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Geosciences Contribution to the *Via Appia Regina Viarum* UNESCO World Heritage Between *Beneventum* and *Aeclanum* (Southern Italy)

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Abstract

The *viae romanae* (Roman roads) were constructed according to precise designs and exceptional engineering techniques, ensuring their strength and durability. They represent an immeasurably important factor in human history. Their impact has been universal, facilitating the movement of people, goods, ideas, beliefs and religions over the centuries. The *Via Appia Regina Viarum*, built between the end of 4th and 1st centuries BCE, connected *Rome* to *Brundisium*, spanning the region of *Latium* and *Apulia*. The road initially crossed the coastal plains of the Tyrrhenian Sea (in *Latium*) before cutting through the reliefs and river valleys of the southern Apennines (in *Campania*) and finally crossing the *regio Apulia et Calabria* via *Tarentum,* to the harbor of *Brundisium,* along the Adriatic coast. In 2024, the Italian Ministry of Culture proposed the '*Via Appia Regina Viarum*' for inscription on the Unesco World Heritage List, recognizing its unique and exceptional testimony to Roman civilization. Later that same year, the nomination was accepted, and today, the *Via Appia* is part of the UNESCO World Heritage List. A significant contribution to this nomination came from the multidisciplinary studies and research conducted along the Via Appia between the ancient cities of *Beneventum* and *Aeclanum* in the Campanian Apennine, including: (1) geoarcheological investigation aimed at identifying the ancient path of the road, which was not well documented in the area between *Beneventum* and *Aeclanum*; (2) studies focused on cultural and geological heritage along the road and its surrounding landscapes, enhancing the value of the nomination; and (3) the organization of social and cultural events designed to disseminate scientific findings and raise awareness among scientists, students, local and national administrators, local food and wine producers, and the general public. This paper highlights the pivotal role of geoscience at all stages of the project: from preliminary field surveys and mapping of landforms and lithofacies, to targeted field and geophysical surveys, to archaeological excavation and geoarchaeological consideration, and to the dissemination of new data through cultural events.

Keywords: cultural and geological heritage; UNESCO world heritage; southern Apennine; roman age; ancient roads; Via Appia

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1. Introduction

Geosciences, including geomorphology, stratigraphy, geophysics, geology, and archaeometry, offer important contributions to archeological research [1–4]. Over recent decades, many archeological sites and historical contexts have been enriched by geoscience approaches [5]. One of the most significant applications of geoscience in archeological research is the use of geomorphological and stratigraphical methods to identify the traces and remains of ancient roads that connected major cities and traversed various territories [6,7]. Among these, the identification of paths of Roman roads is a key topic that involves geoarcheologists in various archeological research projects [8–13]. As a result, researchers from both geoscience and archaeology have developed methods capable of interpreting past landforms and environments, focusing not only on how they changed over time but also on identifying the causes behind these changes. By studying present-day landforms, it is possible to recognize those that have experienced minimal changes in recent history, making them potentially more significant from an archeological perspective. Areas unaffected by significant erosional and depositional processes are more likely to preserve shallow archaeological traces and remains. Consequently, geomorphology and landscape archeology share common objective and methodological approaches. These include the use of historical sources and maps, multiscale topographic maps, aerial photographs, remote sensing and field surveys. Both disciplines contribute equally to understanding the formation processes of the archeological record. Two key concepts often employed by geoarchaeologists are C-Transform (Cultural processes) and N-Transform (Noncultural processes) [14–16]. C-Transform refers to processes such as recycling, reuse, loss, discard, abandonment and burial, while N-Transform involves natural processes like weathering, erosion, transport and deposition. These terms help to identify areas rich in archaeological data and provide the basis for classifying them as potential archaeological sites. Once a potential site is identified, detailed site-scale geomorphological and archeological field surveys, often supported by geophysical investigations, are conducted [17]. These surveys help to identify the specific areas of the site that will undergo excavation. In summary, geomorphology provides crucial insights into ancient landscapes, natural processes, and the interactions between civilizations and their environment. It helps reconstruct the evolutionary history of landforms, protect vulnerable archaeological sites, and understand how geological and geomorphological contexts have influenced human history. With this knowledge, archaeologists can more efficiently interpret the distribution and functionality of sites, as well as the land-use practices and adaptation strategies of ancient populations. At the same time geomorphology and landscape archaeology provide additional information by offering detailed insights into the key features and landforms of the present-day landscape, which can be valued and enhanced for cultural and heritage purposes.

Geoscience plays an important role in supporting archaeological excavation, particularly in the study of stratigraphy [18]. They help to identify the depositional, erosional, pedogenetic and anthropogenic processes that created both the archaeological and natural layers of the site. Additionally, geosciences aid in analyzing the geomaterials and lithotypes used in the construction of the site, including stones, rocks, clays and clay mixtures [19,20]. In archaeological stratigraphy, layers reflecting significant Earth events are often present. These may include evidence of earthquakes, volcanic eruptions, and climatic changes, particularly in specific regions of the world. Notable stratigraphic layers identified in Mediterranean archaeological contexts [19,20], especially in the central and southern sectors of Italy's Apennine range [21,22], encompass: fall layers resulting from disruptions and site abandonments, paleosols and buried soils indicative of past environmental conditions, tephra layers from volcanic eruptions, flood and waterlogging deposits associated with extreme weather events, as well as landslides and eluvio-colluvial deposits, which are

particularly relevant in areas characterized by complex tectonic and volcanic activity, as southern Apennine. Research yields significant results when traces of ancient roads are preserved on the present-day surface or at shallow depths. Conversely, these traces are often absent if they have been eroded or buried by natural processes.

Starting from these considerations, a multidisciplinary approach was developed to trace the ancient paths of the *Via Appia Regina Viarum*, the Roman road that connected Rome to *Brundisium*, specifically in the sector between the ancient cities of *Beneventum* and *Aeclanum* (Figure 1). Several studies [23–25], based on archaeological and historical perspectives, have identified different paths of the Via Appia. Our project, named Ancient Appia Landscapes (AAL), has generated and developed new data on the traces of the Via Appia [26–31]. The project, carried out by the University of Salerno in collaboration with the Superintendence for Archaeology, Arts and Landscape (Caserta and Benevento Office), aims at reading the territory of ancient colony of *Beneventum* from an historical point of view, in its anthropic assets and spatial forms (agricultural divisions, road axes, etc.). The project intends to understand and enhance the features of the eastern area of the city by studying the transformations of the urban and rural landscape over time and reconstructing the route of the ancient Via Appia, thereby highlighting the opportunities and potential of the area for the enhancement of its tangible and intangible cultural heritage.

Similar approaches were performed ed developed in several studies on historical routes within UNESCO World Heritage sites and Global Geoparks [32–34]. Geosciences were applied to connect geological and cultural attractions to support sustainable geotourism and foster local economic development. For example, dedicated geotourism itineraries have been proposed within the Volcanes de Calatrava UNESCO Global Geopark to link volcanic geoheritage and urban cultural sites, providing structured visitor experiences along themed trails [32], as well as in field-trip based geoheritage trails in the Sesia Val Grande UNESCO Global Geopark [33] and transnational cultural-geological routes like the Atlantic Geoparks Route across Europe [34]. In southern Apennines, several studies promote historical and cultural importance of ancient routes, supporting events and initiatives organized occasionally by hiking and cultural associations and local tourism offices. The historical transhumance trails, known as *Regi Tratturi*, connecting the highlands of Molise and Abruzzo regions [35,36], as well as in those in Campania and Basilicata regions, to the Tavoliere plain in Apulia region [37,38], are the best examples of the contribution of geosciences to the enhancement of the interaction between cultural and geological heritage. Unfortunately, in the sector between Beneventum and Aeclanum, Regi Tratturi trails do not coincide with Via Appia path, and for this reason cannot be considered as an additional value to the cultural and geological heritage promotion.

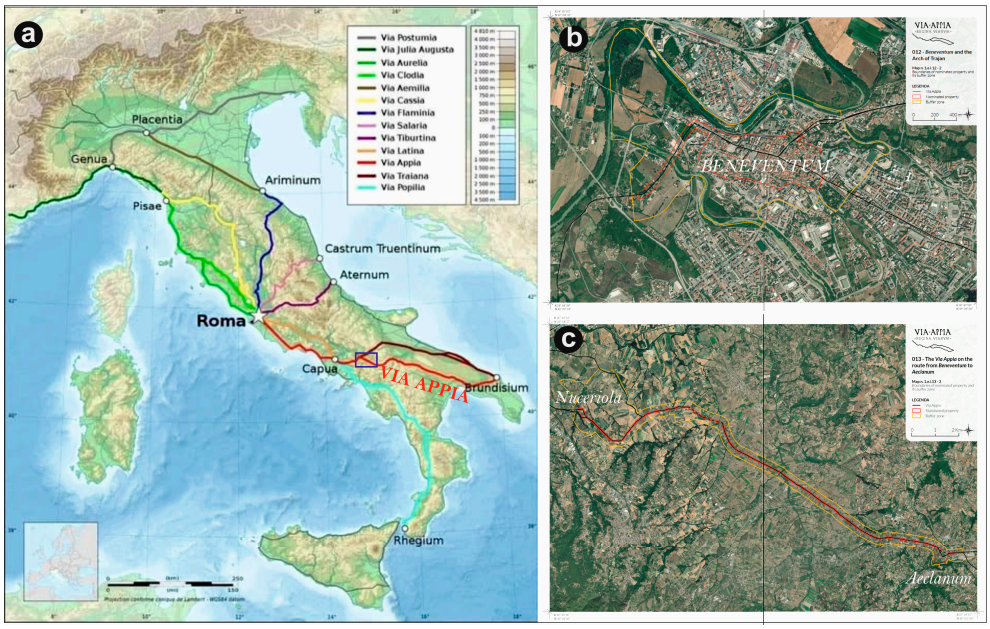


Figure 1. Roman roads and Via Appia. (**a**) Main Roman roads in Italy (modified from Wikipedia). In the blue square, the sector of the *Via Appia* presented in this study; (**b**,**c**) *via Appia* paths between *Beneventum* and *Aeclanum* (modified from: Nomination Format Unesco World Heritage List [35].

2. Methods and Materials

The research involves several steps of analysis, including integrated methods and tools of investigation, from a territorial to an infrasite scale. A multi-temporal and multi-step approach was progressively placed through the project: (1) preliminary field archaeological surveys and geomorphological studies was conducted, (2) the interplay between archeological data and geomorphological interpretation allowed for the identification of areas with higher density of archaeological evidences and traces compared to areas lacking such evidence, particularly those where natural processes have been absent or moderately present over the last millennia. This approach excludes areas affected by erosional and depositional processes, where archeological evidence has either been deleted or buried. It also allows for evaluating how the main landform alignments (such as river networks, terraced surfaces, hills, and ridges) may have influenced the selection of road paths, agricultural cadasters, and centuriation (ancient land division).

