e la linea Ortona-Roccamonfina, caratterizzata da movimenti trascorrenti destri.

The Fucino Plain is the greatest rhomb-shaped basin of the Abruzzi Apennines. As said earlier, strike-slip deformations have been observed immediately to the N and S of this plain (Sangro Valley and Ovindoli

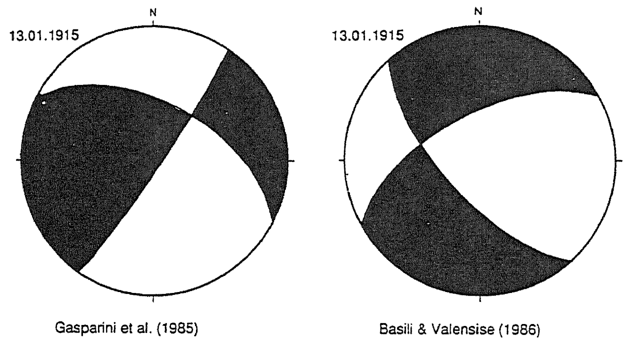

Fig. 11 - Focal mechanisms (lower hemisphere projection) of the 13.01.1915 Avezzano earthquake, after Gasparini *et al.* (1985) and Basili & Valensise (1986).

Meccanismi focali (proiezione emisfero inferiore) del terremoto di Avezzano del 13.01.1915, secondo Gasparini et al. *(1985) e Basili & Valensise (1986).*

area). It is obvious that if the strike-slip deformation began in recent times, the origin of a large basin like the Fucino Plain cannot be related only to transtensional tectonic activity. But this would be possible, if strike-slip movements had occurred also in pre-Quaternary times along the NW-SE faults, as pointed out by Montone & Salvini (1989) and by Corrado *et al.* (1990). On the basis of the state-of-the-art, the only hypothesis that can be made is that the tectonic evolution of the Fucino Plain is probably conditioned by both the pure extensional regime and the transtensional one, but the extent of each is difficult to infer. This kind of evolution is responsible for the complex structural pattern of the basin (C.N.R.-E.N.E.A., 1989).

Strike-slip movements may have contributed to the origin of smaller intra-mountain basins (Piano di Pezza and Campo Felice depressions, Pescasseroli basin). These basins are usually located in the proximity of pre-existing structures having a transverse trend with respect to the general trend of the Apenninic chain. For these reasons, their shapes, principally their dimensions, depart from the classical neoformed basin structures and morphologies related to transcurrent activity (Aydin & Nur, 1982; Mann *et al.* 1983; Sylvester, 1988).

With regard to the seismotectonic setting of the region, another problem is represented by the relationship between Quaternary deformations observed at the surface and seismic activity. Three major instrumental earthquakes occurred in the Abruzzi Apennines. They involved areas adjacent to the Sangro Valley: the 1915 Avezzano (Fucino Plain) earthquake (Ms = 6.9, Basili &

