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ASH: ARCHAEOLOGY AND SOIL HERITAGE. A PRIN PNRR RESEARCH PROJECT ON THE ROLE OF ANDOSOLS FROM LATE PREHISTORY TO ANTIQUITY

1. Introduction

The interaction between ecosystem peculiarities and use of land resources by human communities in the past is a relevant – but yet underdeveloped – field of research. Among the disciplines eligible for collaboration in this perspective are territorial-scale archaeology (often referred to as 'landscape archaeology' and related to survey projects and archaeological topography), pedology, geomorphology, and bio-archaeology (paleobotany, archaeozoology, etc.). The PRIN PNRR two-year ASH research project – scheduled for completion in February 2026 – aims to investigate one of the most promising aspects of this interdisciplinary approach: the historical role played by Andosols, a very fertile type of soils generated by the pedogenization of volcanic ashes. The ASH Project aims at improving – with specific regard to Central Mediterranean – the diachronic archaeological knowledge, in part already established, on the relation between the Andosols distribution, their fertility and the development of dense, complex and long-lasting settlement patterns from Late Prehistory to Antiquity. This improvement in knowledge is intended as a means to investigate and demonstrate the relevance of these soils as a strategic natural resource that has supported dense human populations for millennia, highlighting the need for their conservation and proper management.

2. State of the art

Although volcanoes have often had negative and even catastrophic consequences – e.g. in the well-known cases of Vesuvius (Costa *et al.* 2021) and Etna (Chester *et al.* 2011) – the ash ejected during eruptions often resulted in the development of extremely fertile soils, generating significant long-lasting benefits for human communities (Fiantis *et al.* 2019). Volcanic soils – often classified as Andosols (Soil Taxonomy USDA) – have unique physical, chemical and biological properties which make them among the most fertile soils. In the last decades, research highlighted the occurrence of these soils also far from volcanic ecosystems (Iamarino, Terribile 2008), due to the wind-driven transport of fine ashes. These soils cover approximately 124 million hectares: 0.84% of the world's land surface; while representing a relatively small extent, they are a crucial land resource, as demonstrated by the high human populations density in these regions. This human concentration and

the lack of awareness of their importance, unfortunately led in several cases to a degradation or destruction of these soils. Recent research carried out in Italy on the intense soil sealing and its impact over land capability classes has assessed that, during the last 60 years, this process mainly affected the most fertile soils (e.g. Terribile *et al.* 2013; Vingiani *et al.* 2018).

Among the peculiar soil properties of Andosols there are (i) high porosity, (ii) friable consistency, (iii) high water retention capacity, (iv) large reserves of easily weatherable mineral and glass components (Nanzyo 2002). All these properties make Andosols very suitable for agriculture, even in prehistoric times. In this regard, paradigmatic cases come from the Andosols of the Poro highplain in Calabria (Pacciarelli 2013) and of the Campanian Plain (Talamo 2013; Minieri *et al.* 2020). In the first area archaeological surveys identified an exceptional high density of pre- and protohistoric settlement remains (Pacciarelli 2001), dating to a very long time-span covering several millennia (at least from Late Neolithic to the Iron age, that's to say from 4300 to 700 BC). The human presence and impact in the Poro highplain from Middle Copper Age (3300-2800 BCE) to Final Bronze Age (1150-925 BCE) was also investigated through the study of a pollen core (Di Lorenzo *et al.* 2021). In the Campanian plain, in the last decades, an extraordinary spreading and development of pre- and protohistoric settlements and ploughed fields was recognized in Rescue Archaeology excavations (Laforgia, Boenzi 2011). In both regions, however, historical rural occupation remains to be systematically investigated. In other areas the relation between volcanic environments and intensive occupation of the territory have been observed but never systematically investigated.

