ANNALI DI GEOFISICA, VOL. XXXVI, N. 1, April 1993

Seismic-hazard evaluation in Central Italy: preliminary results of the Rieti Basin project

Fabio Brunamonte(2), Alessandro M. Michetti(2), Leonello Serva(1) and Eutizio Vittori(1)
(1) *ENEA-DISP, Roma, Italia*
(2) *GNDT c/o ENEA-DISP, Roma, Italia*

Abstract
At the northeastern corner of the Rieti Basin (Central Italy), recent trench excavations have revealed Late Quaternary slope deposits displaced by a reverse fault located at the southernmost outcrop of a north-south trending Neogene regional thrust zone. This active feature has recorded several palaeoseismic events during the last 40 000 years (last motion about 5000-6000 y B.P.). In the general extensional stress field that characterizes the western side of Central Italy the reactivation of this fault with reverse motion can be explained as a local effect related to block faulting mechanisms. Other studies are in progress to better assess kinematics and rate of activity of this fault zone. This palaeoseismic evidence is relevant for the seismic-hazard evaluation of the Rieti area, which is characterized by a moderate historical seismicity.

1. Introduction

The Rieti Basin (fig. 1) is a wide Quaternary intermontane depression, located on the western side of the Apenninic orogenic belt. Origin and evolution of this basin, as well as of the other continental basins within the chain (*e.g.*, Fucino, L'Aquila, Sulmona), are related to the post-collisional extensional tectonics that has strongly affected the area since the early-middle Pliocene. The tectonic activity of this basin is evidenced by geological, morphological and seismological features. Normal fault escarpments border the basin. They trend mainly north-south and east-west and affect both the Meso-Cenozoic sedimentary basement and the Villafranchian deposits (Raffy, 1983; Cavinato *et al.*, 1989). The historical database records only moderate seismicity (fig. 2) with maximum intensities MCS of about VIII. A poorly documented event with a larger intensity (IX-X MCS) occurred in 1298 A.D., and is now under investigation (Leggio and Molin, in preparation).

Our purpose is to assess the level of seismic activity in the area by studying the effects of tectonic deformation on the landscape. To reach this goal we have developed an integrated research program (the «Rieti Basin Project») that considers lithology, climate, tectonics and human land-use as «independent variables in an open system» (Bull, 1984), in order to learn how to read the «natural seismic catalog» recorded in the landscape (Leggio *et al.*, 1989). Palaeoseismic investigation is an essential part of this research because of the valuable information it can provide on slip rates, recurrence intervals, size of earthquakes, extending our knowledge far beyond the historical threshold (*e.g.*, Vittori *et al.*, 1991 and references thereafter).

We assume a direct connection between seismicity and faulting because of the following considerations: 1) a large part of the stress accumulation in the upper crust is released through seismic faulting (Jackson, 1989; Sibson, 1982); 2) the largest crustal events, above magnitude ($6 \div 6.5$), generally have surficial expression through coseismic faulting (Bonilla *et al.*, 1984; de Polo and Slemmons, 1990); along active fault zones we generally observe abrupt variations of stratigraphic sequences and morphological fea-

