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Characterization of the recent tectonics of the Upper Sangro River Valley (Abruzzi Apennine, Central Italy)

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Abstract
The geological surveys carried out to define the neotectonic setting of the Upper Sangro River Valley have highlighted the left-lateral transcurrent kinematics of the NW-SE faults. A series of problems arise from fitting the data relative to the Quaternary transcurrent movements of the Sangro River Valley into a regional context characterized at least apparently by recent extensional tectonics. Such problems concern: 1) the need to understand through further investigations whether transcurrent and extensional deformations can coexist on different faults which however have the same orientation, or whether it may be more appropriate to assume that transcurrent and extensional deformations have alternately occurred in time; 2) the relationship between the left-lateral transcurrent structures of the Upper Sangro River Valley and the major right-lateral transcurrent Ortona-Roccamonfina fault zone (trending N-S); 3) the relationships between the structures observed at the surface and the seismic activity.

1. Introduction

The findings that have recently been obtained with the investigations being carried out on the neotectonics of the Abruzzi Apennine are an instance of some of the difficulties that may be encountered when conducting detailed studies in areas characterized by complex successions of deformational events.

The complexity of the tectonic evolution of the Abruzzi Apennine has been highlighted by some geological papers (Accordi, 1966; Parotto and Praturlon, 1975) and more recently by structural studies (Cavinato *et al.*, 1986; Salvini and Vittori, 1982, for instance). It is generally assumed (see mentioned papers) that for this sector of the Apennines, the last deformational phase, which is moreover still active, has essentially extensional characteristics, in agreement with the general models of extensional tectonics following compressional events (*e.g.*, Royden and Burchfiel, 1987; Seguret *et al.*, 1989).

This paper discusses the data relative to the recent tectonics of the Upper Sangro River Valley which show the importance of the recent left-lateral transcurrent activity of the NW-SE faults. The discussion focuses on the problems encountered when seeking to define the meaning of Quaternary transcurrent faults within a regional structural context which appears to be conditioned by extensional movements.

2. Geological setting

The Abruzzi Apennine consists mainly of ridges built up of calcareous rocks of the Meso-Cenozoic carbonatic sequence, with a NW-SE average trend, and separated by valleys often cutting the Miocene clayey-sandy flyschoid sequence.

The building of this sector of the Apennines is a consequence of compressional tectonic events which produced major NE verging overthrusts in the carbonatic units and of the latter over the Miocene flysch. Some important studies

indicate that the movements following the compressional events were mainly extensional in nature and occurred during the Quaternary on faults having mainly vertical throws (Accordi, 1966; Parotto and Praturlon, 1975; Castellarin *et al.*, 1978; C.N.R.-P.F.G., 1987).

The Abruzzi Apennine is characterized by a high seismicity, as witnessed by the number of earthquakes which have occurred in historic times (C.N.R.-P.F.G., 1985) and by the major earthquake of this century (Gasparini *et al.*, 1985); this is also confirmed by the existing paleoseismic data (Giraudi, 1988, 1989a; 1989b; 1989c; Serva, 1989).

3. Stratigraphic setting of the Upper Sangro River Valley

The Upper Sangro River Valley is located at a few kilometres south-east of the Fucino basin; it covers some 60 km^2 between the mountains of the northern sector of the Parco Nazionale d'Abruzzo (fig. 1).

The stratigraphic sequence of the main quaternary continental deposits comprises the Campo Rotondo Formation, the Pescasseroli Formation, the Brecce di Spineta Formation and recent glacial and fluvio-glacial deposits (Galadini and Messina, in preparation).

The Campo Rotondo Formation (Lower Pleistocene), outcropping extensively in the area SW of the Pescasseroli Depression (Galadini and Messina, 1990), and subordinately in many other areas of the Sangro Valley, consists exclusively of carbonatic angular clasts, varying in size from a few centimetres to some cubic metres, with some boulders reaching sizes of 40-50 cubic metres. The outcrops are not such as to permit the identification of the bedding, if any, and/or of the possible presence of a matrix, nor can the original thickness be inferred. This latter value is even more difficult to calculate owing to the presence of some faults. At present the maximum "preserved" thickness is of the order of 60-70 m. The origin of the Campo Rotondo Formation can be referred to very large landslide events.