Interdisciplinary studies combining humanistic and scientific methodologies have been carried out regarding the relationship between Andosols and ancient human settlements systems in some geographical district around the world, such as central Arizona (Nakase *et al.* 2014) or Costa Rica (Ruiz *et al.* 2018), but only few and limited attempts in this regard have been made in Italy. ASH aims to change this scenario, by an organic and integrated study of relevant sub-regions of the central Mediterranean, in the context of a scientific project taking into account archaeological, pedological, archaeobotanical and remotely-sensed data, in order to investigate the connection between Andosols and settlement patterns of ancient societies. In doing so, the project will also demonstrate the urgency to preserve this crucial resource for the future society and human wellbeing.

3. The project

Within the ASH Project, the integration of legacy data (archaeological, environmental, pedological, remotely sensed) from selected sub-regions with new fieldworks aims to expand our archaeological diachronic knowledge on

the interaction between past Mediterranean communities and volcanic soils (Bonnier *et al.* 2019; Brancato 2019). Andosols have a brown (often dark, sometimes reddish) color and a powdery appearance when dry: from the point of view of agricultural use, they are characterized by a very high porosity and fertile structure, high permeability and water retention. The high content of organic matter, its stability given by the presence of low crystalline material and the high cation exchange capacity contribute to the marked fertility of these soils. Thanks to their high fertility, due to the characteristics highlighted above, flourishing crops often develop on these soils in spring, summer and autumn, in a non-irrigation regime.

Since late prehistoric times onwards, areas such as the Campanian Plain, where soils of this type are attested, were widely exploited for agriculture, as is demonstrated not only by the cited protohistoric ploughed fields found under the Vesuvian and Phlegraean Fields eruption levels, but also by traces of Roman centuriation frequently identified in modern landscape. Also the available palynological data, mainly coming from the Sarno Plain and the coastal areas of the Campanian Plain, indicate the occurrence of crops since protohistoric times (Vignola *et al.* 2021 and references therein).

In the Tyrrhenian Calabria region, an archaeological survey revealed an intensive occupation of the Andosols of the Poro highplain over a period of almost four millennia (Pacciarelli 2001), between the late Neolithic (last centuries of the fifth millennium BCE) and the Iron age/Archaic period (first half of the first millennium BC). Also significant is the study of a pollen core taken on the highplain, which reveals a landscape largely deforested and anthropized between the third and second millennia BCE (Di Lorenzo *et al.* 2021). Nevertheless, in both areas the presence of complex settlement patterns of the historical age linked with Andosols has been poorly investigated. ASH therefore aims at developing this research theme by fully highlighting the agricultural potential of these soils as a primary resource in subsistence and a crucial factor in the emergence of complex settlement systems. This goal is urgent considering that, according to specific studies, these types of soils, due to their morphological, physical, and chemical properties, induce a considerable soil fertility but also a great vulnerability to land degradation (James *et al.* 2000).

4. Case studies

The project will focus on the systematic collection and elaboration of heterogeneous evidence to analyze the human occupation and use of volcanic ash landscapes in four selected areas of Italy: Southern Etruria (especially Bolsena lake surroundings), Campanian Plain, Tyrrhenian Calabria (especially Poro highplain) and Ionian-Etnean Sicily (Fig. 1). These case-studies (hereafter, CS) were selected for: 1) the presence of Andosols generated by ash deposits

Fig. 1 – ASH Project: case studies.

from both nearby (e.g. Campanian plain) and distant (e.g. Poro highplain) volcanoes; 2) the advanced archaeological knowledge on the evolution of the settlement systems; 3) the advanced state of soil research, in particular regarding the distribution of Andosols.

CS 1: Southern Etruria (Northern Latium). The landscape of Southern Etruria is characterised by extensive deposits resulting from the activity of volcanoes during the Pleistocene (Bolsena, Vico, Bracciano, etc.). In this area numerous territorial research have been carried out, including those led by the RU 1 (e.g. Pacciarelli *et al.* 2022), aimed at understanding the territorial dynamics through the mapping of settlements especially since Bronze age times. Our research will start from legacy data (of both archaeological and paleobotanical interest) harvesting and digitization of previous studies on areas west of the Bolsena Lake (especially near Gradoli and Piansano), where Andosol concentrations are located (Napoli *et al.* 2019) (Fig. 2). New archaeological surveys will be also carried out.

