



Surface faulting in Norcia (central Italy): a “paleoseismological perspective”

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Abstract

We carried out paleoseismological analyses in Norcia, one of the oldest town of central Italy. Four trenches were dug in late Pleistocene–Holocene deposits, across an unmapped, antithetic splay of the Norcia Fault System. The investigated fault runs through the recent settlement of the town, brushing against the middle-age city walls. We found evidence of repeated surface ruptures in the past 20 ky, the last one dated to a period fitting with the 1703 AD, catastrophic earthquake ($M=6.8$). Our data (i) show definitively the late Pleistocene–Holocene activity of the Norcia Fault System, (ii) strengthen the historical accounts describing surface ruptures during the 1703 event in Norcia, (iii) cast light on the seismogenic behavior of the 70-km-long fault system between L’Aquila and Norcia (central Italy) and (iv) predict the occurrence of normal surface faulting inside the municipality of Norcia during future $M \geq 6$ earthquakes.

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1. Introduction

The *Vetusta Nursia* of the Romans (Old Norcia; Umbria region) is one of the oldest town of Italy presently still inhabited. The area of the present town has been frequented since the prehistoric period, whereas archaeological excavations demonstrated the

existence of a 9th–6th century BC cabin village outside the city walls. Norcia was conquered by the Romans in 290 BC, and during the Republican Age it was already a fully urbanized site, whose importance is testified by the richness of its hellenistic necropolises. At the beginning of the 1st century, Norcia became a Roman *municipium* ruling a vast territory. The importance of the town at this stage is shown by the relics of walls and gates, public buildings and inscriptions still visible in the present town. During the Imperial Age, it became part of the fourth region

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Sabina and Samnium; nowadays the town, which has 5000 inhabitants, is mainly famous for being the native town of Saint Benedict (5th century AD).

The history of Norcia is also the history of its earthquakes. Evidence for seismic activity dated back to the Roman time, when an earthquake destroyed a holy temple of the town (99 BC: [Iulius Obsequens, 4th–5th century AD](#)). This event was so strong that in

Rome (120-km-far from Norcia) the Mars's spears of the *Regia* trembled ([Aulus Gellius, 2nd century AD](#)).

In fact, Norcia lays within one of the most seismic areas of the Apennine chain, very close to active and “silent” seismogenic faults ([Galadini and Galli, 2003](#)), and it feels the effects of both local and adjacent $M \geq 6$ events. During the past seven centuries, it has been hit by earthquakes five times with an $I_s \geq 8$

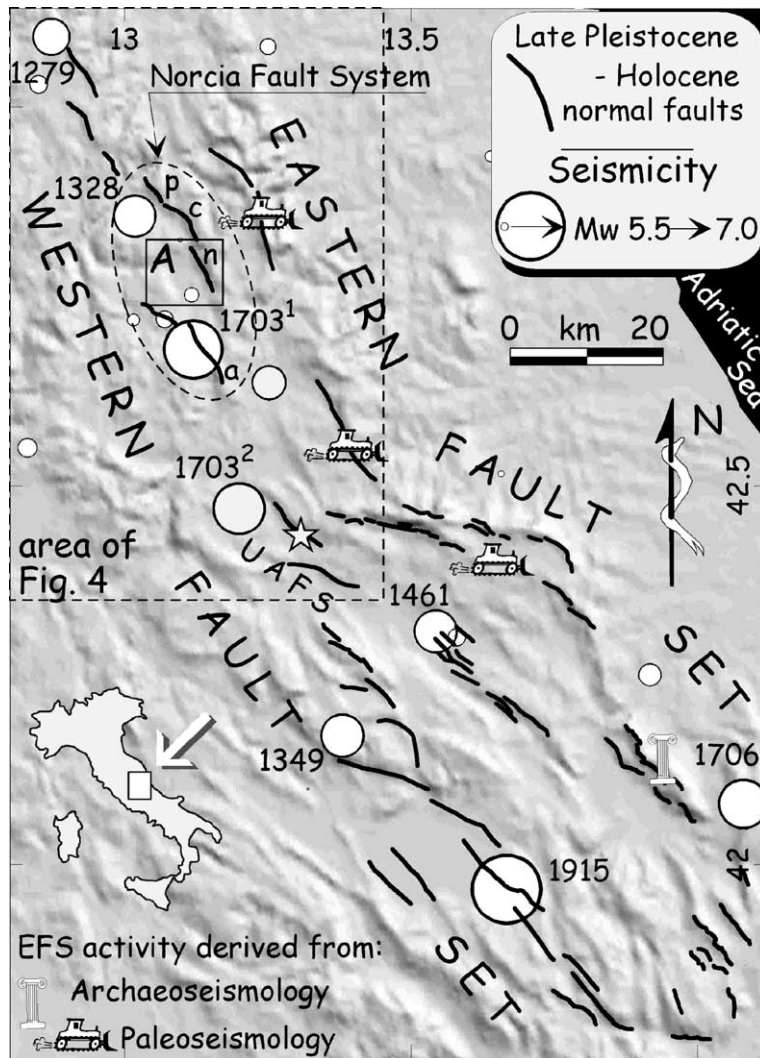


Fig. 1. Shaded relief map of central Apennines, showing the main known active faults (from [Galadini and Galli, 2000](#); downthrown block is always SW) and the associated $M_w > 5.5$ seismicity (mod. from [WG-CPTI, 1999](#)). All the strongest events (labelled) are related to the western fault set, whereas the activity of the eastern fault set (EFS) has been ascertained only through paleoseismological and archaeoseismological studies (the 1706 event is not related to the extensional sector of the chain). Norcia falls inside frame A, which encloses the area of Fig. 2. White star is the location of the paleoseismic analyses carried out on the Mt. Marine fault (Upper Aterno fault system, UAFS) by [Moro et al. \(2003\)](#). a—Mt. Alvagnano fault; n—Norcia fault; c—Campi fault; p—Preci fault.

(MCS local intensity; Monachesi and Stucchi, 1997), the last one in 1979.

In this work, we investigated the fault system responsible for the opening of the Norcia basin; the collected data are the first paleoseismic evidence concerning the causative fault of one of the strongest Norcia's earthquakes (1703 AD, $M_w=6.8$), and show how surface rupture affects the municipality area, running along the old northern city walls (which are built on the top of the fault scarp itself).

