Received: 1 April 2016 | Revised: 25 August 2017 | Accepted: 28 August 2017
DOI: 10.1002/gea.21658

RESEARCH ARTICLE

WILEY

The urban geoarchaeology of Benevento, Southern Italy: Evaluating archaeological potential

Vincenzo Amato[1] | Sabatino Ciarcia[2] | Amedeo Rossi[3] | Alfonso Santoriello[3]

[1]GeoGisLab, Dipartimento Bioscienze e Territorio, Università degli Studi del Molise, Isernia, Italy
[2]Dipartimento di Scienze e Tecnologie, Università degli Studi del Sannio, Benevento, Italy
[3]Dipartimento Scienze del Patrimonio Culturale, Università degli Studi di Salerno, Fisciano, Italy

Correspondence
Vincenzo Amato, GeoGisLab, Dipartimento Bioscienze e Territorio, Università degli Studi del Molise, CdaF. Lappone, 86090, Pesche, Isernia, Italy.
Email: vincenzo.amato@unimol.it

Scientific editing by Monica Bini

Abstract

The city of Benevento in the southern Apennines is located on a Pleistocene fluvial terrace almost entirely bordered by rivers. Its ancient history of human settlements dates back to the Samnitic age (fifth to third centuries B.C.). The urban landscape witnessed extensive transformation, especially during the Roman (fourth century B.C.–sixth century A.D.) and Longobard (6th–10th centuries A.D.) periods, largely as a result of destructive earthquakes and massive floods. As a consequence, large portions of the modern town were built on deep stratified archeological deposits that partially preserve the remains of previous settlements. In order to improve and expand our knowledge of the buried archaeological heritage of this town, archaeo-stratigraphic data were integrated into a geographic information system format and database, the latter further supplemented by a detailed geomorphological study. This new dataset enabled a reassessment of the Benevento subsurface along with its archaeological assets, shedding new light on the archaeological potential of the urban area. Finally, a more reliable map of hidden cultural resources was developed, thus providing a useful tool for more suitable urban planning and project designs to help guide renovation of urban infrastructure.

KEYWORDS
archaeological heritage, archaeological prediction, facies analyses, fluvial geomorphology, urban geology

1 | INTRODUCTION

The shapes and the sizes of modern towns and cities reflect the impacts of hundreds, sometimes thousands years of urban development and expansion. Much of a town's history is reflected in its historic buildings and street plans. Subsurface archaeological remains also provide clues to a city's history and its transformations through time. Since the historical evolution of a town is often shaped by a pattern of destructive events, it is necessary to correctly assess how these critical processes account for the present configuration. The term "archaeological potential" is generally used for evaluating archaeological resource potential in different environmental contexts, mainly for urban areas containing buried archaeological resources. This term implies a set of criteria or rules to describe places where archaeological sites are most likely to occur, that in turn help to avoid or at least mitigate the impacts of modern development (Carver, 2003; Judge & Sebastian, 1988; Kamermans, Van Leusen, and Verhagen, 2009; Verhagen, & Witley, 2011). Generally, archaeological potential is calculated by analyzing and studying a variety of historical archaeological and paleoenvironmental data. The degree to which archaeological potential can be judged is based on the quantity and quality of subsurface data and their spatial and contextual relationships (Anichini, Fabiani, Gattiglia, & Gualandi, 2012; Campeol, and Pizzinato, 2007; De Guio, 2001).

In Italy, studies of buried archaeological potential for specific areas and urban sites are a relatively new development. An example is the recent evaluation of archaeological potential within the urban sections of Pisa that integrated previous archaeological, stratigraphic, and paleoenvironmental data sets (Anichini et al., 2012; Anichini, Fabiani, Gattiglia, & Gualandi, 2013). Given the city's size and its historical and topographic features, the work of Anichini et al. provides an operational model that can be applied to similar cities across Italy and perhaps Europe. The aim of their project was twofold: (i) to identify and preserve significant archaeological sites containing valuable finds for future study and (ii) to transform what is today seen as a "risk" into "potential." Similar approaches and methods have been applied to other urban centers of Italy such as Modena (Cardarelli, Cattani, Labate, & Pellegrini, 2001; Gelichi, and Malnati, 1989), Cesena (Gelichi, & Negrelli, 2009), Venice (Campeol, & Pizzinato, 2007), Comacchio (Campeol, & Pizzinato, 2007), Mestre (Colautti, & Ardizzon, 2006), Faenza (Guarnieri, 2001) and Mantua (Manicardi, 2015). In these studies, the concept of "*archeologia del vuoto*" (archaeology of emptiness) was introduced for the first time to indicate areas of high

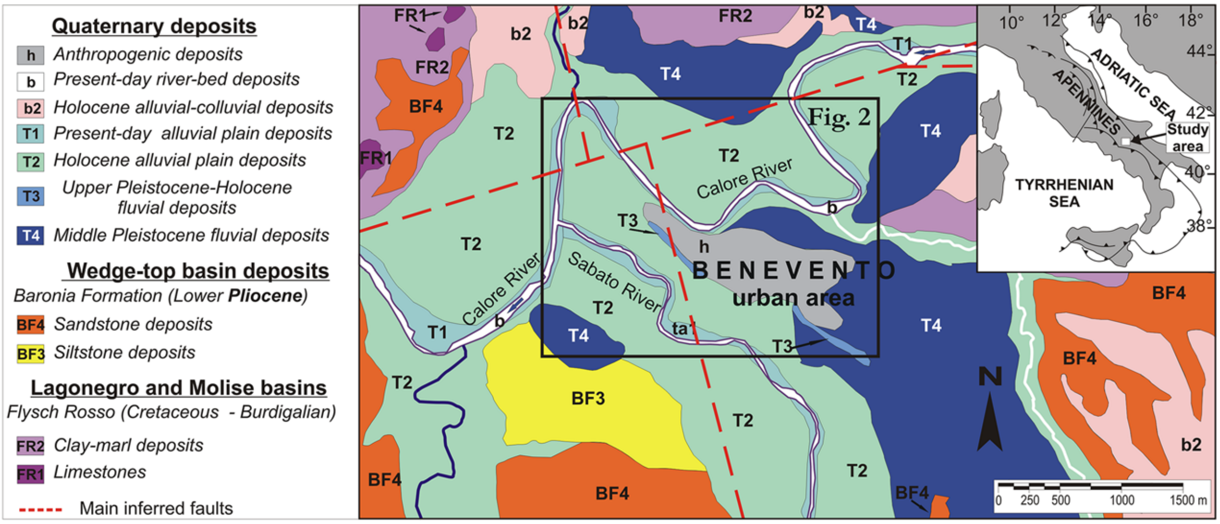

FIGURE 1 Geological map of the Benevento area (modified after ISPRA, 2009; Ciarcia, & Vitale, 2013) [Color figure can be viewed at wileyonlinelibrary.com]

archaeological potential in parts of the city where subsurface information was absent.

Within a context of variable urban archaeological methodologies and objectives, a geoarchaeological study focusing on the city of Benevento (southern Italy) is presented. Since its beginning in 2011, the project relied on a diverse team of research specialists in archaeology, architecture, computer technology, geology, and geomorphology. The study is part of a wider project, the SiUrBe (*Sistema Informativo del Patrimonio Archeologico Urbano di Benevento*), a project partnership between the Benevento Office of the Superintendent of Archaeology in Campania, and the Department of Cultural Heritage Science at Salerno University (Santoriello, & Rossi, 2012, 2013; Santoriello, Rossi, Amato, & Ciarcia, 2013). The main goals of the project are the reconstruction of ancient landscapes of Benevento and its environments since the early Holocene, with a specific focus on the chronology and causes of landscape and cultural changes.

The approach for this project has been centered on evaluating the archaeological potential of the Benevento urban areas. As discussed below, the buried archeological potential was synthesized by integrating available geological, geomorphological, stratigraphic, and paleoenvironmental data with existing archaeological information. Ultimately the primary objective is to structure a predictive model and framework for protecting the city's archaeological heritage and for steering guidelines for future development. One of the outcomes of this research was a map showing spatial information on archaeological potential distribution within the subsurface.