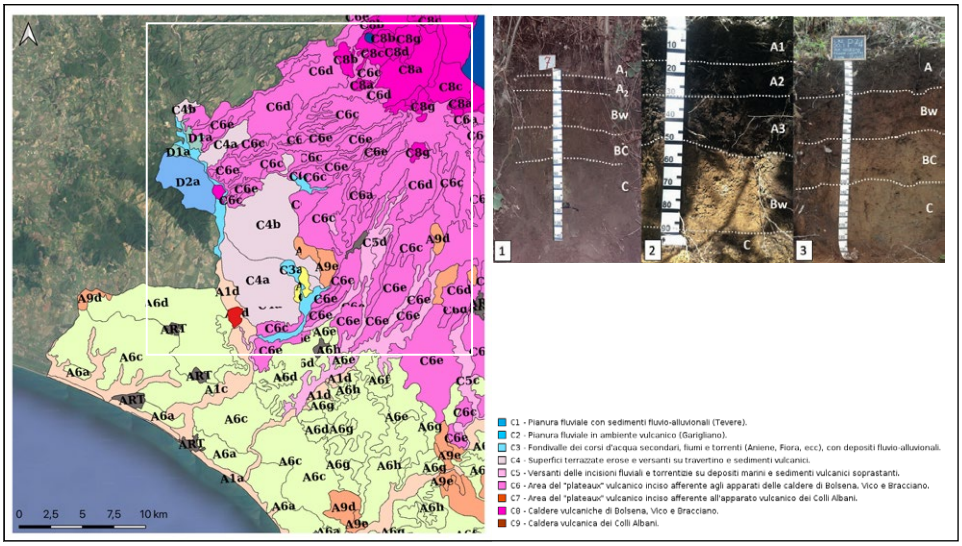

Fig. 2 – Distribution of Andosols and other volcanic-ash deposits in Latium and a section for pedological analysis (after Napoli *et al.* 2019).

CS 2: the Campanian Plain (about 392 kmq), a wide Plio-Pleistocene tectonically depressed area (graben) bounded by Mesozoic and Cenozoic carbonate mountains, is subdivided by the Vesuvius volcano into the Volturno Plain to the NW and the Sarno Plain to the SE. The history of the interaction between human communities and volcanoes is preserved in the Campanian plain's stratigraphy, where systematic or preventive excavations have led to define the framework of settlements and human activities between the Late Neolithic and the historical era (Di Vito *et al.* 2013, with previous bibliography). One of the most important achievements emerging from these excavations is the widespread presence of settlement remains and well-preserved cultivated areas dated mainly between the Late Neolithic and the Bronze age (Di Vito *et al.* 2013; Taylor 2015). Despite the widespread distribution of archaeological evidence, very few are the studies devoted to the reconstruction of the environment and land use history of this territory, especially in its central area, where the ancient urban center of *Atella*, with its centuriation, is located (Figs. 3-4).

Some scattered pollen data come from the Iron age levels of the Longola site (Di Maio *et al.* 2012). More recently, a pollen sequence from Pompeii allowed reconstructing the environmental evolution and the plant landscape of the Sarno floodplain between 900/750 cal BC and AD 79 (Vignola *et al.* 2021), highlighting the occurrence of pasturelands, cultivated fields and olive groves, as well as the introduction of cabbage cultivation in the fourth