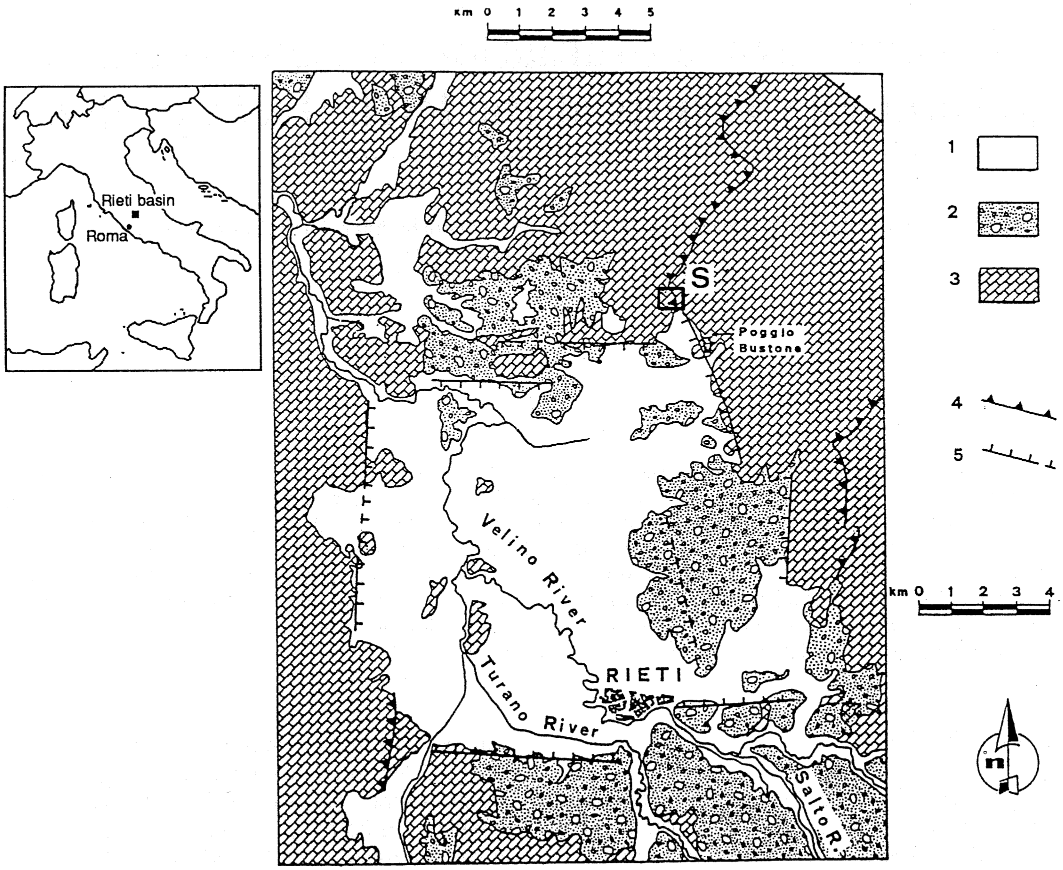

Fig. 1. Simplified structural setting of the Rieti Basin. Legend: 1) Holocene and Late Pleistocene continental deposits; 2) Villafranchian deposits; 3) Mesozoic-Cenozoic sequence, mainly carbonatic; 4) Neogene thrust; 5) Post-Villafranchian normal fault escarpments; S) location of the study area.

tures that require sudden displacements to be explained, and 4) aseismic creep is poorly documented in field studies and, where recognized, characterizes only limited sections along major fault zones. It should be added that the occurrence of aseismic motion at surface does not rule out the possibility for seismic displacements at depth, because of different rheological properties of materials.

We are developing a reliable model of Holocene and late Pleistocene landscape evolution through the multidisciplinary study of the Rieti Basin area. This is necessary for a proper evaluation of the seismic hazard of this area, which is characterized by complex environmental changes and the absence of short-term strong seismicity. This approach might be later applied to other similar areas either in Italy or in the Mediterranean Region.

Within this framework, in this paper we focus on one of the fault zones discovered in the area with probable evidence of palaeoseismicity.

2. Palaeoseismicity

In the northeastern corner of the rectangular-shaped Rieti Basin (near Poggio Bustone, «S» in

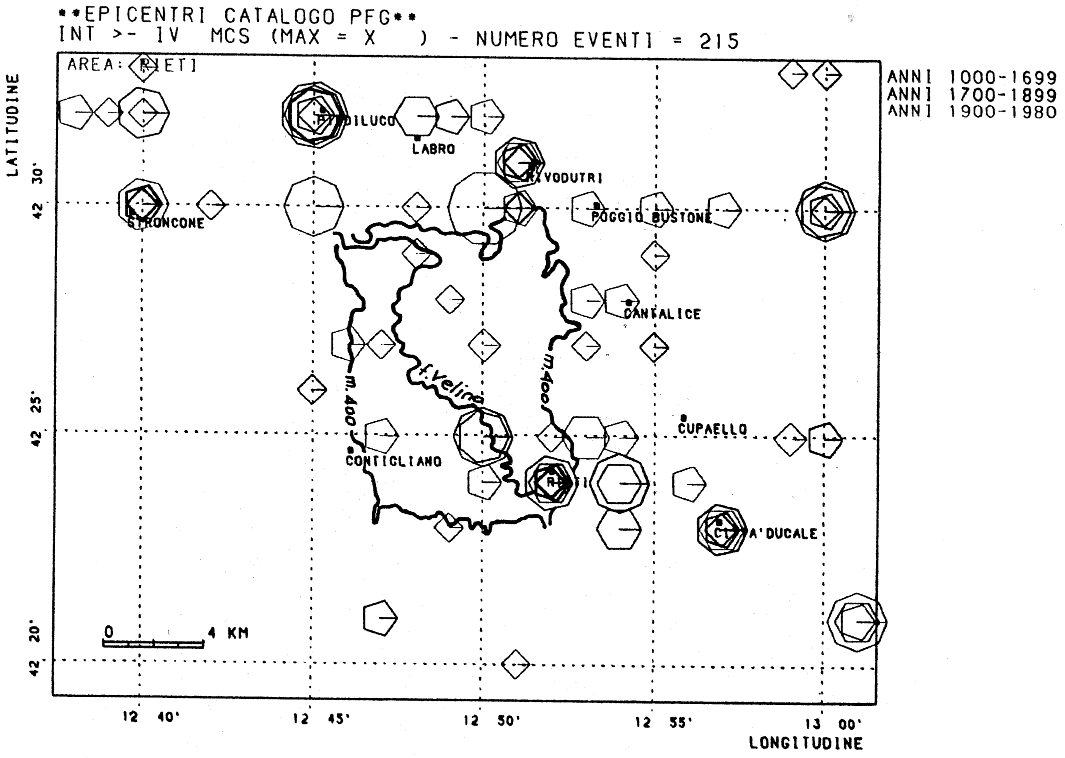

Fig. 2. Historical seismicity of the Rieti Basin area; each side of the polygons represents one MCS Intensity degree (only I > III MCS shown database events; after Postpischl, 1985).