2 | STUDY AREA

2.1 | Geological and geomorphological setting

Benevento is located in a tectonic depression inside the southern Apennine Mountain chain, mainly consisting of clastic Quaternary deposits and subordinately of Pliocene clays and sands and Meso-Cenozoic clay marls and limestones (Fig. 1). Quaternary sediments unconformably cover Neogene bedrock, comprising siliciclastic and carbonatic rocks made of deep-sea successions related to the Cretaceous to early Miocene Lagonegro and Molise basins (D'Argenio, Pescatore, Senatore, Bisogno, & Tocco, 2002). During the lower Pliocene, tectonic deformation of the substrate produced the Benevento trough that was progressively filled with marine wedge-top basin sediments (Ciarcia, & Vitale, 2013) and, subsequently, by Quaternary continental deposits (Chiocchini, 2007; ISPRA, 2009). The tectonic framework of the Benevento basin was generated by ENE-WSW and NNW-SSE trending normal faults (Pescatore, Improta, Romeo, & Iannaccone, 1996). These faults, generally due to an extensional tectonic regime, active in the southern Apennine chain since the Pliocene, controlled the deposition of Quaternary sedimentary successions within the intermontane basins (Amato et al., 2013, 2014, 2017) and were also responsible for historical seismicity. The latter is well documented within the Benevento area by several strong earthquakes (CPTI, 2004; Galli, & Galadini, 2003; Pescatore, Cinque, Senatore, & Rosskopf, 2004).

The Benevento urban area, especially the historical center, lies on top of a Middle Pleistocene alluvial terrace, 60 m high above the base level of the Calore and Sabato Rivers (Fig. 2). The terrace, narrow and elongated NNW-SSE contains well lithified gravelly and sandy layers (Chiocchini, 2007). The conglomerates are polygenic (mostly carbonate clasts), heterometric (from pebble up to boulder in size), well rounded and typically cemented by calcareous crusts. Clasts are embedded in a reddish or brownish sandy matrix probably due to post-depositional precipitation of iron minerals. Sandy and silty intercalations commonly occur within the conglomerates (Chiocchini, 2007). The thickness of these deposits exceeds 100 m. The top of this terrace generally contains a thick dark brown paleosol (Pescatore et al., 1996; Senatore, & Boscaino, 2010).

The Benevento urban area also extends across two large alluvial plains composed of very loose gravelly and sandy layers deposited by the Calore River to the N-NE and the Sabato River to the S-SW

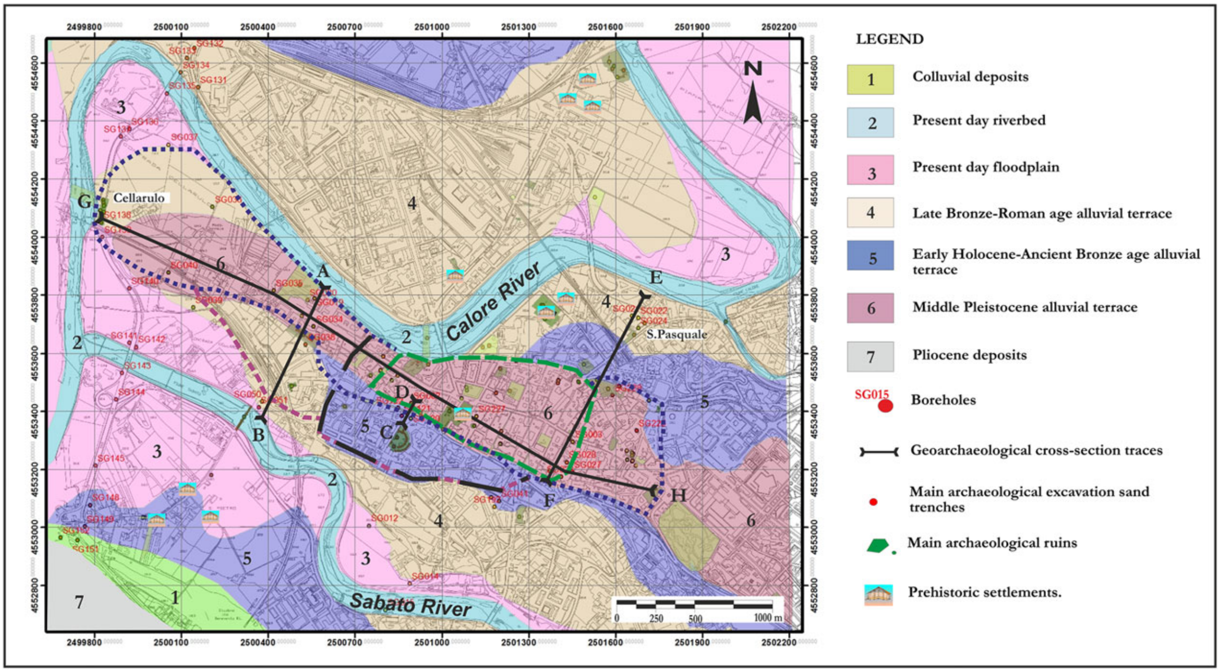

FIGURE 2 Morphostratigraphic map of the Benevento urban area with geoarchaeological cross-sections and archaeological data on previous occupations

Note: Green dashed polygon represents boundaries of the Samnitic town (fourth century B.C.), blue dashed polygon the Roman town of the third to first centuries B.C., purple dashed polygon the Roman town of the first to fourth centuries A.D, and the broken line polygon the Longobard town of the eighth century A.D.

[Color figure can be viewed at wileyonlinelibrary.com]

(Fig. 2). The area contains two Holocene alluvial terraces situated several meters above the modern floodplain. The first one, a 10–15 m high early Holocene terrace, is composed of loose gravelly and sandy layers capped by a thick paleosol, and contains the Avellino tephra layer of the 3945 $\pm$ 10 cal. yr B.P. Vesuvian eruption (Sevink et al., 2014) and isolated to more extensive prehistoric and protohistoric artifacts and settlements dated to the Neolithic to Bronze Age (third–first millennia B.C.) (Paradiso, Tomay, & Amato, 2015). The second late Holocene terrace, is 3–5 m high and also characterized by very loose gravelly and sandy layers, hosting artifacts and settlements of Bronze (20th–10th centuries B.C.) to Roman Age (third century B.C.–sixth century A.D.). Both terraces have been repeatedly flooded during Late Roman and Middle ages (4th–12th centuries A.D.) (D'Argenio et al., 2002; Senatore, & Boscaino, 2010) and more recently during the disastrous floods of 1949 and 2015. These flooding events did not reach the Middle Pleistocene terrace, where Samnitic Age (fifth–third centuries B.C.) and Roman Age settlements were established, although the urban areas were repeatedly rebuilt after destructive earthquakes (CPTI, 2004; Galli, & Galadini, 2003; Pescatore et al., 2004).

2.2 | Archaeological data synthesis

Archaeological data confirm that Benevento was extensively occupied by settlements since prehistoric times, most prominently during the Neolithic and Ancient Bronze ages (Paradiso et al., 2015). In particular, the thick paleosol associated with Avellino tephra contains evidence of human settlements and occupation, specifically tied to dense farming and grazing land use. These settlements are mainly distributed along parts of the early and late Holocene terraces (Paradiso et al., 2015) (Fig. 2).

On the elongated Middle Pleistocene terrace, significant archaeological evidence including monuments and large structures indicate transformations in urban occupation. An initial pre-urban phase, probably consisting of scattered villages, seems to span between the Iron Age and the Archaic and Classical age (10th–5th centuries B.C.). The first urban layout was built in the second half of the fourth century B.C., and expanded considerably with the rise of the Roman colony (268 B.C.) (Giampaola, 2000; Rotili, 2006; Tagliamonte, 1996). The Samnitic old city (fifth–third century B.C.) was located on top of the Middle Pleistocene terrace, occupying its highest elevation (Fig. 2). During the Roman Age, the character and function of the city was reshaped many times, and its layout progressively affected the whole Middle Pleistocene terrace (Fig. 2). Some sectors of the alluvial plain were densely inhabited as witnessed by ruins of bridges, roads, aqueducts, villae, theatres, living quarters, and a necropolis (Giampaola, 2000). During the Longobard and Middle Ages (6th–12th centuries A.D.), the city shrank considerably, retreating to the higher part of the Middle Pleistocene terrace, while the alluvial plain was used mainly as farming, grazing and productive areas (Tomay, 2009). The Longobard city extended SW, by enlarging the terrace area through lateral and vertical placement of landfill (Rotili, 2006) (Fig. 2). After the Middle Ages, the city underwent further phases of rebuilding and reshaping, which continue to the present, especially after destructive earthquakes and floods.