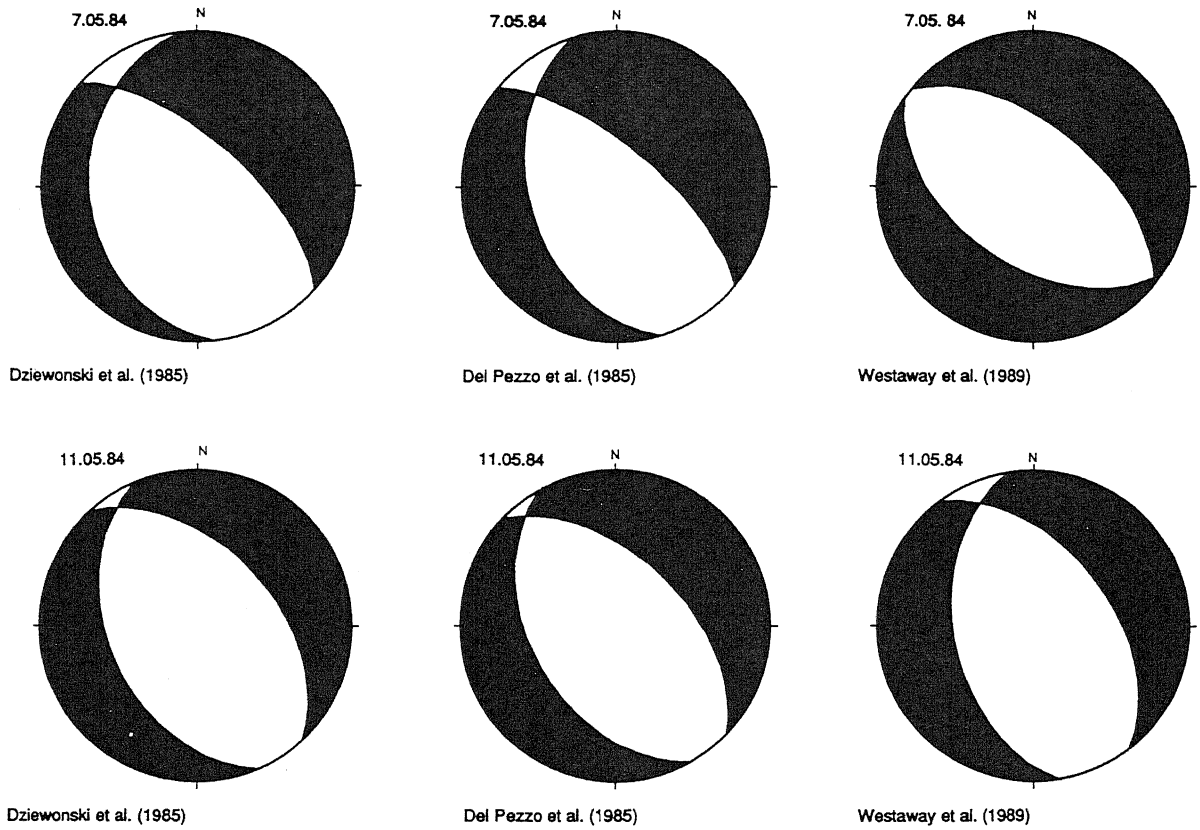

Fig. 12 - Focal mechanisms (lower hemisphere projection) of the S. Donato Val di Comino earthquakes of 7.05.1984 and 11.05.1984, after Dziewonski *et al.* (1985), Del Pezzo *et al.* (1985) and Westaway *et al.* (1989).

Meccanismi focali (proiezione emisfero inferiore) dei terremoti di S. Donato val di Comino del 7.05.1984 e del 11.05.1984, secondo Dziewonski et al. *(1985), Del Pezzo* et al. *(1985), Westaway* et al. *(1989).*

Valensise, 1986) and the 1984 S. Donato Val di Comino earthquakes (Ms = 5.8 and 5.2, Westaway *et al.*, 1989).

Different focal mechanisms have been obtained for the 1915 earthquake by different workers (*e.g.* Gasparini *et al.*, 1985; Basili & Valensise, 1986), probably because of the difficulties in obtaining reliable focal mechanisms from very old seismological data (Fig. 11). Instead the 1984 earthquakes are better defined. They show normal faulting along the NW-SE faults (Westaway *et al.*, 1989; Del Pezzo *et al.*, 1985; Dziewonski *et al.*, 1985, Fig. 12). The epicentres of the earthquakes are located to the south of the Sangro Valley, but Westaway *et al.* (1989) correlate the focus zone with the M. Greco fault (Fig. 1), which is considered, on such seismological basis, a recent normal fault. This correlation and the data about recent strike-slip kinematics of Upper Sangro Valley discussed in this paper seem to create further interpretational problems because of the complex relationship between surface-related and deeper data.

