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# NEW DATA AND REINTERPRETATION OF THE NOVEMBER 23, 1980, M 6.9 IRPINIA - LUCANIA EARTHQUAKE (SOUTHERN APENNINES) COSEISMIC SURFACE EFFECTS

INDEX



ABSTRACT

We have revised and reinterpreted the geological effects produced by the 23 November 1980 Irpinia – Lucania earthquake. We also reviewed the original evidence collected in the field soon after the earthquake, which provided the database for CARMIGNANI *et al.* (1981). We have analyzed and checked these data by means of airphoto interpretation, field survey and eyewitness accounts. Our study indicates that surface faulting and fracturing in the epicentral area of the Irpinia earthquake was much more important and significant from a tectonic and paleoseismic viewpoint, than has been reported so far. In particular, the analysis of preexisting data and our new observation strongly suggest that a set of open fractures and south-southwest-dipping normal fault scarps, each of them a few hundreds meters long, in part already detected by the surveyors just after the earthquake around Castelgrande and Muro Lucano, and extending up to nearby Bella, for a total length of ca. 8 km, are probably a primary tectonic effect, possibly related to the so-called "40s event" (e.g. BERNARD *et al.*, 1993).

Moreover, we report that interviews with eyewitnesses have provided evidence for a previously unnoticed vast coseismic secondary effect, i.e., a several hundreds meters long trench in the limestone bedrock occurred within a deep-seated gravity slope deformation located in close proximity to the same coseismically reactivated normal fault scarp near Bella. Similar to surface faulting effects, the repeated occurrence of coseismic gravity features like this one, which are often described by historical reports on strong earthquakes in Italy, has left an impact on the Apennines landscape. We also suggest that many so-called "karstic basins", like the ones located along the 1980 earthquake rupture at Piano di Pecore and Pantano di San Gregorio Magno, result, in reality, from the interaction of surface faulting, high ground shaking and surficial processes. Large gravity slope deformations and tectonic-karstic basins in seismically active areas such as the Apennines are, in essence, *seismites* (*sensu* VITTORI *et al.*, 1991), and can be used to infer the seismic history of a region. Therefore, our reinterpretations indicate that many surface effects (geomorphic phenomena) in this part of the southern Apennines are typical seismo-tectonic features, and reflect a process that has been going on for many thousands of years.

RIASSUNTO

Sono stati rivisti e reinterpretati gli effetti geologici di superficie prodotti dal terremoto irpino-lucano del 23 Novembre 1980. Si è avuta inoltre l'opportunità di analizzare il rilievo originale della fratturazione al suolo eseguito da un folto gruppo di ricercatori immediatamente dopo l'evento, rilievo che ha fornito i dati di base per il lavoro di CARMIGNANI *et al.* (1981). Questo materiale è stato confrontato con rilievi aerofotogeologici e di terreno e con le informazioni raccolte con interviste a testimoni oculari degli effetti sul terreno prodotti dal terremoto. Il risultato di tali studi indica che i fenomeni di fagliazione e fratturazione in superficie nell'area epicentrale del terremoto irpino sono stati molto più importanti, e significativi dal punto di vista tettonico e paleosismico, di quanto riportato finora. In particolare, l'analisi dei dati preesistenti e le nuove osservazioni effettuate suggeriscono che il sistema di fratture beanti e scarpate di faglia, ognuna delle quali lunga alcune centinaia di metri, riconosciuto dai rilevatori subito dopo l'evento sismico nel settore di Castelgrande e Muro Lucano, e che si estende fino ai confini del territorio di Bella per una lunghezza totale di circa 8 km, può essere interpretato come fenomeno di natura tettonica primaria, probabilmente da mettere in relazione con il cosiddetto "evento a 40 secondi" (BERNARD *et al.*, 1993).

