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Geological and Geophysical Approaches for the Definition of the Areas Prone to Liquefaction and for the Identification and Characterization of Paloeliquefaction Phenomena, the Case of the 2012 Emilia Epicentral Area, Italy

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Abstract

In May–June 2012, a seismic sequence struck a broad area of the Emilia-Romagna region in Northern Italy. The sequence included two mainshocks (on 20th May a ML 5.9 and on 29th May a ML 5.8). The whole aftershocks area extended in an E–W direction for more than 50 km, and included five ML ≥5.0 and more than 1,800 ML >1.5 earthquakes. Instrumental and historical local seismic records show low seismicity rate, the closest and more relevant historical earthquake being the 1570 A.D. earthquake that hit Ferrara. Widespread secondary geological effects were produced by the 2012 Emilia sequence and are mainly related to liquefaction phenomena. A total of more than 1,300 geologic coseismic effects were identified over more than 1,200 km^2. We present some preliminary results concerning the study of the liquefactions occurred during the 2012 Emilia seismic sequence with particular emphasis on: (a) the definition of the areas most prone to liquefaction, (b) the identification and characterization of potential paleoliquefaction events. To identify the zones with high, medium or low liquefaction hazard, we show our quantitative approach defined to obtain a GIS based detailed analysis of the geometric relationships between the observed liquefactions and some peculiar geomorphic features of the 2012 epicentral. Differently, for recognition and characterization of paleoliquefaction events we adopted a multidisciplinary approach involving sedimentology, mineralogy and magnetic properties of the 2012 liquefied sands together with geophysical profiling, coring and dating.

Keywords

Liquefaction • Emilia 2012 • Sand blows • Coseismic effects

184.1 Introduction

The May-June 2012 seismic sequence in Emilia region, characterized by two mainshocks (on 20th May a ML 5.9 and on 29th May a ML 5.8) and including five ML ≥ 5.0 and more than 1,800 ML >1.5 earthquakes (Ml after Mazza et al. 2012), confirmed how the Po Plain is particularly prone to coseismic liquefaction phenomena, mentioned also in reports of some historical earthquakes, like the Ferrara 1570, Soncino 1802 and Salò 1901 events (Galli 2000). The huge amount of data on coseismic liquefaction related to the May-

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G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 5*,
DOI: 10.1007/978-3-319-09048-1_184, © Springer International Publishing Switzerland 2015

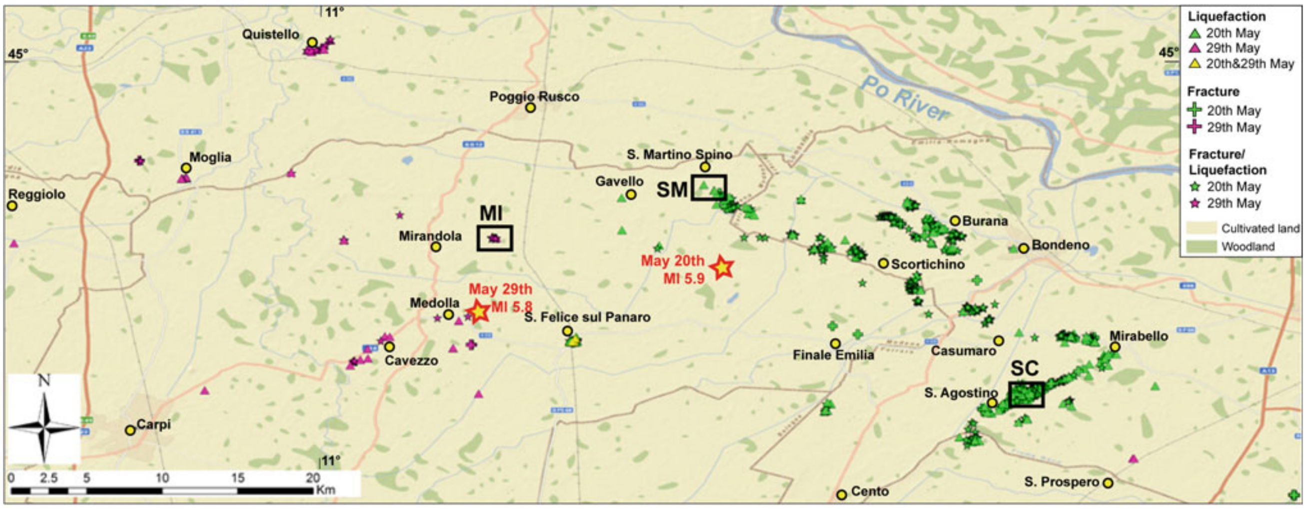

Fig. 184.1 Location of observed geological effects (1,362 data points); the three main categories are described in the legend with the triggering seismic event (modified after Emergeo 2013). The two mainshocks epicenters (stars) are presented together with the three areas (squares) investigated by coring survey, namely Mirandola (MI), San Martino in Spino (SM) and S. Carlo (SC)

June 2012 events (EMERGEO Working Group 2013; Fig. 184.1) offers a unique opportunity to refine our knowledge and methodologies to characterize the liquefaction phenomena.

