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QUATERNARY TECTONICS IN THE EPICENTRAL AREA OF THE 1688 SANNIO EARTHQUAKE (BENEVENTO, ITALY): PRELIMINARY RESULTS

CONTENTS

ABSTRACT

We present here a first part of a research on the active tectonics of the Sannio area, showing the results of geomorphological and mesostructural analyses carried out on Middle-Upper Pleistocene deposits of the Calore River valley (Southern Apennines).

These results are then compared with a reinterpretation of seismological data available in the literature for two seismic sequences, occurred in 1990 and 1997.

Along the Calore River valley we identified five orders of fluvial terraces. The first one can be referred to the Middle Pleistocene, the second to fourth orders to the Upper Pleistocene and the fifth one to the Holocene. Some evidence of normal faulting at the mesoscale characterises the Quaternary deposits of the study area. Differently oriented normal faults involve Middle-Upper Pleistocene deposits of the second and third order fluvial terraces, as well as Pleistocene slope deposits (e.g. Montepugliano, Solopaca). Paleostress fields derived from these data were compared to those derived from published data concerning the 1990 and 1997 seismic sequences.

For the 1990 seismic sequence we obtained a NE-SW extension with a marked transcurrent component. For the 1997 sequence we found instead a mean N-S oriented extension.

Faults to the south of the Calore River resulted characterised by an extensional stress field with a SW-NE oriented σ_3, in good agreement with the present-day extensional stress field as well as with the stress field obtained from the 1990 seismic sequence. Faults to the north of the Calore River returned instead a NW-SE oriented σ_3, roughly perpendicular to the regional active stress field.

Summing up, faulting referred to the lattermost Pleistocene was recognised in the Calore River area, and this deformation shows a certain variability of the related stress field, that in some instances displays an orientation strongly differing from that of the regional stress field.

KEY WORDS: Active tectonics, geomorphology, structural analysis , southern Apennines

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1. INTRODUCTION

In 1688, a severe earthquake (Io = XI, macroseismic magnitude 7.1; GRUPPO DI LAVORO CPTI, 1999) struck southern Italy; the epicentral area was located to the WNW of the town of Benevento, along the Calore River valley (Fig. 1).

This event occurred along the core of the Southern Apennines, as many other strong earthquakes in the past (among the others, from NW to SE: 1805 Molise, 1456 Molise, 1980 Irpinia, 1857 Basilicata). This part of the Apenninic chain is characterised by present-day SW-NE oriented extension (MONTONE *et alii*, 1999), and strong earthquakes are associated to this stress field (*e.g.* BOSCHI *et alii*, 1993).

The identification of the seismogenic structure responsible for the 1688 event is still matter of debate, and the active tectonic framework of the epicentral area is extremely poor. Therefore, this study, that is a work-in-progress, aims at filling this lack of information by integrating surface and subsurface geological and geophysical data.

We present the first results of an original geomorphological study and mesostructural analysis carried out on Middle-Upper Pleistocene deposits. These results are compared with a reinterpretation of seismological data available in the literature.

2. GEOLOGICAL SETTING

Sedimentary successions from two principal paleogeographic domains, the "Apennine platform" and the "Lagonegro-Molise basin" (MOSTARDINI & MERLINI, 1986) characterise the study area (Figs. 1 and 2). The Mesozoic limestones and dolostones of the Apennine platform crop out at the Camposauro and Monaco di Gioia Mts. The Sannio successions ("coltri sannitiche" *sensu* SELLI, 1962), belonging to Lagonegro-Molise basin tectonic units, crop out in a large area to the east of the study area, in the surrounding of the town of Benevento. These are constituted by varicoloured shales with cherty layers, marls, calcarenites and breccias. Siliciclastic sediments (Upper Miocene-Pliocene aged) are present at the top of these successions.

The complex geometry and the relationships among all these successions are mainly due to the compressional tectonics, which caused the stacking of this part of the Apennine fold and thrust belt from late Miocene to early Pleistocene. Normal faults related to a later extensional phase, still active at present, finally dissected the orogenic stack.