Additionally, these alignments could have changed over the centuries due to N-transform processes (see the following Sections 3, 4 and 4.1.1–4.1.4). These approaches help identify areas where more detailed surveys should be conducted. These areas were also subjected to geophysical investigations, such as Ground Penetrating Radar (GPR) and magnetic surveys. (3) data interpretation and synthesis enhanced the identification of the areas of archeological excavation; (4) a multitemporal and multistep archeological excavation was conducted in the Masseria Grasso area, which is hypothesized to be the site of the ancient *Nuceriola*, a way station along the Via Appia, (5) the project aims to verify and confirm the most probable hypothesis regarding the paths of the Via Appia and to provide detailed positioning on maps and, Geographical Information System (GIS)-derived information. Additionally, it seeks to hypothesize whether the multiple paths of the Via Appia resulted from the progressive changes that affected the landscape over time. (6) The project also provides information about the location of other way stations, such as *Calor flumen*, located near a strategic area where the ruins of an ancient bridge over the Calore River, known as *Ponte Rotto* (broken bridge) or *Appian Bridge*, are still preserved (7). Simultaneously with the above steps, the project organizes social and cultural events

aimed at disseminating scientific results to raise awareness among scientists, students, local and national administrators, local food and wine producers, and the broader public. (8) All these data were highly considered to the preparation of the proposal for the inscription of via Appia on the UNESCO World Heritage List. By connecting knowledge across different disciplines and engaging in international, national, and local administrative offices, citizens, and scholars, the *Via Appia Regina Viarum* is now recognized as a UNESCO world heritage site [39].

2.1. Geology and Geomorphology

To highlight the main features of the ancient landscape of the Via Appia, to identify the traces of the route, as well as the changes in the paths that occurred over centuries, geological and geomorphological surveys were conducted simultaneously to the archeological field surveys planned during the AAL project. These surveys were also aimed at identifying the main morphodynamic processes affecting and having affected the Appia territory. This approach allows us to discriminate the areas of the landscape that have been affected by significant geomorphological changes, from those areas that could be essentially unaffected by changing processes. In particular, the study allows the discrimination and mapping of areas subject to erosion versus those in aggradation, and the identification of active or potentially active processes over timescales relevant to archeology. This approach enables a site-specific understanding of areas where erosional/depositional dynamics and anthropic interventions have modified the landscape over recent centuries. Geomorphological aspects of the territory are being analyzed through a detailed study of the Regional Numerical Technical Maps at 1:5000 scale and historical aerial photographs of various years and scales. From the regional technical cartography, in addition to detailed geomorphological maps, thematic maps have been produced, including slope maps, insolation maps, ancient and modern hydrographic networks, and land use maps, all appropriately integrated within a GIS environment. The geological features of the study area were initially examined using the New Geological Cartography of Italy at 1:50,000 scale (Sheets 432 Benevento and 433 Ariano Irpino) and relevant geological literature [18,40–42]. This preliminary study was complemented by a geological field survey, which allowed the mapping, for some sectors of the territory, of both the bedrock and more recent deposits that are poorly represented in official geological maps. During the first field surveys, some stratigraphic sections were also analyzed, documenting, site by site, the main textural characteristics, bedding organization, stratigraphic discontinuities, and the geometry of Holocene sedimentary bodies exposed at the surface. In addition to fieldwork and planned analytical investigations, further stratigraphic information has been derived from a critical review of published archeological sources and the study of stratigraphy from excavations conducted during the multitemporal research program. This integrated geomorphological and stratigraphic approach allowed discrimination, site by site, between the formative and causative processes of the geological and archeological record. Consequently, it provided valuable insights for the reconstruction of paleolandscapes and associated paleoenvironments, as well as for the identification of morphodynamic changes and their driving factors, whether climatic or anthropogenic.

2.2. Archeology

The *Ancient Appia Landscapes* project applies the approaches typical of landscape archeology [43–45] to acquire data aimed at an exhaustive understanding of the Benevento territories. The project is structured around a transdisciplinary framework and integrates numerous tools, analytical methods, techniques, and technologies. Research activities began in 2011 with the collection of published archeological data and archival records,

acquisition of historical and modern cartographic sources, and aero-topographic study of historical aerial photographs. Available data have been integrated with field surveys conducted both intra-site and extra-site. These surveys collected information over an area exceeding 500 hectares, extending from the city of Benevento to the eastern area of the *Ponte Rotto* over the Calore River until to *Aeclanum* Archeological Park.

This dataset was processed into an Archeological Map managed through a GIS (QGIS Open Access, 3.18.1), which enables the contextual mapping of all environmental and anthropogenic factors involved in the formation of the landscape and its transformations over time. This system allows the integration of geomorphological analysis with the identification of traces of medium- and long-term processes, recognizing landscape units. The application of the regressive method made it possible to distinguish stable units of the current landscape from those preserved in fossilized form; it also allowed for the identification of indicators of survival and degradation of ancient landforms, as well as the processes responsible for them. A similar procedure, applied to historical cartography, enabled the comparison of different types of maps produced at varying scales and on different supports through their georeferencing. This approach highlighted the preservation of landforms, the persistence of certain characteristics and elements, such as road junctions, churches, and others, as well as modifications to the characteristic geographical features of the area [46,47].

Field surveys highlighted settlement distribution along the route of Via Appia. In selected contexts where archeological data were more dense, remote sensing, aerial photointerpretation, and geophysical prospections were applied to refine knowledge and investigate the "non-visible" archeological record [31,48]. These investigations allowed us to plan excavation activities at the site of Masseria Grasso and identify *Nuceriola* as a large settlement. Main results highlighted that the settlement was structured from the 4th century BC and subsequently developed, most likely as a *vicus* (little village), with a regular layout along the Appian Way from the late Republican period through the Imperial age [31,32]. The extent of the settlement and the regular articulation of its inhabited spaces were hypothesized by integrating anomalies detected in customized aerial photographs produced using Unmanned Aerial Vehicle (UAV) platforms equipped with different airborne sensors, which were employed to calculate vegetation indices [49].

3. Via Appia Regina Viarum

3.1. Historical Background

The Via Appia was initiated by *Appius Claudius* in 312 BCE, initially linking Rome to Capua (today S. Maria Capua Vetere) (Figure 1a). It was later extended to the southern regions: first to *Beneventum*, 164 miles (264 km) from Rome; then to *Venusia*, and subsequently to *Tarentum*, 320 miles (515 km) from Rome. Finally, the road reached *Brundisium*, where it terminated at 240 BCE, covering a total distance of approximately 365 miles (540 km). *Brundisium* thus became a vital hub for communications with Greece and the East [25,50,51].

Originally constructed for military purposes, the *Via Appia* quickly became a major trade route and a significant vector for cultural diffusion, becoming a *via publica* (public road). The road was maintained by Roman authorities, requiring a dedicated magistracy for its upkeep, and underwent continuous restoration and improvements until the Late Empire. As a result, it remained a model for all roads extending from Rome to the farthest regions of the Roman Empire (Figure 1a) [52,53]. Proudly called the *regina viarum* (Queen of roads), *celeberrima* (most famous), *nobilis* (noble), and *insignis* (notable), it represented roman engineering excellence.

After the republican period, emperors such as *Augustus, Nerva, Trajan, Caracalla, Septimius Severus*, and later *Constantine* worked to upgrade the road. Constantine's involvement

was particularly significant as the Via Appia connected the new capital of the Eastern Roman Empire, *Constantinople*. To improve access between *Beneventum* and *Brundisium*, Trajan ordered the construction of Via Appia Traiana, inaugurated in 109 CE [54,55]. This new road, following the Adriatic coast, spanned 206 Roman miles (just over 300 km) and significantly reduced travel time, providing a more direct link to Italy's most important harbor for eastern trade.

Roman engineers implemented substantial works on the Via Appia, constructing bridges and viaducts that allowed travelers to cross large water courses and natural depressions. Notable among these are the ashlar masonry bridges of Via Appia Claudia and the mudbrick bridges of Via Appia Traiana, some of the longest preserved in Europe. These structures exemplified proven engineering solutions and contributed to the monumentality of the route. The road was further embellished with infrastructure serving travelers, including milestones, which were placed at regular intervals to mark distance and guide travelers, much like modern-day road maps and travel guides. In addition, way stations were established along the route [56]. Initially created for the government postal service (*cursus publicus*), these stations became integral to the road system, often serving as precursors to the development of settlements. In fact, Via Appia contributed to the emergence of new settlements, typically of military (*coloniae*) or trading nature (*statio*), located at crossroads with other routes or near navigable rivers. Moreover, the road influenced the organization of agricultural land, as land registers were often arranged along its axis [57].

3.2. Via Appia Regina Viarum Between Beneventum and Aeclanum

Several hypotheses have been proposed to reconstruct the path of Via Appia, some of which were developed by local scholars in the late nineteenth and early twentieth centuries. A. Meomartini postulated two distinct paths: the first passing through Contrada Cancelleria, identified as the *statio* of Nuceriola [23], and the second, based on archeological findings, placing the *statio* further south, in the area of Contrada Piano Cappella [24]. In the 1980s, L. Quilici hypothesized a path near San Cumano, where some archeological remains were discovered [25] (Figure 2).

In addition, two hypothetical cadastral systems were hypothesized in the territory of *Beneventum*: one from the Triumviral period (Beneventum I, 20 × 20 actus, N 42° E) and the other from the Augustan era (Beneventum II, 16 × 25 actus, N 2° W) [58].

Recent re-evaluations of Beneventan cadastres have proposed new dates: Benevento II is now attributed to the years following the colonia foundation (after 268 BCE), whereas Benevento I corresponds to the Triumviral-Augustan period. The Ancient Appia Landscapes team has also identified certain alignments in the Cubante plain, which may represent traces of a third cadastral system, referred to as Beneventum III [59] (Figure 2).

The ancient *itineraria*, like *Tabula Peutingeriana*, show that Via Appia, after leaving *Beneventum* toward ancient city of *Aeclanum*, crossed two stopping places: *Nucriola* or *Nuceriola*, located at the 4th mile, and *Calor flumen* at the 10th mile. Some scholars [25] hypothesized that Via Appia crossed further north through the Cancelleria district (Figure 2), where various *spolia*, including a milestone, were discovered. Other authors [24] proposed that the road crossed the S. Cumano farmstead (Figure 2), where a re-used milestone dated back to renovations ordered by Jovianus (363–364 CE) has been found. The AAL project based on field surveys, prospecting, and excavations has allowed researchers to trace the road from the town to the area Masseria Grasso, where the way station of *Nuceriola* has been located. This identification is based on the discovery of a road axis and a large settlement that existed from the 4th century BCE to the 6th century CE. The occupation of a large planar surface occurred at the same time as a nearby sacred area was in use, in Centofontane between the 4th and 3rd centuries BCE (Figure 2) [29,60].

