The January 15, 1466 and November 23, 1980 Irpinia (Italy) earthquakes

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ABSTRACT On the night between 14 and 15 January of 1466, an earthquake damaged towns close to those more recently destroyed by the 1980 Irpinia earthquake. It was felt in Naples, about 80 km from the epicentre, resulting in panic and slight damage. To obtain source parameters related to January 15, 1466, the observed macroseismic field of the November 23, 1980 earthquake was reproduced by synthetic peak strong acceleration. The results suggest that the whole of the 1466 faulting was again activated by the 1980 event and that the northern part remained non-activated. Quite possibly, the near southernmost source of the large earthquake of 1456 affected the occurrence of the nearby event ten years later. Furthermore, the value of M_o=7.5 10^{18} Nm obtained makes the medieval event of 1466 one of the most severe recorded in southern Italy.

1. Introduction: the January 15, 1466 event

An earthquake occurred in 1466 on January 15 at about one o'clock (local time) at night. It caused slight damage, but considerable panic in Naples. The people left their homes *en masse*, sleeping in the open, in shelters and pavilions for many days, and participating in religious processions promptly organized by Archbishop Oliviero Carafa. King Ferrante had gone hunting in Apulia; when coming back, he painstakingly avoided the unsafe villages in the epicentral area. According to contemporary epistolary sources, these villages suffered "damage", "inestimable damage" and in some "there was not a person left alive" (Figliuolo and Marturano, 1996). However, to enhance the strength and courage of the sovereign, the effects of this medieval earthquake were recorded, in miniature, by Nardo Rapicano (Gaeta, 1956): frightened people are depicted running out of a crumbling church whereas the fearless King Ferrante, immovable, is shown in prayer.

Underestimated by the Neapolitan chroniclers, probably because the location of meisosismal area was far from the busiest roads, and also because greater damage occurred in the capital and in the Neapolitan kingdom during the extraordinary December 1456 (I_{max}=XI) and November 1461 (I_{max}=X) events, this earthquake was subsequently forgotten (Bonito, 1691; Mercalli, 1883), disregarded (Baratta, 1901) and finally expunged from catalogues (Boschi *et al.*, 2000; CPTI Working Group, 1999). The 1466 event heavily damaged the villages of Balvano, Buccino, Calabritto, Calitri, Caposele, Colliano, Laviano, Muro Lucano, Palomonte, Pescopagano, Quaglietta, Ricigliano, Ruvo, San Gregorio Magno, and Teora (see Fig. 1 for location), close to those tragically hit by the recent 1980 earthquake.

The aim of this article is to find the location and size of the causative fault of this medieval

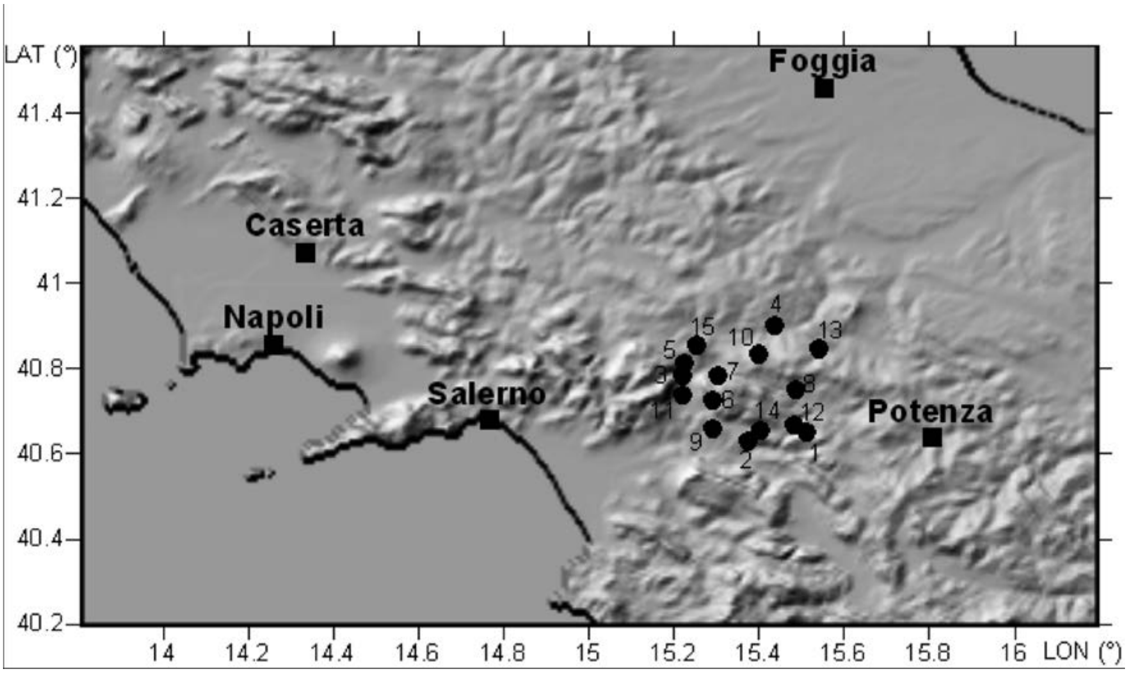

Fig. 1 - Villages heavily damaged by the earthquake of January 15, 1466, 1: Balvano, 2: Buccino, 3: Calabritto, 4: Calitri, 5: Caposele, 6: Colliano, 7: Laviano, 8: Muro Lucano, 9: Palomonte, 10: Pescopagano, 11: Quaglietta, 12: Ricigliano, 13: Ruvo, 14: San Gregorio Magno, 15: Teora.

event comparing its epicentral macroseismic field to the 1980 one reproduced by synthetic peak ground acceleration (PGA).