3 | MATERIALS AND METHODS

The starting point for drafting the map of archaeological potential was the creation of an updated and well-organized geographic information system (GIS) database, documenting all the diagnostic deposits and associations of densely stratified Benevento urban complexes. Data include information on settlement location, chronology, typology, functionality, stratigraphy, and context.

The GIS database was enhanced and improved by archeostratigraphic data derived from approximately 250 boreholes, archived at the Benevento City municipality (https://www.comune.benevento.it/bn2_pagine/notizie/puc.php) and from archaeological excavations conducted by the Benevento Office of the Superintendent of Archaeology in Campania. The purpose was to characterize the strata in terms of chronology, lithology, and paleonvironmental evidence. The strata were also described in terms of color, texture, grain (size, shape) and composition, fossil content, and sedimentary and diagenetic structures, according to the methods of Tucker (2011) and Miall (2006) for facies classification. Using the unconformity boundary stratigraphic unit method (UBSU; after Salvador, 1994) based on lithofacies, unconformities, and presence of tephra layers and paleosols, the successions were divided into sedimentary units and subunits. This approach allows one to distinguish layers potentially containing archaeological remains from those otherwise referred to as "geological bedrock," that is, lacking any archaeological materials.

In order to classify the space–time contexts of the archaeostratigraphic data, two flow charts of the database were compiled. The first flow chart contains information about available archaeological data: identification, location, geographical reference, chronology and typology, depth below ground level, and geomorphological context. The second flow chart provides chronostratigraphic information derived from boreholes: identification, location, geomorphological context, elevation of Middle Pleistocene alluvial deposits (considered as layers without archaeological potential), elevation of archaeological remains, and elevation of tephra layers, especially that from the Avellino Vesuvian eruption. Most of the Avellino tephra layers were identified and stratigraphically related to several archaeological trench successions (Paradiso et al., 2015). In these trenches, a volcaniclastic fall-out layer, constituted by millimetric white and gray pumices and gray ashes with thickness ranging 5–15 cm, is located between Ancient Bronze Age and Late Bronze-Iron Age archaeosurfaces and paleosols, confirming tephra deposition between the 20th and 10th centuries B.C. This tephra can be confidently correlated to fall out products of the Avellino Vesuvian eruption, likely the only volcanic product that reached the Benevento territory during this period (Sulpizio et al., 2010). In addition, the Avellino fall-out deposits have been identified in several similar archeostratigraphic successions within the Campania region (Amato, 2006, 2014; Vecchio et al., 2007) in boreholes and archeological trenches of Benevento (D'Argenio et al., 2002; Senatore, & Boscaino, 2010), where it has been geochemical analyzed and radiometrically dated.

By comparing the two flow charts and taking into account archaeological and stratigraphic data, it is possible to evaluate the "localized archaeological potential" (LAP) both at ground level and in the subsurface, as represented on the maps by points and colored circles. In particular, the great abundance of Roman age remains allows a more precise estimate of the Roman age LAP, while the presence of the Avellino tephra layer allows one to extend the LAP to the prehistoric age.

A detailed geomorphological study, based on 1:5,000 topographic maps, historical maps and aerial photos, supported by digital terrain model (DTM) analyses, was also carried out. The integration of geomorphological and stratigraphic data allowed us to divide the territory into morphostratigraphic units (MUs). Units are characterized by homogeneity of geological-geomorphological features, chronological ranges, specific depositional contexts, and by reconstructed site formation processes. Further support to testing mapping accuracy was a field survey carried out to verify the distribution of geomorphological features, and their continuity and relationships with the geological data. It was possible to expand the LAP data to the entire MU with a good degree of approximation, allowing us to evaluate archeological potential also within those sectors characterized by a lack of precise archaeological and chronostratigraphic data.

The archaeological potential was divided in four classes: "very high," "high," "moderate," and "low". Very high archaeological potential applies to those sectors presenting archaeological structures (buildings, roads, villas, theaters, etc.), either currently preserved or disclosed by archaeological excavations. Very high archaeological potential also applies to those contexts presenting boreholes containing archaeological data (e.g., wall remains and roads). High potential characterizes those MUs presenting borehole and archeostratigraphic successions with abundant scattered and broken archaeological fragments. Moderate values apply to those contexts that did not preserve archaeological artifacts, but contain well-dated deposits (i.e., paleosols, Avellino tephra layer), which enable one to hypothesize the potential occurrence of archeological remains. Finally, low archeological potential applies to those contexts without any archaeological data and those containing stratigraphic units of recent age (i.e., fluvial deposits, anthropogenic infillings). These four classes of archaeological potential are incorporated into a map of the archaeological preservation probability for the Benevento urban area (hereinafter APMap_SiUrBe).

4 | EVALUATION OF BENEVENTO ARCHAEOLOGICAL POTENTIAL

4.1 | Local archaeological potential

Evaluation of archaeological potential began by assessing archaeological heritage based on known archaeological excavation data. All data were managed and developed through GIS spatial analysis. This approach allowed for assessments of local areas, where the presence, importance, and visibility of archaeological evidence could be appraised on the basis of the density of archaeological materials (Fig. 3). In particular, sectors preserving roads, bridges, walls, theatres, buildings, arches, and other exposed or buried archaeological structures were considered at a local level of high archaeological potential. The index of archaeological potential area was estimated on the

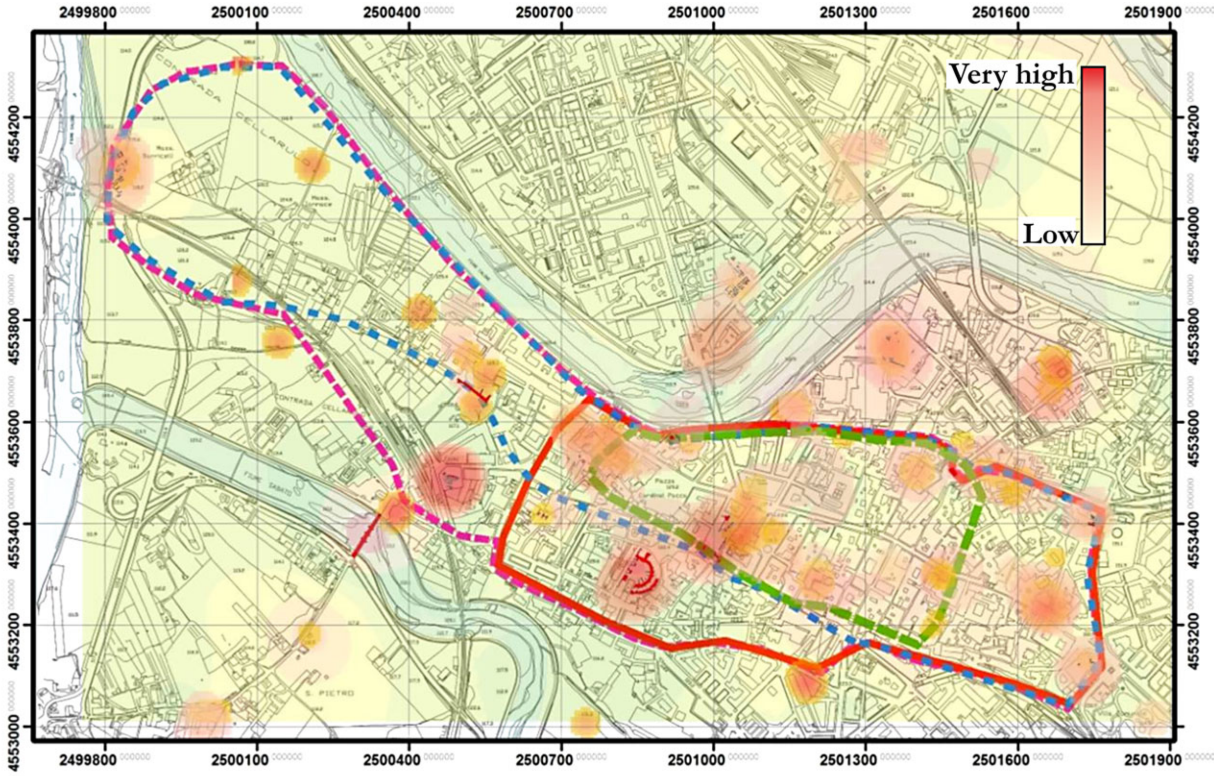

FIGURE 3 Archaeological potential of the Benevento urban area based on GIS spatial analysis of archaeological data
Note: Green dashed polygon represents boundaries of the Samnitic town (fourth century B.C.), blue dashed polygon the Roman town of the third to first centuries B.C., purple dashed polygon the Roman town of the first to fourth centuries A.D., and the red polygon the Longobard town of the eighth century A.D.
[Color figure can be viewed at wileyonlinelibrary.com]

basis of the importance, width, and depth of the archaeological findings. Actually, many sectors of the urban area provide very accurate data regarding the depth of archaeological findings. This is the key criterion for defining the LAP, but, as shown in Figure 3, a large part of the urban area is lacking data.