Inoltre, le notizie fornite da testimoni oculari ci hanno permesso di riportare per la prima volta l'occorrenza, lungo questo stesso sistema di faglie, di un imponente fenomeno gravitativo profondo cosismico ubicato nel territorio di Bella e costituito da una trincea in roccia calcarea lunga alcune centinaia di metri. Questo fenomeno induce a sottolineare il concetto che tali imponenti fenomeni gravitativi evolvono spesso in relazione al ripetersi di forti terremoti, e insieme al ripetersi di eventi di fagliazione superficiale, cui sono tipicamente strettamente associati, conferiscono un'impronta caratteristica, spesso facilmente identificabile, al paesaggio dell'Appennino. Similmente, l'interazione coi processi superficiali produce tipiche morfologie quali *sinkholes* e piccoli bacini endoreici (ad es., quelli di Piano di Pecore e Pantano di San Gregorio Magno, ubicati lungo la traccia della rottura del terremoto del 1980), che sono state spesso interpretate come forme puramente carsiche, anche quando il loro sistematico allineamento lungo faglie capaci dimostrava chiaramente una stretta associazione genetica con i fenomeni di fagliazione superficiale cosismica. Movimenti gravitativi profondi di versante e bacini tettono-carsici simili a quelli riattivati dal sisma del 1980 possono quindi essere considerati a tutti gli effetti come "sismiti" (*sensu* VITTORI *et al.*, 1991), e il loro riconoscimento può assumere particolare importanza nel ricostruire la storia sismica di una regione.

KEY WORDS: coseismic geological effects, deep seated gravitational movement, Southern Apennines

PAROLE CHIAVE: effetti geologici cosismici, movimenti gravitativi profondi, Appennino meridionale

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## 1. INTRODUCTION

The Irpinia - Lucania earthquake of November 23, 1980, was one of the largest normal-faulting events in the Apennines chain ($M_S$ = 6.9 NEIS and seismic moment $M_0$ = 26X$10^{18}$ Nm, WESTAWAY, 1993, epicentral intensity $I_0$ = IX-X MCS, POSTPISCHL, 1985). The main shock took place at latitude 40.724° ± 1.4 km and longitude 15.373° ± 1.4 km; its nucleation point was 10-12 km deep. Three different fault segments ruptured during the main shock, as deduced from the 0, 20 and 40 seconds subevents on seismograms (e.g., WESTAWAY & JACKSON, 1987; BERNARD & ZOLLO, 1989; BERNARD *et al.*, 1993).

The earthquake caused major damage at more than 800 localities, mainly in the Campania and Basilicata regions, and killed ca. 3,000 people (POSTPISCHL *et al.*, 1985). The high magnitude and the local geomorphological setting produced widespread effects on the physical environment (Figs. 1 and 2). Most surface fractures were located within the intensity VIII isoseismal, especially in the epicentral area. The earthquake also induced more than 200 earth slides over an area ca. 20,000 square km wide (ESPOSITO *et al.*, 1998); at least ten liquefaction events were reported both in near and far field areas (GALLI & FERRELI, 1995). Many hydrologic anomalies in the large carbonatic aquifers of this sector of the Apennines were observed before, during and after the shock. Almost 70 springs with mean discharge rate higher than 500 liters/second showed strong discharge and other anomalies, mainly in the high Sele river valley and the Matese area (ESPOSITO *et al.*, 1999).

Soon after the November 23, 1980, Irpinia - Lucania earthquake, several groups mapped the coseismic geological effects in a wide portion of the epicentral area. Some observers did not believe that any of the effects were of tectonic origin and ascribed all of them either to pure gravitational sliding or to debris compaction (CARMIGNANI *et al*, 1981). Other Italian analysts interpreted as tectonic the 7 km long and up to 50 cm high scarp that occurred along the western border fault of the Sele Valley, the 2 km long fracturing at Piano di Pecore on the Marzano ridge (CINQUE *et al.*, 1981), and the 2 km long fracturing at Pantano San Gregorio Magno (BOLLETTINARI & PANIZZA, 1981). As documented by WESTAWAY & JACKSON, 1987 and PANTOSTI & VALENSISE, 1990), two east-dipping, NW-SE trending segments of coseismic normal fault scarps, for a total rupture length of ca. 40 km, were identified, the first along the base of the northern border of the Picentini mountains and the second one across the Marzano ridge and reaching, in several steps, Pantano San Gregorio Magno (Fig. 2). These surface fault features, striking 300-315°, dipping to the northeast and vertically offset 40 to 100 cm (WESTAWAY, 1993; PANTOSTI & VALENSISE, 1993), on the whole, are generally considered primary tectonic in origin and related to the 0 and 18 sec subevents. More difficult to identify was the