The Pescasseroli Formation (limit Lower-Middle Pleistocene) consists of gravels and conglomerates with generally rounded pebbles varying in size from a centimetre to several tens of centimetres.

Near the eastern flank of the Sangro Valley the roundness of the elements gradually decreases and angular or weakly bevelled elements prevail; in some cases there is a transition to slope brec-

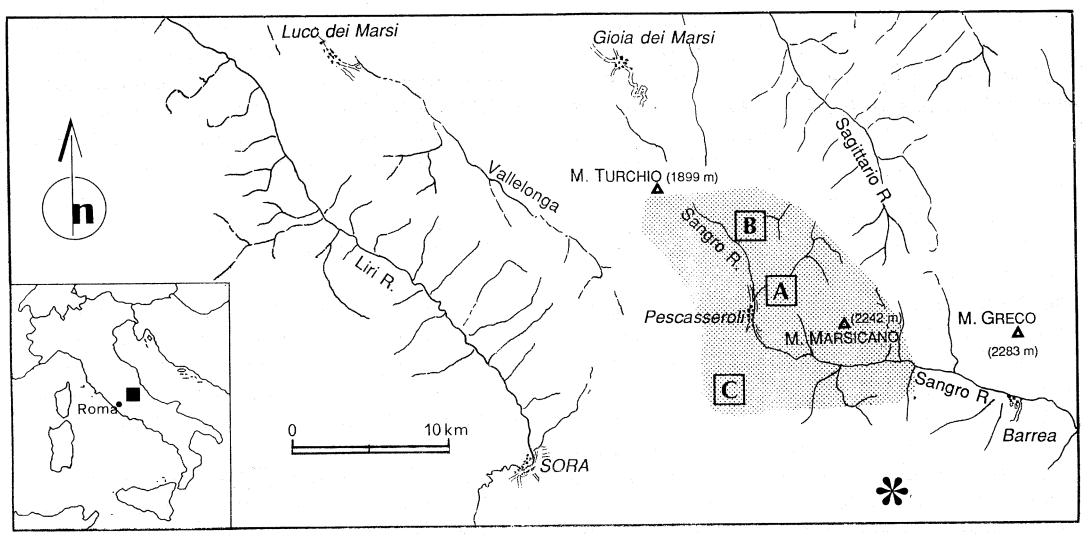

Fig. 1 Location of the investigated area (grey area). Letters A, B and C respectively point to the location of Colli Alti, La Mandrella and Campo Rotondo. The asterisk refers to the epicentral area of the 1984 earthquakes.

cias that outcrop over wide areas. The degree of cementation of the conglomerates varies widely and where they are well cemented they show a layering with a generally sub-horizontal attitude. The matrix is generally calcareous. The maximum thickness of 150 m of the formation is found near the small town of Pescasseroli. Some studies are being carried out to establish the origin of this kind of deposits in the Abruzzi Apennine.

Other bodies of breccias (Spineta Formation, Middle Pleistocene), overlying the Pescasseroli Formation with a clear angular unconformity, have small outcrops in various areas of the basin. They consist of calcareous clasts varying in size from a few millimetres to 10-20 centimetres and are generally cemented by a white or slightly salmon-red-coloured calcareous matrix. The thickness never exceeds ten metres.

Also recent glacial and outwash (Upper Pleistocene-Holocene) deposits have been observed in the investigated area; they consist of till due to the depositional activity of glaciers that had their origin in the cirques at elevations higher than 1600 m, and of gravelly-conglomeratic deposits related to the withdrawal of the glaciers; the moraines (generally lateral and/or frontal moraines) are observable at elevations of up to 1200 m in some instances.

4. Evidence of Quaternary strike-slip tectonics

All the NW-SE faults in the investigated area are characterized by a Quaternary left-lateral transcurrent kinematics. Such indications derive from the direct observation of the displacement of continental deposits (Pescasseroli and Campo Rotondo Formations) and, in one case, by the displacement of unequivocally Quaternary morphologies. Most kinematic indicators, observed in the carbonatic sequence along the fault of the eastern flank of the Sangro Valley, are evidently strike-slip, although the observed striae may also be pre-Quaternary in age.

