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Linking Environmental Archaeology to Geoheritage: a multifaceted approach to unravel and promote past fluvial landscapes

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1a. Abstract

Landscapes are geographic areas perceived by people whose characteristics are the result of the interaction between natural factors and human activities. This definition has been established during the European Landscape Convention (Florence, Italy - October 20th, 2000) when the member States of the Council of Europe debated and proposed guidelines to achieve sustainable landscape development based on a balanced and harmonious relationship between social needs, economic activity and the environment. The landscape has an important public interest role in the cultural, ecological, environmental and social fields, and constitutes a resource favourable to economic activity.

Multi-temporal analysis of landscapes enables the understanding of how geomorphic constraints conditioned the human settlements in the past and how land-use altered the environment natural development. Moreover, the diachronic approach to landscape research helps in evaluating the grade of sustainability of past societies systems and their impact on natural resources throughout the Anthropocene.

This Ph.D. project aims to understand past landscape evolution and in identifying the features derived by the human-environment interplay to promote the conservation of those features through geoheritage plans. To perform the project's objectives a multi-disciplinary approach that combines Environmental Archaeology methodologies and Geoheritage tools in GIS has been applied.

Case studies in fluvial environments have been selected to test the interdisciplinary approach proposed because floodplains represented the most suitable environment for human sustenance in history. The main area considered in this Ph.D. project concerns the evolution of Central Po Plain (Italy) during the Middle Ages (5th - 14th centuries CE) and secondary case studies (in Italy and abroad) have been considered to assess the reliability and versatility of the proposed methodology.

In particular, Structure-from-Motion photogrammetry has been tested as a valuable method to digitise historical cartography in order to use it in a GIS software for spatial analysis. This technique has been employed to digitise historical cartography for the main case study as well as to reconstruct the evolution of the Upper Rhone Valley (Valais, Switzerland) at the end of the Little Ice Age (18th-19th century CE).

Moreover, geoarchaeological and geomorphological tools have been utilised to understand the environmental development of the Central Po Plain and its connection with human settlement dynamics. Geospatial Analysis played a key role in the accomplishment of the project's goals. GIS software were fundamental to combine different kinds of datasets (archaeo-historical information, remote sensing images and geological maps to name a few) and to perform quantitative studies. In this regard, Point Pattern Analysis highlighted the role of alluvial geomorphology in Late-Holocene settlement strategies in Central Po Plain.

Finally, Geoheritage has been used to propose geo-educational plans to encourage the fruition of past landscape features and to increase public awareness on landscape conservation.

1b. Riassunto

I paesaggi sono aree geografiche percepite dall'uomo le cui caratteristiche sono il risultato dell'interazione tra i processi naturali e le attività umane. Questa definizione è stata stabilita durante l' *European Landscape Convention* (Firenze, Italia - 20 ottobre 2000) in cui gli Stati membri del Consiglio d'Europa hanno discusso e proposto linee guida per realizzare uno sviluppo paesaggistico sostenibile basato su una relazione equilibrata e armoniosa tra bisogni sociali, economia e ambiente. Il paesaggio ha un importante ruolo di interesse pubblico nei campi culturale, ecologico, ambientale e sociale e costituisce una risorsa utile all'attività economica. L'analisi diacronica del paesaggio geografico fisico consente di comprendere come le caratteristiche del territorio abbiano influenzato le scelte insediamentali passate e, conseguentemente, come le attività antropiche abbiano modificato il naturale sviluppo del territorio e dell'ambiente. Il medesimo approccio multitemporale, inoltre, permette di valutare quale fu il grado di sostenibilità dei sistemi delle società del passato e il loro impatto sulle risorse naturali durante tutto l'Antropocene.

Il progetto di dottorato presentato in questo manoscritto, si propone di ricostruire l'evoluzione di paesaggi del passato e di identificare le caratteristiche derivate dall'interazione uomo-ambiente al fine di analizzarne il valore in un contesto di patrimonio geologico-geomorfologico (*geoheritage*) e di promuoverne la conservazione anche attraverso itinerari geoculturali. Per realizzare gli obiettivi del progetto è stato applicato un approccio multidisciplinare che combina Archeologia Ambientale e Geoheritage. I dati storici e archaeologici sono stati combinati con analisi geospaziali per valutare come le attività antropiche e i fattori ambientali si siano influenzati a vicenda. Al fine di valutare e testare l'approccio multidisciplinare proposto, sono stati selezionati casi studio in vari ambienti fluviali Le pianure alluvionali, infatti, sono sistemi antropico-ambientali molto complessi in cui l'interazione reciproca tra attività umana e dinamiche fluviali ha influenzato lo sviluppo del paesaggio. La necessita' di terreno fertile e fonti irrigue per l'agricoltura, infatti, hanno portato le popolazioni a prediligere aree prossime ai fiumi per stanziarsi in maniera stabile e strutturata.

Il caso-studio principale considerato riguarda l'evoluzione di un tratto della Pianura Padana centrale (Italia) durante i secoli del Medioevo (V - XIV sec. d.C.). Casi studio secondari (in Italia e all'estero) sono stati presi in considerazione per valutare ulteriormente l'affidabilità e la flessibilità della metodologia proposta. In particolare, la fotogrammetria *Structure-from-Motion* è stata testata come metodo valido per digitalizzare la cartografia storica al fine di utilizzarla nei software GIS per l'analisi spaziale. Questa tecnica è stata impiegata per digitalizzare la cartografia storica per il caso studio principale nella Pianura Padana centrale e per ricostruire l'evoluzione dell'Alta Valle del Rodano (Vallese, Svizzera) alla fine della Piccola Era Glaciale (XVIII-XIX sec. d.C.) . Inoltre, sono stati utilizzati strumenti geoarcheologici e geomorfologici per comprendere lo sviluppo ambientale della Pianura Padana centrale e la sua connessione con le dinamiche insediative umane. L'analisi geospaziale ha svolto un ruolo chiave nel raggiungimento degli obiettivi del progetto. I software GIS si sono rivelati fondamentali per combinare insieme diversi tipi di *dataset* (tra cui, fonti storiche e dati archeologici, immagini satellitari, carte pedologiche, …) e per eseguire studi quantitativi. A questo proposito, la *Point Pattern Analysis* ha permesso di valutare e quantificare come la geomorfologia alluvionale dell'area in esame abbia influenzato le strategie di insediamento tardo-oloceniche in Pianura Padana centrale.

Infine, l'analisi dei beni geoculturali e del patrimonio geomorfologico e geoarcheologico ha permesso di proporre itinerari geo-educativi per valorizzare la fruizione delle forme del paesaggio del passato e promuovere una maggiore sensibilità alla geoconservazione. Nel complesso, i risultati presentati in questa tesi rappresentano un contributo per una migliore comprensione del potenziale utilizzo della Archeologia Ambientale e del Geoheritage per ricostruire i paesaggi del passato e promuoverne la valorizzazione, la tutela e la conservazione.

2. Introduction

2.1 State of Art

Landscapes represent a worthwhile dataset about the millennial human-environment interaction. Therefore, multi-temporal analysis of landscapes dynamics helps in identifying how human economic development and population growth alter natural resources (Paudel and Yuan 2012). Moreover, analysing landscape indices and simulating landscape change dynamics ease users in resolving crucial environmental questions regarding:

- the rate progress of landscape changing
- which kind of spatial pattern of land use are ecologically, socially, and economically beneficial
- sustainable plans for the conservation and the maintenance of natural and cultural resources

Humans are considered the third modifying agent for importance in landscape development (Li et al. 2017), and throughout the centuries the unstable equilibrium between human activities in nature and the ability of the natural system to respond to those activities conditioned the environmental dynamics (Hoffmann 2014) both at a local and a regional scale.

Past landscapes reconstruction enables a better understanding of human resilience to climatic and environmental changes in different periods and places. At the same time, the analysis of past human land-use permit to evaluate the impact of anthropogenic activities on modifying the natural assets of a region, even including early evidence of the inception of the Anthropocene (ArcheoGLOBE 2019). The diachronic study of landscapes has been carried out in different disciplines such as Earth Sciences, environmental sciences and social and humanities sciences that very often interlaced in the attempt of discerning the effect of the human-environment interplay.

Physical geography and Geomorphology are fundamental to comprehend the Earth surface processes, their development under changing climatic conditions and to understand the genesis and evolution of natural landforms (Pelfini and Bollati 2014). In the last decades, the multidisciplinary combination of Earth sciences tools, environmental sciences approach and social and humanities studies led to conceptualize new methodologies. Therefore, sub-fields in Geomorphology such as Anthropogenic Geomorphology (Szabó, Dávid, and Loczy 2010), Cultural Geomorphology and Archaeo-geomorphology (Panizza and Piacente 2003; Butzer 2008 Thornbush 2012) have been developed mostly to study the role of humans in creating landforms and in modifying the physical landscapes.

On the other hand, since the ‘70s, Earth sciences and geographic tools have been adopted in field and in-lab archaeological research especially when the aim is to understand how environmental conditions influenced the human settlements dynamics. Environmental Archaeology has been developed as the discipline that investigates past environments and “*the interaction between them and the human populations which lived in, modified and were modified by them*” (O’Connor and Evans 2005). In particular, Geoarchaeology (Cremaschi 2000; Goldberg and Macphail 2008) is really only one major strand of environmental archaeology, which is the combined study of archaeological records and geological tools to construct integrated models of human-environmental systems and to interrogate the nature, sequence and causes of human versus natural impacts on the landscape (French 2003). A related field of research that studies the ways in which people in the past reshaped and used the environment around them is represented by Landscape Archaeology. It is an interdisciplinary field, but the varying nature and strength of influences from the humanities, the biological and physical sciences, and the social sciences has shaped different approaches (Turner, Shillito, and Carrer 2018). One of these approaches is Archaeomorphology, an analysis focused on the study of human-made landforms and traces of territorial planning. It aims at analysing the historical development of landscape structures over time and embrace the idea of landscapes as cultural palimpsests (Orengo and Palet 2016).

The differences between all these disciplines developed from Geomorphology, Archaeology and their sub-fields are difficult to be perceived because very often same tools and techniques are applied to address similar goals. In particular, in the last decades, the role of Geographical Information Systems (GIS) and spatial analysis has grown exponentially. GIS software are fundamental to manage different types of datasets in a same project. The analytical power of GIS to advance innovative understandings of environmental and social aspects in past landscape has been emphasized by many authors in archaeological studies (Howey and Brouwer Burg 2017) as well as in geomorphological mapping (Bocco, Mendoza, and Velázquez 2001) and monitoring (Bocco, Mendoza, and Velázquez 2001; Remondo and Oguchi 2009). The main advantage of GIS is the integration of spatial and non-spatial information within a unified digital platform, which enables the exploration of complex patterns in the available datasets. Although GIS are routinely used through graphical interface, a growing number of scholars rely on coding to implement the most advanced methods of spatial analysis and map processing. Indeed, the integration of GIS with statistical computing software enabled quantitative spatial analysis improving our comprehension of the scale and the patterns of natural (James, Walsh, and Bishop 2012) and human (Carlson 2017) processes in landscape evolution. The application of geospatial modelling across large areas creates unique opportunities to gain complementary insights into past landscape. The most popular programming language for spatial data analysis is currently R (https://www.r-project.org/).

The multidisciplinary approach derived by the combination of the different disciplines mentioned above is not focused only on the diachronic reconstruction of landscape but on its protection, management and promotion, as well. As established by the Europen Landscape Convention (ELC 2000), its members are supposed to increase awareness of the cultural value of landscapes promoting educational policies on protection, management and planning (ELC 2000). Landscape might be defined as the result of a continuous synergy between natural processes and anthropogenic practices: in effect, the landscape is a palimpsest (Orengo and Palet 2016) recording, the geological and geomorphological history of the Earth and the interactions with human activities and cultural practices (Gordon 2018). Therefore, in literature, many connections between geoheritage (Panizza and Piacente 2003; Reynard and Brilha 2017), cultural heritage and landscape (Reynard and Giusti 2018) have been pointed out as a basis for geoeducational and geotourism activities. The interconnections between geoheritage and the cultural components of the landscape provide: (1) a range of opportunities for enhancing the geotourist experience (Chylińska 2019; Pilogallo et al. 2019); (2) a holistic approach for informing landscape conservation policy, management and planning (Szepesi et al. 2017; Baczyńska, Lorenc, and Kaźmierczak 2018).

2.2 Study Areas

The potentiality of this methodology has been tested mostly on floodplains because fluvial environments have always played a crucial role in human history. The necessity of fertile land and freshwater for agriculture has led populations to settle in floodplains more frequently than in other environments. Floodplains are the most complex human–water systems in which the mutual interaction between anthropogenic activities and environment affected the landscape development.

The Po Valley represents the largest floodplain in Italy and operates as a key area for the interpretation of environmental and cultural influences between the Mediterranean regions and continental Europe. Its complex settlement and land-management history makes it an ideal study-area (SA) to investigate the adaptive dynamics of human communities in alluvial environment. The portion of Central Po Plain (Italy) comprised between the Po River, the Apennines foothills and the two cities of Parma and Modena, has been selected to be the main case study to perform the project goals (Fig. 1, A).

The cooperation with both the geoheritage and geoarchaeological research groups of the Dipartimento di Scienze della Terra "Ardito Desio" (Università degli Studi di Milano, Italy) enables the comparative analysis with secondary case-studies of fluvial environments highlighting the potential of a multidisciplinary approach in past landscape reconstruction (Fig. 1, B-C-D).

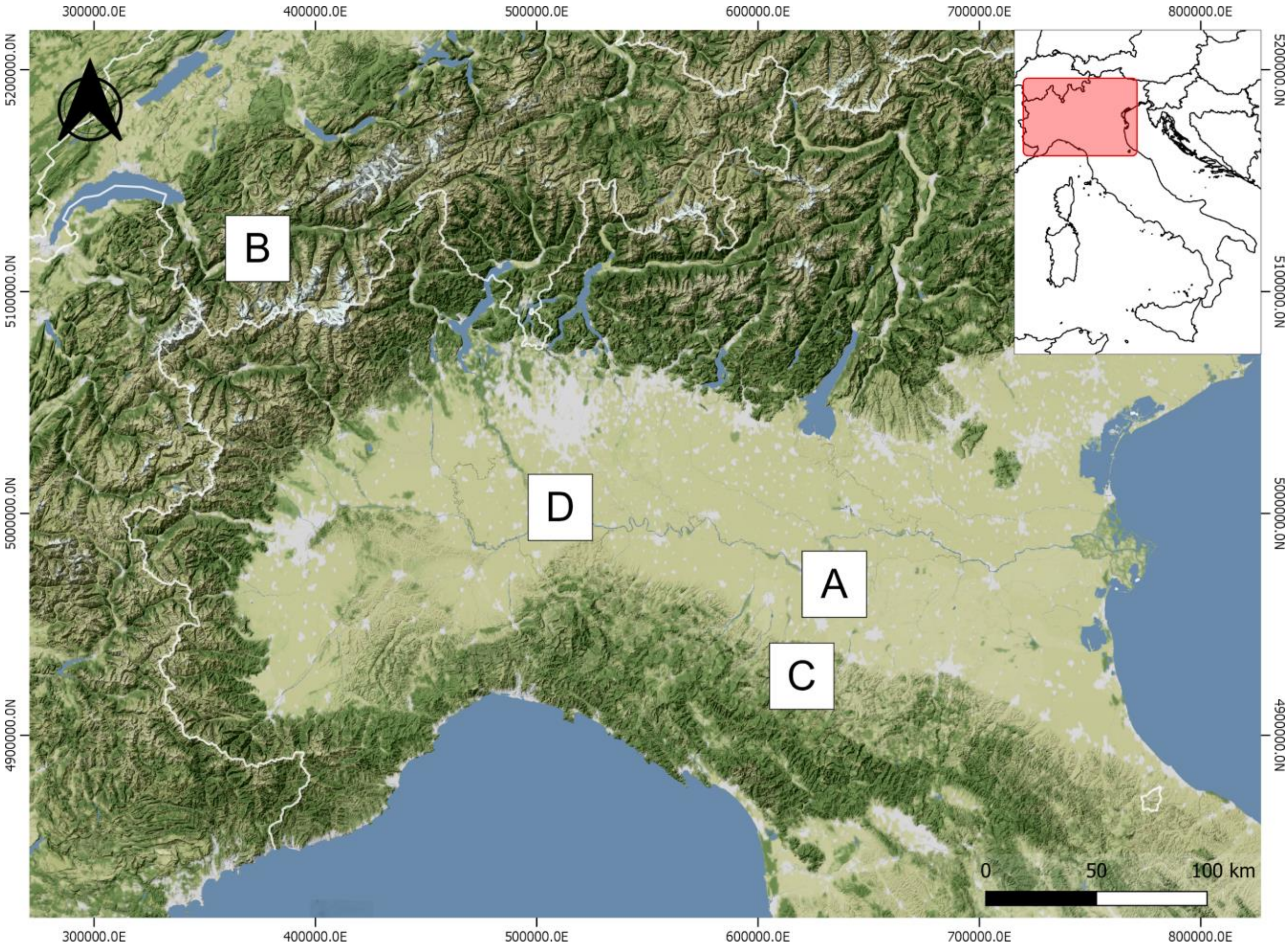

Fig. 1 - Location of the Study Areas (SA) A, B, C, D. (Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under ODbL)

- SA - A (*Central Po Plain, Italy*)

The natural factors that influenced the environmental development of SA-A fluvial landscape are mostly due to alluvial geomorphological dynamics (Fig.1, A). Since the Pleistocene, the Apennine watercourses shaped the landscape developing alluvial megafans with their sediments. In the distal parts of Holocene alluvial fans are characterized by a telescopic shape, a result of subsequent aggradation —entrenchment phases due to the alternation of glacial-interglacial periods; each aggradational cycle (Harvey, Mather, and Stokes 2005) causes an incision on the top of the previous fan, while a new fan prograded in a more distal position (Cremaschi and Nicosia 2012). In the study area, the alluvial ridges of the Enza, Crostolo and Tresinaro, emerging from the flat floodplain, flank depression areas known in fluvial geomorphology as backswamps, which are characterized by deposits of fine silts and clays deposited after flood events (Charlton 2007).

The landscape evolution of this portion of the Central Po Plain has a long-standing connection with human activities as well. Since the Bronze Age (Cremaschi et al. 2018) human communities settled in the Po Valley for its suitability to agriculture, altering the natural fluvial landscape and handling with the flood hazard. In the Roman period, the risk of inundation was managed and mitigated by the construction of embankments and drainages (Marchetti 2002). The transition from Roman into Early Medieval Period (6th - 10th centuries CE) represented a crucial moment for the reorganisation of human settlement strategies in Po Valley. Many authors point out that this transition led to a reduction of the cultivable and settled area due to the collapse of the Po Valley Roman hydrogeological systems (Curtis and Campopiano 2014). The Roman water management system was abandoned and woods, swamps and uncultivated areas became the typical features of the Early Medieval landscape. Channelization and reclamation works started only in the 10th century CE and intensified between the 12th and 13th centuries CE as a consequence of a general increasing demand for cultivated lands throughout Europe (Malanima 2005; Hoffmann 2014). In the Central Po Plain, large-scale ground reclamation is dated to Renaissance (15th century CE), it was renovated and updated many times in Modern Age (17th and 19th centuries CE), and it was completed only in the 20th century CE resulting in the modern completely artificial landscape (Saltini 2005).

The project interdisciplinary approach led to disassemble the cultural landscape palimpsest of this portion of Central Po Plain developed during the Late Holocene. Nonetheless, the significant archaeological and geomorphological features detected have been included in a geoheritage geoturistic plan to promote the public awareness and engagement for sustainable development of this fluvial landscape.

- SA - B (*Upper Rhone Valley, Switzerland*)

The Upper Rhone Valley is located in the Swiss Alps between the Rhone Glacier and Lake Geneva, and it represents the largest inner Alpine basin (Fig.1, B). The Upper Rhone Basin contained some of the thickest Alpine glaciers throughout the Quaternary period (Schlüchter 2009) and it was characterised by subsequent advance and retreat phases due to the alternation of glacial-interglacial periods. During the Last Glacial Maximum (LGM), 22.1 ± 4.3 ka BP, the Rhone Glacier filled the Upper Rhone Basin, outflowed onto the foreland and was the main component of the LGM transection glaciers in the western Alps. The deglaciation and retreat from the LGM position started in 21.1 ± 0.9 ka BP and ice collapse already initiated between 16.8 and 17.4 ka BP (Schoch et al. 2018). The glacial modelling influenced the mountainsides conformation, but frequently the traces of erosional processes have been covered by alluvial fans. Indeed, the tributaries of the Rhone River developed alluvial fans that influenced its course occupying a vast portion of the plain. Even though the 19th and 20th-century channelisation profoundly rectified the river course, between Sierre and Martigny, the influence of the alluvial fans developed by the tributaries is still clearly visible on the sinuous pattern of the Rhone River.

The Medieval chroniclers report the occurrence of severe flood events, and during the Little Ice Age (or LIA, 1350-1850 AD) the Upper Rhone River had certainly a torrential regime as other rivers in the Western Alps. During the second half of the 19th century the river was channelized twice in the periods of 1863–1894 and 1930–1960 (the so-called "Corrections of the Rhone River" (Baud, Bussard, and Reynard 2016) which gave to the river the present-day aspect.
The research performed in SA-B allowed testing the reliability of using only historical cartography to unravel the past landscape features of this portion of Upper Rhone Basin.

- SA - C (*Central Apennine valleys, Italy*)

SA - C lies in Northern Italy, inside the Emilia-Romagna region (Fig.1, C). The area is bordered to the East and West respectively by the Secchia and Enza rivers, to the South by the Apennine main watershed, and to the North by the southern margin of the Po Plain. The main geomorphological features of the region are typical of strongly deformed mountain environments. Landslides of different nature and extension deeply affected the territory in the past. Many of these erosive phenomena are presently active and often enhanced by human impact (Bertolini and Pellegrini 2001).

The establishment of strongholds along the Tuscan-Emilian Apennines belongs to a general fortification process that interested many European regions starting from the 10th cent. CE. In Italy, after the disruption of royal authority (mid-10th cent. CE) many powerful noble families started to construct their own castles (Settia 1999). In the Emilia-Romagna and Tuscany regions, the Canossa rulers led the reorganisation of the landscape with the construction of both defensive and ecclesiastic buildings. The political power of the Canossa family reached its apogee under the reign of his great-grand-daughter Matilda of Tuscany (1052–1115 CE).

The Matilda’s castles have been analysed to understand the relationship between their positioning and the distribution of geomorphological and geological hazards thought the application of geospatial analysis (Kernel Density Estimation).

- SA - D (*Ticino River fluvial terraces, Italy*)

SA - D corresponds to the municipality area of the city of Pavia (Italy). The town is located in the central-western Po Plain (Lombardia Region), ca 45 Km south of the city of Milan and ca 7 km west to the confluence of the Ticino River in the Po River (Fig.1, D).

Significant differences between Alpine and Apennine environments influenced the evolution of the Po Plain along its northern and southern flanks (Mauro Marchetti 2002). The study area is located in the north side of the Po River and is completely modelled in Quaternary alluvial deposits. Therefore, the Pleistocene alternation of fluvial-glacial and fluvial deposition phases - highly intense during the Last Glacial Maximum (LGM) developed a system of fluvial terraced levels (Castiglioni G.B.; Pellegrini 2001). The Holocene climatic conditions increased the erosive activity of the Alpine rivers that shaped the northern side of the Po Plain developing entrenched valleys deeply (M. Marchetti 2001). During the Holocene, entrenchment events have been alternated by less-intensive depositional episodes: the resulting fluvial landscape is characterised by high fluvial terraces that have always represented strategic positions in human settlement dynamics being a functional point of views in proximity to watercourses. In 89 BCE, the Romans founded the colony of *Ticinum,* probably replacing a former Gaul village and the city has been continuously inhabited throughout centuries.

The municipality of Pavia is crossed by a dense hydrographic network of natural (the Ticino River, the Roggia Vernavola and the Carona), partially (Navigliaccio canal) and completely artificial (Navigliaccio and Naviglio Pavese canals) watercourses. The interplay between this hydrographic system and human activities determined the urban development of the city of Pavia in which the distinction between natural and man-made landforms is challenging. The aim of this study was to identify urban geomorphosites (Reynard, Pica, and Coratza 2017; Zwoliński et al. 2018) to propose a geo-educational itinerary to promote the valorisation of landforms derived from human-fluvial terraces interaction.

2.3 Project Materials and Methods

The 3-years PhD project here presented aims to test a GIS-multidisciplinary approach to reconstruct past landscapes and to promote their conservation and valorisation. The project methodology employed environmental archaeology techniques to acknowledge the main phases of the diachronic landscape evolution and geoheritage tools to propose geo-educational plans.

- Archaeological and Historical data

Archaeological evidence (sites and materials) have been retrieved from various records (scientific literature, regional web database, terrain surveys). These data have been digitised in GIS enabling the chronological analysis of landforms identified in SA-A (Central Po Plain). Also, in SA - C, the archaeological sites detected allowed to quantify the impact of geomorphological constraints on medieval fortifications in the Apennines. The 18th and 19th-century transcriptions of medieval chronicles represented an advantageous starting point in the identification of past landscape features such as described precisely fluvial landforms or unknown settlement locations (SA - A). Especially the Modern Age historical cartography helped in understanding the fluvial geomorphological development occurred in SA - A, SA-B and SA-D. SfM-photogrammetry served as a contactless, highly flexible approach to digitise historical cartography producing High Definition (HD) digital copies that eased the georeferencing process in GIS. Historical maps offer a glimpse into a long and dynamic history of landscape change (Green et al. 2019).

- Geopedological data and analysis

The term Geopedology refers to the integration of elements of geomorphology and pedology for soil and landscape studies (Zinck et al. 2016). In SA-A the regional soil map has been implied to detect the maximum extension of the medieval swamps. The sediment deposition in floodplains has a strong correlation with the river flow transport capacity and typically the finer fraction is deposited in a more distal position than the coarser fraction during flood events. The finer sediments provide an indication of waterlogged areas before Renaissance land reclamation since backswamps present a high concentration of clay and silty-clays sediments. On the other hand, the soil map provides a solid proxy for agricultural suitability. Since "heavy" and "light" soils require different types of plough, their distribution may have influenced human settlement dynamic in different epochs.

In SA-C the geomorphological risk-related data (eg. landslides, badlands, fault systems) helped in the detection of the most important factors influencing terrain stability of the region and therefore historical infrastructure stability. Finally, archaeological soil micromorphology (or micropedology) (Macphail and Goldberg 2017) enabled the micro-stratigraphical study of an early medieval rural village located in SA - A. This geoarchaeological technique led to understand the site process formation and the relationship between human settling practices and the fluvial geomorphology of the area.

- Geo-spatial data and analysis

All the archaeological, historical and geopedological data have been managed with GIS software. GIS represents a fundamental tool in landscape studies not only for mapping or monitoring landforms but also to perform geospatial analysis.

In this research, the data retrieved in the national and regional geodatabase (available for each SAs) have been elaborated through the OSGeo4W open-source GIS-software: QGIS 3.4 and GRASS 7.2. In particular, the elevation checkpoints were interpolated through Inverse Distance Weighting method (IDW) in QGIS, to create Digital Elevation Models (DEMs) for SA-A and SA-C while the *r.mapcalc* GRASS function was used to set the regional DEM resolution in SA-B (5m-DEM provided by ASTERGDEM - ©SwissTopo) and SA-D (5m-DEM provided by Geoportale ©Regione Lombardia).

The quantitative spatial analysis performed during the 3-years project are:

➔ Point Pattern Analysis (PPA) (Baddeley, Rubak, and Turner 2015) to assess the role of alluvial geomorphology for human settlement dynamics in SA-A. A point pattern "*is a stochastic model that produces a point pattern under consideration of some parameters*"(Nakoinz and Knitter 2016) and it is increasingly popular in landscape archaeology.

➔ Kernel Density Estimation (KDE) (Nakoinz and Knitter 2016) to determine the potential impact of geomorphological features on medieval settlement locations in SA-C. KDE is a non-parametric approach to evaluate the probability density function of a random variable.

- Geoheritage analysis

The close connection between anthropogenic features and geomorphosite management was explored by Eric Fouache, who proposed the term "geoarcheosite"(E. Fouache and Rasse 2009) and "archaeo-geomorphosite" (Eric Fouache et al. 2012) to define geomorphosites in which human activities played a key role in shaping landforms. Fouache's scientific literature served as a helpful starting point for the geoheritage approach applied in this research.

In SA-A, the landscape cultural palimpsest of the study area was analysed and disassembled defining four different environmental layers, each with peculiar geomorphological and archaeomorphological features developed in the past. Each landscape-layer constitutes the base to propose potential geomorphosites and to define four geo-educational itineraries to promote geoconservation and valorisation practices on the palaeolandscapes detected in SA-A.

In SA-D, geomorphological analysis of fluvial terraces in the city of Pavia (Italy) enables the definition of potential geomorphosites and a geo-educational itinerary in an urban context. The geoheritage literature on fluvial and urban landscape (A. Pica et al. 2016; Del Monte et al. 2016; R. E. Pica and Coratza 2017) studies helped in the definition of the geo-educational itinerary proposed for SA - D.

2.4 Chapters list

The preliminary project results have been submitted and published in peer-reviewed international scientific journals (see Chapter 9, *Publications*) as well as presented in international congresses and conferences (see Chapter 8, *Participation in conferences and congresses*) throughout the 3-years PhD program. Each chapter consists of an array of the papers[1] focused on a specific methodological or conceptual topic of the project:

- Chpt.3 - Integration of historical cartography in GIS analysis

Chapter 3 regards the digitisation of historical cartography that represents an important source of information about our past as well as an invaluable component of our cultural heritage. The regeneration of historic maps in digital form permits to use them in GIS spatial analysis to reconstruct the human-induced modification on the landscape through time. Nevertheless, historical maps are usually deformed, and a common contact - scanning process could damage them. To avoid any physical deformations caused by using flatbed scanners, non-invasive contactless methodologies could represent a reliable solution.

In this regard, in chapter 3.1, Structure-from-Motion (SfM) photogrammetry has been successfully tested as a non-invasive method to digitise historical documentation. This non-contact and harmless scanning method has been developed with the help of the Geomatics Lab for Cultural Heritage (Department of Architecture and Design - Politecnico di Torino, Italy) and it was employed for the digitisation of historical maps at the National Historical Archive of Modena (Italy).

In chapter 3.2, the photogrammetric scanning procedure has been applied to digitalise historical cartography at the Archives de l'Etat du Valais (Sion, Switzerland) during a PhD - internship period at the Institute of Geography and Sustainability (Sion - University of Lausanne, Switzerland) under the supervision of prof. Emmanuel Reynard. The aim of this comparative study was to produce a long-term analysis of land use changes in this section of the Rhone River valley at the end of the LIA, between 1780 and 1860 AD, i.e. before the systematic river training, combining historical maps and GIS analysis. The objective was to create multi-temporal maps to highlight the main landscape changes due to anthropogenic land and water management activities that occurred in this fluvial environment.

- Chpt. 4 - Geoarchaeological tools to understand human-induced landscape modification from micro- to regional scale

Chapter 4 concerns the application of geoarchaeology to evaluate how anthropogenic activities altered the environmental evolution of the main study area. In particular, Chapter 4.1 regards the site formation process of an Early Medieval village (*Castrum Popilii*) that was established in the limits of the Post-Roman era swamp. The local communities adapted themselves to the Medieval palustrine

[1] The full-text of the papers reported in this thesis has been reformatted to homogenise the whole structure of the manuscript. Moreover, the copyright policies of each Editor have been considered to reply text, images and tables in this dissertation (for details see Appendix 3 - *Copyrights*).

environment settling in topographically higher position around the swamps limits and exploiting them for navigation as well as for silvo-pastoral sustenance practices.

Chapter 4.2 investigates the maximum extension reached by the Medieval swamps before the Renaissance land reclamation. Moreover, the impact of land and water management activities on landscape has been explored. Therefore, after the 10th century CE, land reclamation works started to alter the natural assets of the Medieval swamps. Channelizations and embankments were constructed to reclaim waterlogged areas and to create new cultivable land. Especially the *Tagliata Canal* and the *Crostolo River* developed anthropogenic geomorphological features still recognizable in the fluvial landscape of the main research area. The geoarchaeological and geomorphological investigations led to define the “land fill ridges” as Medieval features developed by the human exploitation of fluvial sediments to reclaim waterlogged areas.

- Chpt. 5 - Geospatial analysis to evaluate the influence of environmental factors on Late Holocene land-use and settlement dynamics

Chapter 5 regards the application of Spatial Point Patterns analysis (Baddeley, Rubak, and Turner 2015) in archaeology to quantify the human-environment relationship. The analysis of point patterns appears in many different areas of research, especially In ecology, and can be carried out using the statistical software R (Bivand, Pebesma, and Gómez-Rubio 2013).

Chapter 5.1 aims to assess if the different water management strategies in the Roman and Medieval periods influenced the spatial distribution of archaeological sites, and to evaluate the relative importance of agricultural suitability over flood risks in the two historical phases. Point Pattern Analysis (PPA), increasingly used in archaeological research at different analytical scales (Eve and Crema 2014; Negre, Muñoz, and Barceló 2018), was employed to provide a solid statistical assessment of these landscape dynamics. This research contributed to quantifying how the socio-political factors of past societies played a key role in human resilience to hazards related to alluvial geomorphology and climate changes. Different land-use techniques enabled the Romans to exploit large areas of flood-prone areas successfully. On the other hand, alluvial geomorphology highly influenced settlement strategies during the Early Medieval period, because large landscape infrastructures could not be maintained and developed.

Chapter 5.2 investigates how the location of medieval castles in the Apennines (Italy) aligns to the modern knowledge of geomorphological risk and how these constrains impact on the necessity to establish a capillary control of the territory. In particular, we compared the distribution of strongholds built in the era of Matilda of Canossa with the geological and geomorphological context of northern Apennines in order to investigate the perceived knowledge of geomorphological hazards in that time.

- Chpt. 6 - Promoting the fruition and valorisation of past cultural landscapes through geoheritage

Chapter 6 assesses the role of geoheritage to promote conservation and valorisation of past cultural landscape through geoeducational itineraries.

In chapter 6.1, the main research area has been considered as a cultural landscape palimpsest of four different palaeolandscape layers characterised by peculiar landforms. After an in-depth analysis of present and past geomorphic features deriving from the reciprocal interaction between human and floodplain dynamics since Prehistory, geoconservation and valorisation practices have been proposed. Starting from potential geoarchaeomorphosites, four geo-educational itineraries are proposed to promote future geotourism projects of the area.

Chapter 6.2 regards a comparative study of urban geoheritage (Reynard, Pica, and Coratza 2017; Zwoliński et al. 2018) in the city of Pavia (Italy). This case study enables a very useful comparison between the main research area and a fluvial environment in urban context. The Ticino River fluvial terraces were exploited for their strategic defensive position to establish a Roman colony. In the last two millennia the human-environment interplay shaped the urban landscape of Pavia creating a unique cultural landscape.

2.5 General goals and perspectives

Summarizing, the objectives of this Ph.D. project were to:

1) understanding past landscapes and evolution in different morphoclimatic and morphogenetic environment, with a particular focus on fluvial environment;

2) testing the flexibility and reliability of a multidisciplinary approach that combines archaeological and geomorphological data and methods;

3) evaluating the potentiality of GIS open-access software in managing different types of datasets and in performing geo-spatial analysis in fluvial landscapes;

4) proposing geo-educational itineraries to promote public engagement and awareness on landscape valorisation

3 Integration of historical cartography in GIS analysis

3.1 Structure-from-Motion (SFM) photogrammetry as a non-invasive methodology to digitalise historical documents: a highly flexible and low-cost approach?

[Brandolini, F.; Patrucco, G. *Structure-from-Motion (SFM) Photogrammetry as a Non-Invasive Methodology to Digitalize Historical Documents: A Highly Flexible and Low-Cost Approach?* Heritage 2019, 2, 2124-2136]

Abstract

Historical documents represent a significant part of the world cultural heritage and need to be preserved from physical deformation due to ageing. The restoration of fragile documents requires economic resources that are often limited to only preserve the integrity of exceptional and highly valuable historical records. On the other hand, regeneration of ancient documents in digital form is a useful way to preserve them regardless of the material they are made of. In addition, the digitization of historical cartography allows creating a valuable dataset for a variety of GIS applications as well as spatial and landscape studies. Nonetheless, historical maps are usually deformed, and a contact-scanning process could damage them because this method requires planar positioning of the map. In this regard, photogrammetry has been used successfully as a non-invasive method to digitize historical documentation. The purpose of this research is to assess a low-cost and highly flexible strategy to digitize historical maps and documents through digital photogrammetry using low-cost commercial off-the-shelf sensors. This methodology allows training a wider audience of cultural heritage operators in digitizing historic records with a millimeter-level accuracy.

Keywords: Structure-from-Motion; photogrammetry; 3D model; orthophotos; historical cartography; cultural heritage conservation

Introduction

Historical documents represent an important source of information about our past as well as an invaluable component of our cultural heritage. In particular, in recent years historical cartography has increasingly become a useful source for many research fields such as geomorphology [1,2], geoarchaeology [3,4] and geoheritage [5] to understand the human-induced modification on the landscape through time. Ageing is the main problem for the conservation of fragile material used to create this kind of geographic datasets. The regeneration of historic maps in digital form permits the preservation of these documents as cartographic heritage and to use it in GIS spatial analysis, for instance [6,7].

The conventional approach to digitize historical cartography consists of using the planar scanner, as still indicated for example, by the Central Institute for the Union Catalogue of Italian Libraries and Bibliographic Information [8]. Nevertheless, this method presents many issues: The archival maps may be fragile and difficult to handle, and sometimes the large size of historical maps may also require expensive digital scanners. Moreover, quite often, the digitization by flatbed scanners does not represent a suitable methodology because each map has its specific characteristics due mainly to:

- State of conservation of the map,
- map-sheet thickness [9],
- sensitivity to light [10],

- map format [11]: Through centuries, maps have been realized in a different format in length and width,
- map non-flat material [12,13]: The map could have suffered deformation of the support resulting corrugated. In other cases, the maps could be framed in a rigid wooden structure (as in the map presented in this case study),
- map accessibility [9,10]: It is common to find a map that has been painted on an entire wall, for example, in monasteries or royal palaces. That kind of historical cartography cannot be scanned (with the exception of laser scanners).

To avoid any physical deformations caused by temperature and humidity variations or by mechanical action caused using flatbed scanners, non-invasive contactless methodologies could represent a reliable solution. Nowadays, geomatics provides effective tools in this direction, and digital photogrammetry has been successfully used in order to digitize historical cartography [14]. In the framework of image-based photogrammetric techniques, structure-from-motion (SfM) is one of the most used [15,16] because of its flexibility, ease of use and cost-effectiveness [17]. Starting from 2D images, the epipolar geometry is estimated thanks to feature matching algorithms, for example, SIFT algorithm (scale-invariant feature transform) [18,19]. This approach allows to estimate the external orientation of the images and to reconstruct the 3D geometry of an object. In the last few years, a photogrammetric computer vision approach based on structure-from-motion algorithms has been applied for documentation of cultural heritage [18,20,21 and references therein]. In the present-day, it is widely applied for many purposes in different fields and disciplines such as archaeology [22–24], architecture [25,26], geology [27], and geomorphology [28,29].

In the case of historical cartography digitization, photogrammetry has been applied in two different ways [30]: 2D [9,31] and 3D approaches [10,12,32]. The two-dimensional methodology for historical maps digitization generally consists of the generation of an ortho-projection of the original after a rectification process of the images acquired using a digital camera. If it is not possible to capture in a single shot the whole historical map, several rectified images can be merged in order to provide a single mosaic. These kinds of techniques can be applied only if the historical map has a flat surface or if it is possible to flatten it with no risk of damaging it. When it is not possible to fulfil this condition, it is necessary to use a 3D approach. Three-dimensional models of the maps and digital orthophotos can be obtained from the 3D point clouds generated by using recorded digital images [33]. During several past research experiences [10,12], a 3D photogrammetric workflow has been successfully applied in the framework of historical cartography digitalization, highlighting the reliability and potentiality of the method that enables to reach a metric accuracy below the millimeter [14]. Another advantage provided from this kind of approach is the possibility to consider the map as a 3D object and so taking into consideration the deformations of the support [7].

At state of the art, the use of SfM photogrammetric techniques is a well-known procedure that responds to the necessity of digitizing historical maps and documents without any direct contact. Nevertheless, one of the main issues about this methodology is represented by the necessity of developing a protocol for a “low cost with optimal response” (LCOR) [9] digitization of historical cartographic heritage. In fact, the possessors of old documents are not only wealthy and prosperous individuals but also many institutions and collectors with less available resources.

During the study presented in the current paper, a historic map from the National State Archive of Modena (Italy) was digitized with an SfM photogrammetry approach in order to achieve the following goals:

- Definition of a non-conventional workflow for historical cartography digitization,
- documentation of movable assets belonging to cultural heritage,
- preservation of the integrity of the original maps,
- creation of digital replicas to ease the dissemination to a wide stream audience.

This study aims to evaluate the reliability of an SfM photogrammetric approach to digitize historical cartography, focusing the method on two main principles:

- low-cost approach,
- high-flexibility of the method.

Materials and Methods

The whole approach consists in the digitization of historical cartography by a non-contact and harmless scanning method based on the LCOR basic requirements. Nowadays, low-costs/commercial off-the-shelf (COTS) hardware and software is widely available in the market and is accessible by most of the users operating in the framework of cultural heritage documentation. In this context, the solutions are many, and currently, it is possible to achieve acceptable results with minimal investment. The presented methodology applied consists of:

- Acquisition of overlapped images of the historical map from different points of view by using a low-cost commercial sensor (mobile device camera),
- processing of the acquired images with a photogrammetric SfM-based software in order to generate a 3D model of the map,
- generation of an orthophoto of the digital model of the original map.

The quality of a photogrammetry-generated digital model can depend on many different factors including the state of conservation of the historical map, the lighting conditions during the data acquisition, the camera used, and the experience of the operator influencing the quality of the photographs needed to create the 3D model [34]. In the last few years, technological improvements connected to mobile device cameras allow acquiring digital images characterized by an acceptable radiometric quality. However, nowadays, professional or semi-professional Digital Single-Lens Reflex (DLSR) cameras can be purchased at a relatively affordable price. As for the lighting conditions on the acquisition set, if the illumination is not sufficient, the use of auxiliary artificial lights is recommended (for example using photographic LED (Light Emitting Diode) panels).

In the case described in this paper, in order to emphasize the low-cost aspect of the methodology, the images were acquired using a common mobile device equipped with Snapdragon 821 Mobile Platform hardware (Qualcomm, San Diego, US) [35] and an optical sensor Sensor Sony IMX 298 (Sony,Tokyo, Japan). In Table 1, it is possible to observe the main specifications of the camera used during the data acquisition phase.

Table 1. Main specifications of the camera of the mobile device used.

Mobile Device	**ONEPLUS A3003**
Camera model	Sony IMX 298
Sensor size	1/2.8’’
Megapixels	16
Pixel Size	1.12 µm
Image size	2610 × 4640 pixels

The 3D model was generated using the photogrammetric software Agisoft PhotoScan 1.4 [36]. The data processing of the acquired images was performed on two different workstations, a high-performance one (A, Table 2) (CPU Intel(R) Core(TM) i7-6800K, 3.40 GHz, RAM 128 GB, NVIDIA Quadro M2000), and a commercial off-the-shelf (COTS) laptop (B, Table 2) (CPU Intel(R) Core i7-4710HQ, 2.50 GHz, RAM 16 GB, NVIDIA GeForce GTX 850 M). In this case, the goal was to perform a comparison about the time required by both workstations during data processing in order to evaluate the suitability of the proposed methodology in the framework of relatively low-cost workstation solutions.

Table 2. Main specifications of the workstations used.

Workstation	Processor	RAM	GPU
A	Intel(R) Core(TM) i7-6800K, 3.40 GHz	128 GB	NVIDIA Quadro M2000
B	Intel(R) Core i7-4710HQ, 2.50 GHz	16 GB	NVIDIA GeForce GTX 850M

The proposed methodology was tested on a historical map preserved at the Modena National Historic Archive: "*Pianta Tipografica dimostrativa il Territorio e Giurisdizione di Novellara con la rigorosa posizione de' Cavi, Argini, e Strade, che la girano e con li manufatti pubblici, che vi sono contenuti; rilevata nell'anno 1774*" (Grandi Mappe-4, Archivio di Stato di Modena. 130 63 cm). This map (Figure 1) is dated from 1774, and it represents the landscape assessment of the municipality of Novellara (RE) with the indication of the main channels and roads. This map was realized with colored ink on paper material. Two wood slats mounted at the top and at the bottom of the map surface limited the undulation deformation and kept the surface moderately flat. The focus of this research is to propose a reliable workflow focusing on the suitability for a wide audience.

Figure 1. Topographic map of the Novellara (RE) municipality, 1774. "Grandi Mappe-4". Courtesy of Ministero dei Beni e delle Attività Culturali e del Turismo—Archivio di Stato di Modena". Authorisation prot. n. 1350 class. 28.01.02/21.2, April, 30th 2019.

Work Phases

The application of the methodology proposed is presented in two subsections: Data acquisition and data processing.

Data Acquisition

The map used as a case study during the presented research was selected—in addition to its cultural and historical value—for the presence of a cartographical grid. The dimensions of the grid were estimated before the data acquisition through several manual measures. In particular, the segments of the regular grid were measured in the map extension (using a simple ruler) in order to verify if and where any deformation might have affected the map support. This operation took about 15 minutes to be performed. (Figure 2). The images were acquired at the Modena National Archive in a low natural-light condition with no auxiliary artificial lights. The mobile device was set up to the automatic high-quality mode (HQ) which, according to the producer manual, is the most reliable camera setting in low-light conditions.

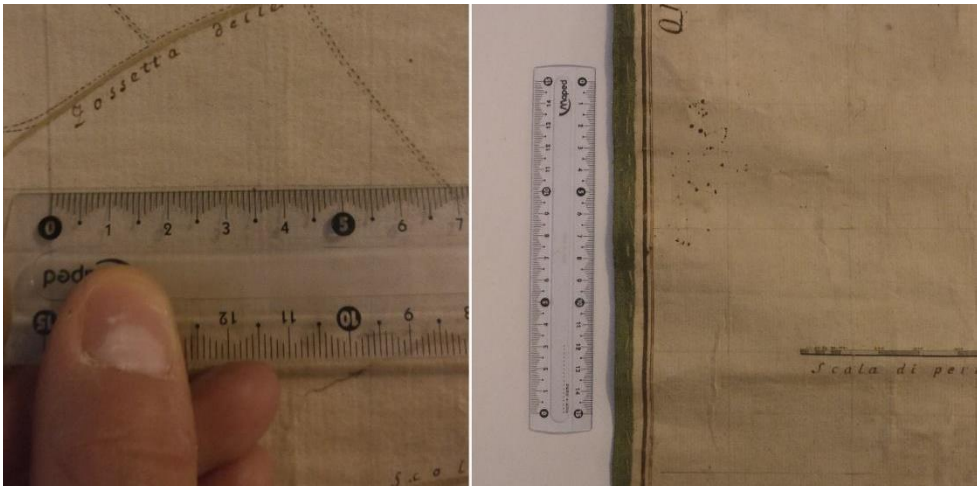

Figure 2. Two examples of manual measures performed on the selected case study.

This feature of the map allowed the identification of a high number of points—from which it was possible to estimate a relative local coordinate system—which could be used as ground control points (GCPs) and checkpoints (CPs) during the photogrammetric process, in order to evaluate metric accuracy. Two different operative workflows were applied. The first one can be applied to maps characterized (as in the considered case) by the presence of a cartographical grid.

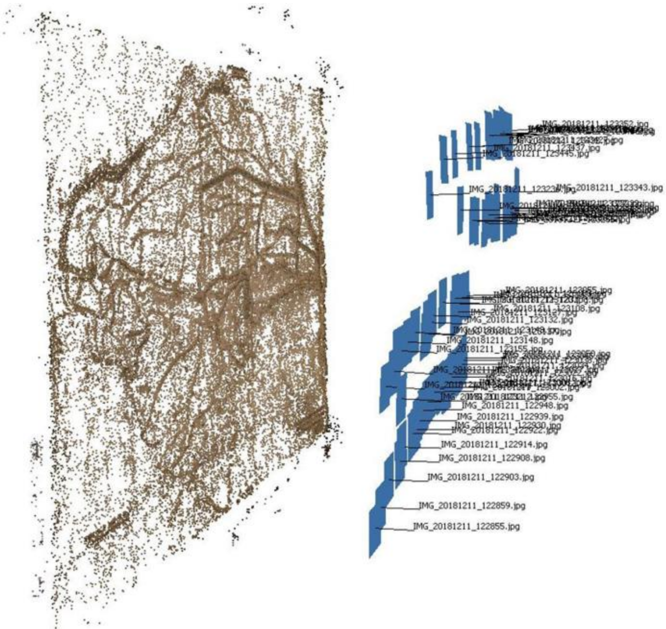

Figure 3. Extracted tie points.

The other one can be applied to all kinds of maps as long as it is possible to approximate their shape to a flat surface. In order to test a low-cost approach, the acquisition of the images was performed with a commercial mobile device camera (as stated in the previous section, a Sensor Sony IMX 298 was employed). Sixty-one images were acquired following the photogrammetric principles [37,38] and allowing sufficient image overlap to facilitate the automatic matching of corresponding points (Figure 3). Image acquisition took only 10 minutes.

Data Processing

Map images were then processed with the photogrammetric SfM-based commercial software Agisoft Photoscan [36] by following a consolidated workflow [39,40]. The calibration of the mobile device camera was determined with the autocalibration implemented in the used software. As stated above, in the first proposed approach, the cartographic grid is used to estimate points with relative local coordinates. Since one of the main goals of this research is to test a rapid and low-cost digitization methodology and considering the good conservation conditions of the map used, the z-coordinates of these points were approximated to 0. Consequently, if the main goal is the generation of an orthophoto, both the tested workflows can be only applied to maps that do not present high deformations due to their conservation status or excessive deterioration of the support.

Generally, a similar approximation needs to be evaluated on a case-by-case basis, depending on the ultimate aim of the end-user. Clearly, the final result will be more accurate as well in case of small discrepancies. During the testing of the first methodology, 69 points of the cartographic grid were used as GCPs and 16 as CPs in order to evaluate metric accuracy (Figure 4). The points were randomly selected in order to cover the entire surface of the map uniformly.

Figure 4. Cartographic grid points used as Ground Control Points (GCPs) (69 points marked in yellow) and Checkpoints (CPs) (16 points marked in red).

In Table 3, it is possible to observe the mean error after the bundle block adjustment. However, in the second case, the same dataset was processed without the use of the GCPs and the CPs; the obtained dense point cloud was scaled using direct measurements taken on the considered map. In total, the model was scaled with 4 manual measurements using as reference the four points of the grid placed near the map edges (alternatively, in the absence of a grid, metric scale bars previously positioned on the acquisition stage can also be used).

Table 3. Mean errors on GCPs and CPs.

	RMSE [mm]			
	X	**Y**	**Z**	**XYZ**
GCPs	0.6	1.0	1.9	2.2
CPs	0.9	1.2	1.9	2.4

In both cases, the final outcome is a dense point cloud constituted by more than 5 million of points (Table 4) from which it is possible to triangulate a three-dimensional triangulated irregular network (TIN).

Table 4. Main details of the photogrammetric process.

N° of Images	Shooting Distance [cm]	Estimated GSD [mm/px]	N° of Tie Points	N° of Points of Dense Cloud
61	≈40	0.101	≈72,000	≈5,500,000

Results

In order to perform a comparison between the obtained point clouds (generated by using the two different approaches), they were then registered together in the same coordinate system with the commercial software 3DReshaper [41]. A cloud-to-cloud registration procedure based on ICP (iterative closest point) algorithm was performed. In Figure 5, it is possible to observe the discrepancies between the two datasets, which can be considered almost insignificant for the purpose of this study.

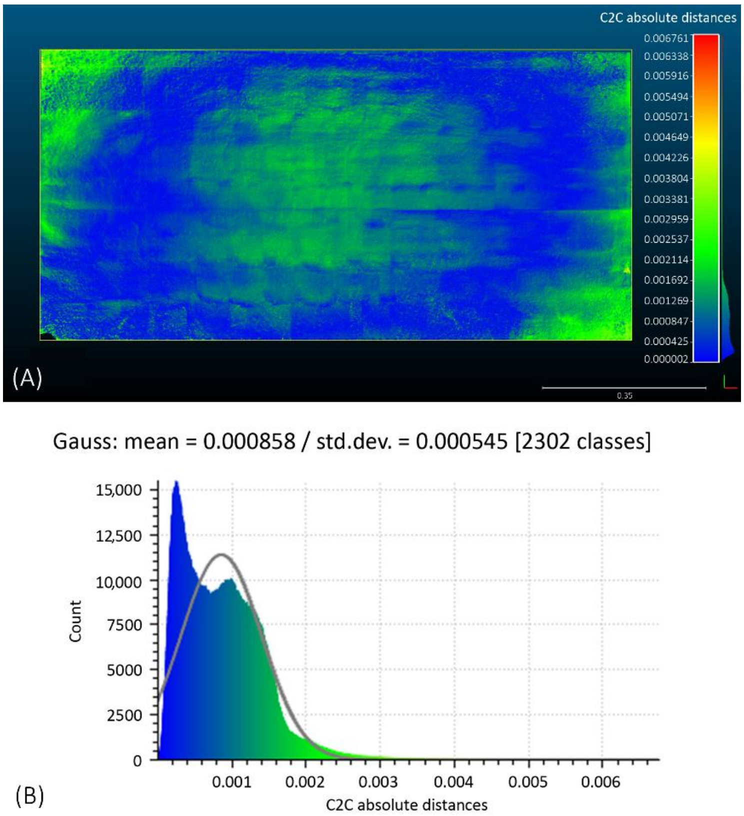

Figure 5. Analysis (A) and histogram (B) of the discrepancies between the two obtained dense point clouds (performed with the open-source software CloudCompare).

In order to obtain an ortho-projection of the 3D model triangulated from the final point clouds, a 3D Cartesian coordinate system (X, Y, Z) is required. With the first observed process, a relative local coordinate system is provided by the coordinates estimated from cartographic grid. However, this is possible only in those cases where a cartographic grid or any other reliable reference to build a 3D Cartesian coordinate system is found on the surface of the historical map (for example the edges of the sheet). In many cases, historical maps do not have such references and, considering the state of conservation of many of these assets, the possibility that the edges of the sheet could be deteriorated has to be taken into consideration. In order to simulate this second extreme case, as for the second point cloud scaled by using the manual measurements, a best-fitting rectangular plane was interpolated (a least square interpolation was performed with 3DReshaper platform) in order to be used as projection plane (the x-axis and the y-axis were set on the sides of the interpolated rectangle, the z-axis was set on the normal direction of the flat surface) (Figure 6).

Figure 6. Projection plane and relative local coordinate system definition.

In Figure 7 it is possible to observe the discrepancies between the best-fitting plane and the dense point cloud.

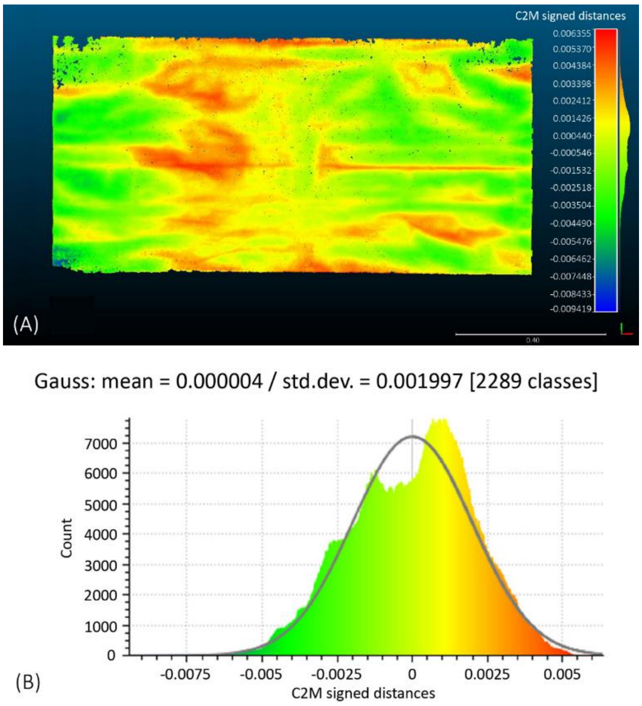

Figure 7. Analysis (A) and histogram (B) of discrepancies between the dense point cloud and the interpolated best-fitting plane, performed with the open-source software [34]. Standard deviation is approximately 2 mm.

In this case, observing that the discrepancies are millimeter-level, the approximation can be considered acceptable for both the approximation of the z-axis coordinates of the points of the cartographic grid and the interpolation of the projection plane. If the residual values were higher, different strategies would have been necessary in order to consider the eventual deformations of the map. As stated in the previous section, the acquired images were processed a first time with a high-performance workstation (Workstation A) and a second time with a COTS laptop (Workstation B). As it is possible to observe in Table 4, even though the required time for data processing using the Workstation 1 is significantly lower, it is possible to perform the described operations even with a less performing computer. In Table 4, the main details about the timing of data acquisition and data processing are summarized. The time required by these procedures depends on the number of the images and their resolution: The higher the number of images and their resolution, the longer the data processing time (Table 5).

Table 5. Data acquisition and processing time. The image acquisition phase was rapid (it only required about 15 minutes to perform the manual measurements on the cartographic grid and about 10 minutes to acquire the digital images). For data processing time the following operations were considered (for both approaches): Image alignment and tie points generation; collimation of GCPs-CPs/setting of scale bars; dense cloud generation; three-dimensional mesh generation; orthophoto generation.

Data Acquisition	Data Processing (Workstation 1)	Data Processing (Workstation 2)
≈25min	≈1h	≈3h

Discussion

In the previous sections, it was possible to observe the workflow of the proposed methodology, underlying its suitability in situations where it is not possible to use a standard planar scanner or other sensors that need direct contact to the fragile map support. Poor conditions and fragility of the materials are an obstacle, and a contactless approach for digitization is desirable in order to prevent damage to irreplaceable assets belonging to our heritage. In these cases, a digital photogrammetric approach represents a reliable and sustainable method for digitizing historical cartography (Figure 8).

