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Looking for seismites in the Fucino basin: preliminary results from an combined geological-geophysical approach.

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Abstract: We present a combined geological-geophysical study on the lacustrine sequence of the Fucino Plain (central Italy). New acquired data on liquefaction features and the recovery of a seimite in the lacustrine sequence are shown. Our preliminary results suggest the occurrence of three seismic events in the last ca. 45 kyr. Moreover, a first attempt to find out the source deposit responsible of the widespread liquefaction phenomena has been performed by means of shallow engine boreholes and ERT profiles.

Key words: Fucino Plain, lacustrine deposits, liquefaction features, seismites.

INTRODUCTION

The 1915 Avezzano earthquake ($M_s=7.0$), which struck the Fucino Plain (central Italy), is one of the major seismic events occurred in Italy over the last few centuries. Due to its relatively recent occurrence, the coseismic effects were extensively illustrated by Oddone (1915) in terms of intensity distribution and detailed description. Extensive paleoseismological research has been performed during '90 years to better understand the seismogenic behaviour of the structure responsible for the 1915 earthquake (see Galadini & Galli, 1999 and references therein). Paleoseismological analysis outlined the occurrence of ten surface faulting events in the past 33.000 years (Galadini & Galli, 1999).

The Fucino Plain is an extensional intramountain basin filled by Pliocene to Quaternary continental alluvial and lacustrine deposits (Cavinato et al., 2002). It was the site of Lake Fucino, a large endorheic lake drained at the end of the 19th century.

Most of the published paleoseismic data on the Fucino Plain derived from on-fault paleoseismic trenching. In our study we investigated the lacustrine sequences to detect the off-fault record of several paleoseismic events by means of methodologies applied in different tectonic settings (e.g. Monecke et al., 2006; Beck, 2009; Kagan et al., 2011; Avsar et al., 2014).

Compared to other terrestrial environments, lacustrine environments may contain relatively well preserved, continuous, and long sedimentary archives. However, unlike the clear seismic origin of coseismic deformations detected by on-fault trenching, sedimentary events in lacustrine sequences may have several triggering mechanisms other than seismic activity, usually of climatic origin. Therefore, temporal correlation with historical seismicity and/or on-fault trenching data is crucial in order to assign a seismic triggering mechanism to lacustrine sedimentary anomalies (Avsar et al., 2014). Here we present an integrated geological-geophysical study on the most recent lacustrine sequence of the

Fucino Plain retrieved by Electrical Resistivity Profiles (ERT), shallow boreholes and the exceptional recovery of a cleaned ditch affected by liquefaction features. Being aware of the fact that several lake level fluctuations occurred in the past due to global climatic variations (Giraudi, 1989),

we focused our research close to the area that apparently displays the longer lacustrine sedimentary sequence and where several coseismic effects of the 1915 Avezzano earthquake were reported and studied (Oddone, 1915; Galadini et al., 1997; Galadini & Galli, 1999).

DATA COLLECTION AND METHODS

Since 1875, when the lake was finally drained, the Fucino Plain became a flat area, intensively cultivated and crossed by many E-W and N-S trending ditches (Figure 1). In spring 2014 a field survey was performed on the Fucino Plain looking for new liquefaction features along many ditches.

Up to now, evidence for liquefaction was found along a single, E-W trending, 1.5 m deep dry ditch. The exposed sequence, properly cleaned and rectified, was photographed, described using coloured nails to separate the main layers/unit, and sampled for radiocarbon and sedimentological analyses. Moreover, several 5m long engine cores were performed both in the present-day depocenter of the Fucino Plain (named "Bacinetto") and close to that area where the longest lacustrine sedimentation record exists (Figure 1). On each PVC core a Computed Axial Tomography (CAT) was performed in order to identify peculiar intervals or sudden changes in the sedimentation otherwise not easily identifiable through a normal visual inspection. After the CAT inspection only the core performed next to the studied ditch was opened, photographed, logged and sampled for sedimentological, paleoenvironmental, tephrostratigraphical and radiocarbon analyses. Apart from C14 dating, the other analyses are still in progress.

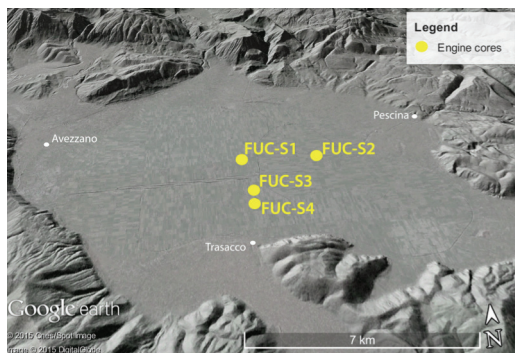


Figure 1: Five meters Digital Elevation Model (DEM) draped over a Google Earth bird's eye view of the Fucino Plain. Yellow pins locate all the engine cores. The investigated ditch and the ERT profile are located in correspondence of FUC-S4.