The Lecce dei Marsi fault has already been discussed in the papers by Frezzotti and Giraudi (1986) and Giraudi (1986), and its prolongation in the SE direction in the Passo del Diavolo area, has been studied recently (Galadini *et al.*, in press). The data acquired on this important NW-SE fault point to a recent kinematics of the left-lateral transcurrent type, dating back to at least the Middle Pleistocene.

The La Mandrella fault has a NW-SE direction and is responsible for the displacement of the Pescasseroli Formation and of the Campo Rotondo Formation. In Galadini *et al.* (1991), the emphasis is placed on the left-lateral transcurrent behaviour of this fault, which can be inferred also from the geological map in fig. 2. The presence of another NW-SE fault at only a few hundreds of metres to the NE of the above-mentioned more evident fault has been hypothesized, on the basis of only morphological considerations (the displacement of a stream valley and some aligned fault scarps of doubtful origin). Moreover, this structure, even though there is no direct evidence of the displacement of Quaternary deposits, appears to be on the NW prolongation of one of the Mt. Palombo faults, reported in A.A.V.V. (1986), which displaces the Jurassic and Cretaceous limestones with a left-oblique kinematics.

The Colli Alti fault (fig.3), which also has a NW-SE trend, is responsible for the displacement of the Pescasseroli Formation with a left-lateral transcurrent kinematics (Galadini *et al.*, 1991). This fault lies just upslope the Colli Alti area, a few hundreds of metres NE of the normal fault responsible for the limestone-flysch contact on the left slope of the valley. It is difficult to understand why the activity, which occurred after the emplacement of the Pescasseroli Formation, should have involved only one of the faults and not the other since they are adjacent to and have the same direction (fig. 3). An evaluation of the reasons underlying this apparent kinematic anomaly must however take into account the fact that the left slope of the Upper Sangro River Valley is conditioned by deep-reaching slope deformations. The hypothesis of the existence of this kind of deformations could be confirmed observing some landforms typical of the deep-reaching slope movements (Zischinsky, 1969), such as frequent irregularities in the slope profile and the curvilinear planimetric trend of the limestone-flysch contact. An element which further complicates the analysis is that in the northernmost sector of the same slope and along its northward structural prolongation forming the northern flank of the Giovenco River Valley,