The Quaternary deposits, mainly fluvial gravels interbedded with sandy-clayey lacustrine deposits exposed in terraces, are essentially linked with Pleistocene-Holocene

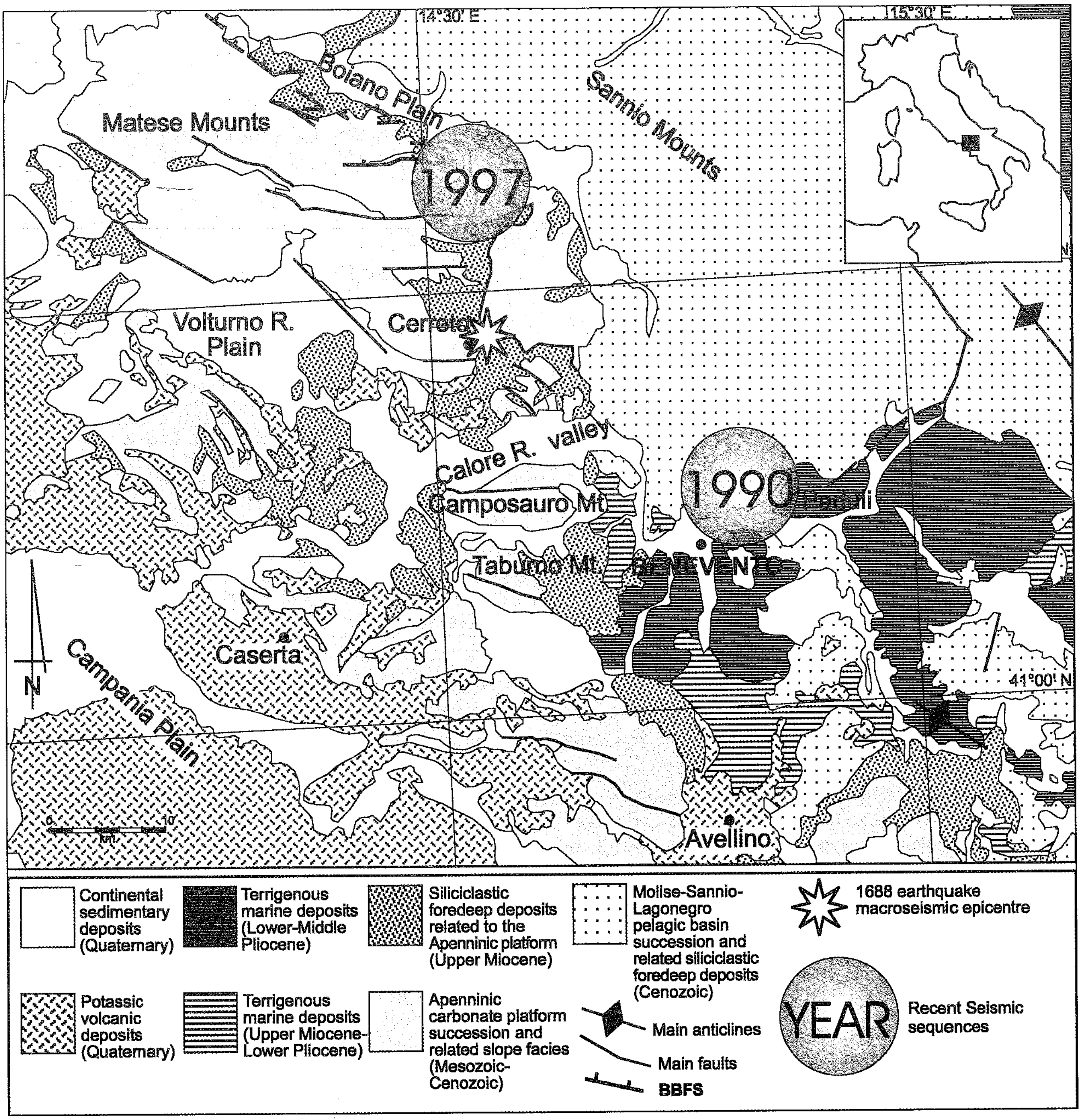

Fig. 1 - Schematic geological map of Sannio-Matese Mts. area. 1990 and 1997 seismic sequences locations are also reported.