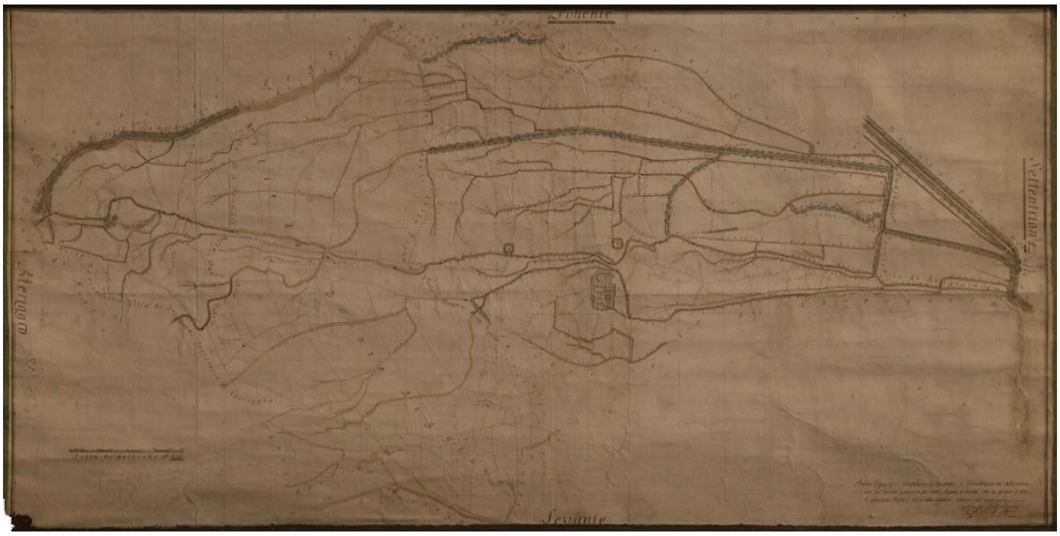

Figure 8. Orthophoto of the map (obtained from the projection on the interpolated best-fitting plane).

Thanks to the technological progress observed in the last few years, image acquisition can be performed with both professional cameras and commercial mobile device sensors (our choice in using a commercial smartphone for data acquisition was taken in order to remark this point). The workflow tested during this research does not necessarily need high-performance workstations in order to be carried out: Of course, less performing workstation takes a longer time to complete data processing, as it is possible to observe in Table 5.

The main advantage of the methodology proposed in this paper consists of being a rapid, contactless, and harmless method that reduces almost completely the risk of damaging the map support. Other advantages include:

- High flexibility of the acquisition workflow, since the map format and size do not constitute a limit (on the contrary with a planar scanner),
- high-resolution of the digitized replica,
- low-cost of the solution.

Regarding the last point, no specific hardware equipment is required: nowadays, mobile devices allow the acquisition of high-definition images, especially when professional cameras are not available. Of course, generally, a higher price range camera would produce better results in terms of image quality and resolution. However, as previously demonstrated, current commercial products achieve more than acceptable results.

The workstations do not require particular specifications, but it is supposed that they will fulfill at least the minimum software requirements. As for the most suitable employed platforms, in this research, licensed commercial solutions (Agisoft Photoscan and 3DReshaper), as well as open-source (CloudCompare), were used. License costs could vary between different versions, but low-cost academic or educational software versions are often provided. Also, free open-source photogrammetric SfM based solutions [42] are improving fast and represent a valid alternative to commercial platforms. A specification is necessary about the role of the operator in the framework of these kinds of digitization operations. Thanks to the improvements in acquisition techniques and implementations of automatic or semi-automatic procedures during data processing phases, the three-dimensional reconstruction of digital models on an image-based approach has become an extremely rapid procedure with high levels of reliability. However, it should be underlined that the management of these types of datasets by the operator remains fundamental for quality check (in terms of verification of metric accuracies) and data interpretation.

In this regard, the main weakness of the studied workflow concerns the metric control of the final product. In the absence of ground control points measured by topographical methods (like, for example, using a total station, which would allow greater control on the z-coordinates of the digitized map here approximated to 0) the accuracy check is based on manual measures taken directly on the map. This allows reaching a millimeter-level accuracy (which is coherent with the mean errors previously observed on GCPs and CPs after the bundle block adjustment) opposed to other methodologies and techniques which obtain submillimeter-accuracies [13]. In any case, if a millimeter-level accuracy is considered tolerable for the intended purposes, both the observed methods allow achieving acceptable 3D models.

Conclusions

The applications of the methodology proposed in this paper enables the preservation of the information associated with cartography and documents stored in historical archives through the creation of high-detailed digital replicas. The digitization of this kind of historical assets could improve the dissemination of the original data to future generations of users operating in the field of cultural heritage. Indeed, the application of 3D modelling techniques represents a reliable method to contrast the inevitable loss of historical documents due to ageing: only by documenting the originals it is possible to reduce the risk of losing irreplaceable data. Another useful application made possible by the digitization of historical cartography is the management of the obtained dataset in GIS environments in order to carry out, for instance, studies in interpretation and valorization of past landscapes [43] or environmental reconstructions [44].

Future perspectives might include the application of a laser scanner to construct a “gold standard” for assessing the reliability of the methodology proposed with high accuracy. Nonetheless, the potentiality of historical documents as datasets of information about the past is unquestionable, and the SfM digital photogrammetric digitization approach represents a rapid, highly flexible, low-cost, and contactless method to preserve and valorize valuable assets, rich of many kinds of information belonging to our cultural heritage.

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3.2 Multi-temporal mapping of the Upper Rhone Valley (Valais, Switzerland): fluvial landscape changes at the end of the Little Ice Age (18th - 19th centuries)

[Brandolini F., Reynard E., Pelfini M. *Multi-temporal mapping of the Upper Rhone Valley (Valais, Switzerland): fluvial landscape changes at the end of the Little Ice Age (18th - 19th centuries)*. Journal of Maps, *submitted*]

Abstract

The Upper Rhone Valley (Valais, Switzerland) has been heavily modified over the past 200 years by human activity and natural processes. A qualitative analysis of the morphological and land-use evolution of the Rhone River floodplain since the end of the 18 th century was carried out using historical maps from 1780 to 1860 processed with Structure-from-Motion (SfM) and Geographical Information System (GIS) tools. This study aims to produce a long-term analysis of river management and land-use change in a stretch of the Upper Rhone Valley around the town of Sion based on a time series of maps, realised in the years 1780-1802, 1820-1845, 1847, 1850s, 1852-57, 1859-1860. The historical maps were digitised, and for each of the corresponding periods, a map was produced within a GIS. The comparison of the maps was completed by using documentary sources or subsequent studies. With the intention to identify the fluvial landscape changes and past river management, six multitemporal maps were produced. Finally, this research aims to provide helpful diachronic information for planning a future sustainable landscape development in Valais.

Keywords: landscape development; land-use change; fluvial geomorphology; Structure-from-Motion photogrammetry; backdating approach

Introduction

The interplay between geomorphological processes, land-use, ecosystems and human influence has always played a special role in the evolution of the fluvial environment since anthropogenic activities started to alter the natural processes (James & Marcus 2006; Li et al. 2017). Land-use change is a dynamic process that links together natural and human systems. Therefore, a historical reconstruction of this process is necessary to evaluate the reciprocal interactions between anthropogenic activities and fluvial environments (Bollati et al. 2018). Historical maps, when available, represent a valuable resource for understanding the causes, mechanisms and consequences of the human-induced changes in fluvial features and support river management at any scale (Pătru-Stupariu et al. 2011; Hohensinner et al. 2013). Moreover, the combination of historical data with geoscience data and remote sensing analysis is essential to study the relationship of natural events such as floods and river diversions with human land-use changes through time (Roccati et al. 2018; Brandolini et al. 2019). In regions that are historically affected by flooding and where urbanisation has increased exposure to floods, historical cartography provides valuable indications for planning more sustainable urbanised alluvial landscapes in the future (Brandolini & Cremaschi 2018). GIS tools are essential to compare digitised historical maps with more recent ones and to carry out a multi-temporal analysis of landscape dynamics (Statuto et al. 2017; Lieskovský et al. 2018).

The Upper Rhone Valley is located in the Swiss Alps between the Rhone Glacier and Lake Geneva, and it is particularly interesting to study since it represents the largest inner Alpine basin with a size of c. 5244 km^2. The Rhone River originates from the Furka Glacier (2341 m asl) and, with a total length of 164 km, dissects the western Swiss Alps with a general NE-SW direction upstream of Martigny and SSE-NNW direction downstream (Fig.1).

The Upper Rhone Basin contained some of the thickest Alpine glaciers throughout the Quaternary period (Kelly et al. 2004; Schlüchter 2009), and it was characterised by subsequent advance and retreat phases due to the alternation of glacial-interglacial periods. During the Last Glacial Maximum (LGM), 22.1 ± 4.3 ka BP, the Rhone Glacier filled the Upper Rhone Basin, outflowed onto the foreland and was the main component of the LGM transection glaciers in the western Alps. The deglaciation and retreat from the LGM position started in 21.1 ± 0.9 ka BP and ice collapse already initiated between 16.8 and 17.4 ka BP (Schoch et al. 2018). The sedimentary succession presents the typical post-glacial Alpine pattern: subglacial stream deposit, lodgement till, ablation till, proglacial lacustrine deposits, glaciolacustrine deposits, bottom-set, foreset and top-set deltaic deposits, alluvial deposits (Stutenbecker et al. 2018). The glacial esaration influenced the mountainsides conformation, but frequently the traces of erosional processes have been covered by alluvial fans. Indeed, the tributaries of the Rhone River developed alluvial fans that influenced its course occupying a vast portion of the plain; two of them (the Illgraben fan near Sierre and the St-Barthélémy fan near Saint-Maurice) had a crucial role in modifying the Rhone River profile. Even though the 19^{th} and 20^{th}-century channelisation profoundly rectified the river course, between Sierre and Martigny, the influence of the alluvial fans developed by the tributaries is still clearly visible on the sinuous pattern of the Rhone River (Reynard 2009).

The Medieval chroniclers report the occurrence of severe flood events, and during the Little Ice Age (or LIA, 1350-1850 AD) the Upper Rhone River had certainly a torrential regime as other rivers in the Western Alps (Bravard 1989). During the second half of the 19^{th} century, the anthropogenic activities had a crucial impact on the Rhone basin. The river was channelized twice in the periods of 1863–1894 and 1930–1960 (the so-called "Corrections of the Rhone River", see (de Torrenté 1964; Baud et al. 2016), which reduced the length of the river (Stutenbecker et al. 2018) and gave to the river the present-day aspect. In the 2000s, after severe flood events, the "Third Correction" began following the "Room-for-River" flood management strategy (Vis et al. 2003) and aims to: 1) widen the river, 2) increase the capacity, 3) secure levees and 4) improve the general environmental quality (Olivier et al. 2009).

Today, the Rhone is a highly regulated Alpine river with an annual mean discharge of 1720 m^3/s at its mouth and a flow regime of 17.8 L/s/km2 specific discharge (Olivier et al. 2009). The flow regime of the Upper Rhone is characterised by low flows during winter while high flows occur in late spring and summer due to snowmelt (see Table 1). Anthropogenic activities such as gravel harvesting and retention in reservoirs have altered the sediment discharge of the river: bedload transport was estimated at 1 Mm^3/year at the beginning of the 20th century, but today it is only 0.2 m^3/year (Thareau et al. 2006).

Table 1 - Main characteristics of the Upper Rhone River Basin (Olivier et al. 2009) and the data registered at the gauging station of Sion (https://www.hydrodaten.admin.ch/en/2630.html): A - catchment area upstream of gauging station. MQ - arithmetic mean annual discharge. SpQ: specific discharge ($m^3/s/km^2$). NQ - lowest measured discharge.
HQ - highest measured discharge (instantaneous value). Q2 - magnitude of a 2-year flood. Q10 - magnitude of a 10-year flood. Q50 - magnitude of a 50-year flood.

<table>
<tr><th colspan="10">General characterization of the Upper Rhone River Basin</th></tr>
<tr><td colspan="2">Mean catchment elevation (m)</td><td colspan="2">Catchment area (km^2)</td><td colspan="2">Mean annual flow (km^3)</td><td colspan="2">Mean annual precipitation (cm)</td><td colspan="2">Mean air temperature (°C)</td></tr>
<tr><td colspan="2">1655</td><td colspan="2">8018</td><td colspan="2">5.77</td><td colspan="2">162.4</td><td colspan="2">4.3</td></tr>
<tr><th colspan="10">Flow regime (in m^3/s) of the Rhone River at Sion (1916-2003)</th></tr>
<tr><td>Data Origin</td><td>Altitude</td><td>A</td><td>MQ</td><td>SpQ</td><td>NQ</td><td>HQ</td><td>Q2</td><td>Q10</td><td>Q50</td></tr>
<tr><td>1</td><td>484</td><td>3349</td><td>112</td><td>33.4</td><td>29</td><td>910</td><td>461</td><td>639</td><td>808</td></tr>
</table>

In the last decades several portions of the Upper Rhone River Valley were studied applying a geohistorical approach (Zanini et al. 2006; Stäuble et al. 2008; Baud et al. 2016) and combining historical maps (Reynard 2009) with geoscience analysis, in particular: between Riddes et Martigny (Laigre et al. 2012; Baud & Reynard 2015; Reynard & Baud 2015); from Viège to Rarogne and Sierre to Sion (Laigre et al. 2010); and the Conthey area (Stäuble & Reynard 2005).

This research was conducted in the area around the town of Sion, precisely between Liène and Lìzerne rivers (Fig. 1). In this portion, the Rhone River presents a sinuous course due to the series of alluvial fans developed by its tributaries Liène, Borgne, Sionne, Printse, Morge and Lìzerne (Fig. 1). The aim of the study is to produce a long-term analysis of landscape changes in this section of the valley at the end of the LIA, between 1780 and 1860 AD, i.e. before the systematic river training, combining historical maps and GIS analysis. The objective is to create multi-temporal maps to highlight the main modifications due to anthropogenic land and water management activities that occurred in that period.

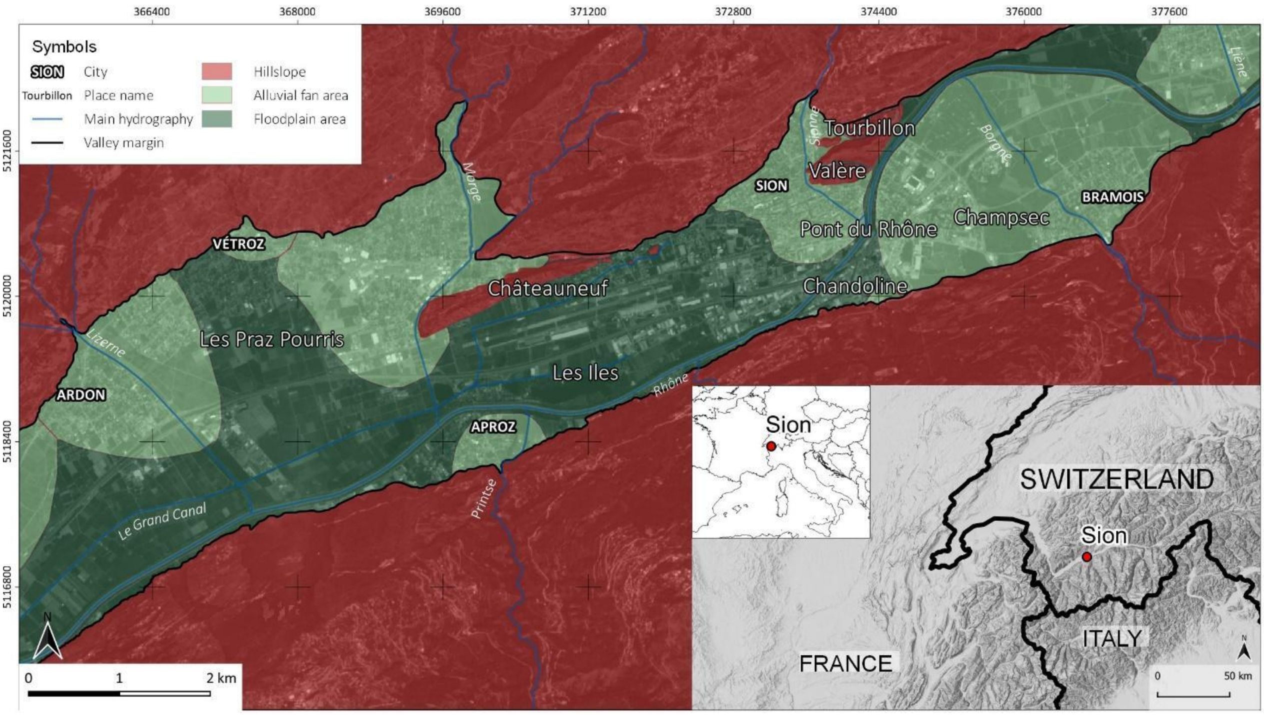

Figure 1 Location of the study area and main units: hillslope, alluvial fan areas and floodplain areas.

Material and methods

In recent years, historical cartography has increasingly become a fundamental source for the analysis of land-use and environmental changes (Leyk et al. 2006). In this study, the geographical reconstruction of the landscape was carried out over a period of 80 years in six-time steps: 1780-1802, 1820-1845, 1847, 1850s, 1852-57, 1859-1860. The specific historical cartography for each period was examined with the aim to create different base maps to make a comparison in time. The chosen periods were determined by the quality and quantity of historical sources available.

Historical maps

The principal maps used in the multi-temporal reconstruction of the 18^{th}-19^{th} century morphology of the Rhone River floodplain and subsequent changes are listed in Table 2 and include: 16 hand-drawn maps from the *Archives de la Bourgeoisie de Sion* (ABS) stored at the *Archives de l'Etat du Valais* (AEV), one hand-drawn map of the AEV, one topographic map of the *Bibliothèque nationale de France* in Paris and one topographic map from the *Office fédéral de topographie* (Swisstopo).

The ABS hand-drawn maps do not cover the territory of the research area uniformly, but they are extremely useful because they have been realised at a large scale and represent in detail the fluvial landscape appearance. On the contrary, the Swisstopo map covers the whole research area, but their small scale does not allow us to identify valuable particularities about the land-use evolution.

The Napoleonic Map was hand-drawn in watercolours by the Napoleon cartographers in 1802. The aim of this map was to plan enhancement of the *Simplon* road that connected Switzerland to Italy for military reasons; close to the road the cartographers represented precisely any roads, villages, woods, fields and watercourses (Lechevalier 2005).

The *Dufour* Map was published in the period from 1845 to 1865 using a scale of 1:100,000. It was realised with an equal-area conic projection after direct surveys in the field, and it represents the first official topographic map of Switzerland (Swisstopo). In this study, we used the original version of the plate XVII Vevey – Sion (1847) that shows the Rhone Valley before the integral river training.

The *Plan du Chemin de fer* (hereafter, 'Railway Map') was made for the construction of the *Simplon* railway (called *Ligne d'Italie*). Even if not dated with precision, it is probably contemporary to the *Dufour* Map and it, therefore, represents the situation of the Rhone River before the channelisation work that started around 1860.

A multi-temporal cartographic comparison was carried out to reconstruct the original morphology of this portion of the Upper Rhone Valley and to identify the most significant transformations, such as modifications to the river channel, reduction of natural and agricultural areas and urban sprawl.

Digitising process

All the historical maps considered in this research were either available in georeferenced format or were georeferenced using Ground Control Points (GCPs) identified on current cartographic sources. The ABS maps were drawn in a different period, scale and style for the upper-middle-class people (*bourgeoisie*) of Sion to map their properties. These large-scale maps represent limited portions of the Rhone River floodplain in details and served as an invaluable source of information about fluvial landscape changes. On the other hand, perspective projection and geometric foundations of the maps production process are unknown, making the georeferencing procedure in GIS problematic.

The first step of the workflow consisted of digitising the maps to be imported into the GIS software. The Napoleonic Map, the Railway Map and the *Dufour* Map were already digitalised by the Valais administration and Swisstopo that provided a georeferenced copy of these files. Concerning the ABS maps, the scanning would have been challenging because of their size, format and, sometimes, their state of conservation. The large size and format of some historical maps (e.g. ABS 99/36 100 x 150 cm; ABS 202/11 60x110 cm) would have required expensive digital scanners to capture the entire map. Moreover, in a few cases, the maps were very fragile (eg. ABS 202/12) and difficult to handle. To resolve all these issues of size and conservation, each map was digitised using a photogrammetric approach (Brandolini & Patrucco 2019) with Agisoft PhotoScan. The elaborated TIFF images (96 dpi resolution) were then imported in the open-source desktop software QGIS 3.4. To perform the georectifying process on the ABS maps, Thin Plate Spline (TPS) and cubic resampling methods (QGIS 3.4) were employed (Baiocchi et al. 2013). A minimum of three GCPs (Oniga et al. 2018) was detected to scale, rotate and locate each map but the absence of a topographic regular grid in the ABS maps made the georeferencing phase extremely challenging. In particular, the *Pont du Rhône* (Rhone Bridge) was the reference key point in geo-referencing ABS historical maps in association with the historical location of the river dykes and groynes. Other essential reference points were the buildings of towns' historic centres and the geomorphological features of *Châteauneuf*, *Tourbillon* and *Valère* hills. Moreover, to minimise the spatial inaccuracy of the ABS maps the 'backdating approach' was employed (Feranec et al. 2007; Bednarczyk et al. 2016): it consists in verifying and correcting the positions of the points in older maps according to recent and most accurate maps (Lieskovský et al. 2018). In particular, two georeferenced copies of the historical topographic maps retrieved from Swisstopo have been employed: the *Dufour* Map for the ABS maps dated before the "First Correction" and the *Siegfried* Map (1870-1922) for all the ABS maps made after the 1861 (for details on these maps see (Stäuble et al. 2008)). This method cannot resolve all the positional inaccuracies mainly due to scale differences (Kaim et al. 2016) but represents the most reliable approach to georeference ancient historical cartography when other more accurate procedures are not available (Lieskovský et al. 2018).

Thanks to this data processing, it was possible to make all ortho-rectified maps comparable in terms of scale and land-use classification, and it was possible to overlay them, in order to assess landscape changes. The ABS maps represent limited portions of the study area, and they have been realised in different periods with different techniques, scale, fonts and even languages. To overcome the limitations of each singular map, we combined them in mosaics of historical maps with the same chronology/style/scale and representing the same time period.

Table 2 List of the historical maps considered in this study. ABS = Archives de la Bourgeoisie de Sion; AEV = Archives de l'Etat du Valais. In bold style, the maps used in the 'backdating approach'.

Period	Historic Map	Date	Source
1780 - 1802	99/35 Cadastre de Champsec	Started: 1741 – 1746 Updated: 1761 – 1772 Last version considered in the research: 1782	AEV, ABS
	99/36 Plan géométrique de la plaine de Champsec/Sion	1782	AEV, ABS
	Napoleonic Map	1802	Bibliothèque nationale de France
1820 – 1845	97/9 Plan du Rhône depuis le confluent de la Liène jusqu'à Uvrier	1827	AEV, ABS
	97/10 Plan du cours du Rhône depuis le Pont jusqu'à Chandoline	1823	AEV, ABS
	97/17 Plan du Rhône entre Bramois et Uvrier	1827	AEV, ABS
	97/18 Plan du Rhône de Chandoline à Aproz	1827	AEV, ABS
	97/19 Plan du Rhône d'Uvrier à Batassé	1827	AEV, ABS
	97/20 Plan du Rhône de Wissigen au Pont du Rhône	1827	AEV, ABS
	98/5 Minute du plan du cours du Rhône vers la grande barrière en haut d'Aproz	1825	AEV, ABS
	97/3 Plan du Rhône depuis Praz Bardy jusqu'à la fin du territoire de Sion	1845	AEV, ABS
	97/4 Plan du Rhône depuis l'Ile de l'Evéché jusqu'à Praz Bardy	1845	AEV, ABS
1847	**Dufour Map**	1847	Swisstopo
1850	Plan du Chemin de fer (Railway Map)	1850s	AEV, DTP, Plans, Railways, 1
1852 - 1857	201/7 Plan de propriétés à Aproz	1852	AEV, ABS
	202/1 Plan du Rhône depuis le pont de Sion jusqu'à la Morge	1856	AEV, ABS
	202/11 Plan de dessèchement des marais de la plaine de Sion	1857	AEV, ABS
1859 - 1860	202/10 Plan de la plaine de Sion pour le dessèchement et le colmatage.	1859	AEV, ABS
	202/12 Plan d'assainissement de la plaine de Sion à Riddes. Avant-projets.	1860	AEV, ABS
> 1860	**Siegfried Map** *(used only for the 'backdating approach' and not considered in the multitemporal maps)*	1870-1922	Swisstopo

For each map, the land-use changes, water uses and fluvial geomorphological features are indicated. The results consist of 6 multi-temporal maps that reconstruct the landscape evolution of this portion of the Upper Rhone Valley from 1780 to 1860.

Results

The characteristics of the historical cartography considered in this research were not suitable for a land-use quantitative procedure (Leyk et al. 2005; Chiang et al. 2016) but enabled a qualitative interpretation on landscape evolution. The description and the main changes (Table 3) for each period are presented here.

Table 3 Main characteristics for each period.

Period	Fluvial Pattern	Water Management	Land-use
1780-1802	Braided	Drainage Canals	Generic agricultural use and woods
1820 – 1845	Braided/Wandering	Dykes, Groynes	Generic agricultural use and woods
1847 – 1850	Braided/Wandering/ Channelised	Dykes, Groynes	-
1850 – 1860	Wandering/Channelised	Dykes, Groynes	Generic agricultural use and woods

1780-1802 (Supplementary Material - Sheet 1/3)

In this period, alternation of braided channels and portions of sinuous unique channel characterises the Rhone River. From the main channel, a series of sub-channels flowed around channel bars especially upstream of the confluence with the Liène River and in the area known in the present-day as *Les Iles* (i.e. The Islands). In the Napoleonic Map (Fig. 2A), a waterlogged area upstream to the Borgne fan in Bramois is reported. Concerning land-use, few data are available. Napoleon cartographers reported agriculture and wood zones (Fig. 2A) without indicating any details about the crops cultivated or the arbour species. ABS 99/35 and 99/36 dating back to the second half of the 18th century (Table 2) were handy to reconstruct the division of the farmland and the owner of each field on the left side of the Borgne River on the alluvial fan (Fig. 3). This portion of the Borgne fan was cultivated at least since 1741 when the cadastre was compiled for the first time, but there is no indication of the specific agriculture use. In this portion of the Borgne fan, an irrigation system was active, and few channels are still active in the present day. Downstream of the *Pont du Rhône* woodland is common but not homogenous. This woodland fragmentation might it be evidence of parallel secondary land-use probably represented by extensive pasturelands. Regarding the hydrographic elements represented in the Napoleonic Map, the Morge River and Lizerne River flowed in the Rhone River following their natural watercourses bordered by forests.

1820 – 1845 (Supplementary Material - Sheet 1/3)

The study of this interval is based on 9 historical maps with the same style and scale, dated between 1823 and 1845 (Table 2). The Rhone River is still partly braided with channel bars and sub-channels. The historical maps of this interval are much more detailed than the Napoleonic Map, so it was possible to reconstruct with more precision the bars features and the braided channels. Moreover, on both sides of the Rhone River dykes and groynes (Fig. 4) testify anthropogenic activities on the river in that period. The aim was to manage the fluvial sediments to reclaim waterlogged areas and to rectify the river watercourse. The groynes, indeed, keeping the fluvial sediments, reduced the number of the sub-channels and filled the floodplain wetlands progressively. Very few indications about land-use are available for this time interval, and historical maps report only woods and meadows along the Rhone River banks.

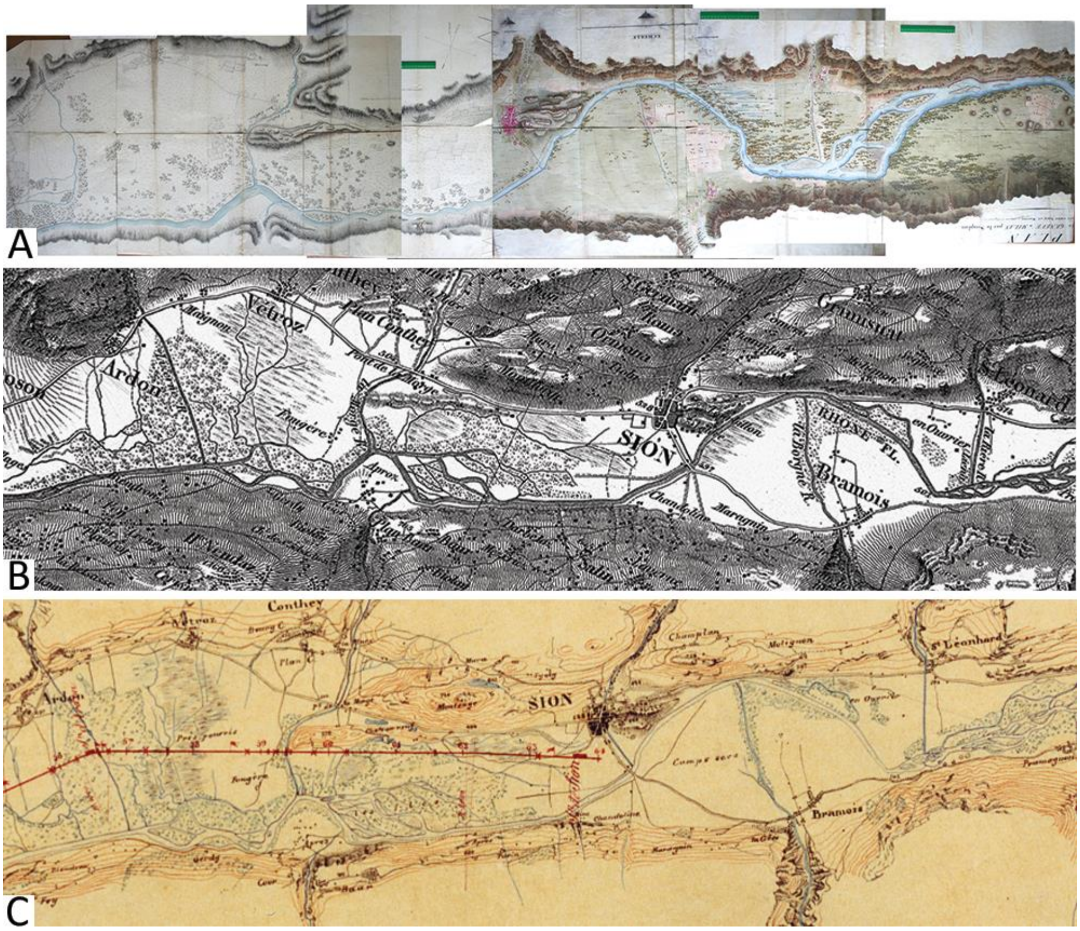

Figure 2 The study area as it is represented in the Napoleonic Plan (A), the Dufour Map (B) and the Railway Map (C). (Courtesy of ©Archives de l'Etat du Valais, AEV and Swisstopo).

Figure 3 "Plan géométrique de la plaine de Champsec/Sion" digitalised with Agisoft Photoscan (Brandolini & Patrucco 2019) (Courtesy of ©Archives de l'Etat du Valais, AEV, ABS 99/36). The map is oriented with South at the top of the map.

Figure 4 “Plan du Rhône entre Bramois et Uvrier” digitalised with Agisoft Photoscan (Brandolini & Patrucco 2019). (Courtesy of ©Archives de l’Etat du Valais, AEV, ABS 97/17).

The *Les Iles* zone represents the most interesting area to understand the river pattern evolution through the 19th century (see “Les Iles detail” box in Multitemporal Maps, Sheets 1/3). Here the place name still indicates the presence of former fluvial bars, depicted in the Napoleonic Map and then represented in the ABS maps with more precision. Furthermore, dykes and groynes seem to have deactivated many sub-channels with the Rhone River fluvial sediments, but the presence of woods only in the centre of the channel-bars suggests that the former braided channels were probably still active occasionally. Therefore, the Rhone River in this period seems to have been characterised by a single-thread sinuous and wandering channel pattern (Fryirs & Brierley 2018). Moreover, plans to build further dykes and groynes in the area are reported. The historical maps for this time interval report some particulars about the land-use along the Rhone River banks: fields, orchards or meadows are indicated even though the cultivations are unknown. The presence of orchards south of the river in the area between the *Pont du Rhône* and Aproz seems to indicate that the protection by the dykes was sufficient to allow, quite close to the Rhone River, land-uses more sensible to floods than meadows or forests.

1847 and 1850s (Supplementary Material - Sheet 2/3)

Two maps have been considered for this interval: the Dufour Map (Fig. 2B) and the Railway Map (Fig. 2C). Both these maps are extremely useful to have a general view of the Rhone River pattern in this period because they cover the whole research area. Besides that, these maps have a too small scale and present no particular details about water management or land-use. The Dufour Map reports woods and wetland areas in *Praz–Pourris* and around Châteauneuf and the Lìzerne River appears rectified and channelised. In the Railway Map, the *Praz - Pourris* wetlands occupy less area than in the Dufour Map and probably depends on the period of the year when the *Plan du Chemin de fer* was made. In both maps the Rhone River seems characterised by a single-thread sinuous pattern except: 1) upstream the of Liène River and between Aproz and Ardon (braided pattern) 2) in the *Les Iles* area (wandering pattern) (Fryirs & Brierley 2018).

1852-1857 and 1859 - 1860 (Supplementary Material - Sheet 3/3)

The historical maps considered in Sheet 3/3 show the Rhone River right before the ‘First Correction’ that occurred in the 1860s (Fig. 5). Compared with the previous periods, the dykes and groynes system seems to have been developed mainly in *Les Iles* zone (see “Les Iles detail” box in Multitemporal Maps, Sheets 3/3). Fields, orchards, woods are indicated generically and without any particular detail while the Rhone River seems almost completely channelised with only a locally wandering pattern.

Figure 5 "Plan de dessèchement des marais de la plaine de Sion (1857)" digitalised with Agisoft Photoscan (Brandolini & Patrucco 2019) (Courtesy of ©Archives de l'Etat du Valais, AEV, ABS 202/11).

Discussion and conclusions

This study enabled us to understand the evolution of the Rhone River in the Sion area between the Liène and Lìzerne rivers in the final phases of the LIA. As reported in other portions of the Rhone Valley as in the Saillon area (Laigre et al. 2012), at the turn between the 18th and 19th century the braided pattern of the Rhone River seems to be limited to some specific parts such as the confluence with torrential tributaries such as the Sionne or the Printse rivers, as well as particularly flat portions of the floodplain upstream of large alluvial fans such as the sector situated just upstream of the Borgne river alluvial fan. In the other sectors, the river presents a sinuous natural pattern.

The land-use was interpreted manually, which might have resulted in human-induced errors, but excluded any misclassification problems present in automatic procedures (Leyk et al. 2005). Also, comparison of the land-use based on diverse cartographic sources may be influenced by the differences in definitions and map purposes (Lieskovský et al. 2018) for these reasons all the maps considered in this study have been analysed with the support of local historians.

The instability of the watercourse may explain the large presence of woods downstream of Sion and upstream of the Borgne alluvial fan. Nevertheless, large sectors of the plain are cultivated on alluvial fans, such as the Borgne River fan, and also in the Rhone River plain itself. Swamps have limited extension in the area. All these indices corroborate the conclusion (Evéquoz-Dayen 2009) that at the turn of the 19th century, the Rhone River plain was far from being unexploited and covered with swamps, as described by foreign travellers (Reichler & Ruffieux 1998).

From the end of the 18th century, the anthropogenic activities modified the natural evolution of the Rhone River, affecting the fluvial dynamics. First of all, the construction of dykes and groynes had the effect of keeping the fluvial sediments reclaiming flood-prone areas. This process took several decades and right before the first river training project (1860s) *Les Iles* area was still characterised by a wandering channel pattern (Fryirs & Brierley 2012). Nevertheless, the presence of orchards closed to the main channel of the Rhone River in the 1840s certainly indicates that the impacts of flooding were becoming less important, partly because of the construction of various dykes in the previous years.

The use of the large-scale ABS historical maps gave us the opportunity to highlight new details about the evolution of the Upper Rhone Valley landscape at a local scale and to understand the impact of human-induced changing on the Rhone River. The main learning concerns the fact that quite systematic building of dykes and groynes happened almost 40 years before the first Rhone correction. The objective was to reduce the lateral extension of the Rhone River by building longitudinal dykes and to concentrate flows by the construction of submersible groynes. This technique that has then been used systematically during the general river training since the 1860s, not only had the objective to concentrate flow but also wanted to provoke artificial sedimentation of the spaces comprised between the dykes and groynes.

To conclude, the information about the land-use change remains limited to few indications about the occurrence of woods, fields, orchards and meadows along the river banks, but no details about the agriculture activities are available. Concerning the fluvial landscape changes, this research highlighted the impact of past flood management on the natural development of the Rhone River. Since the 2000s, local authorities have been proposing sustainable solutions to deal with climate change impacts in the Upper Rhone Basin (Clarvis et al. 2014). Therefore, the “Third Correction” was planned to mitigate flood hazard, e.g. restoring flooding areas on selected stretches upstream of Lake Geneva (Kremer et al. 2015): with this aim the results of the research here proposed might serve as an indication to restore the historical appearance of the Rhone River before the “First Correction”. In general, multitemporal maps could represent valuable tools not only to understand the past evolution of a region but also to plan future sustainable landscape management projects.

Software

The ABS historical maps have been digitalised using the software Agisoft PhotoScan 1.4.4. Data processing and map design were performed with open-source GIS QGIS 3.4 Madeira (2018 QGIS Development Team).

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4 Geoarchaeological tools to understand human-induced landscape modification from micro- to regional scale

4.1 Micromorphology and site formation processes in the Castrum Popilii Medieval Motte (N Italy)

[Brandolini F.; Trombino L.; Sibilia E.; Cremaschi M. 2018 - *Micromorphology and site formation processes in the Castrum Popilii Medieval Motte (N Italy)*. Journal of Archaeological Science: Reports, Vol: 20, Page: 18-32]

Abstract

This paper presents the results of the geoarchaeological study of a medieval motte known in historical documents as "Castrum Popilii" (Poviglio, Northern Italy). The Castrum Popilii motte, for its particular environmental characteristics, represents an exceptional case study for the Early Medieval Age in Po Valley. In 1989 an archaeological rescue excavation revealed an exceptionally well-preserved stratigraphic sequence at the northern side of the Santo Stefano church. The study of the archaeological materials and thin soil sections collected during this campaign, integrated with geoarchaeological observations, allowed the reconstruction of the natural and anthropogenic processes involved in the formation of the Santo Stefano di Poviglio stratigraphy sequence. The area also referred to as "Santo Stefano di Poviglio", exposed the eastern limit of the medieval motte, characterizes by a sequence of occupation deposits, living floors, and wooden structural remains dated between the late 9th and the 11th centuries AD.
The micromorphological study of this archaeological site led to developing a new hypothesis about the use of lime-based plaster in the construction of domestic living floors in a rural early medieval village in Central Po Plain. The sealing of the sequence due to the construction of a stone stronghold in the 15th century, combined with waterlogging, preserved the deposit from reworking by bioturbation and later human activities. On the other hand, water stagnation influenced a series of post-depositional migration and accumulation of iron–manganese and phosphatic features. The geoarchaeological tools applied in this study allowed to maximize the data collected in a rescue situation in 1989 highlighting new information about the genesis and development of Castrum Popilii medieval motte.

Keywords: Medieval motte; Anthropogenic dark earth; Soil micromorphology; Lime-based plaster; Living floors

Introduction

Poviglio is located in Northern Italy, between the cities of Parma and Reggio Emilia (Emilia-Romagna region) in the Central Po Plain (Fig. 1). Here, inside the village, at the right side of the Santo Stefano di Poviglio church, in 1989 an archaeological rescue excavation detected an extraordinarily well-preserved stratigraphic sequence dated back to the Early Medieval Age: it represents an exceptional case study for two reasons. Firstly, the environmental pronounced anaerobic conditions preserved structural wooden remains that allowed integrating the knowledge about the Early Medieval domestic structures (Galetti, 2010) in Central Po Plain. Furthermore, the Digital Elevation Model elaborated in this study shows that the stratigraphic sequence exposed in 1989 pertains to an Early Medieval Motte known in historical documents (Drei, 1924) as Castrum Popilii. This kind of archaeological context is extremely rare in Mediterranean area, very few of those have been studied by archaeologists (Settia et al., 2013) but no one with a geoarchaeological approach.

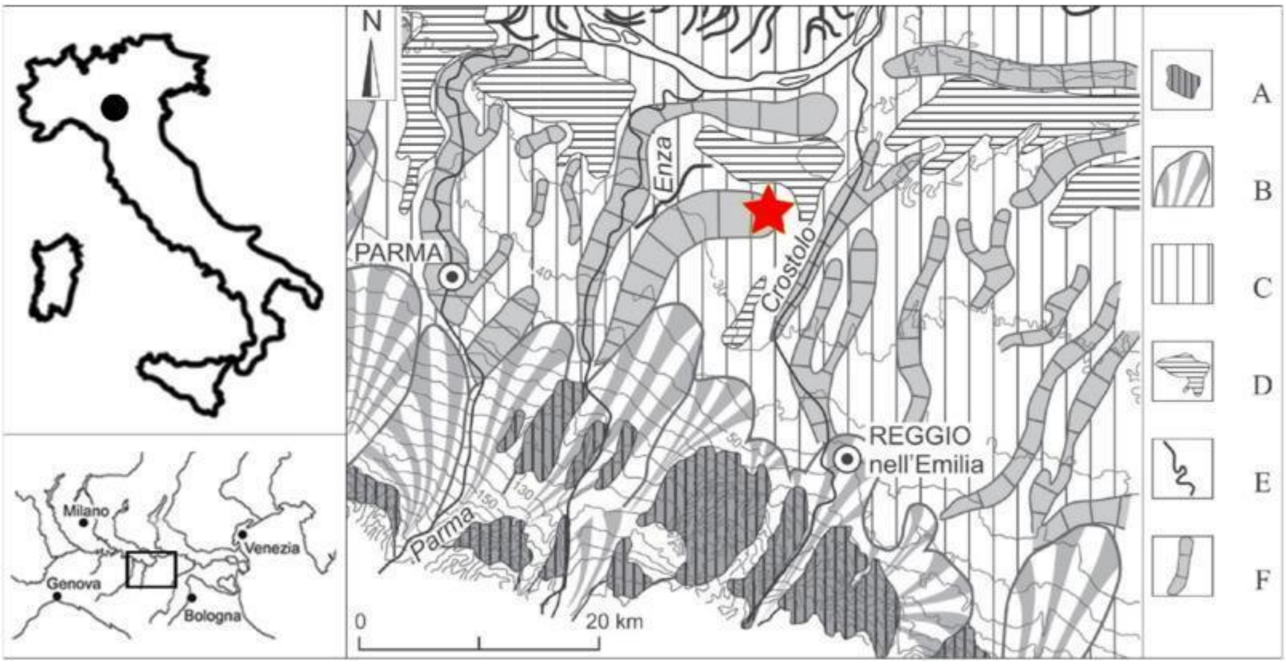

Figure 1. Geomorphological situation of the study area and site location (red star). A- Middle Pleistocene terraces. B - Piedmont alluvial fans. C - Finely-textured alluvial plain. D - Back swamps. E - Paleochannels. F - Fluvial ridges.

In this paper, the study of the 1989s excavation data led to describe the archaeological stratigraphy and to reconstruct the development of the area from the settling of the Early Medieval village to the establishment of the Renaissance stronghold. The dating of the sequence is based, beyond the archaeological context, upon TL measures performed on the baked clay of the hearths intercalated in the deposits. Furthermore, undisturbed samples collected during excavations were used to obtain soil thin sections that were studied by a micromorphological point of view. The micromorphological analysis aims to reconstruct the soil forming processes of the site with particular attention to the interpretation of living floors and the use of lime-based plaster in the construction of domestic spaces in a rural early medieval village.

Geomorphological and historical-archaeological context

Poviglio is situated in the Po Valley, ca. 3 km south of the Po River, between the Crostolo and Enza creeks. By the geomorphological point of view (Fig. 1) Poviglio lies upon the outer margin of the Enza alluvial fan, which originates from the margin of the Apennine and trends to the north toward the centre of the Po plain (Castiglioni and Pellegrini, 2001). The Enza alluvial fan with the other ones occurring along the Apennine margin dates back to the Late Pleistocene/Early Holocene (Rossi et al., 2002; Valloni and Baio, 2009; Cremaschi and Nicosia, 2012). These fans are mostly gravelly in texture, while, at their top, fine-textured alluvial sediments occur (Cremaschi and Nicosia, 2012; Cremaschi et al., 2017). These deposits constitute the sedimentary substrate of the Santo Stefano archaeological site. Several spring watercourses flow along the Enza alluvial fan. Two of them, Rio Cava Vecchia and Fossa Marzana are close to the Poviglio village: the latter most probably crossed the village, constituting the incision observed at the base of the Santo Stefano site and was later artificially deviated outside of it. Evidence of paleochannels flowing to the NE, outside the village is still visible on an aerial photograph (Fig. 2). At the northern fringe of the Enza alluvial fan, a large depression area still exists (Castiglioni et al., 1997; Marchetti, 2002) which was occupied by a vast swamp known as Valle di Gualtieri during the medieval period (Cremaschi and Marchesini, 1978): therefore, the Poviglio village was built on an area topographically higher than the surrounding plain.

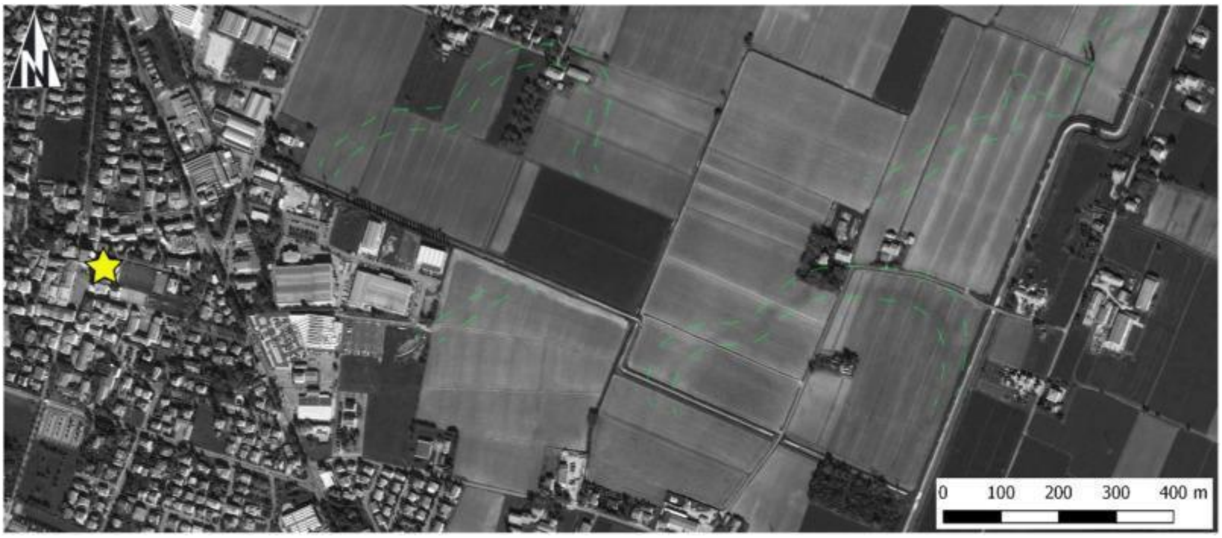

Figure 2. Paleochannels (highlighted in green) recognisable E of the Santo Stefano di Poviglio (yellow star) site using satellite images.

The area of Poviglio, already settled since pre – protohistorical times (Bernabò Brea and Cremaschi, 2004; Cremaschi et al., 2006), was densely occupied during the Roman period, and organized into a rural system known by the Latin term of 'centuriation' (Bottazzi and Bronzoni, 1995). The oldest settlement in the Poviglio village probably dates back to this age: the remains of a villa rustica of roman age were unearthed (Archeosistemi, personal communication; Fig. 4) in the main square of the Poviglio village, in the vicinity of the Santo Stefano Medieval site. The first settlement of Poviglio was likely to be a "curtis", a complex of farms around a central authority such as a church or a stronghold (Settia, 1984; Sergi, 1997; Bottazzi and Bronzoni, 1995) (Fig. 3).

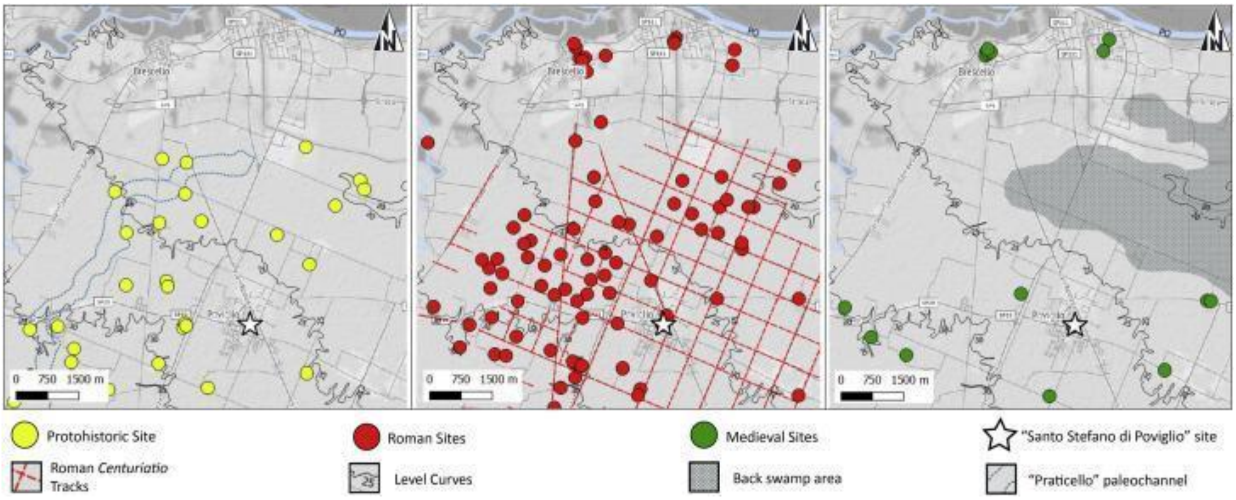

Figure 3. Archaeological sites distribution in the study area during Protohistory (yellow), Roman Era (red) and Medieval times (green).

The first mention of the early medieval village of Santo Stefano di Povilgio site in historical documents (Affò, 1792; Tiraboschi, 1824; Cantarelli, 1882; Drei, 1924; Settia, 1999) is dated at the end of the 10th AD. In 1005 the name of "*Pupilium*" was noted as one of the Episcopal churches of Parma dioceses. In other 11th century documents, "*castrum Popilii*" is described as a strategic fortified village on the main road (known as "Strada Romana", i.e. "The Roman Road") that connected Reggio Emilia to Brescello, a crucial crossing on the Po River. According to historical documents, the "*castrum Popilii*" was fortified with the typical defensive structures used in that period in Northern Italy: a motte with earthen ramparts, wooden fences and a ditch around the settlement perimeter. In 1321, as a consequence of contention between local landholders, Parma razed the fortified village of "*Popilii*" to the ground (Affò, 1792). During the Renaissance, on the Early Medieval motte, a square-shaped stone castle was built (Fig. 5). In 1553, the square-shaped medieval castle was restored and reshaped to withstand attacks by gunpowder weapons. The new star-shaped stronghold of Poviglio was one of the strategic centres of the Po Valley between Parma and Reggio Emilia, and it was continuously restored throughout the 17th century. At the start of the 18th century, the walls and ditches were gradually dismantled (Artoni and Colla, 2015): today, nothing remains of the Poviglio stronghold, and its original perimeter is only recognisable in the modern topography of the town.

Figure 4. On the left: Renaissance stronghold foundations revealed by archaeological excavations. On the right: detail of the stratigraphic section exposed. (Source: ©Courtesy of Studio Foto Bacchi, Poviglio – RE, Italy).

Materials and methods

The archaeological site of Santo Stefano di Poviglio was detected during the construction of a new oratory on the NE side of the Santo Stefano church in 1989 (Fig. 4). The remains of the Renaissance stronghold foundations that preserved the medieval stratigraphy were found; this peculiar feature of the site contributed to the excellent preservation of the archaeological deposits related to the Early Medieval motte. All the archaeological data exposed during excavations have been studied and dated according to the most recent typological record available for Medieval Archaeology in Northern Italy. Chronological analysis has also been performed on pottery and hearth samples by the Physics Department of the University of Milan using a thermoluminescence dating method.

Thin sections, 15 cm long by 8 cm wide, were prepared from the air-dried undisturbed block soil samples collected from the exposed stratigraphic profile, following standard procedures (Murphy, 1986) by Gent University laboratory, and were the subjects of the micromorphological analysis. For thin section description, the terminology of Stoops (2003) was employed, together with the concept of Microfacies Type (hereafter MFT) according to Goldberg and Macphail (2006) and Macphail and Goldberg (2018). Each MFT corresponds to a unique formation process or combination of formation processes and can be linked to cultural developments and their associated specific human activities. Abundances of fabric units are expressed, according to Stoops (2003), as follows: few (5–15%), common (15–30%), frequent (30–50%), dominant (50–70%). Abundances <5% is expressed, according to Milek (2012), as follows: rare <2%, very few 2–5%. The bulk soils of the 1989 rescue archaeological excavation have not be conserved so it was impossible to perform any chemical or microprobe analysis that could have provided more useful data. Finally, a Digital Elevation Model of the historical city centre have been elaborated by the software QGIS with the elevation checkpoints (m.a.s.l.) taken during two field surveys in 2016.

Results

Digital elevation model

The historic city centre of Poviglio is the result of superimposition of anthropogenic deposits since the Post-Roman period. Two main phase conditioned the urban topographical shape: the construction of the Renaissance stronghold and its dismantling occurred between the 18th and the 19th century AD. During the 20th century AD, the urban sprawl changed the historical shape of the town entirely. The Digital Elevation Model of the historical city centre elaborated through the spatial interpolation of 320 elevation points (Fig. 6) shows the ground elevation of Poviglio. In the DEM are recognisable the limits of the Renaissance star-shaped stronghold and, in the middle, an ellipsoidal higher mound that is likely to correspond with the Castrum Popilii Medieval motte. The Santo Stefano di Poviglio site is located in the NE limit of the early medieval mound, at the right side of the Santo Stefano church.

Figure 5. Santo Stefano di Poviglio archaeological site planimetry. In white the area occupied by the oratory built in the 90s. A - Area of the 1989 rescue archaeological excavation; B - Limit of the stratigraphy sequence presented in this paper (see also Fig. 7)

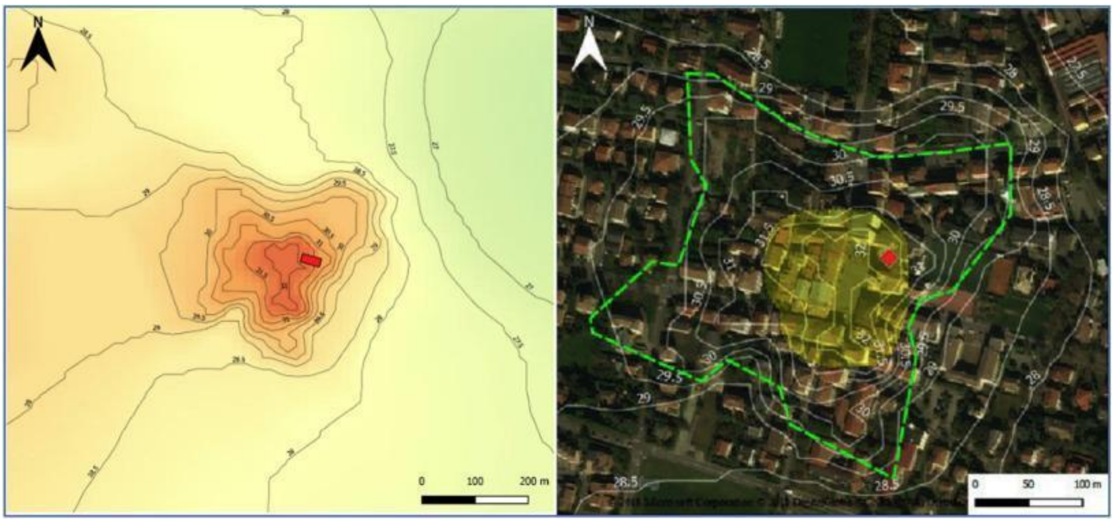

Figure 6. DEM of the study area. On the left: the Poviglio historic city centre ground elevation. The red rectangle indicates the rescue archaeological excavation area. On the right: the Medieval motte (in yellow) and the Renaissance stronghold (in green) area.

The stratigraphic section

The lower level of the exposed stratigraphy (Fig. 7) consists of laminated silty sands intercalated with discontinuous peaty levels. Above the substratum, the anthropogenic deposits consist of two silty clay loam units that differ mainly in the relative frequencies of materials derived from human activities. The stratigraphic sequence is sealed by a clay loam level, which corresponds to the abandonment phase of the Early Medieval village. The studied stratigraphic section is 12 m long and oriented EW (Fig. 7). The stratigraphic units observed in the field are briefly described below in Table 1.

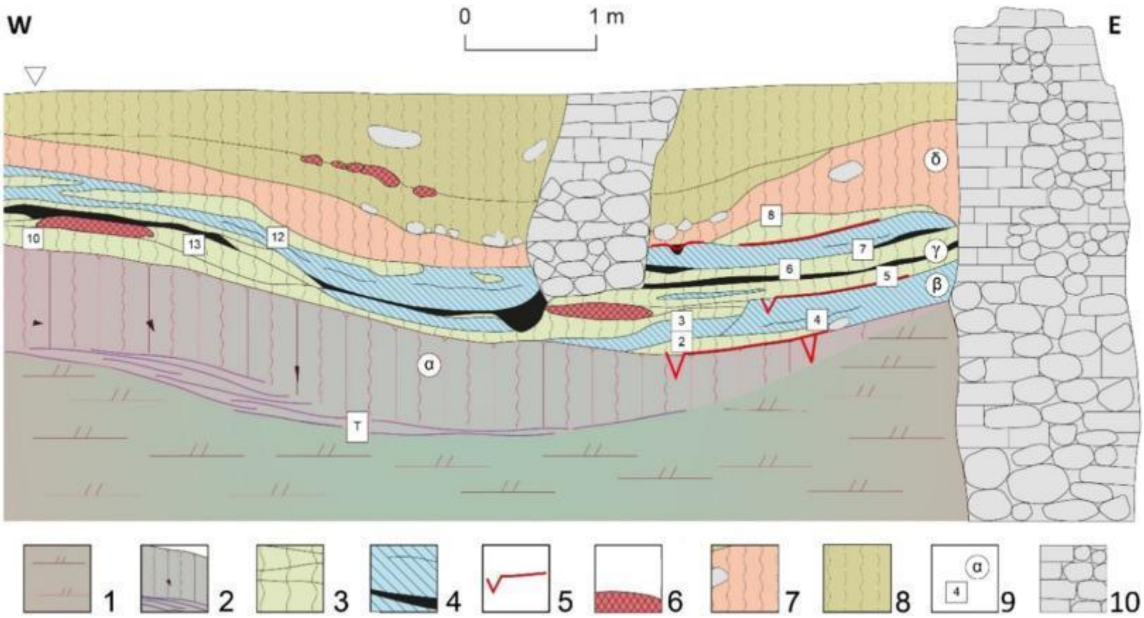

Figure 7. "Santo Stefano di Poviglio" stratigraphic section. 1 - substratum; 2 - Unit α with peat lenses; 3 - Unit β; 4 - Unit γ with layers rich in anthropogenic components; 5 - Wooden structural remains; 6 - hearths; 7 - Unit δ, highly reworked layer; 8 – Topsoil; 9 - Soil thin sections (square) and stratigraphic units (circle) 10 - Renaissance stronghold foundations.

Table 1. Description of the stratigraphic units.