The second step involved enhancement of the database by adding archaeo-tephro-stratigraphic data derived by borehole analyses, serving as the leading reference for the occurrence of archaeological remains and the Avellino tephra layer (Figs. 4 and 5). Although the map reports accurate site placements in terms of depth and typology of archaeological remains, more representative data for a large part of the urban area is still lacking. In areas of high archaeological density, the reliability of archaeological potential assessments was confirmed by recent archaeological excavations (Paradiso et al., 2015; Tomay, 2013).

4.2 | The morphostratigraphic approach to evaluate archaeological potential

The integrated geomorphological and stratigraphic study allowed us to distinguish seven MUs (Fig. 2). As illustrated in Figure 6, relative archaeological potential is tied to landforms, soil and sediment stratigraphy, and chronology. The MU of anthropogenic fillings and historic reclamations, blanketing much of the Middle Pleistocene terrace (T2) and early Holocene terrace (T3), varied in thicknesses between a few and *ca.* 10 m. That stratum was classified as having very high archaeological potential (Figs. 4 and 6). The thick dark brown paleosol and Avellino tephra spanning the top and margins of the T2 and T3 terraces, respectively, extended the time frames of archaeological potential to prehistoric time.

The early Holocene MUs are concentrated on alluvial terrace T3, along the Calore and Sabato alluvial plains (Fig. 6). The deposits, ranging 5–15 m in thickness, have high archaeological potential. Once again, the identification of Avellino tephra layers extended the archaeological potential to prehistoric time.

The historic MU associated with alluvial terrace T4 (Fig. 6) is 3–10 m thick and considered to have high archaeological potential except for its outer portions (low archaeological potential). Sedimentological evidence indicates that historic floods changed the course of the rivers and produced different sedimentological signatures. As a result, the floodplain MU (T4 in Fig. 2), up to 5 m in thickness, is considered to be a low archaeological potential layer. The possibility of archaeological evidence is ruled out in the layers of the Pleistocene terrace MU and in the current courses of the Sabato and Calore rivers MU, because of their old and young ages, respectively. Therefore, the MUs with the greatest archaeological potential are at the top and along the borders of Middle Pleistocene and early Holocene terraces.

The integration of the archaeological and geological data sets allows for assessment of archaeological potential both vertically and horizontally, especially for those areas lacking archaeological

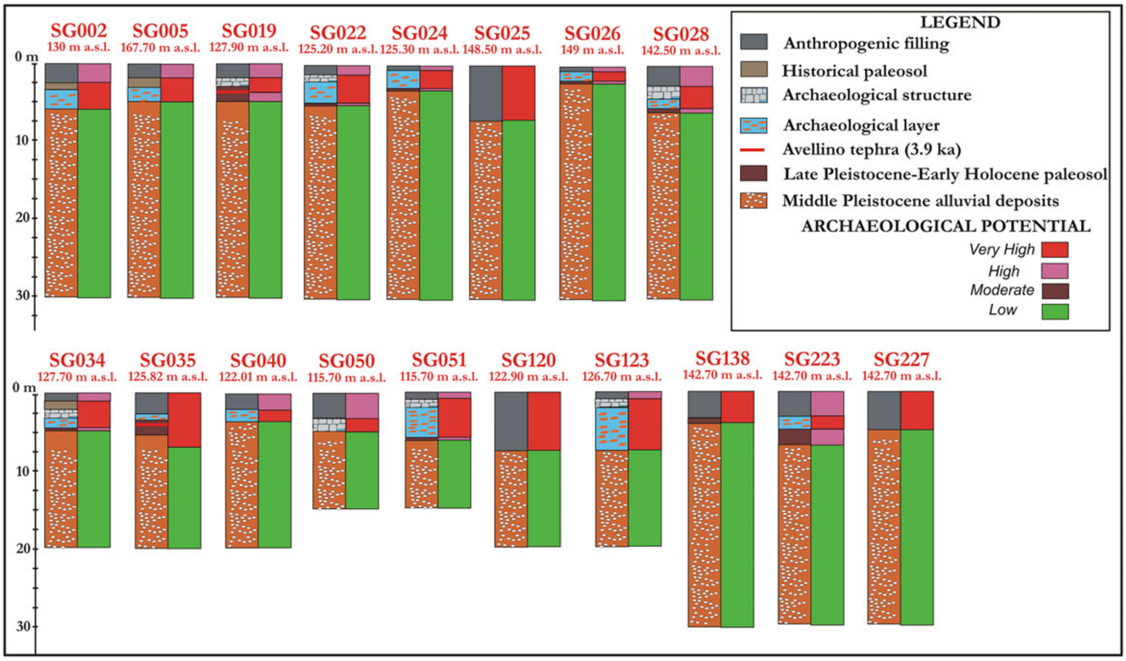

FIGURE 4 Schematic stratigraphic logs of selected boreholes assessed in terms of archaeological potential
Note: Locations are shown in Figure 2.
[Color figure can be viewed at wileyonlinelibrary.com]

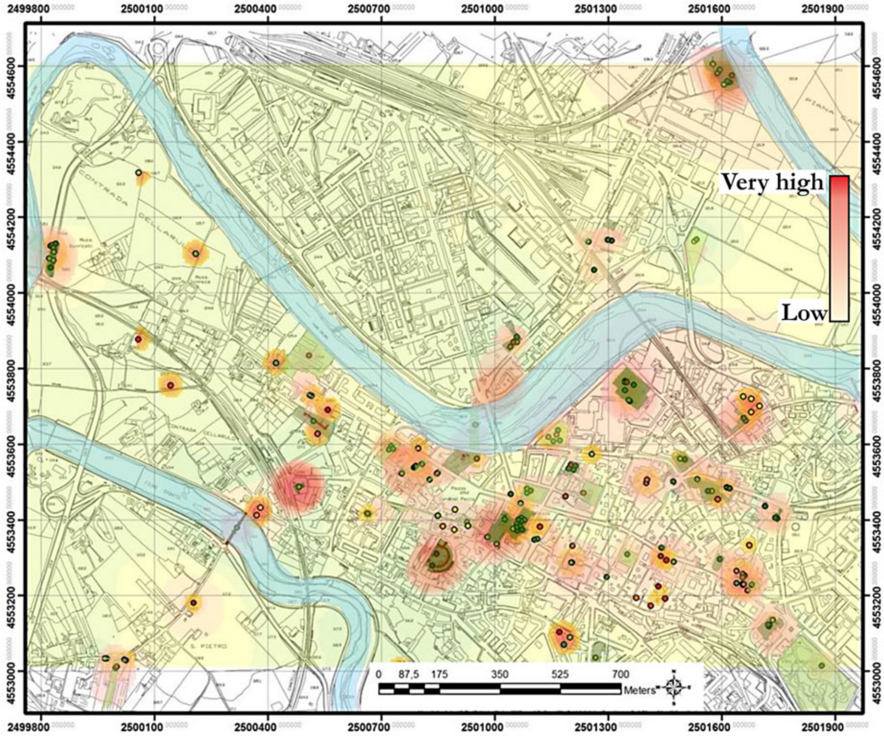

FIGURE 5 Spatial zonation of archaeological potential within the Benevento urban area
Note: Determinations are made on the strength of GIS spatial analysis of the archaeological and geological data. Red and green dots show locations of archaeological data and boreholes containing archaeological and tephra layers.
[Color figure can be viewed at wileyonlinelibrary.com]

evidence. To improve the assessment of archaeological potential, the substrate of the urban segments was investigated by several synthetic geoarchaeological cross-sections. In particular, four selected examples of such cross-sections are illustrated in this paper (Fig. 2). The AB cross-section intersects layers with high archaeological potential (blue layer in Fig. 7) enabling to hypothesize the archaeological potential of an area where the Roman ground level is detectable (red dashed line in Fig. 7). Both in the Via S. Lorenzo 31 excavation and in the SG019 borehole, the Roman layers (Roman road at Via S. Lorenzo 31 excavation and wall remains from SG019 borehole) occur at