fig. 1) a north-northeast striking and 60°WNW dipping Neogene regional thrust fault («Mt. la Pelosa-Scoglio del Bobbo thrust», Cavinato *et al.*, 1989) crops out, forming a morphological saddle in the Mesozoic bedrock of the Mt. Rosato slope (locality «La Casetta», fig. 3). In this saddle, a north-south oriented trench about 80 m long and 5 m large (n. 1, fig. 3), excavated for an aqueduct, has uncovered a reverse fault in the bedrock that also affects a Late Quaternary sequence of slope deposits (fig. 4). This sequence can be divided into 4 Units, which are from top downwards:

Unit 1: carbonatic slope debris mixed with blackish colluvial soil, containing VI-V century B.C. pottery;

Unit 2: blackish colluvial soil containing pre-Roman pottery. It can be divided into two subunits, 2A and 2B, because it is only affected by faulting in its lower part (2B);

Unit 3: coarse carbonatic slope debris, poorly stratified;

Unit 4: reddish-brown clayey paleosol, containing Upper Palaeolithic artifacts.

Archaeological and paletnological assignment are preliminary, pending results from a study in progress by archaeologists of the «Soprintendenza Archeologica per il Lazio - Roma».

Based on the archaeological and radiocarbon dates (table I) we can ascribe Unit 1 to the historical period (from about 1000 B.C. to the present), Unit 2 to the Middle Holocene (about ($7\div3$) ky B.P.), Unit 3 to the Last Stadial-Late Glacial and Unit 4 to the Last Interstadial (about ($40\div20$) ky B.P.). Trench n. 1 shows Units 4, 3 and 2B folded and dragged along a steep reverse fault striking N160, 60° (fig. 4). To confirm this evidence we have deepened the trench n. 1 and

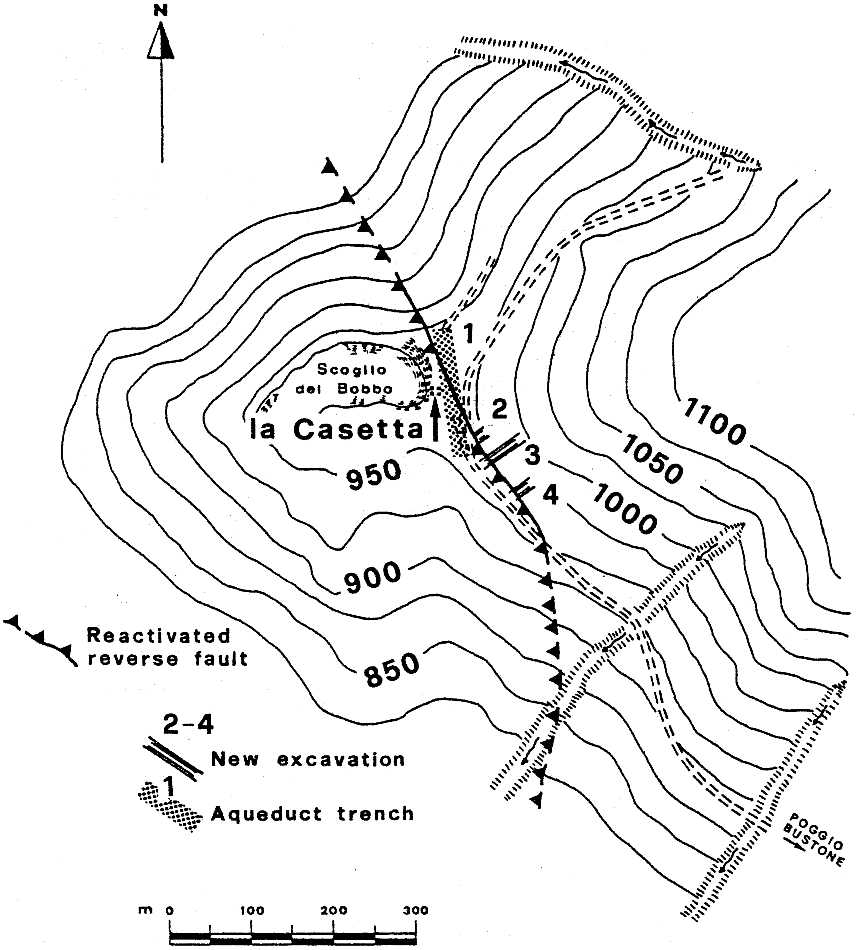

Fig. 3. Map of the «La Casetta» morphological saddle and location of the excavations.