2. The November 23, 1980 earthquake

The Irpinia earthquake of November 23, 1980 was the last large M_s= 6.8 (ISC) - 6.9 (NEIC) event in the southern Apennine mountains. A complex system of normal faults was activated during this earthquake. The rupture was characterized by at least three main different episodes generally indicated as 0-s, 20-s and 40-s sub-events, associated to Carpineta-Marzano-Picentini-San Gregorio and Conza (antithetic) faults respectively. The seismic moment was (2.6±0.2) 10^{19} Nm released in the three main sub-events as 60%, 25%, and 15% respectively (Giardini, 1993).

Nucleation probably occurred in a high-velocity region, at a depth of 10-12 km, over a 60°-

Table 1 - November 23, 1980 earthquake: locations of main shock.

Lat. N (°)	Lon. E (°)	Ref.
40.77	15.30	Del Pezzo *et al.* (1983)
40.83	15.29	Vaccari *et al.* (1993)
40.72	15.41	Westaway (1993)

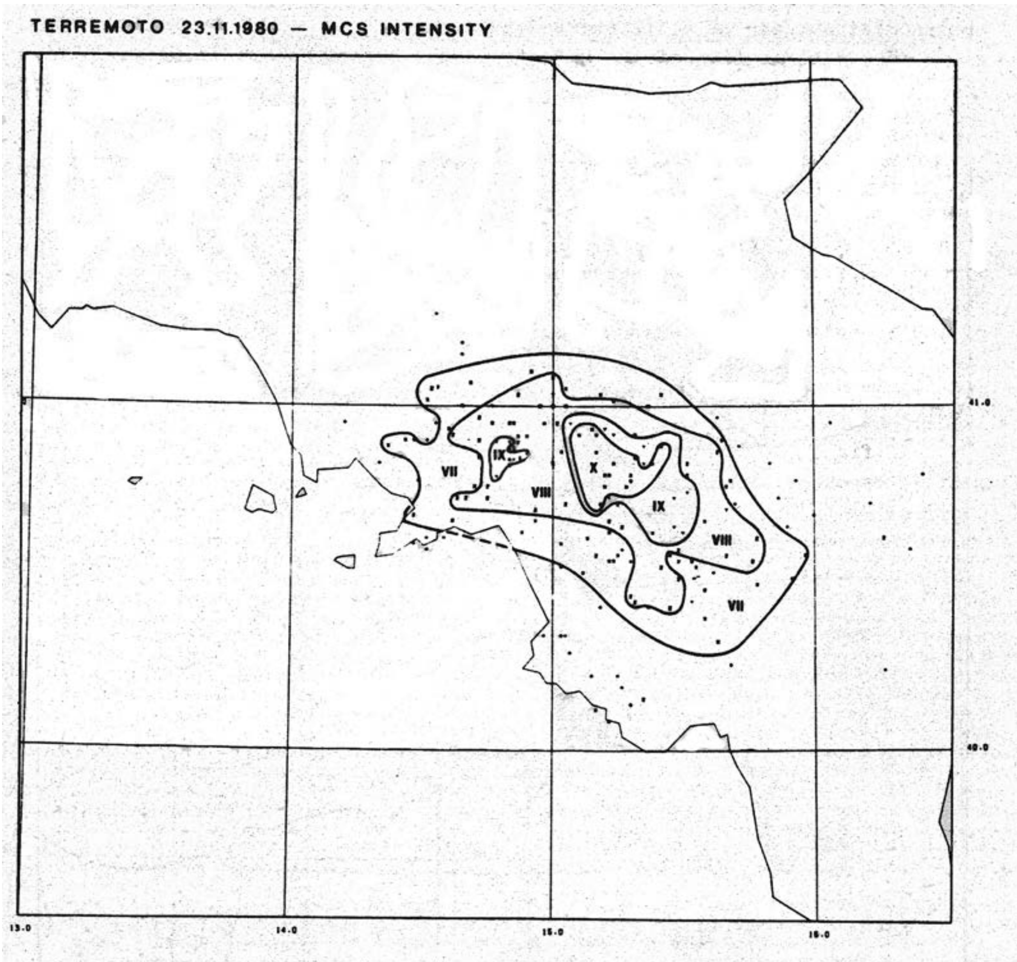

Fig. 2 - Earthquake of November 23, 1980. MCS intensity map of the epicentral area [Fig.13 from Postpischl *et al.* (1982)].

dipping plane with strike 305÷330°N. The main fault nucleation site has oscillated a few kilometers according to contemporaneous surveys and recent literature (Table 1).