5. CONCLUSIONS

Recent studies aimed at defining the neotectonic setting of some areas of the Abruzzi Apennines, show the existence of strike-slip deformations subsequent to the deformations related to the extensional tectonics. The observation of recent transcurrent faults with NW-SE trends raises a number of questions related to the current style of extensional tectonics which is the last deformational event generally recognized in this sector of the Apennines. First of all the data relative to the left-lateral Quaternary deformations need to be placed in a regional framework characterized by extensional tectonics. Another important problem would be that of comparing these data with the few available seismological data.

In terms of recent kinematics the conclusion that emerges from the available data is the necessity of a model that takes into consideration a probable alternation of extensional and strike-slip deformations or the co-existence of normal and strike-slip movements in correspondence to the NW-SE faults of the Abruzzi Apennines.

The data discussed in this paper demonstrate the difficulties that are encountered in complex orogens in attempting to define the recent kinematics, in passing from regional observations to local observations. On the other hand, identifying the mentioned strike-slip events makes it possible to define the path to be followed in future investigations and to identify the significant areas on which research should focus its attention to gain full understanding of the recent tectonics of the Abruzzi Apennines. Only by means of extremely detailed research work will it be possible to answer the questions that have arisen from the data presently available, and ultimately to work out a reliable neotectonic model. To this aim multi-disciplinary approaches appear to be important, beyond structural, stratigraphic and geomorphological studies, the Authors hope in the future availability of the work of other researchers, in the fields of palmeomagnetism, reflection seismic, stress in situ measurements and seismology.

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REFERENCES

Accordi B. (1966) - *La componente traslativa nella tettonica dell'Appennino laziale-abruzzese.* Geol. Rom., **5**, 355-406.

Anadòn P., Cabrera L., Guimerà J. & Santanach P. (1985) - *Paleogene strike-slip deformation and sedimentation along the southeastern margin of the Ebro basin.* In: K.T. Biddle & N. Christie-Blick (eds.), *Strike-slip deformation, basin formation, and sedimentation.* Soc. of Econ. Pal. and Min., spec. publ., **37**, 303-318.

Aydin A. & Nur A. (1982) - *Evolution of pull-apart basins and their scale independence.* Tectonics, **1**(1), 91-105.

Basili A. & Valensise G. (1986) - *Contributo alla caratterizzazione della sismicità dell'area marsicano-fucense.* In: E. Boschi & M. Dragoni (eds.), *Aree sismogenetiche e rischio sismico in Italia*, **II**, 197-214.

Bertini T. & Bosi C. (1976) - *Sedimenti continentali probabilmente pliocenici nella valle del Salto e nella conca del Fucino (Rieti-L'Aquila).* Boll. Soc. Geol. It., **95**(4), 767-801.

Bertini T., Bosi C., Messina P. & Sposato A. (1986) - *Elementi di tettonica compressiva pliocenica nella zona di Borgo S. Pietro (Rieti).* Mem. Soc. Geol. It., **35**, 547-553.

Bigi G., Colacicchi R., Damiani A.V., D'Andrea M., Pannuzi L., Parotto M., Praturlon A. & Sirna G. (1986) - *Carta Geologica.* Ente Autonomo Parco Nazionale d'Abruzzo, Roma.

Blumetti A., Cavinato G.P., Michetti A.M., Tozzi M. & Vittori E. (1986) - *Campo di fratturazione superficiale e tettonica recente nel bacino del Fucino (L'Aquila).* In: E. Boschi & M. Dragoni (eds.), *Aree sismogenetiche e rischio sismico in Italia*, **II**, 259-268.

Bosi C. (1975) - *Osservazioni preliminari su faglie probabilmente attive nell'Appennino centrale.* Boll.

Soc. Geol. It., **94**, 827-859.

Bosi C. & Bertini T. (1970) - *La geologia della media valle dell'Aterno.* Mem. Soc. Geol. It., **9**, 719-777.

