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New paleoseismic data across the Mt. Marine Fault between the 2016 Amatrice and 2009 L'Aquila seismic sequences (central Apennines)

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Abstract

Paleoseismological investigations have been carried out along the Mt. Marine normal fault, a probable source of the February 2, 1703 (Me=6.7) earthquake. The fault affects the area between the 2016 Amatrice and 2009 L'Aquila seismic sequences. Paleoseismological analysis provides data which corroborate previous studies, highlighting the occurrence of 5 events of surface faulting after the 6th–5th millenium B.C., the most recent of which is probably the 2 February 1703 earthquake. A minimum displacement per event of about 0.35 m has been measured. The occurrence of a minimum four faulting events within the last 7,000 years suggests a maximum 1,700 years recurrence interval.

I. INTRODUCTION

The Apennine chain formed since the late Tortonian, contemporaneously to back-arc extension in the Tyrrhenian Sea (Chiarabba and Chiodini, 2013; Chiarabba et al., 2014). Crustal shortening and thrusting progressively migrated towards E and NE and was followed by extension (Fig. 1). The migrating extensional front reached its present position (along the axis of the Apennines) in the Late-Pliocene-Early Pleistocene, nucleating intermontane tectonic depressions that hosted continental deposition. Focal mechanisms, geodetic data and borehole breakouts (e.g. Chiarabba et al., 2009; Mariucci et al., 2010; D'Agostino et al., 2011; Devoti et al., 2011) characterize the present stress field as NE-SW trending extension, mainly concentrated along the axial belt. Extension generates NW-SE trending, mainly SW-dipping, seismically active normal faults, bounding graben and half-graben basins (Galadini and Galli, 2000). The active tectonics of the Central Apennines is characterized by two NW trending parallel fault structures with mainly normal faulting mechanisms (Galadini and Galli, 2000) (Fig. 2).

Galli et al. (2008) infer minimum Mw 6.5 for past events on each fault with roughly 1-2 kyr recurrence interval and 0.4 - 1.2 mm/yr vertical slip rate.

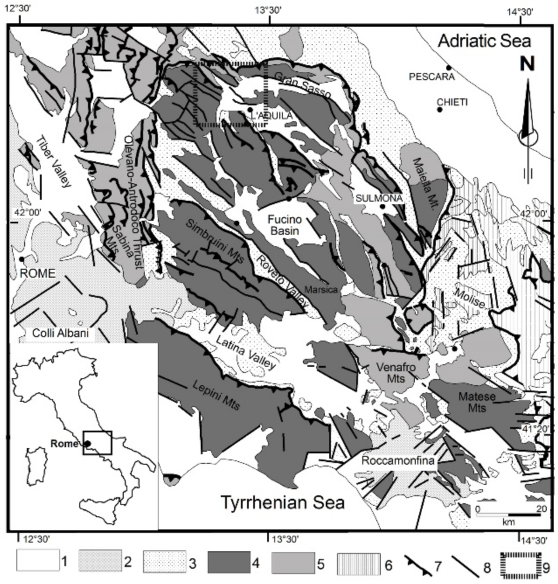

Fig. 1: Simplified geological and structural map of the central Apennines. Legend: 1) Marine and continental clastic deposits (Pliocene–Quaternary); 2) Volcanic deposits (Pleistocene); 3) Synorogenic hemipelagic and turbiditic sequences (Tortonian–Pliocene); 4) Carbonate platform deposits (Triassic–Miocene); 5) Slope and pelagic deposits (Lias–Miocene); 6) Molise–Sannio pelagic deposits (Cretaceous–Miocene); 7) Main thrust fault; 8) Main normal and/or strike-slip fault; 9) Black dashed rectangle define the study area.

Strong historical earthquakes have been associated to the western set of active faults (Fig. 2), whereas the eastern set may have not been activated during the last 1 kyr (Galadini and Galli, 2000).