Table I. Conventional ^{14}C age (total organic carbon) of the buried soils at «La Casetta» site (Rieti Basin).

LOCATION	SAMPLE Nr(*)	^{14}C AGE (y B.P.)	$\delta\,^{13}$C (%)
UNIT 1 (bottom)	GX-16333	3110 ± 90	–25.1
UNIT 2A (bottom)	GX-16337	5040 ± 100	–25.0
UNIT 2B (top)	GX-16332	6425 ± 130	–25.0
UNIT 3 (bottom)	GX-16331	19 800 ± 1650	–25.5
UNIT 4 (top)	GX-16334	20 700 ± 1600	–24.6
UNIT 4 (trench floor)	GX-16846	27 500 + 11 200 – 4500	–25.3

(*) Laboratory: GEOCHRON, Cambridge, Mass.

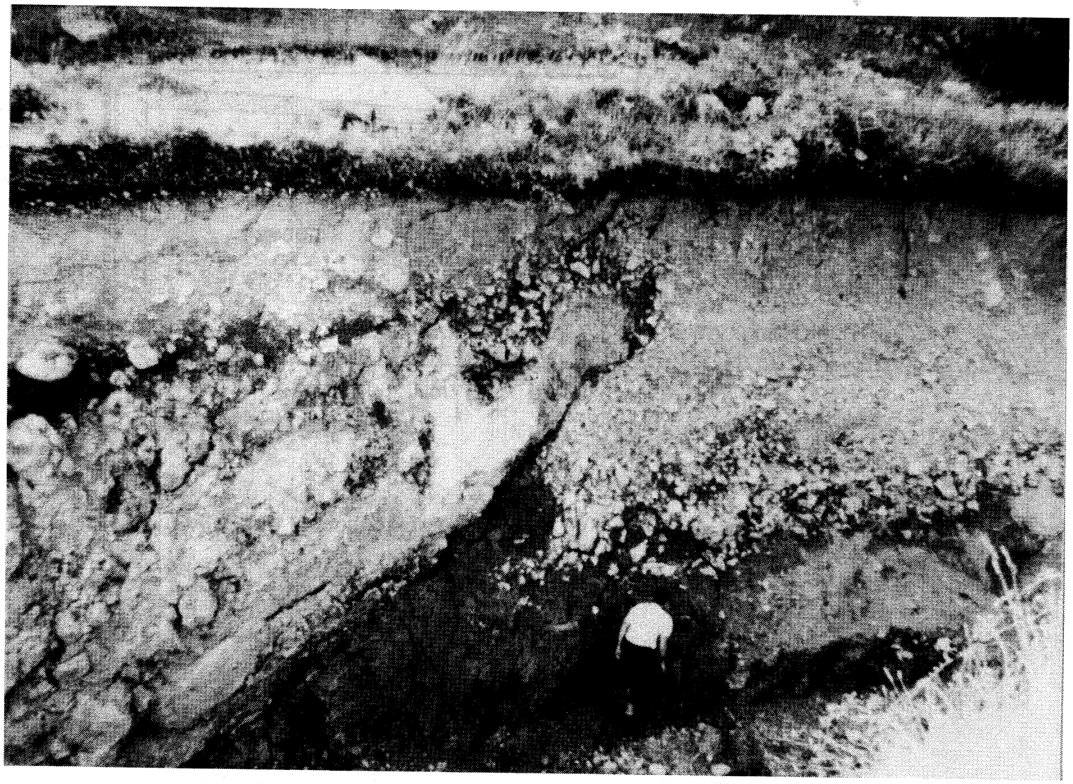

Fig. 4. View of the fault zone in the western wall of the trench n.1 (location in fig. 3; see also fig. 6).

excavated three other trenches (n. 2, 3, 4 in fig. 3). In all the trenches the bedrock overlies the same Unit 4 paleosol, whose thickness exceeds 4 m in trench n. 4 (fig. 5) and 8 m in trench n. 1 (fig. 6).

Due to the small strike angle between the fault and the long axis of trench n. 1 (fig. 3) the walls of this trench do not provide the same picture. In the western wall (fig. 4 and 6), Units 4 and 3 form an overturned fold around the hangingwall of the bedrock fault plane; the thickening of these units in the footwall points out the syntectonic sedimentation associated with the faulting process, starting at least in the Upper Palaeolithic. In the eastern wall (fig. 7), the geometry of the palaeo-saddle has controlled the accumulation of a thicker and more detailed Holocene stratigraphic sequence along the fault zone, allowing a more precise analysis of the last movement of the fault. Here Units 1 and 2 reach their maximum visible thickness. The sub-unit 2B (fig. 7) is corrugated by an intrusion of the Unit 3 coarse debris. The sub-unit 2A and Unit 1 were not affected by faulting. We interpret this geometry as due to a sudden uplift of the hangingwall after deposition of Unit 2B (fig. 8F)-8G)), that produced a scarp (about 1 m high, fig. 7) facing the mountain slope, thus creating a sedimentary trap for the colluvial material. The undisplaced upper deposits (units 1 and 2A) provide a minimum date for offset at this site. The last event occurred during the time-span bracketed by the ages of the top of Unit 2B (about 6400 y B.P., table I) and the lower part of Unit 2A (about 5000 y B.P., table I). Figure 8 summarizes our interpretation of the evolution of this area during the last 40 ky.