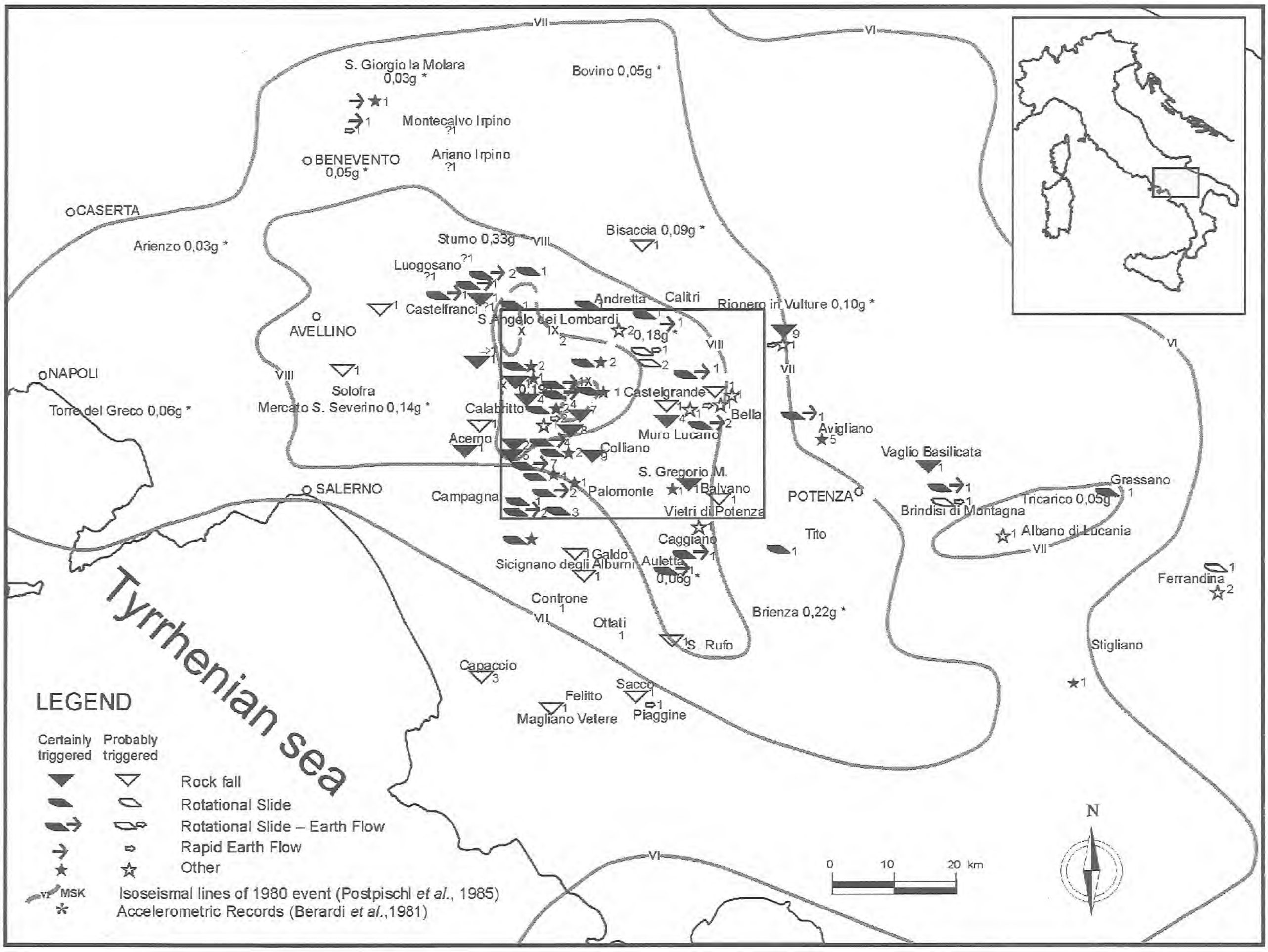


Fig. 1 - Isoseismals of the November 23, 1980, Irpinia – Lucania earthquake and distribution of reactivated landslides. Box embraces the area shown in Fig. 2.

fault responsible for the 40 sec event, notwithstanding comparable magnitudes (Mw 6.2-6.5, 6.4 and 6.3 for the 0, 20 and 40 sec respectively, WESTAWAY, 1993).