Following Westaway (1993), the main rupture from the deep southeast end of the Carpineta fault propagated both northwestwards in the Marzano segment and then, after a short (0.5 s) gap, on the Picentini fault, and southeastwards on the San Gregorio fault. The gap coincided with the Sele Valley at the surface. The sequence consisted of NW-propagating ruptures lasting ~15 s and covering ~40 km ($M_o \approx 1.3 \times 10^{19}$ Nm) and a ~10 km SE ($M_o \approx 2 \times 10^{18}$ Nm) propagating fracture started ~14 s later (Westaway and Jackson, 1987; Westaway, 1993). A further asperity was located near Sturno, in a NW direction (Bernard and Zollo, 1989; Vaccari *et al.*, 1993) near the Castelfranci aftershock cluster where faulting began ~12 s after the initial rupture (Westaway, 1993). Computed solutions from leveling data (Pingue *et al.*, 1993) and main segments of the fault traces (Pantosti and Valensise, 1993) are roughly in accordance with seismological interpretation.

Macroseismic surveys following the earthquake of November 23, 1980 began two days after

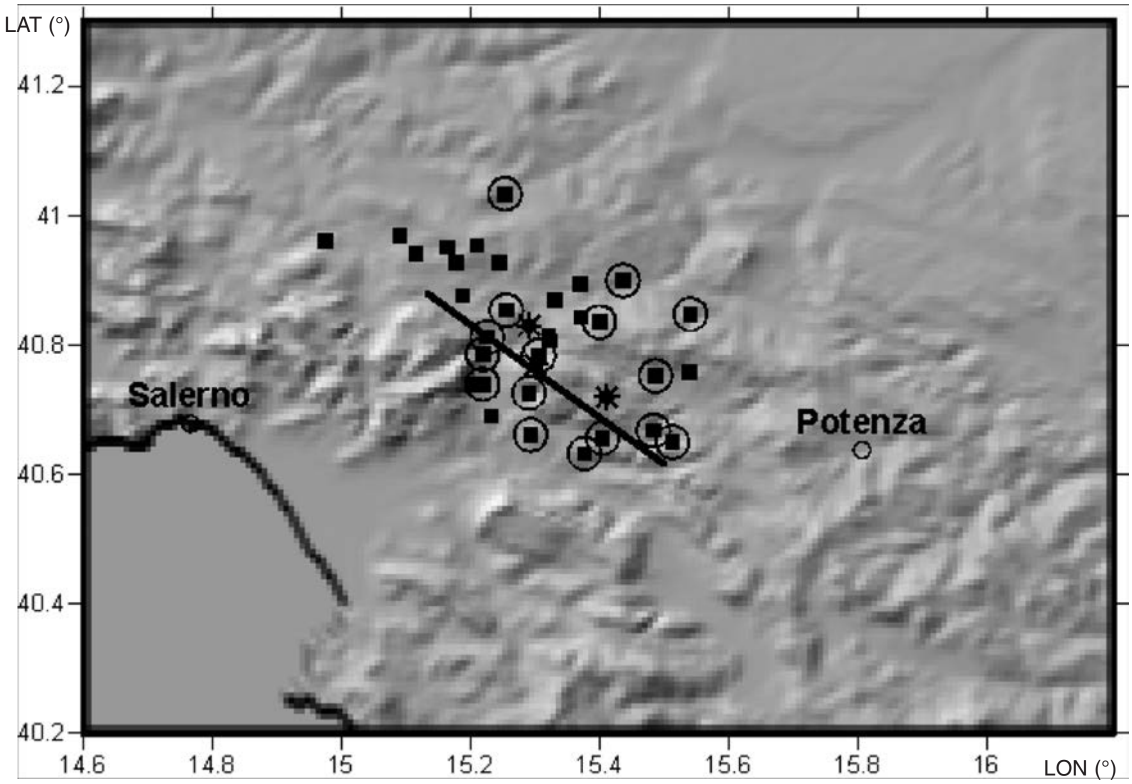

Fig. 3 - Earthquake of November 23, 1980 (squares) and January 15, 1466 (open circles): $I_{(MCS)} \geq$ IX sites. The line is the intersection of the main faults constrained by surface and levelling data (Pantosti *et al*., 1993; Pingue *et al*., 1993) and strong-motion recording (Bernard *et al*., 1993; Westaway, 1993). Stars are used to indicate the epicenters in Table 1.

the event and in 16 days 306 inhabited centers were visited in order to identify $I \geq$VII effects. The results were presented at the Rome (Postpischl *et al*., 1981) and Athens, 7th ECEE meetings (Postpischl *et al*., 1982), utilizing MCS intensities (Fig. 2), and published in the Atlas of Italian earthquakes (Postpischl *et al*., 1985) by MSK intensities. The 1980 earthquake caused considerable panic in Naples: many left their homes *en masse*, sleeping in their cars for several days. A seven-floor building collapsed and most houses in the historic center required subsequent reconstruction and repairs.