Bosi C. & Messina P. (1990) - *Elementi di stratigrafia neogenico-quaternaria tra il Fucino e la valle del Giovenco (L'Aquila).* Mem. Descr. Carta Geol. d'It., **38**, 85-96.

Castellarin A., Colacicchi R. & Praturlon A. (1978) - *Fasi distensive, trascorrenze e sovrascorrimenti lungo la "linea Ancona-Anzio", dal Lias medio al Pliocene.* Geol. Rom., **17**, 161-189.

Cavinato G.P., Salvini F. & Tozzi M. (1986) - *Evoluzione strutturale del settore centrale della linea Olevano-Antrodoco.* Mem. Soc. Geol. It., **35**, 591-601.

C.N.R.-E.N.E.A. (1989) - *Guida all'escursione "Elementi di tettonica pliocenico-quaternaria ed indizi di sismicità olocenica nell'Appennino laziale-abruzzese".* Soc. Geol. It., 31 maggio-2 giugno 1989, 127 pp.

C.N.R.-P.F.G. (1985) - *Catalogo dei terremoti italiani dall'anno 1000 al 1980.* La Ric. Sc., Quad., **114**(2B).

C.N.R. - P.F.G. (1987) - *Neotectonic Map of Italy.* La Ric. Sc., Quad., **114**(4).

Colacicchi R. (1967) - *Geologia della Marsica orientale.* Geol. Rom., **6**, 189-316.

Corrado S., Cosentino D. & Gioia C. (1990) - *Sistema di retroscorrimenti nella Marsica orientale (Abruzzo, Appennino centrale).* Soc. Geol. It. 75° Congr. Naz., *La geologia italiana degli anni '90,* posters abstracts, 59-60.

Del Pezzo E., De Natale G., Iannaccone G., Martini M., Scarpa R. & Zollo A. (1985) - *Analisi preliminare della sequenza sismica dell'Abruzzo mediante i dati di una rete sismica digitale.* Atti 4° Congr. Gruppo Nazionale di Geofisica della Terra Solida, **I**, 79-96.

Demangeot J. (1973) - *Néotectonique et dépôts quaternaires dans l'Apennin.* In: *Moderne vedute sulla geoogia dell'Appennino,* Acc. Naz. dei Lincei, Quad., **183**, 215-240.

Dziewonski A.M., Franzen J.E. & Woodhouse J.H. (1985) - *Centroid-moment tensor solutions for April-June, 1984.* Phys. of the Earth and Plan. Int., **37**, 87-96.

Galadini F. & Messina P. (1990) - *Osservazioni su un deposito a blocchi al margine SW della conca di Pescasseroli (Italia centrale).* Il Quaternario, **3**(1), 23-30.

Galadini F. & Salvi S. (1990) - *Processamento di immagini Landsat per l'interpretazione strutturale in aree tettonicamente attive: un esempio dal margine sud-occidentale della catena del Gran Sasso.* Il Quaternario, **3**(1), 15-22.

Gasparini C., Iannaccone G. & Scarpa R. (1985) - *Fault-plane solutions and seismicity of the Italian Peninsula.* Tectonophysics, **117**, 59-78.

Ghisetti F. & Vezzani L. (1988) - *Geometric and kinematic complexities in the Marche-Abruzzi external zones (Central Apennines, Italy).* Geol. Rund., **77**(1), 63-78.

Giraudi C. (1988) - *Evoluzione geologica della Piana del Fucino (Abruzzo) negli ultimi 30.000 anni.* Il Quaternario, **1**(2), 131-159.

Giraudi C. (1989a) - *Datazione con metodi geologici delle scarpate di faglia post-glaciali di Ovindoli-Piano di Pezza (Abruzzo-Italia centrale): implicazioni.* In: *Morfogenesi e Stratigrafia dell'Olocene*, Mem. Soc. Geol. It. (in press).

Giraudi C. (1989b) - *Datazione di indizi di paleosismicità con metodi geologici nel Massiccio del Gran Sasso.* In: E. Guidoboni (ed.), *I terremoti prima dell'anno mille,* Ist. Naz. Geofisica, 43-52.

