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The 2013 Lunigiana (Central Italy) earthquake: Seismic source analysis from DInSAR and seismological data, and geodynamical implications for the northern Apennines

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ABSTRACT

In this study we use Synthetic Aperture Radar Differential Interferometry (DInSAR) and seismological data to constrain the source of the mainshock of the 2013 Lunigiana (North-western Italy) seismic sequence, namely an Mw 5.1 event occurred on 2013 June 21. The sequence took place in a transfer zone located between the Lunigiana (North) and Garfagnana (South) graben. As the destructive Mw 6.2 earthquake occurred in 1920 has demonstrated, this area is seismically active and is considered the most hazardous area of the Northern Apennines.
Hypocentre relocations of the Lunigiana sequence aftershocks are well fitted by a ~45° N-dipping fault plane, whereas the focal mechanism solution yields a dip-slip mechanism with a slight right-lateral strike-slip component. Surface displacements estimated from ascending COSMO-SkyMed imagery acquired in the time-span of a single day around the mainshock were used to derive an elastic dislocation model. The estimated slip distributions computed on fixed and variable size meshes show peak values of 30 cm and 40 cm respectively. Static stress variation analysis was performed to analyze possible stress overloads on the closest seismogenic sources. Our results provide insight into the tectonics of the Northern Apennines, suggesting the fundamental role of transfer fault zones in intra-mountain basin origin and in the assessment of seismic hazard in an extensional tectonic regime.

1. Introduction

On 2013 June 21, at 10:33 UTC, an Mw 5.1 earthquake struck the Lunigiana area (North-western Italy), one of the most hazardous areas of the Northern Apennines, well known due to the disastrous Mw 6.2 event on September 7, 1920. The focal solution for the mainshock indicates a dip-slip solution with a slight right-lateral strike-slip component. The aftershock sequence lasted for weeks, producing a large number of earthquakes. It occurred in a transfer fault zone, separating the northern Lunigiana graben and the southern Garfagnana graben (e.g. Elter et al., 1975). The study area is also characterized by active faulting along right-lateral strike-slip fault zones (Brozzetti et al., 2007; Di Naccio et al., 2013). At a larger scale the Lunigiana and Garfagnana graben are located in the western portion of the Northern Apennines, characterized by a NW–SE oriented system of extensional structures that crosscut and dissect the older compressive structures of the chain (e.g. Elter et al., 1975).

In this study, we measure the ground deformation due to the 2013 June 21 earthquake using Differential Synthetic Aperture Radar Interferometry (DInSAR). We define the source geometry based on seismological data and on the focal mechanism and subsequently carry out a linear inversion of the surface displacements to retrieve the slip distribution. Static stress transfer, studied through a Coulomb Failure Function (CFF) analysis, is used to understand and verify the possible interactions between the modelled source and other seismogenic sources located close the epicentral area. Finally, we discuss how our study contributes to the interpretation of the Northern Apennines tectonics and the implications for seismic hazard evaluation.

2. Geological setting

The study area is located in the south-eastern sector of the Lunigiana graben, extending for ~45 km along the upper Magra River valley, from the town of Pontremoli to the northern side of the Apuan Alps (Fig. 1). The northern Apennines are a NE verging thrust-and-fold belt formed in the Oligocene after the Corsica–Sardinia and Adria continental block collision (e.g. Elter et al., 1975). The tectonic units can be grouped