We did a comprehensive review of reports and published literature pertaining to the Irpinia earthquake and examined the original material collected in the field soon after the earthquake. Unfortunately the early data gathering and interpretation were intended for a statistical analysis of fractures. Accordingly the data were collected mostly from roadsides and the fractures were not traced into the surrounding terrain. We have thus compared these data with airphoto interpretation, field checks and collection of information from local inhabitants. This paper describes our new findings and interpretation.

## 2. GEOLOGICAL, STRUCTURAL AND SEISMOLOGICAL SETTING

The Southern Apennines are a Neogene, east-verging, fold-and-thrust belt, derived from the deformation of pre-existing Meso-Cenozoic paleogeographic domains (D'ARGENIO *et al.*, 1973). Carbonate shelf sequences of the so called "Apennine shelf unit" (MOSTARDINI & MERLINI, 1986), typically outcrop in the ranges, whereas mainly silico-clastic "Lagonegro" and "Sicilidi" Mesozoic units and Pliocene–Pleistocene deposits crop out in the valleys. These units constitute, respectively, the intermediate, the lowest and the highest thrust sheet, all overthrusted upon the "Apulian carbonatic shelf unit", part of the "Foreland domain" (MOSTARDINI & MERLINI, 1986).

Along the Tyrrhenian side of the Southern Apennines belt, compression has been active from early Miocene through late Pliocene time, while in the southernmost and more external segments of the belt it ceased only in the middle Pleistocene (SCANDONE *et al.*, 1990; CINQUE *et al.*, 1991). Since late Pliocene, crustal extension and regional uplift migrated from west to east, progressively dissecting the compressional architecture. This generated a segmented system of capable normal faults; i.e. active faults that grow by the repeated occurrence of coseismic surface faulting. This fault system shaped the immature basin-and-range topography of the Southern Apennines and is responsible for moderate to strong earthquakes (see, for example, MICHETTI *et al.*, 2000) (Figs. 3 and 4).

Modern seismological observations indicate that the Southern Apennines are characterized by M 5.5 to 7.0 crustal earthquakes (hypocentral depths in the range of 5 to 15 km), typically showing normal faulting focal mechanisms (e.g., ALESSIO *et al.*, 1995).

The 1980 earthquake area was also affected in historical times by at least two other events of similar energy, in 989/990 ($I_0$ = 9.0 MCS), and 1694 ($I_0$ = 10.5 MCS). There is poor information about the 989 event, but much greater data for the 1694 earthquake, which almost perfectly overlaps the 1980 event. The historical sources describe numerous near and far field geological effects of the 1694 earth-