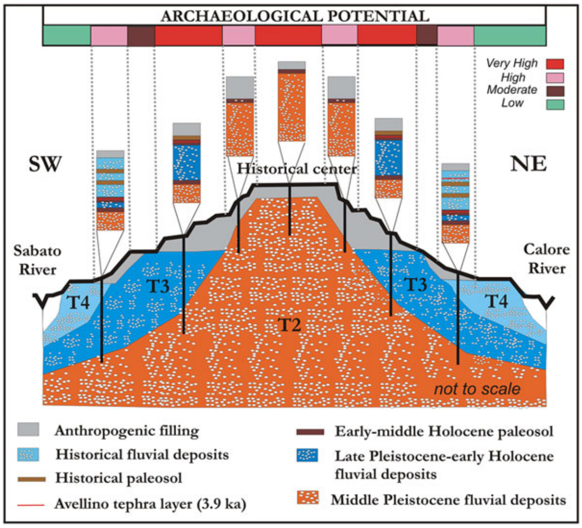

FIGURE 6 Schematic model of the Benevento urban area presenting the main morphostratigraphic units (MUs) and diagnostic stratigraphic logs
Note: Relative archaeological potential for each segment of the landscape is shown in the color-coded bar above the model.
[Color figure can be viewed at wileyonlinelibrary.com]

approximately the same elevation. Elevation of the dark brown paleosol was also consistent with these topographic placements. In the Via S. Lorenzo 31 excavation, remains of prehistoric settlements extended the projection of the archaeological potential of this area to the top of the paleosol. The same topographic and stratigraphic context is recognizable in the area of the Roman Amphitheater (Fig. 8a) and Lungo Sabato excavation (Fig. 8b and c). Therefore, the thickness of the Roman archaeological potential layer on the Middle Pleistocene alluvial terrace MU (historic center) is shallower, but thicker than that on the early Holocene terrace MU and on the Roman age terrace MU.

Geoarchaeological cross-section CD (Fig. 9) illustrates the high potential archaeological layers of the segment between Piazza C. Pacca-Via S. Filippo 28 and Via Manfredi di Svevia, partially sitting on the Middle Pleistocene terrace and partially on its SW border. Here, archaeological potential was more precisely evaluated due to the abundance of archeostratigraphic data. Along the SW border of the terrace, potentially rich archaeological deposits extend more deeply than those on top of the terrace. The discrepancy in sediment thicknesses and extent reflects the great amount of ancient anthropogenic infilling that was laid down to change the size and shape of the terrace, especially during the Roman and Longobard periods. In fact, the Roman layers at the Via San Filippo 28 excavation (Fig. 8d) directly overlie the Middle Pleistocene conglomerates at 0.5–1.0 m below the modern surface, while in the SG123 borehole, remains of the walls were found at similar depths, but the anthropogenic deposits extended laterally and expanded in thickness to 7–8 m.

Cross-section EF (Fig. 10) enables an assessment of high archaeological potential due to the presence of buried soils and vestiges of Roman occupation. Deposits of high archaeological potential on the T2 terrace are thicker than those of the T3 terrace. Potential is greater because of the massive accumulation of anthropogenic fills during historic times. The comparison between geoarchaeological (borehole SG022) and archaeological data (Via S. Pasquale) confirms the high archaeological potential for this sector of the T3 terrace. Corroborative evidence comes from comparisons between SG026 and Corso Garibaldi Roman cistern stratigraphic data on the T2 terrace. The presence of the dark brown paleosol, both on the top of the Middle Pleistocene and early Holocene terraces allows us to extend the archaeological potential to prehistoric times. Unfortunately, this hypothesis has not yet been tested by archaeological excavations.

Cross-section GH (Fig. 11) shows the layers with high archaeological potential for the segment between the Calore River and the central part of the middle Pleistocene terrace, and includes the archaeological area of Cellarulo to the Villa Comunale. Along this section, the depths of archaeological deposits are almost uniform, between 2 and 5 m below the modern ground surface. The thickness tends to increase

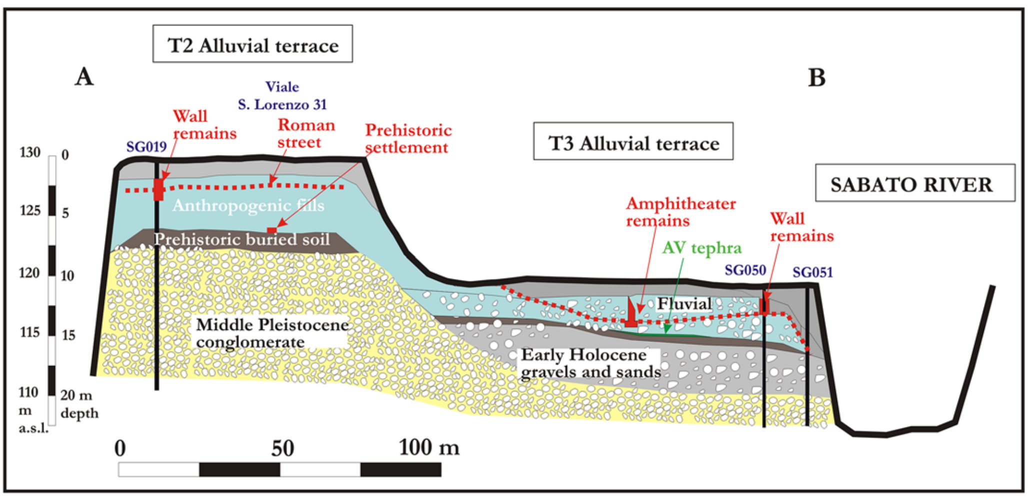

FIGURE 7 Geoarchaeological cross-section of the via S. Lorenzo-Anfitheatre case study (see Fig. 2 for location)
Note: The light blue layer depicts the archeological potential of the Benevento urban area in contact with prehistoric surfaces, while the red dashed line shows the Roman age archaeological potential.
[Color figure can be viewed at wileyonlinelibrary.com]

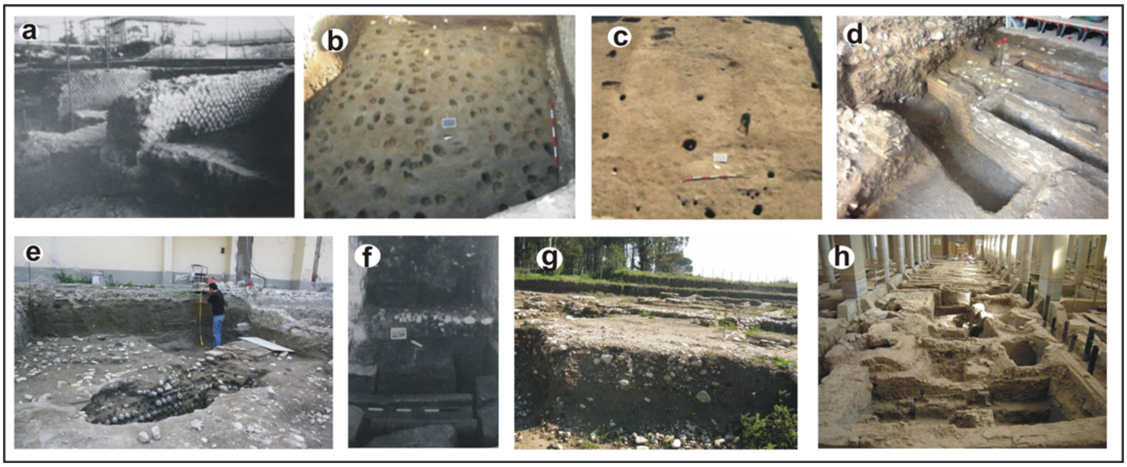

FIGURE 8 Photos of archaeological trenches: (a) amphitheater remains appear at *ca*. 1 to 3 m depth; (b) Lungo Sabato: bovine footprints buried and preserved by Avellino eruption air-fall deposits; (c) Via Valfortore: Bronze age settlement showing post holes of huts buried and preserved by Avellino tephra; (d) Via San Filippo: Roman age tombs, excavated directly into the Middle Pleistocene conglomerate; (e) Via San Pasquale: Roman age drainage system recently excavated to depths of 1.5–2.5 m; (f) Corso Garigaldi: Roman age cistern excavated to *ca*. 2 m depth; (g) Cellarulo Archaeological Park: Roman age structures emplaced directly on the Roman age alluvial terrace (T4); (h) Cathedral: four phases of settlement construction preserved since prehistoric times (Neolithic through Bronze Age); the photo shows the Roman age structures [Color figure can be viewed at wileyonlinelibrary.com]