The $I_{(MCS)}$ ≥IX of 1980 and the villages damaged by the 1466 earthquake, as well as the epicenters of Table 1, are reported in Fig. 3. The figure also shows the fault trace as resulting from geological surveys and inversion of leveling data (Pantosti *et al*., 1993; Pingue *et al*., 1993) as well as strong-motion recording (Bernard *et al*., 1993; Westaway, 1993). Fig. 3 shows that 1466 and 1980 data can be seen to correspond in the southern part.

3. Focal parameters

Most of the villages damaged in 1466 correspond to the historic nucleus of the towns in the

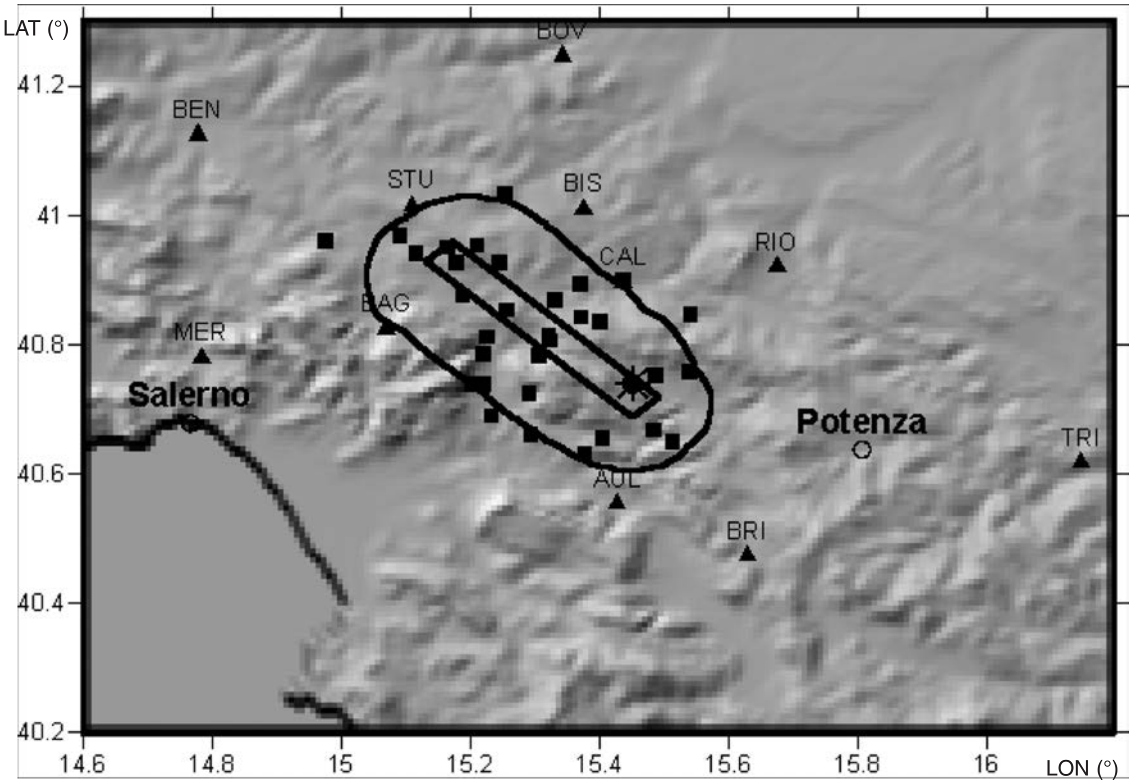

Fig. 4 - Earthquake of November 23, 1980: synthetic I = IX isoseism and surface projection of the causative fault. Squares: $I \geq$ IX sites; star: nucleation point; triangles: strong-motion recording sites, AUL: Auletta; BAG: Bagnoli; CAL: Calitri; STU: Sturno; MER: Mercato; RIO: Rionero; BIS: Bisaccia; BEN: Benevento; BRI: Brienza; TRI: Tricarico; BOV: Bovino.

mesoseimal area of November 1980, characterized by a rough building homogeneity, well contemplated by the MCS scale. The MCS intensities obtained in the macroseismic survey, following the 1980 earthquake, considered the damage suffered only by the historical centers. Hence, we will make use of the MCS 1980 data to compare this to the medieval event. For this purpose, we subdivide the faults into smaller parts summing the single contributions to obtain effects at observation points. The idea of modelling large events by a summation of small ones started with Hartzell (1978), who summed empirical records of foreshocks and aftershocks, with appropriate time delay, to approximate the mainshock record. Later, a number of semi-empirical and theoretical approaches were proposed to represent the source processes, such as the use of observed near-field records, theoretical source time function, and stochastic ω^2 source spectrum (e.g. Somerville *et al.*, 1991; Hartzell and Heaton, 1983; Zeng *et al.*, 1994). A different approach models the propagation effects empirically by using observed dependence of ground motion amplitude and duration on distance.