The age of the detected “consecutive events” allows to reconstruct a recurrence time for $M\sim 6.8$ events (i.e., “characteristic earthquakes”), although the seismic history of the region and the fault segmentation of the Norcia fault system account for a more complex seismogenetic behavior of the zone.

2. Evidence of active tectonics in the Norcia area

The Apennines have been affected by normal and oblique faulting during the Quaternary (e.g., CNR-PFG, 1987), synchronous to the regional uplift (e.g., D'Agostino et al., 1994) and the eastward thrust migration in the Adriatic area (e.g., Patacca et al., 1990). During the late Pleistocene–Holocene, the central sector of the Apennine chain has been characterized by two parallel active fault sets with predominant normal kinematics (Galadini and Galli, 2000, and reference therein; Fig. 1). The distribution of the seismicity (e.g., Working Group CPTI, 1999: from now CPTI) indicates that earthquakes with $M\geq 6.5$ are related to the westernmost fault system (WFS), while the late Holocene activity of the eastern

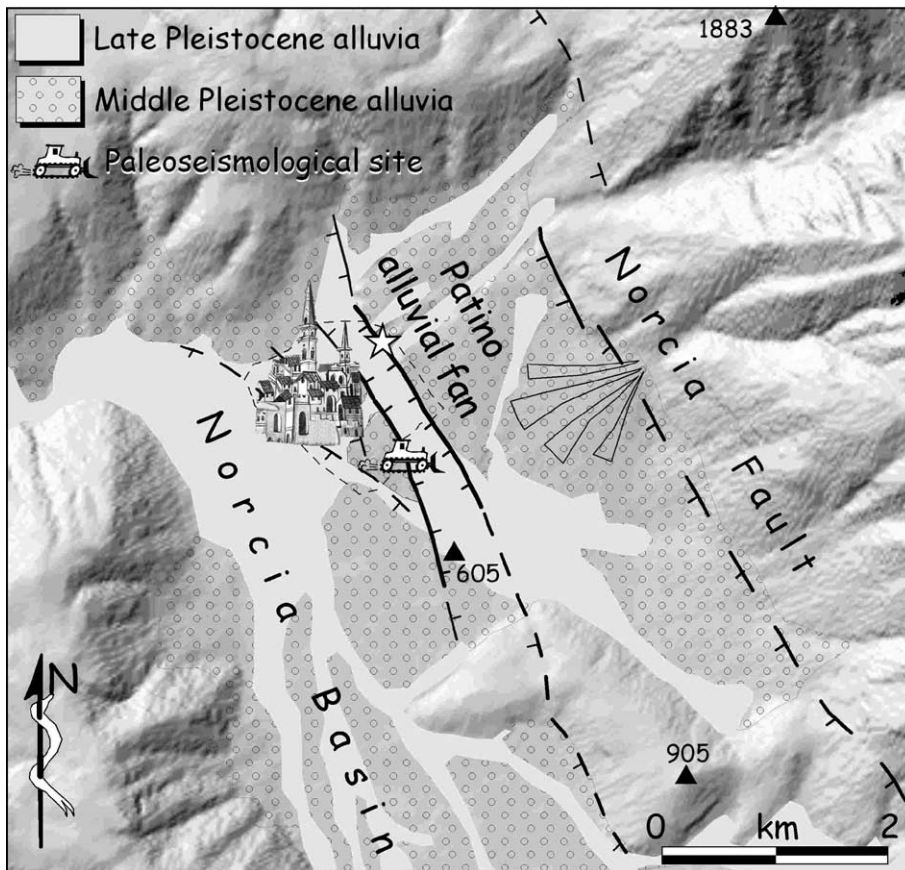


Fig. 2. Shaded relief map of the Norcia basin, showing the Pleistocene alluvial coverage and the active fault system. Bold lines are the investigated graben-like faults. Dashed polyline envelops the area of the Norcia settlement which grew in the past 20 years around the city walls. White star is the location of Fig. 3 (the image of Norcia is from an early 16th century fresco).

system (EFS; not recorded by the historical sources) has been highlighted by means of paleoseismic and archaeoseismic analyses (D'Addezio et al., 2001; Galadini and Galli, 2001, 2003; Galli et al., 2002; Galadini et al., 2003; Fig. 1). For this reason, we consider the EFS as “silent faults”.

Both WFS and EFS drove the opening of intermontane extensional basins, as the one which contains Norcia (i.e., Norcia basin—NB). On its eastern side, this depression is bounded by the Norcia fault (NF; Calamita et al., 1982; Blumetti et al., 1990; Calamita and Pizzi, 1992; Blumetti, 1995; Cello et al., 1997; Roberts et al., 2001), that, together with the Campi-Preci and Alvagnano faults, forms the Norcia Fault System (NFS; Cello et al., 1998a; Galadini and Galli, 2000; WFS. Fig. 1). According to Cello et al. (1998a), also the western side of the NB is bounded by an active, antithetic fault which ruptured in post-Roman times.

The most striking evidence of activity along NFS has been observed on the Mt. Alvagnano and Norcia branches. The former (southern tip of NFS; part (a) in Fig. 1) is marked by a bedrock fault scarp and, according to primary historical sources (i.e., surface breaks cited in Grimaldi, 1703; De Carolis, 1703), was reactivated during the Jan. 14, 1703, earthquake (equivalent magnitude $M_e=6.8$; CPTI, 1999). The NF (Fig. 2) caused the formation of the NB since the early Pleistocene (Calamita et al., 1982) and is responsible for the displacement of late Pleistocene slope deposits (Blumetti, 1995). The NF is manifested by an eroded and retreated, discontinuous fault scarp at the base of the carbonate ridge (eastern slope of the NB), and by fault scarps (related also to antithetic, east-facing splays) carved in alluvial sediments at the foot of the hillslope, east of Norcia (Figs. 2 and 3B). A minimum value of slip rate (0.2 mm/year) has been calculated by Blumetti (1995),