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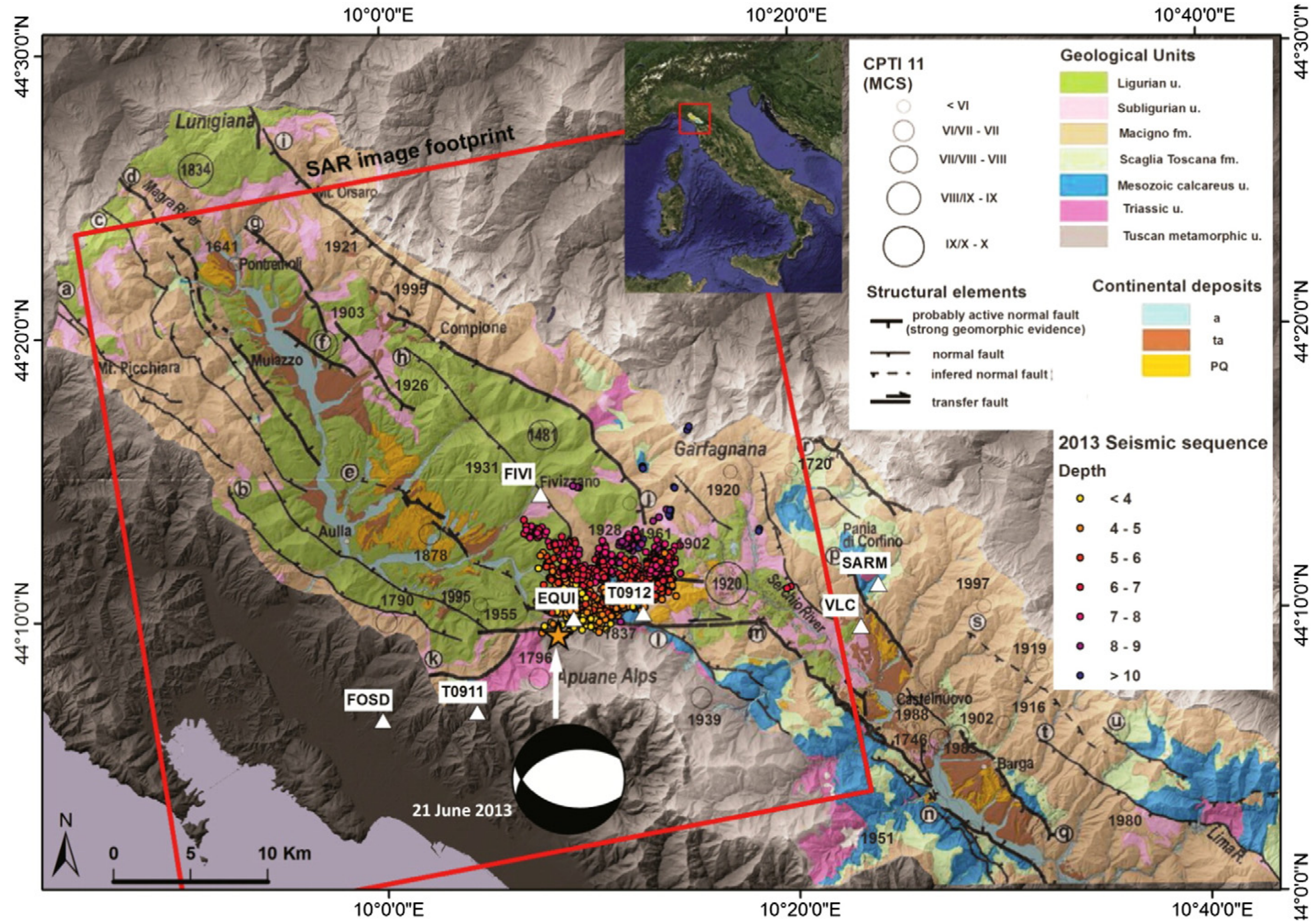