Stratigraphic units	
Unit δ (abandonment layer)	Immediately above the anthropogenic layers, Unit δ seals the archaeological deposits. It consists of a silty loam layer with a weakly developed blocky structure (10YR 3/2) and contains medium cobbles and brick fragments that are horizontally disposed. The profile ends at its top with a yellowish brown (10YR 5/4) clay loam layer with a weakly developed blocky structure which corresponds to the abandonment phase of the Early Medieval fortified village. Above, the foundation of the Renaissance stronghold seals this layer.
Unit β and unit γ (anthropogenic layers)	Moving upward in the profile, anthropogenic layers are found. These consist of interconnected layers of varying thicknesses (from few centimetres to a meter) and abrupt limits; the layers include structures, horizontal beams and posts pertaining to timber-framed houses. Two different units, Unit β and Unit γ, have been described. Unit β consists of silty clay loam planar lenticular layers (5Y4/3 – 4/2 with mottles 5 Y 6/6) with a weakly developed angular blocky structure. It includes thin organic layers alternating with hearths and burned layers poor in anthropogenic materials (Samples 3, 4, 5, 10). Unit γ consist of silty clay loam layers (colours from 5 Y 3/1 to 10 YR 3/2) with a weakly developed sub-angular blocky structure rich in anthropogenic materials (Samples 7, 8). Samples 6, 12 and 13 were taken at the transition between sub-units β-γ.

Unit α (lower layers)	Unit α fills the depression and consists of planar silty, sandy layers (2.5 Y 5/4) intercalated with discontinued peaty lenses (5 Y 2.5/1; Sample T – Fig. 7A) rich in organic materials and containing few Roman tile fragments. On top of Unit α, the transition to a silt-loam decimetric soil horizon A/B b (10 YR 3/3 with mottles 2.5 Y 4/2) has been observed. This horizon is characterized by a weakly developed angular blocky structure and marks a clear linear limit with the overlying anthropogenic layers.
Substratum	The substratum consists of a planar laminated mottled (2.5 Y 3/2) sandy unit (2.5 YR 4/3,), which upper limit is characterized by a shallow depression in the middle section

Chronological analysis

The wood remains related to a series of superimposed structural phases exposed during excavations can be dated, with the help of the associated material culture, to the general period between the late 9th and 11th centuries (Fig. 8).

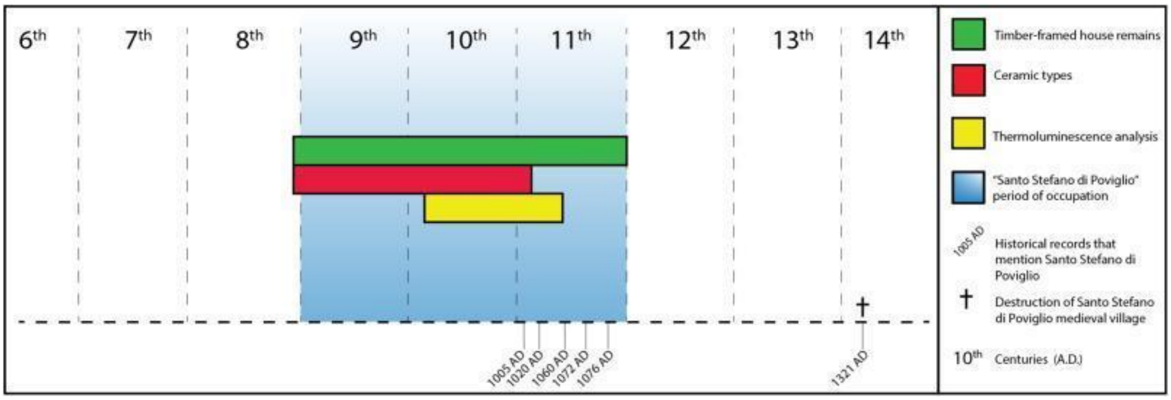

Figure 8. Comparing the chronological data range of medieval timber remains, ceramic types, thermoluminescence analysis and historical records, the site of "Santo Stefano di Poviglio" is likely to be active between 9th and 11th century AD.

Timber-framed house remains have been detected in the Anthropogenic Layers: US 51 in the transition between unit γ and unit δ; US 85 in unit γ; US 98 in unit β (Fig. 9). They consist in wooden floors, boards and beams (Cremaschi and Gelichi, 1990) that are likely to be related to the timber-framed houses types dated to 9th–11th centuries AD in Northern Italy (Augenti, 2004; Brogiolo, 1994; Galetti, 2004; Gelichi, 1994a; Gelichi, 1994b; Guarnieri, 2004; Galetti, 2010; Gelichi and Librenti, 2010; Gelichi et al., 2014).

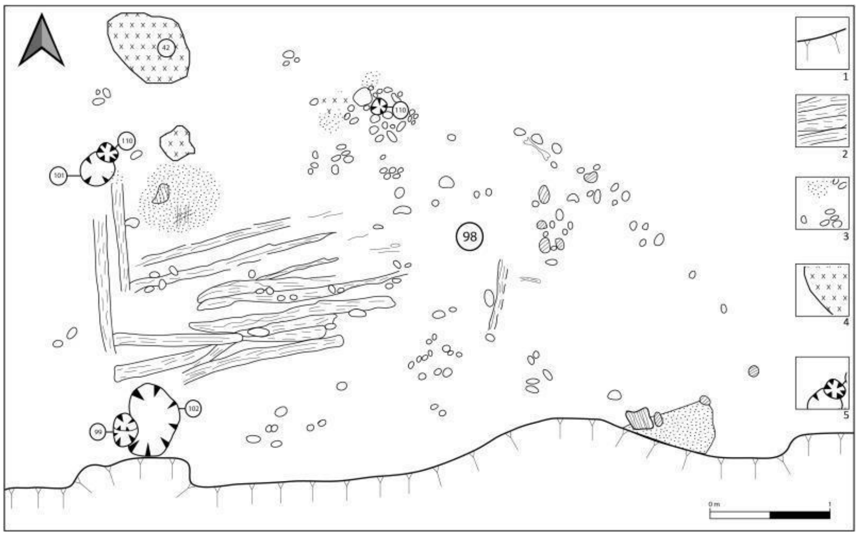

Figure 9. Map of US 98: 1 - Scarp delimiting the excavation area; 2 - timber-framed house remains; 3 - stone and charcoal concentration; 4 - hearths; 5 - postholes.

Ceramic types: all the pottery recovered at Santo Stefano di Poviglio belongs to well-known cooking ceramic classes typical of many Early Medieval sites in Northern Italy (Lusuardi Siena et al., 2004). Only a few fragments of soapstone bowls have been found. Chronologically, all the pottery finds are dated to the 9th–11th centuries AD, except for few fragments dated to the 7th century AD (Cremaschi and Gelichi, 1990).

The thermoluminescence (TL) measurements for dating were carried out on four hearth soil samples (Unit γ) at the Department of Materials Science of Milano University using a home-made system consisting of an oven for controlled heating in ultra pure Nitrogen atmosphere, based on photon counting technique with a bialkali EMI 9635QB photomultiplier coupled to Corning BG12 blue filters. The fine-grain technique (Zimmermann, 1971), which uses the polymineral fraction of the material with a size between 1 and 8 μm, was applied using the Multiple Aliquot Additive Dose protocol. To evaluate the annual dose-rate, the concentrations of the natural radioelements of both sample and burial soil were measured. Correction factors for the effects of humidity were applied (Aitken, 1985). Based on TL analysis, all hearths samples were active around the 10th–11th centuries AD (Table 2).

Table 2. Thermoluminescence dating analysis results (Physics Department, Università degli Studi di Milano).

Unit	Sample	Total dose (Gy)	Annual dose (mGy/yr)	Years BP	Date (AD)
β	Mi91-Po2	5,75 ± 0,15	5,34 ± 0,25	1075 ± 70	915 ± 70
β	Mi91-Po3	5,68 ± 0,28	5,51 ± 0,24	1030 ± 70	960 ± 70
γ	Mi91-Po4	3,17 ± 0,16	3,25 ± 0,17	975 ± 70	1015 ± 70
γ	Mi91-Po5	4,02 ± 0,21	4,12 ± 0,11	945 ± 70	1045 ± 70

Soil micromorphology

Recurring elements have been detected in all of the studied soil thin sections. Firstly, the mineral fraction composition (quartz, feldspar, mica, clayey marl, calcite gastropods casts) is typical of the Po Valley fluvial sediments mineral assemblage, and all samples show a crystallitic b-fabric under crossed polarized light (XPL).

Biospheroids (Fig. 10B, 3–5) found in the micromass are evidence of bioturbation processes that occurred in the profile layers. Anthropogenic materials are very frequent and of variable nature: charcoal, ash, burnt and unburnt bone fragments, eggshell fragments (Fig. 10B, 3), and brick shards (Fig. 10B, 8). Phosphatic pedofeatures (hypocoatings, coatings and nodules) often occur and in some cases (samples: 4, 5, 12, 13) include vivianite crystal intergrowths (Fig. 10B, 1–2–4–7).

Redoximorphic pedofeatures (hypocoatings, coatings, nodules) are also common (Fig. 10B, 6). The soil micromorphological analysis of the thin sections led to the detection of three pedosedimentary phases in the stratigraphy that corresponds to three different Microfacies Types (MFTs) (Fig. 10A and Table 3): A - Peat lenses (in Unit α); B - Anthropogenic living floors and occupational deposits (in Units β and γ); C - Abandonment (in Unit δ).

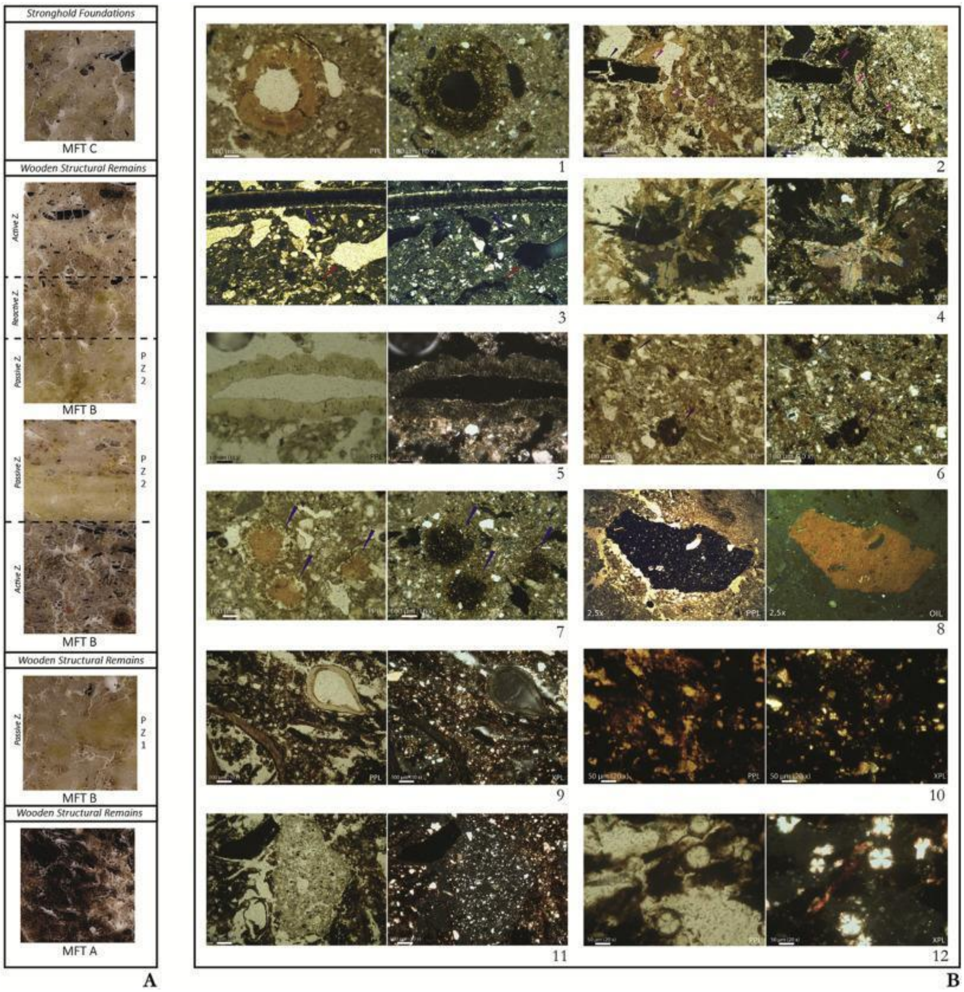

Figure 10 A. Schematic reconstruction of the site stratigraphic sequence. From the bottom to the top, the succession of the MFTs and active, reactive, passive zones. B:1 - Fe/Ca phosphatic coatings (MFT C; SS 8); 2 - Charcoal fragments embedded in Fe/Ca phosphatic coating (MFT B; SS 7); 3 - Eggshell fragment (blue arrow) and coleopteran fragment (red arrow) (MFT B; SS 6); 4 - Impregnative Fe/Ca phosphatic nodules with vivianite crystal intergrowth (MFT B; SS 4); 5 - Coleoptera fragment (MFT B; SS 4); 6 - Fe/Mn impregnative nodules (MFT B; SS 3); 7 - Impregnative Fe/Ca phosphatic nodules (MFT B; SS 3); 8 - Brick fragment (MFT B; SS 3); Peat laminated fabric rich in organic components (MFT A; SS T); 10 - Spherulites (MFT A; SS T); 11 - Ash aggregate (MFT A; SS T); 12 - Calcium oxalate druses (MFT A; SS T).

MFT A - peat lenses

MFT A has been observed only in thin section T, sampled in Unit α. It is composed almost exclusively of organic material (amorphous fine organic material, coarse plant tissue fragments) mixed with rare residues of human activity such as charcoal, ash aggregates, seeds. Also, few faecal spherulites and phytoliths occur randomly distributed in the thin section T. The spongy microstructure often shows sedimentary structures (planar microlaminations), easily identifiable by the distribution trend of grain sands and phytoliths (Fig. 10B, 9), and related to the natural process of peat sedimentation. Peat lenses are likely to have been deposited in the area where a little drainage with a low flow was present.

The microscopical analysis suggests that human activities influenced the site before the foundation of the Early Medieval village. The recurrence of faecal spherulites (Fig. 10B, 10), for instance, may be related to husbandry and the seeds could be residues of agricultural practices. Charcoal and ash inclusions are results of human fire activities. The uppermost part of the MFT A presents rare coarse intrusive calcitic nodules that are likely to be related to secondary cementation of calcite associated with root passages (Karkanas, 2007). (Fig. 11).

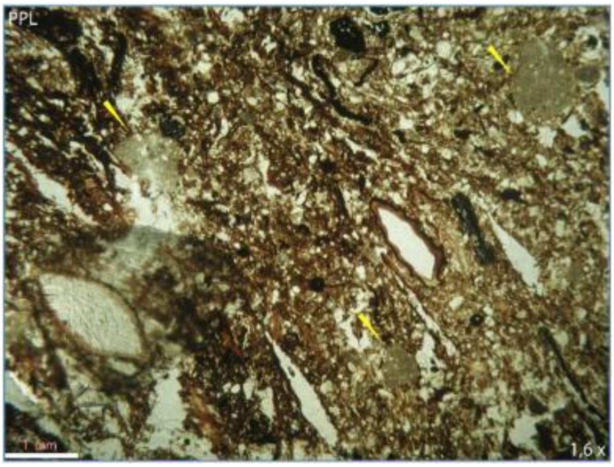

Figure 11. MFT A, rare intrusive (yellow arrows) calcitic nodules.

MFT B - anthropogenic living floors and occupational deposits

MFT B is a complex microfacies formed by the alteration of living floors and layers rich in anthropogenic material. Indeed, the micromorphology analysis shows how the deposits associated with the timber-framed houses consist of alternating layers of trampled and dumped materials from domestic activities; these alternating layers can be attributed to the various occupation phases.

In MFT B floor slabs of clean material are alternated with dark-coloured charcoal-rich occupation accumulations that were re-surfaced with local brickearth and alluvial silt loam: this kind of sequence have been reported in both prehistoric (Karkanas and Van de Moortel, 2014) and medieval (Macphail et al., 2004; Rentzel, 2011; Sveinbjarnardottir et al., 2007; Milek, 2012) European sites. MFT B consists of a polyphase microstructured occupation surface in which is possible to distinguish active, reactive and passive zones (Gè et al., 1993; Macphail and Goldberg, 2018).

- Active zone (Fig. 12) is composed almost exclusively of anthropogenic materials (charcoal, ash, bone fragments, eggshell fragments, brick and pottery flasks), with common Fe-Ca phosphatic pedofeatures. The internal fabric of subangular blocky peds shows high porosity (often vughy microstructure): few complex packing voids occur between charcoal and ash fragments. The coarse fragments show a weakly-expressed, horizontal basic orientation and a horizontal basic banded distribution. Trampling caused the formation of fragmented microartifacts and microaggregates and determined the fabric microlamination (Macphail and Goldberg, 2018; Nicosia and Stoops, 2017). Also, trampling-in of mud seems to be a probable explanation for the distribution of the coleoptera fragments detected (Macphail et al., 2004).

Figure 12. MFT B, active zone.

Table 3. Soil micromorphological analysis.

MFT	Sample	Unit	Microscopic description	Interpretation
C	8	δ	Chaotic distribution of coarse fabric constituents. Moderately heterogeneous. **Microstructure**: weakly developed blocky microstructure with few channels, few planes and very few vughs. **Organic components**: very few burned plant residues **Anthropogenic materials**: few fine/coarse charcoal fragments; very few burned/unburned bone fragments; rare eggshell fragments; rare pottery/brick fragments. **Groundmass**: cloudy calcitic fine silt with crystallitic b-fabric. **Pedofeatures**: few Fe/Ca phosphatic infillings, hypocoatings, impregnative nodules; few calcite coatings often associate with juxtaposed sparitic coatings; few intrusive calcite nodules; very few impregnative Fe/Mn nodules.	Abandonment layer heavily disturbed by the construction of Renaissance stronghold.
B			Polyphase microstructured occupation surfaces composed of active, reactive and passive zones.	Maintained sequence of floors (passive zones) alternated with occupational accumulations (active zones).
PZ1	2, 3, 5, 10	β	Homogeneous. Loam silt shows locally parallel lamination. **Microstructure**: moderately developed subangular blocky microstructure with massive very coarse size peds. Very few voids (channels, planes and vughs). **Organic components**: very few reddish-brown tissue residues (PPL); very few plant residues. **Anthropogenic constituents**: Few fine charcoal fragments and very few coarse charcoal fragments; very few burned/unburned bone fragments; rare coarse brick fragments; rare pottery fragments (m.s.). **Mineral components**: very few phytoliths **Groundmass**: Cloudy calcitic fine silt with crystallitic b-fabric. (PPL: brownish light grey XPL: yellowish light brown OIL: light grey locally yellowish). **Pedofeatures**: common Fe/Ca phosphatic impregnations; Few impregnative Fe/Mn nodules; Few impregnative Fe/Mn hypocoatings; Very few intrusive calcitic nodules occasionally superimposed with Fe hypocoating; Very few impregnative aggregates and concentric Fe/Mn nodules; Rare intrusive calcitic coatings juxtaposed with Fe hypocoating and micritic in the coating.	Clay floor mixed with inclusions of highly impure lime plaster
PZ2	4,6,7,12,13	γ	Homogeneous. Microlamination of sediments. Completely devoid of organic components. **Microstructure**: massive microstructure with only a few vughs and vesicles. **Anthropogenic constituents**: common very fine charcoal fragments; rare burned bone fragments; rare ash aggregates. **Groundmass**: cloudy calcitic fine silt with crystallitic b-fabric. (PPL: whitish light brown; XPL: brownish light grey; OIL: grey locally yellowish). **Pedofeatures**: few impregnative Fe-phosphatic nodules often associated with vivianite random and radial crystal intergrowth; few Fe-phosphatic hypocoatings; very few impregnative Fe/Mn nodules; very few impregnative calcite nodules; rare calcite hypocoatings with the juxtaposed internal sparitic coating.	Impure lime based plaster floors
A	T	α	Discontinuous peat levels intercalated in unit α. **Microstructure**: Moderately developed spongy microstructure. Common vughs and rare channels. **Organic components**: Frequent amorphous fine silty material; common rough sub-rounded fibrous, woody tissue residues. **Anthropogenic constituents**: Few coarse charcoal fragments; few organ residues (seeds), rare ash aggregates. **Mineral components**: few spherulites; very few phytoliths **Groundmass**: Cloudy calcitic and amorphous organic fine silty material with crystallitic b-fabric. (PPL: dark brown, OIL: yellowish/reddish brown; XPL: dark reddish brown) **Pedofeatures**: rare intrusive coarse calcitic nodules.	Peat sediments with the inclusion of material derived from human activity (faecal spherulites→husbandry; seeds→agriculture; ash and charcoal→fire activity residues).

- Reactive zone presents few materials derived from human activities, and it is characterized by a subangular blocky microstructure and low porosity. The reactive zone is located between the passive and active zone. Trampling induced a mechanical deformation of passive zone and the inclusion of human residues from active zones in the groundmass. This process also explains the variable thickness (ca 0.5–2 cm) and the blurred limits of the level.

- Passive zone has a massive microstructure with only a few vughs and vesicles. The microfabric shows a horizontal orientation of components. The coarse anthropogenic materials here are rare and almost absent. The passive zone consists basically of a prepared floor (Macphail and Goldberg, 2018). High concentration of phosphatic staining occurs in the passive zone. The constructed floors, indeed, act as a hydraulic barrier allowing secondary phosphate deposition (Macphail and Goldberg, 2018): it explains the presence of common Fe-Ca phosphatic stainings and pedofeatures in passive zones (Fig. 19) (see Discussion section).

In MFT B have been identified two types of passive zones (PZs), basing on different micromorphological characteristics. Hence, MFT B passive zone can be divided into two subtypes: Type 1 and Type 2.

- Passive Zone Type 1 (or PZ 1) consists of homogeneous loam silt with a locally parallel lamination. Under the microscope, it is characterized by a moderately developed subangular blocky microstructure with massive very coarse peds, a cloudy calcitic fine silt groundmass and a crystallitic birefringence (PPL: brownish light grey XPL: yellowish light brown). PZ1 is almost entirely devoid of archaeological materials (rare charcoal, bone and brick/pottery fragments) produced by domestic activities (hearths). This thick silty loam layer laid on the wooden floor (UUSS 98, 85) and constituted a loamy plaster lining the inside of the structure hypothetically to isolate the domestic setting from the humidity of the underlying units and fire damage caused by open hearths. PZ1 consists of a "clay" floor (Sveinbjarnardottir et al., 2007; Milek, 2012; Macphail and Goldberg, 2018) constructed with local loamy-clayey deposits. The identification of a short sequence of phytoliths (Fig. 13) and Fe/Mn mineralized "stains" might be the remnants of organic temper mixed to the loamy materials to build the floor (Karkanas, 2006; Macphail and Goldberg, 2018).

Figure 13. MFT B, Passive Zone Type 1. A short sequence of phytoliths (blue arrows).

Furthermore, the calcitic high birefringence matrix associated with the presence of few lime lumps with shrinkage fractures and reaction rims with the matrix (Karkanas, 2007), suggest the addition of highly impure lime plaster to the floor preparation (Fig. 14).

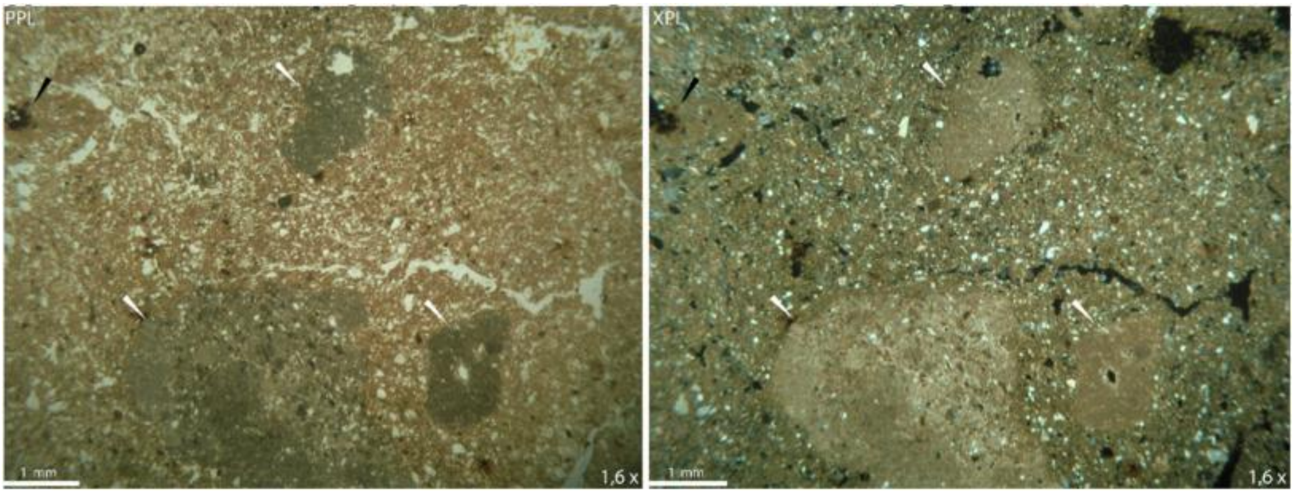

Figure 14. MFT B, Passive Zone Type 1. Lime lumps (white arrows) and Fe/Mn nodule (black arrow).

Evidence of rooting (calcite coatings associated with juxtaposed Fe hypocoatings derived from root decay), waterlogging conditions (Fe/Mn redoximorphic pedofeatures) (Fig. 15) and a high percentage of iron-phosphate pedofeatures will be discussed later (see Discussion section).

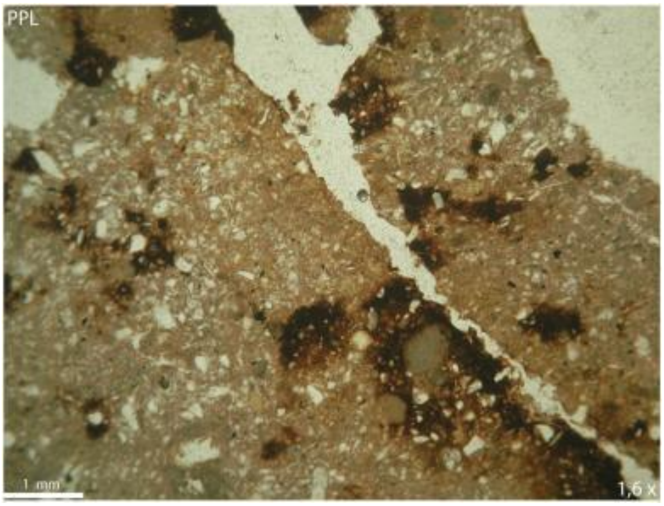

Figure 15. MFT B, Passive Zone Type 1. Fe/Mn pedeofeatures.

- The Passive Zone Type 2 (or PZ 2) corresponds to impure lime-based plaster made floors. PZ 2 presents a massive microstructure with few vughs and vesicles and is characterized by a beige colour (PPL: whitish light brown), high birefringence (XPL: brownish light grey crystallitic b-fabric), and rare coarse anthropogenic constituents. In experimental specimen (Karkanas, 2007) the groundmass light beige colour (PPL) has been reported as the result of lime consisting of poorly reacted quicklime. Frequent very fine charcoal fragments are found embedded in the calcitic microfabric as the result of wood burning as fuel material in the limestone cooking process. Also, few fine calcite grain components are likely to be the residues of the cooking process used to transform limestone into quicklime. Other mineral components detected in PZ 2 (for instance coarse quartz grains) represent impurities in the lime-based plaster. It is likely that lime plaster at this site has been highly mixed with other local sediments in order to build a domestic floor. Due to the high amounts of clay, clastic calcite, and other fine-grained material, the lime matrix in highly impure lime plasters is complicated to distinguish from calcareous sediment, but the identification of lime lumps in the samples supported our interpretation (Fig. 16, Fig. 18). Lime lumps, indeed, represent the most characteristic features of lime plasters and have different origins: half-reacted quicklime, overburnt quicklime or poorly slaked mixed lime (Hughes et al., 2001; Karkanas, 2007; Stoops et al., 2017).

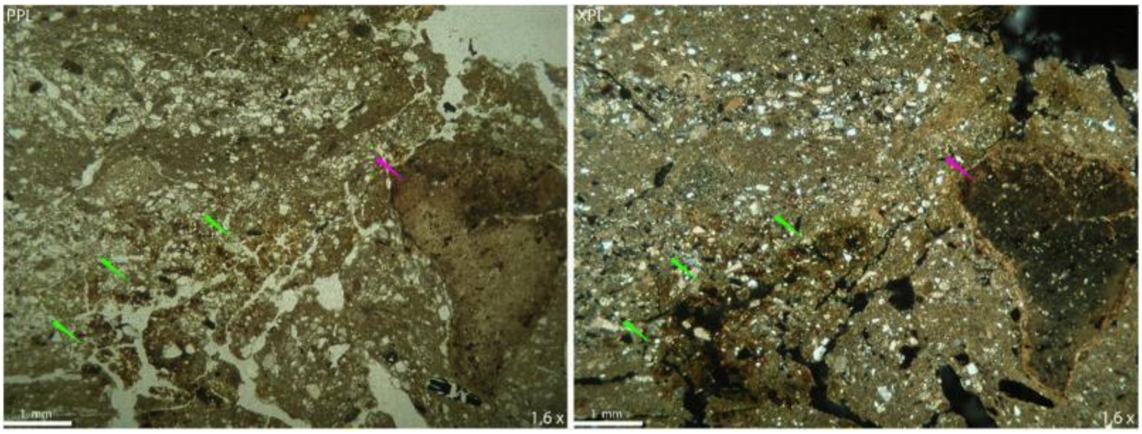

Figure 16. MFT B, Passive Zone Type 2. Lime lump (pink arrow) and phosphatic stainings (green arrows).

Further interesting optical elements have been detected in oblique incident light (OIL): a coarse aggregate of calcite in thin section SS 6 presents a typical whitish border (Macphail and Goldberg, 2010) with reddish dots on the inside: these have been interpreted as diopside (MgSiO3) derived from the burning of limestone at high temperature (≥1000 °C) (Courty et al., 1989) (Fig. 17).

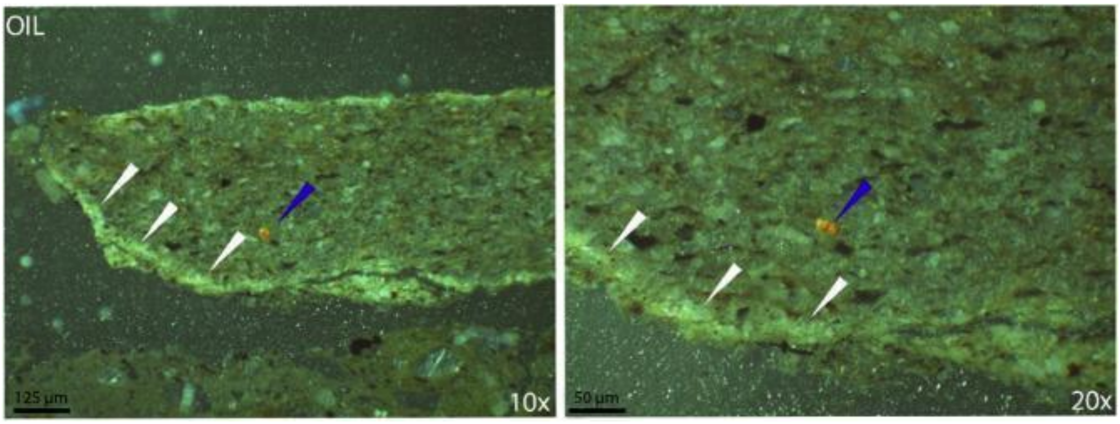

Figure 17. Fragment of lime-based plaster with whitish border (white arrows) and diopsite dot (blue arrow).

Even though further chemical analysis will confirm the presence of diopside, this fragment of well-burned limestone is likely to be a part of the anthropogenic debris added to the impure mixture of lime base plaster than a fragment of the made floors itself. The presence of poorly slaked lime lumps and impurities suggests that PZ 2 is the results of “hot mixing procedure”, a technique that does not requires well-burnt lime and employs only a low amount of water in the slaking process (Karkanas, 2007).

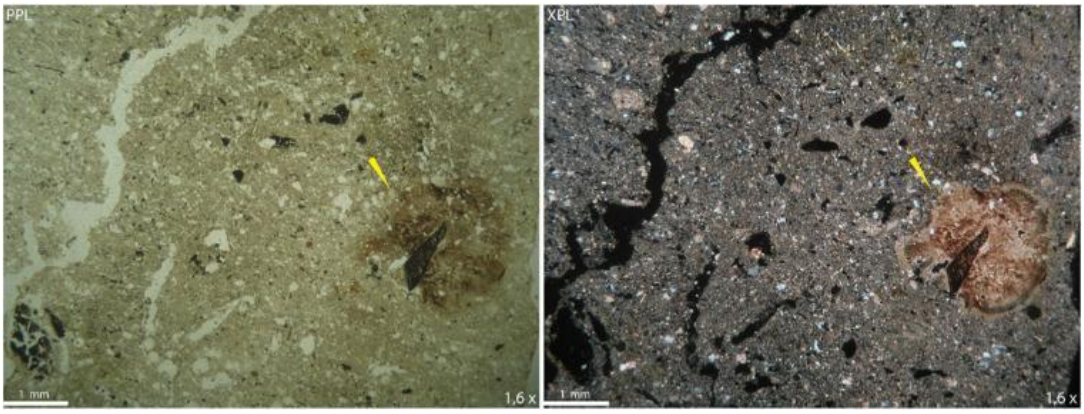

Figure 18. Lime lump with light brown reaction rim. In this case, the lime lump formed around a charcoal fragme*nt.*

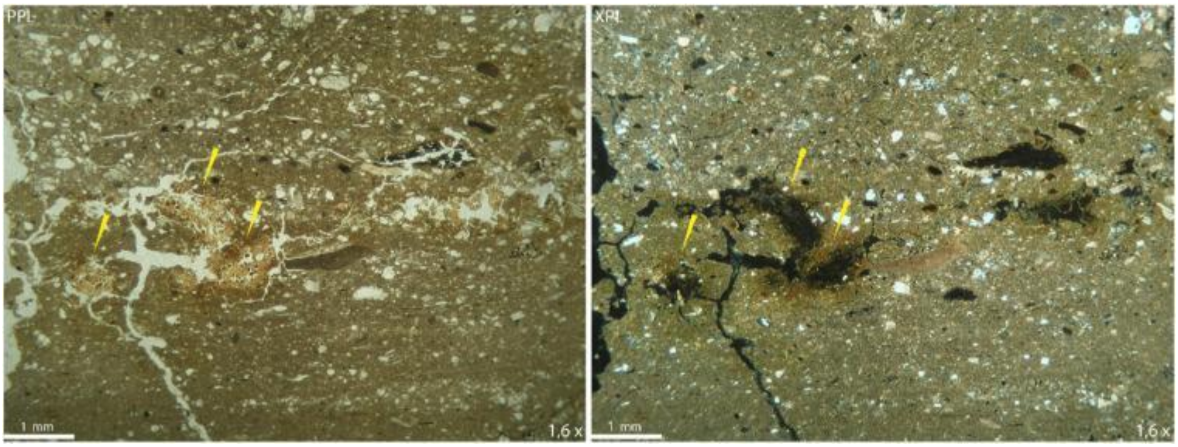

Figure 19. MFT B, Passive Zone Type 2. Massive microstructure and Fe-Ca-P amorphous pedofeatures (yellow arrows).

MFT C – abandonment

The last pedosedimentary phase (MFT C) corresponds with the abandonment of the Early Medieval house. This phase was sampled in thin section 8. The microfabric does not present any microlamination of the sediments, and the anthropogenic materials are few and chaotically disposed. This layer is likely to have been heavily disturbed by the Renaissance stronghold foundation. Dump material (as charcoal fragments) mixed with few calcitic lime lumps (Fig. 20) suggests that the construction of the Renaissance brick pillars reworked the top part of the polyphase microstructured occupation surface sequence observed in MFT B. The evidence of rooting (Fig. 10B, 1) also detected in MFT C suggests that a phase of abandonment of the area occurred between the Early Medieval village and the Renaissance stronghold. The construction of the 16th-century fortress, also, sealed the Early Medieval sequence preventing the typical severe homogenization of Anthropogenic Dark Earth (Nicosia and Stoops, 2017; Macphail and Goldberg, 2018). The MFT C phosphatic pedofeatures (yellow isotropic phosphate infillings) (Fig. 20) resulted by the post-depositional process as liquid waste that percolated downward from the stronghold latrines (see Discussion section).

Figure 20. MFT C. Thin section 8, yellowish phosphatic pedofeatures and coarse lime lumps (green arrows).

Discussion

According to the chronology, the Santo Stefano di Poviglio archaeological site is dated to 9th–11th century and corresponds to the NE limit of an Early Medieval Motte, detected by DEM and mentioned in the historical document as Castrum Popilii. The definition of MFTs has been extremely useful to interpret the sedimentary processes involved in the formation of the Santo Stefano di Poviglio site.

The lower layers of the exposed stratigraphy correspond to the top of the alluvial sequence. Peat lenses detected in unit α are the results of the deposition of organic sediments in an environment with stagnant water or (more probably in this case) in a channel with minimal flow, fitting in shape with the depression observed in unit α. This channel should have been active in Roman times (as suggested by the tile fragments with blunt edges detected in unit α), as well as during the occupation of the nearby villa rustica, the remains of which have been recently found in the Poviglio main square. It cannot be excluded that this paleochannel could have been diverted artificially to have been used as a water supply for the needs of the Roman villa, such as for husbandry or agriculture (MFT A). From satellite images, other paleochannels can be recognised in the Poviglio countryside, especially east of the city, not far from "Santo Stefano di Poviglio" archaeological site. The stratigraphy highlights how, in the Early Medieval Age, a pile-dwelling was established on the site in connection with the paleochannel depression. The house shows two phases of piling, three phases of flooring and three polyphase occupation surface sequences. Since every new wooden plank corresponds to a renovation of the building, its transformation, according to chronological analysis, happened between the 9th and 11th centuries AD. The older timber-framed house (US 98) was partially suspended over the water on one side, and a thick, clayey slab floor was laid over the wooden planks (MFT B, PZ1). In a later phase, this house was replaced by a second building with the same structural characteristics (US 85). The micromorphological analysis shows a sequence of polyphase occupation surfaces that consists of constructed floors alternating with active/reactive zones (MFT B). Indeed, the constructed floor (MFT B; PZ 1 and PZ 2) are alternate with dark-coloured, charcoal-rich occupation accumulations, which represents beaten floor/trampled-in material (MFT B; active and reactive zones) derived from domestic activities (Macphail et al., 2004; Rentzel, 2011; Macphail and Goldberg, 2018). Constructed thin floors of impure lime based plaster (MFT B, PZ 2) resurface the previously accumulated domestic debris (Karkanas and Van de Moortel, 2014) determining a sequence of plastered floors alternated with occupational deposits (Sveinbjarnardottir et al., 2007). Even though in the first building (US 98) micromorphology revealed the occurrence of rare lime lumps (PZ 1) in the clay slab floor, in the second building (US 85) the use of impure lime based plaster (PZ 2) became common. In this second phase, indeed, the floor was also occasionally restored using impure lime-based plaster mixed with clay, sand and very fine charcoal (PZ 2) (Fig. 21).

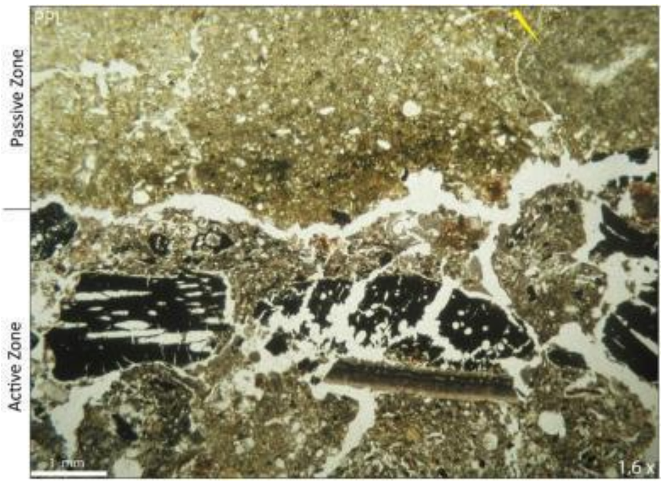

Figure 13. Passage from Active to Passive Zones Type 2 in the Castrum Popilii stratigraphic sequence. In the anthropogenic materials are present charcoal fragments and eggshell fragments. In the impure lime based plaster floor (passive zone) the yellow arrow indicates a lime lump.

This multiple replastered floor sequence that includes surfaces made of debris produced inside the house by domestic activities shows a progressive evolution in the floor construction techniques from clayey floor slabs (PZ 1) to "enhanced" lime based plaster floors (PZ 2) with significant archaeological implications. According to historical-archaeological literature, the production of quicklime was sporadic in Early Medieval Po Valley. The production of quicklime in cities was easily possible with the burning of Roman marble statues and decorations; outside of this process, the cost of producing quicklime was so expensive that high-quality lime-based plaster was only employed by the wealthiest clients, such as bishops or local lords.

In the Castrum Popilii Motte, the micromorphology suggests the impure lime based plaster consisted of a mixture of burnt lime and diverse materials as clay, anthropogenic debris and fine charcoal. Also, the procedure to prepare lime based floor probably followed the “hot mixing” method or “dry slaking” (Karkanas, 2007) as suggested by the occurrence of lime lumps. These features are typical in hot mixing procedure because it implies a low amount of water and a crude mixing with aggregate. Moreover, the light beige colour of PZ 2 could be the results of lime composed of a poorly reacted quicklime, an effect of the hot mixing procedure. This rough technique fits perfectly with the archaeological context of a rural early medieval village as Santo Stefano di Poviglio. Hot mixing process does not require well-burnt lime, and the addition of mixed soils and anthropogenic debris improves the carbonation process (Macphail and Goldberg, 2018). The presence of occasional diopside is not enough to postulate that the quicklime used here was produced burning limestone at 1000 °C. Also, the choice of the raw material used (Stoops et al., 2017) affects the burning process duration and the quality of quicklime (Karkanas, 2007). For example, crushing the calcareous material in small fragments reduce the temperature of quicklime production. Also, experimental studies demonstrate that the soft porous nature of most calcareous materials enhances their reactivity and lowers the temperature of burning to 800 °C (Moropoulou et al., 2001).

Here in Santo Stefano di Poviglio, it is more likely to be that poor quality quicklime was obtained with a less expensive procedure in term of time and resource (both raw material and fuel) spending.

The second structure was eventually replaced by US 51 which sealed the previous anthropogenic deposits. The occupation surface related to the last house phase has not been detected in the stratigraphic sequence. Unit δ, indeed, was highly reworked in Renaissance by human activities related to the stronghold foundations (MFT C). The coarse anthropogenic materials are randomly oriented, and no particular orientation has been detected. The occurrence of channels it might be related to rooting, suggesting that the area was partially abandoned between the end of the Early Medieval village and the Renaissance fortress establishment.

Bioturbation by rooting, indeed, is a post-depositional process that affected the whole stratigraphic sequence. It appears to have been efficient in reworking and displacing the fine elements of the fabric (calcite grains, ash aggregates, and very fine charcoal fragments). In contrast, coarser components such as bones, charcoal, eggshell fragments have not been affected by vertical redistribution by burrowing soil fauna or plant roots; these coarse components are not scattered in the studied profile, indicating the preservation of vertical distribution patterns.

The construction of a stone stronghold in the 15th century had the effect of decreasing the impact of bioturbation activities considerably and later human-related processes, allowing the exceptional preservation of this sequence, avoiding heavy homogenization of Anthropogenic Dark Earth.

Moreover, the condition of water stagnation, probably due to a perched water table, preserved the wooden house structure. In Central Po Valley, wood is strongly subject to decay but here anaerobic conditions well preserved the timber-framed houses remain (Gebhardt and Langohr, 1999 have reported a similar case study in Werken Motte, Belgium). The prolonged water saturation condition led to the formation of typical iron-manganese redoximorphic pedofeatures (Lindbo et al., 2010) in the Castrum Popilii motte stratigraphy. Also, the anaerobic conditions in dwelling context contribute to the development of Fe-Ca-P amorphous pedofeatures (Macphail and Goldberg, 2018). The phosphate migrated through the occupational surfaces layers and accumulated mainly in correspondence of constructed floors, which operated as a hydraulic barrier. The occurrence of crystalline vivianite (iron phosphate) attests the mobilized presence of phosphate, a further consequence of the waterlogging condition that preserved the Early Medieval stratigraphy of Santo Stefano di Poviglio.

Conclusion

The geoarchaeological analyses performed in this study enabled a better understanding of the processes involved in the genesis and development of the S. Stefano di Poviglio site. It has been determined that the accretion of the stratigraphic sequence derived from repeated episodes of human occupation, consisting of a superimposition of trampled domestic occupation deposits and constructed floors. To summarise, in the Early Medieval Age, a pile dwelling was established on the bank of a channel, close to the location of a Roman "villa rustica", in a position higher in relative elevation than the surrounding waterlogged countryside. The identification of three subsequent phases revealed a transformation in the construction techniques, not only in the wooden structure but also in the choice of materials used for the domestic floors. Soil waterlogging conditions allowed for the preservation of the structural wooden remains of the first two construction phases. Also, soil micromorphology revealed that the house floors were repeatedly refurbished between 10th and the 11th centuries and that the clay floors were replaced by pavements enhanced using impure lime-based plaster. In Medieval Archaeological studies, high-quality lime-based plaster is documented in Northern Italy almost exclusively in urban contexts, or in fortress and cathedral construction sites, and not in domestic contexts until the 12th century AD. The impure lime-based plaster floors of "Santo Stefano di Poviglio" open new questions about Early Medieval Age building techniques, in a period where earth and timber were the most used construction materials. In Castrum, Popilii seems that lime plaster was frequently used even if in limited quantities. After a phase of abandonment of the site (MFT C), the establishment in the Renaissance of a stone square-shaped stronghold sealed the Early Medieval archaeological deposits, preserving the stratigraphy and preventing the homogenization of layers, common in Anthropogenic Dark Earth.

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4.2 The Impact of Late Holocene Flood Management on the Central Po Plain (Northern Italy)

[Brandolini, F.; Cremaschi, M. *The Impact of Late Holocene Flood Management on the Central Po Plain (Northern Italy)*. Sustainability 2018, 10, 3968]

Abstract

Fluvial environments have always played a crucial role in human history. The necessity of fertile land and fresh water for agriculture has led populations to settle in floodplains more frequently than in other environments. Floodplains are complex human–water systems in which the mutual interaction between anthropogenic activities and environment affected the landscape development. In this paper, we analyzed the evolution of the Central Po Plain (Italy) during the Medieval period through a multi-proxy record of geomorphological, archaeological and historical data. The collapse of the Western Roman Empire (5th century AD) coincided with a progressive waterlogging of large floodplain areas. The results obtained by this research shed new light on the consequences that Post-Roman land and water management activities had on landscape evolution. In particular, the exploitation of fluvial sediments through flood management practices had the effect of reclaiming the swamps, but also altered the natural geomorphological development of the area. Even so, the Medieval human activities were more in equilibrium with the natural system than with the later Renaissance large-scale land reclamation works that profoundly modified the landscape turning the wetland environment into the arable land visible today. The analysis of fluvial palaeoenvironments and their relation with past human activities can provide valuable indications for planning more sustainable urbanized alluvial landscapes in future.

Keywords: flood management; wetland; land use change; landscape transformation; resilience; late Holocene; medieval age

Introduction

Floodplains are preferred areas for human settlements due to their suitability for agriculture activities, and many studies substantiate the interpretation of floodplains as complex human–water systems [1,2,3]. Indeed, water and land management activities have altered fluvial landscape development to create cultivable land, while simultaneously protecting communities from the risk of flooding events, which are still the most common natural disasters worldwide [4,5].

In Europe, the reciprocal interaction between fluvial environments and human activities has been documented since the Neolithic [6,7], when fluvial landscapes were first altered for agriculture purposes. Today, floodplains are densely cultivated, and the modern European countryside is principally derived from the human landscape modification that occurred in medieval times.

In the Early Medieval Age (6th–9th centuries AD) few cases of large-scale anthropogenic land and water management activities are known (es. Fossa Carolina [8,9]) compared to later centuries. Even though there are some differences between the northern and central Europe and the Mediterranean region, the anthropogenic reshaping of the natural environment was principally a result of overall population growth. Between the 10th and the 13th centuries AD, concurrent with the Medieval Warm Period climate phase [10,11,12], the European population grew substantially, almost tripling (in Northern and Central Italy, the urban population doubled), and increasing the demand for cultivated lands [13,14,15,16]. Cereals became a more significant constituent in the average diet and in the agrarian regime compared to the centuries before, leading populations to reconfigure the medieval natural landscape for agricultural purposes. In creating new land for cultivation and settlement, the European communities triggered a massive landscape transformation through woodland clearance, arable intensification, the development of irrigation systems and the drainage of wetlands. Land reclamations works profoundly modified many European regions: the peatlands in the Netherlands [17,18,19,20]; the coastal marshlands in the UK [13,21] and in North Frisia (Germany) [22] and the alluvial wetlands in the Po Valley (Northern Italy) (Figure 1) [17]. In the latter, specifically the Emilia–Romagna region (Central Po Plain), the earliest evidence of attempts to clear the forests and drain the wetlands is mentioned in historical documents from the late 8th century [23,24], but only from the 10th to the 13th centuries were land and water management activities actually carried out widely. The proponents of those activities were mostly monasteries [25,26,27] such as Nonantola, Santa Giulia, Mirandola, San Benedetto in Polirone [28], and also local lords who contributed to colonizing new farmland by forcing rural people to live into new fortified settlements (incastellamento process [29,30,31]).

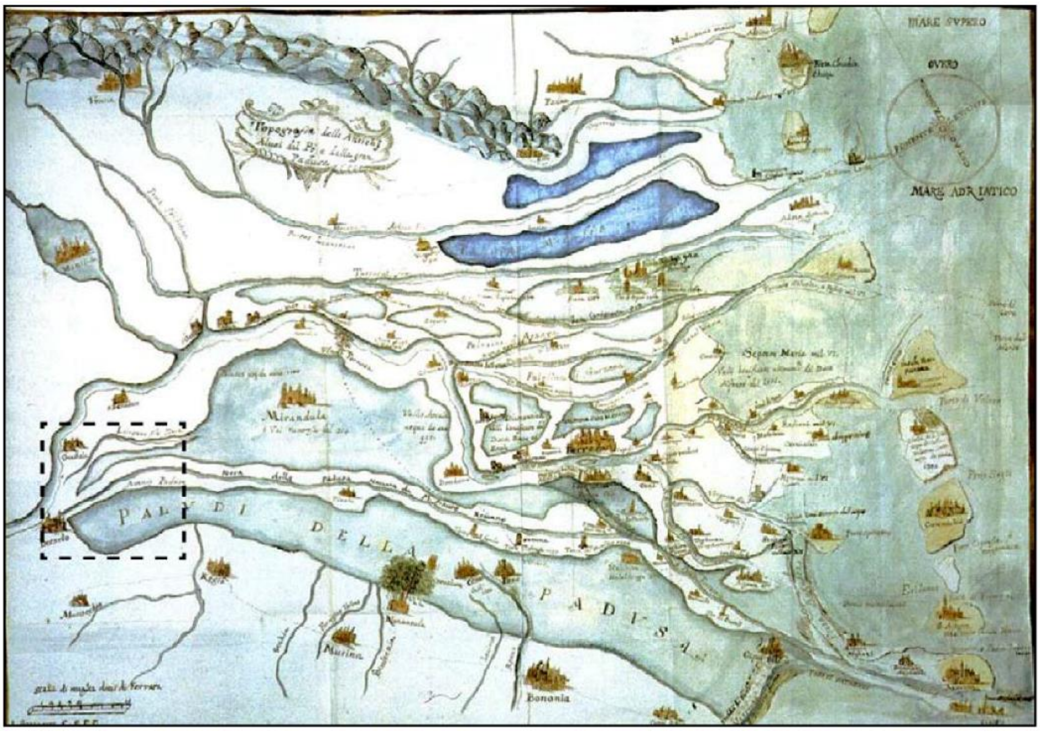

Figure 1. The wetlands in the Po Plain before the Renaissance land reclamation works, 1570 AD. Library of the Univerisità degli Studi di Bologna [32]. The dashed line indicates the research area.

According to historical maps and documents the land reclamation of the Central Po Plain reached its peak during the Renaissance (15th–16th centuries AD) [33] and continued in the Modern Age (17th–18th centuries AD), with the last marsh areas only being reclaimed in the 20th century AD: channels and drainage system are still active and allow the Po Valley to be drained and be cultivatable [34].

During the last two centuries, the height of the Po river embankments have been raised significantly to protect urban areas, and the river has become increasingly controlled, but the debate around future sustainable flood management activities is ongoing. In particular, with steadily increasing embankment heights, the potential flood depth increases, which in turn increases the flood damage if a failure occurs. The heightening of embankments, indeed, represents a component of the so-called ‘levee effect’ [1,35]; flood defenses actually increase overall vulnerability, as protection from regular flooding reduces perceptions of risk and encourages inappropriate development in alluvial floodplains [3]. A possible correct strategy to reduce the flood hazard when considering very large or extreme events consists of exploiting areas outside of the main embankments with the ‘Room-for-River’ approach [36,37]. In the case of the Po River, for example, the main embankments are already very tall along large sections of the river, and their further raising is not environmentally sustainable [2].

The environmental evolution of the Central Po Plain and its relationship to human activities has been thoroughly studied for prehistoric periods and the Roman Era [38,39,40,41,42,43,44];

however, these human–environment interactions in subsequent centuries are less apparent. The post-Roman Era represents a crucial moment in the Late Holocene development of the Po Plain when a large portion of the well-organized Roman countryside turned into vast alluvial wetlands [45]; the Roman drainage system collapsed, and the inhabitants had to deal with living in a waterlogged environment.

This study aims to detect and disentangle the mutual interaction between anthropogenic activities and environmental changes that occurred in the post-Roman Era integrating geomorphological analysis with historical and archaeological data. The application of a multidisciplinary approach enables the quantification of the impact of human activities on the development of the wetland environment in Central Po Plain during the Middle Ages.

Study Area: Geomorphological and Historical Contexts

The research area is located in the Central Po Valley, south of the Po River, a few kilometers north of the Tuscan–Emilian Apennine margin, between the cities of Parma and Reggio Emilia (Figure 2). Since the Pleistocene, the Apennine watercourses shaped the landscape developing alluvial megafans with their sediments (Figure 3). In the study area, the distal parts of Holocene alluvial fans are characterized by a telescopic shape, a result of subsequent aggradation (Aggradation indicates the increase in land elevation, typically in a river system, due to the deposition of sediment.)—entrenchment phases due to the alternation of glacial-interglacial periods; each aggradational cycle causes an incision on the top of the previous fan, while a new fan prograded in a more distal position [41]. In the study area, the alluvial ridges of the Enza, Crostolo and Tresinaro, emerging from the flat floodplain, flank depression areas known in fluvial geomorphology as backswamps, which are characterized by deposits of fine silts and clays deposited after flood events [46].

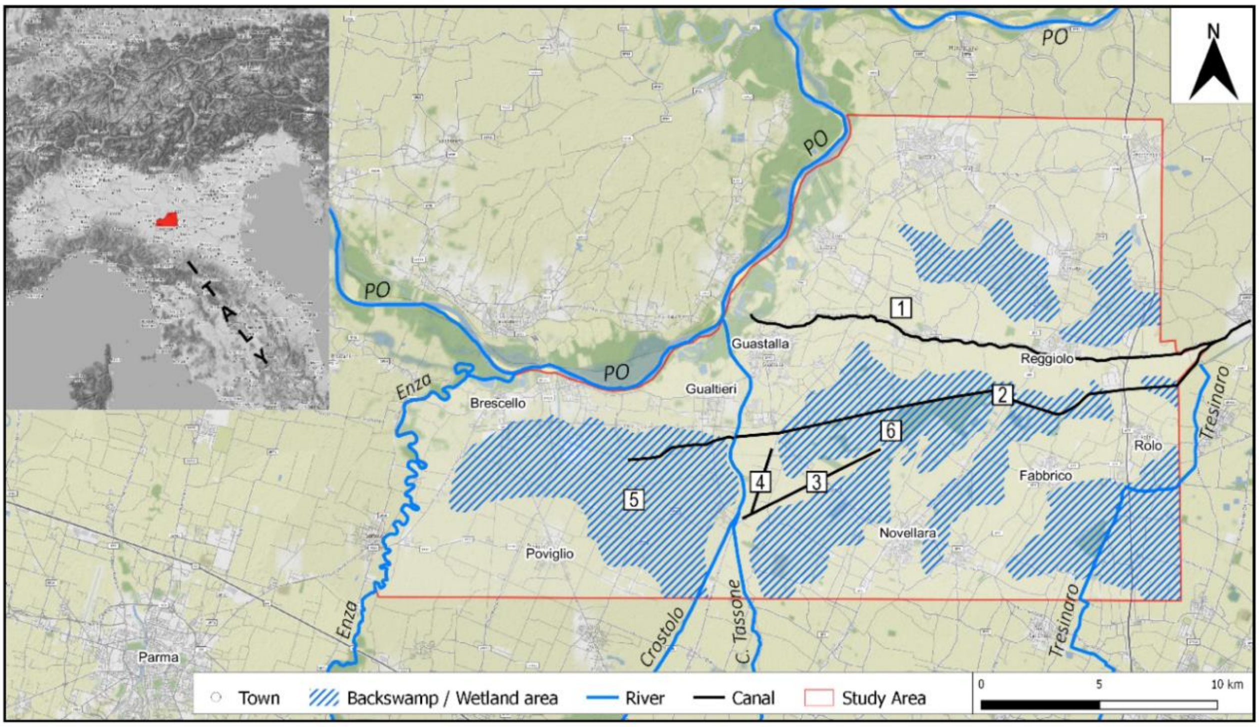

Figure 2. Location of the study area. 1—Tagliata Canal; 2—Parmigiana Canal; 3—Crustulus Vetus; 4—Camporainero area; 5—Valle di Gualtieri backswamp; 6—Valle di Novellara backswamp.

The landscape evolution of this portion of the Central Po Plain has a long-standing connection with human activities. Protohistoric human–environmental interactions have been widely investigated [39,40,41,49,50] but the first historical large-scale land and water management project in the study area is dated to the 2nd century BC. At that time, the Romans colonized the Po Valley and profoundly modified the natural landscape dividing the cultivated land into square fields by a regular grid of roads and ditches [38,51,52].