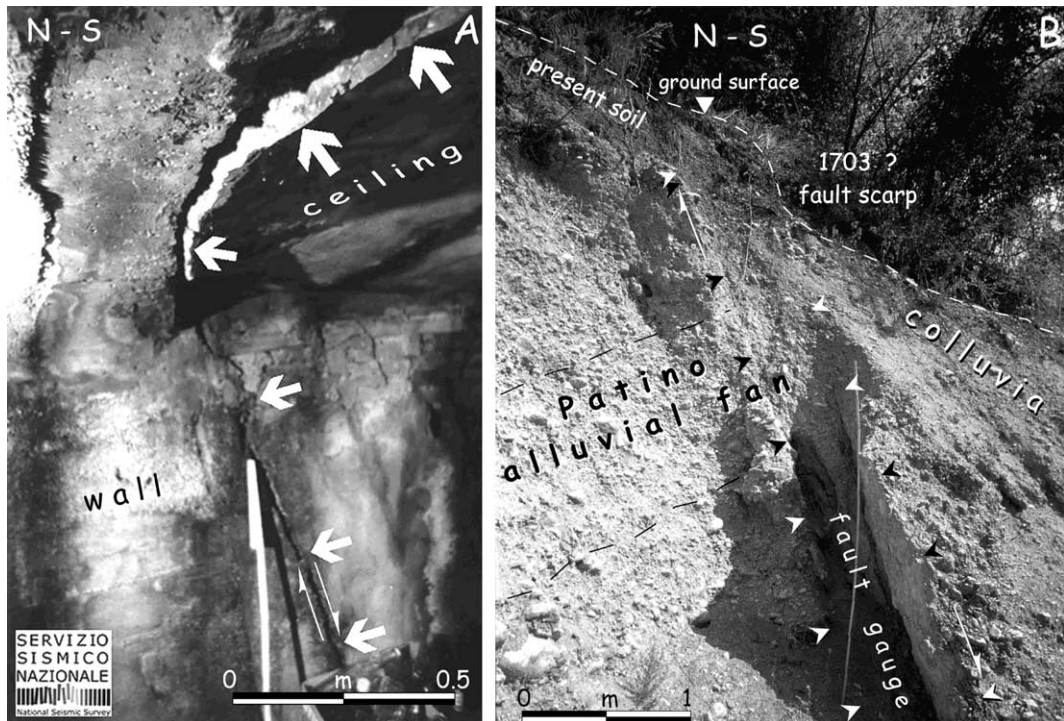


Fig. 3. (A) Norcia: view (looking east) of the plastered wall and ceiling of a cellar, which was excavated inside the cemented Patino fanglomerate, across the Norcia fault (see Fig. 2 for location). The white arrows indicate the 3-D trace of the fault rupture, highlighted by the 4-cm offset occurred during the 1979 earthquake. (B) View of the same fault as panel (A), taken hundred meters eastward. The fault displaces the gravels of the Patino fan against recent slope-debris and colluvia. The scarplet could indicate the rejuvenation due to the 1703 earthquake.

based on the vertical offset affecting a 0.1 Ma secondary alluvial fan. According to high-resolution seismic reflection data (Borre et al., 2003), the SW-facing scarp in front of Norcia (distal portion of the Patino alluvial fan in Fig. 2) subtends a 30-m offset of the top of the buried bedrock (i.e., the same amount as that of the surficial fault scarp), indicating that the entire displacement postdated the deposition of this portion of the alluvial fan.

Finally, instrumental data (CNR-PFG, 1980; Deschamps et al., 1979) and the occurrence of light surface effects (Fig. 3A) suggest that the NF is the causative fault of the 1979, $M_s=5.9$ earthquake, whereas, as part of the NFS, it could be one of the causative faults of the Jan. 14, 1703, earthquake (Blumetti, 1995; Cello et al., 1998a; Galadini and Galli, 2000).

Conversely, neither geological nor geomorphologic evidence of recent activity is available for the Campi and Preci Faults (northern tip of NFS; parts (c) and (p), respectively, in Fig. 1), although a significant seismicity can be related to these branches (e.g., in Galli and Galadini, 1999).

3. Outline of historical earthquakes and associated faults

As mentioned before, the seismicity of Norcia is one of the highest within the central Apennines. Apart from the “extemporaneous” 99 BC event, detailed information concerning earthquakes effects in Norcia and its surroundings are known since 1328, when an $M_e=6.2$ earthquake ($I_o=10$ MCS, CPTI, 1999) hit the town with an $I_s=9-10$ (Monachesi and Stucchi, 1997). Fig. 4 shows the highest intensity datapoint distribution (HIDD) of this event and its hypothetical causative fault (Galli and Galadini, 1999). The same is shown for other strong earthquakes of the region, as the 1599 ($M_e=5.7$, $I_o=8-9$, $I_s=7-8$), 1703 (two mainshocks: (1) $M_e=6.8$, $I_o=11$, $I_s=9-10$; (2) $M_e=6.7$, $I_o=10$; see Fig. 1), 1719 ($M_e=5.0$, $I_o=7-8$, $I_s=6-7$), 1730 ($M_e=5.9$, $I_o=8-9$, $I_s=9$), 1859 ($M_e=5.3$, $I_o=8-9$, $I_s=8-9$), 1979 ($M_e=5.7$, $I_o=8-9$, $I_s=8$) and 1997 ($M_w=6.0$, $I_o=8-9$ MCS, $I=5-6$) events.

It is worth noting that all the events characterized by $M \leq 6$ could be attributed to ruptures occurred on