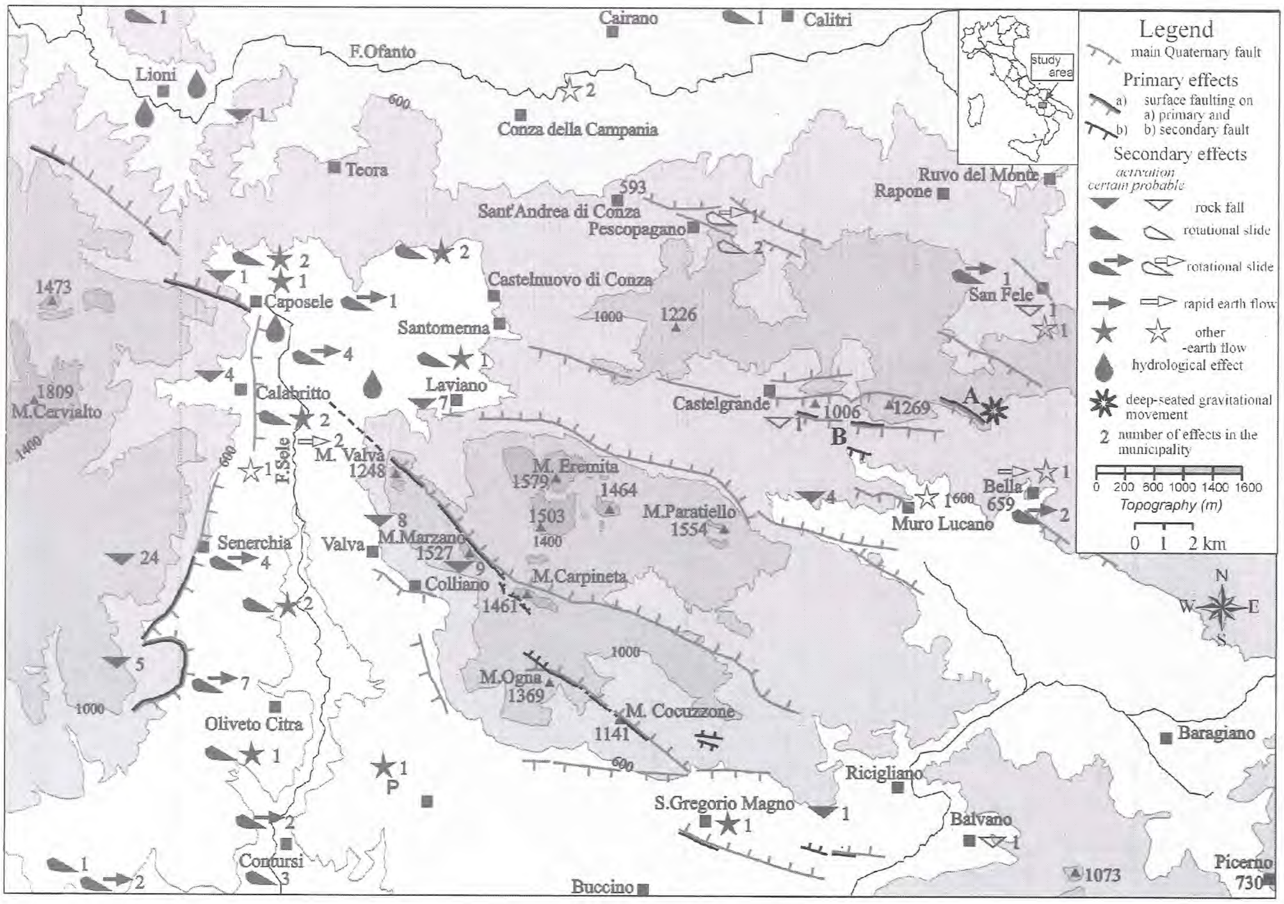


Fig. 2 - Ground effects of the November 23, 1980, Irpinia – Lucania earthquake. A and B are sites with previously unpublished evidence for surface faulting as described in the text: A – Costa Monticello, B – Costa Pannicaro.


Fig. 3 - Landsat image of the Irpinia area (courtesy of Stefano Salvi, INGV, Rome)