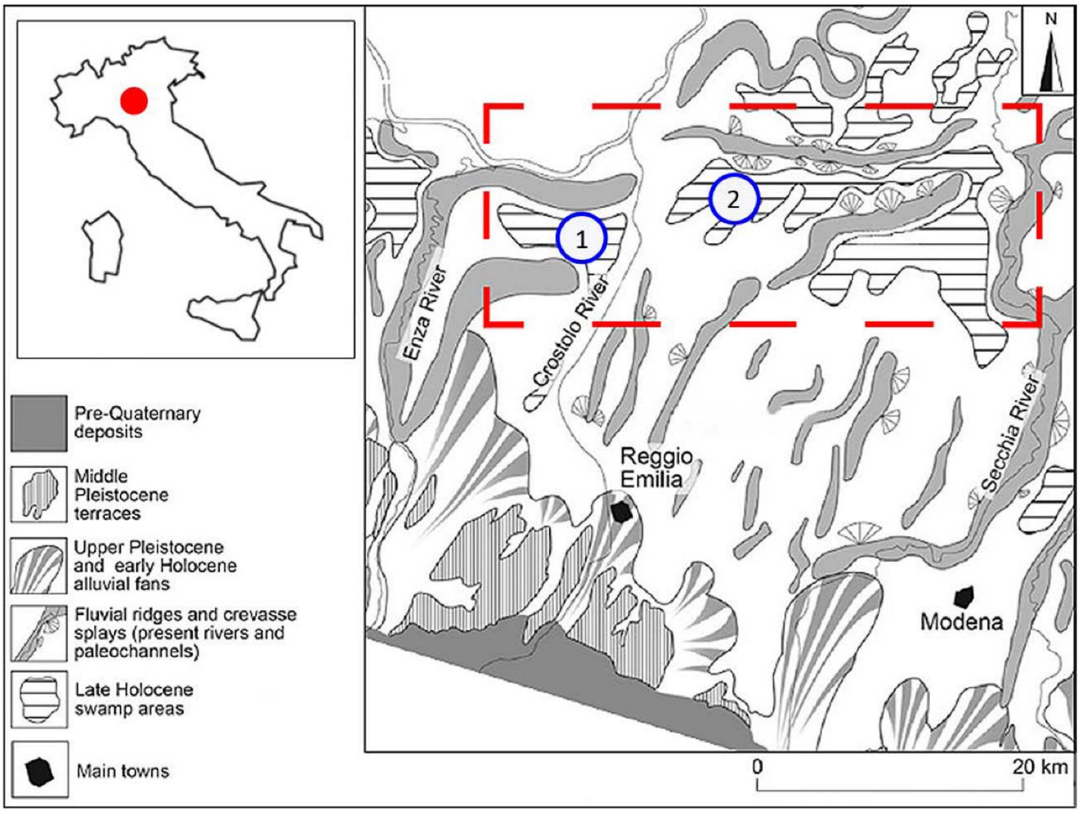

Figure 3. Schematic geomorphic map of the Po plain in the Emilia region (adapted from [47,48,49]). The red dashed line highlights the study area: 1—Valle di Gualtieri; 2—Valle di Novellara.

After the collapse of the Roman Empire (5th century AD), lack of maintenance of the irrigation systems [24] associated with a cooling climate phase (i.e., the so-called Migration Period or the Dark Age Cold Period; [10,11,53] led to the progressive waterlogging of the Po Valley and the natural depressions on the right side of the Po River turned in two vast swamp basins known as Valle di Gualtieri and Valle di Novellara (Figure 3). In particular, the Roman water management augmented the Holocene sedimentary process of Apennine watercourse with consequent aggradation of the river beds. Therefore, in the post-Roman period, channel diversions affected the southern tributaries of the Po River, especially the Crostolo Creek that flowed in the floodplain depressions: vast areas became marshy and Roman sites, and centuriation tracks were often buried under fluvial and palustrine deposits [42,45]. The waterlogging process of the area continued until the 10th century AD influencing human sustenance and settling practices [25,54]. According to historical–archaeological data the wetlands were exploited for fishing as well as for water transport by boat [55,56] while the early medieval sites were settled on the fluvial ridges, in topographically higher and strategic positions relative to the surrounding swampy meadows [24,30,31,57]. In the study area, channelization and reclamation works started in the 10th century AD [58,59,60,61,62] and increased between the 12th and the 13th centuries [25,26,63], promoted both by monasteries [28,64] and by private landowners [65].

Large-scale ground reclamation began during the Renaissance and is known in the literature as Bonifica Bentivoglio, after the name of its promoter, Cornelio Bentivoglio, Lord of Guastalla. The Bonifica Bentivoglio drainage system reclaimed a significant portion of the swampy meadows and was renovated and updated many times in the Modern Age; between 17th and 19th centuries, many homesteads were settled in the reclaimed farmland. The land reclamation of this portion of the Central Po Plain continued for centuries after the Renaissance and was completed only in the 20th century AD [33,34,66], resulting in an entirely artificial landscape.

Materials and Methods

This study has been performed using a multi-proxy record to analyze the Late Holocene transformations of the Central Po Plain: geomorphological tools were combined with archaeological data and historical documents. The geomorphological literature on the Central Po Valley [45,47,48,67,68] constituted a useful starting point in association with a 1-m DEM (produced from high-resolution LiDAR) provided by the national geodatabase [69]. The elevation checkpoints (m.a.s.l.) provided by the regional geodatabase [70] have been elaborated with the software QGIS (2.18) to draw contour lines with an equidistance of 0.5 m and to create the final Digital Terrain Model (DTM) of the research area (Figure 4). Moreover, to enable the interpretation of the geomorphological features detected by the DTM, a 3D model has been created by the software QGIS plugin Qgis2threejs exaggerating the DTM Z-value ×50.

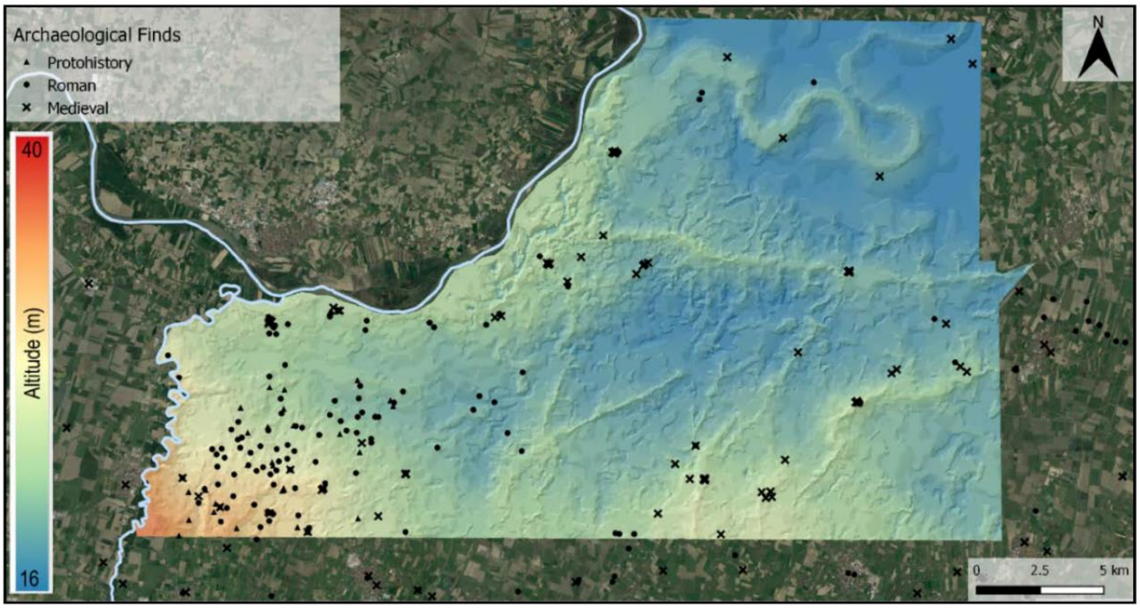

Figure 4. Digital Terrain Model elaborated with software QGIS implemented with archaeological records. In the north of the mapped area, the meandering geomorphological feature corresponds to the so-called Po Morto or Dead Po, active in Roman Times.

The regional soil map has been applied to the 3D model to detect the maximum extension of the medieval swamps before the Renaissance land reclamation works, and our interpretation is based on the different types of sediments and their concentrations.

The landforms detected have been dated and contextualized according to archaeological and historical records. The archaeological evidence (sites and materials) has been compiled from various records [48,51,62,71,72], a regional web database [73] and terrain surveys. The 18th and 19th century transcriptions of medieval accounts and parchments [58,59,60,74] served as an advantageous starting point in the analysis of the historical documents along with the 20th-century editions of medieval documents kept at the Parma and Reggio Emilia National Historical Archives [75,76,77]. Additional information has been collected at the Novellara Historical Archives, including from the archive fund "Cavamenti Acque (1495–1931)" [78]. All of the archaeological (sites and materials) and historical (place names) data have been organized according to epochs in different layers using QGIS software.

Results and Discussion

The multidisciplinary approach allowed us to shed new light on anthropogenic activities related to land and water management in the post-Roman landscape. In medieval times, humans exploited the palustrine environment (Palustrine environment refers to any (no-tidal) inland wetland. Wetlands within this category include inland marshes, swamps and floodplains.) as a resource, until the demand for more arable land led to land reclamation. The impact of medieval human activities on the

landscape resulted in altering the natural shape of the area through the development of anthropogenic geomorphological features.
The results will be discussed in three categories related to the backswamps limits, the Tagliata Canal and the Crostolo River, respectively.

Backswamps Limits

As mentioned above, the collapse of the Roman Empire was associated with a period of climatic instability [79] that led to the progressive waterlogging of the Po Valley; frequent flood events have been reported in historical chronicles between 6th and 7th centuries AD [80]. In the study area, the floodplain on the right side of the Po River turned in two vast backswamps; the Valle di Gualtieri and the Valle di Novellara (hereafter, the two Valli). The backswamps are the lower area of floodplains, poorly drained, and where only finer material accumulates during a flooding event [81].

This palustrine environment served as a resource for silvopastoral practice, especially in the Early Medieval period. Historical documents [75,76,82] report that local communities exploited the Valli swamps for fishing and transport by boat; in sale-purchase agreements "piscationes, paludes et lacus" (i.e., fisheries, marshes, ponds) were traded, as well as any other goods such as fields or vineyards. Despite this central role in the economy of the period, in historical documents, there is no precise information about the swamps' geographical limits, perhaps because their physical boundaries constantly fluctuated during the Middle Ages climatic variations.
To determine accurate limits for the two Valli, a 3D model of the area (Figure 5) has been extrapolated exaggerating the DTM elevation attribute ×50. Superimposing the regional soil map (Geoportale Emilia Romagna) on the 3D model shows a relationship between the concentration of clayey and silt-clayey soils and the lowest areas detected in the DTM (Figure 6). These data are entirely compatible with the geomorphological definition of back swamps as low flat standing areas where fine sediments settle after a flood event. According to the model rendered, the maximum extension of the Valle di Gualtieri and Valle di Novellara covered an area of ≈250 Km2 (Figure 7).

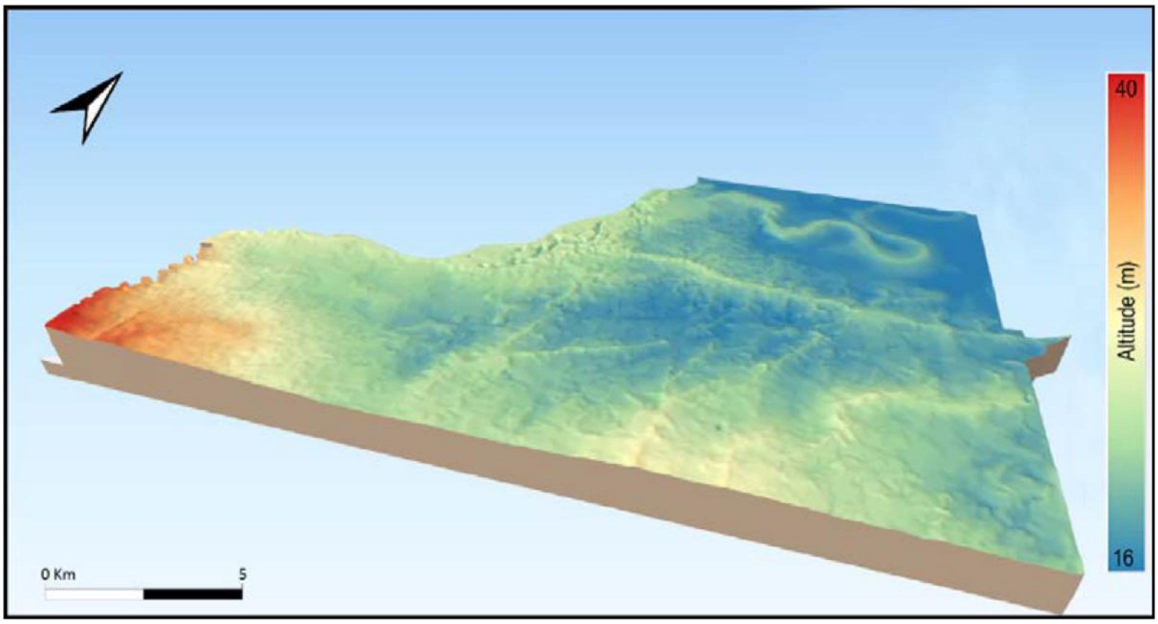

Figure 5. The 3D model: altitude checkpoints attribute ×50.

The medieval archaeological records [30,31,51,52] seems to further confirm the swamps limits as determined by the 3D model; all of the archaeological finds and the historical toponyms [59,75] are distributed surrounding the two Valli. The wetlands had an economic potential, but one that was far below the full agricultural potential of the same land after the reclamation that occurred starting the 10th century AD. Further palaeoecological and geoarchaeological analyses will be useful to provide more information about the character of the wetland environment in the study area.

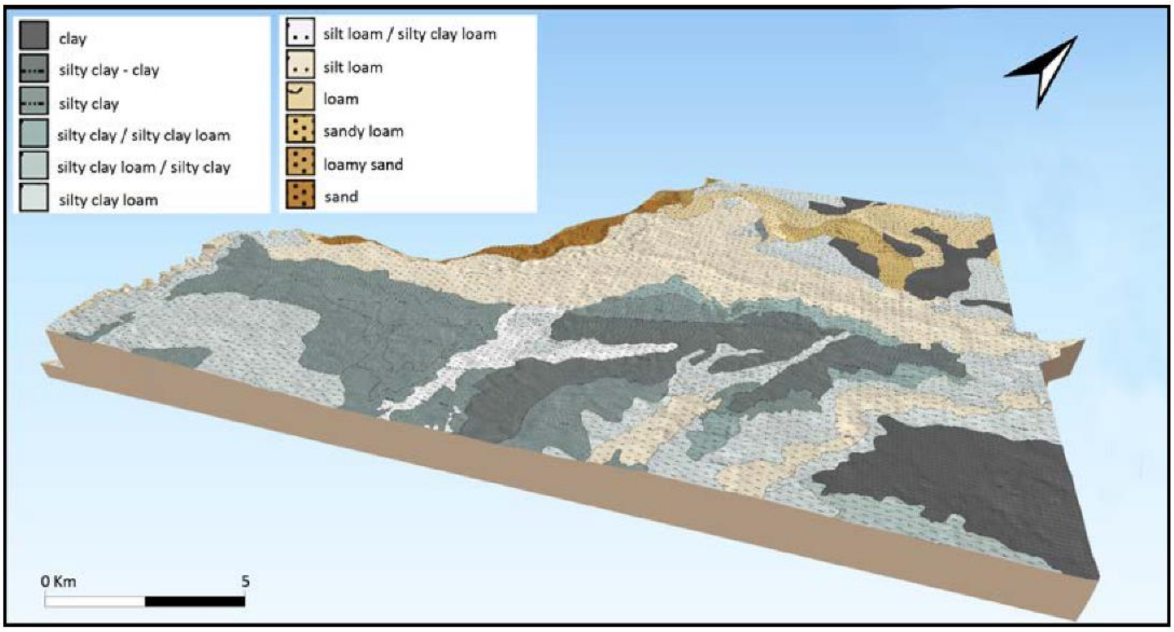

Figure 6. Application of the soil map [70] to the 3D model. Grey and Dark-Grey areas correspond to fine sediments settled after flood events.

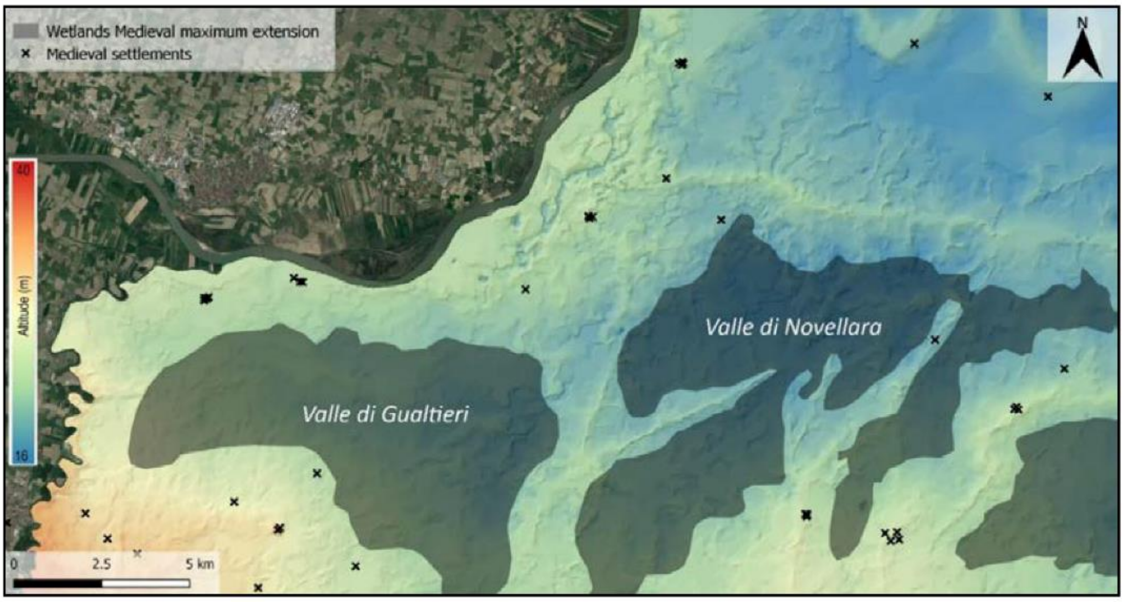

Figure 7. Maximum extension of wetlands before the Renaissance large-scale land reclamation project.

Tagliata Canal

The most valuable data about anthropogenic activities in the medieval environment concern the northern limit of the Valle di Novellara. According to the DTM, this backswamp is delimited in the north by the ridge of the so-called Tagliata Canal. In scientific literature [41,43,47,67,68] the Tagliata Canal is considered a Proto-historic Po ridge characterized by crevasse splays on both sides (Figure 8); however, geomorphological, archaeological, and historical data suggest a new interpretation. First, the distribution of archaeological evidence in the study area shows an absence of Bronze Age and Roman Era findings (both sites and materials) (Figure 9). It is likely that the subsequent reworking of the fluvial landscape has obscured pre-medieval archaeological evidence. The 13th-century chronicler Fra Salimbene de Adam reported that, between the two towns of Guastalla and Reggiolo, there used to be a waterlogged area that was drained only after the excavation of the Tagliata Canal (Table 1, I). Thus, the accretion of Tagliata Canal ridge occurred after the collapse of the Roman Empire, not before.

Figure 8. The Tagliata Canal in the geomorphological map of the Po Plain edited in 1997 [47]. The Tagliata Canal is considered a Proto-historic Po ridge characterized by crevasse splays on both sides.

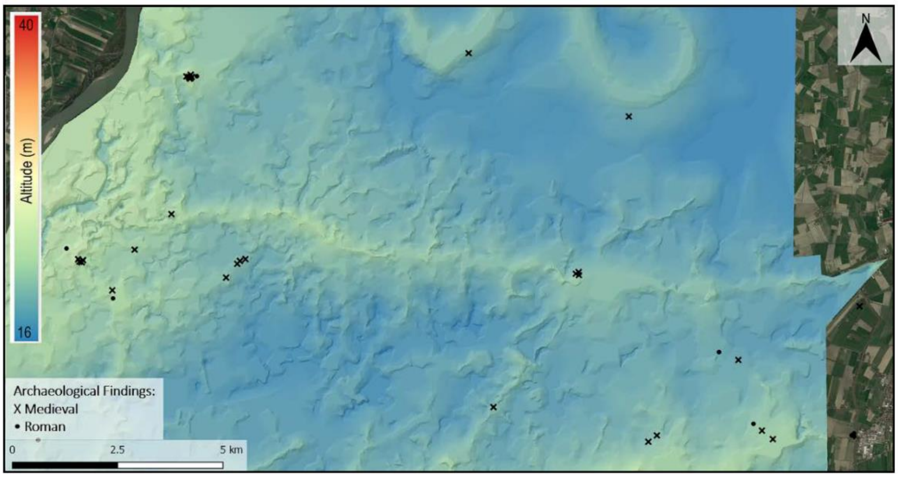

Figure 9. The distribution of archaeological sites and materials in the study area shows an absence of Bronze Age and Roman Era findings suggesting that the Tagliata Canal ridge developed in medieval times.

Moreover, historical documents [59,60,74] report that the Tagliata Canal was artificially excavated in 1218 for commercial purposes. The new canal enabled a bypass of the Po River from Guastalla to Reggiolo for the city of Cremona in order to avoid paying commercial fees to the city of Mantova, which controlled the local waterways. The medieval chroniclers, also, report that the construction of Tagliata Canal had negative implications for the environment with frequent floods in the surrounding farmland. In 1269, for example, the chronicler Fra Salimbene reported a severe flood event (Table 1, II) and many other floods occurred between the 13th and 14th centuries AD [60].

The geomorphological evidence of those medieval floods should be attested via the crevasse splay detected near Fangaia and Villarotta, two villages that were settled on the Tagliata ridge after the canal excavation. Nevertheless, these two villages' place names are reminiscent of flooding vocabulary (i.e., Fangaia from "Fango" → mud, refers to alluvial sediments; or Villarotta from Rotta → breach levee, refers to a crevasse splay event) (Figure 10). The geomorphological analyses provide more nuanced information about the shape of the Tagliata Canal. In the DTM, the morphology of Tagliata Canal ridge seems to be more complicated than what is represented in the geomorphological map of The Po Plain [47]. The crevasse splays show unusual elongated small ridges not compatible with natural fluvial crevasse splays. Information in the historical documents provide a possible explanation for their genesis: the chronicler Affo' [58] reports that since the 13th century AD, people of Guastalla were allowed to breach the artificial levees of rivers and canals in a situation of high, muddy discharge (Table 1, III). This practice had the effect of infilling the swamps with sediments, thus creating new farmland, and the elongated shape of the unusual landforms could be the results of those practices.

Table 1. Historical quotes about the environmental transformation of the research area in medieval times.

N.	Object	Chronicler	Medieval Italian	English Translation
I	Tagliata Canal	Fra Salimbene de Adam (13th century AD) [60] p. 89	*"Tra Guastalla e Reggiolo era una stesa di terreno paludoso le cui acque incanalate nel detto cavo e asciugato il territorio, si conquistarono alla coltivazione ubertosissime campagne […]"*	"Between Guastalla and Reggiolo there used to be a waterlogged area whose waters were channelled in the canal (Tagliata): the land was drained and turned into very fertile farmland".
II	Tagliata Canal	Fra Salimbene de Adam (13th century AD) [60] p. 93	*"Questa Tagliata impaludò larga zona di terreni, distrusse e sommerse molte ville, e dove prima di aveva abbondanza di frumento e di vino, ora si ha copia di pesci di diverse specie"*	"The Tagliata canal flooded a wide area, razed many houses, and in place of wheat fields and vineyards now there is an abundance of fishes of different species".
III	Tagliata Canal	Ireneo Affò (18th century AD) [58] Vol. 8, p. 233	*"[…] La comunità da tempo memorabile aveva diritto di rompere gli argini quando menavano acque torbide perché spandere si potessero nelle valli. E molti uomini testificarono il mirabile effetto che ne era seguito, accennando de campi allora coltivabili nel luogo dei quali a loro memoria solevano i pescatori andare con le barche […]"*	"Since time immemorial, the community (of Guastalla) was allowed to breach the levees when the watercourses carried turbid water to spread them in the wetlands. Many people testified to the admirable effect that followed, and they said that now cultivable fields replaced places in which fishermen were used to going by boat"
IV	Crostolo River	Ireneo Affò (18th century AD) [58] Vol. 8, p. 240	*"[…] fu loro conseguenza permesso di fare un Cavo in Camporainero dal Crostolo […] lungo la* Via di Roncaglio *per cui tirar nelle valli più agevolmente tali acque"*	"(the city council of Guastalla) allowed to excavated a canal from the Crostolo river to the Camporaneiro area, along the Roncaglio Road, in order to divert the (turbid) waters in the wetlands more easily".

Although such flood management practices have never been reported in geomorphological and geoarchaeological studies on Central Po Plain so far, these few cases noted in the literature could support our interpretation. Recently, medieval archaeological excavations in the Ligurian Apennine reported that watercourse sediments and colluvial deposits had been exploited to reclaim palustrine environments [83,84]. In the medieval sites of Mogge di Ertola (Genova—Italy) and Torrio (Piacenza—Italy), marshes were turned into terraces by applying a technique called "colmata di monte": the sediments carried by mountain watercourse were managed to fill palustrine areas and create new arable land and pasture [85]. The process of breaching levees described in Affo' [58], is very similar to the "colmata di monte" reported in the Apennine archaeological sites. The elongated shape of the Canal Tagliata crevasse splays are the results of medieval flood management practices intended to reclaim the backswamp of Valle di Novellara; we decided to define these unique anthropogenic geomorphological features as Land-Fill Ridge (or dosso per colmata) (Figure 10).

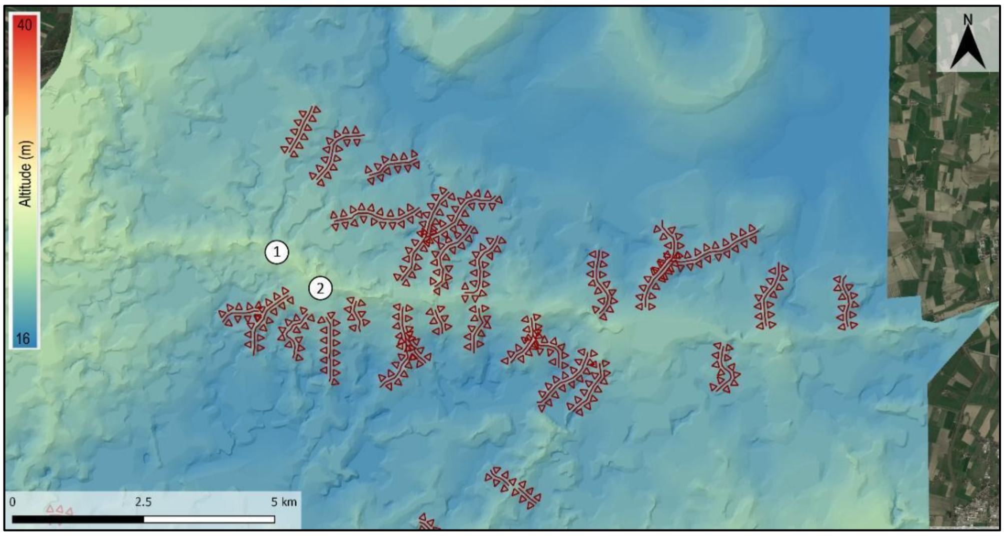

Figure 10. Geomorphological analysis of the Tagliata Canal ridge: crevasse splays and land-fill ridges. 1—Villarotta; 2—Fangaia.

Additionally, the land-fill ridge detected in this study serves as an interesting comparison with the warping practices that occurred in England in the 18th century AD. Research in Humberland Levels [86,87] and the lower Trent Valley [88] wetlands has highlighted the considerable degree to which a combination of natural alluviation and anthropogenic warping deposits have concealed palaeoland surfaces and the archaeological record of the two regions. The warping practices have been carried out since the 18th century AD and consist of the artificial diversion of fluvial sediments in a wetlands area. Warping was conducted mainly to fertilize large areas: where the peats were too acidic, warp deposits served to mask unproductive wetlands with a light, well-drained silty or silty-clay soil. Anthropogenic warping practices also aimed to reduce the impact of the spring tides which had left large areas of the region waterlogged for most of the year. The land to be warped was first enclosed by embankments, then a regular network of small canals (often still visible in aerial images as crop marks) ensured the rapid and even distribution of flood water throughout the compartment, creating a uniform deposit [86,88]. Even though the process that generates land-fill ridges and warps is quite similar (i.e., the artificial exploitation of substantial silt and clay load carried in suspension by canals and rivers), in the research area, there is no historical or geoarchaeological evidence of both embankments and fertilizing practices in alluvial wetlands.

Crostolo River

In the post-Roman era, the Crostolo River diversion channel caused the waterlogging of a large area of the Roman countryside; the river flowed into the Valli backswamps turning the farmland into a palustrine environment (Figure 11). In medieval times, human enterprise on the Crostolo River was concentrated in the portion of the watercourse that crossed the city of Reggio Emilia. Here, to prevent flooding hazards, the river was artificially diverted outside the city walls [49].

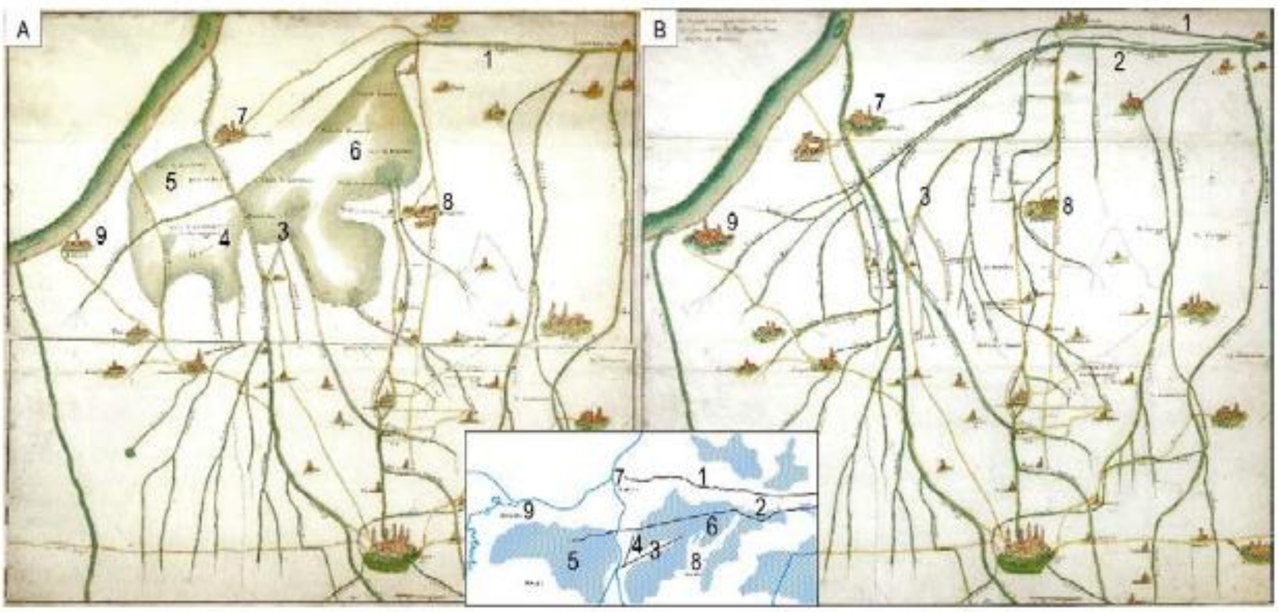

Figure 11. Medieval historical maps (18th-century copies) that show the environmental situation of the study area before (A), (for more details, see also Figure 12) and after (B), (for more details, see also Figure 13) the Renaissance wetland reclamation. The numbers in the schematic box in the center of the image helps to orientate: 1—Tagliata Canal; 2—Parmigiana Canal; 3—Crustulus Vetus; 4—Camporainero area; 5—Valle di Gualtieri backswamp; 6—Valle di Novellara backswamp; 7—Town of Guastalla; 8—Town of Novellara; 9—Town of Gualtieri. (AsMo 52 and 53, XVIIIsec. Modena National Historical Archive—“Congragazione delle Acque e delle Strade, Reggio e Reggiano”) [89].

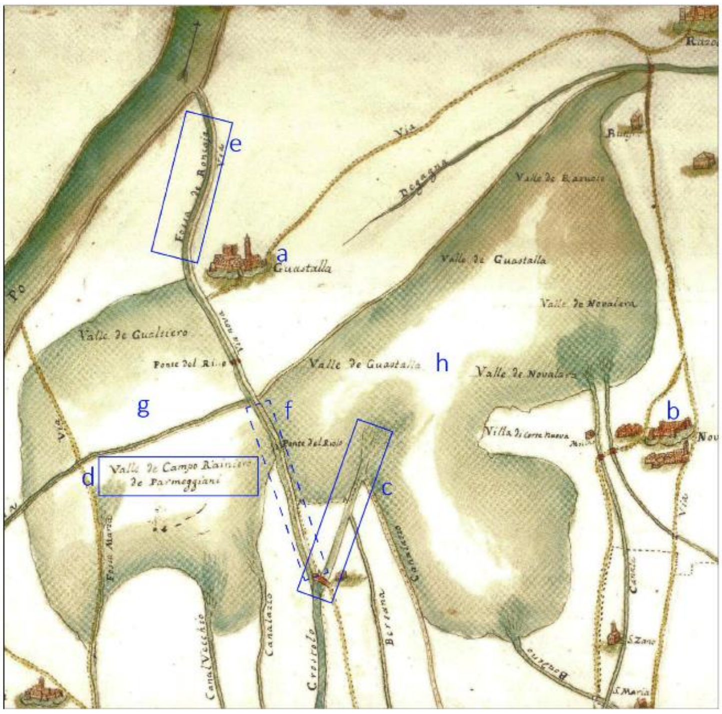

Figure 12. Detail of the medieval historical map that shows the landscape before the Renaissance land reclamation project (Figure 11A). (AsMo 52, XVIIIsec. Modena National Historical Archive—"Congragazione delle Acque e delle Strade, Reggio e Reggiano) [89]. This map shows the project of artificially diversion on the Crostolo River from the Valle di Novellara to the Po Plain through the Early Medieval Fossa di Roncaglio Canal. a—Town of Guastalla; b—Town of Novellara; c—the so-called Crustulus Vetus, still active at that time; d—the wetland area called Camporainero; e—Fossa di Roncaglio Canal; f—the area of the NNE Crostolo ridge, developed to fill the Camporainero area with Crostolo sediments; g—Valle di Gualtieri wetland; h—Valle di Novellara wetland.

Figure 13. Detail of the medieval historical map which shows the landscape before the Renaissance land reclamation project (Figure 11B). (AsMo 53, XVIIIsec. Modena National Historical Archive—"Congragazione delle Acque e delle Strade, Reggio e Reggiano) [89]. This map shows the study area after the Renaissance Bonifica Bentivoglio land reclamation project. a—Town of Guastalla; b—Town of Novellara; c—Crostolo Vecchio or Crustulus Vetus, the medieval Crostolo watercourse that flowed into the Valle di Novellara wetland; d—The artificial diversion of the Crostolo River in the Po River; there are no more indications of both Camporainero and Roncaglio; e—Drained area in place of the Valle di Gualtieri wetland; f—Drained area in place of Valle di Novellara wetland; g—Botte Bentivoglio hydraulic device.

In the study area, the DTM highlights two linear Crostolo ridges, probably the result of anthropogenic activities (Figure 14).

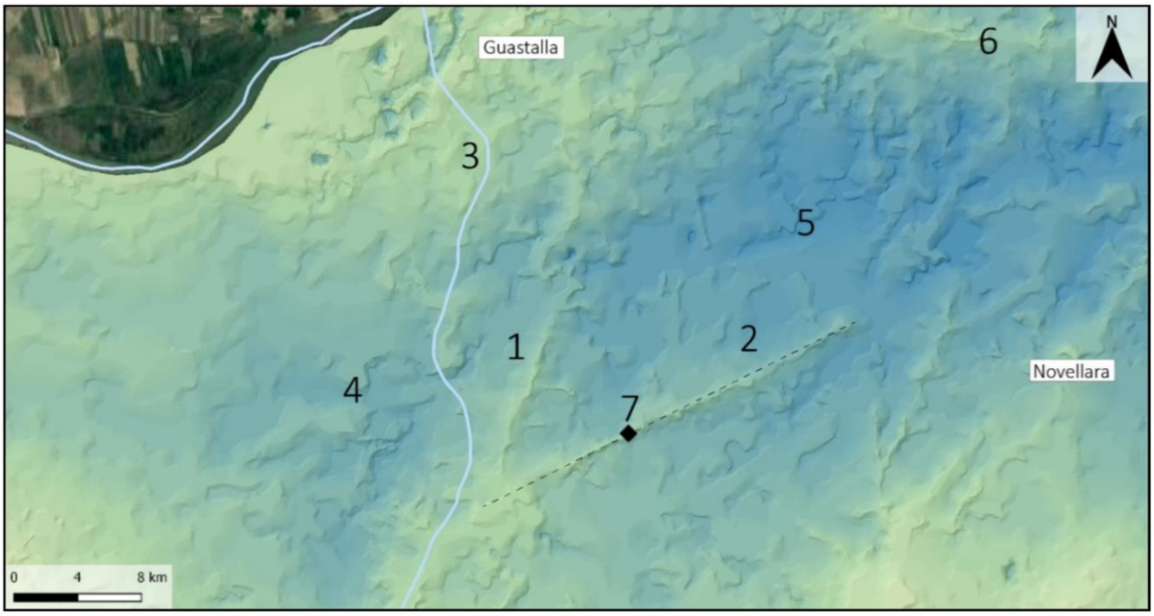

Figure 14. Digital Terrain Model (DTM) of the Crostolo River medieval ridges. 1—NEE Crostolo ridge; 2—NE Crostolo ridge, called Crustulus Vetus; 3—Modern Crostolo River course; 4—Valle di Gualtieri wetland area; 5—Valle di Novellara wetland area; 6—Tagliata Canal ridge; 7—The dashed line indicates the modern Age Fossa Alessandrina Canal, the black square represents the S. Bernardino Church.

According to Affo' [58], when the practice of breaching river and canal levees was forbidden, the city council of Guastalla allowed the excavation of a channel to divert fluvial sediments from the Crostolo River to the backswamps. The geomorphological linear ridges detected in the DTM are likely to be the result of this large-scale flood management activities. The project of the Guastalla city council likely intended to not spread the fluvial sediments in different areas (land-fill ridges) but to concentrate the muddy river discharge in the wetland to create more arable land. The medieval parchments reported by Affo' [58] gives more details about this channel, stating that it was excavated in an area called "Camporainero" along the "Via di Roncaglio"; both the place names are still used and correspond to the area of the Crostolo straight ridge-oriented NNE (Figure 14). Furthermore, a couple of historical maps (17th century AD copies of Late Medieval originals) help in understanding the geomorphological evolution of the area.

As shown in the historical map (Figure 11A and Figure 12), Camporainero is a portion of the Valle di Gualtieri wetland, and the Crostolo River was artificially diverted into the Po River using the Early Medieval canal called Fossa di Roncaglio. The orientation of the NNE ridge match with the historical description provided by the chronicles. In this map the NNE ridge is not indicated, although it is detected in the DTM: probably the original project consisted of the diversion of the Crostolo River using the Camporainero Canal as well as the Fossa di Roncaglio Canal. The Renaissance project was probably adapted and modified because Camporainero Canal ridge is still recognizable, while the Fossa di Roncaglio has been replaced by the Crostolo River. On the other hand, the linear ridge-oriented NE (Figure 14) has always been identified in the available literature [48,62] as the Crostolo paleochannel active in Roman times and called Crustulus Vetus (or Crostolo Vecchio → Old Crostolo). In this study, both geomorphological and historical–archaeological proxies support a new interpretation. First, the ridge leads directly to the Valle Novellara backswamp and it ends in the Roman farmland: here some road and ditches of the centuriation grid are still visible in aerial images [65]. It is not possible that the river watercourse passed here in Roman times. Moreover, along this linear ridge, Roman archaeological finds have never been reported.

Moreover, historical maps dated to the 17th and 18th centuries AD [78] indicate that, along this ridge, a canal called Fossa Alessandrina and was excavated and a church was constructed (the still standing Chiesa di San Bernardino). In Roman times the Crostolo River is likely to have been flanked by artificial levees, and to have flowed into the Po River, north of the medieval Tagliata Canal (Po Morto, see Figure 4). The results of this study support the idea that the Crostolo River in the post-Roman era flowed directly in the Valle di Novellara backswamp developing the fluvial ridge oriented to NE in the DTM. Later, in the 16th century, as recorded in medieval documents, the river was artificially diverted into an area called Camporainero to reclaim wetlands and create new cultivable land for the community of Guastalla. The result is the NNE oriented fluvial ridge detected in the DTM (Figure 14).

The developing of the Camporainero Canal ridge shows similarities to the human management of the crevasses spays reported in the lowlands of the Adige River (Northern Italy) [90]. The first attempts to manage crevasses splays in this area are dated to 12th century AD, and they were finalized at lowering flood hazard and allowing discharge for water mills and navigation through the control of the water intake from the Adige River into the Castagnaro and Malopera Rivers [90].

The Crostolo river was artificially diverted in the Po River only after 1576 during the large-scale land reclamation works called Bonifica Bentivoglio: this project included the excavation of a canal-oriented EW (Parmigiana Canal) to drain the two Valli backswamps and the construction of a hydraulic device that allowed this canal to pass under the Crostolo River. The Bonifica Bentivoglio drastically changed the natural medieval landscape by turning the swamps into farmland and constraining the rivers by artificial embankments (Figure 11 and Figure 15).

Figure 15. The crossing between the Crostolo River (1) with the Parmigiana Canal (2) in the modern completely drained countryside. The white square highlights the 17th century AD structure of the Botte Bentivoglio hydraulic device (3).

Conclusions

This study sheds new light on the evolution of the Central Po Plain landscape in the Late Holocene. The dynamic climatic conditions that occurred after the collapse of the Western Roman Empire led to a significant change in the well-organized Roman countryside, turning large floodplain areas in swamps. In the Early Medieval Age (6th–9th centuries AD) the natural landscape development seems to not have been impacted any significant human-induced changes. On the contrary, the local communities adapted themselves to the post-Roman palustrine environment settling in positions of higher elevation around the swamps limits and using them for navigation as well as for silvopastoral sustenance practices. In contrast, contemporaneous with the Medieval Climate Anomaly (10th–13th century AD), anthropogenic activities altered the landscape to fulfil the new socio-economical needs.

In the research area, the most evident anthropogenic geomorphological features developed in medieval times is the Tagliata Canal ridge. This canal represents a relevant landscape-modifying agent both for natural (flood events) and anthropogenic (land-fill ridges) causes. The exploitation of fluvial sediment to reclaim wetland areas affected the Crostolo River watercourse, as well. The result of human flood management practices was the development of new cultivable land in place of alluvial wetlands. This human-induced landscape transformation is likely not to have happened abruptly, leaving time for the natural environment to adapt to the new anthropogenic landforms. Richard Hoffmann [15] states that "the ecological concept of sustainability is a dynamic equilibrium between human activities in nature and the ability of the natural system to respond to those activities." According to this definition, medieval flood management represented a more sustainable land reclamation technique than the Renaissance large-scale projects that deeply modified the landscape with channelization and artificial levees, turning the palustrine environment into the modern countryside.

Nevertheless, the medieval flood management activities reported in this study constitute an example of the modern "Room-for-River" strategy [36,37]. Indeed, the primary purpose of the medieval practices was to create new arable land, but at the same time, the artificial diversion of fluvial sediments enables the control of floodwaters avoiding the risk of inundation, for example, in urbanized areas or productive farmland. Similar practices have been reported in Northeast Italy [90] were the medieval human management of crevasses splays aimed to control the Adige River discharge to reduce the flood hazard. Understanding the past anthropogenic effect on the landscape is essential for its future sustainable management [91], especially in the Central Po Plain, where the debate around future sustainable solutions to reduce flood hazards is ongoing [3] and the continued raising of embankments is not environmentally sustainable [2].

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5 Geospatial analysis to evaluate the influence of environmental factors on Late Holocene land-use and settlement dynamics

5.1 *Terra, silva et paludes.* Assessing the role of alluvial geomorphology for Late- Holocene settlement strategies (Po Plain - N Italy) through Point Pattern Analysis

[Brandolini F. et al. - T*erra, silva et paludes. Assessing the role of alluvial geomorphology for Late-Holocene settlement strategies through Point Pattern Analysis (Po Plain - N Italy).* Journal of Environmental Archaeology, *submitted*]

Abstract

Fluvial environments represents complex human-water systems, since floodplains have always been the among most suitable environment for human sustenance.This paper investigates, using Point Pattern Analysis, the influence of alluvial geomorphology on settlement strategies of the Po plain during the transition between the Roman and the Early Medieval Period. Alluvial geomorphology influenced settlement strategies and the definition of geomorphological spatial covariates permitted to evaluate the influence of environmental characteristics on spatial distribution of sites. The transition from Roman into Early Medieval Period represented a crucial moment for the reorganisation of human settlement strategies in Po Valley. The collapse of the Roman hydrogeological systems in association with a cooling climate phase triggered a waterlogging process in large portion of farmland: woods, swamps and uncultivated areas became the typical features of the Medieval landscape. This paper aims in assessing if the different water management strategies in the Roman and Medieval periods influenced the spatial distribution of sites, and to evaluate the relative importance of agricultural suitability over flood risks in the two historical phases. This research contributed to quantifying how the socio-political factors of past societies played a key role in human resilience to hazards related to alluvial geomorphology and climate changes.

Keywords: point pattern analysis; settlement strategies; Po Plain; alluvial geomorphology; human resilience; Roman period; Middle Ages

Introduction

Fluvial environments have always played a crucial role in human history, as the need for fertile land and freshwater has led populations to settle in floodplains more frequently than in other environments. Many studies substantiate the interpretation of floodplains as complex human–water systems (Merz et al., 2010): water and land management activities have altered fluvial landscape development to create cultivable land, while simultaneously protecting communities from the risk of flooding events, which are still the most common natural disasters worldwide (Dankers and Feyen, 2009). It is widely acknowledged that the geomorphological characteristics of fluvial environments have influenced settlement strategies in different prehistoric and historical periods, up to the present (Munoz et al., 2015). However, quantitative and question-driven analyses of this correlation are still rare.

The Po Valley represents the largest floodplain in Italy (Castiglioni et al., 1997; ISPRA, 2019) and operates as a key area for the interpretation of environmental and cultural influences between the Mediterranean regions and the continental Europe (Campopiano and Menant, 2015). Its complex settlement and land-management history makes it an ideal study-area to investigate the adaptive dynamics of human communities in temperate alluvial zones. Since prehistoric periods (Cremaschi, Mercuri, et al., 2018; Starnini et al., 2018) human communities settled in the Po Valley for its suitability to agriculture, altering the natural fluvial landscape and managing risk of inundation. In the Roman period, flood hazard was managed and mitigated by the construction of embankments and drainages (Marchetti, 2002). The transition from Roman into Early Medieval Period represented a crucial moment for the reorganisation of human settlement strategies in Po Valley. Many authors point out that this transition led to a reduction of cultivable and settled area due to the collapse of the Po Valley Roman hydrogeological systems (Curtis and Campopiano, 2014). The Roman water management system was abandoned (Brandolini and Cremaschi, 2018b) woods, swamps and uncultivated areas became the typical features of the Early Medieval (6th - 10th centuries CE) landscape. In this scenario, agriculture was largely replaced by silvo-pastoral sustenance practices while many Roman settlements were abandoned or dismantled to reuse building materials in new Early Medieval villages (Gelichi et al., 2005).

The aim of this paper is to assess if the different water management strategies in the Roman and Medieval periods influenced the spatial distribution of sites, and to evaluate the relative importance of agricultural suitability over flood risks in the two historical phases. Point Pattern Analysis, increasingly used in archaeological research at different analytical scales (Eve and Crema, 2014; Negre et al., 2018; Orton, 2004; Visentin and Carrer, 2017), will be employed to provide a solid statistical assessment of these landscape dynamics. Variability in Roman and Medieval settlement patterns is analysed against two related proxies for alluvial geomorphology and agricultural suitability: flood hazard and soil texture. Continuity between Roman and Medieval sites, which might have influenced the average relationship of the latter with the two environmental variables, has also been quantitatively assessed.

Geomorphological and Historical Background

Physical geography

The Po Valley is the largest alluvial plain of the Italian Peninsula. Despite its location in the Mediterranean Basin geographical area, the Po Valley has a range from humid continental to humid subtropical climate (Peel et al., 2007). The conformation of the plain, surrounded by the Alps and the Apennines, and the influence of the Adriatic Sea, cause high levels of relative humidity and rainfalls throughout the year (EEA, 2019); the seasonal pattern precipitation strongly influences the annual regime of the Po River (Zanchettin et al., 2008).

The research area is located in the Central Po Valley (Emilia-Romagna region), between the Po River on the N and the Tuscan – Emilian Apennine margin on the S. The Enza River and the Secchia River represent the western and the eastern limits of the study area respectively, while we consider the distal part of the Holocene alluvial fans as the southern limit (Fig.1). The most of this portion of the Po Valley area was formed by the Holocene aggradation of the Apennine tributaries of the Po River (Marchetti, 2002), but a rapid analysis of the main Quaternary phases of landscape evolution is required to understand these processes.

The Apennine fringe in this part of the Central Po Plain is still tectonically active, since it coincides with a complex belt of folded thrust fronts trending north-northeast developed during the Quaternary (Gunderson et al., 2014); as a result the tectonic forces uplifted the mountain margin and lowered the plain in front of it (Scognamiglio et al., 2012). The majority of the Apennine geological units consists of soft sedimentary lithologies (mainly sandstones and claystones) (Marchetti, 2001) easily erodible by water action (Mariani et al., 2019). Since the Middle Pleistocene, the geomorphological consequence of the interplay of these processes has been the formation of an apron of gravelly mega-fans and the deposition of fine alluvial sediments along their margin (Cremaschi, Storchi, et al., 2018).

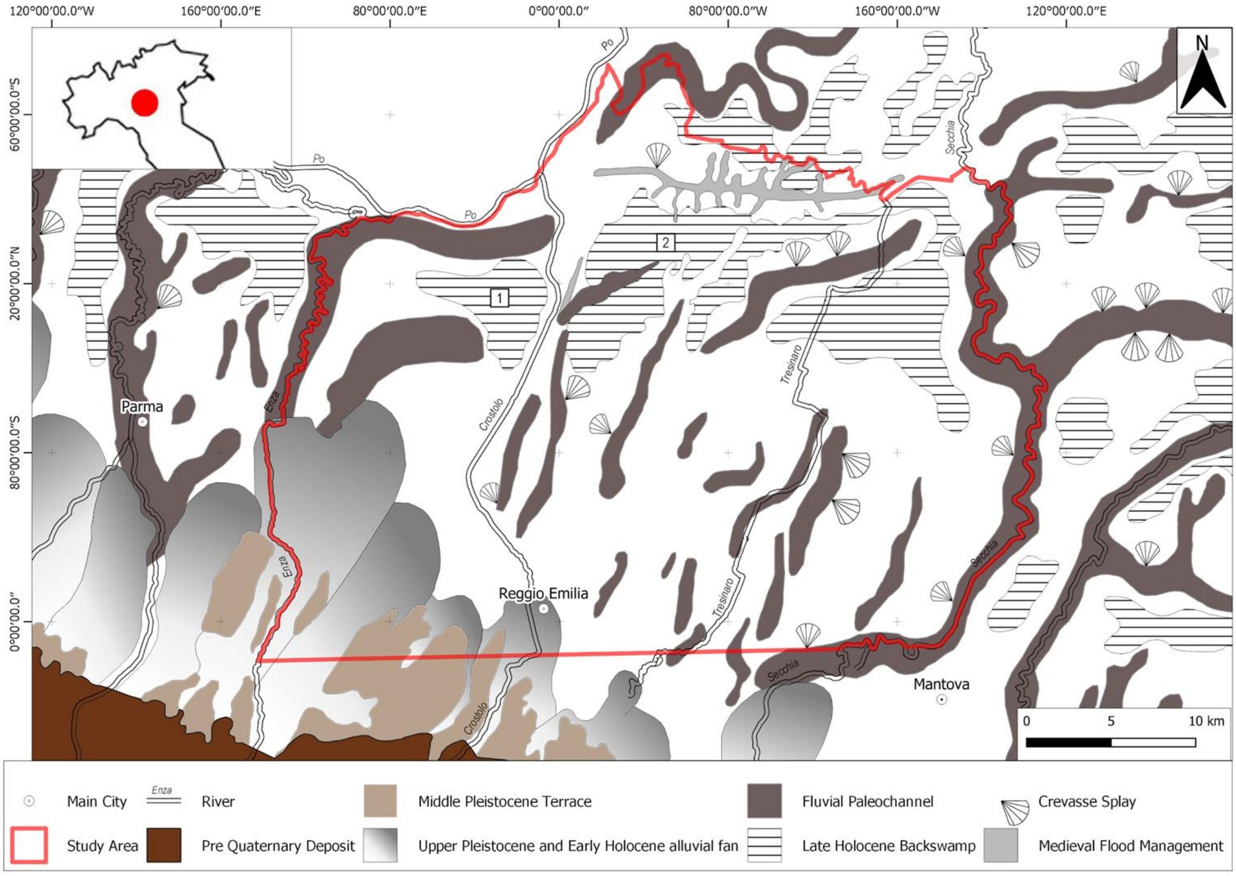

Figure. 1 Schematic geomorphic map of the Po plain in the Emilia region. The red solid line highlights the study area: 1—Valle di Gualtieri; 2—Valle di Novellara.

In the Holocene, the distal parts of the alluvial fans are characterized by a telescopic shape, a result of subsequent aggradation— entrenchment phases due to the alternation of glacial-interglacial periods; each aggradational cycle causes an incision on the top of the previous fan, while a new fan prograded in a more distal position (Cremaschi and Nicosia, 2012). In Late Holocene, the aggradation of the river beds had two main consequence on the landscape: - channel diversions and - frequent inundation of flood-prone areas. In particular, the alluvial ridges of the Enza, Crostolo, Tresinaro and Secchia, emerging from the flat floodplain, flank depression areas known in fluvial geomorphology as backswamps, which are characterized by fine silts and clays deposited after flood events (Charlton, 2007; Szabó et al., 2010). Different sediment textures types indicates which areas were more likely to be flooded in the past and which areas were more suitable for agriculture through centuries; fine and coarse sediments correspond respectively to "heavy" and "light" soils conditioning the agriculture practices in the pre-industrial era.

High flood hazard has always affected Late-Holocene backswamps (Fig.1) due to their lower altitude (compared to the surrounding floodplain) and to their proximity to the Po river and the Apennine watercourses. Nowadays, embankments and drainage systems mitigate but still not entirely resolve the inundation risk in the Po Valley flood-prone areas (Castellarin et al., 2011; Domeneghetti et al., 2015).

Historic landscape evolution

Pre- and protohistoric occupation of the area have been widely documented, especially for the Bronze Age (17th / mid-14th centuries BCE) (Bernabò Brea and Cremaschi, 2004; Cremaschi, Mercuri, et al., 2018) and the Iron Age (8th / 3rd centuries BCE) (Sassatelli, 2003).

Between the 2nd and the 1st century BCE, the Roman colonisation of the Po Valley profoundly modified the landscape and re-organised the cultivated land following the onset of the centuriation (i.e. a regular grid of roads and ditches - Fig. 2) (Bottazzi, 1987; Cremaschi et al., 1980). The grid of decumani (NS roads) and cardi (EW roads) defined regular square areas of m 710 ca per side that correspond to a centuria. Each centuria were divided in rectangular or square subunits (Fig. 2). The Roman land and water management practices in association with a warming climate period - i.e. the so-called Roman Warm Period (Wang et al., 2012) - led to a high agricultural exploitation of the Po Valley. The archaeological data, indeed, testify that numerous Roman farms (i.e. villae rusticae) spread in the countryside among the major municipii (i.e. cities) until the 4th century CE (Bottazzi et al., 1995).

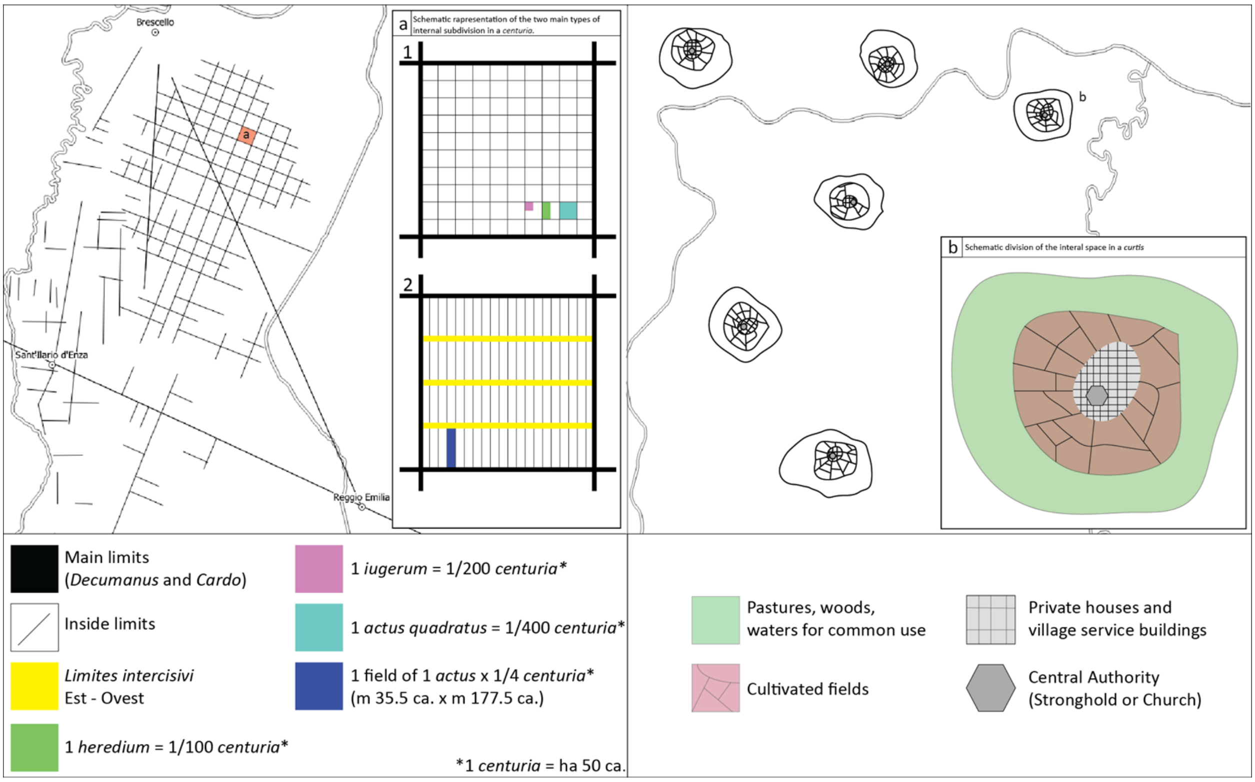

Figure 2. Schematic representations of the Roman (a) and Medieval (b) settlement patterns.