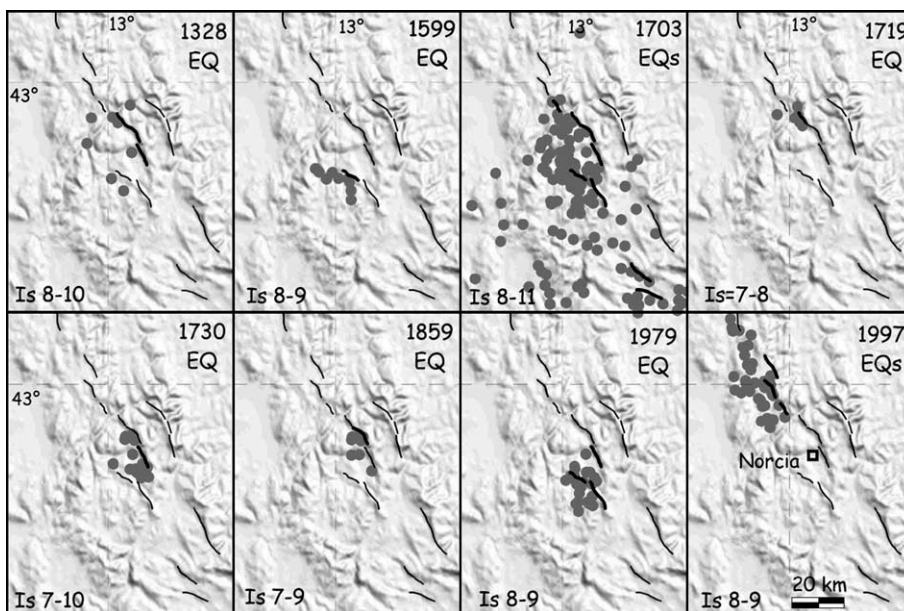


Fig. 4. Highest intensity datapoint distribution (from Monachesi and Stucchi, 1997) of the most severe earthquakes around Norcia (intensity range differs, being shown at the left-bottom of each inset; the considered area is evidenced in Fig. 1). Black lines represent the known active faults (Galadini and Galli, 2000). A tentative association between earthquake and causative fault (bold lines) is shown each time. Note the multiple ruptures related to the 1703 earthquakes (mod. after Galli and Galadini, 1999).

a single or couple of faults (e.g., Colfiorito earthquake of 1997; Basili et al., 1997; Pantosti et al., 1999), while the 1703 multiple event ruptured contemporaneously several fault strands (Blumetti, 1995; Moro et al., 2003). Thus, apart from the small surficial ruptures which we saw during the 1979 or the 1997 events (e.g., in Blumetti, 1995; Galli et al., 1997; Cello et al., 1998b), prominent surface faulting likely occurs only for earthquakes with magnitude comparable to the one of 1703. As a matter of fact, when Norcia was destroyed on January 14, 1703 (resulting in thousand casualties, about 30% of the population), several “noticeable chasms formed in its municipality, and the ground opened in several places in the fields of the Plain” (Bagliivi, 1710), some of these being tentatively related to surface faulting.

4. Paleoseismic analyses

Norcia is founded on a small, conglomeratic plateau gently dipping toward SW. This plateau is a relic of the west shoulder a small tectonic depression (horst-graben-like feature) developed in the distal part

of the Patino alluvial fan (mainly middle Pleistocene according to Blumetti, 1995. Fig. 2). The eastern fault of this graben is marked by a prominent west-facing scarp, which abruptly breaks the flat alluvial fan topset beds. Several pits dug across this scarp in the past years exposed the fault plane separating the fanglomerate and slope-colluvial deposits of undetermined age (Blumetti et al., 1990. Fig. 3B.). The western fault of the graben (i.e., the eastern of the “horst”) is instead characterized by a retreated scarp (Fig. 5). Its smoothing is mainly due to the intensive agricultural works that, since the antiquity, modified the local landscape. The northern tip of this strand runs along the eastern city walls.

We chose to open trenches across this antithetic fault, because of its proximity to the bottom of the graben, which we thought to be filled by late Pleistocene–Holocene sediments and soils, and then, suitable for paleoseismic purpose. We dug four trenches for a maximum depth of 6 m, and 15 m of length, finding net and conclusive evidence of faulting in the exposed sedimentary succession (see Fig. 5 for location; trench 4 did not provide useful paleoseismological data, and, therefore, it is not discussed in the text).

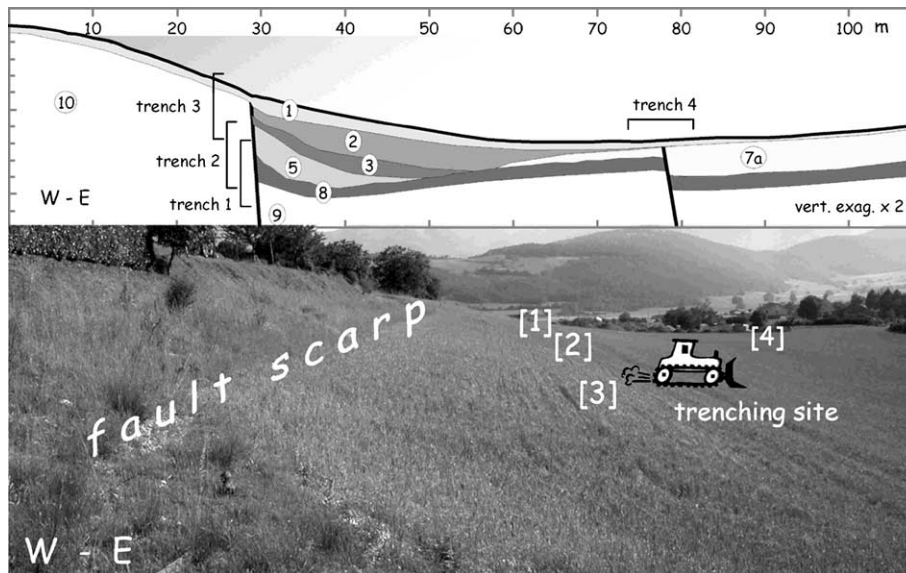


Fig. 5. Below, view looking south of the investigated, smoothed fault scarp (mirrored image). Above, W–E section across the western shoulder of the investigated graben. See units description in Fig. 7 (unit 7a are gravels related to the upper Pleistocene Patino alluvial fan activity; absent in trenches 1–3). Trench 4 is not discussed in the text.

4.1. Stratigraphy

The footwall sequence exposed in trenches is mainly composed by gravels of the Patino alluvial fan; conversely, almost all the units belonging to the hangingwall are of colluvial nature. The parent material of these colluvia are strictly related to the fan-gravel and to the soil developed above the gently dipping, eastern side of the horst-like structure bounded by the investigated fault. Some of these colluvia have been related to known Apenninic climatogenic phases, whereas others could be also associated to the dismantling of coseismic fault-scarp (i.e., colluvial wedge). Colluvial units are separated by pedogenic horizons and by erosional surfaces which account for the lack of some depositional phases. Due to these *hiatus* and to the contemporaneousness of climatogenic and tectonic episodes, in some cases, it was not possible to discriminate the origin of colluvia; in other words, the binomial colluvial wedge/earthquake was not so easily applicable.

The oldest deposits found in trenches (Fig. 7; trenches 1–2) are represented by coarse-to-fine bed load stratified deposits, consisting of carbonate clasts. This sequence is characterized by scour-and-fill structures (e.g., braided channels) indicating that it is part of the distal portion of the Patino alluvial fan (units 10–10a and 9).