An Electrical Resistivity Tomography (ERT) profile along the W-E trending ditch was acquired (Figure 1). We deployed a 64 electrodes and 126 m long array with both Wenner and dipole-dipole quadrupoles configuration using a Syscal R2 resistivimeter (IRIS Instrument). A non-linear smoothness-constrained least-squares optimization technique is used to calculate the resistivity of the model blocks from the apparent resistivity data (de Groot-Hedlin & Constable, 1990; Loke & Dahlin, 2002).

STRATIGRAPHY

From the selected FUC-S4 core a sequence of ca. 5 m was analysed and subdivided in three main units.

Starting from the bottom ca. 3 m thick of laminated gray to green-gray, organic rich silty clay is found (unit A). Furthermore, three different well distinguishable tephra layers (Figure 2) related to the Colli Albani eruptions, basing on morphoscopy and petrographical features, are present in the lowermost 0.5 m (*sensu* Giaccio et al., 2007). Additional chemical analyses on these tephra are still in progress to better discriminate the different eruptions.

In unit A, at about -4.5 m of depth, a peculiar interval, few centimetres thick with several small laminae forming a chevron-fold type shape at small scale, is detected (Figure 2). The acquired CAT images confirmed the presence of this disturbed layer sampled in the PVC tube and enabled us to exclude that a deformation would have occurred during opening and cleaning operations of PVC tube. This feature can be interpreted as the result of seismic shaking (seismitite). Moving up along the core, the following unit B, represented by a gray to hazel oxidized clayey silt rich in manganese nodules, is present between -2.65 and -1.40 m of depth.

The uppermost 20 cm of unit B shows an infill of gray silt that continues also in the uppermost third unit. In fact, the latter unit C composed mainly by silt and clayey silt shows in the lower 0.50 m both lithologies upside down and with vertical contacts. This unit, that represents the most recent in time, is not well distinguishable in the

core and on the ditch walls. Moreover, the CAT analyses showed that unit C is a structureless sediment full of empty spaces and characterized by a reduced cohesion, similar to that of Galadini et al. (1995) defined as "de-structured silty deposits".

Thus, the 1.80 m thick sequence shown on both sides of the ditch walls, likely correlates with the first 1.50 m of the FUC-S4 engine core (unit C and upper part of unit B). On both sides of the ditch a ca 0.80 m thick, pale gray clayey silt, highly oxidized in the lower portion is exposed at ca. -1.80 m below the ditch top soil. Similarly to the core log, this clayey interval is cut by several filled fissures of sandy-silty material that can be likely interpreted as dikes related to liquefaction (Figure 2). This interval is overlaid by an alternation of gray massive and whitish laminated silts with a total thickness of ca. 0.70 m. The top of the ditch sedimentary sequence ends with 0.30 m of agricultural soil (ploughed horizon) whose surface represents likely the lake bottom in 1875 (year of the lake drainage). In fact, due to the superficial drainage system inception, the sedimentation rate in the Fucino Plain can be considered negligible.

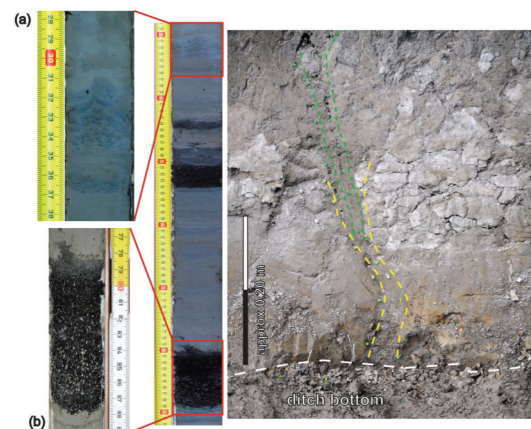


Figure 2: Pictures of the unit A from FUC-S4 core and the ditch wall. On the left side (a) detail of the chevron-fold type shape (seismitite) and (b) the lower tephra layer; on the right a zoom of the N ditch wall showing the two filled fissures related to a double liquefaction phenomenon.

Differently from the core log, the ditch clearly shows how filled fissures developed. In fact, on the same dikes two open vent and fissure generations are present. One older fissuration event likely occurred during the sedimentation of the oxidized gray clayey silt, because of the occurrence of a sill of sandy silt within these fine sediments. Within the same dykes a new filled fissure of sandy-silty material developed and cut only part of the upper silty alternation. This second fissure does not seem to reach the ploughed layer but stops within the upper whitish laminated silty interval.