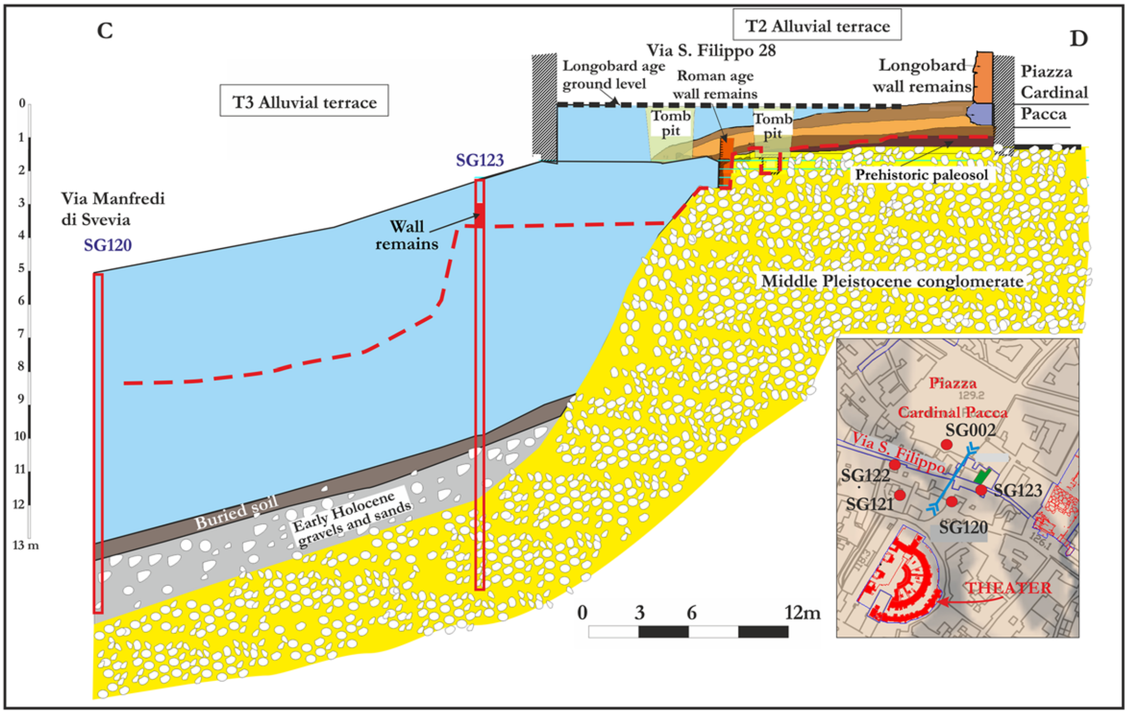

FIGURE 9 Geoarchaeological cross-section CD of the Via San Lorenzo case study
Note: The light blue layer represents the historic archeological potential of the Benevento urban area. The red and black dashed lines denote the Roman and Longobards age levels of archaeological potential, respectively. The brown and orange archaeological layers have been investigated by trenches. Location of cross-section is depicted in Figure 2 and in the location map (lower right hand corner).
[Color figure can be viewed at wileyonlinelibrary.com]

from the upper to lower part of the Middle Pleistocene terrace. In the Cellarulo archaeological area, Roman structures were excavated from the surface to 2 m depth (Fig. 8g). These structures were excavated directly on alluvial deposits of the early Holocene terrace and on 39 ka Ignimbrite Campana volcanic deposits (De Vivo et al. 2001). These two layers can be considered as having negligible archaeological potential due to their ages (early Holocene and Upper Pleistocene, respectively). Also, their depositional facies (braided or multichannel river and pyroclastic flow, respectively) represent high energy deposition that would have swept away any possible archaeological features. On the Middle Pleistocene terrace (Fig. 8h), the thick buried soil at the top of the alluvial deposits is relevant with regards to archaeological potential. This

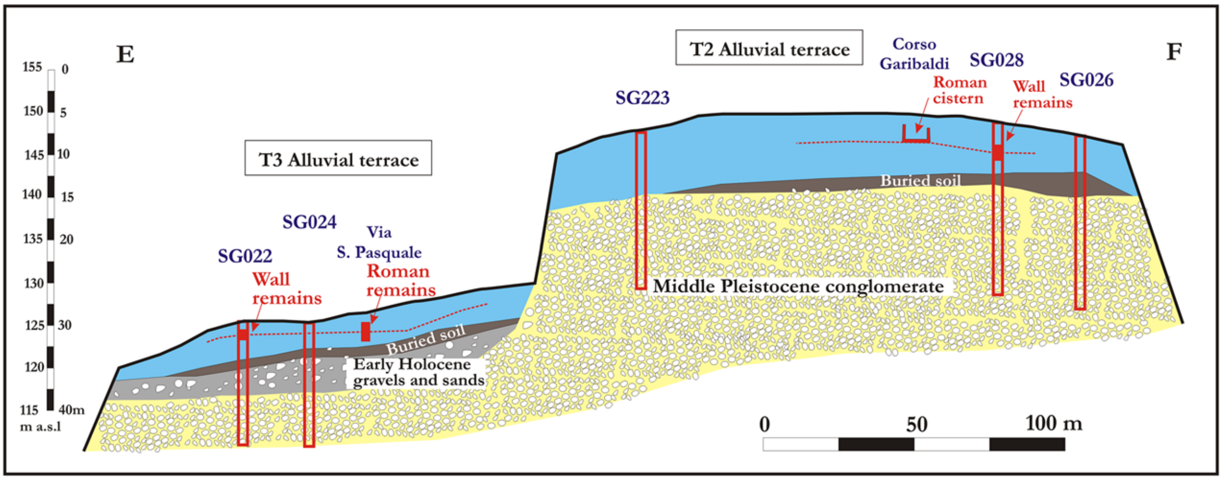

FIGURE 10 Geoarchaeological cross-section EF at Via San Pasquale-Corso Garibaldi
Note: The light blue layer represents the historic archeological potential of the Benevento urban area, that is, deposits above the prehistoric disconformity. The red dashed line marks levels for Roman age deposits. Location of cross-section is shown in Figure 2.
[Color figure can be viewed at wileyonlinelibrary.com]

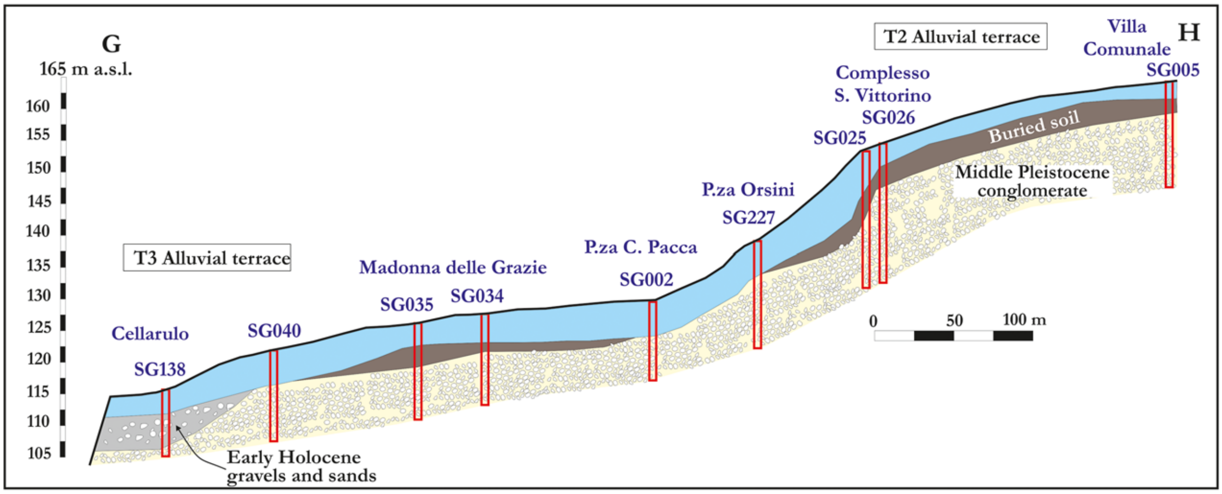

FIGURE 11 Geoarchaeological cross-section GH showing levels of archeological potential (light blue layer) within the Benevento urban area
[Color figure can be viewed at wileyonlinelibrary.com]

buried soil could potentially preserve Neolithic and Ancient Bronze age archaeological remains given that Benevento was densely occupied by these early settlements.

