Quaternary International xxx (2017) 1–14

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Paleoseismicity of the San Demetrio ne' Vestini fault (L'Aquila Basin, Central Italy): Implications for seismic hazard

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A R T I C L E I N F O

Article history:
Received 29 April 2016
Received in revised form
7 December 2016
Accepted 23 December 2016
Available online xxx

Keywords:
Paleoseismology
Surface faulting
Capable fault
Seismic microzonation
Fault displacement hazard

A B S T R A C T

The San Demetrio fault is a NW-SE trending normal fault at the south-eastern tip of the L'Aquila Basin fault zone (Central Apennines, Italy). Detailed field surveys and geophysical investigations, performed in the frame of seismic microzonation studies after the 2009 L'Aquila earthquake in the San Demetrio 'ne Vestini territory, have clearly indicated that it is a capable fault.

This paper illustrates the results of paleoseismic investigations along this fault, confirming its capability. At least five surface faulting events took place during the Holocene and latest Pleistocene, with variable offsets from a few centimetres (four events, the latter one most likely occurred in historical time) to about 50 cm (one event occurred between 16,430–16010 BCE and 7030–6570 BCE). These results are consistent, in terms of displacement per event, with the paleoseismic data collected on adjacent faults (i.e., the Paganica, Roccapreturo, Mt. Pettino and Mt Marine faults).

Concerning seismic hazard, being the San Demetrio fault the southeastern tip of the L'Aquila fault system, its Holocene reactivations should be associated to paleoearthquakes with epicentre located to the northwest centered in the L'Aquila basin, and minimum magnitude ranging between 6.0 and 6.3. Elsewhere, considering its position close to the transfer zone to the Subequana Valley faults system, another option is that surface faulting is sympathetic to larger ruptures produced by the reactivation of this latter faults system.

Based on fault scaling relationships, the offset of 0.5 m occurred before the Holocene may indicate an earthquake of $M > 6.5$, never replicated afterwards on the San Demetrio fault.

1. Introduction

Surface faulting hazard is an engineering hazard locally posed by the occurrence of surface displacements along a capable fault, mainly associated to the occurrence of moderate to strong earthquakes. In Italy, increasing attention to this hazard has been given by the scientific community (e. g. Blumetti and Guerrieri, 2007; Boncio et al., 2012; Peronace et al., 2013. Guerrieri et al., 2014) as well as by the institutions in charge of legislation on seismic zonation that have recently provided precise land planning limitation measures in the presence of capable faults (e.g. DPC, 2015; Abruzzo Region, 2012).

After the April 6, 2009 L'Aquila earthquake (Ml 5.8, Mw 6.3, depth 9 km; Chiarabba et al., 2009) in Central Apennines (Italy), the Geological Survey of Italy (ISPRA) carried out a seismic microzonation study, based on detailed geological, geomorphological and geophysical surveys, of the territory of San Demetrio ne' Vestini, a village severely damaged by the 2009 event (Working Group MS–AQ, 2010).

The study raised a special concern because, while confirming the three major NW-SE trending Quaternary fault segments inside the municipality already recognized by other authors (i.e., Bosi and Bertini, 1970; Bertini and Bosi, 1993; Giaccio et al., 2012; Pucci et al., 2014), it pointed out as capable the one running across the historical centre (i.e., the San Demetrio fault). During the quick response surveys after the 2009 quake, Emergeo Working Group (2009) and Vittori et al. (2011) observed only secondary thin cracks across some streets and walls inside the urban area of the village. Instead, Galli et al. (2009, 2010) reported the reactivation of the fault, although without an evident offset, having observed also ground fissures in a field in the hanging wall of the fault. The recent comprehensive investigations by Galli et al. (2011), Giaccio et al. (2012), Blumetti et al. (2013), Pucci et al. (2014) have reconstructed in good detail the Quaternary tectonic evolution of the San

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http://dx.doi.org/10.1016/j.quaint.2016.12.039
1040-6182/

Demetrio area. However, a paleoseismic record for the San Demetrio fault was still missing.