In the hangingwall, these gravels are mantled by a ~1-m-thick, evolved, dark-brownish clayey paleosol (unit 8). The soil is de-carbonated, and it is truncated by orange, silt-supported, fine gravels colluvium (unit 7), which present a thin stone-line at their top.

Unit 7 is covered by orange, faintly layered, sand-silt-supported fine gravel (unit 5, colluvium), which gradually loses its carbonate skeleton going toward the graben depression (east; 5a). Both units 5 and 7

represent the colluviation of unit 10 and 8, the former constituting the gravelly skeleton and the latter the silty matrix of the deposits.

Between units 7 and 5, a wedge-shaped unit (6) is present; it is mainly composed of clay and silt-supported, brownish sparse gravel. The parent material of this colluvial unit is certainly unit 8, which constitutes the abundant matrix of the colluvium.

Unit 5 is mantled by another well-developed paleosol (unit 4), dark-brown, very rich in organic matter in its upper part. The top of the paleosol contains several potsherds in a coarse brownish ware, dating back to the 9th–6th century BC.

Units 4 and 5 are truncated by an erosive surface, overlain by a dark, grayish colluvial deposit (3). Both units 3 and 4 are truncated by an erosion surface capped by detrital unit 1. Unit 1 is composed of medium-to-fine, clast-supported gravels, faintly layered, with several anthropic hole/canal structures (units 2–2a of Fig. 7) and mainly Modern majolica sherds.

4.2. Dating methods

The age of the succession has been constrained by means of absolute ^{14}C , and archaeological dating. ^{14}C samples were sent to Beta Analytic Inc. (Miami, Florida) for absolute dating. Table 1 summarizes the accelerator mass spectrometer (AMS) and radiometric (R) ^{14}C analyses of sampled detrital charcoal and soil/deposit bulk. The detrital charcoal sample received a standard pretreatment consisting of acid/alkali/acid washes. Conventional ages have been calibrated using program Calib 4.1 (Stuiver et al., 2003); relative 1σ (68%) and 2σ (95%) areas under probability distribution are shown on the right side of Table 1. In the text and in the trench-logs samples have been reported with 2σ calendric age.

Table 1
 ^{14}C ages of samples collected in trenches 1–3

	Sample	Analysis	Dated material	Measured radiocarbon age	Calendric age range (1σ –68%)	Calendric age range (2σ –95%)
Trench 1	NOR-4	R, BLC	Organic silt	27 850 ± 390 BP		
Trench 2	NORN-11	R, BLC	Organic silt	7160 ± 60 BP	8000–7940 BP	8040–7840 BP
	NORN-12	R, BLC	Organic silt	18 470 ± 140 BP	22 470–21 470 BP	22 630–21 310 BP
	NORN-13	R, BLC	Organic silt	10 860 ± 90 BP	12 730–12 660 BP	12 740–12 640 BP
Trench 3	NOR3S-2	AMS	Charcoal	2450 ± 40 BP	2710–2370 BP	2730–2360 BP

As aforementioned, the long historical settlement of Norcia allowed the finding of many artifacts which deserve to be briefly described.

4.2.1. Archaeological finds

Archaeological finds recovered from the trenches cover an extremely large time span, from the Prehistoric period up to the Modern Age. Units 4, 3 and 3a contain two carved flints and thirty-four ceramic sherds in earthenware, dating back to the 9th–6th century BC. Potsherds were dated on the basis of a comparison with archaic pottery similar in fabric, shape and decoration, found in well-dated sites both in Norcia (Cardinali and Manconi, 2002) and in nearby areas (e.g., Amelia, Colfiorito, Gualdo Tadino, Orvieto and Cures Sabini). The most recent potsherd recovered from unit 3 is a sherd in fine black *bucchero*, a ware common between the second half of the 7th and the 5th century BC.

Apart from some archaic potsherds, the bulk of ceramic sherds recovered from unit 2 covers the time span from the early Roman Republican Age to the 16th–17th century AD, thus attesting to settlement continuity in the area. The earliest finds are a body sherd in black-glazed ware and three sherds in a coarse grey ware (two body sherds and a base sherd of a bowl). Black-glazed ware was produced in central and southern Italy from the end of the 4th up to the 1st century BC (Cardinali and Manconi, 2002), whereas bowls in grey ware were widespread in Umbria and Etruria from the end of the 4th through the first half of the 3rd century BC (Stopponi, 1994). The most recent datable potsherds found in unit 2 are three sherds in *majolica*. A body sherd is decorated in copper green, a colour typical of the “archaic *majolica*” produced in central and northern Italy between the 13th and the 14th century AD (Bernardi, 1994). A base sherd of a cup bears a cobalt blue motif characteristic of the so-called “late-Gothic” group, produced in central Italy around the 15th–16th century AD (Bernardi, 2002). A piece of a dish in white *majolica* could be possibly linked to the white *majolica* tableware produced in other Umbrian towns in the 16th–17th century AD (Fiocco and Gherardi, 1988).

Finally, unit 1 contains a few, very small sherds in modern *majolica*, datable from the 15th century AD onwards.

4.3. Age of units

On the basis of archaeological and absolute dating, and by correlating some depositional episodes with dated Apenninic climatic phase, the age of the whole succession (apart from units 9–10, which correspond to the middle Pleistocene alluvial fan unit of Blumetti, 1995) ranges from ~28 ky to ~17th–18th century AD.

Starting from the bottom, the age of the inner paleosol ($27,850 \pm 390$ BP CRA, conventional radiocarbon age) fits with the last period of wet climate in central Italy preceding the last glaciation (see Frezzotti and Narcisi, 1996; Moro et al., 2003). On the other hand, the age of colluvial unit 5 ($18,490 \pm 140$ BP CRA) marks the cold and arid phase (around 21–18 ky; Giraudi and Mussi, 1999) following the LGM (last glacial maximum; 25–21 ky BP). Colluvial unit 7 has no dates, but, obviously, its age is contained between those of the confining units.

The upper paleosol (unit 4, 8040–7840 BP 2σ CA) is indicative, instead, of a new warm, stable and wet phase, the age of which fits the ones reported elsewhere in central Apennine (e.g., soil dated 8120–7910 BP 2σ CA, near the Gran Sasso massif; Giraudi, 2003). Its top is rich in archaic pottery potsherds dating back to the 9th–6th century, which testifies a very long frequentation of the soil top surface.