The total vertical displacement of the bedrock in the last 40 ky in trench n. 1 (fig. 4) exceeds 8 m, providing an average uplift rate > 0.2 mm/y.

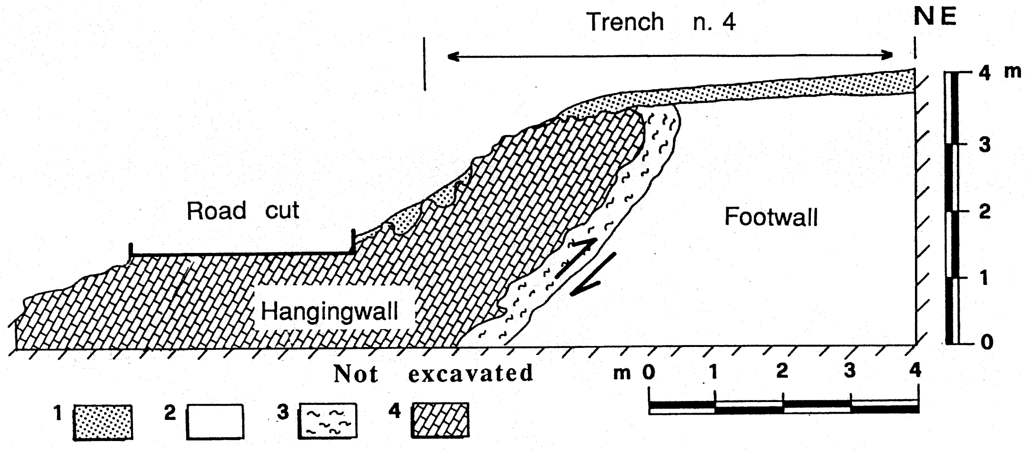

Fig. 5. Log of the trench n.4 (location in fig. 3). Legend: 1) Reworked soil; 2) Unit 4; 3) Triassic marl fault gouge; 4) Triassic dolostone.

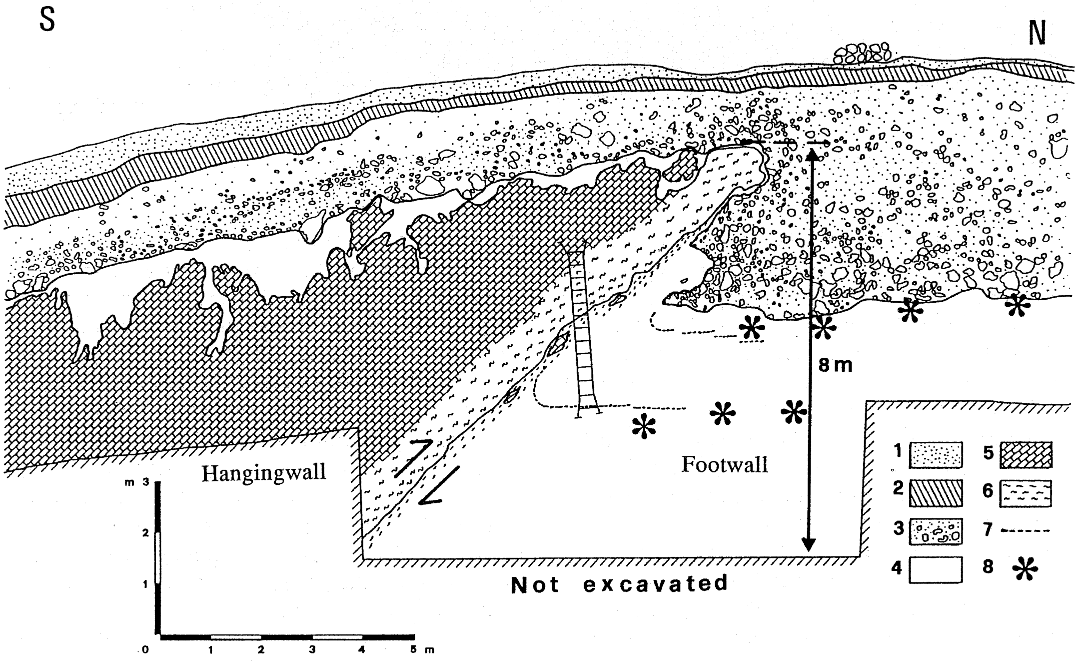

Fig. 6. Sketch of the fault zone in the western wall of trench n. 1. The original drawing was made at scale 1:10. Legend: 1) Unit 1; 2) Unit 2; 3) Unit 3; 4) Unit 4 ; 5) Triassic dolostone; 6) Triassic marl fault gouge; 7) dragged flinty debris level; 8) Upper Paleolithic artifacts.