With the aim of evaluating the surface faulting hazard posed by the San Demetrio fault, in the framework of the Reconstruction Plan after the 2009 earthquake, the necessity arose to precisely locate this capable fault and assess its seismogenic potential, to allow informed decisions regarding the reconstruction/restoration of damaged buildings lying along it. In fact, according to national and regional guidelines, only if the capable fault is precisely located it is possible to constrain the extent of setback area to 30 m, otherwise rebuilding is not allowed over a 400 m wide area across the suspected lineament (Abruzzo Region, 2012; Boncio et al., 2012; DPC, 2015).

To this end, the Geological Survey of Italy was invited by the San Demetrio ne' Vestini municipality to carry out a paleoseismological study based on mapping, geophysics and exploratory trenching, whose results are illustrated in this paper.

2. Tectonic framework of the study region

The tectonic history of the Apennines is tied to the geodynamics of the central Mediterranean (Malinverno and Ryan, 1986; Patacca et al., 1990; Gueguen et al., 1998; Doglioni et al., 1999, 2004; and references therein). The present tectonic structure of the Central Apennines is the result of Messinian - Lower Pliocene northeast-verging thrust tectonics (Patacca et al., 1990) overprinted by northeast-southwest crustal extension, migrating in time and space from west to east. Such extension is still active now along the axis of the chain, as demonstrated by 1) morphotectonic evidence (Demangeot, 1965; Blumetti et al., 1993; Barchi et al., 2000; Galadini and Galli, 2000; Pizzi et al., 2002; Boncio et al., 2004; Roberts and Michetti, 2004; Papanikolaou et al., 2005; Blumetti and Guerrieri, 2007; Lavecchia et al., 2011; Giaccio et al., 2012; Blumetti et al., 2013; Pucci et al., 2014); 2) strong seismicity, as documented by 20th century earthquakes, historical catalogues (e.g., Rovida et al., 2011), and paleoseismological research (e.g., Galli et al., 2008; Galli et al., 2010, 2011; Cinti et al., 2011; Moro et al., 2013); 3) GPS measurements of current velocities across the Central Apennines, which provide extension rates of 3 mm/a (D'Agostino et al., 2011; Devoti et al., 2011). Faure Walker et al. (2010) have proposed a similar extension rate (ca. 3 mm/a), by calculating moment tensors from fault slip data, including also the strain from the 2009 L'Aquila earthquake.

In the L'Aquila region, surface geology and geophysical data reveal a composite structural setting given by several overthrust tectonic units belonging to the transitional domain between the Lazio-Abruzzi carbonate shelf platform and the Umbria-Marche pelagic basin, dissected by a network of Quaternary normal faults (Fig. 1). Seismic and stratigraphic-morphological evidence suggest ongoing activity along several of these faults (Fig. 2) (e.g., Bagnaia et al., 1992; Blumetti, 1995; Moro et al., 2002, 2013; Boncio et al., 2004; Roberts and Michetti, 2004; Papanikolaou et al., 2005; Blumetti and Guerrieri, 2007; Galli et al., 2008; Giaccio et al., 2012; Gori et al., 2012; Blumetti et al., 2013; Pucci et al., 2014).

The cumulative effect of block-faulting over a time interval that spans the last 800 ka has given the Central Apennines its typical morphology, characterized by fault-bounded basins and ranges (Blumetti et al., 1993; Blumetti and Guerrieri, 2007). Notably, all the major basins (Fucino, L'Aquila, Sulmona) have hosted the strongest historical and/or paleo-earthquakes. Some Authors (Blumetti and Guerrieri, 2007 and references therein) consider the size of basins and associated fault escarpments a peculiar attribute, indicative of the local seismic potential; this is referred to as the concept of *seismic landscape*.