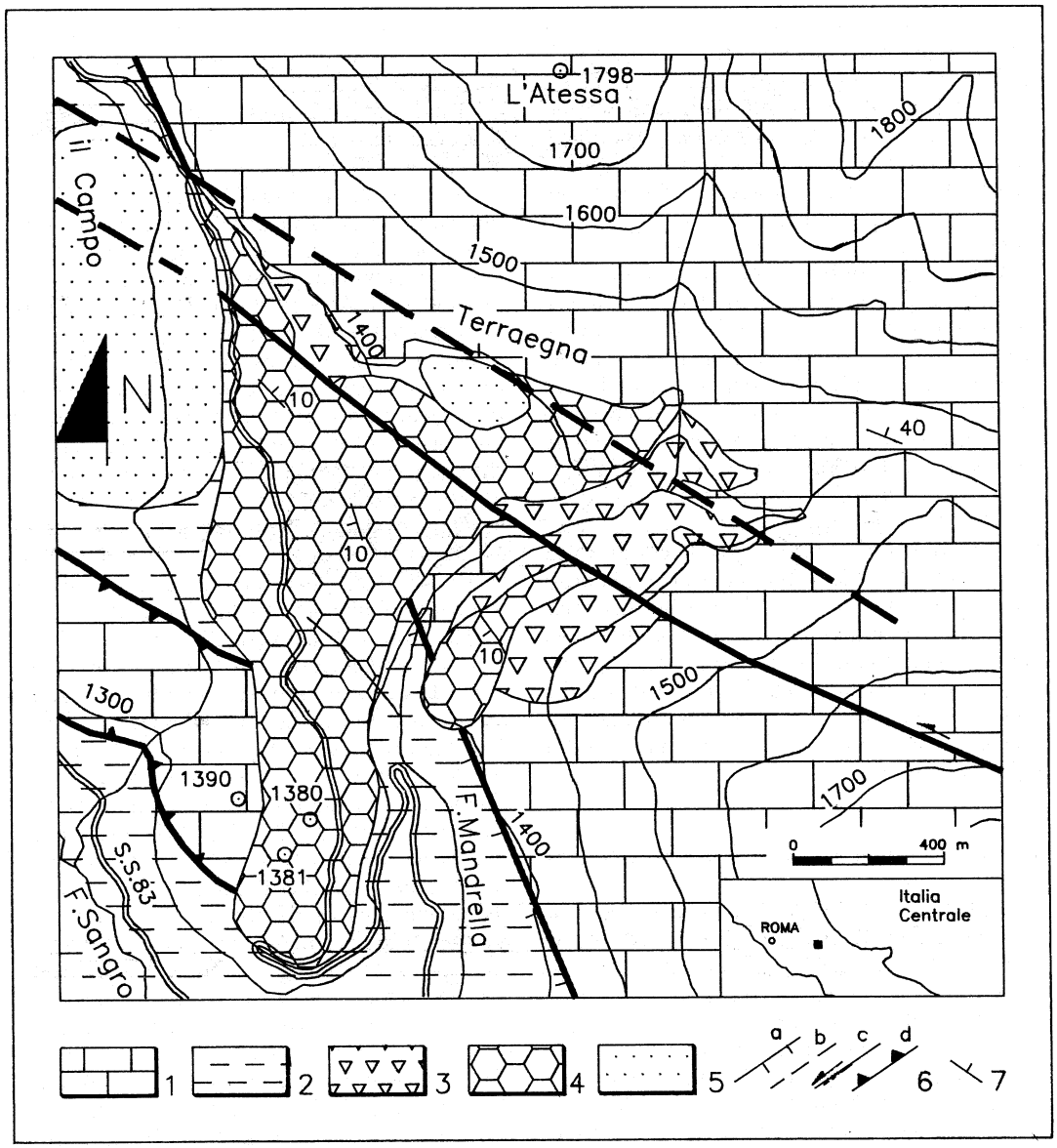

Fig. 2 Schematic geological map of the La Mandrella area. Legend: 1) calcareous rocks of the Mesozoic carbonatic sequence; 2) Miocene clayey-arenaceous flysch; 3) boulders of the Campo Rotondo Formation; 4) conglomerates of the Pescasseroli Formation; 5) colluvial-alluvial deposits; 6) faults (a) normal; b) presumed; c) left-lateral transcurrent; d) thrust); 7) attitude of bedding. (From Galadini *et al.*, 1991.)

Corrado *et al.* (1990) observed some structural features associated with an important back-thrust. On this ground the fault of the eastern flank of the Sangro Valley may be referred to gravitative tectonics or to gravitative movements, typical superficial kinematic expressions