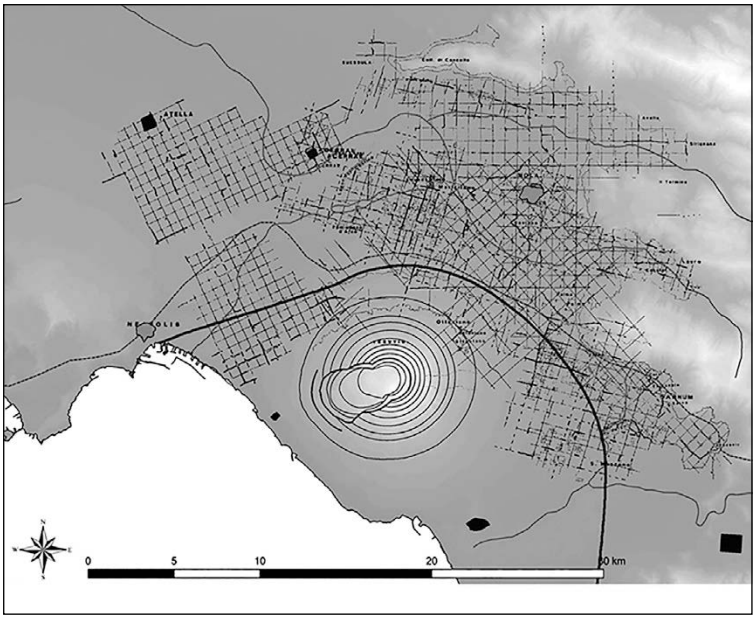

Fig. 3 – Digital reconstruction of Roman agrarian landscapes affected by the AD 79 Vesuvius eruption (after Taylor 2015).

Fig. 4 – Campanian Plain, aerial view of the agrarian landscape at the boundary between the provinces of Caserta and Naples, the present location of the Archaeological Park of *Atella*.

Fig. 5 – View of the Poro highplain (Tyrrhenian Calabria).

century BC. Concerning the Volturno Plain, no pollen data is available from the internal areas, but some interesting pollen sequences come from the coastal lakes of Averno and Literna Palus (Lago Patria). This was surrounded by a mixed deciduous and evergreen forest with local exploitation of olive, grapevine, walnut, and chestnut from the eighth century BC (Di Rita *et al.* 2018). Other data come from Neapolis (1st century BC to 5th century AD), where tree crops and cabbages were cultivated around the Graeco-Roman harbour (Russo Ermolli *et al.* 2014).

CS 3: the Poro highplain (Tyrrhenian Calabria) (Fig. 5) represents a key territory for the development of human communities through Prehistory and Protohistory (Pacciarelli 2001). The intensive archaeological surveys of the last decades demonstrate that this territory was continuously and intensively settled at least from the Late Neolithic to the Iron age (Pacciarelli 2001). The economic reason for this continuous occupation can be found both in the favourable agricultural predisposition of the Andosols, present mainly on the Tropea Promontory top surface (Poro highplain), and the availability of pastures. Archaeological surveys document many phases of human settlement on the Poro highplain dating to the Late Neolithic, to the Copper, Bronze and Iron ages (Pacciarelli 2001, 2017), that is, from the end of the fifth to the beginning of the first millennium BC. Recent pollen analysis highlighted that the Poro Plateau was exploited for agricultural practices (cereal cultivation) and livestock grazing between ca. 3000 and 1000 cal BCE (Di Lorenzo *et al.* 2021). One of the main reasons for this long-lasting – and in some phases very intense – occupation of the highplain is the presence of very light and fertile Andosols, quite suitable for primitive agriculture with wooden plow.

CS 4: the Etnean region in Sicily (Fig. 6), with an extent of 500 kmq, is a perfect case study due to its geographical characteristics and the number of archaeological projects (both excavations and surveys) carried out within it

Fig. 6 – Plain of Catania, agrarian fields seen from the Roman site of Castellito di Ramacca.

in recent decades. The landscape and soils of the Etnean area (Catania, Sicily) have been shaped by the intense activity of Mount Etna, one of the world's most active volcanoes (Branca *et al.* 2015). Etnean volcanic soils supported an intense agricultural exploitation throughout millennia: as the field-use research history has highlighted, here agricultural economy, land colonization and urbanism flourished on the lower slopes of the mountain toward the Ionian Sea and the broad Plain of Catania (Sorbello 1992). The traditional historiography described the Etnean region as capable of producing wheat and other agricultural products in quantities well beyond the consumption requirements of its population. In this area several researches have been carried out, including those led by members of the RU 1 (Brancato 2020), aimed at understanding the settlement systems evolution through field survey research, archaeological mapping and legacy data digital integration. However, for this area research project focused on palaeoenvironment are scarce, with a few exceptions (Brancato 2022; cf. also Castiglioni 2018).