In Italy, recent studies on paleoliquefactions include the coastal plains of Puglia and Sicilia regions (De Martini et al. 2003; Guarnieri et al. 2009) as well as intermountain alluvial plains, like the Aterno River Valley hit by the 2009 L'Aquila earthquake (De Martini et al. 2012). The recognition, characterization and dating of paloeliquefactions is of clear interest for all the alluvial plains located in seismically active areas and these studies are particularly important in case of absence of any historical account describing them, being the geological approach the only one able to provide direct evidence for such coseismic phenomena. A detailed study of the liquefactions characterizing the 2012 Emilia seismic sequence can provide original data to: (a) define the areas where liquefaction is more likely to occur, (b) find evidence for paleoliquefactions.

Considering that some investigations (e.g. spatial analysis of the subtle morphological imprints of the historical and presently active fluvial systems with respect to location of the 2012 sand blows, and magnetic and sedimentologic analyses of some selected ejected sands) were performed at a regional scale, while others (electric tomographic surveys, accurate stratigraphic, magnetic and geo-chronologic studies on core sediments collected in correspondence with the 2012 and 1570 sand blows) were at the scale of the site, the presentation of the results obtained is done in two main paragraphs.

184.2 Regional Scale Results and Considerations

Both the 2012 Emilia and the A.D. 1570 Ferrara epicentral areas show a present architecture that reflects the evolution of the complex fluvial network related to the Po River and its southern tributaries as well as all the reclaiming acivities performed on swamplands. For the latter reason, the outcropping deposits at the surface display different ages from the Neolitico (IV millennium B.C.) to the Late Middle Ages (XIII–XV century A.D.) up to the XVIII century A.D. in the easternmost areas.

The area covered by the 2012 Emilia post-event survey was about 1,200 km^2 and Emergeo (2013) recorded and georeferenced more than 1,300 observations (Fig. 184.1). The liquefaction phenomena (single sand volcanoes, alignment of sand volcanoes and open fractures created by the sand extrusion) were the most prominent features, representing up to 90 % of the total observations. On the basis of the analysis of the spatial distribution of the 2012 coseismic observations, 718 (∼52 %) out of a total of 1,374 elements are located in coincidence with mapped fluvial landforms, with levee and other fluvial ridges hosting together ∼69 % of them while crevasse splays account for ∼23 % (Fig. 184.2a).

Moreover, looking at the coseismic effects falling outside mapped fluvial landforms and taking into account the nearest geomorphic feature (Fig. 184.2b), we noted that most of the effects were located in proximity of levee and other fluvial ridges (∼67 %). Other liquefaction phenomena occurred