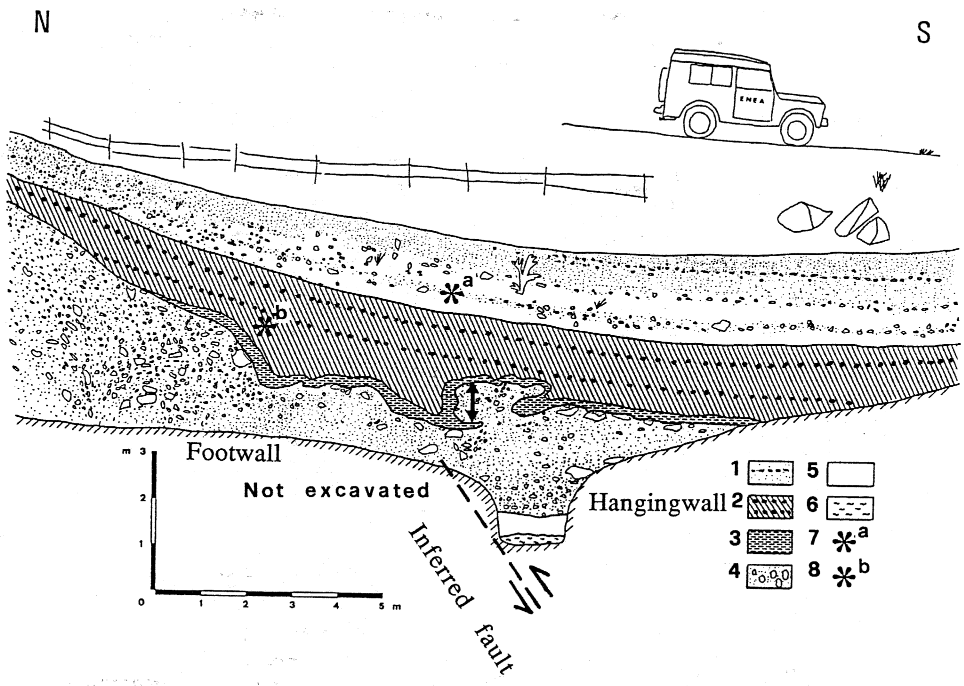

Fig. 7. Sketch of the fault zone in the eastern wall of trench n. 1. The original drawing was made at scale 1:10. The arrow indicates the displacement (about 1 m) produced by the last movement of the fault, occurred after Unit 2B and before Unit 2A deposition. The fault plane, not directly visible, is inferred from the deformed geometry of Units 3 and 2B and from the fault plane attitude in the opposite wall. Legend: 1) Unit 1; 2) Unit 2A; 3) Unit 2B; 4) Unit 3; 5) Unit 4 (Units 1 to 4 described in the text); 6) Triassic marl fault gouge; 7) VI-V century B.C. pottery; 8) Pre-Roman pottery.

Several Late Quaternary surface faulting events occurred at this site if the last movement was characteristic of offset occurring along this fault. Due to the monotonous sedimentation of Units 3 and 4 in the studied sections it is impossible to determine the age and number of events preceding the last one recorded at this site. For example, Meghraoui *et al.* (1988) gave an analogous interpretation for a similar feature observed in a trench along the El Asnam fault.

There are several lines of evidence that allow us to rule out the hypothesis that only one or two large events could be responsible for all the observed displacements:

a) offsets larger than two-three meters characterize seismic events of magnitude 7 or larger and are connected to surface faults many tens of kms long, that are not recognizable in the area. Also the Italian seismic catalog does not record any events of this magnitude.

b) The hangingwall bedrock, densely fractured, would have collapsed if rapidly raised several meters;

c) the hangingwall bedrock probably never came to the surface, as suggested by the presence of the same sedimentary units on both sides, although with very different thicknesses;

d) units 2B, 3 and 4 are thickened in the footwall, indicating the occurrence of several events during sedimentation.

The analysis of the sedimentary setting in the trenches reasonably proves that discrete rapid displacements were responsible for the observed offset at «La Casetta site». In fact, uplift by very