5. Methodologies

ASH project investigates CS areas through the combined use of innovative technologies for the digital recovery, interpretation and management of archaeological, pedological, topographical, environmental legacy data, integrated through new field research and remote sensing. The pedological work in each CS aims at identifying new portions of Andosols starting from the study of remote data (high spatial and temporal resolution - Copernicus, Prima, QuickBird and MIVIS dataset) and the analysis of soil and vegetation index. Archaeological field surveys and excavations scheduled within the project aim at collecting information about the location, distribution and organization of human settlements. The information about archaeological

artefacts and sites found during field researches is systematically recorded and implemented within an open geographical information system infrastructure. The datasets and the relational database are also implemented with all the archaeological legacy data obtained starting from archive research and continuing with bibliographic analysis of previous findings.

Palynology is widely recognized to be one of the most appropriate methods for reconstructing past landscapes and their changes over time, related to natural phenomena or the impact of human activities (Mercuri *et al.* 2019). In particular, the latter can be detected through the careful definition of the anthropogenic indicators (ruderals, crops, etc.) and a quantitative analysis of microcharcoals that can help to understand the regime of fires in the past. Remote sensing (RS) analysis (Lasaponara *et al.* 2007; Forte, Campana 2016, 2017; Traviglia, Torsello 2017; Verhoeven 2018; Argyrou, Agapiou 2022; Wang, Liu 2024) is planned for all study areas. The RS method is aimed to a better understanding and characterization of buried elements in different archaeological sites; in particular relevant archaeological features have been pointed out in several studies making use of optical multi-spectral remote sensing sensors, such as WorldView and Pléiades.

Archaeological proxies, such as soil and crop marks, can be depicted from multispectral datasets due to their different spectral signature in comparison to the surrounding area (Fig. 7). For this purposes, WorldView-2, WorldView-3 (see Di Palma, Merola in this volume), Pléiades-1A, Pléiades-1B, Pléiades Neo (Di Palma *et al.* 2023; Cozzolino *et al.* 2025), Sentinel-1 and -2 images, Prima image, QuickBird images are inspected for each CS (Schreier 2020). Copernicus Sentinel-1 data were acquired in interferometric wide swath (IW) mode, with a 250 km swath, processed to Level-1 ground range detected (GRD) at a resolution of 10 m, orthorectified at VV intensity (vertical transmit and vertical receive) and VH intensity (vertical transmit and horizontal receive) polarisation (Lasaponara, Masini 2020). The VV and the VH polarisations were also extracted from the herein featured Copernicus Sentinel-1 image. The high- and very high-resolution multispectral satellite images (0.50-0.30 m on the ground) are processed, analysed and interpreted using ENVI 4.5, QGIS and a very performant artificial intelligence (AI) software, such as eCognition (see Di Palma, Merola in this volume), with the aim of detecting, identifying and analysing anomalies and traces of archaeological interest (Fig. 8). The methodology integrates traditional topographical analysis, including historical cartography, aerial photographs (see Ditaranto, Giordano in this volume), and historical space photos, with semi-automated and fully automated Machine Learning (ML) and Deep Learning (DL) techniques. This includes the training of convolutional neural networks (CNNs) to detect specific patterns in the landscape.