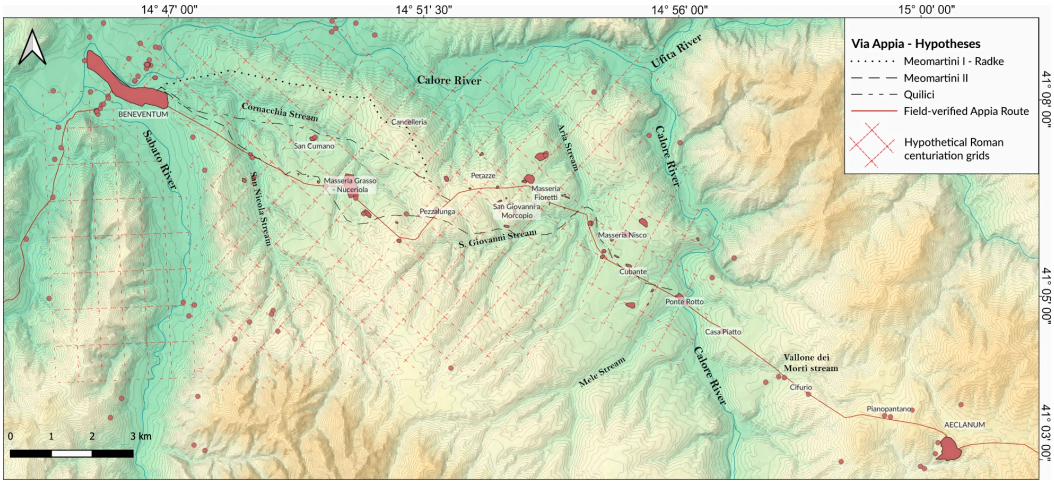


Figure 2. *Appia Viarum* paths, archeological settlements and land division systems on DEM TINITALY [61] with hillshade and 10 m contour lines. Red areas and circles are archeological sites. (elaboration by C. De Vita).

Three different land division systems (*centuratio* or centuriation) have been found in the territory (Figure 2). The first one, with 16 × 25 *actus* plots, can be traced back to the foundation of the Latin colony of *Beneventum* in 268 BCE and is oriented N 42° E, according to the main natural routes that survive in the contemporary landscape. This was replaced by a new system, with the same alignment, with 20 *actus* square plots, dating back to the triumviral colony of 42-41 BCE and, to the early Augustan age. Traces of a third system, with a 20 × 20 actus module and a N 29° E orientation, could be traced back to a *renormatio* from the Trajan-Hadrian age. These traces can be reconducted to this imperial, as testified by the milestones from 123 CE, marking the renewal of the road section between *Beneventum* and *Aeclanum.* It is plausible that renovation was carried out because of the natural instability of the territory, prone to flooding and swamping, as also documented in toponyms (*Paluda nigra, Selva mala*—Black lagoon, Bad woods). Throughout the Imperial age and Late Antiquity, there was a constant pattern of occupation of these areas suitable for agricultural exploitation, with the appearance of new settlements, in a gradual process of population that affected areas increasingly distant from *Beneventum.* Also, the construction of the Appianus bridge, the so-called *Ponte Rotto*, which crossed the Calore River ten miles from the city of Benevento, was probably built in the Hadrian age to replace an earlier wooden structure [50,62]. One arch and at least three piers are preserved, along with the ramp on the western side. The original structure, consisting of six large mud brick work arches on limestone block plinths, should have been at least 170 m long. The damaged bridge was reinforced in the Lombard age with reused material. Near the bridge, it has been recognized as the *Calor flumen* way station, in an area of clay fragments, indicating occupation from the Late Republican age to Late Antiquity. After crossing the Calore, Via Appia continued in a straight line up to *Vallone dei Morti* (Stream of the Dead) (Figure 2). The reuse of architectural elements shows that the road was lined with burial monuments. In the stretch between *Ponte Rotto* and *Aeclanum*, several branches that connected Via Appia with minor centers are clearly recognizable, as well as some alternative roads from the Middle Ages that replaced the Roman one, which had become swamped due to lack of maintenance [63]. The Via Appia then reached *Aeclanum*, a city founded during the 3rd century BCE, which became a *municipium* under Sulla (89 BCE) and a colony, under the name *Aelia Augusta Aeclanum*, in the first half of the 2nd century CE.

3.3. Geological and Geomorphological Setting

The study area is in the external sector of the southern Apennines (Figure 3a), where the Lagonegro–Molise Basin Units are structurally interposed between carbonate successions of the Apennine Platform, located at the top, and the buried Apulian Platform, at the bottom ([64] and references therein). The Meso-Cenozoic allochthonous units are unconformably overlain by the Neogene wedge-top basin deposits, among which the most widespread are the Baronia Formation sediments of the Lower Pliocene age [64]. Plio-Pleistocene fluvio-lacustrine successions seal the above-described substrate deposits [36,37]. The stratigraphic record of the pre-Quaternary sedimentary successions, outcropping in the area crossed by the Via Appia, mainly refers to four units, distributed from oldest to youngest (Figure 3b): (i) Flysch Rosso Formation (FYR); (ii) Numidian Flysch Formation (FYN); (iii) Baronia Formation (BNA); and (iv) Fluvial and lacustrine deposits (SFL). The Flysch Rosso (FYR) consists of Upper Cretaceous-Miocene clastic limestones and pelites. Locally, it includes jaspers at the base, passing upwards to calcareous breccias and calcarenites, alternation of marls, limestones, and clays, and finally to varicolored marls and clays.

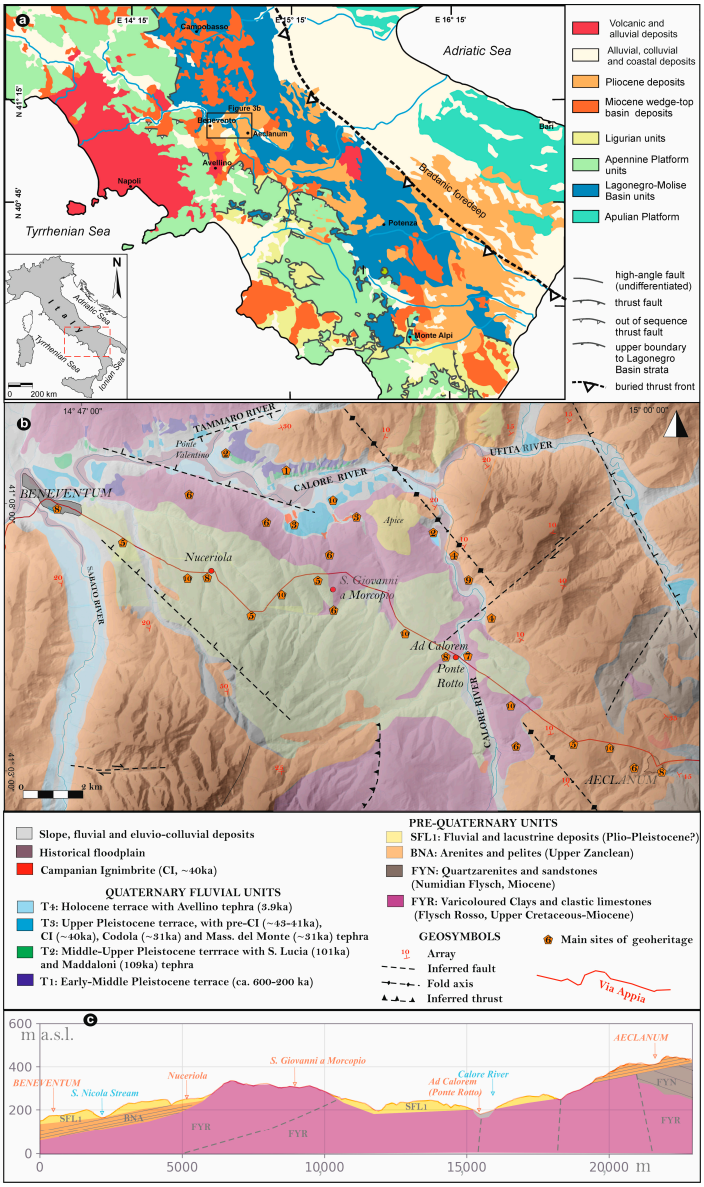


Figure 3. Geological map of the *Via Appia Regina viarum:* (**a**) southern Apennine geology, modified from [64]; (**b**) geology between Beneventum and Aeclanum; and (**c**) geological cross-section of the *Appia viarum* path.

The coarse calcareous deposits consist of beds and megabeds formed by whitish calcirudites and bio-calcarenites, including microfossils of orbitoids, alveolinids, and nummulitids, with subordinate intercalations of clayey marls and reddish and greenish argillites. Upward, the FYR conformably passes into the Langhian Numidian Flysch (FYN), which is exposed only in the eastern sector of the area and is composed mainly of sandstones consisting of rounded, well-sorted quartz grains, organized into medium- to thick beds. These sediments are widespread across the western-central Mediterranean Sea and are interpreted as a regional event that transported desert sands into the deep basins surrounding northern Africa. Other lithotypes associated with Numidian quartz arenites include quartz siltstones, gray-green marly clays, reddish siltstones, and gray calcarenites. The late Zanclean wedge deposits of the Baronia (BNA), which lie unconformably above FYR and FYN, consist of clastic sediments derived from variable alluvial, coastal-marine, and open-shelf paleoenvironments [65,66]. The lower part of this formation consists of alluvial polygenic coarse- to fine-grained conglomerates followed by coastal marine yellowish, weakly stratified sandstones. The succession passes upward and laterally to pelitic lithofacies characterized by clays and silty-marly clays with rare small marine bivalve shells. The overlying yellowish sandstones are organized into medium- and thin-layered units, locally containing abundant shell fragments and valves of Ostreids and Pectinids. A coarse-grained interval of upper conglomerates seals the sedimentary succession and encompasses clast-supported polygenic conglomerate beds intercalated with sandstone. The fluvial and lacustrine deposits of SFL1 are mainly represented by polygenic heterometric gravels, moderately cemented, with a sandy matrix, locally reddish, with non-evident stratification, and lenticular intercalations of grey-green sands and mudstones (Figure 3b).