The stratigraphy retrieved using engine cores and field data seems to be confirmed in first approximation by the interpretation of the ERT profile. In fact, the 2D section (Figure 3) shows a thin resistive layer (ranging from 5 Ω m



to about 50 Ωm) throughout the profile with an average thickness of about 2.0 m (the sequence in the ditch). This superficial interval overlay a low resistive layer, showing resistivity of about 10 Ωm, down to a depth of 5 m. The lower part of the 2D electro-resistivity section indicates a change in the stratigraphy due to the presence of an intermediate, moderately resistive, ca. 5.0 m thin layer with resistivity values ranging from 15 to 19 Ωm, respectively. Therefore, we interpreted this layer to be the response of coarser materials with respect to the uppermost low resistive clayey sediments (unit A).

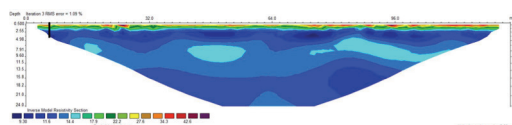


Figure 3: Electrical resistivity tomography result. A logarithmic colour scale for the resistivity model accentuates discrimination of low-to-mid-range resistivities. Solid black line shows the location of the FUC-S4 borehole.

CHRONOLOGY

The age of the investigated deposits can be estimated by 5 AMS C14 dating (Table 1) and tephrochronology. All the ages retrieved from C14 resulted in stratigraphical order and no overlaps or inversion were recognized. Consequently, the lowermost unit A seems to be Upper Pleistocene in age as suggested by the combination of C14 dating and tephrochronology (see samples from FUC-S4 at 2.67 and 4.11 m, respectively in Table 1). In fact, the recognized tephra can be related to the Colli Albani eruptions and dated back to ca. 30-45 kyr (Giaccio et al., 2007).

Unit	Site/depth (m)	Sample	Conventional age (BP)	Calibrated age (2 sigma)
B	Ditch/1.6	FUC 1	4510±30 BP	BP 5305-5045
B	Ditch/1.7	FUC 2bis	4700±30 BP	BP 5580-5320
B	FUC-S4/1.66	FUCS4 (164-166)	8270±40 BP	BP 9415-9125
A	FUC-S4/2.67	FUCS4 (265-267)	22490±80 BP	BP 27060-26555
A	FUC-S4/4.11	FUCS4 (408-411)	27030±130 BP	BP 31190-30950

Table 1: Measured and calibrated ages (according to Calib REV7.0, Stuiver & Reimer, 1993; IntCal13, Reimer et al., 2013) of the samples collected. Measurements were performed at the Beta Analytics Inc. (Florida).

On the contrary, the intermediate unit B resulted to be younger of ca. 27.000 yr and older of ca. 5580 BP. Because of the lack of any dating material in the

sediments no direct age constrains are available for the uppermost unit C. Nevertheless we can say that it was deposited between 5580 yr BP and the 1875 AD. Furthermore, it corresponds to a period were many changes in lake levels took place due to both previously mentioned climatic events as well as to preliminary attempts in controlling the lake water level made at the time of the Ancient Roman period by means of three draining tunnels dug at different elevations (Giraudi, 1989).

RESULTS AND INTERPRETATION

Our geological-geophysical study provided new preliminary results in terms of liquefaction features and seismites as well as for the reconstruction of the lacustrine sequence of the Fucino Plain.

Despite any paleosoil or physical stratigraphical discontinuities were detected, we cannot exclude the presence of depositional gaps in the studied sequence. In fact, during the sedimentation of the oxidized gray clay (unit B), indicating a low lake level, or during the sedimentation occurred after the Ancient Roman period, several discontinuities were reported in the western portion of the plain by Galadini & Galli (1999).

Moreover, in the deepest unit A, an important change in the sedimentation rate occurred, as testified by the ages of tephra layers related to the Colli Albani eruption (ca. 15 kyr in 0.30 m).

The changes in the sedimentation rate occurred in the study sequence, related to climatic oscillation as suggested by Giraudi (1989), are likely responsible for the lack of evidence of some of the seismic events reported by Galadini & Galli (1999) on the basis of on-fault paleoseismological investigations.

Nevertheless, in the ditch two paleo-liquefaction events were identified. The path used by the liquefied sandy silt to reach the surface at the time of the seismic events seems to be the same and, even if sedimentological analysis has not confirmed it yet, the material found in the filled fissures apparently seems to share the same grain size.

Moreover, the ERT profile highlighted a change in the stratigraphy just below the end of the engine core. This lowermost layer can be likely the source of the liquefied sandy-silty material (Figure 3).

Taking into account the radiocarbon dating, the lower paleo-liquefaction event, generated during the sedimentation of the oxidized gray clayey silt (unit B), likely occurred after 5305BP (upper sample FUC1 collected in unit B). Because of the lack of any datable organic material in the youngest unit C, we cannot assign an age to the upper paleo-liquefaction. Nevertheless, it occurred most probably before the 1875 lake draining because the upper fracture termination does not reach the ploughed soil.