In the 5th century CE, the crisis of the Western Roman Empire and the lack of maintenance of the irrigation systems (Squatriti, 1998), associated with a cooling climate phase - i.e., the so-called Dark Age Cold Period (Buntgen et al., 2011; Christiansen and Ljungqvist, 2012) - led to the progressive waterlogging of the Po Valley, and the natural depressions on their right-hand side of the Po River turned in two vast swamp basins known as “Valle di Gualtieri” and “Valle di Novellara” (Fig. 1) (Brandolini and Cremaschi, 2018b). Indeed, in the post-Roman period, channel avulsions affected the southern tributaries of the Po River, especially the Crostolo River, which flowed in the floodplain depressions turning vast areas into marshland (Cremaschi et al., 2016). The riverbed aggradation became evident immediately in 3rd century CE, and it was probably due to the loss of the land preservation systems in the mountain catchment areas (Cremonini et al., 2013).

The waterlogging process of the area continued until the 10th century CE influencing human sustenance and settling practices (Montanari, 1979). During the Early Middle Ages (6th / 10th century CE) the Roman capillary rural settlement systems (aka centuriation) was largely replaced by “curtes” - i.e. (singular, curtis) complex of farms around a central authority such as a church or a stronghold (Fig.2) - located on the fluvial ridges, in topographically higher and strategic position (Brandolini et al., 2018; Settia, 1984). The Early Medieval curtis pattern consists of a settlement surrounded by a belt of cultivated fields and a second belt of uncultivated area for common use (Sergi, 1993) (Fig. 2). According to historical account (Supplementary Material - Historical Dataset), agriculture was replaced by silvopastoral practice in the post-Roman phase: woods became a source of game and fuel while wetlands were used for fishing as well as navigation (Alfieri, 1990). Between the 9th and the 10th centuries CE several of these early medieval villages were fortified with earth ramparts and wooden fences, following a general fortification process known as incastellamento (Settia, 1999). By the 11th cent. CE, the north Italian political power was scattered in several local authorities with social and cultural consequences (Galetti, 2009; Settia, 1984): the incastellamento process had an indirect impact on the landscape due to the fact that local lords contributed to colonizing new farmland by forcing rural people to live into new settlements under their control. Between the 10th and the 14th century CE, forest clearance and wetland reclamation intensified because of increased demand for cultivated land as a consequence of general population growth in Europe (Hoffmann, 2014). In the study area, channelisation and reclamation works started in the 10th century CE (Canzian and Simonetti, 2012; Cortonesi et al., 2002) and increased between the 12th and the 13th centuries CE (Fumagalli, 1999, 2014). The exploitation of fluvial sediments through flood management practices led to a partial reclamation of the swamps and the creation of new arable land (Fig. 1, Medieval Flood Management) (Brandolini and Cremaschi, 2018a).

Also, new agriculture tools and techniques enabled the cultivation of “heavy” - clayey soils. These types of soil resisted the older Roman wooden scratch-plough (known as ard) created for the sandy soils of the Mediterranean basin, where agriculture is mainly concerned with moisture conservation (Andersen et al., 2016). In the Po Valley, whose environmental and geomorphological characteristics are closer to continental Europe (as pointed out above), the more suitable heavy plough was adopted in Late Medieval times (Cherubini, 1972; Montanari, 1979).

Large-scale ground reclamation started in the Renaissance (14th / 17th centuries CE), continued during the The Little Ice Age cooling phase (15th / 19th century CE) and was completed only in the 20th century CE (Saltini, 2005), resulting in today’s entirely artificial landscape (Brandolini et al., 2019).

Materials and Methods

Datasets

The intensive and complex human-environment interaction in the Po Valley during the Roman and Medieval periods is mirrored by the significant archaeological evidence and historical information available. For the study-area, 371 Roman sites and 168 Medieval sites have been compiled from various sources (Supplementary Materials - Archaeological Dataset), especially regional archaeological maps and online databases. This initial set of data was complemented by the results of additional terrain surveys. The 18th and 19th century CE transcriptions of Medieval accounts and parchments provided a reliable starting point for the analysis of the historical documents, along with the 20th-century editions of medieval documents kept at Parma and Reggio Emilia National Historical Archives. Additional information has been gathered through historical cartography kept at the Modena National Historical Archive (Supplementary Materials - Historical Dataset). Archaeological sites and historical place names, managed as a GIS point layer, have been divided in two macro-categories according to their period: Roman and Medieval. Key assumption is that the archaeological knowledge of the study-area, and the distribution of sites does not depend on research biases, but primarily on past locational strategies.

Elevation checkpoints (m a.s.l.) provided by the regional geodatabase (http://geoportale.regione.emilia-romagna.it) have been interpolated through Inverse Distance Weighting (IDW) in GRASS 7 (using r.idw), to create a Digital Elevation Model (DEM) of 50-m cell size (Fig. 3). This resolution has been selected to minimize the effects of modern small-scale anthropogenic manipulation of morphological features. Since the geomorphological context of the study area (Fig. 1) is assumed to present the same main characteristics throughout the Late Holocene, the DEM has been considered as a reliable proxy for Roman and Medieval landscape structure.

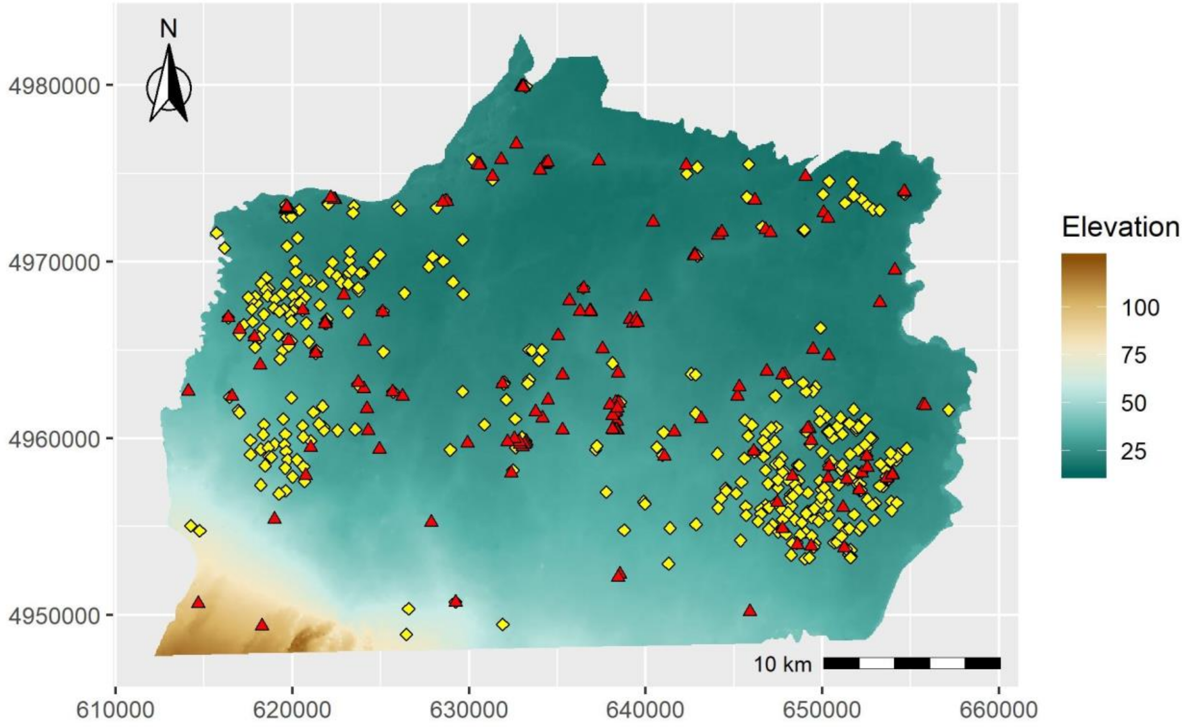

Figure. 3 DEM of the research area and location of archaeological sites. The yellow squares represent Roman sites, the red triangles represent Medieval sites.

Use has been made of regional soil map as well (http://geoportale.regione.emilia-romagna.it) . The sediment deposition in floodplains has a strong correlation with the river flow transport capacity and typically the finer fraction is deposited in a more distal position than the coarser fraction during flood events (Malmon et al., 2004). The finer sediments provide an indication of waterlogged areas before Renaissance land reclamation, since backswamps present a high concentration of clay and silty-clays sediments. On the other hand, the soil map provide a solid proxy for agricultural suitability. Since "heavy" and "light" soils require different types of plough (see above), their distribution may have influenced Roman and Medieval locational preferences within the study-area.

Point Pattern Analysis

The use of Point Pattern Analysis (PPA) to investigate past settlement patterns is increasingly popular in landscape archaeology (Bevan et al., 2013). A point pattern corresponds to the location of spatial events generated by a stochastic process within a bounded region (Diggle, 2003). The density of the point pattern is proportional to the intensity of the underlying process. The intensity, in turn, can be constant within the region (Homogeneous Poisson Process - HPP) or spatially variable (Inhomogeneous Poisson Process - IPP), thus influencing the uniformity of distribution of spatial events. Another property of a point patterns accounts for the spatial interaction (aggregation or segregation) of events, beyond their homogeneous or inhomogeneous density. The effects of point process intensity (first-order properties) and spatial interaction (second-order properties) are extremely difficult to disentangle, but the latter is often recognized at small scale, whereas large-scale variation is usually associated to the non-stationary intensity of the underlying process (i.e. IPP).

These complementary properties of point patterns can be exploited to investigate the locational strategies of Roman and Medieval sites. As discussed before, the research questions of this study address how alluvial geomorphology and agricultural suitability influenced settlement patterns in the Roman and Medieval period, and whether pre-existing Roman occupation attracted Medieval sites. In order to address these research questions, two complementary null hypotheses will be tested through PPA:

H_a: At large-scale, the density of Roman/Medieval sites is uniform (the intensity of the point pattern is stationary and isotropic, HPP).

H_b: At small-scale, the distribution of Medieval and Roman sites are spatially independent (the point patterns are realisations of independent univariate spatial point processes).

Spatial covariates

The easiest way to address H_a is assessing whether a selected inhomogeneous model describes the spatial variability of a point process more accurately than the stationary homogeneous Poisson model. This is often done parametrically, using an equation to estimate point process intensity, or semi-parametrically, by fitting external covariates which are supposed to influence the point process. Since the main aim is to evaluate the influence of environmental parameters on site distribution, a semi-parametric approach has been used, and two spatial covariates have been produced for this purpose: flood hazard (MTI) and soil texture (Soil) (Fig.4).

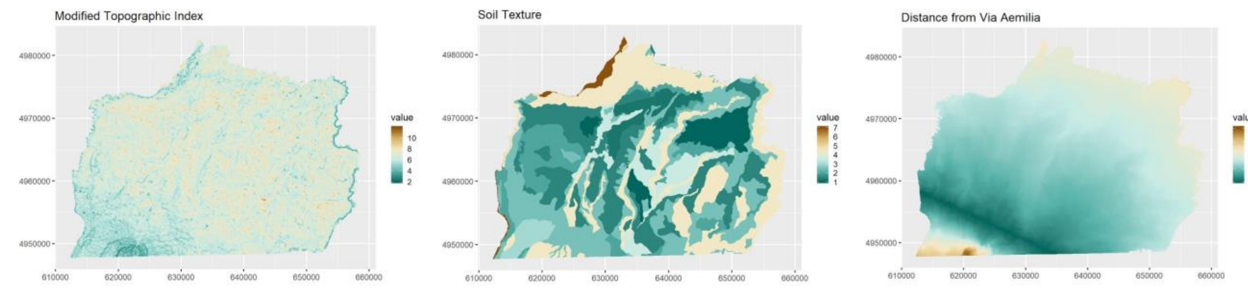

Figure 4. Spatial covariates of the PPA

In order to produce the flood hazard map, the r.hazard.flood tool for GRASS 7 has been used (Di Leo et al., 2011). The function calculates flood-prone areas using a Modified Topographic Index:

$$MTI = log\frac{((A+1)*c)^n}{tan(\beta+0.001)}$$

Where A is a flow accumulation map created using r.watershed tool, c is the cell-size, β is the local gradient map created using r.aspect.slope tool, and $n = 0.016(c^{0.46})$.The threshold value of MTI ($\tau = 10.89n + 2.282$) enables the creation of a binary map of flood (1) and non-flood prone areas (0). However, the estimation of $\tau$is based on tests carried out under controlled and comparable hydrological conditions (Manfreda Salvatore et al., 2011), and does not apply to our case-study, which consider a large time-span subjected to significant changes in precipitation patterns. Besides, the reliable prediction of the flooded area using this tool can be quite poor. Therefore, exclusive reliance on MTI map was preferred.

Sediment map has been rasterized from the vector shapefile provided the regional geodatabase. Soil texture types and characteristics defined by USDA textural classes of soils (Shirazi et al., 1988) have been considered and a numeric value has been assigned to each soil type (United States Department of Agriculture), to rank the soil texture from the finest to the coarsest (Table 1).

Common names of soils (General texture)	**Sand** (%)	**Silt** (%)	**Clay** (%)	**Textural class**	**Raster Value**
Sandy soils (Coarse texture)	86-100	0-14	0-10	Sand	7
	70-86	0-30	0-15	Loamy sand	6.5
Loamy soils (Moderately coarse texture)	50-70	0-50	0-20	Sandy loam	6
Loamy soils (Medium texture)	23-52	28-50	7-27	Loam	5
	20-50	74-88	0-27	Silty loam	4.5
	0-20	88-100	0-12	Silt	4
Loamy soils (Moderately fine texture)	20-45	15-52	27-40	Clay loam	3.5
	45-80	0-28	20-35	Sandy clay loam	3
	0-20	40-73	27-40	Silty clay loam	2.5
Clayey soils (Fine texture)	45-65	0-20	35-55	Sandy clay	2
	0-20	40-60	40-60	Silty clay	1.5
	0-45	0-40	40-100	Clay	1

Table 1. Soil texture types and characteristics as defined by USDA textural classes of soils. The last column indicates the values used to generate the raster soil map.

Locational pattern of Roman and Medieval sites

PPA for Roman and Medieval sites have been performed in R using the package ‘spatstat’ (Baddeley and Turner, 2013). GRASS maps have been managed in R environment through ‘rgrass7’ (Bivand et al., 2018). Thematic maps have been produced using ‘ggplot2’ (Wickham et al., 2019). In order to foster reproducibility of the implemented analysis, the code used for this project is provided as supplementary material (Supplementary Materials - Code).

A semi-parametric estimator of intensity has been created by fitting the two covariates (flood hazard and sediment type) to the point patterns of sites. The performance of the resulting IPP model (Model 1) is evaluated through the comparison with alternative models. Model 0 is a HPP model created by fitting a constant value to the point patterns. If the investigated sites are uniformly distributed in the study region and alluvial geomorphology does not influence their locational pattern (H_a), Model 0 is expected to overperform Model 1. Schwarz’s Bayesian Information Criterion (BIC) has been employed to assess the performance of the two covariates in Model 1 and to compare the two models (Zimmerman, 2010). BIC is calculated as the difference between the maximised likelihood of the model and the product of covariates and number of observations (points), therefore the lower BIC the better the model performs. Following the principle of parsimony, stepwise selection of covariates enables the identification of the combination of covariates that minimizes BIC values. BIC weights, instead, are used to provide a normalised estimation of the relative performance of two models (Eve and Crema, 2014).

Separate Model 0 and Model 1 have been created for Roman (R) and Medieval (M) sites. Stepwise BIC model-selection has been performed on Model 1R and 1M (Table 2). Both covariates are retained in Model 1M, whereas MTI is dropped in Model 1R, and only soil type is retained. The significance of BIC-selected covariates have been validated against stationary models (Model 0R, Model 0M), using BIC weights (Table 2). The results show that point process intensity is clearly inhomogeneous, and the null hypothesis (H_a) can be rejected.

Model R	Selected Covariates	Discarded Covariates	BIC	df	Weights Model 0-1	Weights Model 0-2
0	-	-	12105.6924097207	0	0.2120797	0.2019007
1	Soil	MTI	12103.0675395649	1	0.7879203	0.7501032
2	VAE	-	12108.5657215732	1	-	0.0479961

Model M	Selected Covariates	Discarded Covariates	BIC	df	Weights Model 0-1	Weights Model 0-2
0	-	-	5389.1070746156	0	0	0
1	MTI, Soil	-	5328.23728184886	2	1	1
2	VAE	-	5384.96043368587	1	-	0

Table 2. Result of the BIC stepwise covariates selection and model selection based on BIC weights, for PPA of Roman (top) and Medieval (bottom) sites

The coefficients of Model 1M (Table 3) show a direct correlation of the locational pattern of Medieval sites with the soil texture, and an inverse correlation with flood hazard. On the other hand, the coefficients of BIC-selected Model 1R (Table 3) show a weak negative correlation between Roman sites pattern and soil texture. It is worth pointing out that the assessed inhomogeneity of the settlement pattern does not necessarily imply a strong correlation between the selected covariates and the Roman or Medieval settlement strategy. The IPP underlying site distribution might be more efficiently explained by other spatial covariates. In order to assess the dependency of site distribution on the geomorphological characteristics of the study-area, an alternative inhomogeneous estimator has been tested, fitting the distance from via Aemilia (a cost-distance map created in GRASS 7 using r.cost tool) as covariate (Model 2). The choice of this comparative model is motivated by the well-known regional importance of this consular road both in Roman and in Medieval period, which suggests a possible influence on landscape organisation and site clustering (Uggeri, 2002) (Fig.4).

BIC-selected Model 1R and Model 1M have been compared with Model 2 (Table 3). BIC weights suggest that alluvial geomorphology better explains the location of sites than the proximity to via Aemilia. This result suggests that the selected environmental covariates had a significant influence on the spatial distribution of Roman and Medieval sites within the study area.

Covariate	Estimate	S.E.	CI 95% lo	CI 95% hi	Z test
Intercept	-14.6722443	0.11880191	-14.9050918	-14.43939686	<0.001
Soil	-0.1091445	0.04187692	-0.1912218	-0.02706728	<0.001

Covariate	Estimate	S.E.	CI 95% lo	CI 95% hi	Z test
Intercept	15.6301581	0.58337830	-16.7735585	-14.48675762	<0.001
MTI	-0.2500458	0.08401723	-0.4147165	-0.08537507	<0.001
Soil	0.4513779	0.05929057	0.3351705	0.56758524	<0.001

Table 3. Covariates of the BIC-selected Model 1R (top) and Model 1M (bottom).

Assessing the spatial interaction of Medieval and Roman sites using cross-*K* function

The previous analysis assumes complete independence for Medieval and Roman sites, namely that the distribution of Roman sites did not influence the Medieval settlement pattern (the opposite is implicitly impossible, for obvious chronological reasons). However, as explained above, archaeological investigations have shown that numerous Medieval sites are located within or in close proximity to Roman settlements or urban centres. This seems to suggest that, beyond the inhomogeneity of their respective point processes, at local scale Medieval settlement pattern tends to be influenced by the presence of Roman sites. To test this observation, and assess the independence of the two-point processes (H_b), second-order properties of the point patterns of must be investigated.

Second-order properties (aggregation and segregation of events in a point pattern) are routinely assessed using K-function, which measures the number of events at different distances from any event (Ripley, 1977). The multivariate version of K-function is used to assess spatial interaction between labelled events (events assigned to different types), by measuring the number of type j events within given distances from any type i events. Bivariate K-function (cross-K function) has been largely used to investigate spatial interactions between bivariate object types within archaeological assemblages (Giusti and Arzarello, 2016; Orton, 2004) and spatial organisation at intra-site level (Biagetti et al., 2016), but to our knowledge it has never been used to analyse two sets of archaeological sites at landscape-scale. In this study, this statistical method will be employed to evaluate the spatial interaction between Medieval and Roman sites. If the proximity to pre-existing Roman sites did not influence Medieval settlement strategies ($H_b$is true), K-function would show no aggregation. In the previous section, multi-model selection has shown that the point process underlying Medieval and Roman sites distribution is a realisation of an IPP (H_a is rejected). Therefore, the second-order interaction of these two point patterns should not be calculated under Complete Spatial Randomness (CSR), but adjusted for spatially varying intensity.

A non-parametric estimation of the IPP intensity using Gaussian kernel smoothing has been considered more solid and reliable than the use of the semi-parametric models tested in the previous section. It is general knowledge that bandwidth value selection is critical in kernel density estimation, but the criteria behind it vary according to the characteristics of the point pattern and the purpose of the analysis. Three alternative Gaussian kernels were produced using bandwidth corresponding to the 10th, 20th and 30th percentile of the distance between sites (Fig. 5). The 10th percentile bandwidth produces maps showing distinct density clusters (particularly for Roman sites), whereas the 30th percentile bandwidth produces excessively smoothed density maps (particularly for Medieval sites). Following this visual assessment, the 20th percentile bandwidth (corresponding to ~5.5 km for

Roman sites and ~8.5 km for Medieval sites) has been selected to estimate the intensity of the point processes.

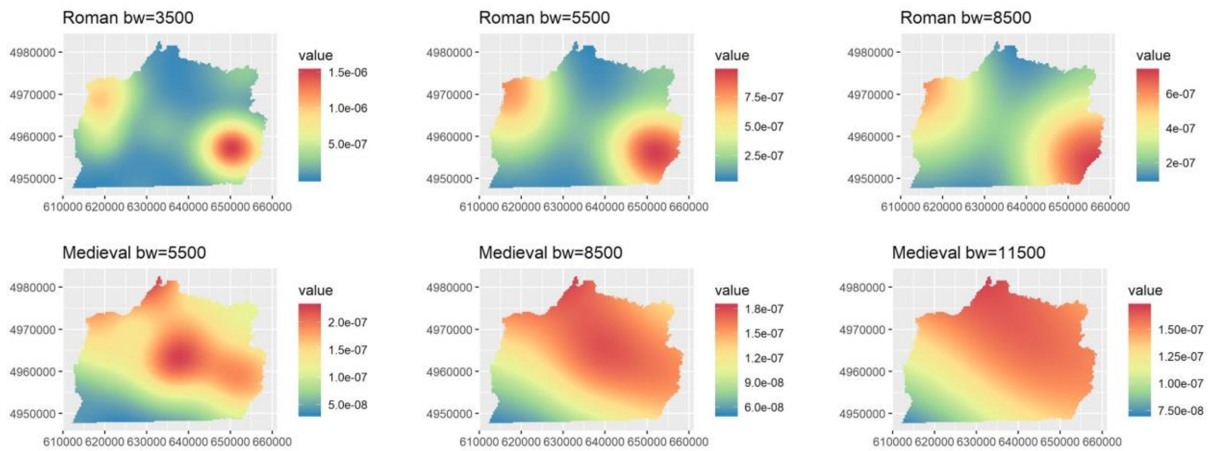

Figure 5. Estimated bandwidth corresponding to the 10th, 20th and 30th percentile of the distance between sites.

The inhomogeneous cross-K function has been calculated from the Medieval (i) to the Roman (j) sites, as well as for 999 Monte-Carlo simulated bivariate point patterns. In order to visually estimate the impact of first-order properties of the point patterns on their second-order properties, a homogeneous cross-K function has also been computed. Since spatial interaction tends to occur at small scale, the estimation of K has been limited to 3 km distance. Location accuracy is not uniform for all the investigated sites, therefore a cautionary 100 m lag has been utilised for K calculation at different distances. K values of the investigated and simulated datasets have been plotted against distance lags; observed values exceeding the 95th percentile of simulated values (the highest limit of the confidence envelope) suggest a statistically significant aggregation of Medieval and Roman sites for the given distance lag. The significance of non-stationary intensity on small-scale point interaction is evident when comparing the homogeneous and inhomogeneous plots. The inhomogeneous cross-K function shows a significant deviation of the observed values from the confidence envelope between 0 and 1.2 km. At larger distances, the aggregation and segregation between Roman and Medieval sites seem to be explained by their underlying IPPs. These results suggest that H_b hypothesis can be rejected. The distinct Roman and Medieval settlement strategies do not explain the proximity of Medieval and Roman sites when sites are closer than 1.2 km.

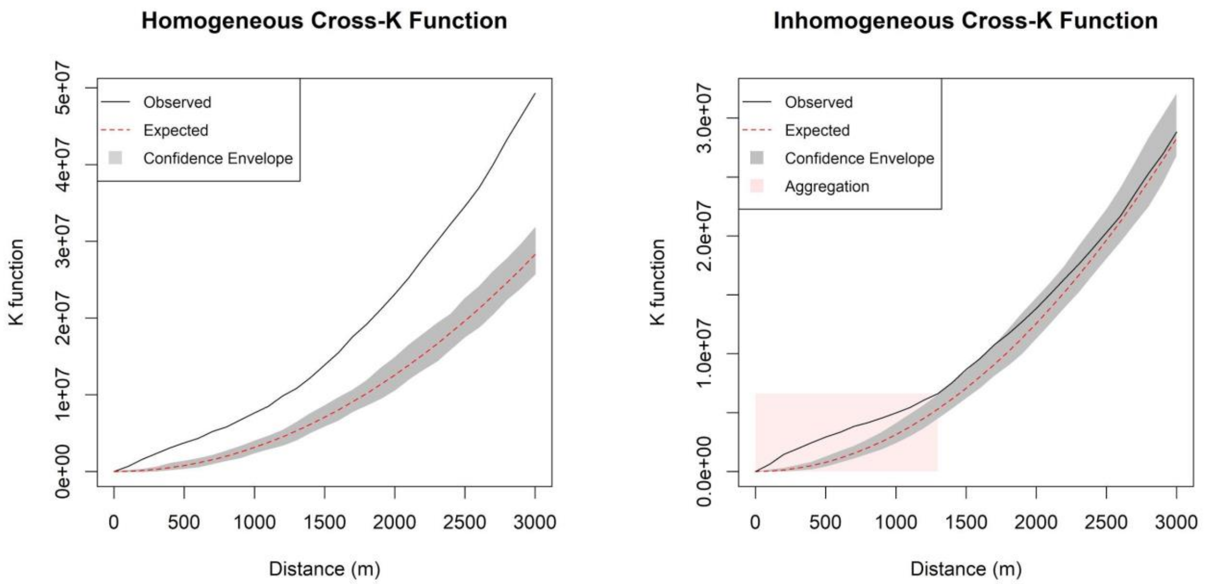

Figure 6. Homogeneous and inhomogeneous cross-K function measurements.

Discussion

PPA suggests that Roman sites distribution in the area has no correlation with flood hazard (MTI covariate), but show a weak inverse correlation with soil texture (Soil covariate). An inverse correlation with flood hazard (MTI covariate) and a direct correlation with soil texture (Soil covariate) have been identified for Medieval sites. In order to inspect these complex patterns at local level, Poisson process residuals have been calculated both for Model 1R and Model 1M. The measure of residual values for Poisson Process is a diagnostic process that allows to verify the model validation. Residuals are obtained by subtracting the fitted intensity function from the observed counts for each region of the model quadrature (Baddeley et al., 2015). By plotting the smoothed version of residual for the whole area, spatial variability in model prediction can be visually assessed: positive residuals occur where the model underestimate the true intensity (i.e. site density), negative residuals occur where the model overestimate the true intensity (Fig. 7).

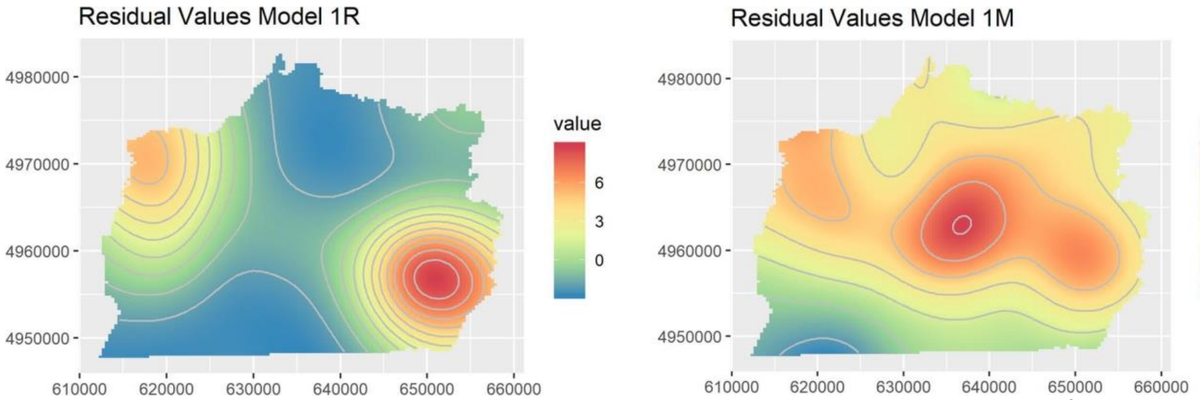

Figure 7. Smoothed residuals value for Model 1R and Model 1M (values multiplied x10^9)

The smoothed residual values for Model 1R enable the inverse correlation between Roman sites and Soil covariate to be investigated in detail. The plot of residual values for Model 1R evidently displays a significant positive autocorrelation (similar values are close to each other) (Cliff and Ord, 1973) , thus suggesting the occurrence of unexplained underlying processes that needs to be further explored. The model underestimated true intensity of sites in areas where Roman grid of roads and drainage system (centuriation) has been archaeologically recorded. Roman land management through centuriation enabled the drainage of flood prone areas (backswamps), and transformed the strategies of human occupation of the territory. This explains the absence of significant correlation Roman sites distribution with MTI covariate in Model 1R. Nevertheless, Roman occupation of drained flood-prone areas implies additional land-use constraints, since backswaps fine sediments were not suitable for agriculture in Roman times (relying on the scratch-plough or ard: see above). It can be argued that the exploitation of drained clayey and silty-clayey soils was instead connect to grazing activities. As a matter of fact, this area of the Po Valley is known to have been exploited for husbandry (especially breeding of pigs) during Roman times (Marcone, 2016). The inverse correlation between Roman settlements and soil texture could be explained with the occurrence of a diversified land-use in the area: agricultural activities associated with “light” coarse sediment and animal grazing related to “heavy” clayey soil. The palynological analysis carried out in the Modena area supports this hypothesis: the herb taxa, indicator of grazing, are prevalent in Roman phases and fairly gradually decreased in Early Medieval phases (Bosi et al., 2015). The lowering of herb taxa in palynological record is likely to be a consequence of the waterlogging process that affected the Po Valley in 5th / 10th century CE reducing the grazing areas and “reactivating” backswamps.

Model 1M displays a more uniform and less autocorrelated spatial distribution of residuals, and overall a more uniform level of prediction. A cluster of positive residuals is at the centre of the study area, possibly related to a recent and intensive survey campaign promoted by the local city council (Novellara), which might have led to an overrepresentation of scattered finds. In light of these data, it can be reasonably argued that the alluvial geomorphology of the area strongly conditioned the medieval settlement strategies. Swamps were relevant environments for sustainable practice in the Middle Ages, but according to spatial analysis their exploitation had a complex correlation with settlement patterns. Waterlogged areas influenced the distribution of Medieval sites, but the risk of inundation fostered the occupation of protected areas, surrounding the backswamps. Therefore, the relationship between Medieval sites and coarser sediments, suggested by the model, is likely not to be driven by land-use strategies, but rather to be an indirect consequence of the necessity to avoid floodings. The coarse fraction of fluvial sediments is concentrated in the proximity of the watercourse and in the research area their deposition developed the palaeochannels ridges that flanked the waterlogged areas. Even if it is undoubted that in Early Medieval era “lighter”- coarse soils were more suitable to agriculture than “heavy”-clayey soils (i.e. the heavy plough was adopted gradually only in Late Medieval times), the strong correlation between sediment type distribution and flood hazard prevents a reliable assessment of this assumption.

Further interesting insights are related to the low impact of the distance from the via Aemilia on the Roman and Medieval site distribution. This suggests that, surprisingly, this important communication route did not influence local settlement pattern. Such preliminary inferences deserves further investigations, which are beyond the scope of this research. It can be preliminarily suggested that this lack of correlation might depend on the prevalent rural nature of the sites in the area, which make them more dependent on local land use than on the proximity to primary communication routes.

Cross-K function enabled the assessment of spatial interaction between Medieval and Roman sites. A significant proximity of Medieval sites to Roman sites have been observed for short distances, up to 1.2 Km (Fig. 7). This implies that, even considering the different responses to alluvial geomorphological conditions in Roman and Medieval times, in a radius of 1.2 Km, the Medieval sites are closer to Roman sites than expected. Continuity between Roman and Early Medieval periods had already been observed in few archaeological sites in the area, and can be attributed to the exploitation of building resources or upstanding structures (Bottazzi et al., 1995). However, significant spatial aggregation at intermediate-scale (0.5 to 1.2 km) suggests possible functional or locational correlations that need to be further explored. These correlations are even more significant when considering the aforementioned dissimilarity of settlement dynamics in the Roman and Medieval periods, and might point towards a stronger continuity of landscape management in some sectors of the study areas than previously inferred from available archaeological sources.

Interesting insights about human resilience to environmental changes in Medieval times in the area are provided by the comparative analysis of land-use in the Po valley in the following centuries. During the Little Ice Age cooling phase (15th - 19th century CE) the risk of inundation in the Po Valley increased but it was mitigated through large scale land reclamation works promoted by regional local authorities (Brandolini and Cremaschi, 2018a). This confirms that, during the Modern Age, as much as during the Roman and Medieval periods, resilience and adaptive strategies were determined more by socio-political factors than geomorphological constraints.

Conclusion

The application of PPA and multi-model selection methods enabled the investigation of Roman and Medieval settlement strategies in the Po valley. Human resilience to Late Holocene environmental changes has been investigated thought the definition of two alluvial geomorphological spatial covariates: flood hazard (MTI) and soil texture (Soil). The spatial analysis performed shows that Roman and Medieval settlement patterns mirror two different human responses to the geomorphological dynamics of the area. Roman land- and water-management were able to minimize the flood hazard, to drain the floodplain and organize a complex land use on different soil types. In the Medieval period, the alluvial geomorphology of the area, characterised by wide swampy meadows and frequent flood events, affected the spatial organisation of settlement, which privileged topographically prominent positions. Social and cultural dynamics played a crucial role in responding to alluvial geomorphological environmental challenges in different times. In the Roman period, landscape reorganisation, prompted by well structured political and economical institutions, led to a lower reliance on environmental conditions and major importance of human interventions. Different land-use techniques enabled the Romans to exploit large areas of flood-prone areas successfully. On the other hand, alluvial geomorphology highly influenced settlement strategies during the Early Medieval period, because large landscape infrastructures could not be maintained and developed. Beyond these evident differences in settlement patterns in the two periods, a clear spatial correlation has been highlighted at local scale, which might suggest a degree of land-use persistence that deserves further investigations in the future.

In conclusion, this research contributed to quantifying how the socio-political factors of past societies played a key role in human resilience to hazards related to alluvial geomorphology and climate changes. The flood-hazard in Po Valley still represent a problem whose resolution is challenging (Castellarin et al., 2011; Merz et al., 2010) and understanding how human communities addressed it in the past might be useful to guide future decision-making. From a methodological point of view, PPA proved to be particularly suitable for disentangling the relationships between settlement dynamics and environmental covariates, and for providing reliable insights on past adaptive strategies. In particular, the use of inhomogeneous cross-K (or cross-L) function displayed a great potential for the study of spatial dependency in complex archaeological landscapes, and enabled the identification of spatial interactions that could not be inferred using visual assessments and traditional non-formalized approaches. Therefore, a wider use of these methodologies in archaeological research is highly recommended, to strengthen the reliability of our inferences and provide a solid understanding of past landscape and land-use processes.

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5.2 Mapping Matilda's castles in the northern Apennines: geological and geomorphological constrains

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Abstract

The positioning and construction of castles in ancient times responded not only to strategic opportunity, but also to the issue of geomorphological risk. We investigated castles and strongholds built in the era of the Great Countess Matilda of Canossa in part of the northern Apennines (Italy), in order to study the relationship between their positioning and the distribution of geomorphological and geological hazards. We observe how the location of castles follows clear patterns of avoidance of potential hazards: castles are kept far from the main fault systems and stream networks, and are mainly at a safe distance from landslide- and badlands-susceptible terrains. The knowledge of Medieval communities on landscape hazards was sufficiently advanced to minimise risks, while maintaining the strategic value of fortifications.

Keywords: Geomorphological risk, landslides, castles, Middle Ages, Apennines, Matilda of Canossa

Introduction

Castles and strongholds represent a relevant component of both the cultural and geological heritage of a territory. Fortifications, frequently positioned on natural buttresses, enhance the value of geosites (sensu Reynard, 2004) in terms of geohistorical importance (Bollati, Zucali, & Pelfini, 2014; Booth & Brayson, 2011). Their location and distribution mainly respond to logistic and strategic needs related to their cultural function. Nevertheless, castle – as well as settlement – positioning in past times had to deal also with georisks (Roberts, Nadim, & Kalsnes, 2009). Today, modern urban planning and construction techniques take full account of the geological and geomorphological characteristics of building areas (McCall, 1992). To this end, our current advanced knowledge of underground and surface geological processes allows accurate predictions of terrain fragility and its possible impact on the vulnerability of structures and infrastructures. The development of geology as a science is quite recent, dating to the beginning of the 19th cent. CE.

However, very precise assessments of landscape stability and geological hazards are also often present in the archaeological and historical past. The establishment and development of settlements reflects the balance between strategic opportunity and geomorphological stability, especially for large structures. A careful evaluation of risks and benefits is testified by those same structures, which have fulfilled their function during their time and in many cases still survive to this day. Many areas of Europe saw during the Middle Ages the development of castle and fortification systems, which had to interact with different geomorphological hazards (Knight & Harrison, 2013). Among other areas, the Alps and Apennines are particularly characterised by a marked geomorphological instability, mainly triggered by seismic and hydrogeological processes. Studies focusing on risk management and mitigation in ancient times are scanty.

In this paper, we investigate an area of the northern Apennines (Italy) in which a gradual expansion of fortifications following the spread upward of human settlements in Medieval times. Our main aim is to verify how the location of these structures aligns to the modern knowledge of geomorphological risk. and how these constrains impact on the necessity to establish a capillary control of the territory (Figure 1). In particular, we consider the system of castles and strongholds built in the era of Matilda of Canossa and compare their distribution with the geological and geomorphological context of northern Apennines in order to investigate the perceived knowledge of geomorphological hazards in that time.

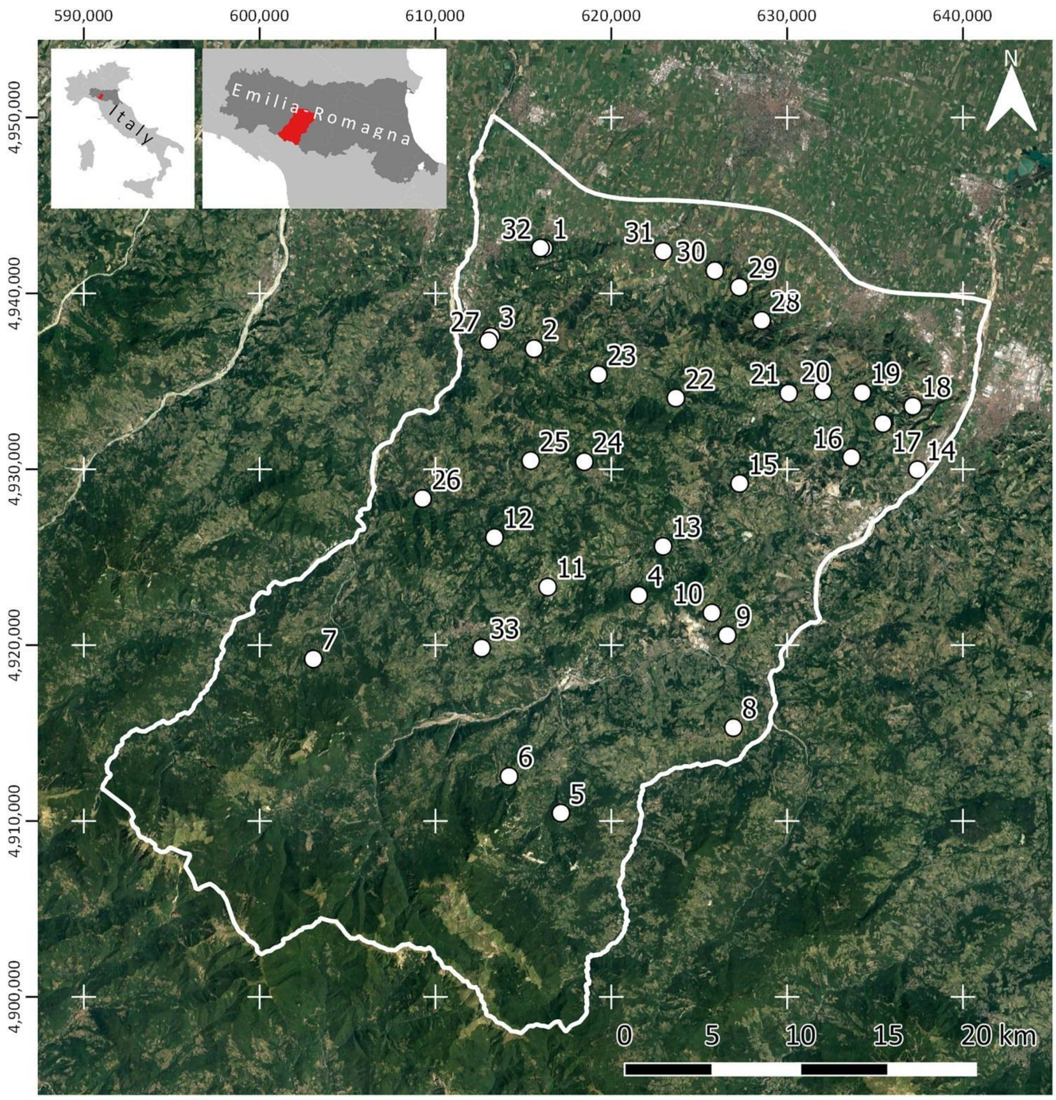

Figure 1. GoogleEarth™ satellite imagery illustrating the study area and indicating the distribution of the Matilda's castles; the insets show the position of the region in northern Italy. Coordinate system: UTM 32N, grid units in metres. Key: (1) Monte Zagno; (2) Canossa; (3) Rossena; (4) Carpineti; (5) Cà Vecchia; (6) Minozzo; (7) Teggie; (8) Massa; (9) Bebbio; (10) Casteldaldo; (11) Torre Felina; (12) Montecastagneto; (13) Mandra; (14) Castellarano; (15) Baiso; (16) Gavardo; (17) San Valentino; (18) La Rocca; (19) Montebabbio; (20) Rondinara; (21) Viano; (22) Montalto; (23) Paullo; (24) Sarzano; (25) Leguigno; (26) Crovara; (27) Guardiola; (28) Borzano; (29) Montericco; (30) Albinea; (31) Mucciatella; (32) Monte Lucio; (33) Pietra di Bismantova.

Area of study

The mapped area (Figure 1) lies in Northern Italy, inside the Emilia-Romagna region, and corresponds to a slice of the Apennine chain from the main watershed to the terraces at its foot (Reggio Emilia province). The area is bordered to the East and West respectively by the Secchia and Enza rivers, to the South by the Apennine main watershed, and to the North by the connection of the Apennine range to the southern margin of the Po Plain. Altitudes range from 58 m a.s.l. at the foot of the piedmont to the 2121 m a.s.l. of Mt. Cusna, the highest peak of the area (Mariani, Cremaschi, Zerboni, Zuccoli, & Trombino, 2018). From a geological standpoint, the northern portion of the Italian Apennines is an orogenic arc verging NNE composed by heavily deformed sedimentary units. Rock formations both precede and concur with the formation of the chain mainly during the Secondary and Tertiary Eras (Bosellini, 2005; Vai & Martini, 2001). Foreland deposits as well as elements of oceanic crust dislocated by compressive uplift compose the local bedrock. The inner arc of the chain, beyond the watershed, is structurally complex and characterised by extensional tectonics and consequent rifting and uplift (Vai & Martini, 2001). The outer arc is composed by a regular sequence of outward migrating deformational belts characterised by widespread folds and thrusts following the direction of the deformation (Gelati, 2013).

Consequently, the stratigraphy of the northern Apennines follows a classic series of silicoclastic turbidite foredeep wedges (Pini, 1999; Vai & Castellarin, 1993) arcing from the inside to the outside of the chain and variously folded and bent. From a lithological point of view, turbiditic claystones and sandstones dominate the outcropping lithologies, interspersed with calcareous formations mainly composed of limestones and marls. Ophiolitic domes, as well as isolated metamorphic outcrops appear sparsely in the studied area. Extensive fault systems produced by the complex compressive and extensive tectonics characterise this part of the arc. The shallow location of the main faults combined with the active uplift of the external rim of the outer chain enhances greatly the surface effects of seismic events. Strong earthquakes appear both in historical records (Boschi et al., 2000; Guidoboni & Comastri, 2005), and in recent catastrophic events in the northern (2012 Emilia seismic sequence: Tertulliani et al., 2012) and the central Apennines – see for instance the 2016–2017 Central Italy seismic sequence (Chiaraluce et al., 2017). The main geomorphological features of the region are typical of strongly deformed mountain environments. Folds and thrusts produced during the uplift of the chain remain in the landscape as elevated reliefs, forming monoclinal ridges and occasionally tabular structures eroded and partially dismantled by surface processes (Main Map). Among these, slope processes are particularly widespread: the northern Apennines are characterised by very active slope dynamics due to their distinctively soft lithologies combined to the high frequency of seismic events. A variety of gravity- and water-controlled slope landforms dot the landscape, ranging from gently rolling hills and badlands (in Italian calanchi or biancane) on clay materials to jagged cliffs modelled in more resistant sandstone or limestone formations. Landslides of different nature and extension deeply affected the territory in the past, often in response to climate variations (Bertolini, 2007). Slope instability and landslide reactivation phases are also recorded for the present time (Bertolini & Pellegrini, 2001). When coupled with the action of running water, intense slope incisions produce steep erosional cliffs and gorges, or solifluction lobes and mass-wasting deposits. Apennine badlands take different aspects and classifications (Bollati, Reynard, Lupia Palmieri, & Pelfini, 2016). Many of these erosive phenomena are presently active and often enhanced by human impact. The highest part of the chain was noticeably modelled by glaciers until the Last Glacial Maximum (Losacco, 1949, 1982).

Historical and archaeological context

The establishment of strongholds along the Tuscan-Emilian Apennines belongs to a general fortification process that interested many European regions starting from the 10th cent. CE. In Italy, the encastellation process (in Italian incastellamento) aimed to contrast the threat of Saracens, Magyars, and Norseman invasions through the construction of fortified castles (Settia,1984). Originally, the regent of the Italic Kingdom was the only one in charge of granting to the local lords the right to build strongholds, but after the disruption of royal authority in Italy (mid-10th cent. CE) many powerful noble families started to construct their own castles (Augenti, 2000; Augenti, Cirelli, Fiorini, & Ravaioli, 2010; Borrelli et al., 2014; Settia, 1984). By the 11th cent. CE, the north Italian political power was scattered in several local authorities with deep social and cultural consequences. In the Emilia-Romagna and Tuscany regions, the Canossa rulers led the reorganisation of the landscape with the construction of both defensive and ecclesiastic buildings. The political power of the Canossa family started with Adalberto Atto of Canossa (977–984 CE) and reached its apogee under the reign of his great-grand-daughter Matilda of Tuscany (1052–1115 CE) – aka the Great Countess, one of the most influential personalities of her time. In the study area, Matilda enhanced the Canossa fortification system with the renovation of castles, and likely built new ones. The exact establishment of Canossa castles is not certain: dating is limited at ante quem (i.e. before) or post quem (i.e. after) data derived from medieval chronicles as well as cadastre (Table 1). In fact, historical documents report that 90 out of 186 castles in the province of Reggio Emilia were founded between the 10th and 11th cent. CE (Galetti, Fiorini, Morini, & Zoni, 2014; Settia, 1984), but the archaeological records rarely confirm this periodisation. Canossa castles, indeed, were restored during the Italian Comuni (i.e. city-states) period (Manenti Valli, 1987; Saggioro et al., 2018), and the most ancient phases documented are dated between the 12th and 13th cent. CE (Brogiolo & Cagnana, 2012). The Canossa fortified system guaranteed protection over the main ways that connected the Po Valley with Central Italy through the Apennines (Zoni, Mancassola, & Cantatore, 2018). The historical and political influence of the Canossa dynasty during the 10th and 11th cent. CE led to create a sort of mythic aura around one of the most prominent medieval noble families in Europe. Recently, several investigations were carried out to study the Canossa defensive system. In particular, archaeological excavations included the castles of: Canossa (Manenti Valli, 2001; Saggioro et al., 2018); Carpineti (Lenzini, 2015) (Figure 2); Pizigolo (Toano) (Mancassola, Cantatore, & Zoni, 2018); Sarzano (Baricchi, Podini, & Serri, 2015); Pietra di Bismantova (Mancassola et al., 2014); Monte Lucio (Quattro Castella) (Augenti, Fiorini, Galetti, Mancassola, & Musina, 2011); Rossanella (Manenti Valli, 2009; Zoni, 2015).

CASTLE	DATE OF FOUNDATION	CANOSSA RULER	PERIOD
Canossa*	940 (*post quem*)	Adalbert Atto of Canossa	977–984 CE
S. Valentino	1010 (*ante quem*)	Tedald of Canossa	984–1007 CE
Rondinara	1010 (*ante quem*)		
Massa	1035 (*post quem*)	Boniface III, Margrave of Tuscany	1007–1052 CE
Mucciatella	1037 (*ante quem*)		
Castellarano	1039 (*ante quem*)		
Montalto	1052 (*ante quem*)		
Albinea	1057 (*ante quem*)		
Rossena*	1070 (*post quem*)	Matilda, the *Great Countess* of Tuscany	1052 – 1115 CE
Minozzo	1070 (*ante quem*)		
Sarzano*	1070 (*ante quem*)		
Carpineti*	1077 (*ante quem*)		
Monte babbio	1092 (*ante quem*)		
Baiso	1100 (*post quem*)		
Monte Lucio*	1100 (*post quem*)		
Bismantova*	1100 (*post quem*)		
Pizigolo *	1100 (*post quem*)		
La Rocca	1107 (*ante quem*)		
Monte castagneto	1111 (*ante quem*)		
Bebbio	1115 (*ante quem*)		
Mandra	1115 (*ante quem*)		
Torre Felina	1116 (*ante quem*)		
Monte Zagno	1147 (*ante quem*)	-	
Casteldaldo	1184 (*ante quem*)		
Paullo	1197 (*ante quem*)		
Leguigno	1197 (*ante quem*)		
Guardiola/Rossenella*	1200 (*post quem*)		

Table 1. List of Canossa's dynasty castles in the study area. All the date derived from medieval historical documents and gave only a ante quem or post quem date of foundations. The majority of the Canossa castle is likely to have been established or enhanced during the reign of the Great Countess Matilda. The star indicates the castles that have been recently interested by archaeological studies and castles whose considerable architecture are still standing. References about each sites are available on the Regional Database (http://www.4000luoghi.re.it/).

Materials and methods

Historical and archaeological data on castles come from recent archaeological studies (Augenti et al., 2011; Baricchi et al., 2015; Lenzini, 2015; Mancassola et al., 2014; Mancassola et al., 2018; Manenti Valli, 2001; Manenti Valli, 2009; Saggioro et al., 2018; Zoni, 2015), as well as from an online local database (Provincia di Reggio Emilia, 2019). These sources allowed to select the most suitable sites for the purpose of this study. As stated above, the chronology for the establishment of the chosen castles is indicative and known only in general terms. The cartographic effort on the study area took place mainly through remote sensing, with the acquisition and processing of topographical, geological and risk-related data, compared with the historical-archaeological data. To draw the Main Map, we acquired data both from the field and from digital archives. Reference topography derives from contour lines (5 m) retrieved from the Geological Survey of Emilia-Romagna (Regione Emilia-Romagna, 2017). The construction of a Digital Terrain Model (DTM) through GIS software (QGIS version 3.4) provided the basis for terrain analysis, as well as slope and hillshade layers produced from this model. Geological cartography and related names and acronyms were retrieved from the 1:10000 scale geological map constructed by the Geological Survey of Emilia-Romagna (SGSS, 2019). Naming conventions for the geological formations conform to the Geological Map of Italy at 1:50000 scale (CARG Project: ISPRA, 2019).

Figure 2. An example of a castle from the study region: (a) view of the monoclinal relief hosting the Carpineti castle (indicated by the arrow); (b) detail of the monoclinal-type relief illustrating the escarpment and the outcrop of sandstone strata; (c) a detail of the Carpineti castle.

Geomorphological risk-related data for the territory (hydrographic network, landslides, badlands, fault systems) were provided at 1:10000 scale by the Geological Survey of Emilia-Romagna (SGSS, 2019). In our work, we chose to focus on structural features and slope processes: other than producing the most widespread landforms in the landscape, these represent the most important factors influencing terrain stability of the region and therefore infrastructure stability. To compare the potential impact of geomorphological features on castle locations landslides and faults on the map were transformed into point layers (100 m equal interval points for fault lines, centroids for landslide polygons, area-weighted random points for badlands polygons) and visualised as influence areas through analyses of density based on kernel method (di Lernia et al., 2013; Silvermann, 1986), with a radius of 500 m. This method allows to produce heatmaps representing the main hotspots for the considered features, in order to identify high-risk areas (Bonnier, Finné, & Weiberg, 2019; Danese, Lazzari, & Murgante, 2008).

Results

Distribution of castles and strongholds strategy

The distribution of castles inside the landscape seems to follow some common principles. Most of the castles are located in the North, in the lower portion of the outer Apennines: this area is also the more exposed to potential threats from the well-populated Po Plain. Their distribution then thins out towards the higher (southern), less populated part of the chain. Most of the buildings lie on slopes, over peaks, ridges or escarpment rims, and generally on high ground (Figure 3). Mid-slope positions appear with less frequently; only one castle among those investigated (Rondinara) is built directly on a valley floor. Slope steepness canvary, reaching extreme cases: some castles, in fact, occupy the rim of low and high scarps (such as Torre Felina, Guardiola, and Pietra di Bismantova). All castles are clearly far from waterways: only one (Rondinara) is found directly at the passage of a watercourse. In all other cases, proximity to a stream is frequent, but always from an elevated position (for example, Castellarano lies on a hill directly above the river), or at considerable distances. Moreover, when comparing dates of foundation retrieved from literature (Table 1), the distribution of castles in the region appears to follow a chronological trend. While such records are not completely accurate, it is still visible a colonisation expansion in time towards the inner Apennines, coupled with a progressive increase in the number of strongholds in the areas already settled.

Geological and geomorphological features

From the geological layers of the Main Map appears a series of evident folds and thrusts, oriented NE to SW perpendicular to the direction of the main orogenetic deformation, which represent the main structural motif of the Apennine chain (Abbate, Bortolotti, Passerini, & Sagri, 1970). Although spread throughout the area, these are more linear and better visible to the North, in the outer portion of the chain, where these structures are more recent and have undergone only minor disruptions. The main faults similarly lie in a NE to SW direction; lesser faults are instead mainly perpendicular to the previous ones. Most of the faulting concentrates in two separate areas. A major portion of faults and seismogenic structures rests on an elongated belt located in the outer portion of the arc only a few kilometres from the plains. The upper half of the chain to the South hosts the main part of the remaining lineaments, including the majority of the thrust faults. The geomorphological evolution of this sector of the Apennines strongly relies on the presence of compressional structures. Folds and thrusts divide the landscape in a series of variously set monoclinal structures, mostly parallel to the chain and in correspondence to the outcrop of anticlines and overthrusts. A few isolated mesas can also be found: some of them have become iconic elements of the local landscape.

For instance, the Pietra di Bismantova geosite (Borgatti & Tosatti, 2010) that is an elevated sloping limestone tabular mesa surrounded by vertical cliffs (Mancassola et al., 2014). Monoclinal structures are common and variously related to the channel network. Streams and rivers mostly flow around these structures, but sometimes cut them: in many instances these large structures are broken by the passage of a stream. This often happens near fractures and fault systems, which produce structural weaknesses that water can exploit as a breach. The expansion of watersheds and the action of other surface processes work to hide the presence of large monoclinal structures, especially in the upper part of the chain, where they are often found as broken isolated elements not immediately traceable to longer escarpment alignments. The other major constraint to castle distribution is the high occurrence of landslides. These are uniformly distributed over the territory in response to a substantial similarity of its lithological features and decrease in frequency only in the lowest and highest portions of the chain.

Figure 3. Examples of geological and geomorphological settings of selected castles (satellite imageries from GoogleEarth™): (a) the Pietra di Bismantova castle on top of a mesa-type relief; (b) the Carpineti castle on the rim of a monocline structure; (c) the Canossa Castle on a residual hill of sandstone surrounded by badlands developed on marls and clays; (d) the Guardiola (bottom) and Rossena (top) castles built on top of ophiolite domes.

A vague clustering in strips parallel to the main lineament of the chain does appear, especially in the North. The map takes into consideration both active and inactive landslides. We argue though that many of the latter are dormant, and subject to potential reactivation, in accordance with the dynamic setting of the Apennines (Dramis & Bisci, 1998; Piacentini, Ercolessi, Pizziolo, & Troiani, 2015). It is therefore plausible to assume that most of these landforms could have already been active 1000 years ago, with only a fraction of them being completely posterior.

6. Discussion: military strategy vs. geomorphological risk

The primary function of a fortification is to provide defence and control over a territory (Creighton, 2002, 2012): its position in the landscape must therefore facilitate this purpose. Oftentimes, remote elevated positions and vantage points represent ideal locations, since a larger visual on the territory allows efficient control and the possibility for easy communication with a community scattered on the territory. The reduced accessibility and relative isolation in the landscape provided by elevation also enhance their defensibility. On the other hand, locations close to main roads and passages (for example Rondinara and Carpineti) allow a strict control of traffics and a closer relationship with the settlements themselves, with the added value of physical protection. However, such ideal conditions need to come with terms with the constraints found in the landscape (Creighton, 2002). Considering the geomorphological setting of the area, there is a visible correspondence with the construction of castles and the main monoclinal structures. Several ridge locations are in fact directly associated with the top of larger structural forms (for example Viano, Baiso, Sarzano and, much more spectacularly, Carpineti; Figures 2 and 3b); in other cases, although not on the main ridge, castles are still located in their vicinity. Isolated reliefs are another chosen location: in fact, several castles are located both on mesas or on isolated mounds formed by selective erosion of sedimentary successions (Torre Felina and Pietra di Bismantova; Figure 3a), and on isolated domes of resistant ophiolitic materials (Guardiola, Rossena, and Minozzo; Figure 3d). Of the various elements of risk, hydrology is perhaps the most evident and the simplest to mitigate. Outside clear strategic necessities, as in the case of Rondinara, all the castles are in fact at enough distance from riverbeds and the surrounding floodplains to easily avoid the effects of floods. In general, while proximity to the main water network is usually very important for settlements, apparently castles can be more independent from this resource. The relationship between castles and fault systems, highlighted by kernel density (Figure 4a), seems to follow a rather common pattern of avoidance. In the area of the piedmont, the first line of castles looking over the Po Plain is mainly isolated and far from faults or overthrust systems. In the inner portions of the chain, fortifications tend to be either outside or at the perimeter of high concentrations of fractures. Alternatively, there are examples of castles located near fault systems of small dimensions (Massa) or very close to single isolated faults (Carpineti). This strategy seems to achieve a dual purpose. Such distribution leads to low seismic risk for constructions, which in a high-hazard area such as the Apennines is a considerable advantage. Furthermore, it also allows to rely on stronger slope stability, lowering the likeliness of hazardous slope phenomena triggered by fracture-enhanced substrate degradation.