We reproduced the observed epicentral macroseismic field of 1980 by synthetic PGA following a semi-empirical technique recently proposed by Midorikawa (1993) based on the use of regional attenuation relations that account for the rupture geometry and propagation

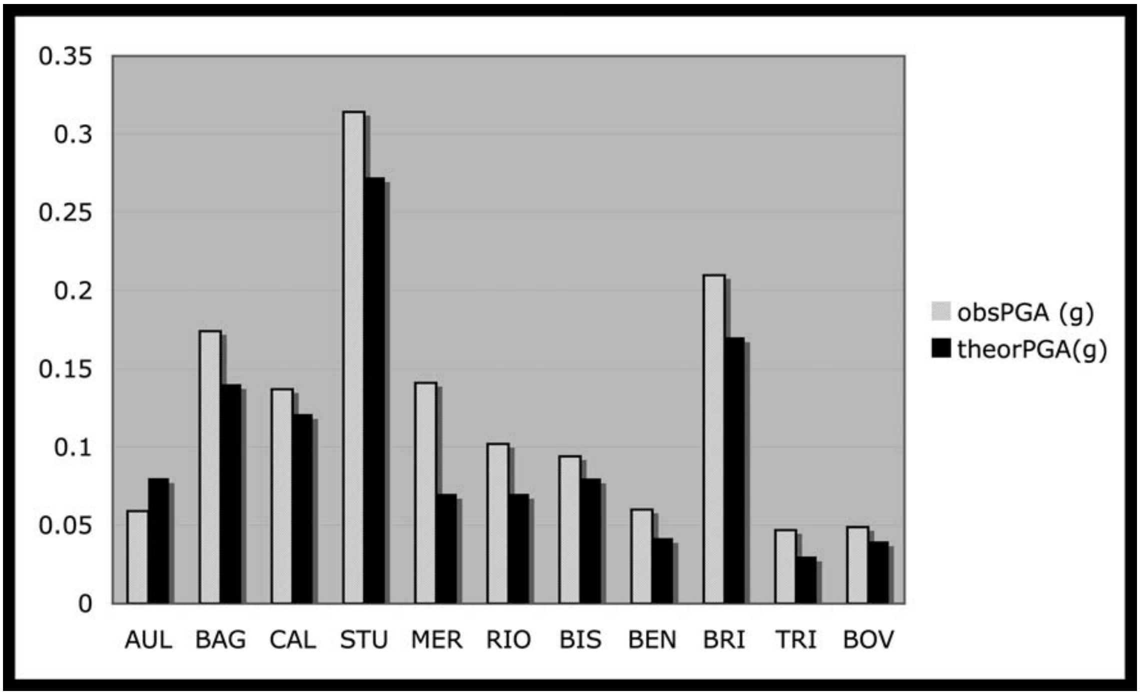

Fig. 5 - Earthquake of November 23, 1980: recorded and calculated PGA (g) values

characteristics of the medium. In this approach, the source of the earthquake is modelled as a rectangular rupture, and the simulation technique is based on the EGF technique of Irikura (1986). This method employs an acceleration envelope as Green function, whereas the empirical Green function technique uses an aftershock event. In Midorikawa's (1993) technique, the shape of the envelope function is estimated using empirical relations applicable in the source region, and the source is consistent with the ω^2 source model in the high frequency range. In this approach, the source of an earthquake is treated as a finite fault generating a target earthquake of magnitude M. This fault is further divided into subfaults or small elements and each element releases the acceleration envelope waveform as the rupture front approaches the center of the element representing earthquakes of magnitude M'. The acceleration envelope waveform is determined from the empirical relation and the summation of envelopes from each element gives the resultant envelope.

We applied this technique to analyze the characteristics of the 1980 earthquake, assuming a homogeneous model of the Earth (Vs = 3.3 km/s; Vr = 0.8 Vs = 2.7 km/s; where Vr is the rupture velocity). The relation given by Bommer *et al*. (2003) that includes the coefficient for normal faulting, was used for computing the horizontal PGA (in g):

$$\log \text{PGA} = -1.482 + 0.264\, M - 0.883 \log \sqrt{r^2 + h^2} + 0.117 - 0.088.$$

According to Midorikawa (1993) and Joshi and Midorikawa (2005), the shape of the envelope