Regarding the only one disturbed layer reported at ca. 4.5 m, we may suggest its relationship to a seismic event occurred before ca. 31 kyr BP. In fact, this event occurred before the age of the deepest C14 sample (see FUCS4 at -4.11 m in Table 1).



Comparing our results with those published by Galadini & Galli (1999), we can suggest that the liquefaction phenomena discovered in this study may have been triggered by the same events reported as E4 (3944-3618 BC) and E2 after 426-782 AD, respectively. Moreover, in the same age interval of our unique evidence of seismite, Galadini & Galli (1999) reports an old surface displacement event (or group of events, E10) occurred between 32.520 ± 500 yr BP and about 20,000 yr BP. Because liquefaction occurrence and location is strongly related to local conditions at the time of the earthquake that may vary substantially in time, more extensive investigations of the lake area are needed to produce a complete liquefaction history of this area.

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References

- Avsar, U., A. Hubert-Ferrari, M. De Batist, G. Lepoint, S. Schmidt & N. Fagel, (2014). Seismically-triggered organic-rich layers in recent sediments from Gollükoy Lake (North Anatolian Fault, Turkey). *Quaternary Science Review*. 103, 67-80.
- Beck, C., (2009). Late Quaternary lacustrine paleoseismic archives in north-western Alps: examples of earthquake-origin assessment of sedimentary disturbances. *Earth-Science Review*. 96, 327-344.
- Cavinato, G.P., C. Carusi, M. Dall'Asta, E. Miccadei & T. Piacentini, (2002). Sedimentary and tectonic evolution of Plio-Pleistocene alluvial lacustrine deposits of Fucino basin (central-Italy). *Sedimentary Geology*. 148, 29-59.
- Galadini, F., P. Galli, (1999). The Holocene paleoearthquakes on the 1915 Avezzano earthquake faults (central Italy): implications for active tectonics in the central Italy. *Tectonophysics*. 308, 143-170.
- Galadini, F., P. Galli & C. Giraudi, (1995). Individuazione ed analisi di deformazione geologiche associate a liquefazioni indotte da terremoti. *Geologia Applicata e Idrogeologia*. 30 (1).
- Galadini, F., P. Galli & C. Giraudi, (1997). Paleoseismologia della Piana del Fucino (Italia centrale). *Il Quaternario*. 10, 27-64.
- Giaccio, B., A. Sposato, M. Gaeta, F. Marra, D.M. Palladino, J. Taddeucci, M. Barbieri, P. Messina & M.F. Rolfo, (2007). Mid-distal occurrences of the Albano Maar pyroclastic deposits and their relevance for reassessing the eruptive scenarios of the most recent activity at the Colli Albani Volcanic District, Central Italy. *Quaternary International*. 171-172, 160.
- Giraudi, C., (1989). Lake levels and climate for the last 30000 years in the Fucino area (Abruzzo, central Italy): A review. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 70, 249-260.
- de Groot-Hedlin, C., S. Constable, (1990). Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data. *Geophysics*. 55, 1613-1624.
- Kagan, E., M. Stein, A. Agnon & F. Neumann, (2011). Intrabasin paleoearthquake and quiescence correlation of the late Holocene Dead Sea. *Journal of Geophysical Research*. 116, B04311. <http://dx.doi.org/10.1029/2010JB007452>.
- Loke, M.H., T. Dahlin, (2002). A comparison of the Gauss-Newton and quasi-Newton methods in resistivity imaging version. *Journal of Applied Geophysics*. 49, 149-162.
- Monecke, K., F.S. Anselmetti, A. Becker, M. Schnellmann, M. Sturm & D. Giardini, (2006). Earthquake-induced deformation structures in lake deposits: a late Pleistocene to Holocene paleoseismic record for Central Switzerland. *Eclogae Geologicae Helvetica*. 99, 343-362.
- Oddone, G., (1915). Gli elementi fisici del grande terremoto marsicano-fucense del 13 gennaio 1915. *Bollettino Società Sismologica Italiana*. 19, 71-215.
- Reimer, P.J., E. Bard, A. Bayliss, J.W. Beck, P.G. Blackwell, C. Bronk Ramsey, P.M. Grootes, T.P. Guilderson, H. Haflidason, I. Hajdas, C. Hattz, T.J. Heaton, D.L. Hoffmann, A.G. Hogg, K.A. Hughen, K.F. Kaiser, B. Kromer, S.W. Manning, M. Niu, R.W. Reimer, D.A. Richards, E.M. Scott, J.R. Southon, R.A. Staff, C.S. Turney & J. van der Plicht, (2013). IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years cal BP. *Radiocarbon*. 55 (4).
- Stuiver, M., P.J. Reimer, (1993). Extended 14C database and revised CALIB radiocarbon calibration program. *Radiocarbon*. 35, 215-230.