Giraudi C. (1989c) - *Datazione di un evento sismico preistorico con metodi geologici e radiometrici: piani di Aremogna e delle Cinque Miglia.* In: E. Guidoboni (ed.), *I terremoti prima dell'anno mille,* Ist. Naz. di Geofisica, 53-64.

Locardi E. (1982) - *Individuazione di strutture sismogenetiche dall'esame della evoluzione vulcano-tettonica dell'Appennino e del Tirreno.* Mem. Soc. Geol. It., **24**, 569-596.

Locardi E. (1988) - *The origin of the Apenninic arcs.* Tectonophysics, **146**, 105-123.

Mandl G. (1988) - *Mechanics of tectonic faulting. Models and basic concepts.* Elsevier, Amsterdam, 407 pp.

Mann P., Hempton M.R., Bradley D.C. & Burke K. (1983) - *Development of pull-apart basins.* J. Geol., **91**, 529-554.

Mattei M. & Miccadei E. (1989) - *Strike-slip tectonics between the Marsica range and the Molisan basin in the Sangro valley (Abruzzi, Central Italy).* Meeting on *La geologia strutturale ed i possibili contributi all'interpretazione della sismica profonda.* (abstracts), Università di Pisa, 26-27 ottobre 1989, p. 58.

Montone P. & Salvini F. (1989) - *Evidences of NW-SE Late Miocene strike-slip tectonics in Central Apennines near Tagliacozzo, Abruzzi.* Meeting on *La geologia strutturale ed i possibili contributi all'interpretazione della sismica profonda.*, (abstracts), Università di Pisa, 26-27 ottobre 1989, p. 33.

Naso G., Tallini M. & Tozzi M. (1989) - *Indizi di tettonica recente nell'area di Colli al Volturno (Molise): dati preliminari.* Rend. Soc. Geol. It., 12, 3-6.

Patacca E. & Scandone P. (1987) - *Structural evolution of the outer margin of the Apennines and related foredeep system.* In: A. Boriani, M. Bonafede, G.B. Piccardo & G.B. Vai (eds.), *The lithosphere in Italy. Advances in earth sciences research.* Acc. Naz. dei Lincei, 139-142.

Patacca E., Sartori R. & Scandone P. (1990) - *Tyrrhenian basin and apenninic arcs: kinematic relations since late Tortonian times.* Soc. Geol. It.

75° Congr. Naz., *La geologia italiana degli anni '90*, abstracts of oral communications, 102-107.
Salvini F. & Vittori E. (1982) - *Analisi strutturale della linea Olevano-Antrodoco-Posta (Ancona-Anzio Auctt.): metodologia di studio delle deformazioni fragili e presentazione del tratto meridionale.* Mem. Soc. Geol. It., **24**, 337-355.
Serafini S. & Vittori E. (1986) - *Primi risultati di uno studio statistico sulle mesostrutture della Val Roveto e dell'area di Sora (Lazio meridionale).* Mem. Soc. Geol. It., **35**, 631-646.
Serva L. (1989) - *Effetti sui suoli di terremoti antichi e recenti nella Piana del Fucino.* In: E. Guidoboni (ed.), *I terremoti prima dell'anno mille*, Ist. Naz. di Geofisica, 530-536.
Sylvester A.G. (1988) - *Strike-slip faults.* Geol. Soc. of Am. Bull., **100**, 1666-1703.
Ward S. N. & Valensise G. R. (1989) - *Fault parameters and slip distribution of the 1915 Avezzano, Italy, earthquake derived from geodetic observations.* Seism. Soc. of Am. Bull, **79**(3), 690-710.
Westaway R., Gawthorpe R. & Tozzi M. (1989) - *Seismological and field observations of the 1984 Lazio-Abruzzo earthquakes: implications for the active tectonics of Italy.* Geoph. Journ., **98**, 489-514.

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