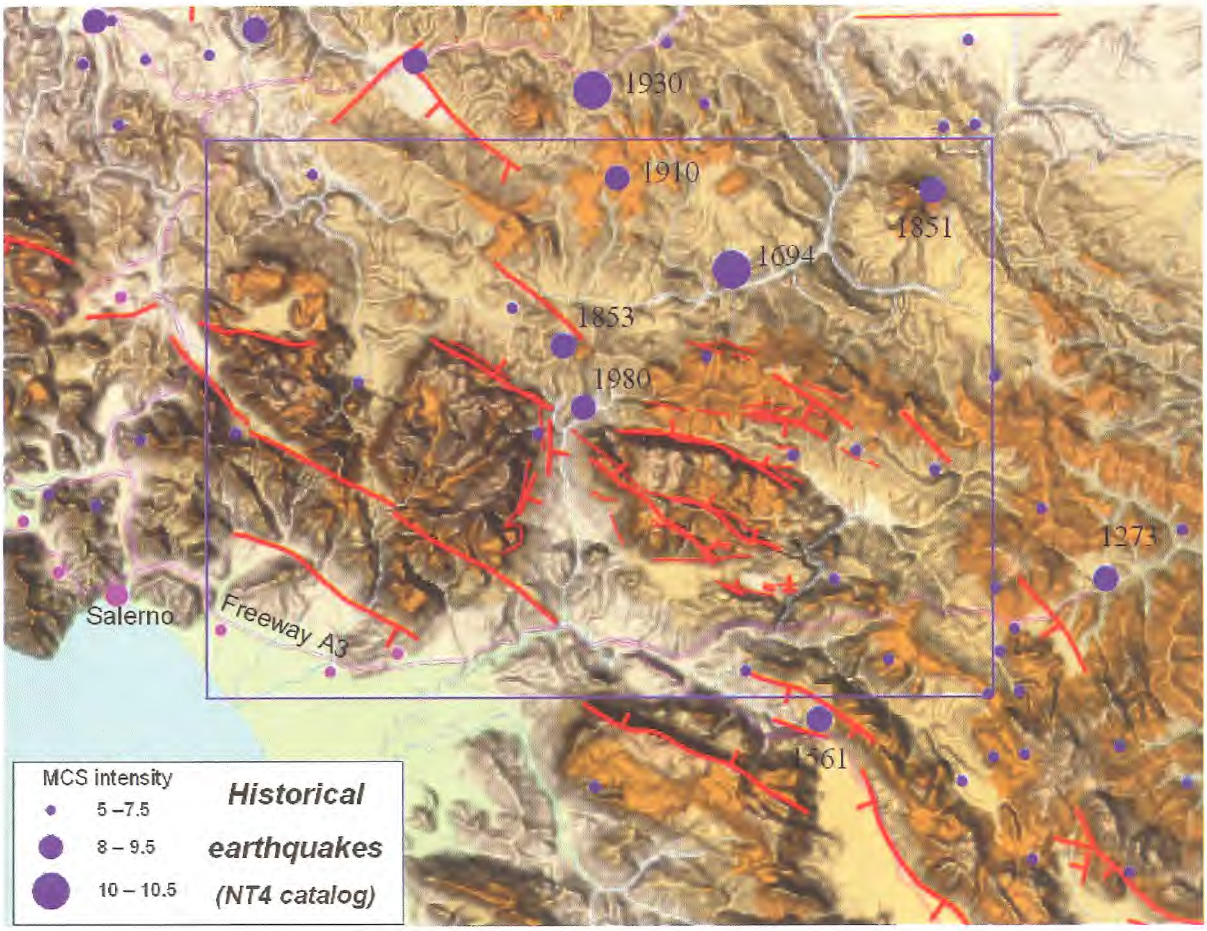


Fig. 4 – Distribution of active faults (according to ITHACA database, MICHETTI *et al.*, 2000) and historical earthquakes (NT4 catalog, CAMASSI & STUCCHI, 1998). Box embraces the area shown in Fig. 3.


Fig. 5 – Surface faulting along the bedrock fault scarp near Senerchia: a) reactivated fault plane affecting striated, poorly cemented, *eboulis*, and displacement of the roadway; b) free-face at the base of the limestone fault plane. Photos taken on 04.04.1981, at close distance along the road behind the village; courtesy of Prof. Albert Pissart.

quake, especially ground cracks and slides. Noteworthy is the occurrence of a 17 km long fracture in the mountain near Teora (location in Fig. 2). During the earthquake several springs increased or reduced their discharge, or even dried up temporarily. Water turbidity and gas emissions were also observed (SERVA, 1981; BOSCHI *et al.*, 1995; ESPOSITO *et al.*, 1998).

## 3. REVIEW OF THE COSEISMIC SURFACE EFFECTS AND DESCRIPTION OF NEW DATA

Our review of pertinent literature, coupled with air-photo interpretation, field survey and eyewitness interviews allow us to portray the landslides, deep-seated gravity slope deformations, soil fractures and tectonic surface ruptures associated with the November 23, 1980 Irpinia-Lucania earthquake (Fig. 2).

As for surface faulting effects, in addition to published reports (including CINQUE *et al.*, 1981; BOLLETTINARI & PANIZZA, 1981; CARMIGNANI *et al.*, 1981; WESTAWAY & JACKSON, 1984; PANTOSTI & VALENSISE, 1990), we examined the original field maps drawn immediately after the earthquake by CARMIGNANI *et al.* (1981). Also, we collected unpublished materials from researchers who visited the epicentral area few days to few months after the earthquake. Our field inspections, coupled with new eyewitnesses reports, permit us to reinterpret the extent and origin of earthquake related surface effects. In particular, we note that ground ruptures near Senerchia (Fig. 5) and Costa Monticello-Costa Pannicaro (sites A and B in Fig. 2) exhibited features typically associated to coseismic surface faulting in central-southern Apennines. In this paper we focus

Fig. 6 - Costa Pannicaro fault-generated range front. Arrows indicate location of fractures mapped by CARMIGNANI *et al.* (1981).

Fig. 7 - Costa Pannicaro site (B in Fig. 2; arrows in Fig. 6), Sabina points to a broken wall which suffered a vertical displacement of nearly 20 cm, being located right above the 1980 fault rupture; the old woman witnessed the event.