Finally, the abundant pottery sherds found in units 1–3 span from the 9th–6th century BC, through the Roman Age up to the 18th century AD. Particularly, unit 3 contains carved flints and archaic coarse ware sherds, dating back to the 9th–5th century BC. The most recent potsherd recovered from unit 3 is a piece of *bucchero* ware, dating between the second half of the 7th and the 5th century BC. The ^{14}C dating of a charcoal sampled in this unit provided an age of 2730–2360 BP, (2σ CA. 780–410 AD; NOR3S02, trench 3) which, together with the pottery, constrains the age of this unit to the 6th–5th century BC (Fig. 7 shows also the age obtained on a bulk of dark, soft pebble of this colluvial unit – 12740–12640 BP 2σ CA – which should strongly account for the age of its “older” parent material).

Apart from some archaic potsherds, ceramic sherds recovered from unit 2 cover a long time span, from the early Roman Republican Age up to the 15th–16th century AD (e.g., “late-Gothic” *majolica*). This find-

ing indicates that the deposition period of this colluvial unit occurred during, or post, the Little Ice Age (LIA; e.g., post-1550 AD, see Lamb, 1977).

4.4. Paleearthquakes

Almost the entire sedimentary succession is affected by sub-vertical, E-dipping fault planes (Figs. 6–9). The oldest unit (10) shows a complex tectonic fabric (i.e., shear fabric), characterized by pervasive shear planes, rotated clasts (with long axes which approximately parallel the fault), and a 1-m-thick fault-gouge, whereas the upper units are affected by several secondary splays (W-dipping). In trench 3 (Fig. 8), the fault zone is characterized by a 10- to 15-cm-thick clayey gouge, packed and dragged along the fault. The flower-like geometry depicted by the fault splays (Fig. 7) seems to account for a horizontal component of the motion.

Paleoearthquakes are not clearly detectable in the older units of trenches 1–2. As mentioned before, this is due to the erosive nature of most of the stratigraphic limits which obliterate the primary relationships among the units, providing an incomplete and not-sequential paleoseismic record.

The period of climatic (and tectonic?) stability represented by the thick paleosol (unit 8) seems abruptly interrupted by colluvial unit 7, which is carved inside unit 8. The limited outcrop of unit 7 does not allow to explain whether the colluvium was deposited due to tectonic, or climatic causes. Conversely, a possible first tectonic event (E1; Table 2; Fig. 7) could be testified by unit 6, a wedge-shaped deposit (i.e., colluvial wedge; see in McCalpin, 1996) that seals a thin stone-line developed over units 8–7. This wedge is formed by sparse carbonate pebbles in abundant brownish sandy-clayey matrix; this material should belong to the dismantling of the coseismic paleoscarp carved in paleosol 8. E1 occurred after the burial/erosion of the paleosol, at the beginning of the cold-arid phase here represented by units 7 and 5, that is around 18 ky BP (CRA; before 22,630–21,310 BP, 2σ CA).

Units 5 and 6 have been then faulted (we do not know how many times) a time before the deposition of unit 3 (that is before the 6th–5th century BC) as suggested by the fault splays sealed by unit 3. For this reason, we put event horizon E2 at the interface between these units (Fig. 7); however, we are not able to provide a date for this event.

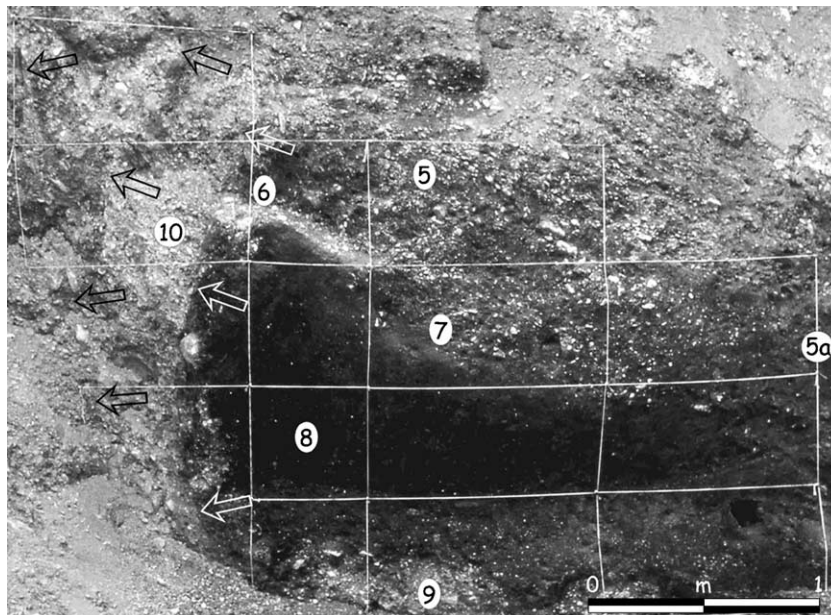


Fig. 6. View of the northern wall of trench 1. Labels as in Fig. 7. Arrows indicate the faults trace.