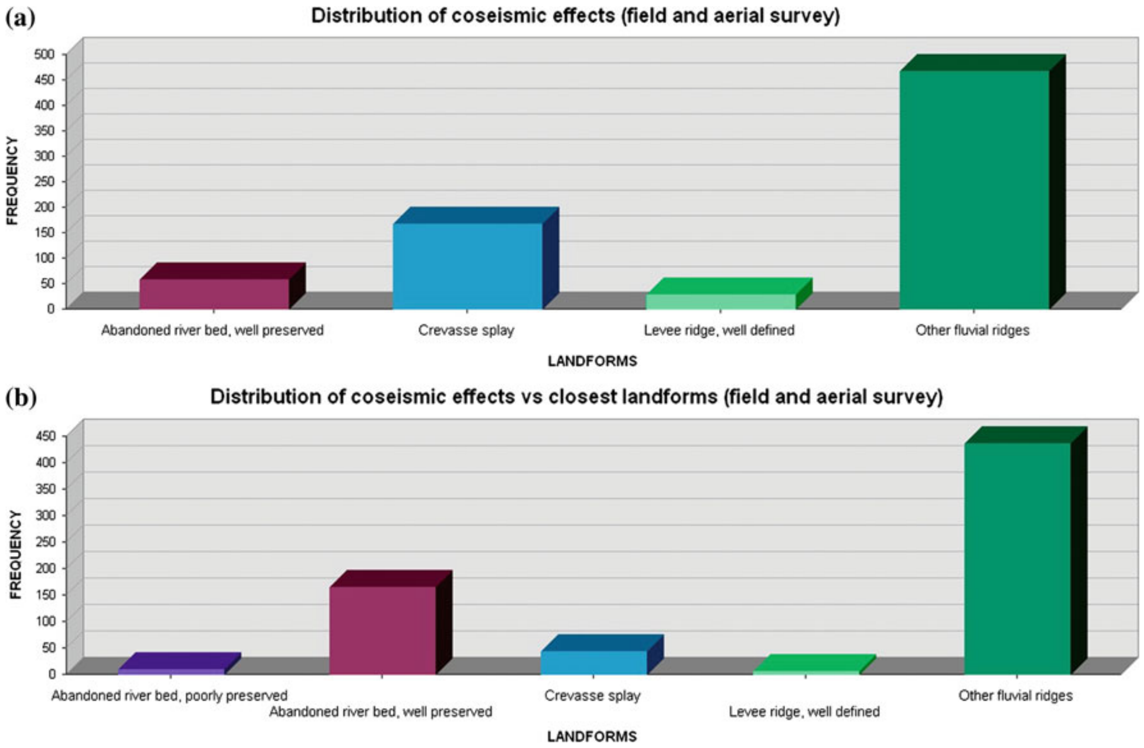

Fig. 184.2 **a** *Vertical bar* plot of the distribution of the observed coseismic effects with respect to mapped fluvial landforms; **b** *Vertical bar* plot of the distribution of the coseismic effects falling outside mapped fluvial landforms. Landform attribution is based on the proximity of the relative landform

near well preserved abandoned river-beds (~25 %) as well as crevasse splays (~7 %).

Preliminary sedimentologic results suggest that sediment samples can be subdivided into four main groups based on particle size distribution (from moderately sorted fine sand to poorly sorted sandy-silt, Fig. 184.3). Interestingly, grain size distribution diagrams of the described sediment groups plotted against grain size envelopes proposed by Obermeier (1996) as indicative of potentially and high potentially liquefiable soil, show that grain size distributions of Emilia 2012 sand blow samples largely fall within the "most liquefiable" area (Fig. 184.3).

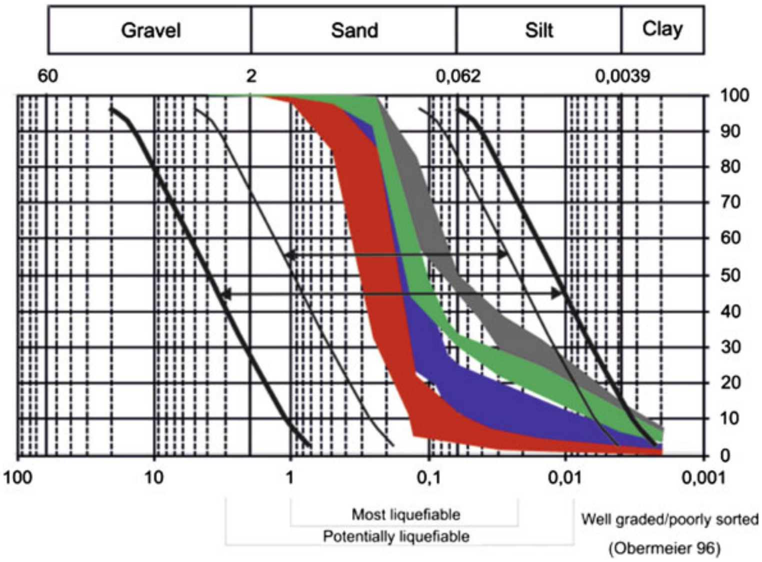

Fig. 184.3 Grain size distribution of 57 Emilia samples plotted against boundaries for potential and high potentially liquefiable soils according to Obermeier (1996). Diverse colored bands represent the four major grain-size groups

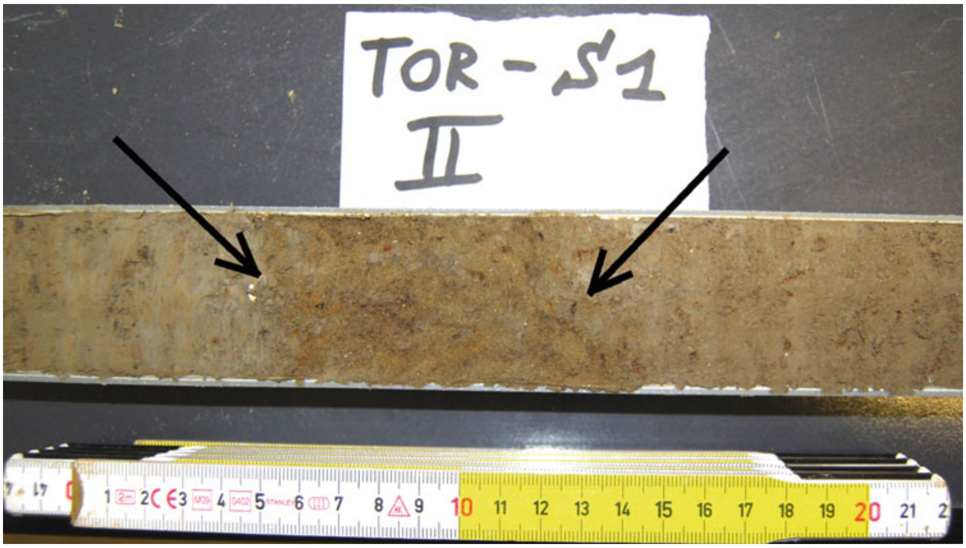

Fig. 184.4 Picture of the inferred paleoliquefaction deposit in core TOR-S1. The *arrows* mark the *top* and *bottom* of this peculiar layer