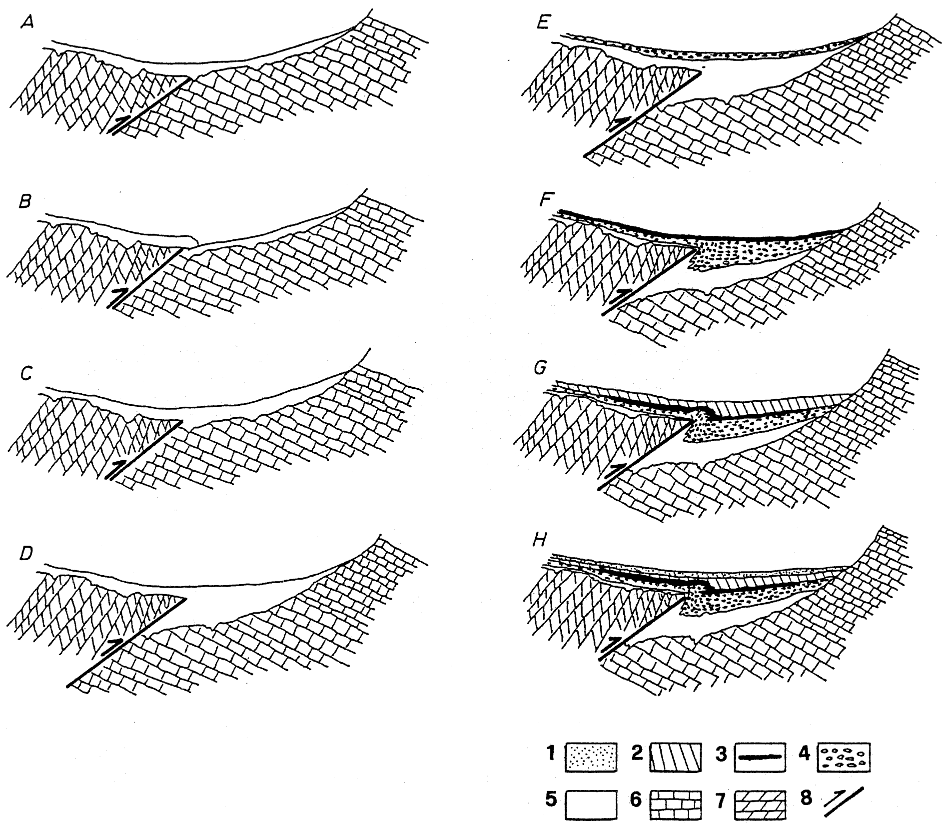

Fig. 8. Reconstruction, based on trench profiles and inferred deformational history recorded at «La Casetta» site. The simplified cross-sections (not to scale) strike about east-west. Legend: 1) Unit 1; 2) Unit 2A; 3) Unit 2B; 4) Unit 3; 5) Unit 4; 6) Cretaceous limestone footwall; 7) Triassic dolostone hangingwall; 8) reactivated reverse fault; A) starting Unit 4 deposition (ca. 40 ky B.P.); B) one displacing event, during deposition of Unit 4; C) after this event; D) after several events during deposition of Unit 4; E) beginning of Unit 3 deposition (ca. 20 ky B.P.); F) after several events during deposition of Unit 3; beginning of Unit 2B deposition (ca. 6.5 ky B.P.); G) after the last event (occurred between 6.4 and 5 ky B.P.), just before Unit 1 deposition (ca. 3.2 ky B.P.); H) present setting.

slow movements would have permitted the erosion of the hangingwall, that instead has constituted a dam for the coarse slope wash materials, allowing their fast accumulation.

Within the seismotectonic framework of the Central Apennines, which is characterized by shallow ((6÷15) km) crustal earthquakes (*e.g.*, Blumetti *et al.*, 1987; Pantosti and Valensise, 1989; Vittori *et al.*, 1991), the surface faulting events here described should relate to earthquakes of magnitude higher than 6.0÷6.5 (Bonilla *et al.*, 1984; de Polo and Slemmons, 1990). These events occurred before historical times and have a return period that, although not directly assessable, should be at least several thousand years long.

3. Conclusions

At present, we have not yet reached a complete view of the active faults in the Rieti Basin.

Nevertheless, we can already reasonably state that the Late Pleistocene-Holocene reactivation of the «La Casetta» reverse fault would not have a simple explanation within the known tectonic framework of this area (or in general of the Central Apennines) if related to a deep-seated shortening. In fact, all the available structural and geomorphological data point out that the Rieti Basin is a Quaternary extensional depression. Also the focal mechanisms agree with an extensional geodynamic realm (*e.g.* Gasparini *et al.*, 1985). Preliminary surveys along the «Mt. la Pelosa-Scoglio del Bobbo thrust», north and south of the «La Casetta» saddle, have not revealed any significant evidence of recent compressional deformation.

Strike-slip components along the Rieti basin boundary faults are a possible alternative explanation for the «La Casetta» reverse fault. Pull-apart mechanisms have been recently proposed to explain the origin of some intermontane basins in Central Apennines (*e.g.*, Galadini *et al.*, 1991). In general, negative evidences for this model are the absence, so far, of demonstrated significant horizontal components on Quaternary faults (shown either by geomorphology and slip indicators on fault planes) and the predominant presence of extensional focal solutions of large earthquakes. Regarding the studied site, slip indicators collected in the fault zone have only a minor left-lateral horizontal component. The geomorphic analysis (based on detailed airphoto interpretation and field survey) does not show evidence of strike-slip offset along the main basin faults near the studied site. Therefore, based on available data, we can reasonably assume that a locally complex stress pattern is acting in this corner of the Basin within a general extensional environment. In this view, phenomena similar to the one we have described can be explained by a block-faulting tectonic model, like that proposed by Nijman (1971) for the Velino-Sirente area, or Wallace (1980) for the Basin and Range region of the western U.S.. In such a model reverse movements might originate from differential tilting of rigid blocks.