The path of the Via Appia between *Beneventum* and *Aeclanum* extends across the central-eastern sector of the Campanian Apennine range, characterized by hilly to moderately mountainous relief developed on Cenozoic sedimentary successions (FYR and FYN in Figure 3b), intensely deformed by Apennine tectonics, and partially on Plio-Quaternary deposits (BNA and SFL in Figure 3b), organized in a step of fluvial terraces. The morphological framework consists of NW–SE-oriented ridges, consistent with the main structural trends of the southern Apennines, alternating with longitudinal fluvial valleys and intramontane depressions filled with Quaternary continental deposits. Within this setting, the Calore River basin represents the main hydrographic element, having deeply incised the bedrock and shaped steep slopes and fluvial terraces.

Between *Benevento* and *Aeclanum*, the ancient route crosses a gently hilly landscape, generally ranging in elevation between 250 and 450 m a.s.l., characterized by alternating clayey-marly and sandstone ridges and secondary valley incisions (Figure 3c). The outcropping lithologies include clays, marls, and sandstones attributable to Miocene flysch successions (FYR and FYN in Figure 3c), as well as Pliocene sandstones (BNA in Figure 3) and Quaternary alluvial and colluvial deposits within valley bottoms. From a geomorphological perspective, the prevailing processes are related to fluvial dynamics and slope evolution. Slope instability phenomena, such as shallow landslides, earth flows, creep, and solifluction, are common, favored by the clay-rich nature of the soils and temperate climatic conditions, with rainfall concentrated in the autumn and winter months.

These environmental factors significantly influenced the choice of the Roman road alignment, which generally follows mid-slope routes and stable ridge lines, avoiding flood-prone valley floors and the most unstable slopes. The unique sector of the path crossing the Calore River valley is the *Ponte Rotto* area, which is well known for its active fluvial morphodynamic during the last centuries (see Sections 4.1 and 4.1.3). In this area, a monumental bridge ruin, known as *Ponte Rotto* (broken bridge), is still visible, but it was repeatedly subjected to structural and positioning changes because of several floods. Close

to *Aeclanum*, the landscape becomes more open, with subplanar surfaces developed on fluvio-lacustrine deposits and alluvial terraces. The availability of local building materials (limestones and sandstones), with clay-rich sediments, also provided essential resources for construction and infrastructural works.

From a topographical and geological point of view, in the sector located east of *Beneventum* until the *Nuceriola* site, the Via Appia runs on Plio-Quaternary terraced deposits, made mainly of sandstones and siltstones of BNA and loose gravelly sands of the SFL fluvial terrace (Figure 3b). The landscape and lithologies change as the road climbs up to the structural high of San Giovanni a Morcopio, where the clays and marls of the FYR outcrops are (Figure 3c). Locally, these lithologies are buried by reworked volcanic deposits from Campi Flegrei (such as Campanian Ignimbrite, 39 ka) and Vesuvius volcanoes (such as Avellino eruption, 3.9 ka) [40]. These volcanic products are preserved mainly where the landscape is flat, contributing to the development of thick soil covers. To the East of S. Giovanni a Morcopio high, the road goes down toward the Calore River valley, running over a well-developed step of fluvial terraces of Quaternary age, made mainly of an alternating of gravelly and sandy layers. The crossing of the river valley was chosen in the sector where the valley is narrowest, with a not-well developed floodplain and surrounding hills that were easy to cross. Here, the ruins of the Appian bridge (*Ponte Rotto* in Figure 3c) are still partially preserved. Several renovations are still visible in the stones of the bridge, probably due to catastrophic floods that occurred in the last millennia. After crossing the floodplain, the road first climbs up the step of Quaternary river terraces located on the opposite flank of the valley and then continues toward the slope leading to the structural high where the city of the *Aeclanum* is located. The slope and the hill of *Aeclanum* settlement are made mainly of Pliocene (BNA) and Miocene (FYN) sandstones that are in unconformity with Miocene clay and marls (FYR). On the top of the *Aeclanum* surface are also present small outcrops of Campanian Ignimbrite deposits and thick soils developed on it. All the slopes around the *Aeclanum* settlement are affected by fluvio-denudation processes that involve both deep and shallow landslides. The latter also affected several parts of the settlement, and they are still active in more points of the Archeological Park.

4. Results and Discussion

In this study, results and discussion are presented in a single section to allow a direct evaluation of the contribution of geosciences to the identification of the route and to the full process leading up to the UNESCO nomination.

4.1. Geocontribution to the Mapping of Via Appia Between Beneventum and Aeclanum

A different research approach was used to identify some environmental changes that have affected, and continue to affect, the present-day landscape. This was achieved through the selection of geomorphological units that constitute its structure. The mapping distinguishes areas affected by environmental changes (N-transform) from human processes (C-Transform), allowing for the creation of a hierarchy of territorial features and enabling us to differentiate stable areas from those subjected to erosion and deposition. The geomorphological data were overlaid on hillshade created from a 5 m resolution Digital Elevation Model (DEM), alongside the archaeological finds collected during the survey (Figure 4).

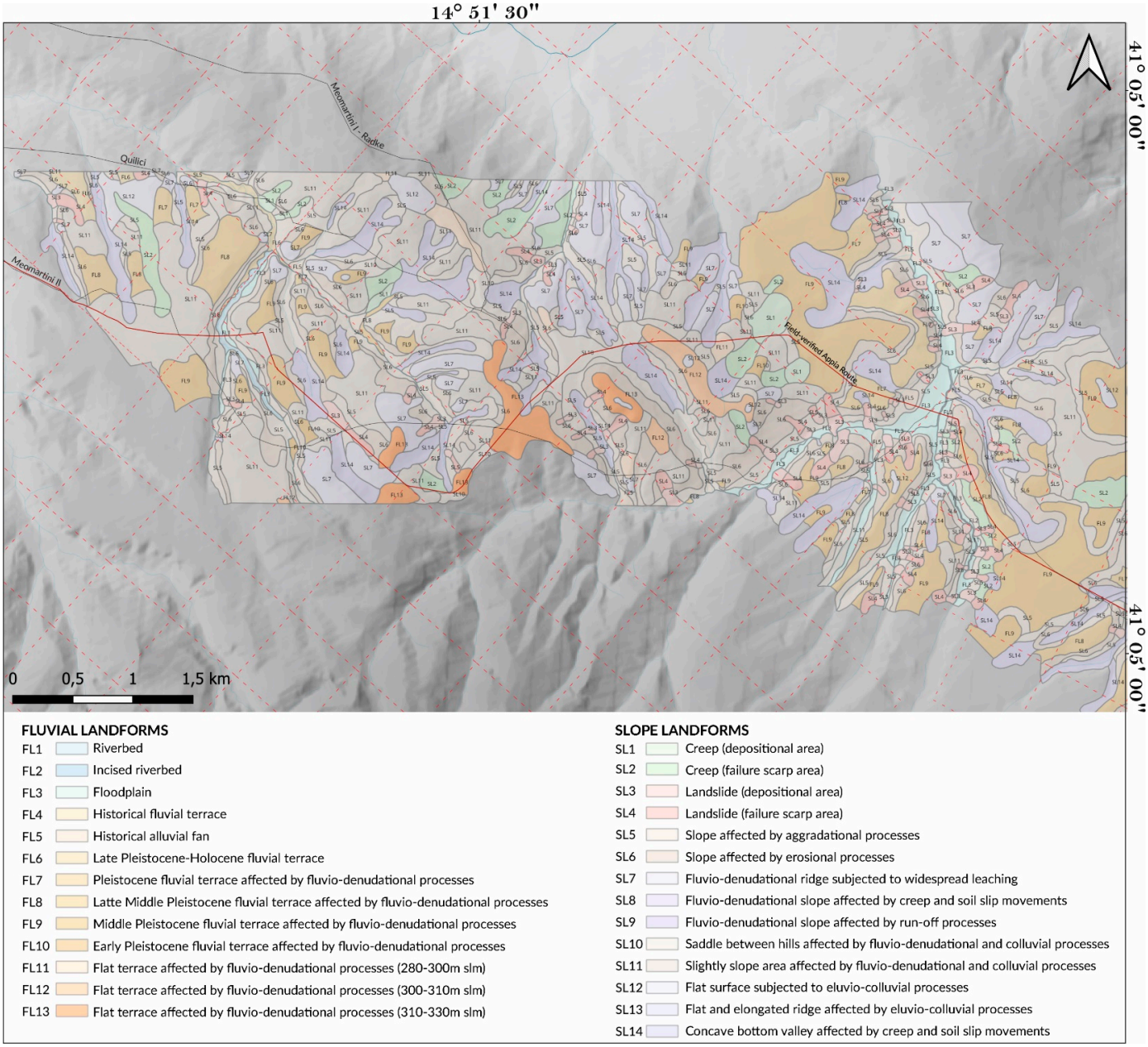


Figure 4. Geomorphological map of the Via Appia: Landscape units and Via Appia paths hypothesized by archeological literature [22–24] and field-verified new data. Also, land division systems are overimposed on DEM TINITALY [61].

This approach allows for a direct comparison between geomorphological processes and the density of the archeological record, thus defining the impact of post-depositional processes on the spatial integrity of the archeological data. It also facilitates the identification of in-site, out-of-site and sub-in-site materials. The latter category refers to cases where, despite minor phenomena of dislocation, artifacts can be re-associated with their original context through the assessment of a direct genetic link [16].

Fluvial and slope landforms have been identified (Figure 5). Historical fluvial landforms consist of alluvial plain geomorphological units, such as riverbed, incised riverbed, floodplain, fluvial terrace, and alluvial fan. These units are considered areas with low archeological potential because they formed by fluvial dynamics in the last millennia. For this reason, it is highly unlikely that traces of the Via Appia will be found in these geomorphological units. The terraced river landforms that predate the Via Appia (from the Early Holocene to the Plio-Pleistocene) are, on the other hand, considered to have high

archeological potential, as they are decidedly stable areas where traces of the Via Appia may have been preserved over the last few millennia.