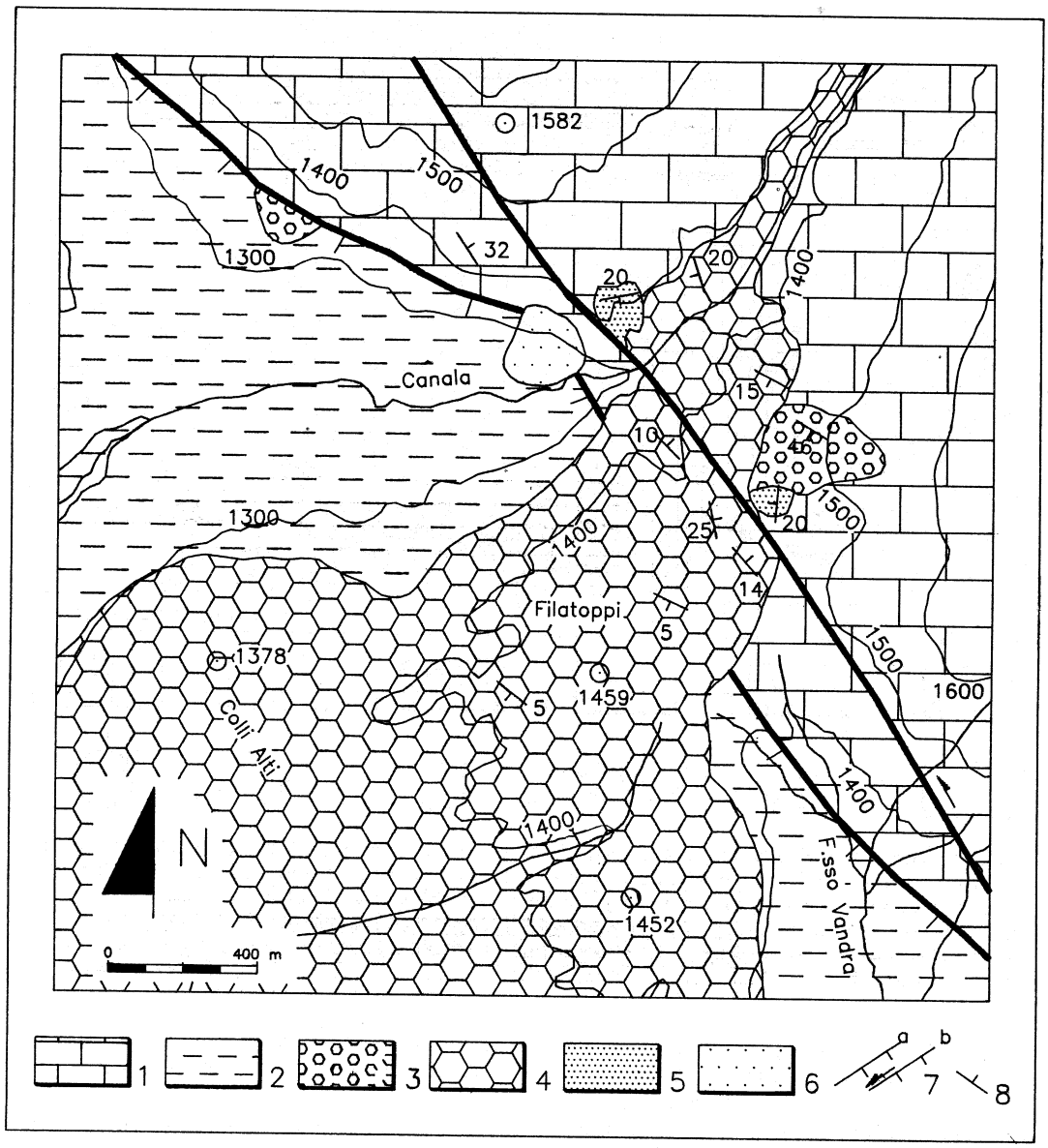

Fig. 3 Schematic geological map of the Colli Alti area. Legend: 1) calcareous rocks of the Mesozoic carbonatic sequence; 2) Miocene clayey-arenaceous flysch; 3) calcareous breccias of the Pescasseroli Formation; 4) conglomerates of the Pescasseroli Formation; 5) calcareous breccias of the Spineta Formation; 6) non-cemented talus debris; 7) faults (a) normal; b) left-lateral transcurrent); 8) attitude of bedding. (From Galadini *et al.*, 1991.)

of compressional fronts (see, for example, fig. 9 in Foose, 1973 and fig. 14 in Fairbridge, 1968).

The Campo Rotondo Formation has been displaced by at least two NW-SE faults (fig.4). The left-lateral transcurrent kinematics of one of the faults (F2) can easily be reconstructed (the