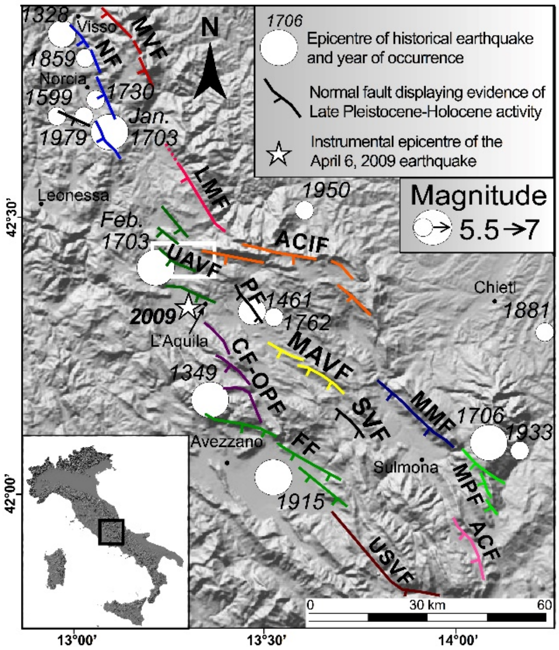

Fig. 2: Active faults of the central Apennines and epicentres of large historic earthquakes (faults: MVEF, Mt. Vettore; NFS, Norcia; LMF, Laga Mts.; UAVFS, upper Aterno Valley; CIFS, Campo Imperatore; CF-OPF, Campo Felice-Ovindoli-Pezza; MAVFS, middle Aterno Valley; SVF, Subequana Valley; MMF, Mt. Morrone; FF, Fucino; MPF, Maiella-Porrara (Pizzi et al., 2010); ACF, Aremogna-Cinquemiglia; USFS, upper Sangro Valley). White rectangle defines the area in Fig. 4. Modified after Falcucci et al. (2011) and references therein.

One of the most destructive earthquake that occurred along the western set of active faults is the February 2, 1703 (Me=6.7) event. One splay of the causative fault is located along the south-western side of Mt. Marine with a NW-SE trend, bounding the Upper Aterno intermontane basin (Fig. 3). The Mt. Marine Fault (hereafter MMF) is part of a normal fault system comprising four main segments – among which the Paganica fault (PF), activated during the 2009 L'Aquila earthquake (Galli et al., 2010; Moro et al., 2013), with en-echelon pattern, developed between the Capitignano and L'Aquila basin (Fig. 2) (Moro et al. 2013; Galli et al. 2011). The 1703 seismic sequence caused relevant environmental effects as open fractures, chasm creation, sulfurous gas emission and white water escape (Moro et al., 2002 and references therein). As shown in figure 3 MMF is located in the sector between the 24 August-30 October 2016 Amatrice-Norcia sequence (Mw 6.0, Mw 6.5) and 2009 L'Aquila (Mw 6.3) seismic sequences, where the increase of static stress took place after the 2009 event, greater than 0.4 bar (9 km at depth) (Falcucci et al., 2011) (Fig. 4). Different Quaternary units, mainly represented by fluvial, lacustrine and slope deposits, have been recognized in the area (Bosi et al., 2004 and references therein) (Fig. 3). Moreover some fault scarps (WNW-ESE trending), have been identified at the base of Mt. Marine; these scarps are related to the recent fault activity, as showed by Moro et al. (2002) and Galli et al. (2011). The presence of the fault multiple parallel scarps suggested to perform further paleoseismological analyses in the area to improve the timing of past earthquakes along the MMF.

II. PALEOSEISMOLOGIC INVESTIGATIONS

We dug two trenches at two different sites, across two 10-20-m-high and WNW-ESE trending fault escarpments (Fig. 3). The excavations walls exposed evidence for faulting and displacement of the exposed colluvial, organic rich and "cultural" sediments, and paleosols. In particular, in trench A (Fig. 5),