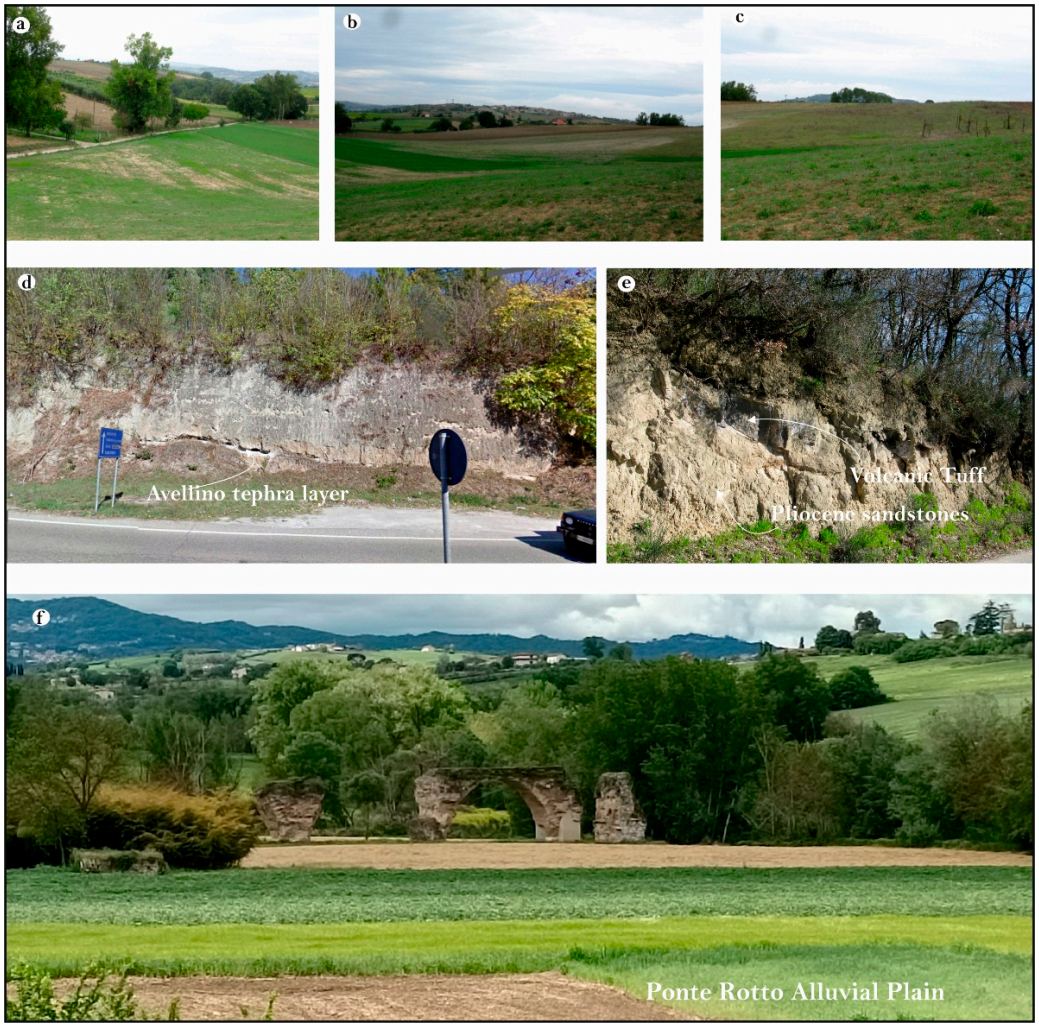


Figure 5. Landscapes, landforms and geological outcrops of the Via Appia. (**a**–**c**) hilly landscapes between *Benevento and Aeclanum*, (**d**,**e**) geological outcrops in the Apice Muncipality, (**f**) alluvial plain of the *Ponte Rotto* area.

In these landscape units, archeological field-surveys have identified a high concentration of ceramic materials dating from prehistory to the present day, confirming the hypothesis that these are the most stable areas in terms of landscape change processes. Historical slope landforms, such as creep and landslide areas, slope aggradation and erosional areas, as well as all those affected by fluvial denudation processes, were considered areas with low archeological potential where traces of the Via Appia and archeological remains had little chance of being preserved. Among these landforms, those predominantly affected by depositional processes may have preserved archeological evidence in the deeper layers and were not visible on the surface. On the other hand, erosional landforms may not have preserved archeological evidence. Slope landforms, as saddle between hills, areas affected by eluvio-colluvial processes, flat surfaces and elongated ridges may have preserved archeological traces in the shallow layers. To confirm this geomorphological suggestion, field archeology identified a good concentration of materials. The overlaying of the geomorphological units and the three hypotheses of centuriation, namely Beneventum I, Beneventum II, and Beneventum III, confirms that areas that better preserve archeological traces respect others where traces were deleted or buried by erosional and depositional

processes. In addition, the land division systems seem to follow natural landforms, such as river networks and ridge orientations.

Based on the above-mentioned approaches and suggestions, the analysis has focused on 4 significant sectors covered by the project. Two of them correspond to new archeological settlements and Via Appia traces: *Nuceriola* and San Giovanni in Morcopio. The other two are the main monumental sites along the Via Appia, such as *Ponte Rotto* and *Aeclanum* Archeological Park.

4.1.1. Nuceriola Site Location

From a geomorphological perspective, the site alternates stable areas, represented by pre-holocene fluvial and fluvio-denudation terraces, to slopes affected by erosional and colluvial processes, such as creep and soil slip movements (Figure 6).

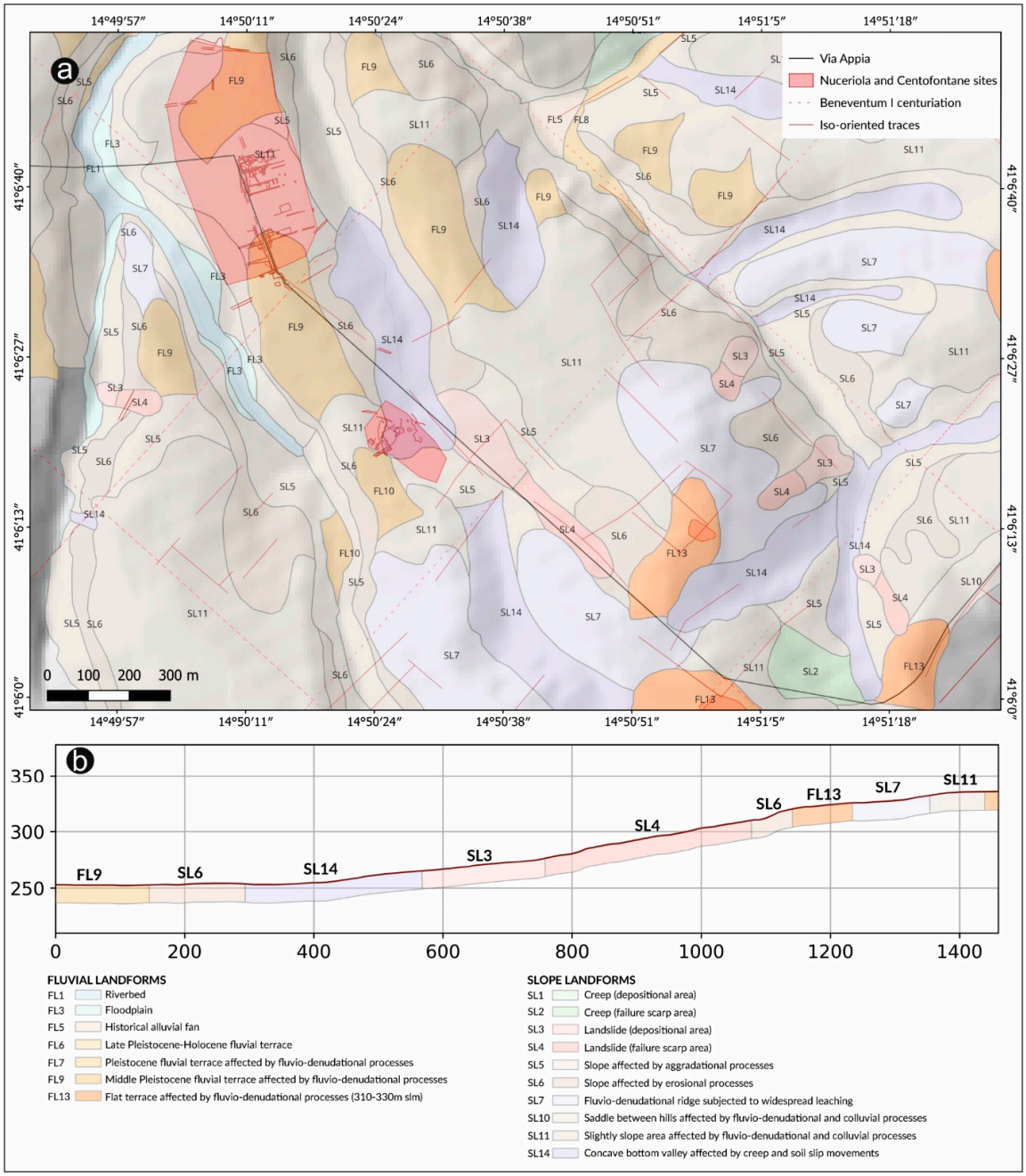


Figure 6. (**a**) geomorphological map of Masseria Grasso integrated by archeological traces of land division, ancient routes including *Appia Viarum* (black lines), and areas investigated with geophysical

and remote sensing surveys (red poligones); (**b**) topographic section of the supposed Via Appia path, projected on geomorphological units.

The archeological surveys allow us to hypothesize that the central parts of terraced areas have therefore suffered minor dislocations, almost exclusively due to recent plowings. Archeological surface survey documented a large settlement concentrated in the central sector of the terrace, with a maximum extent of approximately 14 hectares, possibly already reached during the Samnite period, as suggested by the homogeneous distribution of materials dating to the 4th–3rd centuries BCE. The settlement was occupied from the 4th century BCE to the 6th century CE and experienced phases of contraction rather than clear chronological breaks. Considering these hypotheses, archeological diagnostic investigations, geomagnetic survey, ground-penetrating radar (GPR), aerial photointerpretation, and remote sensing were conducted. The results reveal a complex settlement layout organized along parallel and orthogonal axes. These axes are uniformly oriented and arranged at modular intervals corresponding to the Roman metric unit of the actus (35.5 m). This layout defines blocks aligned along a very wide central linear feature, measuring approximately 6–7 m in width and visible in aerial photos for approximately 115 m (Figure 6). Along its western side lies an artisanal complex uncovered during excavation and located on the southern periphery of the settlement. This complex was used to produce thin-walled pottery between the second half of the 1st century BCE and the Flavian period. Slightly further south, the linear anomaly curves toward the south-east, adopting an orientation of 42° (Figure 6).