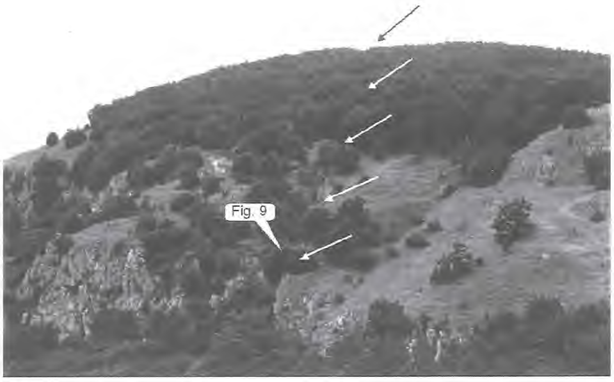


Fig. 8 – Landscape view of Costa Monticello, where previously unreported earthquake ground effects were discovered, as described in text. Arrows show location of the *sackung* trench reactivated in 1980 in the Mesozoic limestone bedrock. View toward west.

Fig. 9 - Details of the trench, down to 4 m deep, shown in Fig. 8.

on the latter sites. A set of ground fractures and fault scarps mapped by CARMIGNANI *et al.* (1981) at the Costa Pannicaro site (arrows in Fig. 6), between Muro Lucano and Castelgrande (Fig. 2), each a few hundred meters long, clearly represents evidence for surface faulting, and is associated with a down-to-the-southwest vertical displacement of 10 to 20 cm (Fig. 7) over a total length of ca. 4 km (location B in Fig. 2).

At nearby Costa Monticello, eyewitnesses described the coseismic reactivation of (a) a sackung with the formation of a ca. 200 m long, up to 2 m wide and 4 m deep, trench in the limestone bedrock, east-west trending, on the hill slope (Figs. 8 and 9), and (b) a southwest-dipping limestone bedrock fault scarp at the base of the mountain range (Figs. 10 and 11a), with the formation of a ca. 20 to 30 cm free-face (Fig. 11b) over a distance of nearly 2 kilometers (location A in Fig. 2). It is important to note that, to our knowledge, there is no previous written account of the effects at the Costa Monticello site, which are described and mapped here for the first time.

The entire surface effects described above are located along a set of parallel faults which are part of the same tectonic structure (Figs. 3 and 4). This is a limestone horst, bounded on the north and on the south by normal faults and on the east by a thrust fault through which the limestones of the "Apennine shelf unit" overhang marly deposits of the "Upper Lagonegro unit". The tectonic features are at the base of mountain escarpments (Fig. 6), and thus reflect the recurrence of normal faulting. In contrast, the sackung has developed at the extreme eastern-end of the structure, where limestones are thrust over less competent marls.

## 4. INTERPRETATION AND CONCLUSIONS

The Costa Monticello (A in Fig. 2) and Costa Pannicaro (B in Fig. 2) sites are located along the same Quaternary tectonic structure, including three main southwest-dipping normal faults that show geomorphic characteristics typical of capable faults (*sensu* AZZARO *et al.*, 1998) in the Southern Apennines (MICHETTI *et al.*, 1997; MICHETTI *et al.*, 2000). Assuming the whole structure ruptured during the 1980 earthquake, the end-to-end rupture length would be about 8 km. This surface rupture might have been associated with the sub-event that occurred at 40 seconds along a SW-dipping fault (Ms = 6.2, WESTAWAY & JACKSON, 1987; Ms = 6.3, WESTAWAY, 1993). The Costa Pannicaro and Costa Monticello fault traces lie very close to the surface projection of "the likely 40-s fault plane" interpreted by BERNARD & ZOLLO (1989; see their Fig. 10) based on levelling and seismological data.

This hypothesis requires verification. Additionally, even with our new data and reinterpretation, the extent and ultimate primary (tectonic) vs. secondary (gravitational) nature of at least some ground effects is still unknown. Nevertheless, we interpret the Sele valley effects, described by CINQUE *et al.* (1981) and CARMIGNANI *et al.* (1981) as tectonic in origin, occurring on a branch or at least on a sympathetic fault.