activity of the Calore and Tammaro Rivers fluvial systems. Moreover, slope taluses and many alluvial fans border the high relief-energy carbonate mountains and hills (Camposauro Mt., Monaco di Gioia Mt., Acero Mt.), that frequently show structural slopes. These alluvial fans are interfingered with the Calore River deposits. Finally, travertine deposits, associated to the rising of mineral waters, occur near Telese, and wide outcrops of Upper Pleistocene pyroclastic deposits ("Ignimbrite campana" Fm., 0.039 Ma; De Vivo *et alii*, 2001) are present in the whole area.

3. NEW DATA

Along the Calore River valley, between Telese and Ponte, we identified five orders of fluvial terraces (Figs. 2 and 3).

The first order (230-250 m a.s.l.), mainly of erosional type, is shaped in the Lagonegro-Molise successions which widely outcrop only on the right (i.e. northern) side of the Calore River valley. From a geomorphological point of view, this order of terraces represents the extension toward the valley of a wide erosional glacis (Fig. 1).

The second order (150-200 m a.s.l.) constitutes the highest depositional terrace of the Calore River and is formed by mainly sandy-pebbly, well cemented sediments with interlayered lacustrine deposits. Locally we found a thin brown pyroclastic layer at the top of this terrace.

The third one (125-150 m a.s.l.), of depositional type, is constituted by polygenic, sandy-gravel, well cemented, deposits. A grey-white pyroclastic layer is locally interbedded with coarse sand and conglomerates within this fluvial succession. Travertines cropping out at Telese (Fig. 1) developed on top of this terrace and are still depositing at present.