It reconnects with a road excavated in 2015, which, based on its width (5.6 m, equivalent to 19 Roman feet), and associated ceramic finds, dating its use from the late 4th century BCE to at least the 6th century CE, has been identified as Via Appia. The change in direction brings the road into alignment and the same orientation as other traces preserved in the modern road network, farm tracks, field boundaries, and anomalies detected through aerial photography. The route of Via Appia continued north-eastward, ascending the valley slope, and then crossed a series of hilly saddles connecting this sector with the San Giovanni a Morcopio area in the direction of *Ponte Rotto* (Figure 6). Along this stretch, the road intersects several roads and field boundaries still in use, which are slightly divergent or displaced from the 42° orientation. This route crosses depositional and erosional zones that likely influenced changes in its alignment, as evidenced by cross-section analysis (Figure 6). These alignments preserve forms of continuity derived from earlier spatial organization, attributable to agrarian divisions that are still recognizable in the contemporary landscape, both as surviving features and as fossilized or degraded forms. The centuriation grids were theoretically reconstructed on cartographic bases through the verification of metric intervals observed in the field. They relate to the territorial reorganization carried out during the triumviral–Augustan period (modules of 20 × 20 *actus*). This system, in turn, appears to derive from an earlier intervention associated with the foundation of the Latin colony of *Beneventum* in 268 BCE, which was organized in modules of 16 × 25 *actus* and shared the same fixed points and orientation, corresponding to that of the excavated road.

4.1.2. San Giovanni a Morcopio Site

In the San Giovanni a Morcopio area, natural and cultural processes are further supported by the analysis of historical cartography and toponymy (Figure 7). The area corresponds to the floodplain at the confluence of two streams (Vallone Fiego and Vallone San Giovanni) and to the slopes of the structural high of San Giovanni a Morcopio. Along these slopes, natural outcrops show that stratigraphy is mainly made up of colluvial and volcaniclastic deposits and paleosols. Volcaniclastic deposits are attributable to the Avellino Vesuvian eruption (c. 3.9 ka) (Figure 5d). They consistently occur at the same elevation

(220–225 m above sea level) along the valley flanks and slopes. This pattern highlights that deposition occurred along the margins of a fluvial-marshy basin (Figure 7a,b). The basin likely formed because of water stagnation caused by a downstream landslide that obstructed the drainage of the streams. The pumice and ash deposits are associated with Bronze Age ceramic fragments collected during surface surveys on the surrounding terraces. Evidence of settlement during this period completes the picture of a predominantly marshy or lacustrine landscape, in which human occupation was closely linked to the water body as a source of resources.

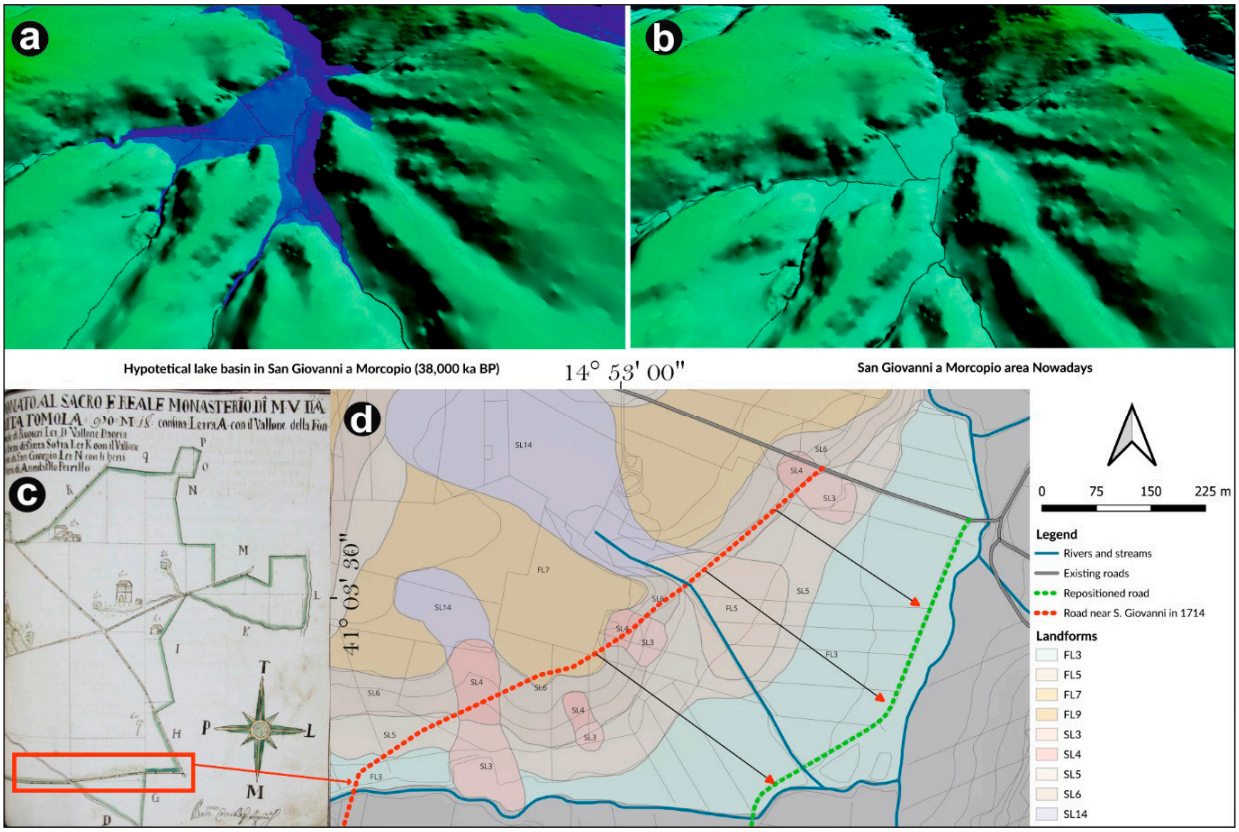


Figure 7. San Giovanni a Morcopio site: (**a**) reconstruction of the fluvial-marshy basin (*Paluda Nigra* and *Silva Mala*) at the confluence of Aria and Fiego Stream during the Avellino eruption (3.9 ka) and (**b**) nowadays landform; (**c**) historical map (1714) showing main roads with one of these corresponding to the Via Appia path; (**d**) geomorphological map and reconstructed path of via Appia. For the legend of the geomorphological map see Figure 2.

To support this reconstruction there are other episodes of swamping, which are highlighted by local toponymy. The terms *Silva Mala* (Wicked Woods), attested in the 13th century, and *Paluda Nigra* (Black Marsh), used in cartography from the second half of the 17th century, highlight the existence of a hostile environment [28]. Despite these conditions, the area appears to have functioned as a natural corridor toward *Ponte Rotto* and Irpinia territories. This is indicated by the place named *Varco di Puglia* (Passage to Puglia), which was assigned at the end of the 17th century to the passage across the Aria stream [28]. Geomorphological analysis also revealed widespread erosional and landslide processes and general slope instability (Figure 7). The frequency and intensity of these phenomena are documented by repeated slope stabilization interventions aimed at restoring crossing routes in this sector and ensuring eastward connectivity. An illustrative example is provided by the degradation of ancient route traces. A former road, recorded on a map of the Abbey of Montevergine in 1714, once crossed the slope of San Giovanni a Morcopio (Figure 7, bottom left). Aerial photographs from the 1950s show that this path was later

diverted toward the Aria stream and displaced downslope because of landslides, and the erosion of fluvial–denudational concave landforms (Figure 7d).

Therefore, it is likely that, during the first half of the 20th century, stabilization work was required. These included terracing structures, visible in historical aerial photographs and now partly buried due to the same active morphodynamic processes. In the more stable areas of this sector, such as fluvial terraces and flat surfaces, the landscape shows a higher degree of preservation, such in the case of the segments of the modern road network and land boundaries that reproduce earlier layouts and forms. The San Giovanni a Morcopio sector was subjected to a detailed analysis of historical cartography and anomalies identified in both historical aerial and UAV photographs (Figure 7c). Recurrent orientations, modular metric intervals, and the use of Roman units of measurement, combined with associated archeological evidence dating from the 4th century BCE to Late Antiquity, such as material scatters, ceramic fragments, and structural remains, suggest their attribution to ancient agrarian layouts [28]. A long anomaly, identified in the field through a linear dispersion of stone materials visible in aerial photos as soil cropmarks, can be attributed to the ancient Via Appia, which descends into the valley at this obligatory crossing point (Figure 7c). Other similar traces allow the reconstruction of a crossroad leading toward the area of the church of San Giovanni. Here, the surface distribution of materials, integrated with the analysis of active morphodynamic processes, suggests that the finds are largely in situ. This evidence has led to the identification of ancient sites arranged according to a coherent and regular layout that follows the road network.

4.1.3. Ponte Rotto Area

The area of *Ponte Rotto* takes its name from the remains of a monumental Roman bridge that allowed the Via Appia to cross the Calore River (Figure 8). Given its geographical position and strategic role within the ancient road network of Samnium, the bridge was likely preceded by a ford. It may also have had an initial construction phase in the late Republican period, consisting of a wooden superstructure on massive piers built in *opus quadratum* [62]. A major construction phase was attested in the Hadrianic period, when restoration works along the Via Appia were documented by milestones (CIL IX, 6075) [50].

The importance of this infrastructure required further restoration during the Lombard period, prompted by structural deterioration, likely intensified by flooding and river overflows. In the medieval period, the river crossing was relocated downstream to a smaller bridge. On the one hand, this suggests that any intervention on the Roman bridge was considered ineffective, possibly due to shifts in the riverbed. On the other hand, the new structure testifies to the long-term use of this eastward route. On the left bank, within the municipality of Calvi, the ramp supporting the embankment marks the bridge access. On the right bank, three piers and one arch are now located within a field, documenting changes in the river's course over time. In this area, the Ancient Appia Landscapes project studies allow the identification of *Calor flumen*, a second *statio* recorded in the *Tabula Peutingeriana* after *Beneventum* toward *Aeclanum*, and investigation of its relationship with the river. The indication of VI *milia* from the previous stop, *Nuceriola*, combined with the results of field surveys, places the settlement on the left bank of the river, east of Masseria De Gregorio, and north-west of the bridge ramp. Here, a site covering approximately 2.5 hectares was identified in a strategic position to the river crossing (Figure 8). The archeological evidence indicates a chronology spanning the entire Imperial and Late Antique periods, with limited attestations in the Hellenistic and Republican phases. This occupation corresponds to the period of maximum use of the bridge and to a settlement system characterized by *villae* and large sites distributed across the Cubante plain [26,30].