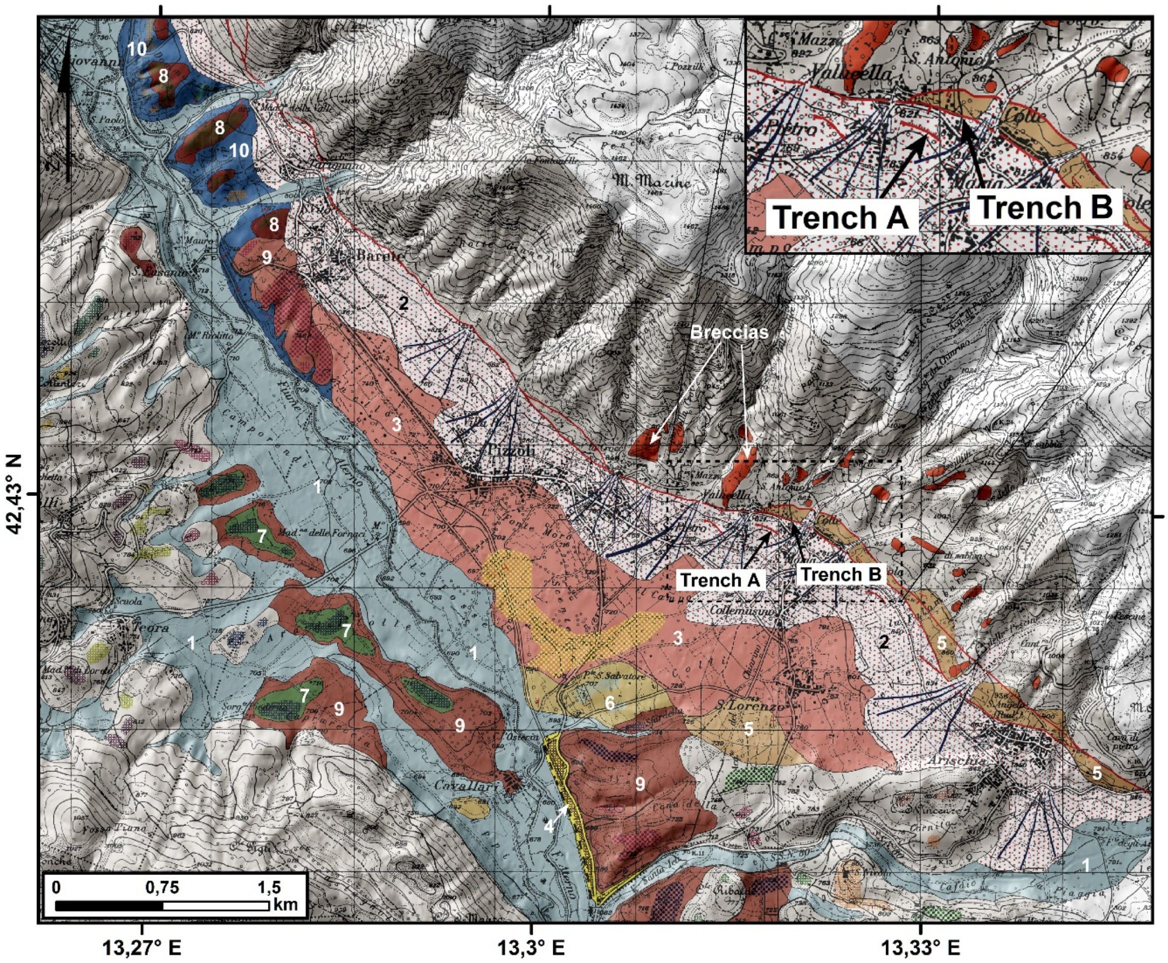

Fig. 3: Quaternary geological map of the Upper Aterno basin modified after Bosi et al., 2004. Legend: 1) sandy-silty and alluvial deposits (Holocene); 2) colluvial and slope deposits (Upper Pleistocene-Holocene); 3) gravels, silt and clay (Upper Pleistocene-Holocene); 4) alluvial and gravel deposits (Upper Pleistocene-Holocene); 5) alluvial uvial deposits (Upper Pleistocene-Holocene); 6) alluvial gravel deposits (Upper Pleistocene-Holocene); 7) sandy-silty alluvial deposits (Upper Pleistocene-Holocene); 8) silty-sandy alluvial deposits (Middle Pleistocene); 9) alluvial gravels (Middle Pleistocene); 10) gravel and sand alluvial deposits (Upper Pliocene). Grey color represent the bedrock units. Dots polygons represent the depositional and erosional paleosurfaces associated with the underlying deposits. The inset represent a magnification showing the trench sites.

units 1, 2, 3 and 4 where cultural units made of sandy-gravelly colluvial deposits with pottery fragments are intensely reworked by human activity. Unit 5 was made of silt, sand and gravel with carbonate clasts. Units 6 and 7 were made of silty-clayey colluvial deposits with sparse carbonate clasts. Unit 8 is a stratified slope debris deposit made of gravel in a silty-sandy matrix with rare sandy layers. The stratigraphic sequence exposed in trench B (Fig. 6) was represented by: units 1, 2 and 3 were silty-clayey-sandy colluvial deposits with carbonate clasts and pottery fragments, intensely