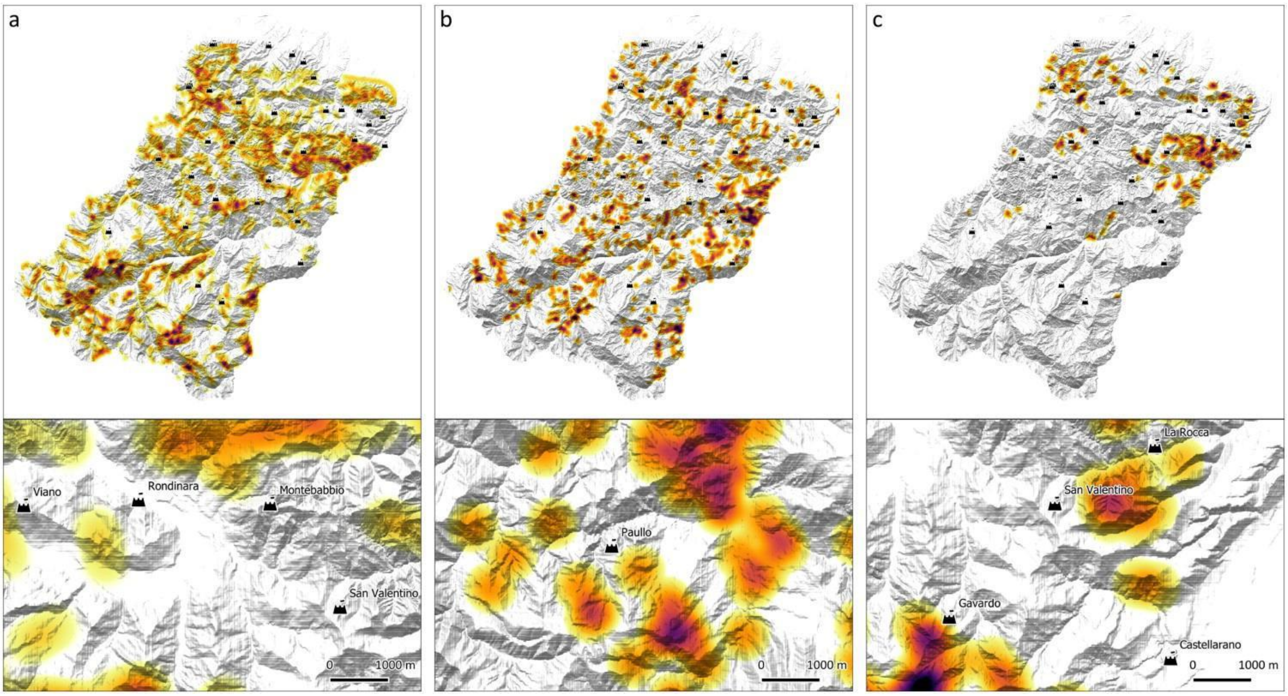

Figure 4. Analyses of density of the investigated geological and geomorphological parameters locations based on kernel density. Elaborations represent the whole region (see Figure 1 for scale) and details for each: (a) analysis of density of faults vs. castles location; (b) analysis of density of landslides vs. castles location: (c) analysis of density of badlands vs. castles location.

Conversely, the relationship with landslide events, which are more uniformly spread over the territory, is less straightforward (Figure 4b). Kernel density shows how in many cases castles seem to be located close (within a few hundred metres) to single land- slides or inside areas containing evident slope hazards. These are often connected to the presence of steep slopes and scarps (Pietra di Bismantova, Carpineti) or to widespread badlands formation (Monte Zagno, Canossa) (Figure 4c). Nevertheless, oftentimes a short linear distance does not imply influence, as many castles occupy positions unrelated to these landforms, sometimes as different slopes or different lithologies (Figure 3c). A large majority of the castles is anyway quite far from unstable areas, especially on the piedmont, where the occurrence of landslides is rare. At a first glance, the occurrence of fortifications in the proximity of these landforms would indicate a lower attention or ability to recognise this type of geomorphological hazard. Nevertheless, this interests only a fraction of cases. Many factors need to be considered: of all processes, landslides are very complex events, which can be triggered and enhanced by multiple factors such as structural instabilities, lithology, hydrology, seismicity and climate, especially in the northern Apennines (Bertolini & Pellegrini, 2001). To assess with accuracy the areas at higher risk, and even more to effectively mitigate such risk, is still today a considerable task (Lee & Jones, 2004; McCall, 1992).

7. Conclusions

The positioning and construction of castles during Matilda's Age was the result of both military strategy and geomorphological safety. A careful balance between these two aspects was fundamental in the choice of the most suitable locations for important and expensive enterprises, as testified by the various examples found in the territory. We can therefore assume that in this period of the Middle Ages advanced knowledge on rock engineering and behaviour was already available. Even without the modern understanding of geology, the grasp of medieval populations on the variety and occurrence of landscape hazards was sufficiently advanced to allow an efficient assessment of the terrain and especially of slope stability. This knowledge also extended to the main surface processes and the fundamentals of geomorphological and hydrogeological risk mitigation (floods, landslides, probably avalanches). In conclusion, the mapping of Matilda's castles and the analysis of their distribution referred to geodiversity and geomorphological features and changes (Pelfini & Bollati, 2014; Reynard & Giusti, 2018) suggest a multi-layered planning in the identification of locations for each stronghold. We suggest that even in past times military strategy and territorial control were only two of the factors followed in planning infrastructures, and the awareness of the many possible environmental risks of a region was higher than we would expect.

Matilda's castles, northern Apennines: geological and geomorphological constraints

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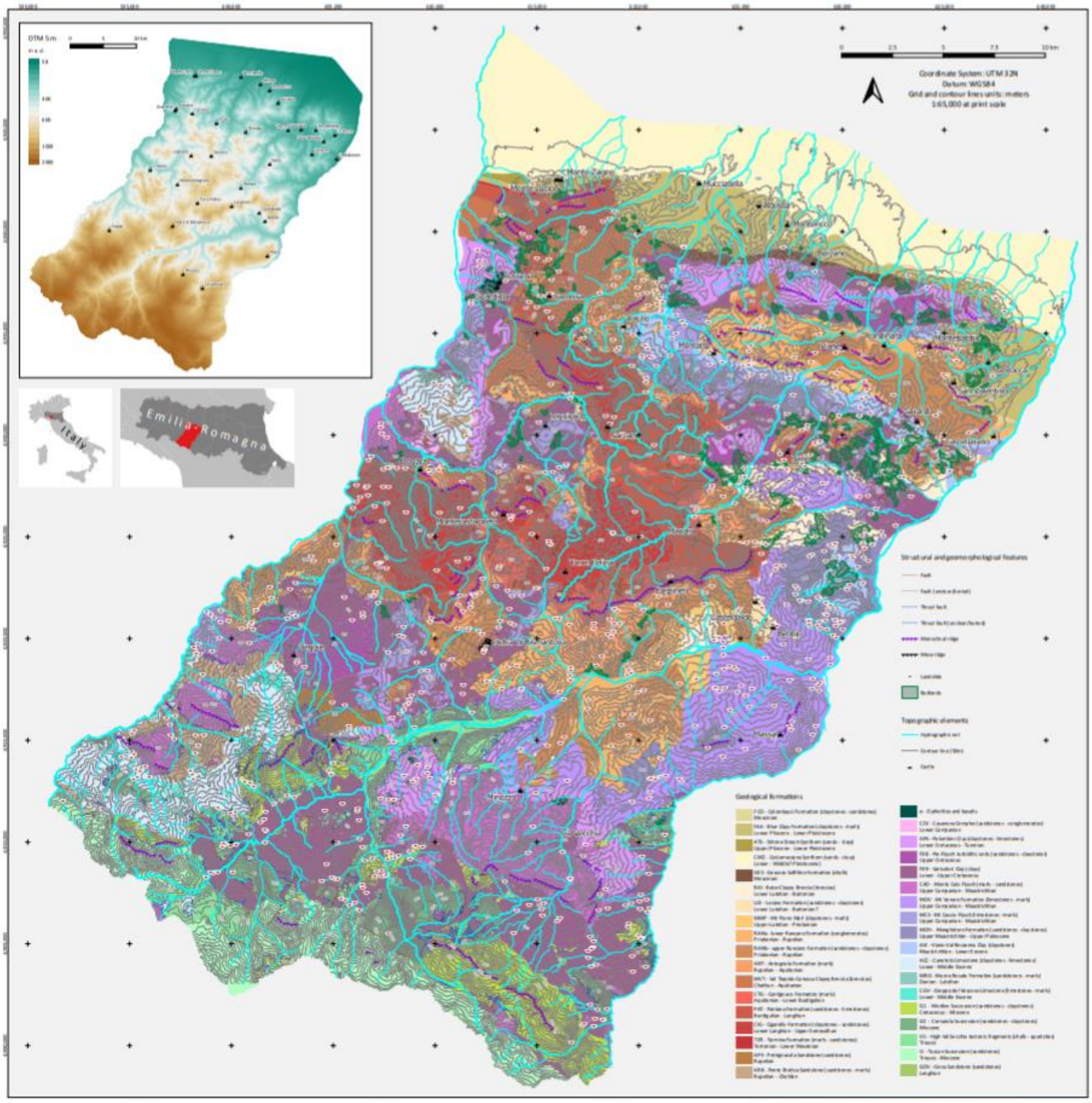

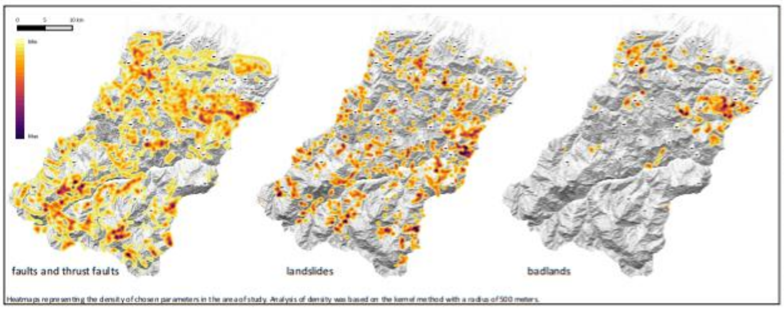

Heatmaps representing the density of chosen parameters in the area of study. Analysis of density was based on the kernel method with a radius of 500 meters.

View of the castle of Carpineti: a still-standing Matilda's castle built on sandstone.

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6 Promoting the fruition and valorisation of past cultural landscapes through geoheritage

6.1 Estimating the potential of archaeo-historical data in the definition of geomorphosites and geo-educational itineraries in the Central Po Plain (N Italy)

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Abstract

Alluvial plains represent the preferable areas for human settling for their suitability to agriculture activities, and many studies strengthen the interpretation of floodplains as complex human–water systems. The Late Holocene development of the Central Po Plain has a long-lasting connection with anthropogenic activities. In the study area, human land and water management, in association with different Late Holocene climate phases, deeply affected the geomorphological evolution of the Central Po Plain. The geomorphological and archaeomorphological features detected in this study represent valuable datasets of information about the evolution of this portion of the Po Plain in the Late Holocene. This paper aims to quantify the potential of archaeological and historical data in contextualising the anthropogenic geomorphological features and reconstructing how man affected the natural geomorphological processes. Through a multi-disciplinary approach that combines archaeomorphological and geomorphological investigations, we identify visible and invisible landforms developed in four different historical periods, and that corresponds to potential “geoarchaeomorphosites”. In the study area, the modern landscape consists of a cultural palimpsest of four different palaeolandscape layers characterised by peculiar landforms. After an in-depth analysis of present and past geomorphic features deriving from the reciprocal interaction between human and floodplain dynamics since Prehistory, this study suggests geoconservation and valorisation practices. Finally, starting from potential geoarchaeomorphosites, four geo-educational itineraries are proposed to promote future geotourism projects of the area.

Keywords: Archaeomorphology; Anthropogenic Geomorphology; Fluvial Geomorphology; Geoarcheomorphosite; Geoarchaeology; Landscape changes; Central Po Plain; Late Holocene

Introduction

Human settlements, from small villages to the major metropolitan areas, represent the result of the reciprocal influence between natural processes (geological, geomorphological) and human actions over time. In the beginning, the local geomorphological characteristics have conditioned the settlement's position (Benito-Calvo and Pérez-González 2015), but as time goes by more incisive anthropic action has reworked and reshaped the landscape, modifying the natural range of geomorphic processes. The human impact on the environment often has consequences in term of hazard and risk (Aquaotta et al. 2018), in dismantling landforms and in reworking/creating new ones. Nowadays, Man is considered the third important geomorphological agent (Li et al. 2017).

The interactions between geomorphological processes, climatic changes, environmental changes and human presence have generated the interest of different kinds of researchers, who are paying great attention to both geoheritage and geohazard-georisk in cities and urbanised areas. The recent literature on urban geomorphology (Cardarelli et al. 2004; Kleinhans et al. 2010; Rhoads et al. 2015; Ninfo et. al. 2016; Pérez and Pidal 2016; Pica et al. 2016; Brandolini et al. 2017; Pica et al.

2017; Del Monte et al. 2017), geoarchaeology (Pope et al. 2003; Fontana 2006; Lewin 2010; Ortalli 2010; Stefani et al. 2010; Dall'Aglio et al. 2011; Van Dinter 2017; Cremaschi et al. 2018; Mozzi et al. 2018) and geoheritage in urban areas (Del Monte et al. 2016; Pica et al. 2016; Dall'Aglio et al. 2017; Pelfini et al. 2018) highlights the impressive role of anthropogenic geomorphology in modifying landscape (Szabó et al. 2010). All these disciplines underline the necessity of integrated research approaches to quantify the human impact on landscape evolution. Nonetheless, the progressive anthropogenic reworking of landforms is often missing geoheritage data. Clivaz and Reynard (2017), highlight the importance of inventory not only for present-day landforms and geosites (sensu Wimbledon 1996; Panizza and Piacente 1993; Pelfini and Bollati 2014), but also for the ones dismantled or hidden by human intervention. The two authors report that in the Rhone River valley (Switzerland) the river flood mitigation, industrialisation, intensive agriculture and urban development have profoundly modified channels and the surrounding areas, but some landscape features are still recognisable thanks to historical documentaries (historical maps, iconographic material, written archives, place names). Other authors pointed out the application of the geohistorical approach as a tool of great relevance in reconstructing hydrogeomorphic dynamics (Perez and Pidal, 2016) as well.

The current methodology to identify potential geomorphosites considers archaeological information as Additional Values (Brilha 2017; Bollati et al. 2017), but geoheritage and geoconservation studies emphasised the relevance of archaeological data (Giordano et al. 2016) in cultural geomorphosites (Niculiţă and Mărgărint 2017) and geo-archaeoheritage sites (Taha and El-Asmar 2018) to promote geotourism. The close connection between archaeology, geoarchaeology and geomorphosite management was explored by Eric Fouache, who proposed the term geoarcheosite to indicate archaeological site located on a geomorphosite (Fouache and Rasse 2009). The same author also proposed the term archaeo-geomorphosite to define a geomorphosite with archaeological interest, and in which the geomorphological study has been prompted by historical and archaeological questions (Fouache et al. 2012).

A very recent interdisciplinary and diachronic approach is represented by archaeomorphology, an analysis that synthesises aspects of geomorphology, archaeology and environmental history to study the anthropogenic effects on landscape evolution in the past (Vion 1989; Matteazzi 2014; Canfora and Di Luzio 2014). Archaeomorphology is focused on the study of human-made landforms and traces of territorial planning. It aims at analysing the historical development of landscape structures over time and embrace the idea of landscapes as cultural palimpsests (Orengo and Palet 2014).

The case study proposed in this paper offers a relevant example of anthropogenic geomorphology in Northern Italy. In the research area, geomorphological tools combined with archaeo-historical data made it possible to reconstruct the Late Holocene interactions between humans and the environment, and their effects on the physical evolution of the Central Po Plain (Brandolini and Cremaschi 2018a).

This paper aims to reconstruct the main evolutionary landscape stages due to human activity in Central Po Plain through the identification of visible (landscape management evidence) and invisible (hidden features) landforms. A further goal is to evaluate the potential of archaeological and historical data in defining potential geomorphosites (sensu Panizza 2001; Reynard and Panizza 2005) to propose geo-educational itineraries in alluvial plains.

Background

Geomorphological context

The research area is located in the Central Po Valley, few kilometres north of the Tuscan – Emilian Apennine margin, between the cities of Parma e Reggio Emilia, among the rivers Enza, Po and Secchia, and the distal part of Holocene alluvial fans (Fig.1, Pre-Quaternary deposits).

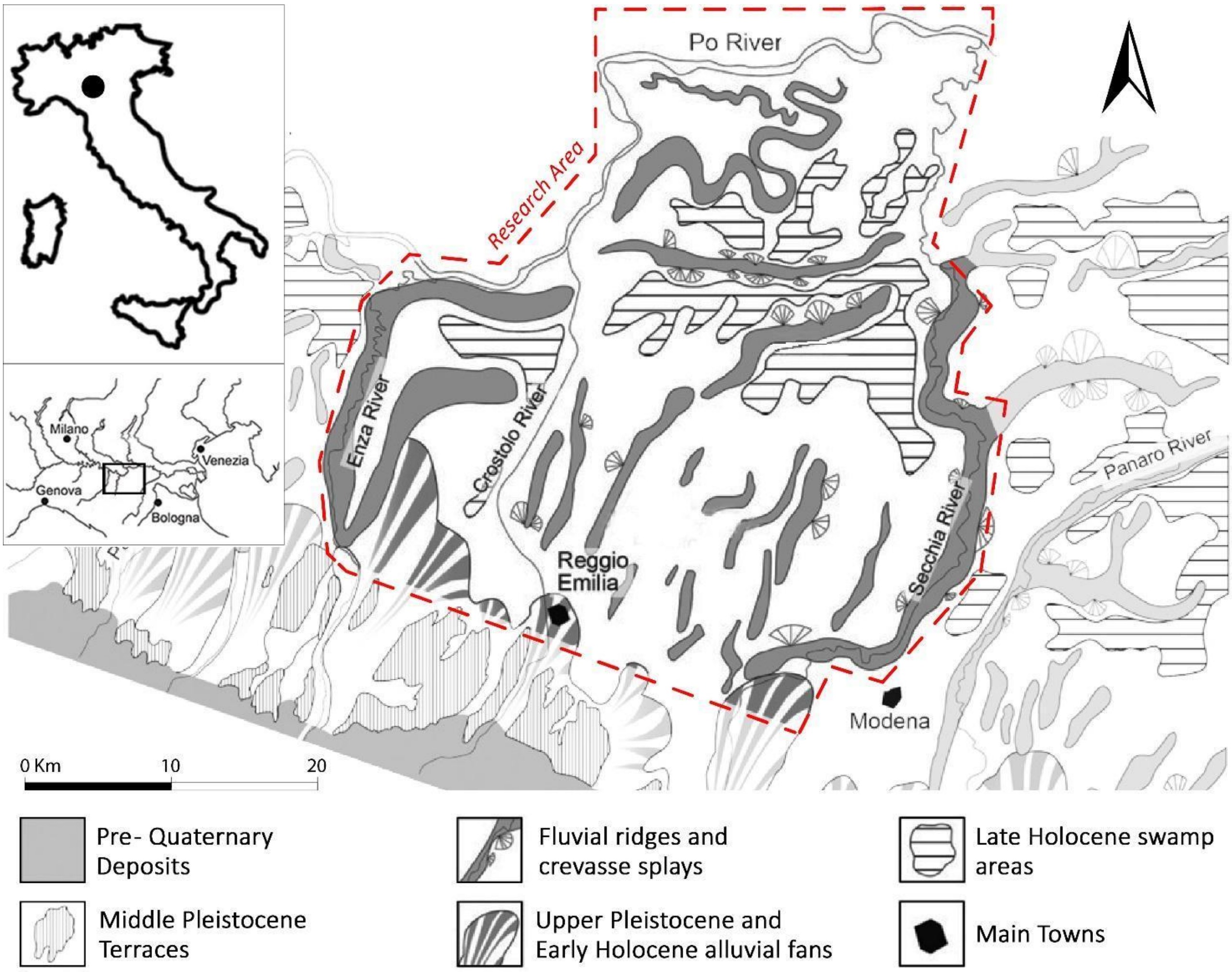

Figure 1. Geomorphological context of the research area (Modified from Cremaschi, M. et al. 2018).

The Apennine fringe in this part of the Central Po Plain is still tectonically active, since it coincides with a complex belt of folded thrust fronts trending north-northeast developed during the Quaternary (Pieri and Groppi 1981; Barbacini et al. 2002; Gunderson et al. 2014; Cremaschi et al. 2018); as a result the tectonic forces uplifted the mountain margin and lowered the plain in front of it (Scognamiglio et al. 2012). Since the Middle Pleistocene, the geomorphological consequence of these processes has been the formation of an apron of gravelly mega-fans and the deposition of fine alluvial sediments along their margin (Cremaschi 1987; Cremaschi Nicosia 2012; Cremaschi et al. 2018). Climatic fluctuations characterised by glacial and interglacial cycles in the Middle and Upper Pleistocene together with the recent tectonic processes influenced shape, size and degree of preservation of those landforms (Rossi et al. 2002; Valloni and Baio 2009; Marchetti 2010; Gunderson et al. 2014). Remnants of Middle Pleistocene terraced fans, covered by thick polygenetic paleosols and loess sheets, spread among the Apennine foothills (Cremaschi 1987; Busacca and Cremaschi 1998). A well-preserved system of late Pleistocene to Holocene alluvial fans extends northward between the Apennine foothills and the Holocene plain (Cremaschi and Marchetti 1995; Castiglioni and Pellegrini 2001). As well explained in Cremaschi and Nicosia (2012), their telescopic shape is a consequence of subsequent aggradation – entrenchment phases due to the alternation of glacial-interglacial periods: each aggradational cycle, indeed, implied an incision on the top of the previous fan, while a new one prograded in a more distal position. Fine fluvial deposits accumulated on the distal part of the Holocene alluvial fans during the transition between Atlantic and Sub-Boreal periods; their sedimentation occurred in a phase of climatic instability that followed the Holocene Climatic Optimum. Alluvial ridges of the Apennine watercourses connect the fringe of the Apennine alluvial fans with the Po floodplain (Cremaschi and Nicosia 2012).

In the study area, the alluvial ridges of the Enza and Crostolo rivers, emerging from the flat floodplain, flank depression areas occupied by swamps during medieval times. These depressions, or backswamps (Charlton 2007; Szabo et al. 2010), are characterised by deposits of fine silts and clays settled after flood events.

Archaeological - Historical Context

The human-induced landscape transformation conditioned the natural evolution of this portion of the Central Po plain since Protohistory, and the main environmental, historical phases of the study area (Table 1) are presented here.

The first conversion of the natural landscape by human action is dated to the Bronze Age (17th and the mid-14th centuries BC). In this period the alluvial fan was fully stable and, on its surface, some of the most prominent Terramare Culture (hereafter TC) villages in the Po Valley were established (Bernabò Brea et al.1997, Bernabo' Brea and Cremaschi 2004; Cremaschi et al. 2006). The TC villages were surrounded by a moat connected to an adjoining watercourse through a canal network to irrigate the cultivated fields around the site (Mele et al. 2013). The human occupation of the Po Valley in the Iron Age (8th – 3rd centuries BC) is known for sporadic archaeological findings on the surface of the alluvial megafans and along the course of paleochannels. Ceramics types led to identifying a few of these sites as belonging to the Etruscan culture (Malnati 1988).

In the 1st century BC, the Romans colonised the Po Valley and deeply modified the natural landscape dividing the cultivated land in square fields by a regular grid of roads and ditches (Settis and Pasquinucci 1983; Bottazzi 1985; Bottazzi 1987). The remnants of this land management system, known as centuriation, in some cases are still recognisable in present-day cultivated fields (Dall'Aglio 1981) or in buried soil marks and crop marks (Brandolini and Cremaschi 2018b). The considerable archaeological data testify that numerous Roman farms (i.e. villae rusticae) spread in the countryside among the major municipii (i.e. cities) of Mutina, Regum Aemilia and Augusta Parmenesis (i.e. Modena, Reggio Emilia and Parma) until the 4th century AD (Bottazzi et al. 1995).

In the 5th century AD, the crisis of the Western Roman Empire and the lack of maintenance of the irrigation systems (Squatriti 1998), associated with a cooling climate phase (Lamb 1995; Hoffmann 2014), led to the progressive waterlogging of the Po Valley.

The waterlogging process of the area continued until the 10th century AD influencing the human sustenance and settling practices. According to historical-archaeological data, Early Medieval (6th – 10th century AD) sites settled on the fluvial ridges, in topographically higher and strategic position in the surrounding wetlands (Brandolini et al. 2018): silvopastoral practice partially replaced agriculture and the wetlands were exploited for fishing as well as for transport by boat (Tiraboschi 1824; Drei 1924; Settia 1984; Bottazzi et al. 1995; Squatriti 1998; Settia 1999). Between the 10th and the 14th century AD, the European population grew progressively and almost tripled, increasing the demand for cultivated lands (Hoffmann, 2014). Cereal grains gained a more significant role in the diet and the agrarian regime compared to the centuries before leading the human enterprise to reconfigure the medieval natural landscape to agricultural purpose: clearance of forests and wetland reclamation shaped the Po Valley (Brandolini and Cremaschi 2018a).

In the study area, channelization and reclamation works started in the 10th century AD (Affò 1786; Affo'1792; Tiraboschi 1824; Cantarelli 1882; Mancassola 2012) and increased between the 12th and the 13th centuries (Fumagalli 1985, Fumagalli 1999; Fumagalli 2014; Rao 2016), promoted both by monasteries (Fumagalli 2007; Ambrosini De Marchi 2010; Rao 2016) and by private landowners (Brandolini and Cremaschi 2018b).

Large-scale ground reclamation is dated to Renaissance and is known in the literature as Bonifica Bentivoglio, by the name of its promoter, the lord of Guastalla Cornelio Bentivoglio. The Bonifica Bentivoglio drainage system reclaimed a large portion of the swampy meadows and was renovated and updated many times in Modern Age: between 17th and 19th centuries many homesteads were settled in the reclaimed farmland (Baricchi 1989). The ground reclamation of this portion of the Po Plain continued after the Renaissance and was complete only in the 20th century AD (Mori 1923; Gabbi 2001; Saltini 2005) resulting in the modern completely artificial landscape.

Period	Land and Water Management	Scale
Protohistory	Canal networks to irrigate fields around the TC villages.	Local
Roman	Cultivated land divided into square fields by a regular grid of roads and ditches.	Regional
Medieval	Settlements located in a topographically higher position in the surrounding wetlands. Silvopastoral sustenance practice.	Local
Post-Medieval	Channelisation and wetland reclamation works.	Regional

Table 1. Main historical human-induced landscape transformations and their scale.

Materials and Methods

Many authors have underlined the importance of integrated approaches in urban and cultural landscapes (Butzed 2008; Giordano et al. 2015), with studies on geomorphological heritage with assessment, inventories, cartography (Reynard et al. 2017), multi-temporal cartographic and photographic comparison, geo-thematic cartography and documentation (Faccini et al. 2017), specific legend (Faccini et al. 2017; Bollati et al. 2017), LiDAR data (Hofler et al. 2015), archaeo-stratigraphic data, geographic information system format and database (Amato et al. 2018), dendrochronological reconstructions (Cremaschi et al. 2009; Bollati et al. 2018) and dendrochemical analysis (Kocic et al. 2014, Vezzola et al. 2017), sedimentology, malacology, palaeontology and archaeology (Bkhairi et al. 2014), historical maps, written archives, digital terrain model and iconographic sources (Clivaz and Reynard 2017).

This study has been performed using both geomorphological tools and archaeological-historical data. The geomorphological literature on the Central Po Valley (Cremaschi and Marchesini 1978; Cremaschi et al.1980; Castaldini 1989; Castiglioni et al. 1997; Castiglioni and Pellegrini 2001; Marchetti 2002) constituted a useful starting point in association with a preliminary remote sensing analysis performed by using both Google Earth and Bing maps images (acquisition date, 2016-2018) and UAV images.

The Digital Terrain Model (DTM, 0,5-meter of resolution) of the research area has been elaborated with the software QGIS starting from the national DEM (1-meter of resolution) produced from high-resolution LiDAR (Geoportale Nazionale) and regional elevation checkpoints (m. a.s.l.) (Geoportale Emilia Romagna).

The archaeological evidence has been collected through literature (Degani 1974; Cremaschi et al. 1980; Baricchi 1989; Bottazzi et al. 1995; Mancassola 2012), regional web databases and during field surveys. The 18th and 19th centuries transcriptions of medieval account and parchments (Bolognini 1780; Affo' 1792; Tiraboschi 1824; Cantarelli 1882) constituted a valuable starting point in the analysis of the historical documents along with the 20th century editions of medieval documents kept at the Parma and Reggio Emilia National Historical Archives (Torelli 1921; Drei 1924).

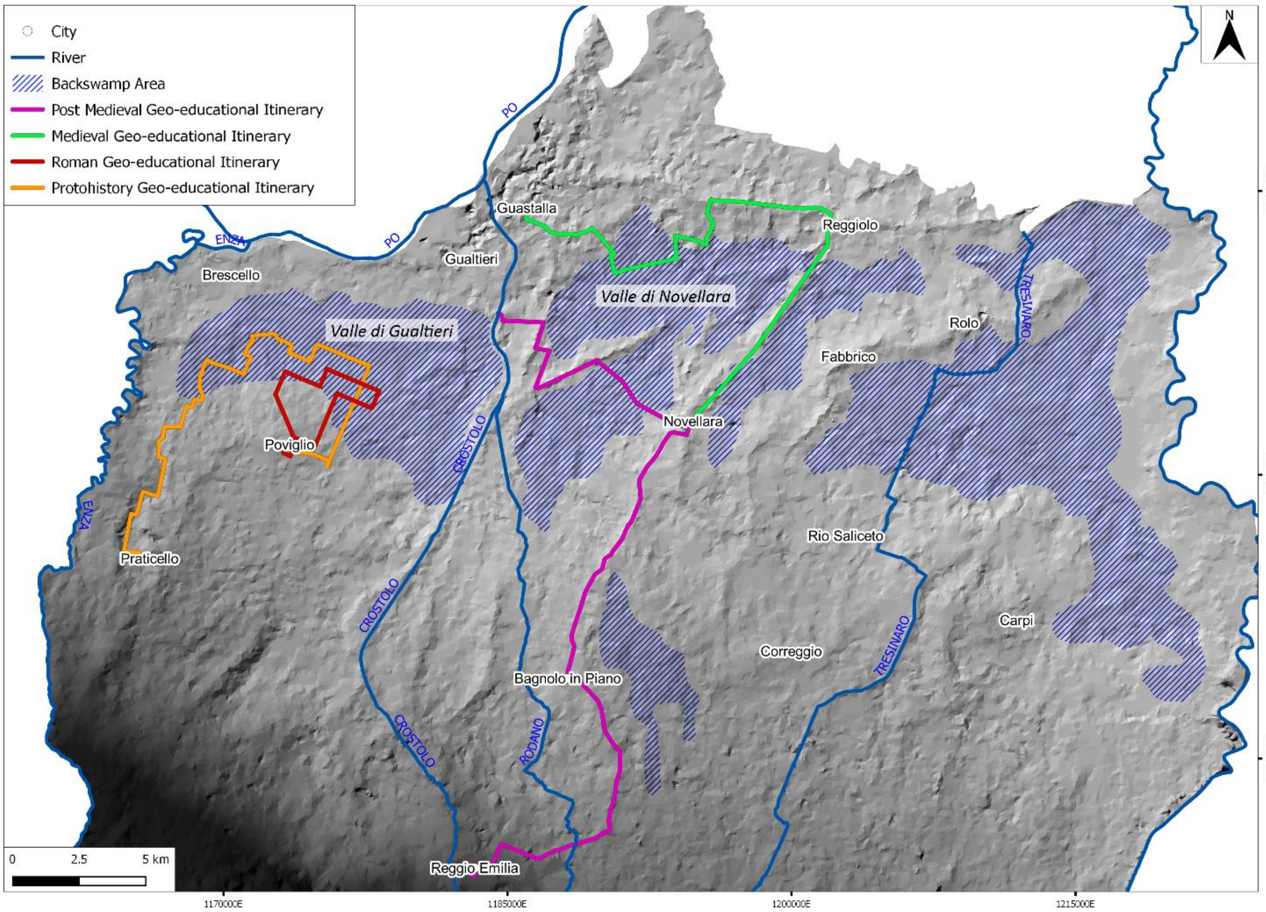

Figure 2. Digital Terrain Model of the study area elaborated with software QGIS. In four different colours are indicated the four Geo-educational itineraries (GeI) proposed.

The historical-archaeological data (documents, historical maps, place names, archaeological excavation reports) were added to the DTM and allowed us to date and contextualise the landforms detected. The archaeomorphological analysis of historical-communication routes and their definition constituted an advantageous approach to understand the landscape evolution dynamics. The landscape cultural palimpsest (sensu Orengo and Palet 2014) of the study area was analysed defining four different environmental layers, each with peculiar geomorphological and archaeomorphological features developed in four historical time periods: Protohistory, Roman Era, Medieval Times and Post-Medieval period. Each layer constitutes the base to propose potential geomorphosites and to define four geo-educational itineraries (Garavaglia and Pelfini 2011) (hereafter GeI) to promote geoconservation and valorisation practices on the palaeolandscapes detected. Finally, in this study, the term geoarchaeomorphosite (hereafter GAm) indicates any geomorphosite (sensu Panizza 2001; Reynard and Panizza 2005) resulted by human-induced landscape changes and for which the archaeo-historical data are essential to 1- comprehend its genesis and development; 2- evaluate its scientific and cultural/historical values.

Results

The four GeIs proposed have been reported on the DTM elaborated (fig. 2). Each GeI is articulated in multiple-stops trails that connect the potential GAms proposed. Table 2 summarises the main geomorphological and archaeomorphological elements detected, the potential GAms (both hidden or not hidden), the trail-length and its travel time in three different transport modes: walking, cycling and driving.

Geo-educational Itinerary (GeI)	Fluvial Geomorphology	Archaeomorphology	Potential GeoArcheo-morphosites (GAm) h – hidden	Length (Km)	Modes of transport and Travel Time
Protohistoric (Fig. 3)	Enza-Praticello Paleochannel	TC buried villages and hydraulic structures	1- Praticello mound (h) 2- Mid-course of Praticello Paleochannel 3- TC village *Le Grazie* (h) 4- TC village *Santa Rosa di Poviglio* (h) 5- TC village *Monticelli di Castelnuovo* (h)	36	Walking: 7 h 10’ Cycling: 1h 40’ Driving: 45’
Roman (Fig. 8)	Accentuation of the sedimentary process of Apennine watercourse with consequent aggradation of the river beds (an effect of Roman land and water management)	*Centuriation* tracks: Hidden / Buried roads and ditches; Regular grid restored in Renaissance	6- Roman *centuriation* tracks 7- *Via Romana*	20	Walking: 4 h Cycling: 1 h Driving: 25’
Medieval (Fig. 10)	Backswamps; Tagliata Canal Crevasse splays; *Crustulus Vetus* paleochannel	Tagliata Canal; Land-fill ridges	8- the star-shaped medieval city of Guastalla 9- *Valli Nuove di Guastalla* (h) 10- Medieval hydraulic device on the *Tagliata Canal* landform 11- Medieval wetland between Novellara and Fabbrico (h)	37	Walking: 7 h 25’ Cycling: 1 h 50’ Driving: 45’
Post-Medieval (Fig. 17**)**	(Artificial) diversion of Apennine watercourses	*Fossa Alessandrina* canal; Channelisation and wetland reclamation works	12- *Botte Bentivoglio* hydraulic device 13- San Bernardino Church – *Crustulus Vetus* paleochannel 14- Post-medieval road along the Water-Mills canal 15- Bagnolo in Piano, artificial diversion of Rodano River in *Canalazzo Tassone* 16- Gavassa, *Naviglio di Correggio* Canal 17- Reggio Emilia, artificial diversion of Crostolo River (h)	50	Walking: 10 h Cycling: 2 h 30’ Driving: 1 h

Table 2. For any geo-educational itinerary (GeI) are indicated the main fluvial geomorphological and archaeomorphological features, the potential geoarchaeomorphosites (GAms), the trail-length and its travel time in three different transport modes: walking, cycling and driving.

Henceforward each GeI is presented in detail.

Protohistoric Geo-educational Itinerary

In the Protohistoric Period, the human enterprise was limited to settling in the most favourable landscape places without modifying its natural shape in large-scale. The geomorphological features dated to Protohistory are the results of the meandering nature of the Apennine rivers and creeks.
The Protohistoric GeI follows the path of the river Enza's Praticello paleochannel (Fig. 3) that represents the most relevant protohistoric landform in the area. The itinerary starts from the little town of Praticello from which the Enza river paleochannel takes its name: here (Fig. 3, n. 1) at ground level is perceivable the paleochannel slope detected in the DTM (Fig. 4). Also, in the Praticello village, Tirabassi (1996) believes that the mound (GAm 1, Table 2) where the town church is located corresponds to a Bronze Age settlement: no archaeological data confirm this hypothesis, also because in medieval times the Bronze Age mottes were often re-used to settle fortified villages or churches making difficult to detected protohistoric evidence.

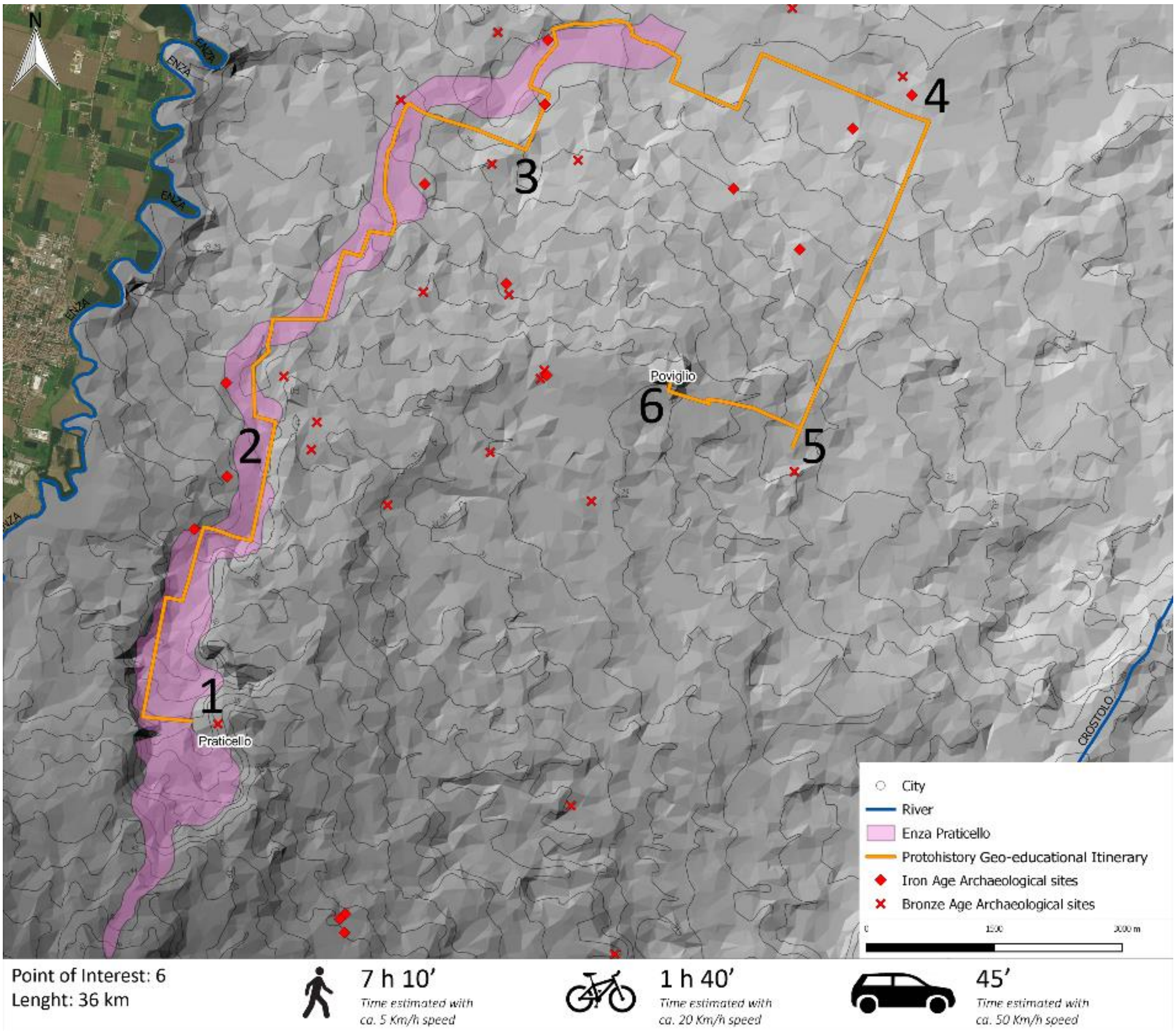

Figure 3. Protohistoric geo-educational itinerary. Six point of interest along 36 Km are proposed: 1 – Village of Praticello (GAm 1, Table 2); 2- Mid-course of Praticello paleochannel (GAm 2, Table 2); 3 – Terramare Culture Village Le Grazie (GAm 3, Table 2); 4- Terramare Culture Village Santa Rosa di Poviglio (GAm 4, Table 2); 5- Terramare Culture Village Monticelli di Castelnuovo (GAm 5, Table 2); 6 – Poviglio Archaeological Museum.

Even though the land and water management seems not to have affected the natural development of the Praticello paleochannel, this landform is strongly linked with human protohistoric settlements. In fact, along with these geomorphological features many archaeological findings related to the Bronze Age TC (16th - 12th centuries B.C) have been reported in the last decades (see Degani 1974; Cremaschi et al. 1980; Bottazzi et al. 1995). The TC is considered the first urbanisation occurrence in the history of Po Valley for sites capillarity and its complex structural villages. The land and water management activities of this culture were limited to clearance and channelisation for agricultural purposes around the villages. No large-scale anthropogenic practices occurred in protohistory times, at least no one that altered the natural physical evolution of the landscape. The archaeological excavation of the TC sites (see Bernabò Brea et al.1997, Bernabo' Brea and Cremaschi 2004; Cremaschi et al. 2006; Mele et al. 2013) unearthed complex water systems both to irrigate the cultivated fields and to defend the villages.

Through dirt roads, the Protohistoric GeI reaches the second stop (Fig. 3, n. 2), located in the mid-course of the Enza river Praticello paleochannel (GAm 2, Table 2). In this area (Fig. 5), archaeological excavations and survey reported both Bronze Age and Iron Age finds: their distribution along the palaeochannel banks seem to confirm that this fluvial geomorphological feature was still active in the pre-roman era. As mentioned previously, after the decline of the TC, due to climatic and ecological causes (Bernabò Brea et al. 1997), the Po plain was abandoned and recolonised only centuries later, at the beginning of the 8th century BC. During the Iron Age (7th – 3rd centuries BC), the human settling was scattered in rural locations and not concentrated in larger fortified sites as in the Bronze Age. In addition, in this period human enterprise did not affect the morphological development of the environment. The Iron Age drainage systems detected consist of local land and water management activities related to small/medium farmholds (Dall'Aglio 2014).

The Protohistoric GeI continues to the place called "Le Grazie" (Fig. 3, n. 3). Here (GAm 3, Table 1) the archaeological survey reported the existence of a little TC village settled on a motte. The next stops, Santa Rosa di Poviglio (Fig. 3, n. 4) and Monticelli di Castelnuovo (Fig. 3, n. 5) are buried Bronze Age settlements. These archaeomorphological features are buried remnants of the ancient landscape and represent potential hidden geomorphosites (Brilha 2017; Clivaz and Reynard 2017). The TC village of Santa Rosa di Poviglio (GAm 4, Table 2) has been widely studied since the 1980s and complex hydraulic structures have been discovered (see Bernabo' Brea and Cremaschi 2004; Cremaschi et al. 2006; Mele et al. 2013) (Fig. 6). Monticelli di Castelnuovo (GAm 5, Table 2) has never been excavated so far, but the aerial images and ground survey suggest an archaeological context very close to Santa Rosa di Poviglio (Fig. 7).
The Protohistoric GeI ends at the Poviglio Archaeological Museum (Fig. 3, n. 6) that exposed the TC archaeological materials.

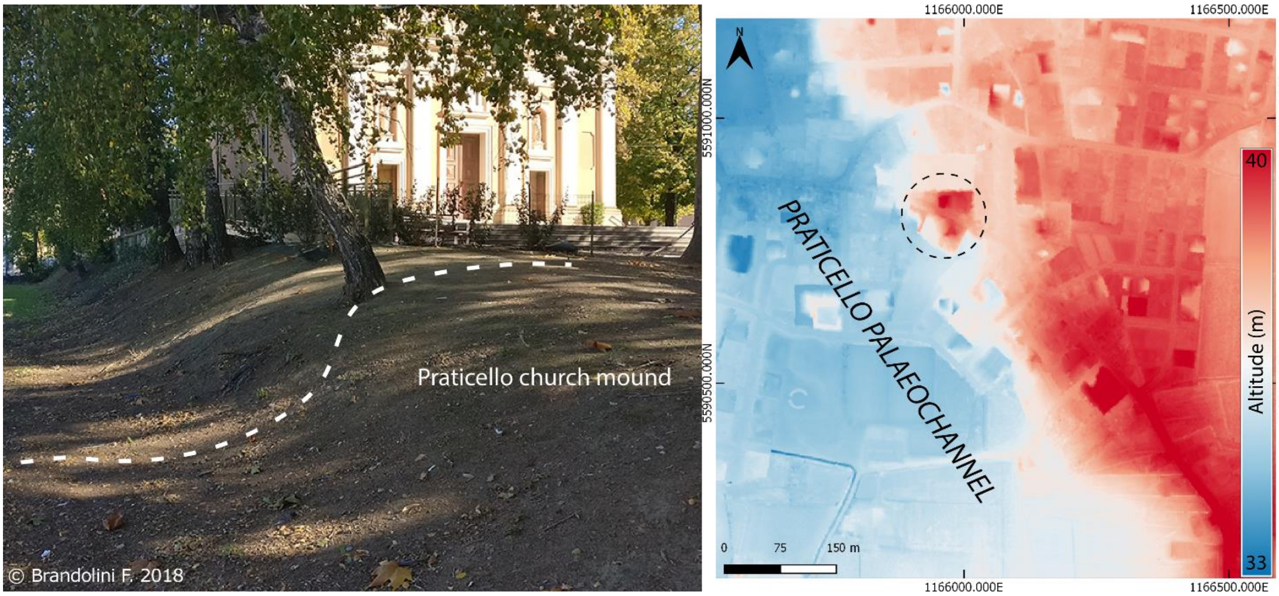

Figure 4. Protohistoric geo-educational itinerary, geoarchaeomorphosite 1: the town church of Praticello (on the left) settle on an earth mound (dashed circle on the right) along the Enza Praticello Paleochannel.

Figure 5 Protohistoric geo-educational itinerary, geoarchaeomorphosite 2: mid-course of the Enza river Praticello paleochannel.

Figure 6 Protohistoric geo-educational itinerary, geoarchaeomorphosite 4: Santa Rosa di Poviglio (Bronze Age Terramara Culture Village). On the left, the aerial image of the hidden archaeomorphological features: earth ramparts and moat. On the right: two pictures were taken in the 90s during archaeological campaigns led by Università degli Studi di Milano (Italy).

Figure 7 Protohistoric geo-educational itinerary, geoarchaeomorphosite 5: Monticelli di Castelnuovo - (Bronze Age Terramara Culture Village). On the left, aerial view of the hidden archaeomorphological features (modified from ©Google Earth 2018). On the right, the same hidden landforms visible at ground level.

Roman Geo-educational Itinerary

The Roman colonisation in Central Po Plain started in the 2nd century BC and constituted the first large-scale landscape structuration in the Po Valley. Between 2nd century BC and 6th century AD, the area was drained and converted to farming with the onset of centuriation, a division of the cultivated land by a regular grid of roads and ditches. The centuriation tracks are the most relevant archaeomorphological features of the Roman Period. The significant amount of archaeological data available for that period (see Bottazzi et al. 1995) (Fig. 8) reveals that the Roman colonisation occupied ridges and paleochannels already active during the Bronze Age, overlapping to the Protohistoric landforms. In the Roman Period, for instance, the Enza River abandoned the Praticello paleochannel that was turned in cultivable land.

Furthermore, the natural geomorphological development of the Apennine watercourses was modified by the construction of artificial levees that increased the load sediment discharge of the Po River and its tributaries. The Roman drainage system was oriented in order to ease the water outflow from the small ditches to the main channels, avoiding the risk of flood events (see Dall'Aglio and Franceschelli 2007; Dall'Aglio 2014).

The proposed Roman GeI consists of a path along the centuriation tracks: it starts from the Archeological Museum in Poviglio (Fig. 8, n.1) where Roman artefacts are exposed.
The plain degrades progressively from Poviglio to the village of Fodico (Fig. 8, n.2): here (GAm 6, Table 2) centuriation tracks are well preserved also because they have been renovated in Modern Age during land reclamation works. Walking through the modern fields from Fodico to stop n. 3 (Fig. 8, n. 3) the plain degradation is still perceivable as it follows the geomorphological shape of the Valle di Gualtieri backswamps. Often, ploughing activities in the area reveal outcrops of Roman archaeological material: here (Fig. 8, n. 3) a large amount of bricks and pottery fragments suggests the presence of a buried Roman settlement.

The Roman GeI comes back to Poviglio (Fig. 8, n. 4). The Roman roadways network often survived after the decline of the Western Roman Empire not only as cultivated field limits but also as pathways. The diagonal axis from Brixellum (i.e. Brescello) to Regium Aemilia (i.e. Reggio Emilia), for instance, played a crucial role in the post-Roman era, surviving until nowadays with the name of “Via Romana” (i.e. Roman Road) (GAm 7, Table 2) (Fig. 9). The Roman roads are the most relevant archaeomorphological features of the Roman period in the area.

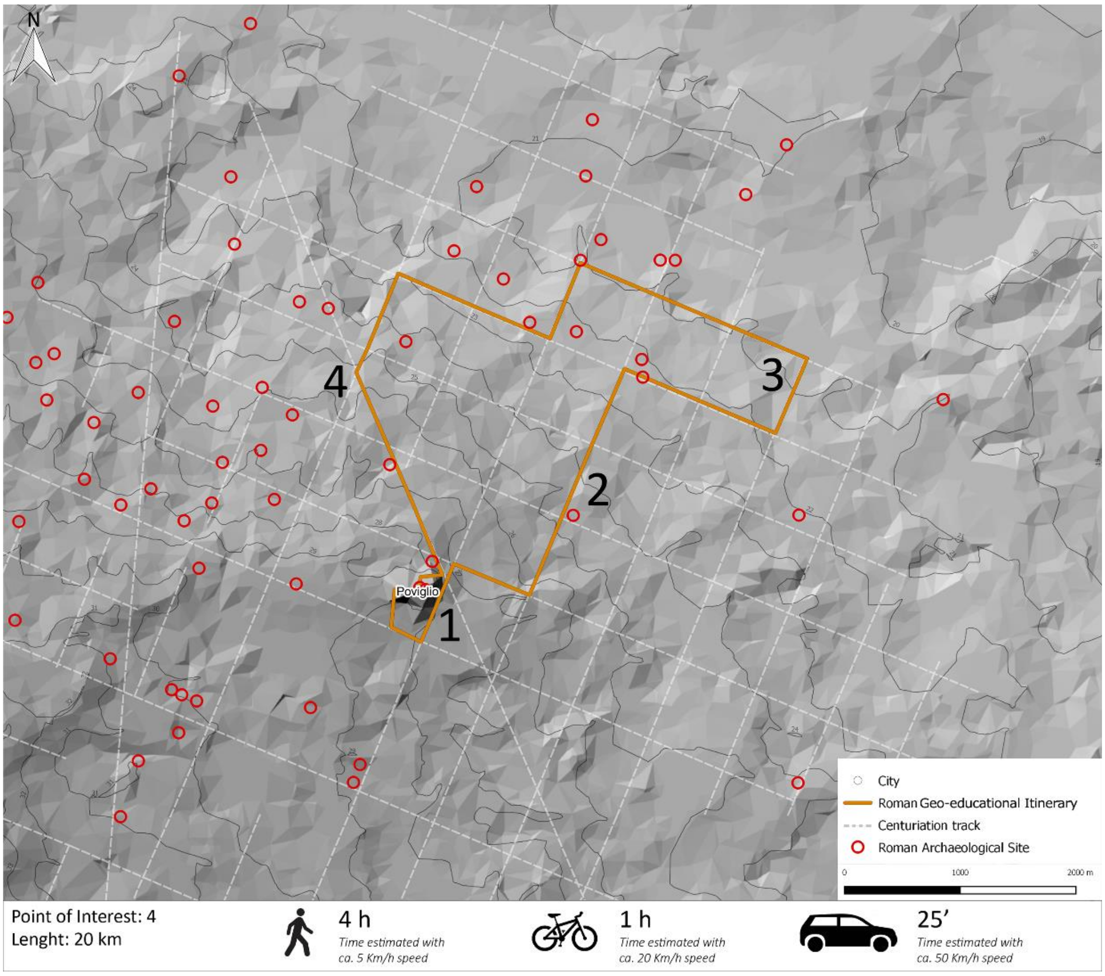

Figure 8. Roman geo-educational itinerary. Four points of interest 20 Km are proposed: 1 – Poviglio Archaeological Museum; 2- Roman centuriation tracks (GAm 6, Table 2); 3 –Outcrop of Roman archaeological material; 4- Via Romana (GAm 7, Table 2).

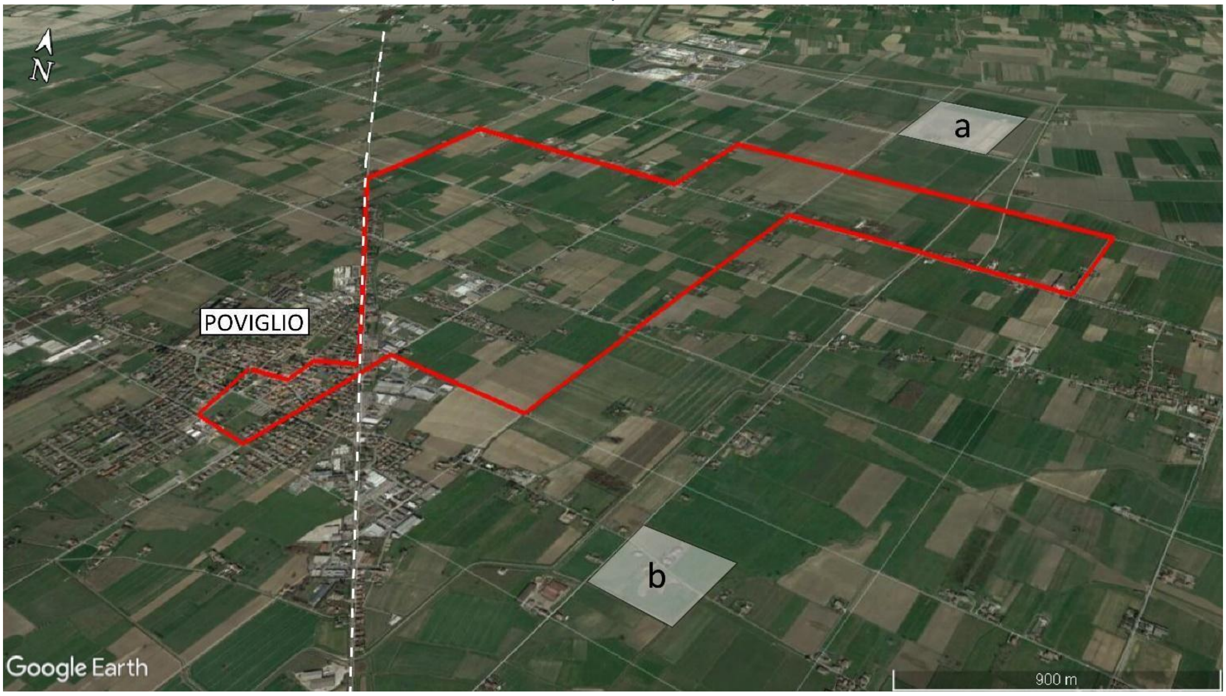

Figure 9. Bird's eye view of the Roman archaeomorphological features. The dashed line indicates the Via Romana (GAm 7, Table 2). The solid white lines indicate the Roman centuriation track still visible on the terrain. The two white squares indicate the position of the two TC villages of S. Rosa di Poviglio (a) and Monticelli di Castelnuovo (b). The red line corresponds to the Roman GeI proposed (modified from ©Google Earth 2018).

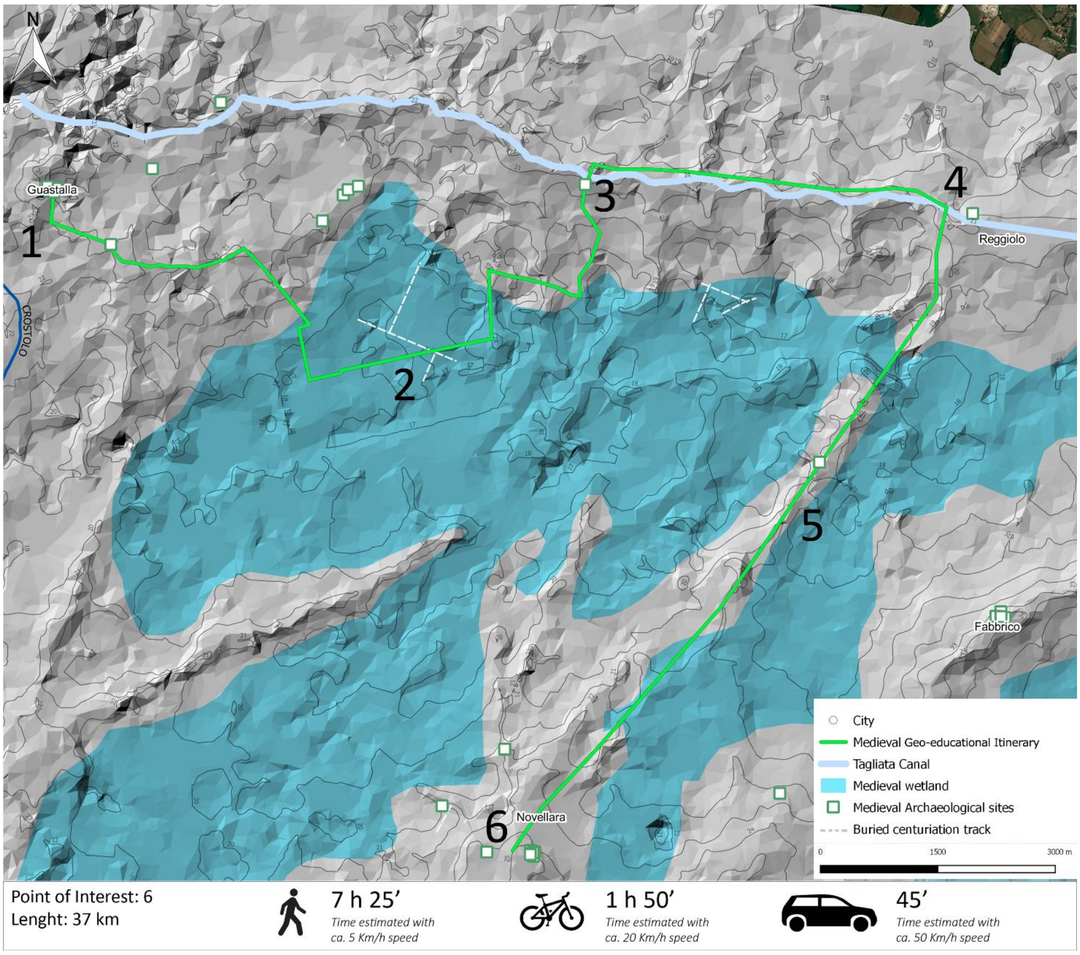

Figure 10. Medieval geo-educational itinerary. Six points of interest along 37 Km are proposed: 1 – the Star-shaped Medieval city of Guastalla (GAm 8, Table 2); 2- Valli Nuove di Guastalla: inside the medieval wetlands. Here buried Roman centuriation tracks have been detected (GAm 9, Table 2); 3 – Medieval Hydraulic device on Tagliata Canal (GAm 10, Table 2); 4- the Medieval city of Reggiolo; 5 – Backswamp waterlogged in Medieval times between Novellara and Fabbrico (GAm 11, Table 2); 6- the Medieval city of Novellara.

