

## PEDOSTRATIGRAPHY AND MICROMORPHOLOGY OF SOIL THIN SECTIONS AS A TOOL IN PALEOSEISMOLOGY: DECIPHERING PAST PROCESSES INTERACTING WITH TECTONICS

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**Introduction.** Paleoseismology aims at identifying and characterizing past earthquakes using geological evidence (e.g., McCalpin, 2009). In particular, relevant information can be gathered thanks to the crosscutting relationship existing between pedosedimentary deposits and tectonic structures, usually investigated through trenching. In such approach, the detailed study of soils/paleosols and pedostratigraphic sequences has been extensively included. Nevertheless, soils have been usually considered as simple marker horizons and in very few cases the interplay between tectonic deformation and typical soil microfeatures has been investigated (e.g., Nelson 1992; Previtali 1992; Amit *et al.*, 1996; Livio *et al.*, 2014). Soil microfeatures (e.g., clay coatings, nodules, *papulae*) can be analysed and identified through the micromorphology of soil thin sections, allowing including additional constraints into the paleoseismological reconstruction built up on the basis of crosscutting relations.

Previtali (1992), applied the study of soils in these terms, stating that “*seismic events could disturb the internal arrangement of many soils, leaving behind macroturbations*”. He used the term “*seismipedoturbations*” (introduced by Boul *et al.* 1973) for indicating “*upsets, deformations and collapses in soil profile due to tectonic activity*”. This issue was no longer discussed afterwards, except in describing stress features in the glaciotectonic context (Khatwa and Tulaczyk, 2001; Larson *et al.*, 2016; Menzies and Reitner, 2016).

In some recent works, we take up this topic (e.g., Livio *et al.*, 2014; Zerboni *et al.*, 2015; Frigerio *et al.*, in press), integrating paleoseismology, structural analysis and pedostratigraphy, in order to disclose the earthquake-related evolution of two sites in northern Italy, located in compressional tectonic environment and characterized by complex sequences of Late Pleistocene loess-paleosols. In the following we briefly summarize the main results and observations related to this topic.

**Monte Netto site (northern Italy - BS).** The site is located in the central portion of the Po Plain foredeep. Monte Netto is an isolated hill, deriving from a tectonic uplift, induced by an outcropping secondary anticline with some related faults (Figs. 1b, 1c). In a quarry exposed at the top of this hill, we identified a thick and complex loess-paleosols sequence, resting upon fluvial/fluvioglacial deposits. The analyses of thin sections of undisturbed soil blocks, allow deciphering at least two deformation event. Fig. 2 shows a thin section of sediment sampled in a system of subvertical fractures deforming fine sand fluvial sediments. At the macroscale (Fig. 2a), the slide shows planar voids, ascribable to fractures, filled by a clay-rich plasma (visible at the microscale, Fig. 2b-d’), which displays different generations of clay infillings characterized by different colours and textures. These differences indicate several infillings, whose formation required a multistep process of fissures opening and infilling by pedogenetic clay (illuviation); these events are related to subsequent coseismic movements.

**Pecetto di Valenza site (northern Italy – AL).** At the Pecetto di Valenza site (Figs. 1d, 1e) we analyzed a 10 m long and up to 4 m deep stratigraphic section, located in the vicinity of the southern margin of the Valenza Plateau, in the eastern sector of the Monferrato Arc (western Po Plain). This site is characterized by a recent paleoseismic reverse surface faulting affecting a complex pedosedimentary sequence, characterized by, from the bottom, a marly bedrock, followed by a colluvial deposit cover with two loess covers at its top. Also here, the paleoseismological history has been constrained thanks to the study of some soil thin sections, obtained from undisturbed blocks taken in correspondence with damage features.