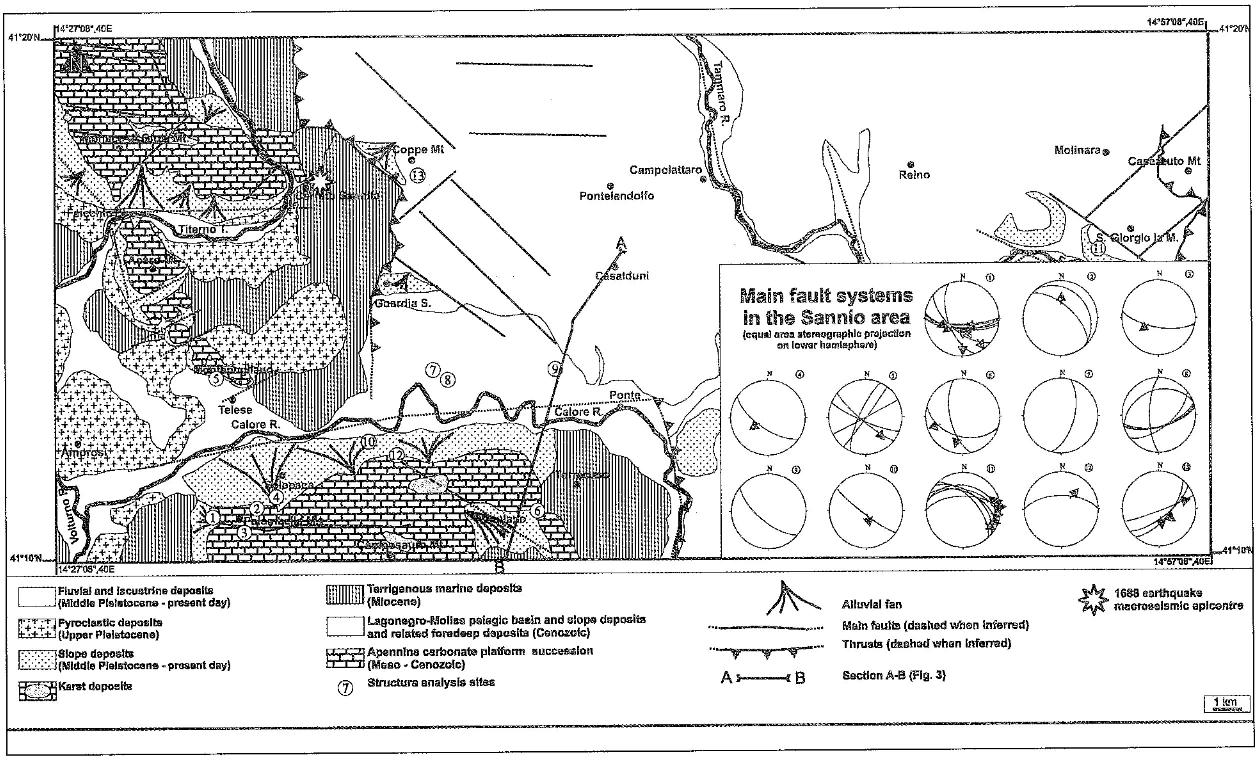

Fig. 2 - Geological map of the study area and structural analysis sites. In the lower right sketch plots are reported (equal-area projection, lower hemisphere) concerning faults (black lines) and relative kinematic indicators (black arrows). Numbers refer to the sites in the map.

The fourth order of terraces (70-90 m a.s.l.), of depositional type, shows lithologies comparable to the third one but in this case poorly cemented. The elevation of the fourth order is comparable to the elevation of the top of the "Ignimbrite campana" Fm., well exposed in the western part of the studied area (e.g. in the surroundings of Amorosi, Fig. 1).

Finally, sandy-gravel fluvial deposits with baked clay crocks constitute the fifth and, so far, last order of terraces (50-70 m a.s.l.).

According to the literature, the first order of terraces can be referred to the Middle Pleistocene, the second to fourth orders to the Upper Pleistocene and the fifth one to the Holocene (MALATESTA, 1959; BERGOMI *et alii*, 1975; DI NOCERA *et alii*, 1995).

Some evidence of normal faulting at the mesoscale characterises the Quaternary deposits of the study area. For instance, at Palombella Mt. (Fig. 2) an extensional fault involves not only Cretaceous carbonate rocks, but also Pleistocene slope deposits containing grey-black volcanic sands (Fig. 2, sites 1 and 3). In the surroundings of Telese, reddish slope deposits exposed in a quarry include grey-black volcanic layers faulted by E-W striking normal faults (Fig. 2, site 5). Moreover, normal faults in Quaternary deposits are frequent in alluvial fan and slope deposits which border the northern slope of Camposauro Mt. For example, near Solopaca we found recent slope deposits as well as alluvial fans involved in a NW-SE striking normal fault (Fig. 2, sites 4 and 10).

Normal faulting in Quaternary deposits also occurs in the deposits of the fluvial terraces on the right side of the Calore River (Fig. 3; Massa, 2003). In particular, fluvial deposits belonging to second and third order terraces are involved in normal faulting in some places between Telese and Ponte (Fig. 2, sites 7-9).

Quaternary deposits derived from terrigenous substratum are also faulted (Fig. 2, site 11 and 13), but the low mechanical quality of this material usually prevents a clear recognition of these structures.

Samples from pyroclastic beds often occurring in terrace and slope deposits are presently object of radiometric analysis. This will hopefully provide better constraints on the timing of the hosted brittle deformation.

4. REINTERPRETATION OF PUBLISHED SEISMOLOGICAL DATA

We analysed the focal mechanisms available in the literature for the 1990 and 1997 seismic swarms (ALESSIO *et alii*, 1996; MILANO *et alii*, 1999).