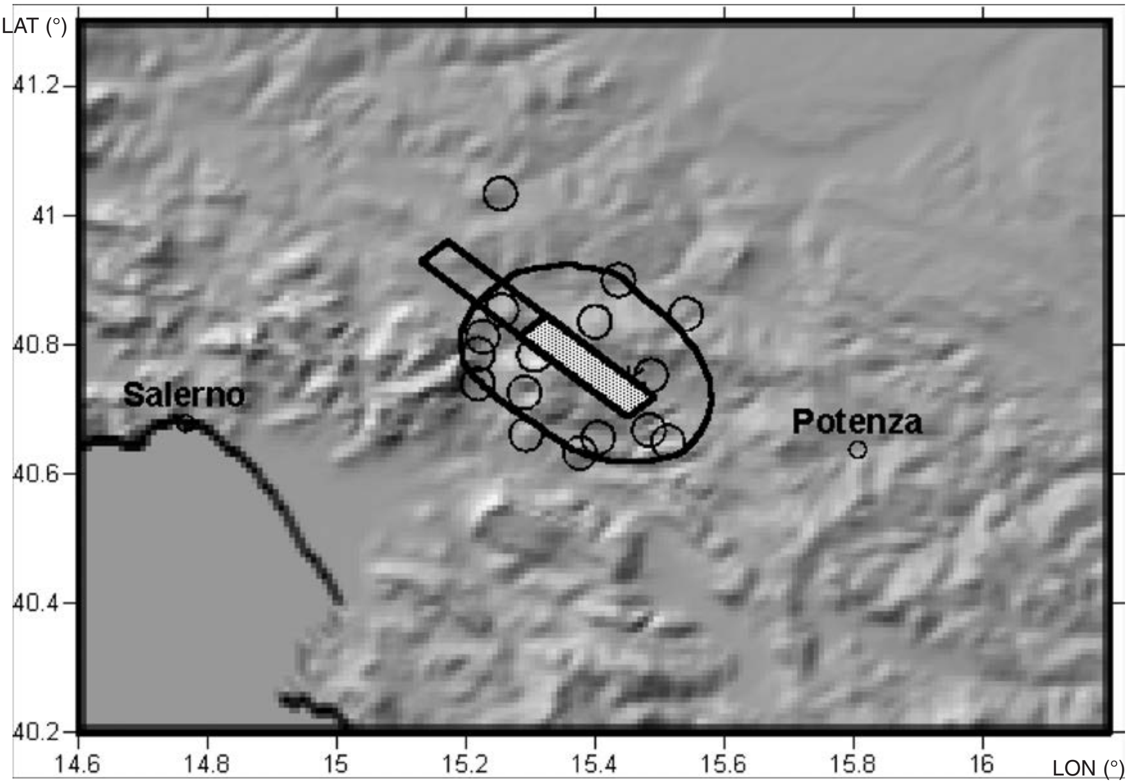

Fig. 6 - Earthquake of January 15, 1466: synthetic I = IX isoseism, $I \geq$ IX sites (open circles), nucleation point (star) and surface projection of the causative fault (shaded rectangle). The causative fault of 1980 is also reported (see Fig. 4).

function of the acceleration waveform used is based on the function proposed by Kameda and Sugito (1978):

$$e(t) = \{(a(g)\,t)/Td\}\ exp\,(1\text{-}T/Td)$$

In this expression $a(g)$ is the PGA and Td is the duration parameter.

The seismic moment ratio between the target and event earthquake is defined according to Kanamori and Anderson (1975):

$$N = (M_0/M_0')^{1/3}$$

where N are the elements within the rupture plane, M_0 and M_0' the seismic moment of large and small events, respectively.

A total of 15 models for 5 x 3 number of elements was considered for the rupture plane 10 km in width modelled as dipping toward 60° NE according to instrumental data. Among these, the models with the nucleation point at the extreme southern corner give comparable values of $I \geq$IX at near field samples. For the comparison, the peak acceleration is converted into intensity by