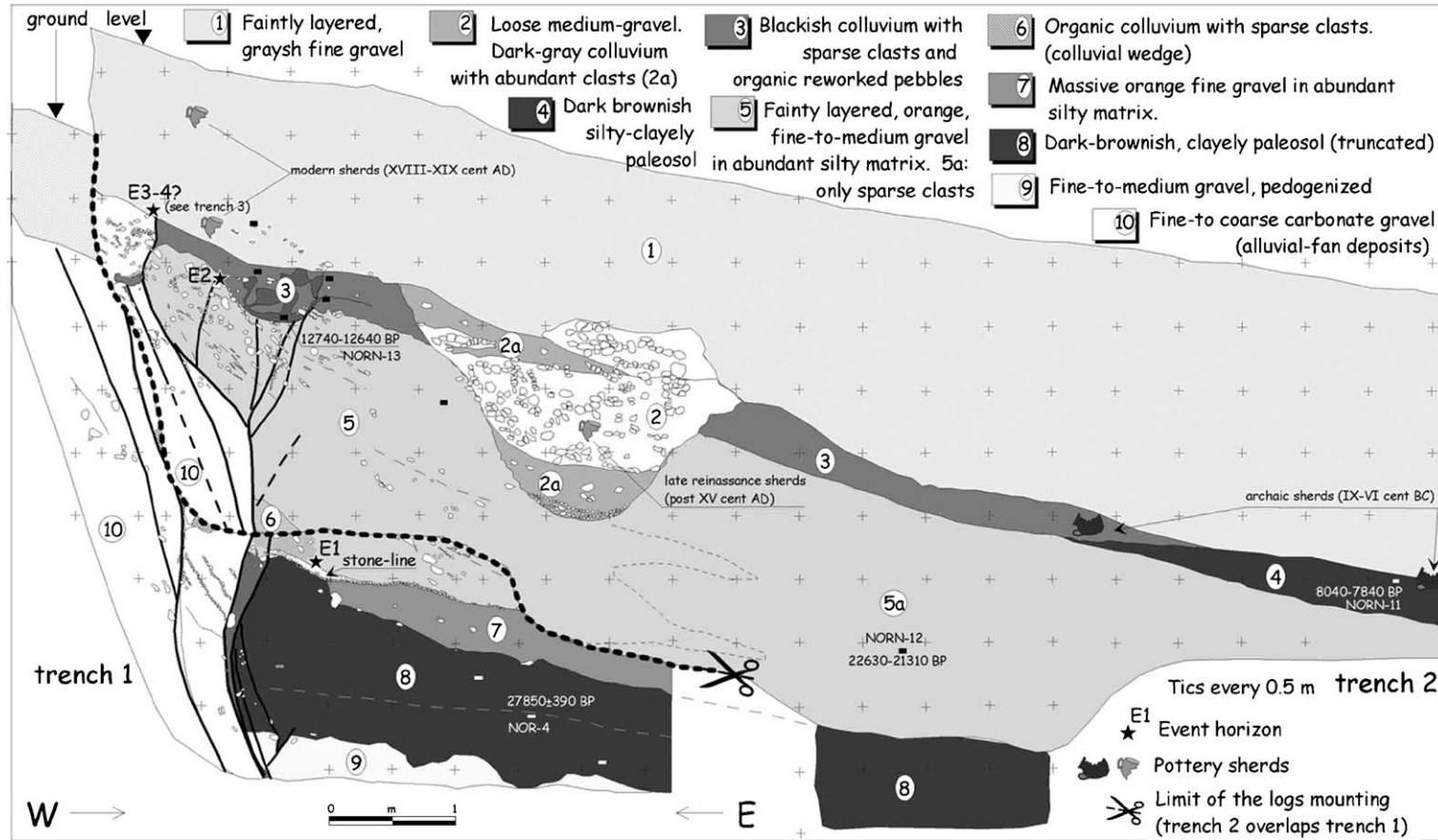


Fig. 7. Sketches of northern wall of trenches 1 and 2. The two logs have been juxtaposed, trench 2 overlapping trench 1. Units 9–10 belong to the Patino alluvia-fan deposits. The remaining units are soil, colluvium and debris of the late Pleistocene–Present. More details on the stratigraphy, with respect to the short legend, are in the text.

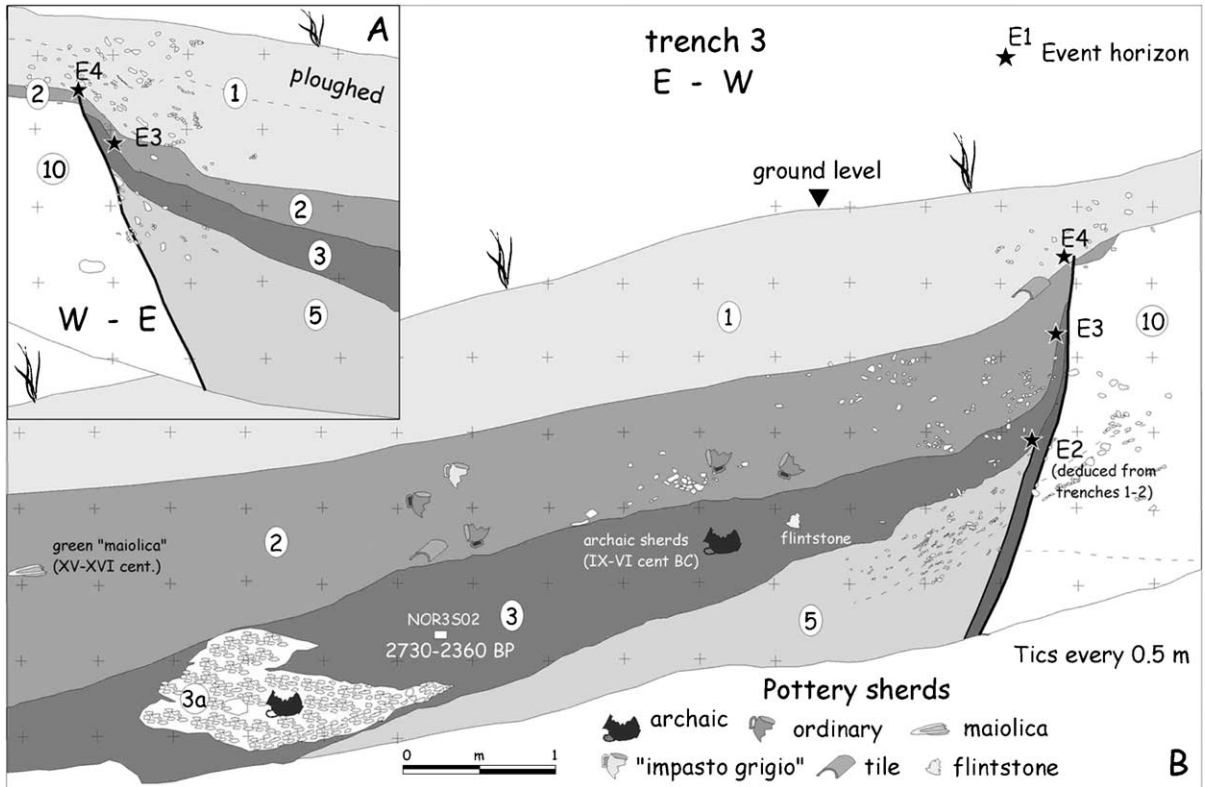


Fig. 8. Sketches of the northern (A) and southern (B) walls of trench 3. Event horizon 4 (E4) represents the 1703 earthquake. E2 is deduced from trenches 1–2.