The 1990 seismic swarm interested the Benevento area from April to May 1990; over 300 earthquakes were recorded in a 100 km^2 area (Fig. 1). These events were generated in the first 15 km of crust with a maximum magnitude M = 3.6 (ALESSIO *et alii*, 1996). For 19 events, ALESSIO *et alii* (1996) determined the focal mechanisms. We processed these focal mechanisms using MESURE and TENSOR softwares (ANGELIER, 1990) and estimate the principal stress axes and the ϕ ratio (ANGELIER, 1979). We plotted focal mechanism data using the Schmidt equal area net to determine the P, T, and B axes positions. All the 19 published events were used to evaluate the σ_1, σ_2 and σ_3 axes positions with *TENSOR* (ANGELIER, 1990), using the *Direct Inversion Method* (ANGELIER, 1990).

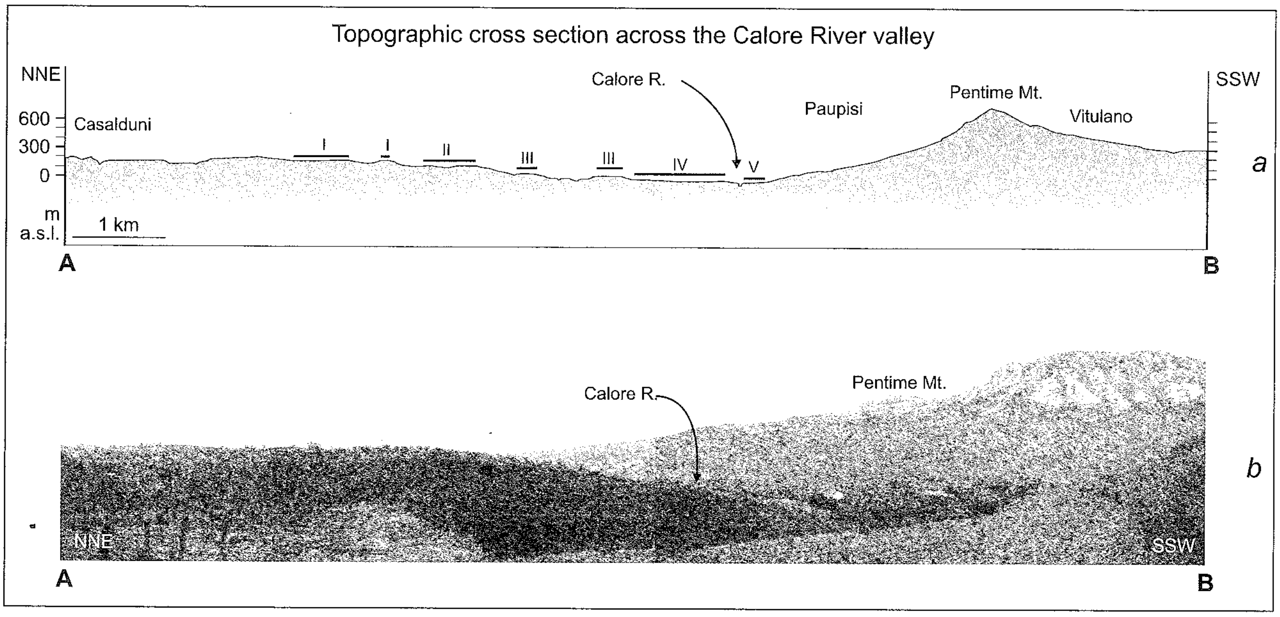

Fig. 3 - Topographic cross section across the Calore River valley (*a*) and related landscape (*b*). See Fig. 2 for location.

The obtained a NW plunging σ_1 and a slightly SW plunging σ_3, with a $\phi = 0.706$, indicate a NE-SW extension with a marked transcurrent component. These results are comparable with the NE-SW extension obtained using other specific softwares, such as *RDTM* (Ramsay & Lisle, 2000) or *GINKGO* (Yamaji, 2003 and 2003).