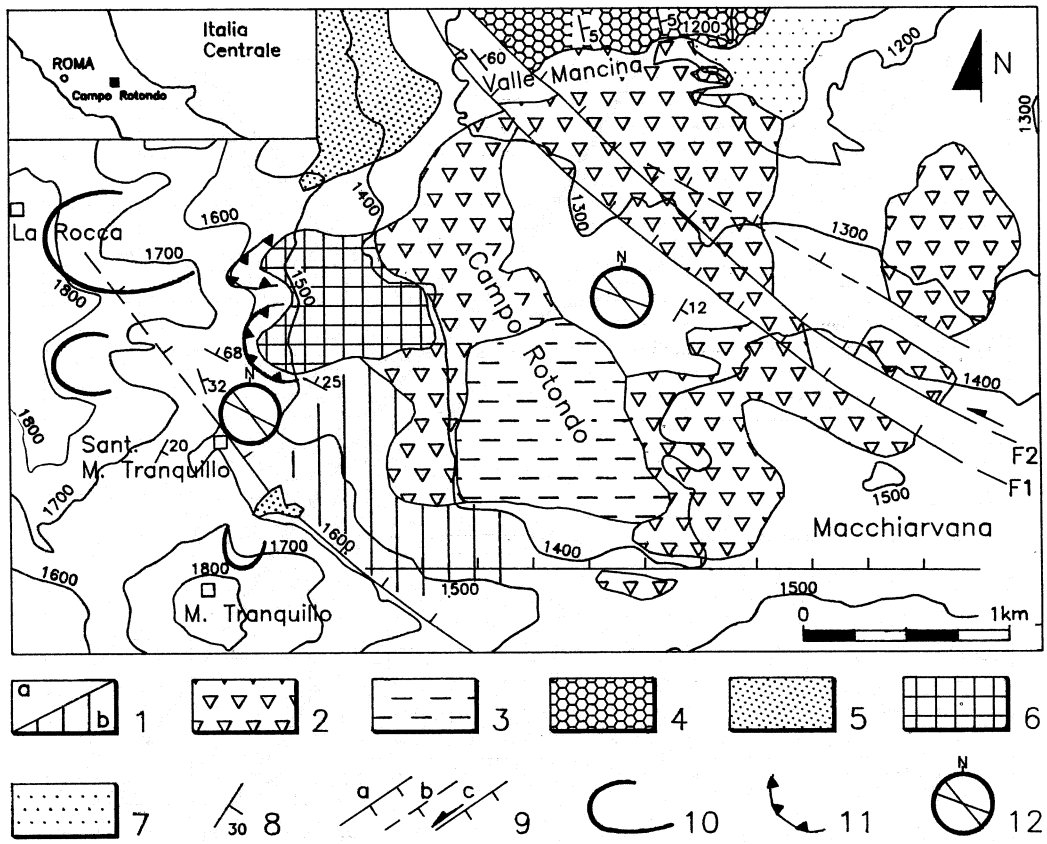

Fig. 4 Schematic geological map of the Campo Rotondo area. Legend: 1a) calcareous rocks of the Mesozoic carbonatic sequence; 1b) calcareous bedrock with evidence of gravitational deformations; 2) boulders of the Campo Rotondo Formation; 3) probably pre-Würmian glacial deposits; 4) conglomerates of the «Pescasseroli formation»; 5) Würmian glacial deposits; 6) present landslide deposits; 7) alluvial deposits; 8) attitude of bedding; 9) faults (a) normal; b) presumed; c) left-lateral transcurrent); 10) glacial cirques; 11) landslide scarp; 12) pattern of the main sets of fracture. (From Galadini *et al.*, 1991.)

amount of horizontal displacement is more than twice the vertical displacement). As regards the other fault (F1), it is rather difficult to reconstruct its kinematics owing to the erosion of the Campo Rotondo Formation in the Valle Mancina area. For the former the vertical component of the movement is of the order of 35-40 m, while the horizontal displacement is about a hundred metres.

5. Discussion

The problems arising from the data collected on the recent tectonics of the Upper Sangro River Valley can be summarized into two points:

1) role of left-lateral transcurrent deformations in the regional context;

2) relationship between recent left-lateral transcurrent deformations and seismic activity.