In the passage from the Roman period to the Middle Ages, the landscape profoundly changed as revealed by archaeomorphological analysis.

The waterlogging of the Valle di Gualtieri and Valle di Novellara (Fig. 2) occurred in the post-Roman period and affected human sustenance and settling practices until the 10^{th} century AD. At the end of the Roman Empire, lack of maintenance on the Roman drainage and hydraulic systems had severe implications for the environment with frequent channel diversions that affected the southern tributaries of the Po river. The Roman embankments themselves accentuated the Holocene sedimentary processes of the Apennine water courses with consequent aggradation of the river beds (see Marchetti 2002; Dall'Aglio 2014); it constituted one of the primary causes of the diversion of rivers and creeks in the post-roman period. The Crostolo river, for example, started to flow in the Valle di Novellara backswamp, inundating vast roman farmland areas (Brandolini and Cremaschi 2018a). When the population decreased, many Roman farms were abandoned, and alluvial sediments often buried the centuriation road and ditches.

According to historical-archaeological data, the early medieval settlements (6^{th} – 10^{th} centuries AD) concentrated on the fluvial ridges in the new palustrine landscape. These topographically higher positions around the swampy meadows were strategic to control the waterways and the sustenance resources. The castrum represents the typical early medieval age settling pattern (Brandolini et al. 2018): a village often raised around a previous Roman villa rustica or a church and fortified with earth ramparts, wooden fences and moats. In the research area, these fortified villages (or castra) are known only by historical documents (Tiraboschi 1824; Torelli 1921) and constituted the first core of the further Late Medieval and Renaissance towns: es. Castrum Popilii

– Poviglio; Wardestalla Castrum – Guastalla; Luciaria Castrum – Luzzara; Castrum Gualtieri – Gualtieri; Faurice Castrum – Fabbrico; Brixellum Castrum – Brescello; Nuvellare curtis – Novellara.

The Medieval GeI starts from Guastalla (Fig. 10, n. 1), one of the most important cities settled in the Early Middle Ages with the name of Wardistalla. This town (GAm 8, Table 2) is characterised by a star-shaped frame developed in Medieval times and still well preserved in the modern urban plant (Fig. 11).

Figure 11. Geoarchaeomorphosite 8 (Table 1): the Medieval star-shaped city of Guastalla. (modified from ©Google Earth 2018).). The white dashed line represents the Medieval geo-educational itinerary proposed.

From here the path goes downhill to the medieval swamps. This area (Fig. 10, n. 2), today is known by the name of "Valli Nuove di Guastalla" (i.e. the new Guastalla Valleys) (GAm 9, Table 2). It corresponds to the deeper part of the medieval swamp developed in the Valle di Novellara backswamps and was reclaimed only at the beginning of 20th century AD (Gabbi 2001; Saltini 2005). As previously mentioned, the centuriation tracks have often been buried by alluvial sediments during the Early Medieval Age (6th – 10th Century AD), a consequence of frequent flood events. Here aerial image analysis reveals the remnants of few centuriation regular grids. These crop marks and soil marks are relevant evidence of hidden archaeomorphological landforms, cultural landscape features active in the past and now buried under more recent geomorphological elements. In this portion of the study area the overlapping of different geoheritage cultural layers is visible: first Roman tracks, then medieval swamp sediments, finally the present-day rural drainage system (Fig. 12)

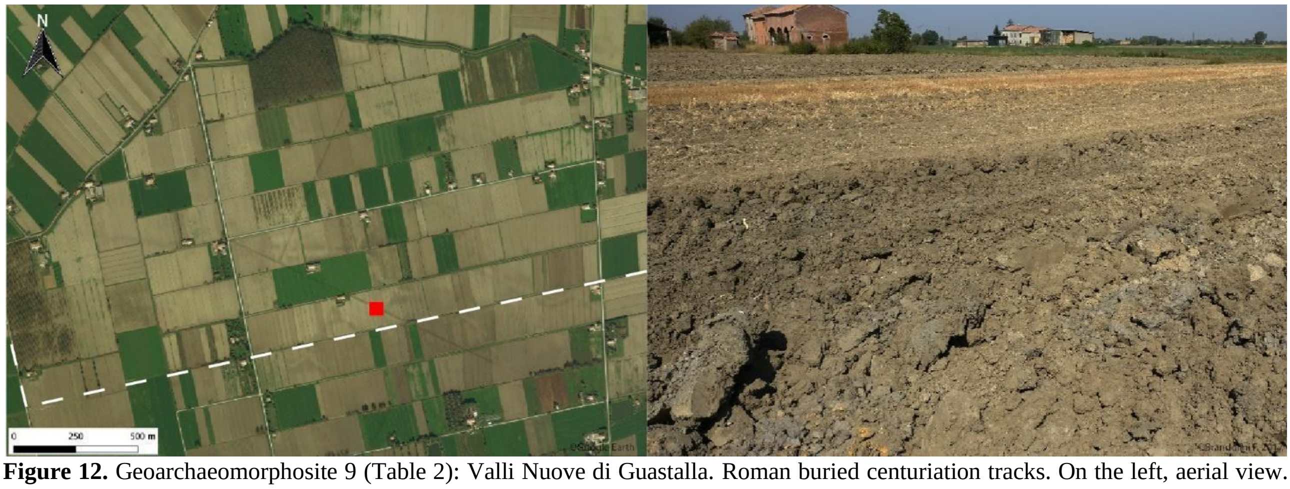

Figure 12. Geoarchaeomorphosite 9 (Table 2): Valli Nuove di Guastalla. Roman buried centuriation tracks. On the left, aerial view. The white dashed line corresponds to the Medieval geo-educational itinerary proposed (modified from ©Google Earth 2018). The red square (Stop n.2 in the itinerary) corresponds with the terrestrial view acquisition point (on the right).

From the medieval swamp, the path climbs up to the Tagliata Canal ridge (Fig. 10, n. 3), the most prominent archaeomorphological features developed in Medieval Times. This landform is the result of the channelisation enterprise started in the 12th century AD and is the most relevant geomorphological feature developed in Medieval times in the research area. In 1218 the allied cities of Cremona and Reggio Emilia started the construction of this new waterway parallel to the Po river in order to avoid paying commercial fees to the rival city of Mantova (Cantarelli 1882; Affò 1792; Tiraboschi 1824).

The fluvial ridge of this canal is still recognisable in the landscape, and its shape is the result of both natural and human events. The medieval chroniclers reported that the opening of the Tagliata Canal had negative implications for the environment, with frequent floods in the surrounding farmland between the 13th and 14th centuries AD (Cantarelli 1882; Affò 1786; Affò 1792). The results of these historical flood events are the crevasse splays detected in the DTM (Fig. 8) and using aerial images (Fig. 13).

Also, it is interesting that the place names of villages located along the Tagliata canal still remember the occurrence of floods: es. Fangaia (from "Fango" □ "Mud", refers to alluvial sediments) or Villarotta ("Villa Rotta" □ "Breach Ville", refers to a crevasse splay event). Moreover, the DTM (Fig. 2) reveals elongated straight landforms that are likely to be the results of anthropic activities of flood management to obtain new farmland filling the swampy meadows with alluvial sediments: these anthropic geomorphological features have been called land-fill ridges by Brandolini and Cremaschi (2018a). GAm 10 (Table 2) is located at the mid-course of the Tagliata Canal, in an area where is possible to visit a still-standing medieval hydraulic device (Fig. 14), not far from crevasse splays resulted from Late Holocene floods.

Figure 13. Canal Tagliata. The white dashed line indicates the Medieval geo-educational itinerary proposed between the stops 3 and 4. The red square indicates the geoarchaeomorphosites 10 (Table 2) where is located a Medieval hydraulic device on the Tagliata Canal (Fig. 13). The light blue line indicates the Tagliata Canal watercourse. The white squares highlight the crevasse splays developed between the 13th and 14th century AD (modified from ©Google Earth 2018).

Following the Canal watercourse, the medieval town of Reggiolo (Fig. 10, n. 4) can be reached; it was settled in 10th century AD as a fluvial port, and then in the 13th century AD it was turned in a stronghold to control the trades along the Tagliata Canal

Figure 14. Medieval Hydraulic device on the Tagliata Canal. Point of interest n.3 along the Medieval geo-educational itinerary proposed.

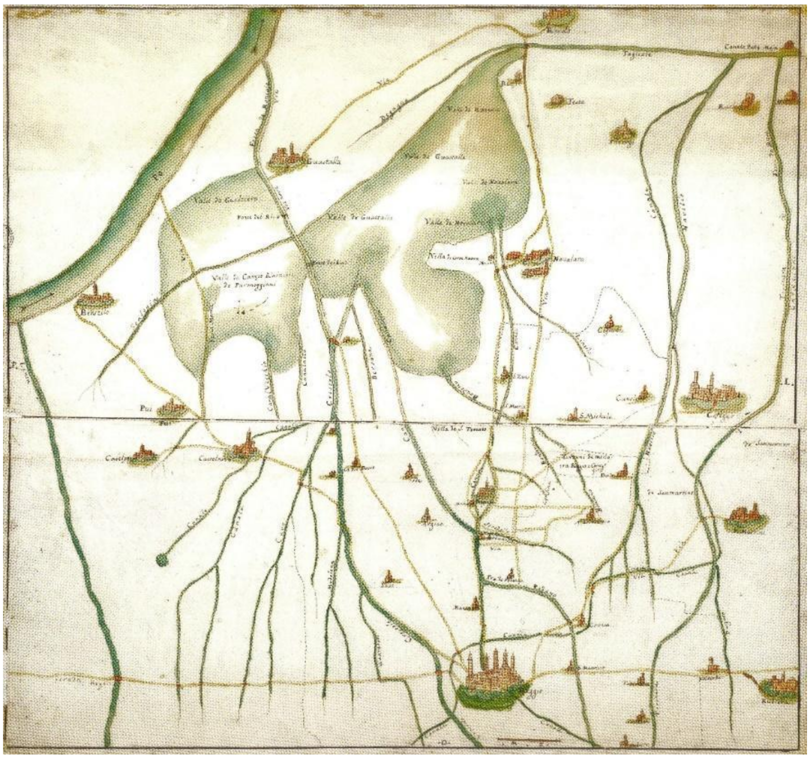

Figure 15. Medieval historical map that shows the landscape before the Renaissance land reclamation project. (AsMo 52, XVIIIsec. Modena National Historical Archive – "Congragazione delle Acque e delle Strade, Reggio e Reggiano). (Adani et al. 1990)

In the 16th map of the two swamps, drawn before the Renaissance large-scale land reclamation project (Fig. 15), the hydrological and channelised system, as should have appeared in Late Medieval times (11th – 15th century AD), is represented. The map shows that roadways integrated the waterways medieval communication networks. Although canals and rivers were preferred to land routes in Medieval times for safety reasons, new roads were built along the course of the main waterways: one of those was Reggio Emilia – Bagnolo in Piano – Novellara - Reggiolo; and two roads along the Crostolo river and the Tagliata canal.

Figure 16. Medieval geo-educational itinerary, the point of interest n. 5. The black arrows indicated a portion of the medieval swamps of Valle di Novellara (GAm 11, Table 2).

The proposed Medieval GeI follows the medieval road reported in the historical map that connected Reggio Emilia to Reggiolo through the city of Novellara. We propose the point of interest n. 5 (Fig. 10, n. 5) where the modern national road follows the medieval historical path along the medieval Linarola canal: it was renovated in the 18th and 19th centuries and now is part of the 20th drainage system (Fig. 16). Looking at the fields from here, the dark soil zones are the areas where there used to be the medieval swamps before the Renaissance wetland reclamation. The Medieval GeI ends in the city of Novellara (Fig. 10, n. 6): this town, founded in 9th – 10th century AD, settles on a fluvial ridge, a strategic higher position to control waterways in medieval times.

Post-Medieval Geo-educational Itinerary

In the 16th century AD, a large-scale land reclamation project promoted by the lord of Guastalla Cornelio Bentivoglio profoundly transformed the medieval environment. The project started in 1560 and consisted in the construction of and hydraulic device called Botte Bentivoglio, located at the intersection between the Parmigiana channel and the Crostolo River. This structure allowed the Parmigiana canal to pass under the Crostolo River and to drain waters from the two valleys in the Secchia River (Mori 1923; Gabbi 2001; Saltini 2005). The Post Medieval GeI starts at the Botte Bentivoglio (Fig. 17, n.1). The Renaissance building was renovated in 18th century AD as mentioned by a 1760s epigraph: it remembers renovation works occurred to the Botte after a Po River severe flood event. This location (Fig. 18) is the perfect synthesis of geomorphological and historical-archaeological evidence and represents the most important archaeomorphological feature of the Renaissance landscape in the area.

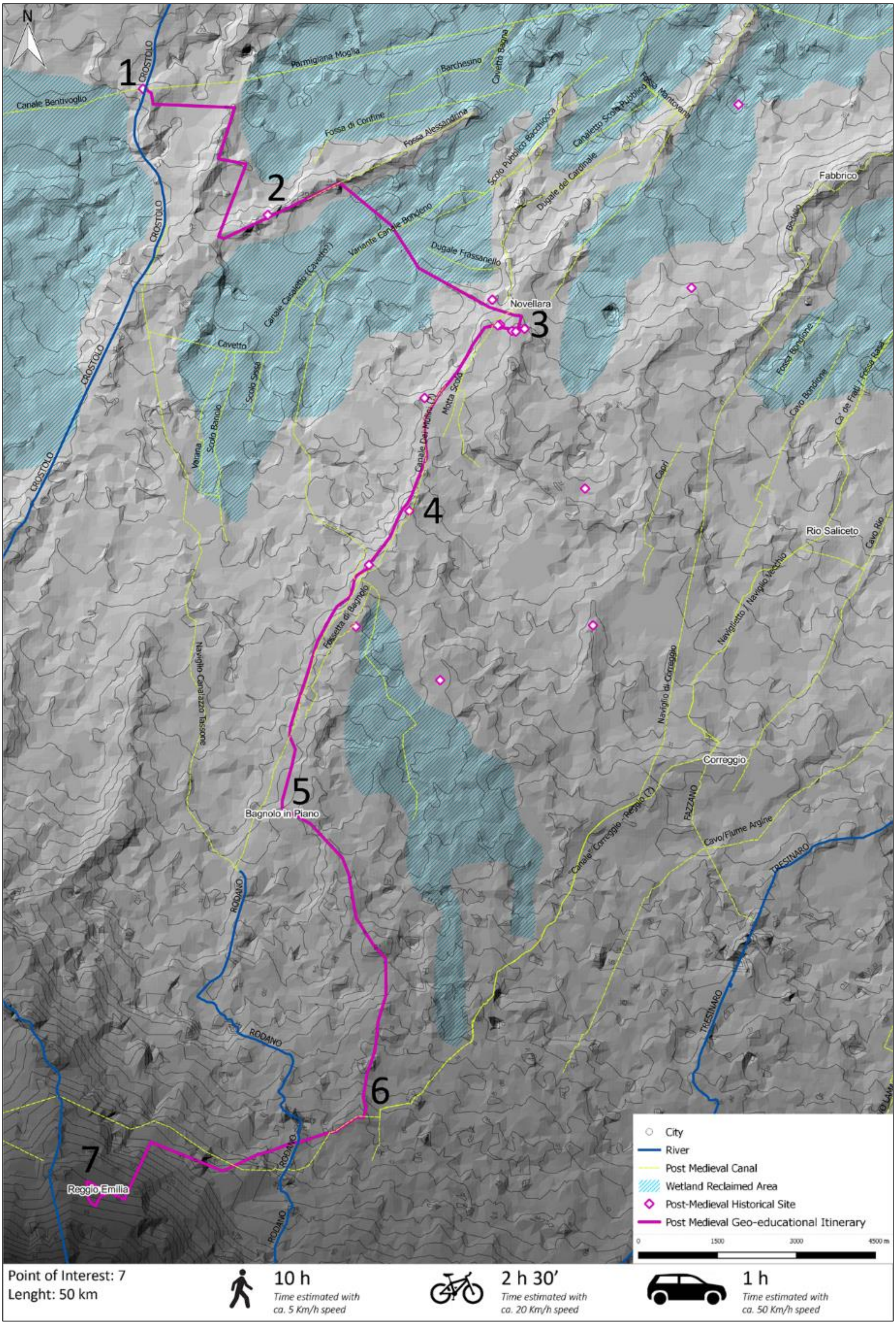

Figure 17. Post Medieval geo-educational itinerary. Seven point of interest along 50 Km are proposed: 1 – Botte Bentivoglio hydraulic device (GAm 12, Table 2); 2 – San Bernardino Church along the Crustulus Vetus / Fossa Alessandrina ridge (GAm 13, Table 2); 3 – Novellara; 4- Post-medieval road along the Mills Canal (GAm 14, Table 2); 5 – Bagnolo in Piano (GAm 15, Table 2); 6 – Gavassa (GAm 16, Table 2); 7- Reggio Emilia historic center (GAm 17, Table 2).

Figure 18. Geoarchaeomorphosite 12 (Table 1): the "Botte Bentivoglio" hydraulic device at the interserction between Crostolo River and Parmigiana Canal.

A map dated to 1698 (Fig. 19) represents the hydrographical landscape situation of the study area after the Bentivoglio land reclamation works, and historical documents report details about the opening of new canals and the upgrading of medieval ones. The channelisation in Post-Medieval times was promoted both for commercial and agriculture reasons (Bolognini 1780; Badini 1990).

Figure 19. Medieval historical map that shows the landscape after the Renaissance land reclamation project. (AsMo 53, XVIIIsec. Modena National Historical Archive – "Congragazione delle Acque e delle Strade, Reggio e Reggiano). (Adani et al. 1990)

After crossing the Crostolo River, the path moves southward, to the Crustulus Vetus paleochannel (Fig. 18, n. 2). This geomorphological feature developed in medieval times when the Crostolo River, as said before, flowed in the Valle di Novellara backswamp (Brandolini and Cremaschi 2018a). This paleochannel was abandoned in Renaissance when the Crostolo River was artificially diverted in the Po River. In 17th – 18th centuries AD, historical documents and maps report that a drainage canal (Fossa Alessandrina) was excavated on the Crustulus Vetus ridge (Cremaschi et al. 1980; Brandolini and Cremaschi 2018a). The San Bernardino 17th-century church represents the stops n. 2 in the Post Medieval GeI proposed. (Fig. 20).

The Post Medieval GeI continues to Novellara crossing a portion of the Medieval swamp (between stops 2 and 3). Here post-medieval canals as the artificial Bondeno canal are still active and allow the farmlands to be irrigated and drained. The town of Novellara (Fig. 18, n. 3) continued its growth during the Renaissance and Modern Age as a strategic centre of the Central Po plain. In Post Roman period new roads and canals were built from Novellara to Reggio Emilia, and some parts of this connection network are still active and walkable (Fig. 18, n. 4). At the medieval town of Bagnolo in Piano (Fig. 18, n. 5) the Post Medieval GeI goes East to Massenzatico and Gavassa (Fig. 18, n. 6), two little centres reported in the post-medieval historical maps. Here the Post Medieval GeI meets the remnants of the canal and the road that connected Reggio Emilia to Correggio.

Figure 20. Geoarchaeomorphosite 13 (Table 1): Crustulus Vetus paleochannel in the modern farmland. The San Bernardino 17th-century church represents the stops n. 2 in the Post Medieval geo-educational itinerary proposed.

Figure 21. Geoarchaeomorphosite 17 (Table 2): the artificial diversion of the Crostolo River in the Reggio Emilia historic city centre. The course of the Crostolo River was artificially diverted outside Reggio Emilia during the Roman age and in the years A.D. 1250 and A.D. 1571, largely because of westward stream migration (modified from ©Google Earth 2018).

This canal was probably part of the Navigli (i.e. canals) waterways network in Medieval and Renaissance times but was deeply modified by later drainage works. In addition, close to Gavassa, the Rodano creek flows (Fig. 18, n. 6). This Apennine watercourse was artificially channelled in the Canalazzo Naviglio in the 16th AD, and nowadays it still flows in the Crostolo River through the canal Canalazzo – Tassone. The Post Medieval GeI ends in the Reggio Emilia city, the main centre of the Medieval and Post Medieval radial communications network. The final part of the itinerary follows Corso Garibaldi, a road built on a medieval Crostolo River paleochannel (Fig. 21). The city was very recently studied also by an urban geomorphology point of view by Cremaschi et al. (2018).

Discussion

The complex interrelations between natural landscape dynamics and human activities have been widely treated in environmental reconstruction as well as in urban geomorphological studies. A key concept in the study of anthropised landscapes is the definition of hidden landforms and hidden geosites as partially or completely invisible geomorphological features that have been covered or destroyed by urban infrastructures (Reynard et al. 2017; Clivaz and Reynard 2017). In the case of alluvial plains, the proposal of geo-educational itineraries for geoheritage is more challenging because, very often, fluvial landforms are difficult to be perceived at ground level because of the low relief of such features.

In the research area, the Man acted as a landscape-modifying agent since Protohistoric era, and the ancient anthropogenic landforms are often buried or destroyed by later human activities. The result of this complex man-environment interaction is a superimposition of different anthropogenic and geomorphological features developed in the last fifteen centuries. Archaeology and Environmental History played a crucial role in the understanding of this complex system of anthropogenic-geomorphological features: for these reasons, we emphasise how Archaeomorphology overlaps in part with Anthropogenic Geomorphology and underlines human features with more precision. The study object of the two disciplines is indeed very similar (Table 3), but the approach is different: Archaeomorphology emphasises the role of archaeological and historical data in the study of past human impact on the landscape while Anthropogenic geomorphology underlines the human role in shaping the landscape and in affecting geomorphic processes. The Archaeomorphology may be considered as a subset of Anthropogenic Geomorphology focused on the recognition of past human landforms through the use of archaeo-historical data.

Discipline	Definition	Reference
ANTHROPOGENIC GEOMORPHOLOGY	is the study of the role of humans in creating landforms and modifying the operation of geomorphological processes such as weathering, erosion, transport and deposition.	Szabó et al. 2010
ARCHAEOMORPHOLOGY	is focused on the study of human-made landscape forms and traces of territorial planning, such as roads, field systems, terraces or water channels. It aims at analysing the historical development of landscape structures over time and embrace the idea of landscapes as cultural palimpsests.	Orengo and Palet 2014

Table 3. Comparing the definitions of Anthropogenic Geomorphology by Szabó (et al. 2010) and Archaeomorphology by Orengo and Palet (2014).

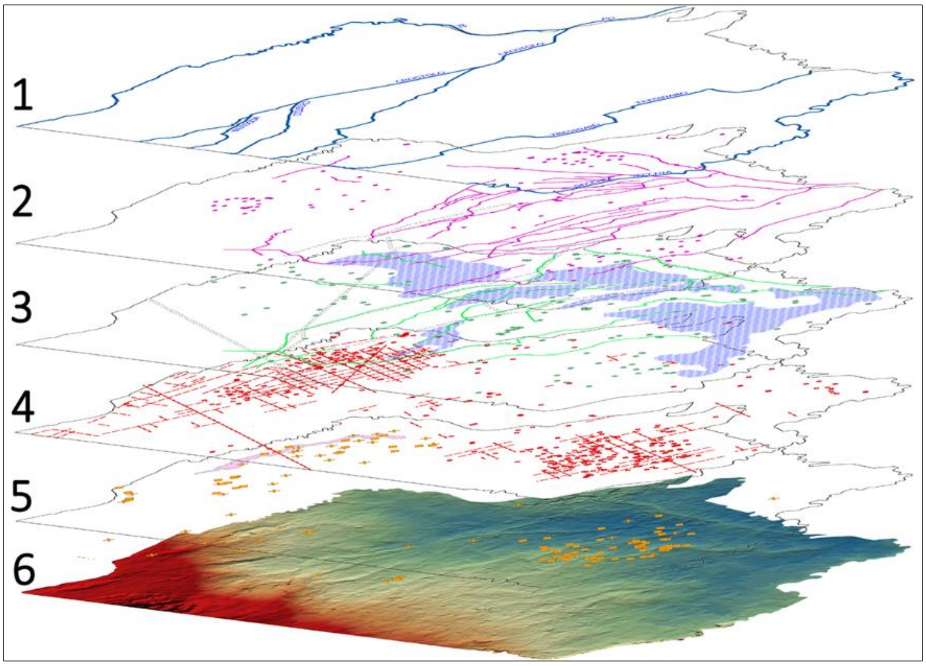

Figure 22. Landscape cultural palimpsest. 1 – Modern river watercourse; 2- Post-medieval archaeomorphological features; 3- Medieval geomorphological and archaeomorphological features; 4- Roman archaeomorphological features; 5- Protohistorical geomorphological and archaeomorphological features 6 – Digital Terrain Model.

In the research area, without any historical and archaeological data, it would have been impossible to know how, why and sometimes when human activities influenced the natural landscape evolution creating human-made landscape features (or archaeomorphological features) such as roads, canals, embankments or field systems. In this portion of the Central Po plain the result of the mutual interaction between humans and the environment consists of a cultural palimpsest of archaeomorphological (es. Protohistoric buried settlements; Roman centuriation tracks; Medieval and Post Medieval roads and ditches) and geomorphological landforms (es. Paleochannels; backswamps and crevasse splays) (Fig. 22).

In Protohistory, the TC settlements appeared as earth mounds (3-4 meters high) emerging in the flat floodplain, but they were deliberately razed in 19th century AD because the local farmers believed that the dark and high-organic soil of those mounds was suitable to fertilise fields. The TC archaeological sites represent hidden archeomorphological features: they are recognisable only from an aerial view or with ground survey during ploughing periods. These hidden features can represent potential GAms because they testify two different phases of land use in this portion of the Po Plain in the past: 1- human settlements in the Bronze Age; 2 - Land management activities in Modern Age (19th century AD).

Furthermore, in Roman Times the establishment of a regular grid of roads and ditches (i.e. centuriation) had such a high impact on reshaping the natural landscape that large portions of the Roman drainage system are still recognisable in the fields. More important, the Roman embankments accentuated the Holocene sedimentary processes of Apennine watercourses with consequent aggradation of the river beds (Marchetti 2002; Dall’Aglio 2014) and when the Roman Empire collapsed, the lack of maintenance on drainage systems and fluvial dykes had severe consequences on the environment with frequent diversions of rivers and creeks in the backswamps. Valle di Gualtieri and Valle di Novellara used to be wetlands, but today only through archaeo-historical data we could encourage valorisation these areas as hidden GAms. Also, in Middle Ages, channelisation and flood management conditioned the geomorphological development of Tagliata Canal and Crostolo River (Brandolini and Cremaschi 2018a): the exploitation of fluvial sediments to reclaim wetland areas modified the geomorphological process of transport and deposition. The results of such activities were the increase of flood hazards between the 13th and 14th century AD and the development of archaeomorphological features (land-fill ridges, sensu Brandolini and Cremaschi 2018a). As observed by Sellier (2013) and Clivaz and Reynard (2017), the detailed study of place names can help in understanding geomorphological processes, and along the Tagliata Canal, the place names still remember the occurrence of floods. Starting from the 16th century AD, the Medieval wetlands were progressively reclaimed: again, the human enterprise profoundly modified the geomorphological processes creating a new human-made landscape.

Our research points out the relevance of using an archaeomorphological approach to understand the landscape evolution of the study area better. Moreover, here we use the term geoarchaeomorphosites (GAms) as the archaeo-historical data represent relevant information in the definition of the potential geomorphosites proposed, especially in case of hidden GAms (es. Protohistoric TC settlements). According to the current geoheritage methodology (Brilha 2017; Bollati et al. 2017), the archaeological information is considered as Additional Values in the definition of geomorphosites, but here this kind of data have proved their potential to propose GAms and geo-educational itineraries in an alluvial environment (Fig. 23).

The terminology proposed by Eric Fouache to indicate archaeological sites that are integrated into the aesthetic landscape (geoarchaeosite, see Fouache and Rasse 2009) and to define geomorphosites with archaeological interest (archaeo-geomorphosite, see Fouache et al. 2012) surely allow to propose complex or composed geomorphosites with high cultural value. Nevertheless, in our case study, the archaeo-historical data had an “active” role in the understanding the landscape geomorphological evolution while in Fouache (2009 and 2012) it is evidenced as an additional value (geoarchaeosite) for some geomorphosites or a prompt (archaeo-geomorphosite) to geomorphological studies. For this reason we proposed the term geoarchaeomorphosites to indicate any geomorphosites derived by the dynamic interaction between natural (mainly fluvial) and human events (es. Protohistoric TC settlements; Roman regular field system; Medieval canals and artificial river diversions) and for which the archaeo-historical data are crucial to assess its genesis and development during different historical times, and to enhance the geomorphosites scientific and cultural/historical values.

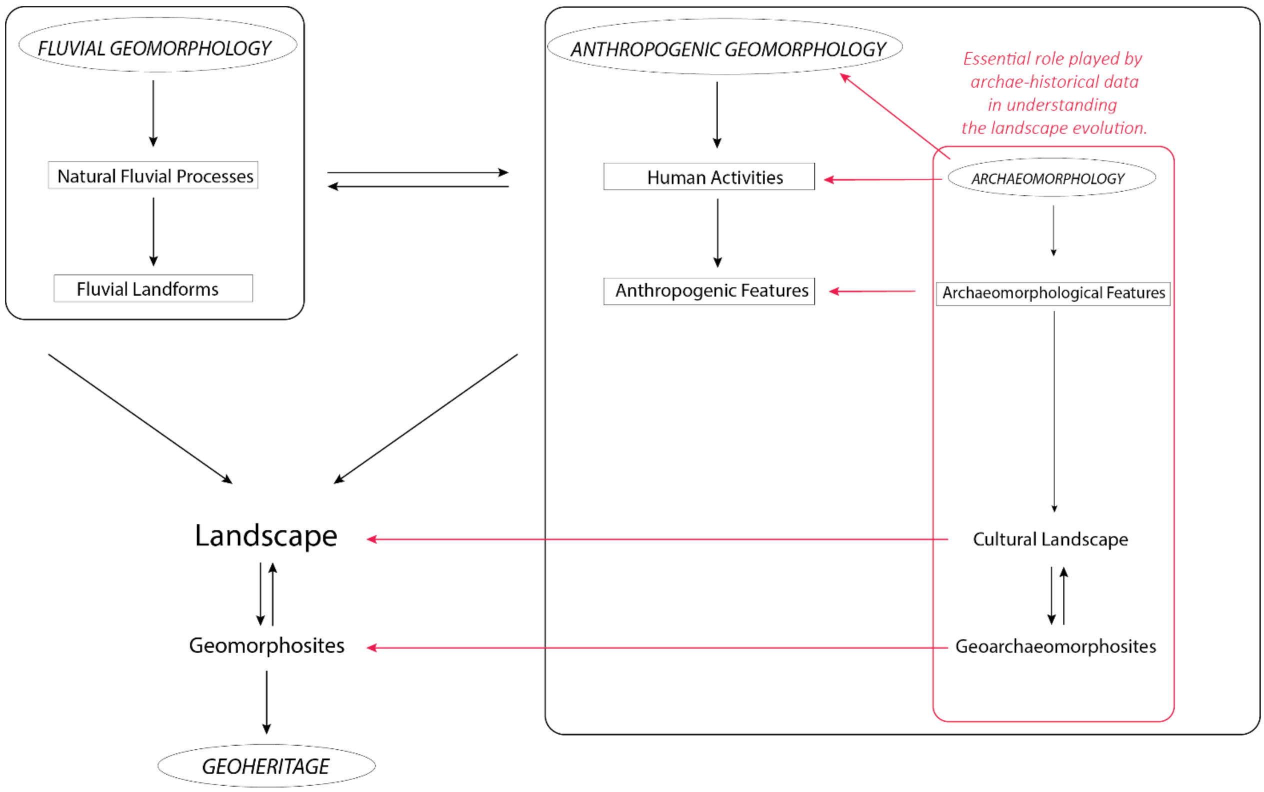

Figure 23. Conceptual map that shows of the archaeomorphological approach has been integrated into the geoheritage study of this portion of the Central Po Plain.

Conclusion

The analysis performed in this study led to identify and contextualise the palaeolandscapes developed in the past.

Landscape features identified by an archaeomorphology – based study constitute a cultural, geomorphological and historical archive of today's landscape and play an essential role in the definition of geo-educational itineraries. The local landscape may be not conceived only as the array of the geographical-geomorphological characteristics or as an assemblage of ecosystems in mutual interaction: landscape, in cultural terms, refers to the human experience and to the anthropogenic activities that modified the physical world surroundings. Hence, the analysis of archaeo-historical and cultural factors that influenced the landscape development is fundamental.

The results of this research point out the high potential of using archaeo-historical data in the definition of geo-educational itineraries, especially in a fluvial environment as the Central Po Plain. Here the fluvial landforms are hardly recognisable at ground level because of their low relief and the human intervention occurred through the past centuries: historical documents and archaeological records allowed to disentangle the different cultural layers that form the modern cultural landscape palimpsest. Moreover, in this study, we evidence the potential geoarchaeomorphosites (GAms) deriving from the interferences of human actions on the natural geomorphological dynamic and the role of archeo-historical data to understand the genesis and development of such landforms.

As here discussed, the close connection between Anthropogenic Geomorphology and Archeomorphology in Geoheritage studies underlines the great potential of archaeo-historical data in understanding the role of humans in shaping the landscape acting directly on fluvial processes.

The proposed four geo-educational itineraries (GeIs) allow i) to present the current landscape as the result of a continuative man-nature interaction, ii) to encourage the valorisation of geomorphological and archaeomorphological landforms through the definition of potential GAms iii) to promote the conservation of this landscape cultural palimpsest.

Through GeIs, it should be possible to spread academic topics such as landscape changes, human-environment interaction, landscape valuation and conservation to a wide non-academic audience. Indeed, to enhance the role of the researcher and the impact of scientific research on society is fundamental to make people understand science results. In the case of the GeIs proposed in this paper, a practical future perspective may be the development of a mobile app for public geoturistic fruition in the area. The application of GeoGuide mobile apps has been successfully tested in the urban contexts (Pica et al. 2018, Gambino et al. 2019) where they contribute to the promotion of the links between cultural and geological heritage. An app is environmental sustainable since they do not have any physical impact on the field.

Moreover, the app could be updated with information about touristic facilities (such as accommodations, local cuisine, local temporary events, etc.) with a positive impact on the local economy (Gálvez et al. 2017). Future perspective may include a cooperation with the local authorities to create an app useful to describe the GeIs; - georeference each GAms to ease their approachability; - provide historical, geomorphological and cultural information for each GAms; - to enhance the perception of the hidden and the highly human-disturbed GAms through Virtual Reality (VR) and Augmented Reality (AR) tools (Mota et al. 2019). Mobile applications represent useful instruments for geotouristic projects as well as for geo-educational projects (Bollati et al. 2014, Pelfini et al. 2018) in order to enhance the personal perception of the past landscape evidence.

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6.2 *Papia civitas gloriosa*: urban geomorpholology and geocultural heritage for a geoeducational itinerary in the city of Pavia

[Pelfini M., Brandolini F., D'Archi S., Pellegrini L., Bollati I. *Papia civitas gloriosa: urban geomorphololgy and geocultural heritage for a geoeducational itinerary in the city of Pavia*. Journal of maps. *submitted*]

Abstract

The interaction between geomorphological processes and anthropogenic activities produces an impressive association of geomorphological and archaeological heritage in urban contexts. In this study, we analysed the urban geomorphology and the geo- and cultural- heritage in the town of Pavia (Northern Italy). The city is located on a series of fluvial terraces that have always represented a strategic position since Romans times. In Late Middle Ages and the Modern Era, Pavia sprawled outside the Roman city-walls, creating new urban areas and modifying the landscape assessment. Geomorphological and GIS-spatial analyses integrated with anthropic landform surveying, archaeological data and historical cartography were performed. This multi-disciplinary approach allowed investigating the interaction between urban development and fluvial geomorphology and detecting the landforms generated by this complex interplay. As a result, a geoeducational itinerary is proposed for linking the geoheritage with the cultural heritage and for disseminating urban geomorphology key concepts.

Keywords: urban geomorphology; landscape changes analysis; geoheritage; cultural itinerary, geoeducation, Pavia.

Introduction

Urban geomorphology and urban geoheritage are becoming even more investigated topics as they represent the starting point in understanding the relationship between natural modelling processes and anthropic activities, in geoheritage assessment and geoarchaeological studies (Stefani and Zuppiroli 2010; P. L. Dall'Aglio et al. 2011; Del Monte et al. 2016; A. Pica et al. 2016; Pier Luigi Dall'Aglio et al. 2017). At first, the geomorphological landscape was determinant for the positioning of settlements (Benito-Calvo and Pérez-González 2015), but later, human activities progressively became more incisive in reworking morphological features and in conditioning surface geomorphic processes. Nowadays, the effects of the human-environment interplay are extremely evident in heavily populated urban areas where landforms can be dismantled, buried and reworked with consequences in terms of hazard and risk (Acquaotta et al. 2018), as well as in terms of geoheritage degradation and masking (Clivaz and Reynard 2017; Garcia et al. 2019). At the same time, cultural heritage has been progressively growing, acquiring value considering archaeological, historical and architectonic components (Brandolini, Cremaschi, and Pelfini 2019).

Floodplain represents the most suitable environment for human settling and sustenance since the introduction of agriculture activities. The necessity of freshwater, as well as the risk of flooding, led humans to modify fluvial landscapes with irrigations systems and flood-barriers since Prehistory. Where natural landforms have been deeply modified in urban contexts, some geomorphic features and geomorphosites (Panizza 2001; Reynard and Panizza 2005; Pelfini and Bollati 2014) can still be recognised, thanks with a geomorphological and archaeo-historical integrated approach (Brandolini, Cremaschi, and Pelfini 2019).

In this study, we analyzed the urban geomorphological development of the town of Pavia (Northern Italy) in the last two millennia, in order to i) map the former topographic and geomorphic features in relation with artefacts; ii) propose an itinerary to disseminate cultural and geo-heritage in the city context.

The study area and geomorphological setting

The town of Pavia is located on a series of fluvial terraces in the western part of the Central Po Plain, a few kilometres upstream from the confluence of the Ticino River into the Po River and approximately 45 Km south of Milan (Fig.1).

The current morphology of the plain sector within which Pavia rises is fundamentally due to the river's activity that since the Pleistocene up to the present, have shaped the present landscape, through alternating phases of alluvial sedimentation and incision. The river terraces are the most striking and characteristic elements, but also other typical features of the alluvial plains, such as fluvial ridges, crevasse splay, traces of abandoned riverbed and scarps, can be found (Castiglioni et al. 1997).

The portion of the plain to the north of the Po River is a wide surface, clearly defined by terrace borders, known as "*livello fondamentale della pianura*" (main surface of the plain), interpreted as the product of fluvioglacial and fluvial aggradation phases of the pede-Alpine plain as a consequence of the Last Glacial Maximum (Castiglioni G.B.; Pellegrini 2001). In the late Pleistocene, this surface was abandoned by the main rivers, which, concerning the change in the climatic conditions that marked the passage to the Holocene, began to the plain itself, digging increasingly higher scarps. The series of Holocene valleys entrenched one inside the other, which today can be easily recognised, and within which the rivers Po, Ticino, Adda, Oglio, etc. flow, are the result of this activity (Ravazzi et al. 2012). Alternating phases of erosion and deposition have also taken place during the Holocene. The result was a remarkable articulation of the plain, with high terraces overlooking the river below, constituting areas that from a strategic and functional point of view were the primary objects of the settlement choices by ancient populations.

Beyond the municipal boundaries, to the west of the city, two significant morphological features have been catalogued as geosites (Pellegrini and Vercesi 2005): the "*Dosso Boschetto"* (Boschetto fluvial ridge) and the "*Cuspide di terrazzo of Cascina Santa Sofia*" (Cascina Santa Sofia terrace cusp). The first one, which rises about 4–6 m on the surrounding plain, has been interpreted as the result of the juxtaposition of natural banks and/or river bars. It testifies a depositional phase, preceding at least the LGM, surviving to the following burying by the sediments constituting the main surface of the plain. This hypothesis would be supported by the intense alteration of these red-orange coloured materials, possibly relative to pedogenesis in a tropical environment. The second one, the "Cuspide di Terrazzo di Cascina Santa Sofia", is located within the Ticino terraced system. It represents the typical example of a fusion between two escarpments due to the dynamic of the meandering river channel which has totally dismantled the intermediate terrace as a consequence of lateral erosion (Pellegrini and Vercesi 2005). The highest plain, therefore, overlooks the river that flows about 20 m lower. Because of its dominant morphology, the site was chosen to build a church that the tradition attributes to Charles "The Great" (Tozzi 1995).

Historical urban development

The city of Pavia lies on a system of fluvial terraces that slope down towards the river, from the main surface of the plain through a series of terraces down to the Ticino that flows at about 58 m (a.s.l.) Although the large surface available allowed the new urban layout to be perfectly adapted to the morphological features that characterised the plain, the relatively high difference altitude between the intermediate and lower terraces was not considered as a limit for the town. On the contrary, the city crossed, from southwest to northeast, these escarpments, which at specific points, especially near the Ticino, showed differences in height even in the order of 10 metres. At the base of this decision, there had to be the choice to privilege a direct relationship with the river and to control it (Tozzi 1974). Moreover, the possibility to exploit the presence of terrace springs that were found in the correspondence of the scarp was interesting (Tozzi, 2005).

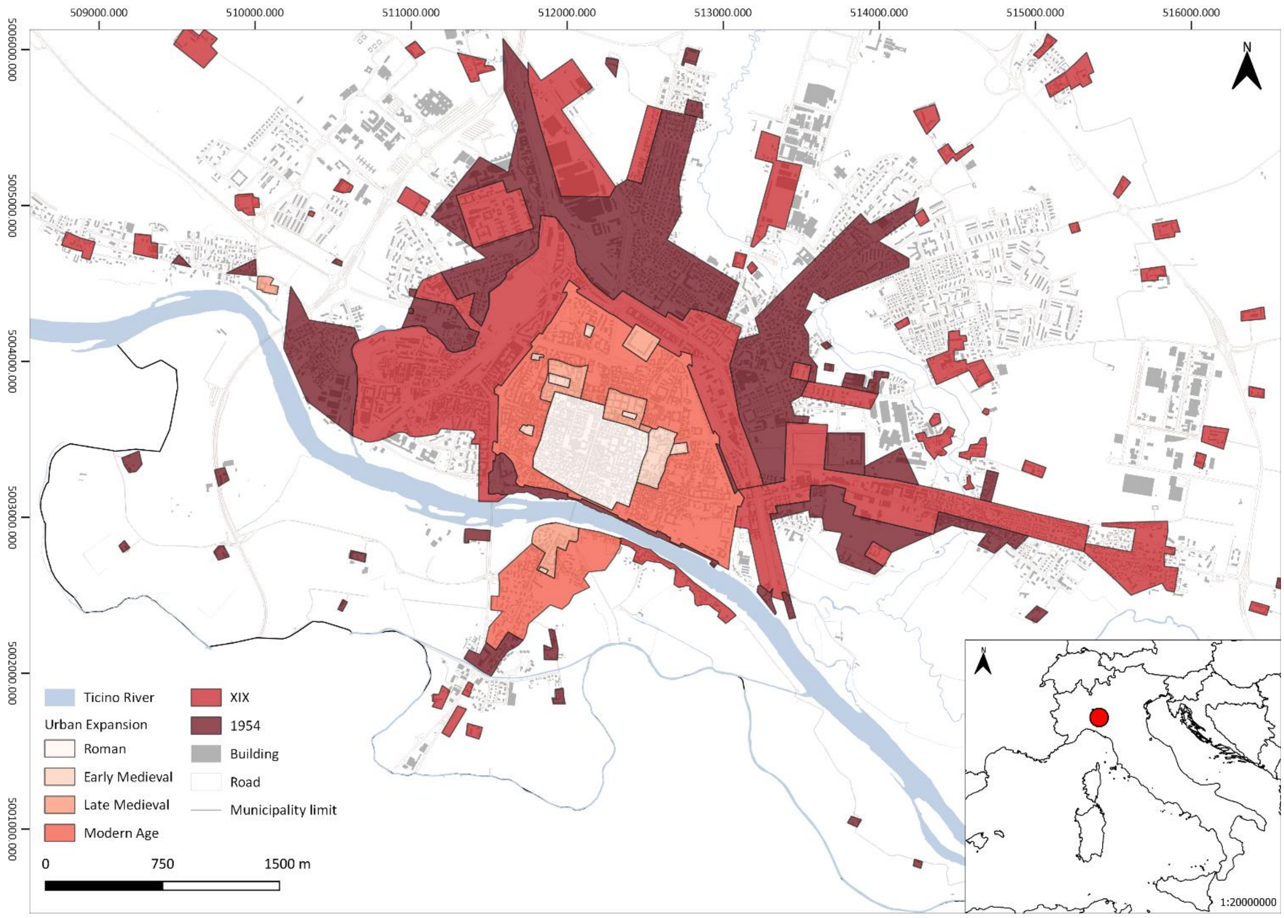

Figure 1 Location of the study area and schematic representation of the historical urban development of Pavia.

The geomorphological setting of Pavia and surroundings has guided the choice for the first human settlement. The Roman colony of *Ticinum* (Roman name of Pavia) was founded in 89 BCE on the banks of the river Ticino, probably replacing a former Gaul village (Tozzi, 2007). Its natural boundaries, constituted by the incised valleys of the Ticino and the two minor watercourses, Navigliaccio and Vernavola, identified an area naturally well defended. The town core was also artificially delimited by two branches of the ancient Carona stream (P. L. Dall'Aglio et al. 2011). The Roman plan of the city consisted of squared districts defined by a regular grid of roads (*cardi and decumani*) still recognisable in the historic city centre layout. During the Middle Ages, the city expanded, especially to the North and East since new royal palaces, churches, and monasteries were founded (Hudson 1981; Blake 1995; Nepoti 2000). In 1359 CE the city of Milan conquered Pavia and its ruler, Galeazzo II Visconti promoted the establishment of a new castle (the Visconti Castle; Vicini, 1991) that was built at an altitude of about 80-82 m on the main surface of the plain. In Modern Age the battle of Pavia (1525 CE) marks a watershed in the city's fortune with the beginning of the Spanish occupation which lasted until 1713; then, the city was ruled by the Austrians until 1796. After the Napoleonic period (1815), it returned under Austrian control until the Second War of Italian Independence in 1859. In the 19th century, the most relevant intervention on the Pavia urban assessment was the opening of a new artificial waterway that connects Milan to the Ticino River: the Naviglio Pavese. This 33 km waterway completed in 1819, was intensely used for commercial purposes until the beginning of the 20th century CE. During the 20th century, the city spread its historic city centre, reaching the actual extension (Fig.1).

Methods

To achieve an interdisciplinary understanding of the interplay between geomorphological processes and human activities, geomorphological survey and GIS-spatial analyses were integrated with anthropic landform surveying, archaeological data and historical cartography.
A detailed geomorphological survey has been realised as the current morphology of the city slopes has undergone an anthropic reworking over the centuries, that sometimes makes the distinction between natural and Man-made forms challenging.
The cartographic effort on the study area took place mainly through remote sensing, with the acquisition and processing of topographical and geomorphological data to be compared with the historical-archaeological data. To draw the Main Map, we acquired field data and data available at several archives. Reference topography is derived from Digital Elevation Model (5-meters resolution) retrieved online from the Geoportale of the Lombardia Region (http://www.geoportale.regione.lombardia.it/) and elaborated through software GRASS 7 (OSGeoProject) to fix DEM resolution (tool *r.map.calc*). The historical-archaeological data have been extracted from historical cartography. The historical maps of Pavia have been scanned using a high-resolution and contactless methodology based on SfM-photogrammetry (Brandolini and Patrucco 2019) and then imported in QGIS 3.4 (OSGeoProject) to be georeferenced (*Georeference* plug-in). Symbols refer to the last version of the geomorphological maps legend edited by the Italian Institute for Environmental Protection and Research-ISPRA (Campobasso et al., 2018), and, concerning the geo-anthropic elements, they were used according to Del Monte et al. (2016). The geoheritage literature on fluvial (Brandolini et al. 2019) and urban landscape (A. Pica et al. 2016; R. E. Pica and Coratza 2017; Pelfini et al. 2018) helped in the definition of the geoeducational itinerary here proposed. In order to detect the most evident variations in altitude of the town, crossing the terraces of the different orders, a series of topographic transects were elaborated. The QGIS Profile tool has been used to extract the topographic profiles from the DEM. Some elements were chosen to be crossed by the profiles: i) terrace scarps and river edges (Dall'Aglio et al., 2011; Morandotti, 1934; Tozzi, 1995); ii) historical relevant elements (bridges, churches, ancient spa) whose location was mainly guided by the geomorphological elements.

Results

The main map synthesises the geomorphological evidence still recognisable in the urban context of Pavia and shows the transformation of fluvial landforms into anthropic landforms. Moreover, a cultural itinerary (geoeducational path on the Main map, GP from now on) is proposed. The GP runs in the city centre inside of the Modern Age city walls, from the Visconti castle, crossing the IV orders terraced surfaces down to the Ticino River and going finally up toward the railway station.

Distribution of terrace escarpments evidence along the urban cultural path

1 – *Piazza Castello*. The Visconti castle lies on the southern edge of the Pleistocene main surface of the plain, the highest and oldest terraced surface of the area, extending northwards without interruption. This surface has been assigned the code T1 (Terrace Order 1 in Fig. 2).

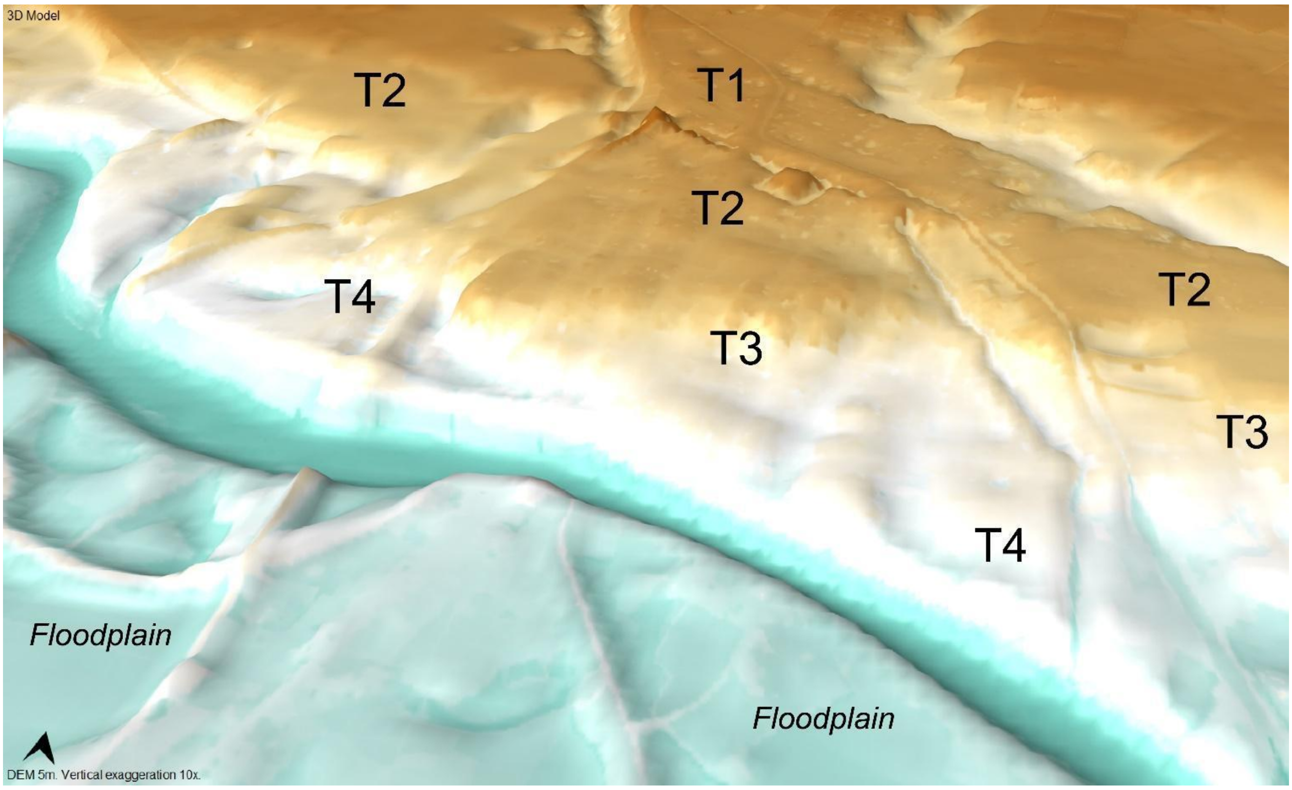

Figure 2 3D model of the fluvial terraces sequence of Pavia (vertical exaggeration 10x).

2 – *The university main building*. Like most of the city centre, it is located on the terraced Holocene surface (T2, Terrace Order 2, in Fig. 2) which is imperceptibly lower (about less than 5 meters) than the surface of the castle area. The university courtyards present a large variety of stones constituting the architectonic elements that offer the opportunity for observations in lithodiversity (Sacchini et al., 2018) and stone provenance.

3 – *San Tommaso building (Piazza del Lino)*. The building is located on the edge of the surface T2 and, partly, also on its scarp. The historical sources identify this as the place of foundation of the city, describing the site as rich in water springs. Indeed, the high scarp, which cut the T2 terrace, highlights the impermeable silty deposits that support an aquifer below the gravel (Fig. 3). When this water table is loaded, the springs, intercepted by the scarp, are activated (Tozzi, 2017).

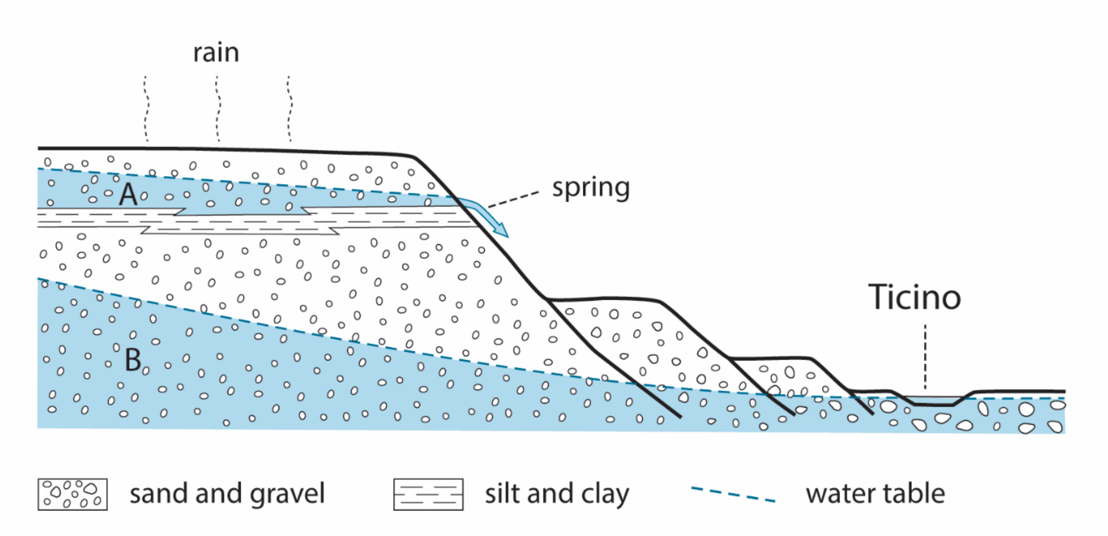

Figure 3 Schematic representation of a terrace water spring.

4 – *Piazza Municipio*. The square lies on the edge of the T2, and the steep Via Porta runs transversally to the terrace scarp. This scarp, in its continuation towards the East, shows a clear change of direction as evidence of a meandering river channel during the ancient incision phase (see Fig. 2).

5 – *San Michele_church*. It is located on the T3 (Terrace Order 3, Fig. 2), whose surface is discontinuous as a consequence of the lateral river erosion or due to the incision of small river valleys developed perpendicularly to the Ticino river into which they flow. ɪt seems that part of the churchyard has been extended with artificial fillings. The church was built using sandstones with carbonate cement (Monte Arzolo sandstones) that has an outcropping relatively near the town and is characterised by pleasant colours. Despite the high malleability of the material, chemical weathering on this lithotype is responsible for ruining stones and artistic sculptures.

6 – *Porta Nuova*. It is located in the lower area of the city (T4, Terrace Order 4, Fig. 2), and it is separated from the river by a high artificial levee on which a road runs. Despite the levee, during the major floods, this area may be flooded.

7 – *Piazzale Lungo Ticino*. The perspective of the city from here highlights the upward development and the anthropic remodeling interventions to allow the road (Corso Strada Nuova) leading to the castle to overcome the height difference of about 18-20 meters. Looking at the watercourse, the riverbank defences and some lateral and mid-channel bars can be observed. On the right bank, opposite to the Pavia city centre, the "Borgo Ticino" district is located. It lies a level approximately similar to T4, and houses without protection are frequently submerged by floods.

8 - *Porta Calcinara*. This lower area is at the same altitudinal level of Porta Nuova (T4); a very steep street (Via Rotari dei Longobardi)(nome?) leads directly to T2 terrace, missing the T3 surface terrace.

9 – *San Teodoro Church*. Not far from Porta Calcinara, on a portion of the T3 surface, the San Teodoro Church is located. Here, an interesting mural painting by Bernardino Lanzani (1522) is present: the town seems to "rise" from the river while the Abbot Antonio protects the town from the French soldiers. Together with its cultural and historical value, the piece evidences the urban planning of the city, its declivity toward the river and the related access to the riverbank.

10 – *Piazza della Vittoria e Piazza Duomo*. The itinerary returns to the T2 terraced surface, where, during the excavations in 1960 for the building, the underground market brought to light important Roman remnants represented by an impressive network of sewer pipes (Tozzi, 2007).

11 – *Sant'Agata al Monte*. The place's name (today *Piazza XXIV Maggio*) refers to the existence of a Medieval monastery settled in a topographically higher position than the surrounding neighborhood. This church was established in the 7th century CE in a prominent position on terrace T2 (about 76,5 m a.s.l.), hanging directly on T4 terrace. The monastery was dismantled at the beginning of the 20th century CE. The only remains of this hidden archaeo-geomorphosite consist of some stone epigraphs that were reused to construct the building that replaced the Sant'Agata medieval church (Tolomelli 2000).