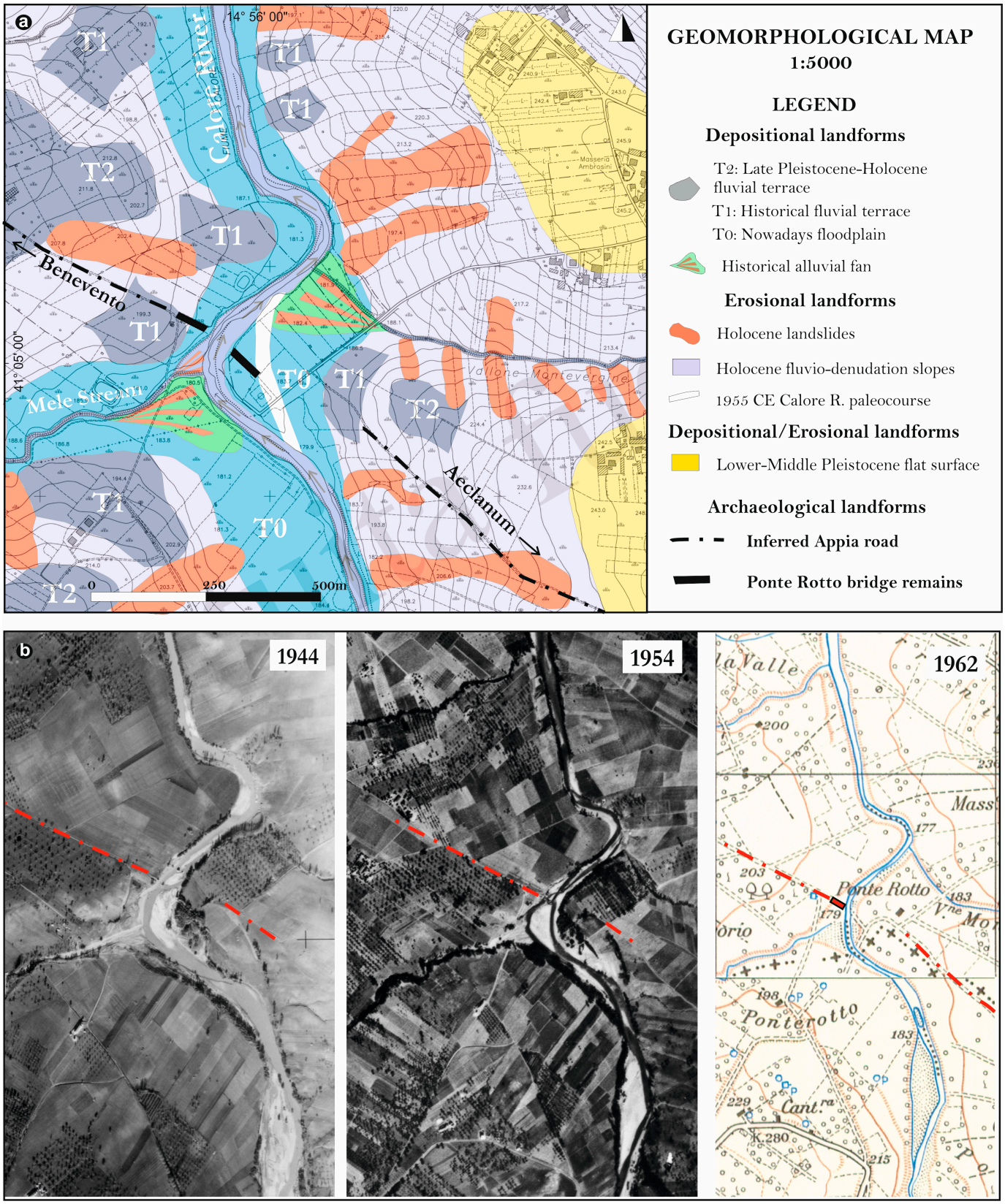


Figure 8. *Ponte Rotto* geomorphological map (1:5000 in scale) showing the traces of the Via Appia (**a**) and their dislocation along the times. The traces (red dashed lines) and their shifting along time are also documented in the historical aerial photo (1944 and 1955) and historical map (1962 IGM 1:25,000) (**b**).

Analysis of the distribution areas of the archeological finds, their surface preservation, and degrees of abrasion was integrated with geomorphological data (Figure 8a). This approach made it possible to assess the impact of both quiescent and active morphodynamic processes on the spatial arrangement of the archeological record. Finding concentration on the terraces, characterized by well-preserved fragments, can be considered largely in situ and related to stable settlement forms. By contrast, the slopes, beginning at the edges of terraces, yield smaller and more abraded fragments, albeit still in high concentrations.

These assemblages reflect ongoing erosional processes and displacement from their original depositional contexts. On the opposite bank of the river, within the territories of Apice and Mirabella Eclano, surface surveys resumed in 2025. These have so far focused primarily on the slope, crossed by a path that appears to follow the course of the Via Appia after the crossing of the Calore River [63]. Fragmentary materials affected by similar erosional processes and landslides document a relatively homogeneous scatter, with a slight increase in density near the boundary of the alluvial plain. In addition, in the sector of the Calore River alluvial plain, the study of historical cartography, remotely sensed imagery, and early twentieth-century photographic documentation highlights the extreme instability of the river, which has undergone repeated shifts in its riverbed over time (Figure 8b). These data confirms that the sector of the alluvial plain was a necessary passage for crossing the river along the last millennia, despite its high fluvial vulnerability. In fact, several interventions of renovation in the bridge ruins are documented, probably carried out after disastrous floods and earthquakes. Also, different orientations of the bridge ruins are still visible in the historical cartography (Figure 8).

4.1.4. Aeclanum

The foundation of Aeclanum probably dates to the 3rd century BC in a strategic role in the Irpinia territory. After the sack carried out by Sulla's troops in 89 BC, the city was elevated to the status of *municipium* (Municipality) and, in the Hadrianic period, to a colony under the name *Aelia Augusta Aeclanum*. This phase marked the peak of urban and monumental development, with the construction of the thermal complex, the *macellum*, and an extensive residential district. Attested as an episcopal see in the early 5th century AD, the center entered a phase of progressive decline from the second half of the 6th century onward; in the early Middle Ages, the new settlement of *Quintodecimo* developed over part of its ancient structures. Regarding the Via Appia traces, after crossing the Vallone dei Morti streams (Figure 2), they continue toward the city, reaching *Aeclanum* near the north-western gate (Figure 9) [63].

Here, the road split into two branches: an urban branch, coinciding with one of the main axes of the city layout, and a suburban branch running parallel to the northern walls [54]. The two routes rejoined beyond the north-eastern gate, where in 2020 a significant paved stretch was uncovered near the north-east gate: the carriageway, approximately 8 m wide, narrows as it approaches the walls and is flanked by two paved lay-bys. Further east, four additional road sections paved with large local limestone *basoli* have been identified, showing clear signs of wear from traffic [63]. Beyond *Aeclanum*, the reconstruction of the route remains uncertain: two possible directions have been proposed, one toward the Ufita Valley and the other toward the Ansanto Valley [63]. From a geomorphological point of view, the archeological site of *Aeclanum* is located on a triangular-shaped hilly ridge, mainly oriented NW-SE, bordered by two seasonal streams (Figure 9). The ridge consists of a flat surface and two modest hills, the larger of which is featured by a rounded landform, located a few dozen meters to the SW of the Archeological Park. Both the flat surface and the modest hills are subject to widespread shallow runoff during extreme weather events. These processes are mainly concentrated toward the edges of the surface and in the areas

where the latter meets the rounded hill. The connecting surfaces between the flat surfaces and valley floors consist of fluvial-denudation slopes set on soft lithologies and subject to shallow gravitational processes (creep and soil slip movements). The processes mainly characterize areas with a greater topographic gradient, whereas widespread runoff processes characterize areas with a lower topographic gradient. In some cases, the slopes are affected by morphologies caused by landslides, which are no longer active or are in a dormant phase. Only toward the valley floor, the landslides show signs of recent reactivation. Together with the slow sliding of silty-clayey soils, these contribute to the aggradation of the valley floor with thick successions of debris and colluvial deposits. Creep processes are also concentrated in the concave areas of slopes where there are small fluvial-denudation valleys with or without catchment basins for collecting surface water. The latter are unable to drain rainwater, especially in cases of intense rainfall, thus enhancing surface creep movements from the sides of the small valleys. Much of the Archeological Park is in these geomorphological contexts, with some of the excavated structures involved in slow creep movements. In this morphological context, which has not been well preserved, it is very difficult to find traces of the Via Appia, especially in the south-western and western sectors. The only sector presenting conservative landforms is the ridge of Piano Pantano, located in the WNW of the ancient city. Today the ridge hosts the SS90 route, which connects Campania with the Apulia region. Unfortunately, the ridge is strongly anthropized by modern dwellings, which do not allow the hypothesizing of the Via Appia.