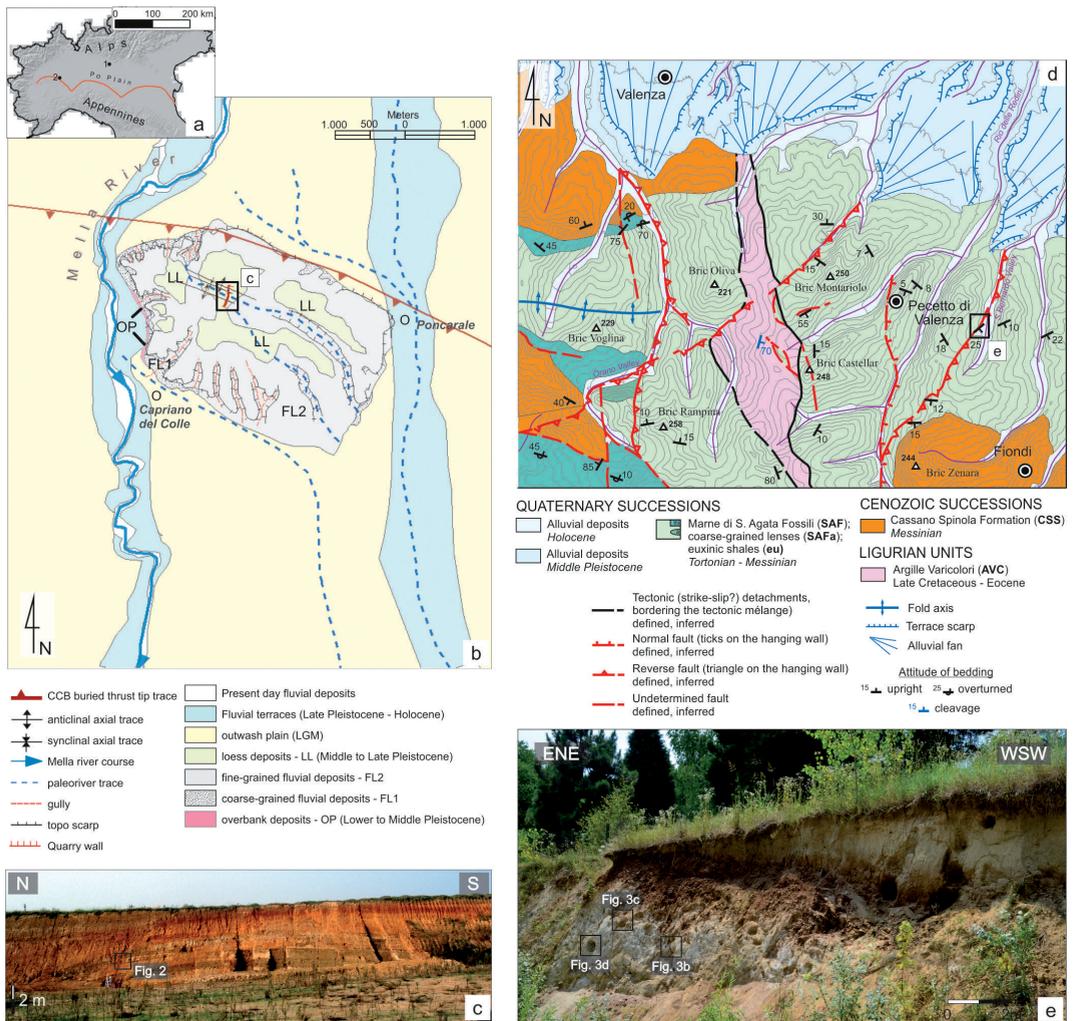


Fig. 1 – a) Location map of the studied sites (1: Monte Netto; 2: Pecetto di Valenza); the traces of the major frontal arcs of the N Appennines are also shown (from ITHACA database modified, <https://goo.gl/55FwDH>); b) geological sketch map of the Monte Netto area (modified after Livio *et al.*, 2014); the black box locates Fig. 1c; c) general view of the Monte Netto quarry wall, showing the south verging anticline analysed in detail: the box suggests the position of the sampled undisturbed block for the soil thin section shown in Fig. 2; d) geological map of the Pecetto di Valenza area (modified after Frigerio *et al.*, in press); the location of the Pecetto site is indicated in the black box; e) general view of the Pecetto di Valenza section; the boxes indicate the position of samples collected for the soil thin sections shown in Fig. 3.