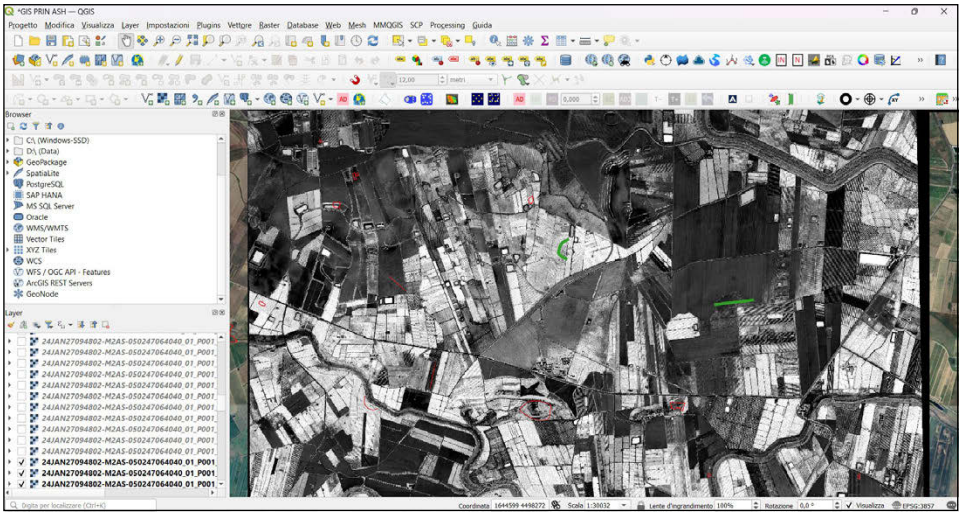

Fig. 7 – Application of the Normalized Difference Water Index (NDWI) to the WorldView-3 satellite image (27/01/2024), with subsequent vectorization of potential dump-marks and their integration in the QGIS platform.

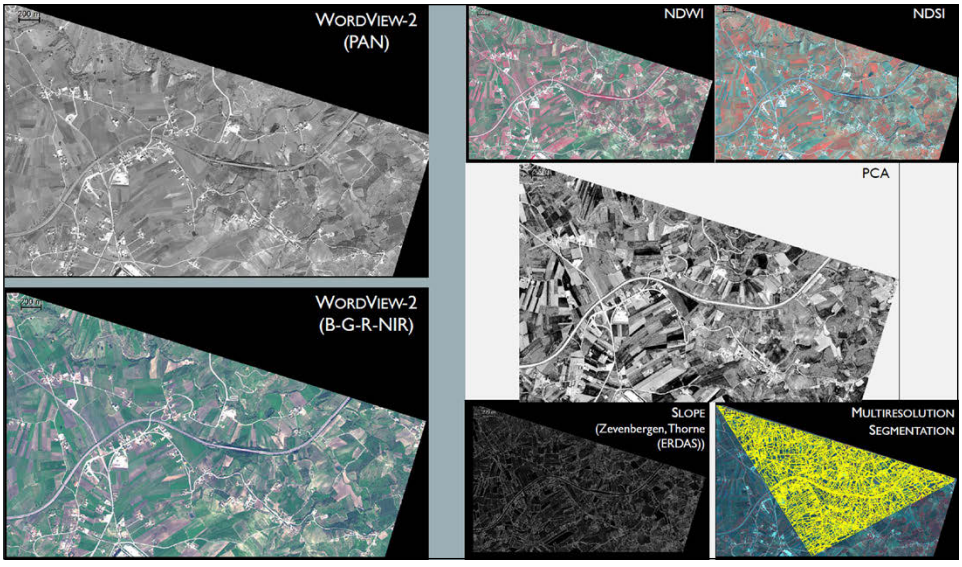

Fig. 8 – The eCognition experiments involved processing, analysis, and evaluation, including spectral index calculation (NDWI, NDSI in false colour), Principal Component Analysis (PCA), slope estimation using ERDAS, and segmentation.

The systematic collection, integration, and publication of heterogeneous sources are managed within a dedicated geographic information system designed *ab initio* to comply with the Istituto Centrale per il Catalogo e la Documentazione (ICCD) standards and the Istituto Centrale per l'Archeologia (ICA) principles (Calandra 2022). The geodatabase (PostGIS) is structured around core archaeological entities – sites, findspots, survey units, features, cores/samples, and interventions – whose descriptive, spatial, chronological, and bibliographic attributes adopt ICCD Normativa semantics and authority lists to guarantee terminological consistency and catalogue interoperability at national level. This modelling enables the harmonisation of legacy datasets with newly acquired field observations and laboratory outputs, following a workflow for heterogeneous-data integration already tested in Mediterranean landscape archaeology (Brancato 2019), where archival records, survey evidence, and remote-sensing proxies converge in a single, queryable analytical space.