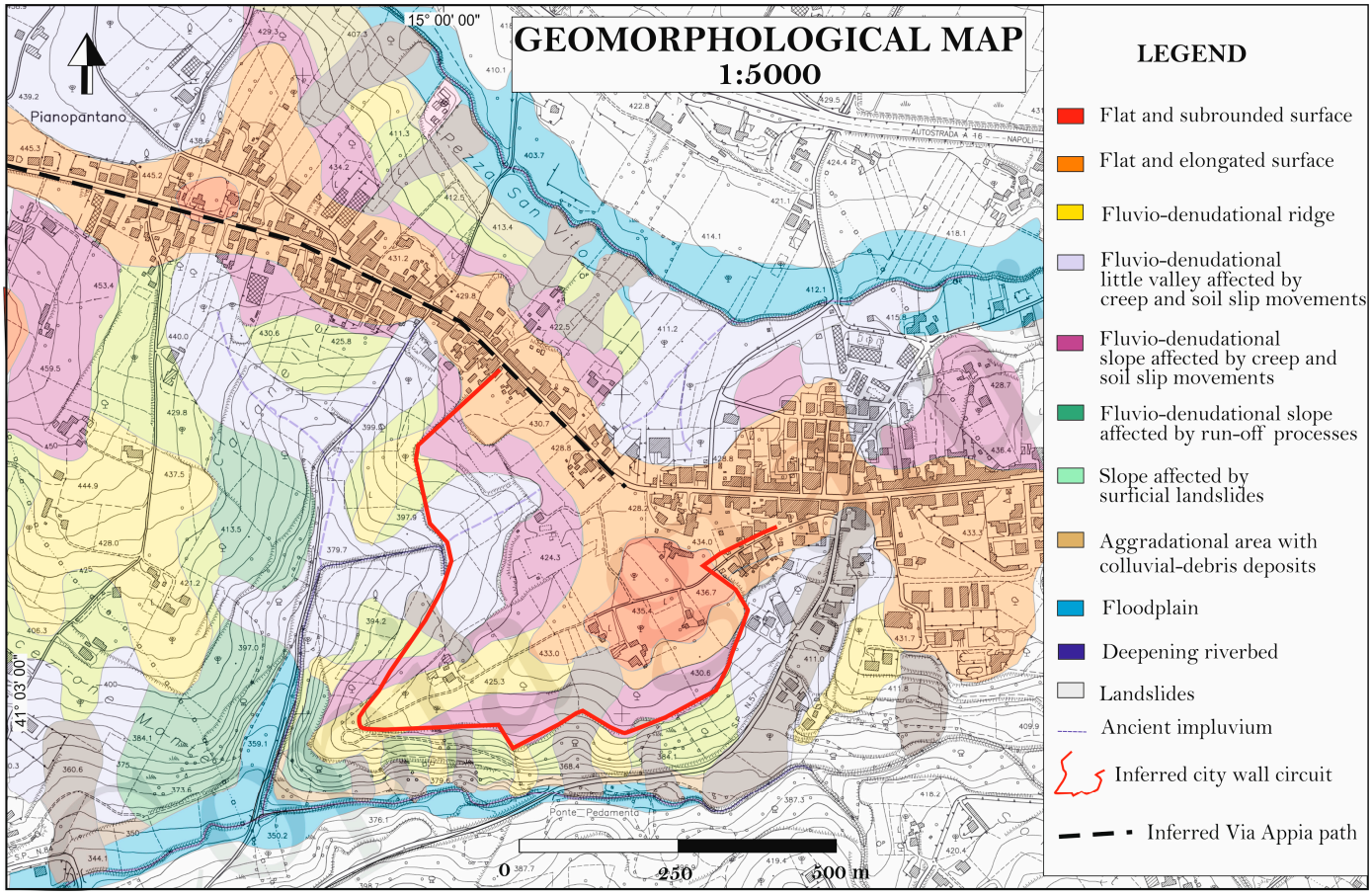


Figure 9. Geomorphological map of the Archeological Park of *Aeclanum*.

4.2. Scientific Dissemination, Social Events, Public Engagements, and Proposal for Inscription in the UNESCO World Heritage LIST

The dissemination of knowledge generated by the *Ancient Appia Landscapes* project has represented, from its earliest stages, a structural component of the research activities, developing in parallel with field investigations within a synergistic process aimed at the enhancement of the Via Appia territories between Benevento and *Aeclanum*. The development of a robust knowledge framework, based on the integration of archeological and geomorphological datasets, has enabled not only the interpretation of the landscape in terms of its historical, cultural, and environmental stratifications but also the development of dissemination and public engagement actions oriented toward sustainable land use. Within this perspective, the project promoted actions to transform scientific knowledge into a strategic resource for local development and the improvement of quality of life, fostering awareness and encouraging the reappropriation of the territory's historical and productive vocations.

An initial step in this direction was the development of a project brand, represented by a logo depicting the remains of the Roman bridge known as *Ponte Rotto* over the Calore River, an iconic and widely recognized element of the landscape's historical identity. The brand was subsequently adopted to produce the wine "*Ponterotto. Aglianico dell'Appia*", produced by the local enterprise Genti delle Alture (https://gentidellealture.com), using indigenous grape varieties. This initiative contributed to strengthening territoriality embedded production chain grounded in practices that respect the historical and landscape context (Figure 10). At the same time, it represented an initial channel between research activities and local stakeholders, particularly farmers and local entrepreneurs. A share of the proceeds was allocated to support ongoing research, thereby consolidating the link between scientific knowledge, the local economy, and the broader community [67]. In parallel, the project implemented a structured program of dissemination and public engagement activities. The excavation at Masseria Grasso was conceived as an "open site", systematically welcoming visitors, local residents, students, teachers, administrators, and institutional representatives (Figure 10). Research activities and preliminary results were communicated daily through a targeted communication strategy, including the use of social media platforms, thereby expanding audience reach and encouraging active participation. These actions were further supported by dedicated initiatives such as the Open AAL Days, which integrated the presentation of archaeological investigations with opportunities of social interaction and the tasting of local products, as well as public meetings organized within local cultural associations to discuss project results (Figure 10). Such events contributed to strengthening dialogue with local communities and to the co-construction of a shared narrative of the landscapes. A further level of engagement involved institutional interaction with local authorities. The interest of the municipalities crossed by the Via Appia in the Benevento and Irpinia areas was formalized through a Protocollo d'Intesa, signed in April 2017, aimed at the cultural, economic, and social revitalization of the territories connected to the ancient consular road.

Simultaneosly, a survey and inventory of the geosites and localities containing explicative elements of the interaction between geological and geomorphological processes was performed (Table 1 and Figure 3b).



Figure 10. Social, cultural, and scientific dissemination events of the AAL Project for the inscription of the Appia Viarum on the Unesco World Heritage List.

The geoheritage of the Via Appia and surrounding localities significantly contributes to enhancing the value of archaeological and landscape assets, as it provides the physical and environmental framework within which human activities have historically developed. Its integration into heritage interpretation allows for a more comprehensive understanding of the interactions between natural processes and cultural evolution. From this point of view, geoheritage sites were chosen both for their tangible value, such as localities with outcrops of the main rocks and panoramic views of the main landforms, and both for their intangible value, such as "talking" geosites. They encompasse the processes that shape the Earth and the knowledge and interpretations associated with tangible geoheritage such as rocks, minerals, fossils and landforms Several studies encompass intangible geosites/geomorphosites as additional value to the ecological, economic, aestetic and cultural heritage [68–72], also connecting geoheritage to mythology [73–75].

Within this framework, a long-term objective of the project is the establishment of a linear Museum along the Via Appia, conceived as a distributed system for the promotion of landscape knowledge, strengthening of heritage awareness, and enhancement of local cultural, environmental, and productive resources [76]. This model of diffuse heritage enhancement has received significant institutional recognition. The data and results generated in recent years have contributed to the initiative promoted by the Italian Ministry of Culture for the nomination of Via Appia to the UNESCO World Heritage List. Overall, the process undertaken presents the Benevento area as a case study of advanced cooperation between

scientific research, local institutions, and communities, oriented towards an innovative and shared model of landscape conservation and management [77]. Finally, the Via Appia was declared UNESCO World Heritage in July 2024. In this process and in all the steps of the AAL Project geosciences played a key role.

Table 1. Inventory of the main sites of geoheritage of the Via Appia.

Nickname	Names of Geosite	Locality	Interest	Tangible	Intangible	Talk
1. RIFTS	Calore **R**. **F**luvial **T**erraces **S**tep	Between Benevento and Paduli towns	Stratigraphic, geo-morphologicand sedimentologic	Outcrops	Landscape	Quaternary landscape evolution and Apennine tectonics
2. TEPHRA	Vesuvius and Campi Flegrei **tephra** layers	Valentino Bridge on Via Appia Traiana; Ancient Apice town	Volcanic and stratigraphic	Outcrops	Geochemistry and mineralogic	Explosive activity of the volcanoes
3. CI	Tufo Grigio Campano (**C**ampanian **I**gnimbrite)	Cornacchia and Aria streams	Volcanic, stratigraphic and sedimentary	Outcrops	Geochemistry and mineralogic	The greater eruption of the Mediterranean area during quaternary age
4. PLIOM	**PLIO**cene **M**arine deposits	Apice	Sedimentologic, petrographic and paleontologic	Outcrops and fossils		Ancient marine environemnts and their fossil associations
5. HILL	**HILL**y morphology	Between Benevento and Aeclanum	Geomorphology		Landforms	Landscape evolution
6. SLIDE	Land**SLIDE** morphology	Between Benevento and Aeclanum	Geomorphology		Landforms	Geomorphologic processes
7. PROOF	**P**onte **RO**tt**O** **F**loodplain	Ponte Rotto Bridge on Via Appia	Geomorphology		Landforms	Historical evolution of the floodplain
8. APPRO	Via **APP**ia, Ponte Rotto bridge and archeologic **RO**cks	Between Benevento and Aeclanum	Petrographic and archeologic	Outcrops		Geological and archaeological history of the used rocks
9. GHOST	Apice **GHOST** Town	Apice ancient town	Geomithologic	Touristic trial		As geological process caused the abandonment of the town
10. SOIL	**SOIL**	Between Benevento and Aeclanum	Soil science and land use	Outcrops	Landforms, Mineralogy and soil productivity	As geolithology and geomorphology develops different soils and land uses

5. Conclusions

The integrated approach combining landscape archeology and geomorphological analysis plays a fundamental methodological role in the research framework. The investigations of landforms, morpho-dynamic processes and hydrographic evolution enable the reconstruction of the environmental conditions that influenced settlement patterns and infrastructure choices, while also identifying the landscape changes induced by human

activity. Archeological surveys, supported by geomorphological investigations and remote sensing techniques, the main tools of geosciences, constitute essential tools for reconstructing rural settlement dynamics, agricultural exploitation networks, and long-term processes of anthropisation. Within this methodological perspective, road infrastructure represents a key analytical element to examine the interaction between environmental constraints and the human organization of space. A significant application of this approach is provided by Via Appia, which represents a key case study for analyzing the dynamics of interaction among infrastructure, settlement systems, and the natural environment. Functioning as an organizing axis for both urban and rural landscapes, the road has acted as a catalyst for long-term territorial transformations. Along its route, a dense stratification of anthropogenic interventions attests to the continuity of use and ongoing renegotiation between functional needs, socio-economic structures and environmental constraints. At a theoretical level, this perspective implies viewing the landscape as a complex and multilayered system, resulting from continuous interaction between the biophysical matrix and human activity. It allows us to move beyond a static view of archeological evidence and advance a dynamic model of territorial processes.

Morphological and infrastructural features that have survived over time, exemplified by Via Appia, constitute key indicators for interpreting long-term processes and society–environment interactions. Within a historical perspective, changes in the Mediterranean landscape appear to be the result of long-term anthropogenic processes, which reached a critical turning point during the Roman period, when the infrastructural organization of the territory induced profound restructuring of settlement patterns and production networks. In this context, the Roman road system functioned as a central instrument of territorial planning and political-administrative control, having a substantial impact on landscape configuration. Roman roads, engineered according to criteria of maximum functionality and linearity, overcame natural morphological constraints through complex interventions, such as cuttings, embankments, bridges, and viaducts, becoming key structuring elements of the territory and vectors of the Romanization process. Awareness of the long-term nature of these processes and their persistent imprint on the contemporary landscape leads to the practical application of this research. In current debates, landscape archaeology and geosciences play an important operational role, contributing to the design of strategies for the protection and enhancement of cultural heritage based on scientific knowledge of the territory. From this perspective, UNESCO's recognition of the Via Appia underscores the need for management models based on interdisciplinary and participatory approaches, in which knowledge of geomorphological, geological and archeological dynamics constitutes a prerequisite for sustainable planning and active conservation of historical landscapes.

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