In our viewpoint, the effects on sympathetic faults belong to a category of surface features that are both tectonic and gravity induced (see discussion in BLUMETTI, 1995). For example, the purely gravitational effect of the sackung reactivation at Costa Monticello is the last step in a scale of phenomena ranging from entirely tectonic (e.g.,


Fig. 10 – a) bedrock fault scarp near Costa Monticello. This site is right beyond the ridge of Fig. 8, seen from opposite direction. View toward east-southeast.

primary surface faulting) to entirely gravity-driven (e.g., large deep seated landslides), passing through all the possible combinations of gravity and tectonic components. As in many other regions shaped by Quaternary crustal extension, these seismically-induced effects are widespread in the Apennines, and sometimes totally characterize a given area.

We likewise believe that there was a significant gravity-driven component in the coseismic surface rupture along the Mt. Marzano segment, which extends for nearly 8 km near the top of the mountain ridge and cuts many apparently "karstic" depressions. For instance, similar effects have been described for the 1703 earthquake sequence in Central Italy (BLUMETTI, 1995). As noted by GIORGETTI & SERVA (1990), many surface faulting features affected small closed basins, such as Piano di Pecore, Piano Neurale, Piano il Parco and Pantano di San Gregorio Magno (for location and description see for example PANTOSTI & VALENSISE, 1990, 1993). This is a common feature along many capable faults in the Apennines, where karst-like depressions develop where earthquake ruptures are located.

Therefore, we interpret the tectonic-karstic basins

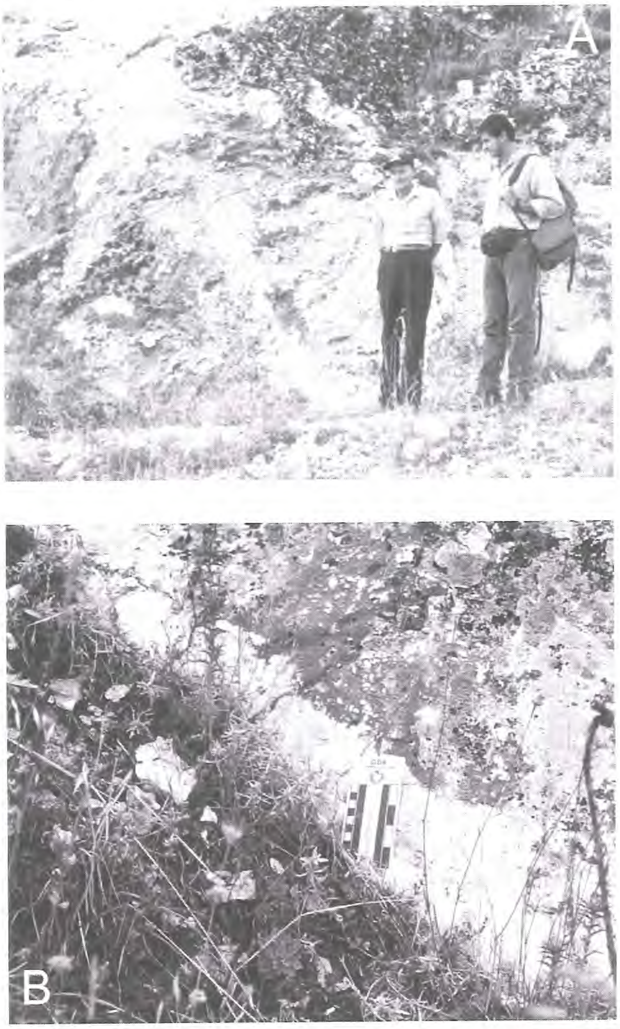


Fig. 11 – a) free-face due to primary surface faulting along the bedrock fault scarp near Costa Monticello; b) detail of the 1980 coseismic reactivation (vertical offset nearly 20 cm). Location is slightly west of the site of Fig. 10. Mr. Ferracane (left) witnessed the event and provided precious information.

and gravity-driven phenomena, as observed during the 1980 Irpinia earthquake, as seismic landforms or *seismites* (*sensu* VITTORI *et al.*, 1991). We regard all effects of the Irpinia earthquake as typical of the ongoing tectonic evolution in this part of the Apennines. In essence, we conclude that the Southern Apennines are not entering a new stage of tectonic deformation, as suggested by some authors (e.g., PANTOSTI & VALENSISE, 1990). Rather, the Irpinia earthquake and its tectonic effects are normal processes, and are the latest event in a long history of seismo-tectonic impacts on the landscape.

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