Fig. 3a shows a thin section coming from a pocket of colluvium located along the main fault strand (Fig. 1e). At the mesoscale (Fig. 3a), the slide presents a set of sub-vertical fractures (corresponding to planar voids at the microscale) and some coarse fragments from the marly bedrock. At the microscale, the coarser elements of the micromass present a parallel sub-vertical orientation (Fig. 3b) aligned along tectonic strain axis. These stress features helped constraining one of the main tectonic deformation phases after the deposition of the colluvium, which has been involved in the displacement.

Figs. 3c and 3d show thin sections sampled in correspondence of the fault gouge (Fig. 1e). The groundmass of the first slide (Fig. 3c) appears chaotic, with highly weathered soil fragments, coming from the colluvium and pinched in the weathered marl. The second slide (Fig.

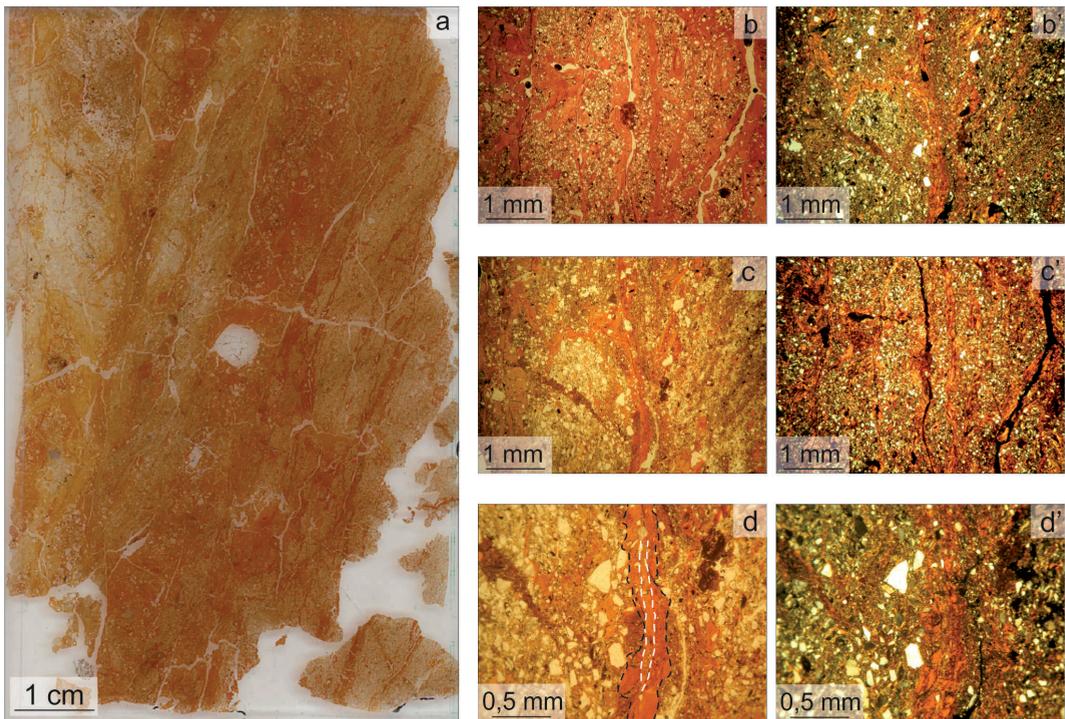


Fig. 2 – a) Scan of a thin section from the Monte Netto site, sampled along one of the main damage zone; b-c') photomicrographs of a system of sub-vertical fractures filled by illuvial clay (Fig. 2b-c plain-polarized light; Fig. 2b'-c' cross-polarized light): note, in the close up Fig. 2d (plain-polarized light) and 2d' (cross-polarized light), the occurrence of an external coating of red clay (black dashed lines), filled by yellow clay (white dashed lines). Modified after Livio *et al.*, 2014.