The 1997 seismic sequence occurred in the Sannio-Matese Mts. area (Fig. 1). It began on March 19th with a M = 4.1 earthquake, followed by up to 2800 events with 5 to 15 km hypocentral depths (Milano *et alii*, 1999). The analysis of the first P wave recordings led Milano *et alii* (1999) to determine 67 focal mechanisms grouped into three temporal stages.

After a preliminary check, these focal mechanisms were used to evaluate the σ axes orientation using *TENSOR* (Angelier, 1990), *RDTM* (Ramsay & Lisle, 2000) and *GINKGO* (Yamaji, 2002 and 2003) softwares.

The applied methods defined the persistence, during the three stages of the 1997 seismic sequence, of an extensional stress field characterised by a sub-vertical σ_1 and by σ_2 - σ_3 axes switching about the σ_1 axis. NNW-SSE extension, characterising temporal stages 1 and 2, rotated toward a NNE-SSW extension active at temporal stage 3 (Massa, 2003). As a whole, this seismic sequence results to be characterised by a mean N-S oriented extension.

5. DISCUSSION AND CONCLUSIONS

At this stage of our work, the preliminary field analysis shows the existence of differently oriented normal faults in Middle-Upper Pleistocene deposits of the Calore River valley. At present, only published age data are available to reconstruct the faulting chronology in this area. Faults occur mainly in slope deposits and in deposits of the second and third order fluvial terraces. The ascription of a terraced surface to a specific order is sometimes not univocal because it depends on the considered river section. We tried to give the most objective terracing model, following the development of terraced deposits along the entire E-W striking section of the Calore River valley, between Ponte and the confluence with the Volturno River (near Amorosi; Fig. 2).

The elevation of the fourth order terraces, in the Telese area, is comparable to the elevation of the Ignimbrite campana Fm. top surface. This may be due to the fact that the deposition of the Ignimbrite campana generated a morphological threshold which caused the deposition of wide fluvial deposits now preserved as our fourth order terrace. Considering that the Ignimbrite Campana is dated at 0.039 Ma (De Vivo *et alii*, 2001), we therefore infer that our fourth order terrace is younger, and that deposits of the second and third order terraces developed during the late Pleistocene, before the Ignimbrite campana deposition (i.e. 0.125-0.039 Ma). Therefore, faults on deposits related to the fourth order terrace post-date the latter age.

Plots in Fig. 2 suggest that the analysed faults may be related to different stress fields, which significantly change from north to south of the Calore River.

Faults to the south of the Calore River show variable orientations (from E-W to NW-SE), however with consistent kinematics, characterised by an extensional stress field with a SW-NE oriented σ_3. This is in good agreement with the present-day extensional stress field from break out data (Montone *et alii*, 1999), as well as with the stress field obtained from the seismic sequence that occurred in 1990 in the surroundings of the town of Benevento, and characterised by a mean SW-NE extension. However, it has been previously noted that the stress field obtained by the 1990 earthquake sequence shows a dominant strike-slip component, as focal mechanisms of this sequence display a certain degree of heterogeneity, being in a number of cases characterised by NW-SE oriented P axes (Alessio *et alii*, 1996).

Faults to the north of the Calore River are mainly

SW-NE oriented and can be associated to a stress tensor significantly different from the previous one: in this case, the direction of maximum extension is NW-SE oriented, roughly perpendicular to that of the regional stress field.

Summing up, we present here a first part of a research on the active tectonics of the Sannio area. Faulting referred to the lattermost Pleistocene was recognised in the Calore River area, and this deformation shows a certain variability of the related stress field. In some instances the latter displays an orientation that strongly differs from that of the regional stress field.

We are presently carrying out radiometric analyses aimed at dating pyroclastic deposits from fluvial terraces of the Calore River and from outcrops showing evidence of faulting of pyroclastic deposits resting on carbonate rocks of the substaratum. We are also integrating surface data with subsurface information (seismic lines and deep well logs). The results of this second part of the research will hopefully allow us to obtain a better understanding of the active tectonics of the Calore River valley seismogenic area.

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