5 | THE ARCHAEOLOGICAL POTENTIAL MAP OF BENEVENTO

Integration of the previously discussed data allowed us to compile an archaeological sensitivity map, APMap_SiUrBe (Fig. 12), that considers the potential depth of cultural deposits. Archeological sensitivity was mapped to include all time frames back to the prehistoric period. In this projection, all sectors of the Benevento urban area are ranked by relative degrees of archeological potential ranging from very high to moderate values, distributed between 1–2 and 12–13 m depth, except in the modern river channels. The T2 terrace and its margins accounts for a higher archaeological potential since primary archaeological deposits and artifacts tend to be preserved in these contexts. In contrast, the lower T3 and T4 terraces, present a lower preservation potential.

Minimal depths of archaeological deposits (1–5 m) are concentrated in segments cross-cutting the Middle Pleistocene terrace (the top of T2), early Holocene (T3), and Roman (T4) age terraces and at the margins of the current floodplains. The maximum depths (5–13 m) are concentrated especially along the SW border of the Middle Pleistocene terrace (SW in Fig. 12), and in the NE sector of the urban area, currently between Piazza Risorgimento and bus terminal areas (NE in Fig. 12). In the SW area the depths and thicknesses of the archaeological layers are a consequence of frequent and deep accumulations of anthropogenic sediments emplaced in different periods, in part to enlarge the Middle Pleistocene terrace toward the SW. In the NE area, the deep anthropogenic fills are the product also of recent human activities, built up during the last few centuries.

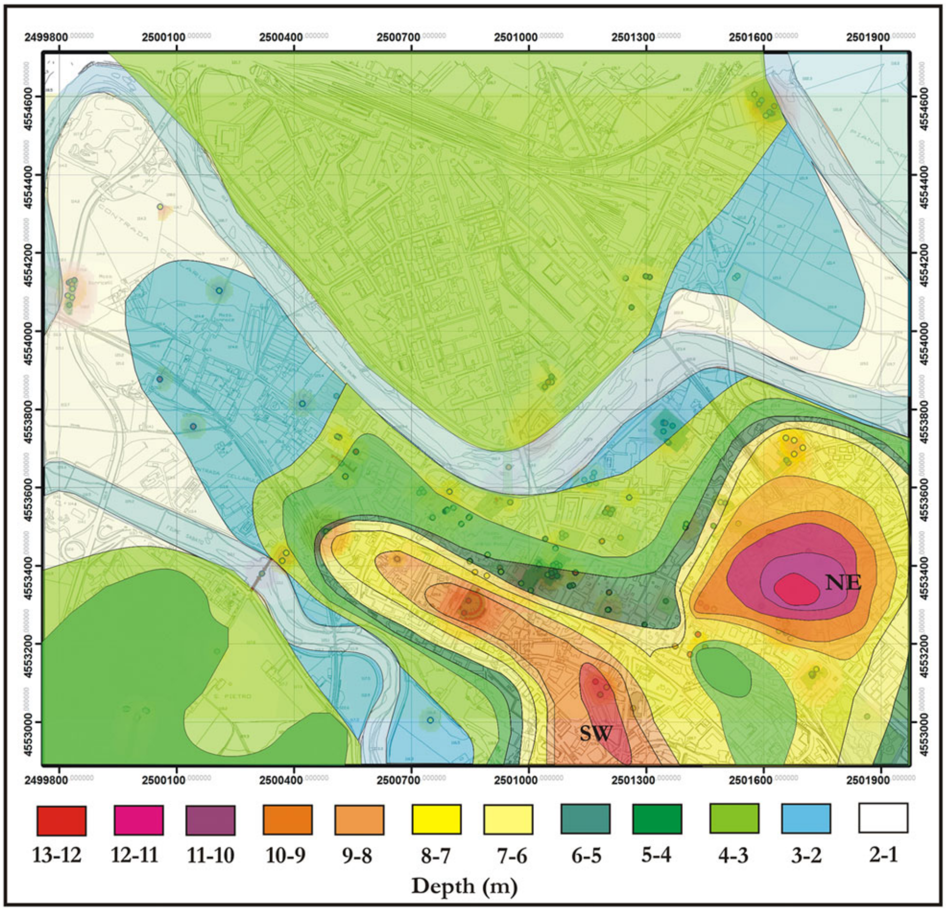

FIGURE 12 Archaeological potential map of the Benevento urban area in relation to depth of deposits (in meters)
Note: The map is a predictive tool for archaeological density and preservation potential in the subsurface.
[Color figure can be viewed at wileyonlinelibrary.com]

6 | CONCLUSION

The adopted multidisciplinary approach, selected as an integrated archeostratigraphic and geomorphological methodology, was proven to be successful for the evaluation of archeological potential, especially for densely urbanized areas of Benevento. This nondestructive approach is based on a protocol that integrates historical archaeological records with relevant geological data, thus giving back reliable geomorphological reconstructions and sensitivity maps. The GIS data integration allows to draw hypotheses on archaeological sensitivity in an inductive way based only on probabilities and the limited database acquired in earlier phases of data acquisition.

Mapping the archaeological potential of Benevento provides a powerful tool for safeguarding its archaeological heritage. This predictive tool is framed as a model for space–time mapping and reconstructing early social organization based on changes in settlement density through time within the Benevento urban footprint. The map also represents a tool for urban planning that seeks to balance the needs of public/private urban expansion with community interest in protecting and safeguarding the common heritage. Our hope is that the APMap_SiUrBe be used by public administrations and private citizens to help schedule, plan, estimate, and budget renovation work or construction of new buildings in Benevento.

ACKNOWLEDGMENTS

The authors wish to gratefully thank Luigina Tomay, past head archaeologist of the local office (Benevento) of the Superintendent of Archaeology for the Campania region, for supporting research and the SiUrBe Project. We are grateful to the students and researchers of Salerno University involved in the SiUrBe and Ancient Appia Landscape projects. We are also grateful to the reviewers and editors of the manuscript for their useful suggestions. Special thanks to the editors of this special issue and to S. Siano and A. Langella for help on revisions for this paper.

ORCID

Vincenzo Amato http://orcid.org/0000-0003-1977-0905

REFERENCES

Amato, V. (2006). *La risposta di alcuni tipici sistemi morfodinamici della Campania (Italia meridionale) alle variazioni climatiche oloceniche* (Unpublished doctoral dissertation). University of Naples "Federico II". Retrieved from https://www.fedoa.unina.it/636/1/Dottorato_Amato.pdf.

Amato, V. (2014). Le variazioni climatiche dell'Olocene: Esempi di cambiamenti morfo-sedimentari desunti dal record archeo-tephrostratigrafico della Campania (41°N, Italia meridionale). *Miscellanea INGV*, *18*, 50–56.

Amato, V., Aucelli, P. P. C., Bellucci Sessa, E., Cesarano, M., Incontri, P., Pappone, G, & Vilardo, G. (2017). Multidisciplinary approach for fault detection: Integration of PS-InSAR, geomorphological, stratigraphic and structural data in the Venafro intermontane basin (Central-Southern Apennines, Italy). *Geomorphology*, *283*, 80–101

Amato, V., Aucelli, P. P. C., Cesarano, M., Jicha, B., Lebreton, V., Orain, R., & Russo-Ermolli, E. (2014). Quaternary evolution of the largest intermontane basin of the Molise Apennine (central-southern Italy). *Rendiconti Fisiche Accademia Lincei*, *25*, 197–216.