Another visible event (E3; Fig. 8) affects unit 3, which is warped and dragged along the fault. Unit 3, which we interpret as a climatogenic colluvium (enriched by human debris; i.e., canal 3a, plus artifacts), was then eroded in the footwall, where unit

2 directly overlaps unit 10 (Fig. 8A). The event occurred then after the 6th–5th century BC, but probably before the 3rd–1st century BC (possible lower age of unit 2). The upper boundary of the event-window fits with the historically known 99 BC

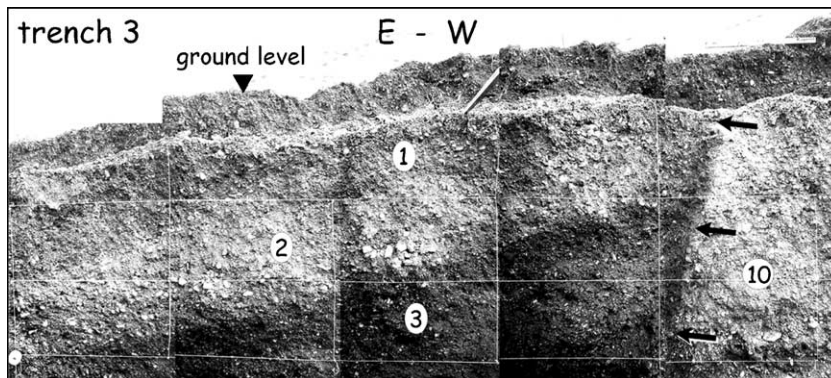


Fig. 9. Photomosaic of the southern wall of trench 3 (particular of the fault zone; labels same as Fig. 8). The dragging of the historical colluvial against the Patino fan gravel is evident (arrows indicate the fault plane).

Table 2

Archaeological/absolute ages of the faulting events recognized in trenches, and tentative associated historical earthquakes

Events	Archaeological age	¹⁴ C age	Trench	Historical and/or preferred date
E4 (ultimate)	Post-15th–16th century	–	3	Jan. 14, 1703
E3 (penultimate)	Post-6th–5th century Ante 3rd–1st century BC	Post-2730–2360 BP	2–3	99 BC?
E2	Ante 6th–5th century	Post-22 630–21 310 BP	2	?
E1	–	Post-27 850 ± 390 Ante 22 630–21 310 BP	1	~18 ka

earthquake. Making no claims to being conclusive, it is thus possible that E3 is the 99 BC event.

The last event (E4, Fig. 8) cuts also unit 2, being sealed by unit 1. It is, thus, subsequent to the age of unit 2 (which contains “late-Gothic” majolica dating back to the 15th–16th century AD), and we related it to the 1703 earthquake.

5. Discussion and conclusions

The paleoseismic analyses carried out in Norcia have been focused on an antithetic splay of the NF (central strand of the Norcia Fault System). The prominent erosive hiatus existing within the exposed sedimentary succession yielded a poor recording in terms of consecutive events and earthquake recurrence (Table 2). Nevertheless, at least four surface faulting events have been identified in the past 20 ky, the last one being strictly consistent, in terms of dating and location, with the $M_e=6.8$, Jan. 14, 1703, Norcia earthquake. The penultimate event is supposed occurred between the 6th–5th and the 3rd–1st century BC (99 BC event?), thus providing an interval time of 1700–1900 years between the past two consecutive faulting events.

As far as vertical slip-rate is concerned (horizontal components, possibly accounted by the “flower-structure” depicted by the fault splays, were not measurable), considering the minimum throw of the oldest paleosol (~6 m since E1, assuming that the paleosol mantled both footwall and hangingwall), a minimum rough value of 0.3 mm/year can be obtained. This value, although measured on an antithetic fault, is consistent with the rates known through paleoseismological analyses in central Apennines (Galadini and Galli, 2000 and reference therein).

From this point of view, these results are the first direct and dated geological evidence for the Holocene-historical activity of the NF.

Finally, taking into account that surface faulting due to the second 1703 mainshock (Feb. 2, 1703; $M_e=6.7$) has been found along the Mt. Marine fault (Upper Aterno fault system in Galadini and Galli, 2000; UAFS in Fig. 1), near the town of L’Aquila (Moro et al., 2003; see the star in Fig. 1), fault ruptures related to the entire 1703 sequence extended, although discontinuously, over 70 km. This means that the entire active fault system recognized between L’Aquila and Norcia (Blumetti, 1995; Cello et al., 1998a; Galadini and Galli, 2000) ruptured progressively within 15 days in 1703. Considering that for normal-oblique faults the Coulomb stress raises laterally to the fault tips (e.g., in Nostro et al., 1997), it is possible that the Norcia fault system rupture of January 14, 1703, “loaded” the nearby Upper Aterno faults, which ruptured in February 2. Moreover, the rupture process passed through an intermediate structure (Montereale fault in Blumetti, 1995), which possibly caused the subevent of January 16, 1703 (Baglivi, 1710; De Carolis, 1703).

It is worth noting that both strong earthquakes (i.e., surface faulting events) and events with $M < 6$ (characterized by weak or absent surficial breaks) have occurred along the NFS; the former were caused by the rupture of the entire system, whereas the latter by segments acting as independent sources. From this point of view, the seismogenic behavior of the faults of the Norcia system could not be related simply to the occurrence of “characteristic earthquake” sensu Schwartz and Coppersmith (1984).

As a concluding remark, since this fault branch was neither known nor mapped, a notable implication

of our finding is that the fault itself has been ignored in the town-planning drawing up. During the 1703 earthquake, when Norcia was held by its walls, the ruptures likely affected gardens and fields (Baglivi, 1710); today, due to the 20th–21st century building growth all over the fault zone (houses, hotels, schools and sports facilities), the effects of surface faulting due to both $M \leq 6$ (e.g., 1730 and 1979 earthquakes) and, especially, $M > 6$ (e.g., 1328 and 1703) earthquakes should be carefully taken into account for building location and planning.

Apart from the sparse cases of known surface faulting of ancient settlement (Galli and Galadini, 2001, 2003), this is the first case of “paleoseismological prediction” of future surface rupture through an urban, inhabited settlement in Italy.

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On the basis of these results, on Jan. 2005, the Regione Umbria (i.e., the Regional Authority) appropriated funds for a Project of seismic microzonation of Norcia, which foresees, for the first time in Italy, a paleoseismological campaign for a civilian settlement. The view and conclusion contained in this paper are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Italian Government.

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