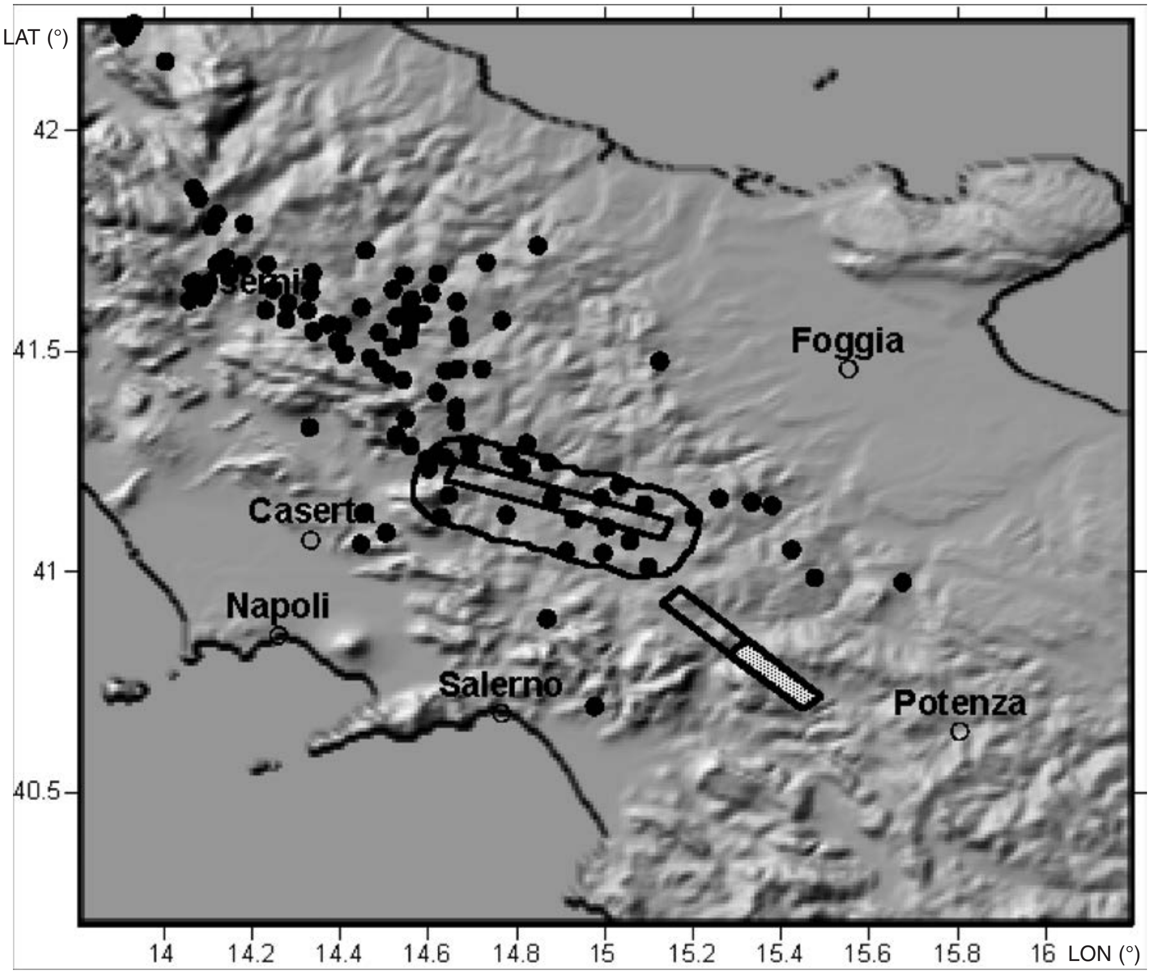

Fig. 7 - Earthquake of December 5, 1456: synthetic *I* = IX isoseism, *I* ≥ IX sites (closed circles), and surface projection of the causative C-fault (southernmost source of 1456). The causative faults of 1466, 1980 are also shown (see Figs. 4 and 6).

using the threshold *a*(*g*)>0.15 and *a*(*g*)>0.30 for *I*=IX and *I*=X respectively, according to Sirovich and Chiaruttini (1993) and Panza *et al*. (1997).

In Fig. 4 the synthetic *I*=IX isoseism and the surface projection of the causative fault for the 1980 earthquake are reproduced. Fig. 4 also reports the distribution of the strong-motion stations closest to the fault.

An attempt was made to compare recorded and calculated PGA. The result is reported in Fig. 5 utilizing the main rupture proposed for 1980 (Table 2) and two additional sub-sources north- and southwards respectively as previously proposed (e.g.: Cocco and Pacor, 1993; Sirovich and Chiaruttini, 1993; Vaccari *et al.*, 1993). The largest recorded-calculated PGA value corresponds to Mercato San Severino (MER), where a site effect had already been hypothesized (e.g. Cocco and Pacor, 1993).

By using the same nucleation point and acceleration threshold, the source for the 1466

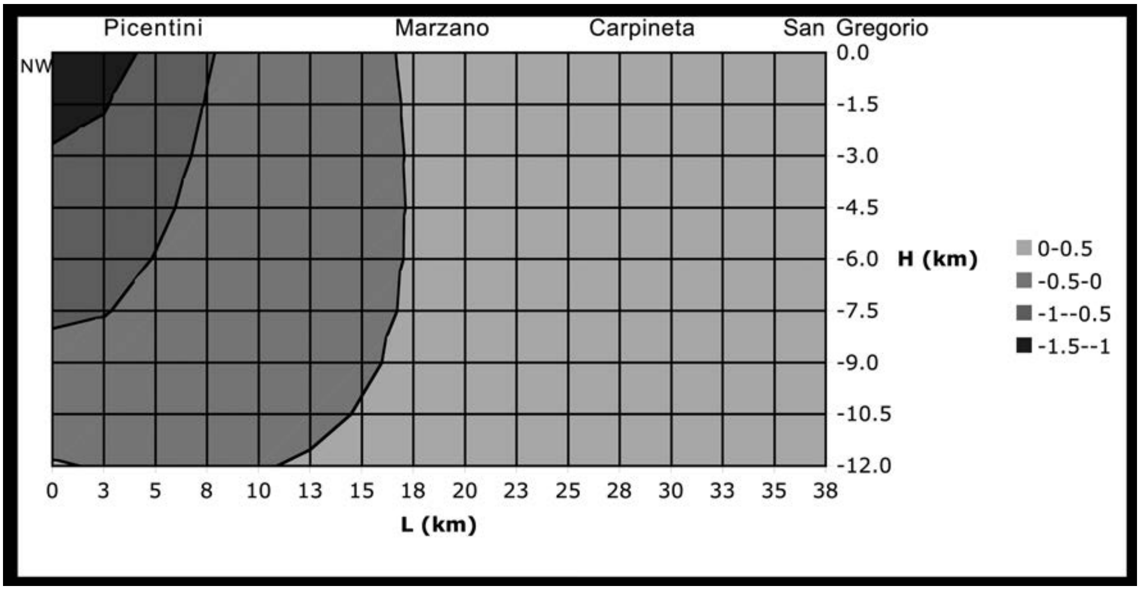

Fig. 8 - Coulomb stress change (Mpa) caused by C-fault (M=7.0; L=44 km; M_0= 4 10^{19} N m) on the 1980-1466 fault surface. The lines show areas of relatively increased (northwestwards) and decreased Coulomb stress where events are favorably triggered and suppressed respectively.