12 – *Via dei Molini*. Even today, we can recognise depressions oriented around north-south, which were probably incised by the waters running towards the Ticino (see the main map). Some of these were run through by canals used for various human needs. The *Via dei Molini* street was probably crossed by the "*Carona dei Mulini*", a canal serving these mills and not very evident now. On the side of *Viale Cesare Battisti*, on the other hand, there is a deep valley that had to be scoured by the "*Carona degli Orti*" to irrigate urban vegetable gardens in the past. The latter could have constituted an ancient limit to the city on the western side.

Discussion

The use of an integrated approach for reconstructing urban geomorphology and history undoubtedly represents a key strategy not only for a better knowledge of today's city's features and characteristics but also to comprehend better the fluvial dynamic and possible risk scenarios as well as the role of the urban landscape as a cultural resource (Pelfini et al. 2018). The itinerary goes from stop 1 to stop 12, but the selected sites can be fruited under a free organization. Each stop allows different approaches and various interdisciplinary strategies as urban geomorphology represent the starting point for scientific and humanistic studies.

Urban itineraries moreover represent a wonderful source of educational opportunities (Caironi et al., in press, Pelfini et al. 2016) and outdoor laboratories; they allow experimenting fieldwork and field activities that are considered strategic for students in acquiring knowledge, competencies and abilities (Bollati, Pelfini, and Pellegrini 2012). This is the case of stop 2 (at university), where geodiversity (Bollati, Pelfini, and Pellegrini 2012; Brilha et al. 2018) and references herein) is considered support for architectural choices. At stop 4, weathering is an example of what an intense alteration on weak lithology can produce in term of damages on cultural heritage, etc. Similar projects have been performed in other cities during the school-work internship projects, also using new technologies (Caironi et al., in press). So the proposed itinerary represents not only a way to allow common people to better understand the topography and the morphology of the city, the related geo and the cultural heritage, but also to help students in acquiring knowledge about man and landscape history in a linked and radical way.

The analysis of the proposed geo-cultural itinerary is mainly focused on the strict urban area, even if considerations have also been made about the possibility of linking these most man-modified landforms in anthropic contexts, with the original remnants of natural fluvial surfaces in the city surroundings described in the study area (geosites officially catalogued by the Pavia province (Pellegrini and Vercesi 2005).

Conclusions

The application of this multi-disciplinary approach allowed evaluation of the role of anthropogenic actives in reshaping the landscape and, on the other hand, to investigate how the urban development of Pavia was adapted to the natural fluvial evolution of the Ticino River in terms of terraces and meanders modifications.

The urban geomorphological analysis of the city of Pavia and the proposal of a geoeducational itinerary have pointed out the importance of interdisciplinary researches which allows better comprehending the dynamic fluvial role in generating key sites for settlements and the role of humans in reshaping the landscape. Nevertheless, the urban landscape conserves and stores geomorphological evidence sometimes partially dismantled or buried and then hidden. Their identification can be extremely representative of human history and can confer adding values to morphological features. Landforms can become geomorphosites when they acquire values for their scientific, cultural, economic and scenic components (Bollati et al. 2017) in relation to the human perception (Panizza and Piacente 2003; Garavaglia et al. 2012). Moreover, the reconstruction of fluvial landscape changes in urban contests becomes of extreme importance in river management (Faccini et al. 2017; Filippo Brandolini and Cremaschi 2018). Urban geomorphology in these contexts represents a precious archive of data coming from geomorphological processes and human intervention analyses which respond to a different input (social, economic, cultural, etc.).

Papia civitas gloriosa: urban geomorphological analysis of Pavia (N Italy) to develop a geoeducational itinerary

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WGS 84 / UTM zone 32N

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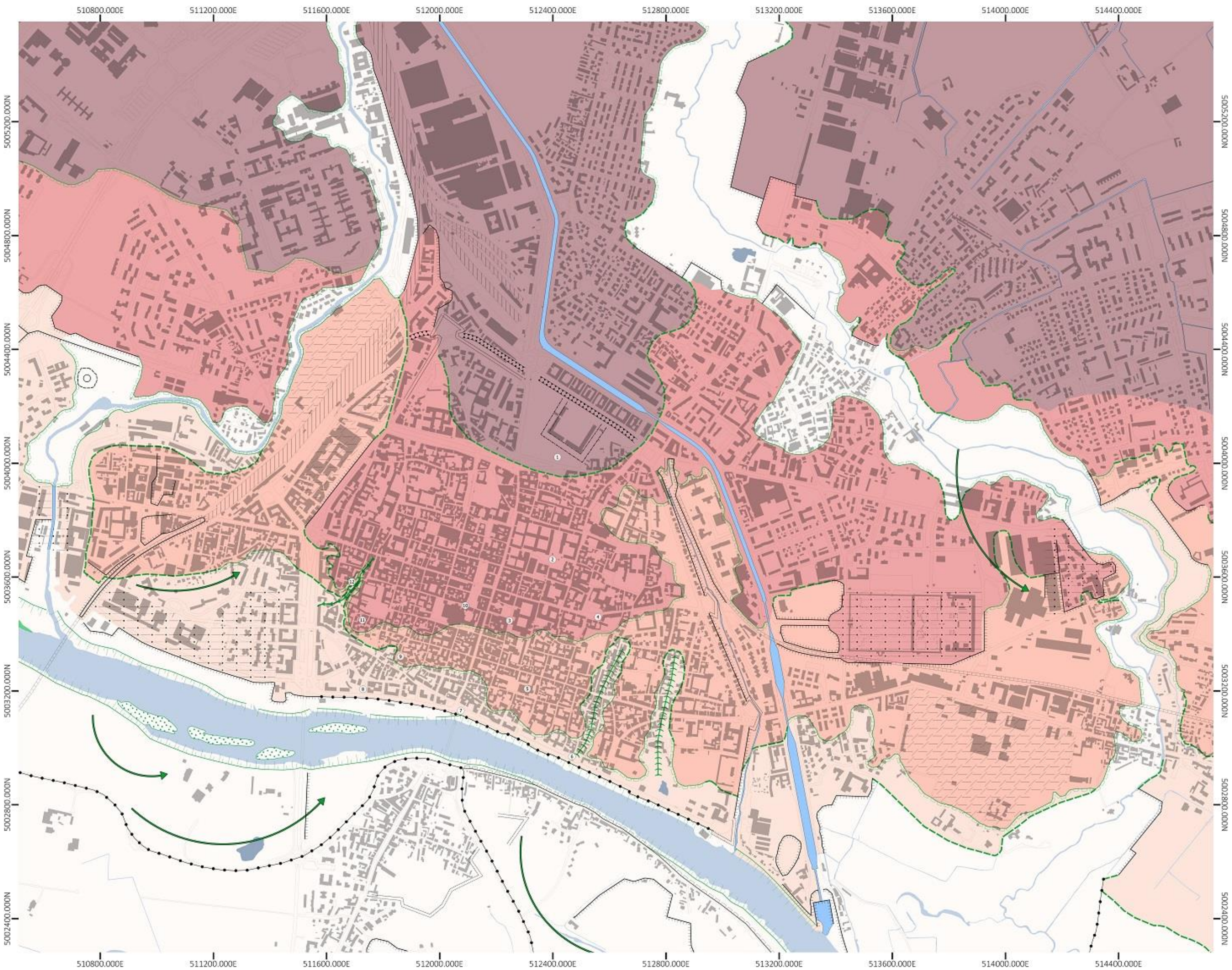
Fig. 1 Location of Pavia.

Fig. 2 Study area within the Pavia municipality.



Legend

Fluvial Terraces
- Terrace 1
- Terrace 2
- Terrace 3
- Terrace 4
- Floodplain

Hydrography
- Watercourse
- Pool
- Artificial Channel

Natural and Modified Fluvial Landforms
- Fluvial erosion scarp
- Hypotetic fluvial erosion scarp
- Channel Bank
- Point-Bar
- Bars
- Through-shaped valley
- Gully

- Palaeo-flow direction

Anthropogenic Landforms
- Road
- Building
- Artificial_Hill
- Embankment
- Riverbank protection
- Man-made scarp edge
- Archaeological Debris
- Ancient Walls
- Ancient_trench
- Surface remodelled for building construction
- Railway Area Embankments
- Railways Line Embankment
- trench
- Artificial Levee
- Itinerary Stops

Geoeducational Itinerary stops list	
1- Visconti Castle Square	7- Lungo Ticino square
2- University main building	8- Porta Calcinara
3- San Tommaso building	9- San Teodoro church
4- Town Hall Square	10- Duomo e Vittoria squares
5- San Michele church	11- Sant'Agata al Monte
6- Porta Nuova	12- Mulini Street

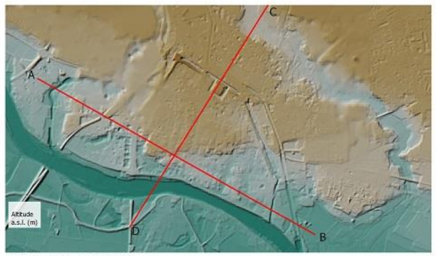


Fig. 3 Digital Elevation Model of Pavia historic centre.

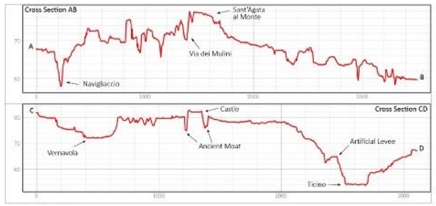


Fig. 4 Cross Sections of the city.

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7 General Discussion and Conclusion

The multi-disciplinary approach proposed has been tested in four different study areas (SAs) to evaluate the reliability and flexibility of the methodology. In general, geopedological, archaeological and historical data have been combined and managed through GIS open-access software enabling the reconstruction and mapping of past landscape features in fluvial environments (Fig. 2).

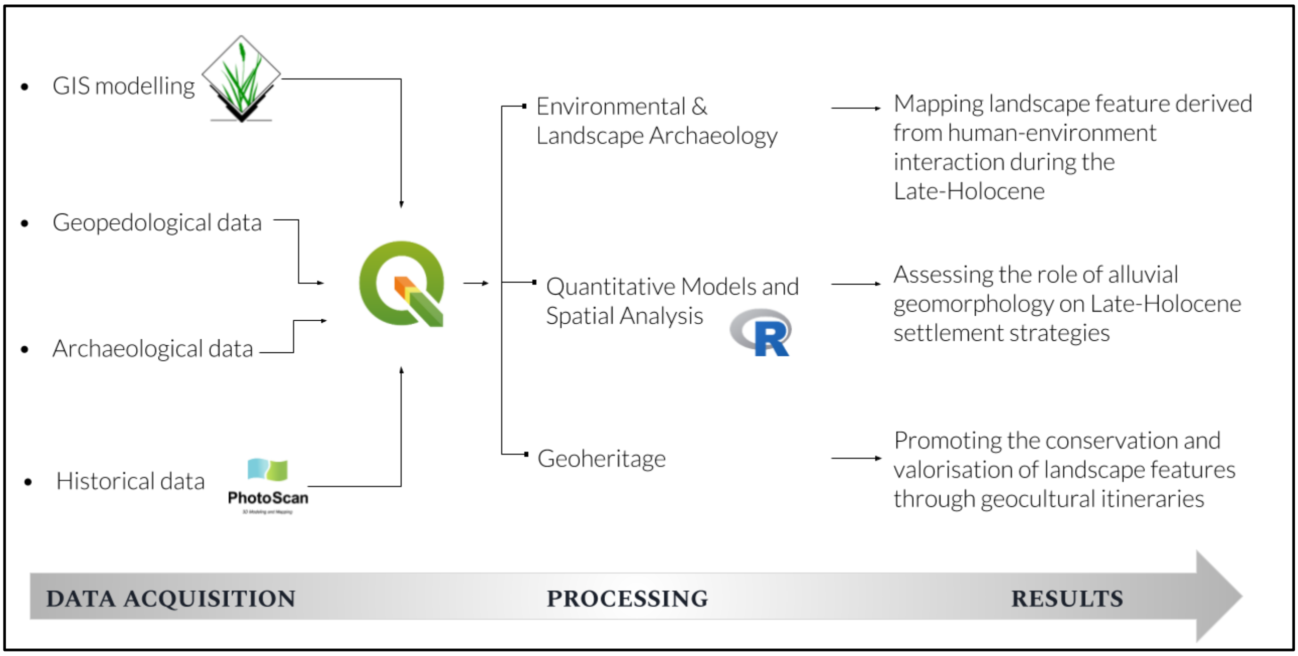

Figure 2 Schematic representation of the overall methodological workflow proposed and tested in this Ph.D. research.

The digitisation of historical cartography throughout SfM-photogrammetry (Chpt. 3.1) permits to obtain high-definition digital copies of fragile dataset that can be georeferenced and managed with GIS software in order to carry out interpretations of past landscapes. The combination of SfM digitisation and GIS georeferencing and mapping were tested successfully in the Upper Rhone Basin (SA-B, Chpt. 3.2) where long-term analysis of land-use changes at the end of the Little Ice Age (1780 and 1860 CE) have been carried out. The resulted multi-temporal maps highlight the main landscape changes due to anthropogenic land and water management activities that occurred in that period. Moreover, in the city of Pavia (SA-D, Chpt. 6.2), historical maps helped in detecting archaeological (e.g. dismantled 16th-century city walls and medieval canals) and geomorphological (e.g. Ticino River's fluvial terrace scarp edges and channels) evidence that have been "hidden" by the 19th and 20th-century urbanisation. Therefore, in areas where urbanisation altered deeply the natural and cultural features, historical cartography may represent the most reliable source to understand the landscape evolution of an area.

In the main research area (SA-A, Central Po Plain) the historical cartography available enabled the understanding of the Renaissance land reclamation plan (Chpt. 4.2) and the identification of the Modern Age drainage systems (Chpt. 6.1). Indeed, the historical maps, in association with the archaeological dataset, had a crucial role in dating and contextualising the geomorphological features detected with GIS-spatial analysis and geopedological data. In Chpt. 4.2 application of a geoarchaeological approach highlighted the potentiality of combining geopedology with archaeo-historical data: the soil characteristics of SA-A were fundamental to detect the medieval backswamps limits but only with the support of medieval chronicles and archaeological records it was possible to have a full comprehension of the evolution of this past fluvial landscape. In addition, geoarchaeological tools were decisive to analyse the evolution of a medieval village settled nearby the contemporary (back)swamps. In Chpt. 4.1, indeed, the archaeological soil micromorphology highlighted the site formation processes with particular focus on the medieval house construction techniques implied to settle in a waterlogged environment.

Tha geoarchaeological (and geopedological) analysis had an essential role to understand in-site (i.e. large scale) human settlement dynamics (Chpt. 4.1) as well as to have a general overview of the medieval past landscape characteristics (Chpt. 4.2), but only through geo-spatial analysis it was possible to quantify the role of alluvial geomorphology in Late- Holocene settlement strategies in SA-A (i.e. small scale). From a methodological point of view, the Point Pattern Analysis (PPA, Chpt. 5.1) proved to be particularly suitable for disentangling the relationships between settlement dynamics and environmental factors, and for providing reliable insights on past adaptive strategies.

Social and cultural dynamics played a crucial role in responding to alluvial geomorphological environmental challenges in different times. Roman land- and water-management were able to minimize the flood hazard, to drain the floodplain and organize a complex land use on different soil types. In the Medieval period, alluvial geomorphology of the area affected the spatial organisation of settlement, which privileged topographically prominent positions. Those different settlement strategies reshaped the natural landscape creating anthropogenic landforms that represent an important part of our cultural heritage.

Geo-spatial analysis have been performed also in SA-C throughout the application of the Kernel Density Estimation (KDE, Chpt. 5.2). The relationship between castles and fault systems, highlighted by KDE, seems to follow a rather common pattern of avoidance. Moreover, spatial analysis in SA-C suggests that the positioning and construction of castles during Matilda's Age was the result of both military strategy and geomorphological safety while proximity to the main water network was not apparently crucial for the castle's locations. Even in this case-study an interdisciplinary approach and the combination of different datasets (in SA-C geomorphological, geological and archaeological datasets) in GIS enabled a full comprehension of the past landscape of the area and its landforms.

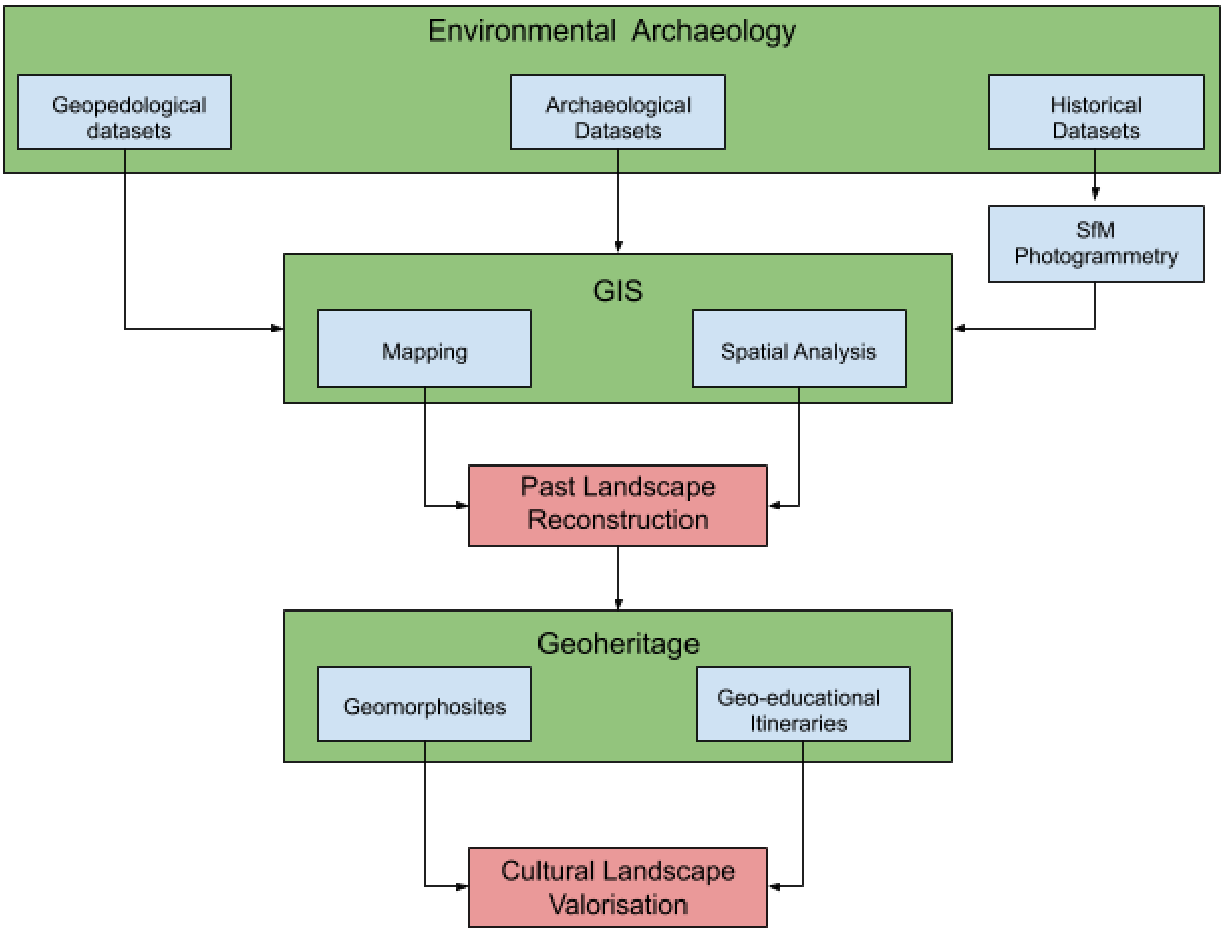

Figure 3 Conceptual map of the multidisciplinary methodology proposed and tested in this Ph.D. research.

The past landscape reconstruction only represented the first step of the general goals of this research (Fig.3). In SA-A (and in fluvial environment in general) fluvial landforms are hardly perceptible at ground level because of their low relief and the human alterations occurred through the past centuries but environmental archaeological methods and GIS tools enable the identification of those features. The past landforms (both anthropogenic and natural ones) have been mapped in GIS representing a new dataset for geoheritage studies. According to the results of Chpt. 6.1, archaeo-historical data enhance our perception of cultural anthropogenic landforms developed in the past. Fouache considered the archaeology only as an additional cultural value of geomorphosites (E. Fouache and Rasse 2009; Eric Fouache et al. 2012) while in SA-A archaeo-historical data had an essential role in the understanding the landscape evolution or the area. Therefore, the term geoarchaeomorphosite (Chpt. 6.1) has been proposed to indicate any geomorphosites derived by the dynamic interaction between natural (in SA-A, fluvial) and human events. The geomorphosites and geoarchaeomorphosites mapped in GIS have been considered to promote geo-educational initiative.

In SA-A four itineraries have been proposed and each of those is focused on a specific period of human past (Protohistory, Roman Era, Medieval Period, Post-Medieval Period) and characterised by peculiar landforms. Moreover, in SA-D the research focused on the relationship between urbanisation and geomorphology (Reynard, Pica, and Coratza 2017) in historical periods (Zwoliński et al. 2018). In the city of Pavia, the geomorphosites and geoarchaomorphosites have been organised in an urban geo-educational itinerary to encourage the valorisation of the landforms heritage of the town. The definition of geo-educational itineraries (both in urban and rural areas) aims to present the current landscape as the result of a continuative human-nature interplay and to promote the conservation of the heritage values of a landscape palimpsest.

To sum (Fig. 3), digitised historical documents (3.1) represent a valuable proxy to integrate geoarchaeological data (4.2) as well to help in understanding the landscape evolution in urbanised area (6.2) or in zones where the anthropogenic activities had a severe impact on the natural environmental development (3.2). Furthermore, geopedological data and geoarchaeological methodologies enabled the understanding of the past landscape from in-site (4.1) to a regional scale (4.2). In addition, GIS open-access software were extremely helpful in managing all of these various datasets, mapping cultural and natural landscape features and performing quantitative geospatial analysis (5.1, 5.2). Once "reconstructed", the natural (geomorphosites) and cultural (geoarchaeomorphosites, see 6.1) landscape features need to be preserved and promoted for their heritage values. Geoheritage approach is crucial to propose geo-educational itineraries both in rural (6.1) and urban (6.2) environment with the aim of increasing public engagement and awareness on landscape conservation. The Horizon 2020 Expert Group on *Cultural Heritage report Getting cultural heritage to work for Europe* highlighted the divide between 'nature' and 'cultural' heritage in landscape management, and the weakness of monodisciplinary approaches[2]. This PhD project asses the potentiality of the multidisciplinary approach in landscape studies. Environmental archaeology served as a invaluable discipline to reconstruct past landscape and to understand its evolution processes derived by a combination of natural factors and human activities. Then, the application of the geoheritage methodology allowed to classify the surveyed landforms in geomorphosites and geoarchaeomorphosites and to propose geo-educational itineraries for their conservation and valorisation. The only limit of this multi-disciplinary approach is represented by the heterogeneity of data that need to be considered to have a full comprehension of the evolution of past landscapes. In this regard, GIS software are the most effective solution to this problem because through them we are able to: 1) manage all the various data needed 2) map the cultural landscape palimpsest 3) quantify the role of humans and environment in shaping landforms

[2] European Commission, 2015. Getting Cultural Heritage to Work for Europe. Report of the Horizon 2020 Expert Group for Cultural Heritage. DG Research and Innovation. Luxembourg. Available at: https://ec.europa.eu/programmes/horizon2020/en/news/getting-cultural-heritage-work-europe, p.9 (Last access, 13/08/2019)

8 - Future Perspectives

Future research will aim to investigate the degree of sustainability of landscapes themselves especially for what concerns soil loss and degradation, through a multidisciplinary approach that combines archaeology, historic studies, geospatial analysis and modelling. Even if it is undoubted that landscapes need to be preserved for their role of datasets of the millennial human-environment interaction, it is necessary to evaluate if the conservation of past landscapes is sustainable, especially in fragile ecosystems. The analysis of Historical Landscape Characterisation (HLC) together with GIS-modelling, could be useful for combining the cultural and environmental values of land-use to create a model for the sustainable conservation of past landscapes. Environmental sustainability and historic landscape conservation are typically treated as two separate fields, but future projects should aim to develop a transformative model for interdisciplinary research, proposing a new way to embrace both cultural and natural values as components of the same landscape management plans.

Appendix 1 - Participation in conferences and congresses

- Filippo Brandolini, Mauro Cremaschi, Manuela Pelfini - Historical Cartography As A Geomorphological Dataset To Assess The Human-Induced Modification On Fluvial Landscapes, Congress Abstract, **VIII Italian Young Geomorphologists' Days**, "Sharing experiences on geomorphological research in different morphogenetic and morphoclimatic environments", 26th-28th June 2019 (Milan & Veny Valley, Italy).

Poster Session.

Fluvial environments have always played a crucial role in human history. Since anthropogenic activities started altering the evolution of natural landscapes, floodplains represented complex and dynamic human–fluvial systems, where the interplay between geomorphological processes, land-use, ecosystems, and human activities was distinctive and fundamental in shaping natural environments. Being land-use changes a dynamic process linking natural and human spheres; the historical reconstruction of such processes is mandatory to evaluate the mutual interactions between anthropogenic activities and the fluvial environment. Historical maps, if available, offer a valuable archive of data to understand the causes, mechanisms, timing, and consequences of the human-induced changes in fluvial landforms and support river management at any scale. Moreover, the combination of historical data with geomorphological interpretation and remote sensing analysis of the landscape is essential to study the relationship between natural events and land-use changes through time. The digitalisation and GIS elaboration of historical cartography is therefore fundamental to interpret the landscape and land-use changes in a region. The use of Structure-from-Motion (SfM) photogrammetric techniques is a suitable procedure that responds to the necessity of digitalising historical maps and documents avoiding any direct contact with the often-fragile analogic support.

HISTORICAL CARTOGRAPHY AS A GEOMORPHOLOGICAL DATASET TO ASSESS THE HUMAN-INDUCED MODIFICATION ON FLUVIAL LANDSCAPES

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Fluvial environments have always played a crucial role in human history. Since anthropogenic activities started altering the evolution of natural landscapes, floodplains represented complex and dynamic human–fluvial systems, where the interplay between geomorphological processes, land-use, ecosystems, and human activities was distinctive and fundamental in shaping natural environments.

1)Historical maps, if available, offer a valuable archive of data to understand the causes, mechanisms, timing, and consequences of the human-induced changes in fluvial landforms and support river management at any scale (Brandolini & Cremaschi 2018)

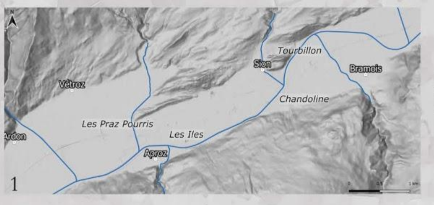
(Courtesy of ©Archives de l'Etat du Valais, AEV)

Historical Cartography

Digitalisation

2)The digitalisation of historical cartography allows creating a valuable dataset for a variety of GIS application as well as spatial and landscape studies.

Georeferencing



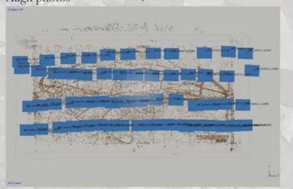
4) The georeferencing of historical cartography allows to combine geospatial information (DEM, 1) with historical data on past landscapes (2). The result consist in multi-temporal maps (3) of past land-use and fluvial geomorphological features. (Brandolini, Reynard, Pelfini 2019)

Software
Agisoft PhotoScan 1.4.4 - https://www.agisoft.com/
QGIS 3.4 Madeira - https://www.qgis.org/en/site/

3)Structure-from-Montion photogrammetry (SfM): a non-invasive methodology to digitalize historical documents (Brandolini & Patrucco 2019).

Historical Map

Align photos



Tie-points extraction

Generate cloud points

Extract an ortophoto projection of the map

Past Landscape Reconstruction

5) Conclusion
The combination of historical data with geoscience and remote sensing analysis is essential to study the relationship of natural events such as floods and river diversions with human land use changes through time (Brandolini, Cremaschi, Pelfini 2019). In regions that are historically affected by flooding and where urbanisation has increased exposure to floods, historical cartography provides valuable indications for planning more sustainable urbanised alluvial landscapes in the future. GIS tools are essential to compare digitised historical maps with more recent ones and to carry out a multi-temporal analysis of landscape dynamics.

References
- **Brandolini F. & Patrucco G. 2019**. Structure-from-Motion (SFM) photogrammetry as a non-invasive methodology to digitalise historical documents: a highly flexible and low-cost approach?. Heritage 2019, *in press*
- **Brandolini F., Reynard E., Pelfini M. 2019.** Multi-temporal mapping of the Upper Rhone Valley (Valais, Switzerland): fluvial landscape changes at the end of the Little Ice Age (18th - 19th centuries). Journal of Maps, 2019. *in press*
- **Brandolini F., Cremaschi M., Pelfini M. 2019**. Estimating the Potential of Archaeo-historical Data in the Definition of Geomorphosites and Geo-educational Itineraries in the Central Po Plain (N Italy). Geoheritage 2019, https://doi.org/10.1007/s12371-019-00370-5
- **Brandolini F., Cremaschi M. 2018.** The Impact of Late Holocene Flood Management on the Central Po Plain (Northern Italy). Sustainability 2018, 10(11), 3968, https://doi.org/10.3390/su10113968

▪ Filippo Brandolini, Mauro Cremaschi, Manuela Pelfini – Geoarchaeological interpretation of historical cartography to understand the human-induced modification on fluvial landscapes, Congress Abstract, Geoarchaeological records of human-landscape interaction: from a nature-dominated world to the Anthropocene. **European Geosciences Union General Assembly 2019 (EGU)**, 7th–12th April 2019, Vienna (Austria).
Oral Session.

ABSTRACT

Fluvial environments have always played a crucial role in human history. The necessity of fertile land and fresh water for agriculture has led populations to settle floodplains more frequently than other environments. Since anthropogenic activities started altering the evolution of natural landscapes, floodplains represented complex and dynamic human–fluvial systems, where the interplay between geomorphological processes, landuse, ecosystems, and human activities was distinctive and fundamental in shaping natural environments.
Being landuse changes a dynamic process linking natural and human spheres, the historical reconstruction of such processes is mandatory to evaluate the reciprocal interactions between anthropogenic activities and fluvial environment.

Historical maps, if available, offer a valuable archive of data to understand the causes, mechanisms, timing, and consequences of the human-induced changes in fluvial landforms and support river management at any scale. Moreover, the combination of historical data with geoarchaeological interpretation and remote sensing analysis of the landscape is essential to study the relationship between natural events (e.g. floods and river diversions) and landuse changes through time. The digitalization and GIS elaboration of historical cartography is therefore fundamental to interpret landscape and landuse changes in a region. The use of Structure-from-Motion (SfM) photogrammetric techniques is a suitable procedure that responds to the necessity of digitalizing historical maps and documents avoiding any direct contact with the often-fragile analogic support. In this contribution, we discuss to application of SfM to reconstruct the historical evolution of two fluvial environments: (i) the central Po Plain (Emilia Romagna, Italy), and (ii) the upper Rhone basin (Valais, Switzerland). In both cases, the application of a geo-historical multidisciplinary approach enables the quantification of the impact of human activities on the development of the fluvial environment during the Middle Ages (Po Plain) and at the end of the Little Ice Age (Rhone basin).

- Guido S. Mariani, Filippo Brandolini - Castles and the elevated landscape: using the geomorphological tool to unveil unexpected interactions between cultural and natural environment in medieval communities, Congress Abstract, Geoarchaeological records of human-landscape interaction: from a nature-dominated world to the Anthropocene. **European Geosciences Union General Assembly 2019 (EGU)**, 7th–12th April 2019, Vienna (Austria).

Poster Session.

ABSTRACT

The human exploitation and transformation of the landscape does not rely exclusively on the management of material resources. More abstract principles such as strategic control or spiritual beliefs have always played a strong role in the development of settlements in past and present societies. In recent years, the application of Geoarchaeology to medieval studies has reshaped our understanding of these communities, stressing the connection between places and their associated territories. During the Middle Ages, scattered communities located in mountain territories relied heavily on the surrounding geomorphology, and this reflects on many aspects of their urban and rural development. In particular, their choices in the construction of functional buildings not dedicated to productions, such as castles, abbeys or sanctuaries, took strongly into consideration the immaterial services provided by the landscape. For example, elevated areas and vantage points can offer many tactical advantages: a larger visual on the territory, controlled accessibility, isolation, easy communication to the rest of the community.

We investigated an area of the Northern Apennines (Italy) from the plain up to the main watershed, with a method combining historical and archaeological data with geological and geomorphological tools, in order to give a clearer understanding on the use of territory of mountain communities in the Middle Ages. We produced a systematic mapping of the most relevant non-productive landmarks belonging to a period between the X and XII Century, complete with detailed information about their construction. The combination of these data with the surrounding geological and geomorphological setting uncovered relationships between human activity and the diversity of the mountain landscape. The presence of these landmarks is associated with elevated terraces such as mesas, cuestas, slope deformations and surfaces on harder lithologies formed by differential erosion. These findings highlight how the shape of the territory influences human adaptation in less tangible ways.

▪ Filippo Brandolini, Mauro Cremaschi - Medieval genesis and development of wetlands in Central Po Plain (N Italy), Congress Abstract, Towards a Landscape Archaeology of Wetlands: on-site data to macro-scalar view. The **5th Landscape Archaeology Conference**, 17th – 20th September 2018, Newcastle/Durham (UK).
Oral Presentation.

ABSTRACT
The landscape evolution in the Central Po Plain, and especially the development of freshwater environments, has a long-lasting connection with human activities. Protohistoric human-environmental interactions have been widely investigated, less is known on more recent natural and anthropic forcings on the evolution of the hydrology of the central Po Plain. To fill this gap, we applied geoarchaeological tools to reconstruct the Medieval genesis and development of wetlands in a wide area (1700 Km2) between the cities of Parma and Reggio Emilia (N Italy). After the collapse of the Roman Empire that coincides with a cooling climate phase, the natural depressions on the right bank of the Po River turned into vast swamps. The alluvial plain aggraded quickly, and Roman roads and ditches were often buried under fluvial and marsh sediments. Historical documents report that local communities exploited the wetland environment for food resources (fishing and gathering), and waterways (commercial transports) between 5th -10th centuries AD. Only after the 10th century AD, in coincidence with consistent demographic growth, the needing of new farmland led the communities to reclaim cultivable land from swamps. The exploitation of fluvial sediments through flood management activities modified the wetlands shape and extensions creating new ‘higher’ fields than the surrounding swampy meadows. Despite these Medieval land and water management practices, the wetlands persisted until the 15th century AD, when a large-scale operation of land reclamation started, turning the palustrine environment in the nowadays farmland. This study aims to detect and disentangle the mutual interaction between human and environment along ten centuries of history (5th - 15th centuries AD) integrating geomorphological analysis to historical-archaeological data. The application of a multidisciplinary approach highlights the role both of historical hydrography and human activities in the wetland environmental development during the Middle Ages.

▪ Irene Bollati, Filippo Brandolini, Sara D'Archi, Luisa Pellegrini, Manuela Pelfini - Geomorfologia Urbana e insediamento storico: creazione di un itinerario geoturistico nella citta' di Pavia (Lombardia), **Forme dell'abitare e forme del territorio: un approccio multidisciplinare alla lettura del paesaggio**, Bologna - 22nd June 2018.
Poster Session.

▪ Filippo Brandolini, Manuela Pelfini – From Archaeogeomorphology to Geoheritage through the Po Plain, **SIGEA 2018**, Il Patrimonio Geologico: dallo studio di base al geoturismo sostenibile, Sasso di Castalda - Potenza 26th - 27th April 2018.
Poster Session.

Il Patrimonio Geologico: dallo studio di base al geoturismo sostenibile
Sasso di Castalda - Potenza (Italy) 26 - 27 aprile 2018

FROM ARCHEOGEOMOPHOLOGY TO GEOHERITAGE THROUGH THE PO PLAIN

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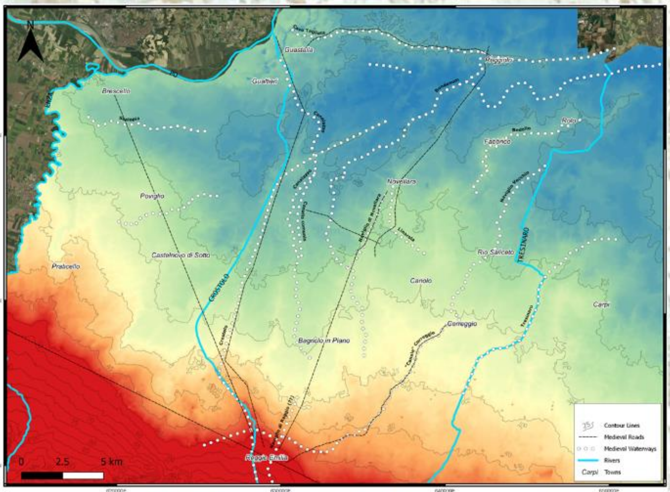
The anthropogenic land and water management activities in the last two millennia affected the natural geomorphological development of the Po Valley deeply. The research area is located in the Emilia Romagna region (N Italy), few kilometres south of the Tuscan – Emilian Apennine margin, between the cities of Parma e Reggio Emilia, among the rivers Enza, Po and Secchia, and the distal part of Holocene alluvial fans. After the collapse of the Roman Empire, the natural depressions on the right side of the Po River turned in vast swampy meadows. A very recent interdisciplinary and diachronic approach is represented by archeomorphology, an analysis that synthesizes aspects of geomorphology, archaeology and environmental history to study the anthropogenic effects on landscape evolution in the past. By definition, archaeomorphology is focused on the study of human-made landscape forms and traces of territorial planning, such as roads, field systems, terraces or water channels. It aims at analysing the historical development of landscape structures over time and embrace the idea of landscapes as cultural palimpsests. Throw the identification of landscape management evidence and hidden landforms we propose a cultural itineraries, which follow the main historical routes active in Meddle Ages.



Materials and Methods

This study has been performed using both geomorphological tools and archaeological-historical data. The elevation checkpoints (m a.s.l.) available on GeoPortale Emilia Romagna database were used to draw the contour lines with an equidistance of 0,5 m. On the basis of reconstructed contour lines, a Digital Terrain Model of the study area was elaborated with the QGIS software. Moreover, to ease the interpretation of the geomorphological features detected by the DTM, a 3D model have been elaborated exaggerating the altitude checkpoints attribute x70. The historical-archaeological data to the DTM as concentration maps and allowed us to date and contextualized all the forms detected. The morphological analysis of historical-communication routes and their definition constituted an advantageous approach to understand the landscape evolution dynamics.

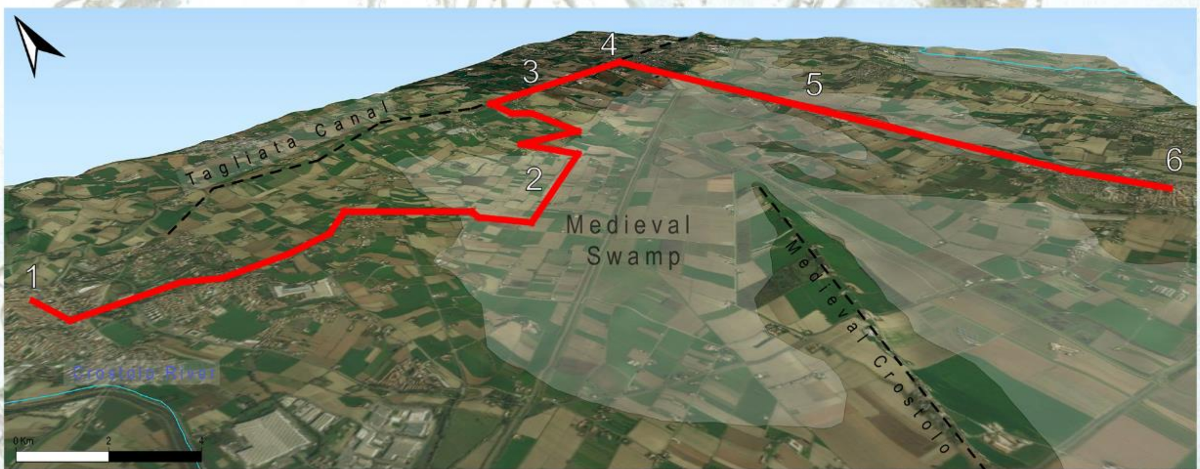
Results

According to historical-archaeological data, the Medieval settlements concentrated on the fluvial ridges in the new palustrine landscape. In the research area, these fortified villages (or castra) are known only by historical documents and constituted the first nucleus of the further Late Medieval and Renaissance towns: es. Castrum Popilii – Poviglio; Wardestalla Castrum – Guastalla; Luciaria Castrum – Luzzara; Castrum Gualtieri – Gualtieri; Faurice Castrum – Fabbrico; Brixellum Castrum – Brescello; Nuvellare curtis – Novellara. New roadways and waterways originated from the main centre of Reggio Emilia and spread in the surrounding landscape exploiting the medieval environmental situations:
- waterways to connect the city to rivers and swampy meadows;
- few main roads along ridges to connect the main centres to the Via Aemilia in Reggio Emilia.

The archeomorphological evidence of the Medieval communication networks that originate from Reggio Emilia are:

Waterways: the "unknown" river Bondenum; Fossa di Roncaglio; Canal Scalopia; Canal Bedollo; Canalis Comunis or Canale di Reggio; Naviglio Vecchio in Correggio; Naviglio from Reggio to Novellara; Canal Linarola; Canal Canalazzo; Canal Tagliata; Canal Bersana;Canal Moglia; Water-Mills Canal.

Roadways: Via Romana (Reggio Emilia – Poviglio – Brescello);Unknown road (Reggio Emilia – Bagnolo in Piano – Novellara); Unknown road along the Crostolo river; Unknown road along the Canal Tagliata; Unknown road: Reggio Emilia – Correggio



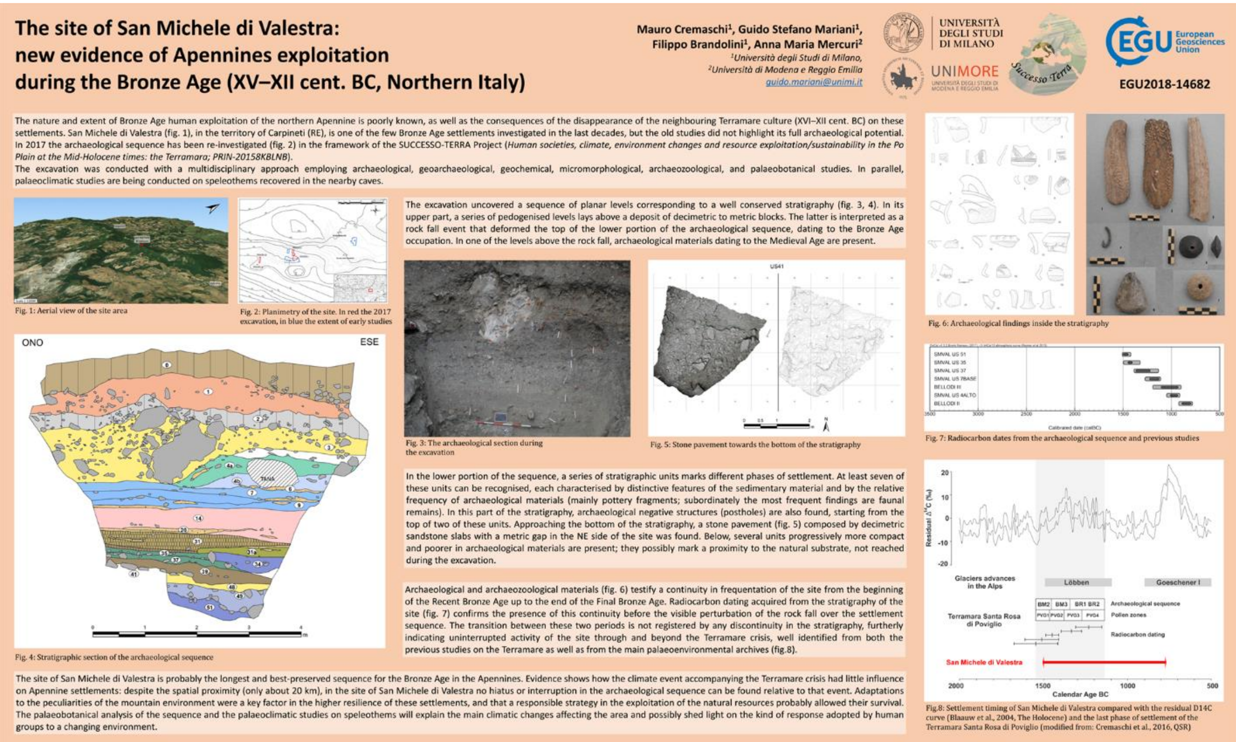
Itinerary

The Medieval Itinerary (fig. 12) starts from Guastalla, one of the most important cities settle in the Early Middle Ages with the name of Wardistalla (1). From here the path goes downhill to the medieval swamps. This area (2), today is known by the name of "Valli Nuove di Guastalla" (i.e. the new Guastalla Valleys) and was the deeper part of the medieval swamp developed in the Valle di Novellara backswamps. This waterlogged area was utterly reclaimed only in the 20th AD. Aerial images analysis revealed some soil marks related to Roman centuriation tracks buried as consequence of the waterlogging process occurred between the 5th and the 10th centuries AD. From the medieval swamp, the path climbs up to the Tagliata Canal ridge (3), the most prominent geomorphological features developed in Medieval Times. This landform is the result of the channelization enterprise started in the 12th century AD. The flood events reported by the historical record are still recognizable in some toponyms and in aerial images soil marks. Following the Canal watercourse, we reach the medieval town of Reggiolo (4) that was settled in 10th century AD as a fluvial port and then became a stronghold to control the trades along the Tagliata Canal. From the Reggiolo castle, the path goes down again in the medieval swamps (5) towards Novellara. The proposed itinerary follow a medieval road reported in historical maps that connected the trades from Reggio Emilia to Reggiolo through the city of Novellara (6). This town, founded in 9th – 10th century AD, settles on a fluvial ridge, strategic higher position to control waterways in medieval times.

▪ Mauro Cremaschi, Guido Stefano Mariani, Filippo Brandolini, Anna Maria Mercuri - The site of San Michele di Valestra: new evidence of Apennines exploitation during the Bronze Age (XV–XII cent. BC, Northern Italy), Congress Abstract, **European Geosciences Union General Assembly 2018 (EGU)**, 8th-13th April 2018, Vienna (Austria)
Poster Session.

ABSTRACT

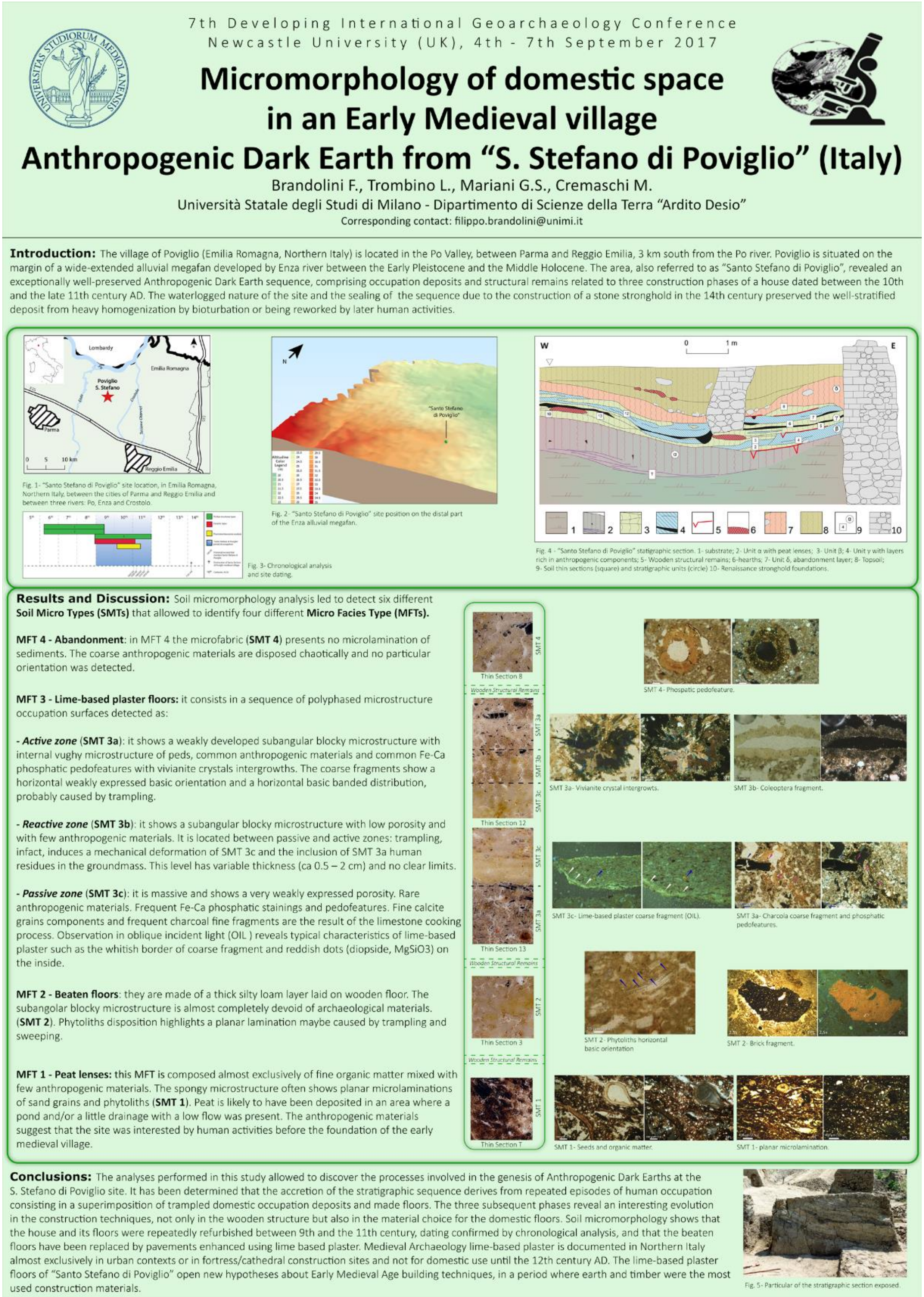
The nature and extent of Bronze Age human exploitation of the northern Apennine is poorly known, in particular in correspondence to the disappearance of the neighbouring Terramare culture in the Po Plain (N Italy) around 1150 BC. The principal reason for this knowledge gap is the scarcity of archaeological excavations in the area during the last decades. The archaeological sequence of San Michele di Valestra was re-investigated in the frame of the SUCCESSO-TERRA Project (PRIN-20158KBLNB), following a multidisciplinary study combining tools from different disciplines ranging from geoarchaeology, to archaeology, and palaeoenvironmental science, as well as palaeoclimatic studies on speleothems recovered in nearby caves. The excavation uncovered a stratigraphic sequence marking different phases of settlement. Successive frequentation levels sometimes marked by archaeological negative structures (postholes) are found, as well as a stone pavement composed by decimetric sandstone slabs towards the bottom of the stratigraphy. Archaeological and archaeozoological materials retrieved from the sequence testify a continuity in frequentation of the site from the beginning of the Recent Bronze Age up to the end of the Final Bronze Age, indicating uninterrupted activity of the site through and beyond the Terramare crisis. The site of San Michele di Valestra is probably the longest and best-preserved sequence for the Bronze Age in the Apennines, and offers the opportunity to understand the subsistence strategies in this environment. The evidence found shows how the climate event accompanying the Terramare crisis had little influence on Apennine settlements. Adaptations to the peculiarities of the mountain environment were a key factor in the higher resilience of these settlements, and a responsible strategy in the exploitation of the natural resources probably allowed their survival. The palaeobotanical analysis of the sequence and the palaeoclimatic studies on speleothems will explain the main climatic changes affecting the area and possibly shed light on the kind of response adopted by human groups to a changing environment.



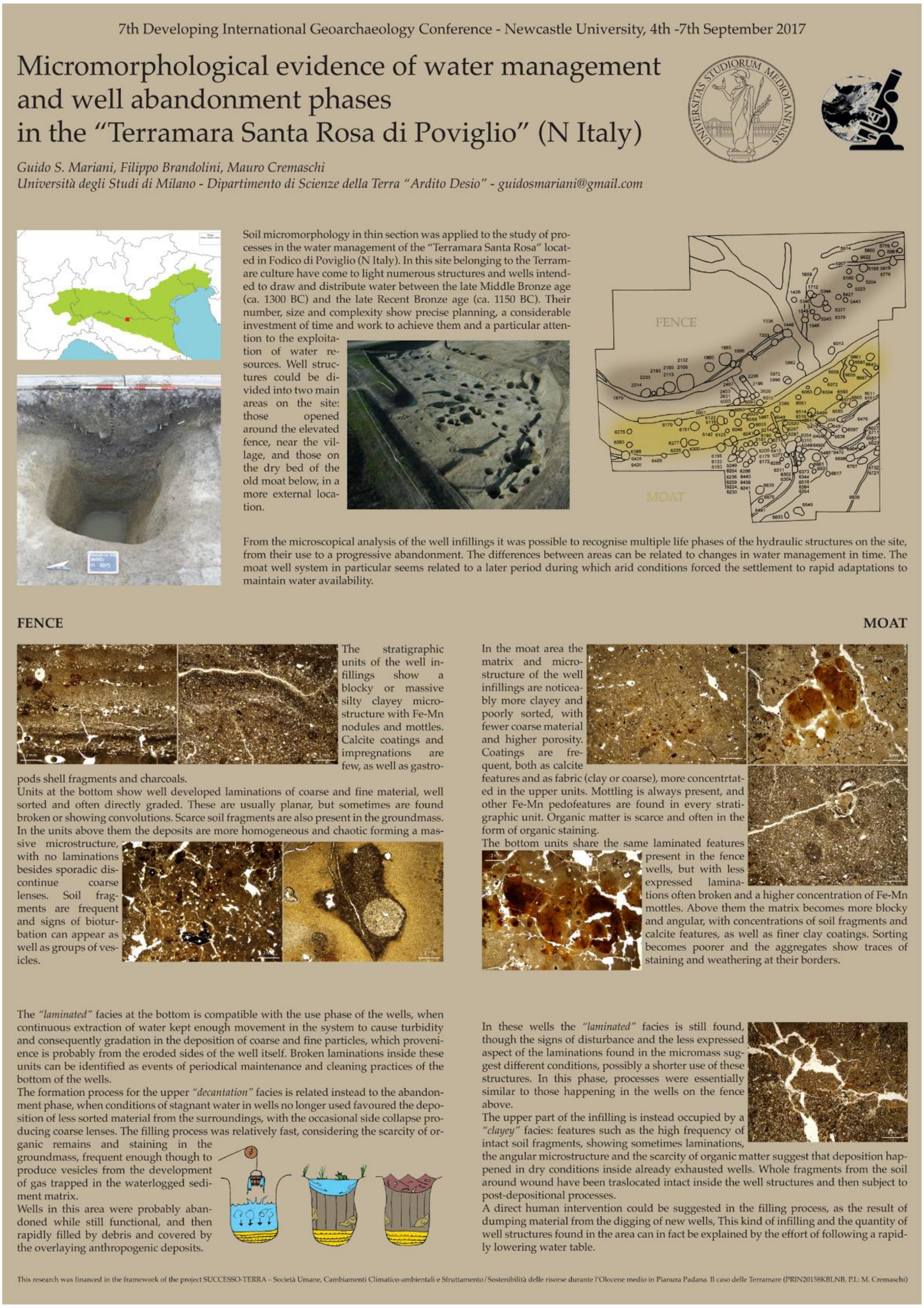
- Filippo Brandolini, Mauro Cremaschi - Medieval environmental changes and flood management in the Central Po Plain (N Italy), Congress Abstract, Humans and environmental sustainability: Lessons from the past ecosystems of Europe and Northern Africa, **14th Conference of Environmental Archaeology**, 26th – 28th February 2018, Modena (Italy)
Oral Presentation.

Abstract
The landscape development of the Central Po Plain has a long-lasting connection with human activities. After the collapse of the Roman Empire that coincides with a climate changing phase, the natural depressions on the right side of the Po River turned in vast swamp basins. This lacustrine environment characterised the landscape until the land reclamation that started in Renaissance and was completed only in 20th century AD. During the Middle Ages, humans coped with the environmental change using land and water management practices for agriculture purpose which modified the palustrine landscape. In particular, the exploitation of fluvial sediments had the effect to fill the swamps obtaining new farmland. The application of geoarchaeological tools has made possible to recognise anthropogenic landforms derived from this sustainable landscape management in the Middle Ages.

▪ Filippo Brandolini, Luca Trombino, Guido S. Mariani, Mauro Cremaschi - Micromorphology of domestic space in Early Medieval village: Anthropogenic Dark Earth from Santo Stefano in Poviglio (Italy), Congress Abstract, **DIG (Developing International Geoarchaeology) 2017**, November 4th -7th 2017, Newcastle (UK)
Poster Session.



▪ Guido S. Mariani, Filippo Brandolini, Mauro Cremaschi - Micromorphological evidence of water management and well abandonment phases in the "Terramara Santa Rosa di Poviglio" (N Italy), Congress Abstract, **DIG (Developing International Geoarchaeology) 2017**, November 4th -7th 2017, Newcastle (UK)
Poster Session.



Appendix 2 - Publications

- Filippo Brandolini et al. - Terra, silva et paludes. Assessing the role of alluvial geomorphology for Late-Holocene settlement strategies (Po Plain - N Italy) through Point Pattern Analysis. *Journal of Environmental Archaeology*, 2019. *submitted*

- Manuela Pelfini, Filippo Brandolini, Sara D'Archi, Luisa Pellegrini, Irene Bollati - Papia civitas gloriosa: urban geomorphological analysis of the city of Pavia (Northern Italy) for the development of a geotouristic itinerary. *Journal of maps*, 2019. *submitted*

- Filippo Brandolini, Emmanuel Reynard, Manuela Pelfini - Multi-temporal mapping of the Upper Rhone Valley (Valais, Switzerland): fluvial landscape changes at the end of the Little Ice Age (18th - 19th centuries). *Journal of Maps*, 2019. *submitted*

- Filippo Brandolini, Giacomo Patrucco - Structure-from-Motion (SFM) photogrammetry as a non-invasive methodology for historical documents digitization: a highly flexible and low-cost approach?. *Heritage* , 2019, 2, 2124-2136

- Andrea Zerboni, Michele Degli Esposti, Ying-Li Wu, Filippo Brandolini, Guido S. Mariani, et. al. - Age, palaeoenvironment, and preservation of prehistoric petroglyphs on a boulder in the oasis of Salut (northern Sultanate of Oman)'. *Quaternary International*, Online First, accepted 2 July 2019

- Guido S. Mariani, Filippo Brandolini, Manuela Pelfini, Andrea Zerboni - Matilda's castles in the northern Apennines: geological and geomorphological constrains. *Journal of Maps*, 15 (2), 2019

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