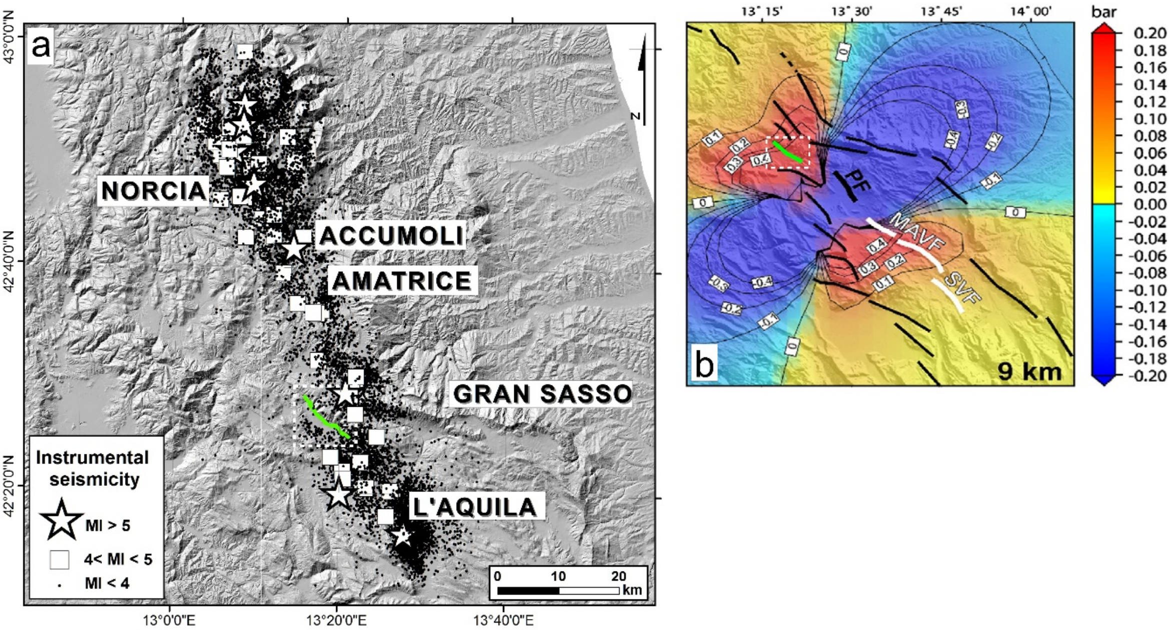

Fig. 4: a) Instrumental seismicity of the study area during the 2009 and 2016 seismic crisis. Green lines within the white dashes rectangle represents the Mt. Marine fault trace. b) Coseismic ΔCFF patterns, evaluated 9 km at depth. Each contour line evidences a CFF variation of 0.1 bar (Falcucci et al., 2011).

reworked by human activity; unit 4 was interpreted as a colluvial wedge – i.e. a wedge of deposit formed by erosion of a coseismic scarp – composed by silty-sandy sediments with carbonate clasts; unit 5 was intepreted as a colluvial wedge as well, composed by carbonate clasts in a silty-clayey matrix (clast supported); units 6 and 7 are silty-clayey colluvial deposits with sparse carbonate clasts; unit 8 is a slope deposit made of succession of gravels alternating with layers of sands and clays.

The analyses of the trench walls provided evidence of two and four faulting events in trench A and trench B, respectively (Fig. 5 and 6). In trench A, the most recent event, E1A, caused the displacement of the entire stratigraphic sequence, including unit 2. Radiocarbon dating (Tab. 1) of charcoals collected within unit 2 constrains E1A in a time frame close to 1669-1780 A.D, therefore likely confirming MMF activation during the February 2, 1703 earthquake. An older event, E2A, displaced unit 4 and was sealed by unit 3 containing a charcoal fragment which provided a ^{14}C age of 123 B.C. – 18 A.D., aging E2A prior to this date. Also in trench B (Fig. 6) the most recent event, E1B, affected the whole stratigraphic sequence, up to unit 2. Considering that unit 2 is a colluvial deposit intensely reworked by human activity and that the two charcoals collected gave ^{14}C ages of 776–383 B.C. and 3339–3205 B.C., we can hypothesize the first age (776–383 B.C.) as a *terminus post quem* for E1B. A previous event, E2B, is inferred by the presence of the colluvial wedge unit 4 for which ^{14}C dating gave ages of 3247 – 3100 B.C. and 3346 – 3088 B.C.; this leads us to consider E2B soon before this period. Colluvial wedge of unit 5 suggests another