L'Aquila basin is a tectonic depression with a total length of about 35 km between the Gran Sasso and the Monti d'Ocre morphotectonic units within the inner sector of the Meso-Cenozoic Apennines orogenic belt (Figs. 1 and 2). It is a complex system of northwest-southeast-trending coalescing tectonic depressions evolving since the Early Pleistocene (Bagnaia et al., 1992; Blumetti et al., 2002; Boncio et al., 2004; Blumetti and Guerrieri, 2007). From north to south, these depressions are named Upper Aterno Valley basin (UAVB, *sensu* Blumetti, 1995), L'Aquila-Scoppito basin (AQSB) and Middle Aterno Valley Basin (MAVB, sensu Blumetti et al., 2013; Pucci et al., 2014), i.e., the basin extending from Paganica to San Demetrio ne' Vestini, named by Giaccio et al., 2012 Paganica-San Demetrio-Castelnuovo basin (Fig. 1). Therefore, the L'Aquila basin is considered the result of a long-term activity along a primary normal fault system about 35 km long, that comprises the UAVB bounding fault (i.e. the Mt Marine fault), the Pettino fault and the Paganica-San Demetrio fault system (Figs. 1 and 2; Blumetti, 1995; Blumetti and Guerrieri, 2007; Galli et al., 2011; Blumetti et al., 2013).

Thus, in this paper we consider the Paganica and San Demetrio faults parts of the same fault system. Instead, for Galadini and Galli (2000), the "Middle Aterno Valley fault system" comprises the San Demetrio and the Fontecchio -Roccapreturo fault systems, having its southern tip in the area of Molina Aterno (see Fig. 1). Falcucci et al. (2011, 2015) and Gori et al. (2012) have proposed a direct kinematic link between the San Demetrio fault and the Middle Aterno Valley-Subequana Valley fault system, and just a "sympathetic" relationship with the Paganica fault.

3. Quaternary evolution of the L'Aquila Basin

The Quaternary evolution of the local area surrounding L'Aquila, common to most of the Abruzzi Apennines, can be summarized in two phases. A first phase (Early Pleistocene) was dominated by a lacustrine environment. At that time, even if active normal faults already bordered the basins, the landscape was characterized by gentle morphologies and low energy relief (D'Agostino et al., 2001). Inside the lacustrine deposits west of L'Aquila (Madonna della Strada site, close to Scoppito, Figs. 1 and 2), remnants of *Arkidiscon meridionalis vestinus* were found (Azzaroli, 1983) that date them to the final Early Pleistocene (late "Villafranchian" Auct.). Paleomagnetic studies and pollen analysis on the Madonna della Strada sequence indicate for it an Early Pleistocene age older than the Jaramillo Subchron (1.07 Ma) and younger than MIS 40 (approximately 1.3 Ma; Palombo et al., 2010). In the Middle Aterno Valley basin, the lacustrine sedimentation is represented by a thick sequence of whitish carbonate silty deposits (San Nicandro Fm. of Bertini and Bosi, 1993), which widely crop out northeast of San Demetrio (Fig. 3). Spadi et al. (2015), based on freshwater ostracods, have established a Late Piacenzian-Gelasian age for the base of the San Nicandro Fm.

At the end of the Early Pleistocene (second phase), the environment of the Abruzzi Apennines experienced a dramatic change (Demangeot, 1965; D'Agostino et al., 2001), caused by an abrupt uplift that led to regressive erosion, drainage of the lacustrine basins and accumulation of thick gravel deposits. Indeed, an about 100 m thick sequence of both sub-horizontal and clino-stratified conglomerates blankets the San Nicandro lacustrine deposits, partly interfingered with them near their top surface (Bagnaia et al., 1992; Galli et al., 2010; Giaccio et al., 2012).

These conglomerates are interpreted as braided river fluvial deposits of a paleo-Aterno river by Bagnaia et al. (1992). Instead, Galli et al. (2010) and Giaccio et al. (2012) ascribe them to a deltaic gravel-sand complex (former Valle Orsa and Valle dell'Inferno Formations; Bosi and Bertini, 1970; Bertini and Bosi, 1993). The second hypothesis implies that during this phase the regressive