earthquake was obtained by reducing the length of the rupture fault calculated for 1980.

In Fig. 6 the synthetic I=IX isoseism and the surface projection of the causative fault for the 1466 earthquake are reproduced together with those of 1980, for comparison.

The epicentral effects of the two earthquakes are nearly superimposed, suggesting a similar source mechanism. Only the northward part of the 1980 faulting seems to be non-overlapping (Fig. 6). In particular, the source of the 1466 event appears to have activated the San Gregorio, Carpineta and Marzano segments of the 1980 seismic source. The Picentini northwestwards, on the contrary, was a non-activated fault segment.

4. Discussion and conclusion

As stressed above, similar source mechanisms and location link the 1466 and 1980 events. The

Table 2 - Modelling parameters of rupture plane for November 23, 1980 and January 15, 1466 Irpinia earthquakes. Parameters for C-fault (southwestward source of December 5, 1456 earthquake) are also reported. M: surface wave magnitude according to Wells and Coppersmith (1994); Mo: seismic moment according to Lay and Wallace (1995); L: length of rupture plane; N: total number of elements of the rupture plane.

earthquake	M	Mo (Nm)	L (km)	dip (°)	strike (°)	N
23.11.1980	6.9	2.8 10^{19}	38	65	315	15
15.01.1466	6.5	7.5 10^{18}	20	65	315	15
05.12.1456	7.0	4.0 10^{19}	44	65	290	15

1466 source, however, activated only the southern part (San Gregorio, Carpineta and Marzano segments) of the 1980 rupture. By contrast, the northern part (Picentini segment) remained non-activated.

Indeed, an extraordinary event occurred only 10 years before the medieval earthquake, on December 5, 1456, the largest recorded southern Apenninic Italian earthquake (Figliuolo, 1988). It developed as a multiple event on structures subsequently reactivated by the November 3, 1706 (Maiella), July 26, 1805 (Molise), and June5, 1688 (Sannio) major earthquakes (Figliuolo, 1988; Teramo *et al.*, 1999) as well as neighbouring seismogenic structures as evidenced by the wide distribution of high degree effects. In Fig. 7 the sites affected by intensity $I \geq$ IX(MCS) are reported for the 1456 earthquake.

An earthquake alters the state of stress on nearby faults in such a way as to increase or decrease the probability of failure on them. Reasemberg and Simpson (1992) formulated this idea quantitatively in terms of change $\Delta\sigma_f$ in Coulomb failure stress along a potentially failing fault due to rupture of a nearby fault:

$$\Delta\sigma_f = \Delta\tau + \mu' \,(\Delta\mu_n)$$

where $\Delta\tau$ is the change in shear stress, $\Delta\mu_n$ is the change in normal stress and $\mu' = 0.4$ is the effective coefficient of friction. Possible changes in pore fluid pressure are not considered.

Was the proximity to failure of the seismogenic Picentini-Marzano-Carpineta-San Gregorio area (entirely reactivated by the 1980 earthquake) relatively changed by the nearby 1456 event? For this purpose, we supposed a causative pure normal fault (C-fault), responsible for the southern part of 1456 macroseismic effects (Fig. 7 and Table 2), and the stress changes caused by the C-fault 1456 on the plane containing the 1980-1466 fault were calculated following King *et al.* (1994) and Nostro *et al.* (1997). Only the static stress changes due to co-seismic dislocations [using the formulas of Okada, (1992)] were evaluated, considering the postseismic crustal relaxation significant for longer scale time (tens of years).

The results (Fig. 8) show areas of relatively increased (southwestwards) Coulomb stress, and suggest that the subsequent ruptures along the San Gregorio, Carpineta and Marzano segments (activated in 1466) were favorites by the southernmost part of the rupture of the 1456 event and that the Picentini fault (activated in 1980 but not in 1466), on the contrary, was suppressed.

Active seismogenesis of this area is also testified by paleoseismological data, even if this investigation indicates high (1684-2150 years) average recurrence times (Pantosti *et al.*, 1993). In the light of our results, different recurrence times could be evaluated for the fault segments activated on November 23, 1980, and the January 15, 1466 earthquake considered the closer ancestor of the 1980 main event. Finally, in accordance with the model proposed above, a seismic moment of 7.5 10^{18} Nm can be assigned to the 1466 earthquake characterized by a source mechanism like that of 1980.

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