Table 1

Sample	Unit	Material	Lab. Code	Technique	14C age B.P.	2σ Cal. age
PIZZ10	2	Charcoal	Poznan-Poz72297	AMS	2400±70	776-383 B.C.
PIZZ18	4	Charcoal	Poznan-Poz72381	AMS	4515±30	3247-3100 B.C.
PIZZ3	2	Charcoal	Poznan-Poz59894	AMS	4465±35	3339-3205 B.C.
PIZZ6	4	Charcoal	Poznan-Poz59895	AMS	4485±35	3346-3088 B.C.
PIZZ8	3	Charcoal	Poznan-Poz59896	AMS	4450±35	3141-3009 B.C.
PIZZ12	6	Charcoal	Poznan-Poz60042	AMS	5900±90	4993-4547 B.C.
MAR13	3	Charcoal	Poznan-Poz59889	AMS	2050±30	123 B.C.-18 A.D.
MAR19	2	Charcoal	Poznan-Poz59890	AMS	140±30	1669-1780 A.D.
MAR20	2	Charcoal	Poznan-Poz59892	AMS	1975±30	43 B.C.-79 A.D.

Table 1: Measured and dendrochronologically calibrated 14C age of samples collected in the trenches. Sample location and age are shown in Figures 5 and 6.

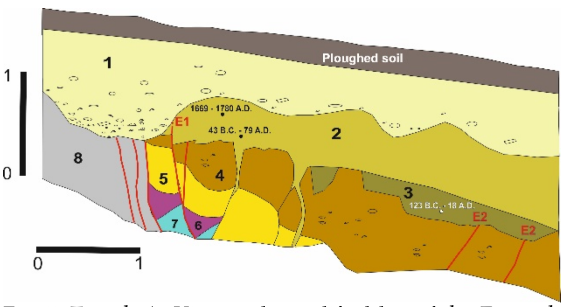

Fig. 5: Trench A. View and simplified log of the E trench wall. Black dots indicate dated radiocarbon samples. Stratigraphic units and deformation zones are described in the text.

event, E3B, for which no radiocarbon determinations are available. Nevertheless, as unit 5 is stratigraphically superposed to unit 6 dated 4993 – 4547 B.C. was obtained, which can be hence considered a *terminus post quem* for E3B. Moreover, these latter ages represent a *terminus ante quem* for the ancient event recognized in trench B (E4B), inasmuch its evidence is represented by the displacement of the base of unit 6.

III. CONCLUSIONS

Two new trenches have been dug along the Mt. Marine fault, in a sector located between the 2016 Amatrice and 2009 L'Aquila seismic sequences, to better understand the late Holocene behavior of the fault and timing of past earthquakes. Using radiocarbon ages and considering the colluvial nature of deposits (that generally indicate a *terminus post quem*), the most recent faulting event recognized in trench A is probably ascribable to the 1703 event. A penultimate event E2 observed in both trenches probably occurred between 776 B.C. and 18 A.D. Previous events, E3 and E4, observed in trench B, may have occurred between 3088 B.C. and 4993 B.C. The last event observed in trench B (E5) occurred before 4993

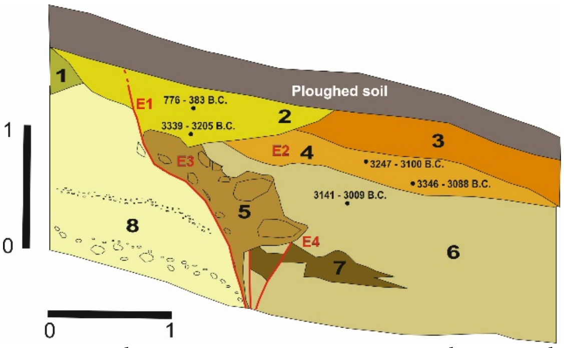

Fig. 6: Trench B. View and simplified log of the E trench wall. Black dots indicate dated radiocarbon samples. Stratigraphic units and deformation zones are described in the text.

B.C. Minimum displacement per event, of about 0.35 m, can be estimated by the offset of the base of unit 2 in trench B. This value represents a minimum value for the MMF since it is estimated only along two fault splays of the whole structure, as further slip is expected to be accommodated along other fault splays. Paleoseismological analyses indicate the occurrence of at least four displacement events within the last 7,000 years, the most recent of which is probably ascribable to the 2 February 1703 earthquake. A maximum recurrence interval of about 1,700 years can be tentatively estimated. This is in agreement with the mean recurrence interval of fault activation defined by Galadini and Galli (2000) and Galli et al. (2008) for the central Apennine active faults, i.e. 1400–2600 years for M≥6.5 seismic events.

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