3d) presents common Fe-Mn oxides-hydroxides along planar voids, which at the macroscopic scale correspond to systematic joints. The latter are crosscut by a fault gouge, interested by illuvial clay, and locally deformed in a small-scale kink band anticline, due to a rotational component along the fault gouge. The joints filled by Fe-Mn oxides-hydroxides and illuvial clay helped marking the first stage of the deformation history of this site. Instead, the fault gouge including some fragments of illuvial pedofeatures from the base of the colluvial deposit, implied that during a further step of the tectonic history of the site, the topographic surface was coseismically offset after the deposition of the colluvium.

**Discussion and conclusion.** In both the cases the micromorphological approach highlights:

- the usefulness of paleosols in giving an additional data to reconstruct the relative chronological framework of seismic deformations;
- the recognition of repeated tectonic events that disturbed/formed specific pedofeatures is possible in the case of continuous pedogenetic processes;
- a better possibility of recognizing colluvial wedges, even at microscale, also resulting from the reworking of pre-existing soils, thanks to the individuation of specific pedofeatures (i.e., orthic Fe-Mn nodules and papulae; multi-generation of clay coatings);
- the potential applicability of this tool to sedimentary and geomorphological settings characterized by e.g., low or discontinuous sedimentation rates, high erosion activity etc.

Therefore, we think that it would be necessary to systematically consider, into the current paleoseismological practice, data from pedostratigraphy and micromorphological analysis. The

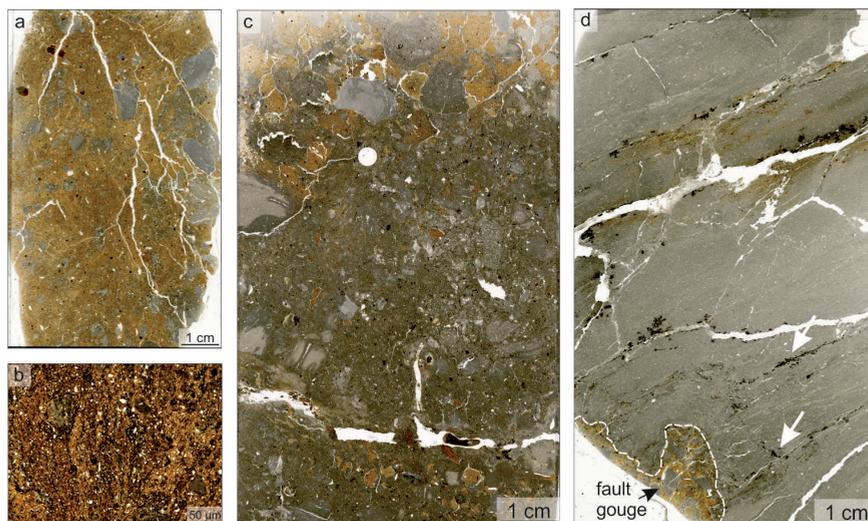


Fig. 3 – a) Scan of a thin section from a pocket of colluvium, involved in tectonic deformation, at the Pecetto di Valenza site; b) photomicrograph of the slide of Fig. 3a, illustrating the orientation of the constituents of the micromass, parallel to the main tectonic strain axis (plain-polarized light); c-d) scan of two thin sections sampled from the fault gouge: c) shows the presence of illuvial clay widespread in the weathered marl; d) the white arrow indicates joints ascribable to a first deformation phase, crosscut by the gouge associated to a later faulting event (modified after Frigerio *et al.*, in press).

reconstruction of the local paleoseismological evolution, in fact, may take great advantages from the description of pedofeatures related to seismic stress, identified in soil thin sections, if considered together with the well-established stratigraphic approach.

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