Preliminary results from the measurement of mass magnetic susceptibility (χ) on 98 discrete samples collected from several 2012 coseismic sand blows suggest that in general lower values of χ are concentrated in the southern sector of the study area while higher values characterize the northern sector. This observation may reflect the different provenance of the deposits highlighting those coming from the Apennines with respect to those from the Alps.

184.3 Local Scale Results and Considerations

We selected three different areas, namely Mirandola, San Martino in Spino and S. Carlo within the 2012 epicentral area (Fig. 184.1), together with one located 3 km south of Ferrara city (Torre della Fossa site). This decision was based on the opportunity to perform detailed investigations (morphologic and historic studies, electric tomographic surveys, coring campaigns and related analyses) on sectors of the 2012 epicentral area characterized by alluvial deposits related to different rivers, distinct stratigraphy and diverse age of the surface. For each area we selected one specific site taking into account: the presence of 2012 coseismic liquefactions (or historical accounts describing them), favorable logistic conditions and permission of the landowner for coring and/or trenching.

Both at Mirandola and San Carlo area we discovered the sandy dike (conduit) that fed the liquefactions in 2012. At Mirandola, San Martino in Spino and San Carlo sites, we believe that on five cores out of six we intercepted at depth the 2012 liquefied sandy layer; sedimentologic and magnetic data will provide the definitive answer to this question.

In general, there is a good agreement between the electric tomographic profiles and the stratigraphy recorded in the cores. A good correlation also acts between the stratigraphy and the magnetic susceptibility (SI) measured in continuous on cores.

No evidence for paleoliquefaction events was found in the 2012 epicentral area, while a possible evidence for paleoliquefaction deposit is found at the Torre della Fossa site (Ferrara) in the core TOR-S1. The internal structure and geometry coupled with the grain size "anomaly" of this thin layer suggest that it could be the remnant of a paleoliquefied deposit. Thanks to radiocarbon dating, we can say that this layer is most probably related to the A.D. 1570 Ferrara event (Fig. 184.4).

The sedimentation rate of the four areas investigated is quite high, with minimum and maximum values being around 4 and 20 mm/yr, respectively. This helped us in understanding that our maximum coring depth (about 5 m) was able to catch only the sediments relative to few centuries of deposition, leaving the question about potential paleoliquefaction events unsolved.

Acknowledgments This study has benefited from funding provided by the Italian Presidenza del Consiglio dei Ministri—Dipartimento di Protezione Civile (DPC). This paper does not necessarily represent DPC official opinion and policies.

References

De Martini PM, Cinti FR, Cucci L, Smedile A, Pinzi S, Brunori CA, Molisso F (2012) Sand volcanoes induced by the April 6th 2009 Mw 6.3 L'Aquila earthquake: a case study from the Fossa area, Italian. J Geosci 131(3):410–422. doi:10.3301/IJG.2012.14

De Martini PM, Burrato P, Pantosti D, Maramai A, Graziani L, Abramson H (2003) Identification of tsunami deposits and liquefaction features in the Gargano area (Italy): paleoseismological implication. Ann Geophys 46(5):883–902

EMERGEO Working Group (2013) Liquefaction phenomena associated with the Emilia earthquake sequence of May–June 2012 (Northern Italy). Nat Hazards Earth Syst Sci 13:1–13. doi:10.5194/nhess-13-935-2013

Galli P (2000) New empirical relationships between magnitude and distance for liquefaction. Tectonophysics 324:169–187

Guarnieri P, Pirrotta C, Barbano MS, De Martini PM, Pantosti D, Gerardi F, Smedile A (2009) Paleoseismic investigation of historical liquefactions along the Ionian Coast of Sicily, J Earthquake Eng 13(1):68–79. ISSN: 1363–2469. doi:10.1080/13632460802212030

Mazza S, Basili A, Bono A, Lauciani V, Mandiello AG, Marcocci C, Mele F, Pintore S, Quintilliani M, Scognamiglio L, Selvaggi G (2012) AIDA—Seismic data acquisition, processing, storage and distribution at the National Earthquake Center, INGV. Ann Geophys 55(4):541–548. doi:10.4401/ag-6145

Obermeier SF (1996) Use of liquefaction induced feature for paleoseismic analysis. Eng Geol 44:1–76