In terms of seismic-hazard analysis, the area is now considered moderately active, with historical events generally below Intensity VIII-IX MCS. Only one event (1298 A.D.) with intensity ca. X could have occurred within the basin, but its location and magnitude are still debatable. If confirmed by ongoing studies, this event would fit in the model of seismic hazard (in terms of maximum potential) suggested by palaeoseismic studies. In any case, the palaeoseismic evidence here described is relevant for the area under investigation, being indicative of events with magnitude above 6.0÷6.5. Studies on other possible palaeoseismic features around the Rieti basin, although still preliminary, are confirming these conclusions. Therefore, palaeoseismological investigations are providing essential information for a correct seismic-hazard evaluation in the Rieti area and for delineating a realistic picture of its recent geological evolution.

REFERENCES

BLUMETTI, A.M., A.M. MICHETTI and L. SERVA (1987): The grounds effects of the Fucino earthquake of Jan. 13th, 1915; an attempt for the understanding of recent geological evolution of some tectonic structures, in *Proc. ENEA-IAEA Int. Workshop "Historical seismicity of central-eastern mediterranean region", Rome, 27-29 Oct. 1987*, pp. 297- 319.

BONILLA, M.G., R.K. MARK and J.J. LIENKAEMPER (1984): Statistical relations among earthquake magnitude, surface rupture length, and surface fault displacement, *Bull. Seismol. Soc. Am.*, **74**, 2379-2411.

BULL, W.B. (1984): Tectonic geomorphology, *J. Geol. Educ.*, **32**, 310-324.

CAVINATO, G.P., F. CHIARETTI, D. COSENTINO and L. SERVA (1989): Caratteri geologico-strutturali del margine orientale della Conca di Rieti, *Boll. Soc. Geol. It.*, **108**, 207-218.

DE POLO, C. M. and D. B. SLEMMONS (1990): Estimation of earthquake size for seismic hazards, *Geol. Soc. Am., Reviews in Engineering Geology*, **VIII**, 1-28.

GALADINI, F., R. GIULIANI and P. MESSINA (1991): Characterization of recent deformational sequences in some areas of the Abruzzi Apennines (Central Italy): implications and problems, *Il Quaternario*, **4**(1a), 85-98.

GASPARINI, C., G. JANNACCONE and R. SCARPA (1985): Fault-plane solutions and seismicity of the Italian peninsula, *Tectonophysics*, **117**, 59-78.

JACKSON, J.A. (1989): Active normal faulting, in *Continental extensional tectonics*, edited by M.P. COWARD, J.F. DEWEY and P.L. HANCOCK, Geological Society Special Publication n. 28, pp. 3-18.

LEGGIO, T., A.M. MICHETTI, L. SERVA and E. VITTORI (1989): Processi naturali ed attività antropica a confronto nei tempi storici: metodologie adottate e ricerche programmate in un'area campione (Conca di Rieti), *Mem. Soc. Geol. It.*, **42**, 61-66.

MEGHRAOUI, M., H. PHILIP, F. ALBAREDE and A. CISTERNAS (1988): Trench investigations through the trace of the

1980 El Asnam thrust fault: evidence for paleoseismicity, *Bull. Soc. Seismol. Am.*, **78**(2), 979-999.

NIJMAN, W. (1971): Tectonics of the Velino-Sirente area, Abruzzi, Central Italy, *Koninkl. Nederl. Akademie van Wetenschappen, Proc., B*, **74**(2), 156-184.

PANTOSTI, D. and G. VALENSISE (1989): Riconoscere il terremoto «caratteristico»: il caso dell'Appennino centro-meridionale, in *I terremoti prima del 1000* (Ed. SGA, Bologna), pp. 536-552.

POSTPISCHL, D. (Editor) (1985): Catalogo dei terremoti italiani dall'anno 1000 al 1980. C.N.R., Prog. Fin. Geodinamica, *Quad. Ric. Sci.*, **114**(2B), Roma.

RAFFY, J. (1983): *Le versant tyrrhenien de l'Apennin Central: étude géomorphologique* (C.N.R.S., Paris).

SIBSON, R.H. (1982): Fault zone models, heat flow and depth distribution of earthquakes in the continental crust of the United States, *Bull. Seismol. Soc. Am.*, **72**, 151-163.

VITTORI, E., L. SERVA and S. SYLOS LABINI (1991): Palaeoseismology: review of the state-of-the-art, *Tectonophysics*, **193**, 9-32.

WALLACE, R.E. (1980): *Tectonic analysis of active faults*, U.S. Dep. Int. Geol. Surv., Summary of technical reports, X, Open File Rep. n. 80-842.