Within the ICA Geoportale Nazionale per l'Archeologia (GNA) application for archaeological data management, descriptive and authority information is encoded using the ICA's standards (Brancato *et al.* 2024). ISAD(G) (i.e. General International Standard Archival Description) specifies which elements (fields) are used to describe archival units – for example title, dates, scope and content – so that every dataset or collection record exposes a predictable set of metadata. ISAAR(CPF) (i.e. International Standard Archival Authority Record for Corporate Bodies, Persons and Families) defines authority records for the agents involved (survey teams, institutions, individual researchers), ensuring that names, roles, and histories are recorded once and reused consistently across records. Each operation across the data lifecycle – digitisation, georeferencing, classification, sampling, laboratory analysis, and interpretative synthesis – will be uploaded in the GNA as a discrete event with explicit paradata. Descriptive metadata will be also exposed according to standards, facilitating data provision to Italian and European e-infrastructures for archaeology and digital cultural heritage (Richards *et al.* 2021; Caravale *et al.* 2024). Interoperability/FAIR are ensured through standardised exports and crosswalks, open long-term formats (e.g., GeoPackage), metadata APIs, and authority control (DOI for publications; ORCID/VIAF for agents). In line with the dissemination plan and the decision to avoid a public WebGIS, discovery and preservation rely on deposition to the ICA GNA via automated end-of-project batch upload, guaranteeing citability and governance consistent with ICCD/ICA compliance. The bibliography is curated in Zotero and exposed as Linked Open Data (LOD) in CSL-JSON, JSON-LD, and RDF with stable identifiers; GIS records link back to the specific sources underpinning each interpretation. The LOD bibliography is accessible via the project website (https://archeomaplab.it/progetti/progetto-ash-prin-2022-pnrr/), which also hosts open-access reports and publications.

6. Objectives

This standards-based, provenance-aware infrastructure provides the analytical backbone for organic comparisons across the case studies. By integrating legacy archives, field-survey outputs, pedological and palynological datasets, and remote-sensing interpretations within a single environment – together with authoritative cataloguing (ICCD), archival accountability and linkage, automated deposition on the GNA, and LOD-based bibliographic exposure – the project ensures methodological transparency and long-term reusability. Following an interdisciplinary approach, ASH pursues the following objectives:

– reconstruct settlement dynamics by integrating legacy and newly collected survey data with remote sensing in the sample areas, mapped against multi-layer cartography (soil, topographic and geological maps, digital elevation models);
– detect and characterise Andosols using multi-temporal Copernicus imagery, evaluating their influence on vegetation phenology and productivity through NDVI-derived metrics;
– compile and analyse pollen-core legacy data, to reconstruct major palaeoenvironmental trends;
– compare the distribution of volcanic soils with settlement (and socio-economic) systems and land uses across regions and periods.

Results to date are substantial but currently under analysis; publications in preparation will present the full datasets, methods, and implications for the project objectives.

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ABSTRACT

ASH investigates the role of Andosols, i.e. volcanic-ash soils, in four case studies in central and southern Italy (Southern Etruria/Northern Latium, the Campanian Plain, the Poro highplain in Calabria, and the Ionian–Etnean area of Sicily). It studies how the distribution and properties of these soils shaped agricultural productivity, settlement systems, and long-term landscape use from Late Prehistory to Antiquity. The research combines archaeological records (new fieldwork and legacy data) with pedological and archaeobotanical studies and multi-temporal remote sensing (historical satellite images, multispectral imagery, spectral indices mapping, integrated machine-learning and deep-learning analyses). A standards-based GIS supports cross-domain integration and spatial modelling. The project advances knowledge of human-environment relations, highlighting the strategic importance – and vulnerability – of volcanic-ash soils as a crucial subsistence resource. It also establishes a basis for transdisciplinary work linking archaeology, remote sensing, pedology, and environmental research, and provides evidence to inform responsible management of soil and landscape heritage today. Newly collected datasets and GIS mapping enable reproducible analyses and open deposition to benefit future research and heritage governance.