Fig. 1. Geostructural map of the 21 June 2013 earthquake showing the Lunigiana and Garfagnana graben modified from Di Naccio et al. (2013). The map shows the normal fault systems, the main geologic units of the bedrock and the continental deposits, as detailed in the legend. The 2013 seismic sequence (depth-coloured dots) and the 21 June 2013 focal mechanism are also reported in the map. Fault names: a) Mt. Picchiara F., b) Mt. Grosso F., c) Mt. Carmuschia F., d) Mulazzo F., e) Olivola F., f) Mocrone F., g) Arzengio F., h) Fivizzano F., i) Groppodalosio F., j) Compione–Comano F., k) north Apuan transfer fault zone F., l) Minucciano F., m) Casciana–Sillicano–Mt. Perpoli F., n) Bolognana–Gioviano F., o) Verrucole–S. Romano F., p) Corfino F., q) Barga F., r) Mt. Prato F., s) Colle Uccelliera F., t) Montefegatesi–Mt. Memoriante F., and u) Mt. Mosca F. Continental deposits: a = alluvial deposits (latest Pleistocene–Holocene); ta = terraced alluvial deposits and fanglomerates (middle–late Pleistocene); PQ = clays, sands, and conglomerates of lacustrine and alluvial environment (early Pliocene (Ruscinian)–to early Pleistocene (late Villafranchian)). Sources: Bernini and Papani, 2002; Carmignani et al., 2000; Coltorti et al., 2008; 1:10,000 geologic maps of the Tuscany Regional Authority available at http://159.213.57.103/geoweb/listmet/lista_metadati_10k.htm; 1:50,000 Italian Geologic Map of the CARG project available at http://www.isprambiente.gov.it/MEDIA/carg/toscana.html; Brozzetti et al., 2007. Historical seismicity from CPTI 11 catalogue (Rovida et al., 2011).

from top to bottom in: a) the Ligurian allochthon; b) the Subligurian unit; and c) the Tuscan unit (Bortolotti et al., 2001; Carmignani et al., 2001; Castellarin, 2001; Vai and Martini, 2001, and references therein). The first one consists of an upper Cretaceous stratigraphic succession, folded and thrusted during the late Cretaceous–Eocene subduction of the Liguride–Piedmont oceanic lithosphere. The Subligurian unit is a Paleocene–Oligocene stratigraphic succession originated in an intermediate position between the Ligurian oceanic domain and the Tuscan continental domain. The latter consists of upper (non metamorphic) and lower (metamorphic) units varying from Triassic to Neogene (Vai and Martini, 2001, and references therein).

The current tectonic setting of the Lunigiana area consists of a large NW–SE oriented graben delimited by normal fault systems, which are NE-dipping to the west and SW-dipping to the east, as highlighted by many authors based on seismic reflection profiles (e.g. Argnani et al., 2003). These tectonic features represent the result of the extensional tectonics started during the early Pliocene that dissected the compressive tectonic structures inherited from the previous contractional phase (Argnani et al., 2003; Bartolini et al., 1982; Bernini and Papani, 2002; Bernini et al., 1991; Carmignani and Kligfield, 1990; Carmignani et al., 2001; Elter et al., 1975; Raggi, 1985). Continental deposits cover the central part of the basin, recording the early Pliocene to Quaternary tectonic evolution (Bernini and Papani, 2002; Bernini et al., 1991; Bertoldi, 1997; Federici, 1978). In fact, these sediments are locally offset or strongly controlled in the deposition by normal faults (e.g. Bernini and Papani, 2002). Moreover the drainage network is now incising the continental deposits because of the present regional-scale Quaternary uplift that, according to Argnani et al. (2003), has accelerated during the last 1 Ma. The NE-dipping normal faults generally show dip angles between 30° and 60°, with cumulative displacements >4 km. In contrast, the dip angles of the SW-dipping faults vary between 50° and 70°, with relative cumulative displacements <2.5 km, showing a significant asymmetry (Bernini and Papani, 2002; Bernini et al., 1991; Castaldini et al., 1998; Raggi, 1985). Moreover, Argnani et al. (2003) show how the two NE- and SW-dipping fault systems are the shallower crustal splay of a major NE-dipping detachment fault plane, representing the northern termination of the NE-dipping normal fault system and characterized by low dip angles, extending along the entire northern Apennines (Barchi et al., 1998; Boncio et al., 1998; 2000).

At its southern termination the Lunigiana Graben is delimitated by the Minucciano Fault (label "l" in Fig. 1), a nearly E–W strike-slip fault, characterized by N-dipping and normal-oblique right-lateral