With regard to the first item some remarks have already been made in Galadini *et al.* (1991). In this paper the emphasis is placed on the problems arising from the finding of NW-SE faults characterized by left-lateral transcurrent Quater-

nary activity in the Abruzzi Apennine. Furthermore, a comparison between the data relative to the Upper Sangro River Valley and those relative to more or less adjacent areas has brought up some problematic issues that can be clarified only by future investigations: a) possibility that the left-lateral transcurrent deformations observed on the NW-SE faults are related to the right-lateral Quaternary transcurrent activity of the Ortona-Roccamonfina fault zone, with average N-S direction (Quaternary activity assumed by Patacca *et al.*, 1990) according to the scheme proposed by Galadini *et al.*, (1991); b) with regard to general remarks and on the basis of existing data, Galadini *et al.* (1991) emphasize the need to understand whether the Abruzzi Apennine underwent a deformational history consisting of alternating transcurrent and extensional movements, or whether it may be more appropriate to assume the coexistence of the two types of deformations; in this latter case the relationship between structures of a different order suggested in point a) would be more difficult to define.

If we focus our attention only on the Upper Sangro River Valley, on the basis of a comparison of existing data about the deformations recorded by the Meso-Cenozoic successions (Corrado *et al.*, 1990), with data relative to the activity of Quaternary faults, a deformational history of alternating events of trascurrent and extensional deformations can be assumed. Evidence of such alternation could be the succession of pre-Quaternary events reported in Corrado *et al.* (1990), where the emphasis is placed on the existence of a back-thrust system that is probably referrable to transcurrent deformations over a major NW-SE lineament, followed later by extensional events. On the basis of the data collected in this study it can be assumed that transcurrent deformations resumed during the Quaternary. There is no evidence of movements along normal faults subsequent to the deposition of the Pescasseroli Formation.

From a seismotectonic point of view a problematic issue is the relationship between seismic activity and the Quaternary deformations observed at the surface. Three major earthquakes have been recorded in the investigated area during this century: the 1915 Fucino Plain earthquake (M_S=6.9; Ward and Valensise, 1989) and the two 1984 S.Donato Val di Comino earthquakes (M_S=5.8 and M_S=5.2; Westaway *et al.*, 1989). Various focal mechanisms have been identified for the 1915 earthquake (Gasparini *et al.*, 1985; Basili and Valensise, 1986), but the substantial differences between them (probably due to the scarcity of the data) do not permit to use them for their seismotectonic implications (Galadini *et al.*, 1991).

Better instrumental data are available for the 1984 earthquakes. The focal mechanisms show extensional movements on NW-SE faults (Del Pezzo *et al.*, 1985; Dziewonski *et al.*, 1985; Westaway *et al.*, 1989). Westaway *et al.* (1989) correlate the hypocentres (10 km deep) of the earthquakes (the epicentres being located ten kilometres south of the area under investigation) with the Mt. Greco fault (see fig. 1 for location of Mt. Greco). This major structure borders the middle Sangro Valley about 5 km east of the investigated area, where studies are being carried out to define the Quaternary kinematics. The correlation between the deeper structure and the superficial one suggested by the above-mentioned authors would raise additional problems with reference to the recent and active tectonics. Indeed, owing to the fact that Mt. Greco lies adjacent to the structures investigated in this study, there would emerge a contradiction, at least apparently, between surface-related data pointing to the exclusive existence of recent transcurrent movements on NW-SE faults subsequent to the deposition of the Pescasseroli formation, and deep-related data, relative to earthquakes connected to NW-SE normal faults.

6. Conclusions

The investigations on the recent tectonics of the Upper Sangro River Valley have highlighted the importance of left-lateral transcurrent deformations during the Quaternary. A series of problems deriving essentially from the need to place the observed Quaternary transcurrent movements in a regional context characterized by strong evidence of extensional tectonics have been discussed on the basis of direct observations and of the processing of the collected data. The questions relative to the Quaternary tectonics are

still open even though recent studies tend to emphasize the importance of transcurrent deformations on NW-SE and N-S faults across Central Apennines (Alfonsi *et al.*, 1989; Giraudi, 1989a; Montone and Salvini, 1991; Naso *et al.*, 1989; Galadini *et al.*, 1991). The authors feel that a reliable Quaternary kinematic model for the Abruzzi Apennine can result only from further and more detailed investigations. Future studies will have to aim at unravelling the space-time relationships between transcurrent and extensional tectonics and ultimately at finding solutions to the problems that have been highlighted in the Discussion of this paper.

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