Amato, V., Aucelli, P. P. C., Capozzi, A., De Benedittis, G. F., Pappone, G., & Rosskopf, C. M. (2013). Environmental changes in the Boiano intramontane basin (Molise, Italy) since the times of ancient Bovianum (IVth century BC). *Alpine And Mediterranean Quaternary*, *26*, 15–29.

Anichini, F., Fabiani, F., Gattiglia, G., & Gualandi, M. L. (2012). *MAPPA. Methodology applied to archaeological potential predictivity* (Vol. I). Retrieved from https://www.mappaproject.org/wp-content/uploads/2011/08/Mappa_vol-1_en_intero.pdf

Anichini, F., Fabiani, F., Gattiglia, G., & Gualandi, M. L. (2013). *MAPPA. Methodology applied to archaeological potential predictivity* (Vol. II). Retrieved from https://www.mappaproject.org/wp-content/uploads/2013/07/MAPPA-VOL.2.pdf

Campeol, G., & Pizzinato, C. (2007). Metodologia per la valutazione dell'impatto archeologico. *Archeologia e Calcolatori*, *17*, 273–292.

Cardarelli, A., Cattani, M., Labate, D., & Pellegrini, S. (2001). Il sistema MUTINA: Esperienze ed2 evoluzione. In M. P. Guermandi (Ed.), *Rischio archeologico: Se lo conosci lo eviti* (pp. 200–210). Firenze:All'Insegna del Giglio Editore.

Carver, M. (2003). *Archaeological value and evaluation*. Mantova: Società Archeologica PAD.

Chiocchini, U. (2007). *Note illustrative della Carta Geologica d'Italia in scala 1:50.000*. Foglio 432 Benevento: Servizio Geologico d'Italia. Retrieved from https://www.isprambiente.gov.it/Media/carg/note_illustrative/432_Benevento.pdf

Ciarcia, S., & Vitale, S. (2013). Sedimentology, stratigraphy and tectonics of evolving wedge-top depozone: Ariano basin, southern Apennines, Italy. *Sedimentary Geology*, *290*, 27–46.

Colautti, C., & Ardizzon, V. (2006). Mestre archeologica, tracce di identità dal sottosuolo. *Atti del Convegno di Mestre 2005*. Trento: Publistampa Arti grafiche-Pergine Valsugana.

CPTI. (2004). Catalogo Parametrico dei Terremoti Italiani, versione 2004 (CPTI04), INGV, Bologna. https://doi.org/10.6092/INGV.IT-CPTI04

D'Argenio, A., Pescatore, T., Senatore, M. R., Bisogno, G., & Tocco, G. (2002). Effects of natural events on ancient Benevento, Southern Italy. *Rendiconti Accademia Scienze Fisiche e Matematiche, Napoli*, *69*, 13–26.

De Guio, A. (2001). Superfici di rischio" e C.I.S.A.S. se lo conosci, non lo eviti. In M. P. Guermandi (Ed.), *Rischio archeologico: Se lo conosci lo eviti* (pp. 265–306). Firenze: All'Insegna del Giglio Editore.

De Vivo B., Rolandi G., Gan, P. B., Calvert, A., Bohrson, W. A., Spera, F. J., & Belkin, H. E. (2001). New constraints on the pyroclastic eruptive history of the Campanian volcanic Plain (Italy). *Mineralogy and Petrology*, *73*, 47–65.

Galli, P., & Galadini, F. (2003). Disruptive earthquakes revealed by faulted archaeological relics in Samnium (Molise, southern Italy). *Geophysical Research Letters*, *30*, 1266.

Gelichi, S., & Malnati, L. (1989). Lineamenti per una carta del rischio archeologico della città di Modena. *Modena dalle origini all'anno Mille* (pp. 413–414). *Studi di archeologia e storia*, *I*. Modena: Panini Editore.

Gelichi, S., & Negrelli, C. (2009). *A misura d'uomo. Archeologia del territorio cesenate e valutazione dei depositi*. Firenze: All'Insegna del Giglio Editore.

Giampaola, D. (2000). Benevento: Dal centro indigeno alla colonia latina. In A. La Regina (Ed.), *Studi sull'Italia dei Sanniti* (pp. 36–46). Milano.

Guarnieri, C. (2001). Pianificazione urbana e carta archeologica: Il caso di Faenza. In M. P. Guermandi (Ed.), *Rischio archeologico: Se lo conosci lo eviti* (pp. 215–222). Firenze:All'Insegna del Giglio Editore.

ISPRA. (2009). *Carta Geologica d'Italia in scala 1:50.000 Foglio 432 Benevento e note illustrative (a cura di U. Chiocchini)*. Servizio Geologico d'Italia. Roma.

Judge, W. L., & Sebastian, L. (1988). *Quantifying the present and predicting the past: Theory, method and application of archaeology predictive modeling*. Denver: Bureau of Land Management.

Kamermans, H., van Leusen, M., & Verhagen, J. W. H. P. (Eds.) (2009). *Archaeological prediction and risk management: Alternatives to current practice*. (Archeological studies Leiden University; no. 17). Amsterdam: Amsterdam University Press.

Manicardi, A. (2015). Mantova: Topografia e potenziale archeologico della civitas vetus dalla tarda antichità all'alto medioevo. *Documenti di Archeologia*, *58*, 1–122.

Miall, A. D. (2006). *The geology of fluvial deposits. Sedimentary facies, basin analysis and petroleum geology*. Berlin and Heidelberg: Springer-Verlag.

Paradiso, S., Tomay, L., & Amato, V. (2015). Reconstructing the ancient landscapes and environments along the Sabato River (Benevento, Southern Italy) since the Bronze Age: New geoarchaeological measurements. Proceedings of 1st International Conference on Metrology for Archaeology, Benevento, Italy, October 22–23, 2015.

Pescatore, T., Improta, L., Romeo, R., & Iannaccone, G. (1996). Geologia della città di Benevento: Caratteristiche litostratigrafiche di base per una microzonazione sismica. *Bollettino della Società Geologica Italiana*, *115*, 307–324.

Pescatore, T. S., Cinque, A., Senatore, M. R., & Rosskopf, C. (2004). Historical-geological events and their impact on man. *Field trip guide book P14, 32nd International Geological Congress, Firenze 2004.*

Rotili, M. R. (2006). *Benevento nella tarda antichità. Dalla diagnostica archeologica in contrada Cellarulo alla ricostruzione dell'assetto urbano*. Napoli: Pigna Editore.

Salvador, A. (1994). International stratigraphic guide. A guide to stratigraphic classification, terminology and procedure. Denver, CO: International Union of Geological Sciences and the Geological Society of America, 1–284.

Santoriello, A., & Rossi, A. (2012). Sistemi di informazione e sistemi di conoscenza. SIURBE: Il sistema informativo del patrimonio archeologico urbano di Benevento. In L. Campanella & C. Piccioli (Eds.), *Diagnosis for the conservation and valorization of Cultural Heritage* (pp. 192–200). Napoli: Atti del Terzo Convegno Internazionale.

Santoriello, A., & Rossi, A. (2013). Il Sistema Informativo Archeologico Urbano di Benevento (SIURBE): Una esperienza integrata tra flussi di conoscenza e gestione dei dati. Proceedings of "Opening the past" Congress, Pisa, 13–15 Giugno *2013*, 48–51.

Santoriello, A., Rossi, A., Amato, V., & Ciarcia, S. (2013). The SiUrBe project (Sistema informativo del patrimonio archeologico Urbano di Benevento (SiUrBe): A geoarchaeological approach as a tool for the definition of the archaeological potential. Proceedings of "Opening the past" Congress, Pisa 13–15 Giugno 2013, 65–68.

Senatore, M. R., & Boscaino, M. (2010). *The history of Benevento and natural catastrophic events. Evidences from the sedimentary succession of Cellarulo. Scienze Naturali e Archeologia.* (pp. 221–225). Roma: Aracne Editrice.

Sevink, J., van Bergen, M. J., van der Plicht, J., Feiken, H., Anastasia, C., & Huizinga, A. (2014). Robust date for the Bronze Age Avellino eruption (Somma-Vesuvius): 3945+/-10 cal. B.P. (1995+/-10 cal. B.C.). *Quaternary Science Review*, *30*, 1035–1046.

Sulpizio, R., Cioni, R., Di Vito, M. A., Mele, D., Bonasia, R., & Dellino, P. (2010). The pomici di Avellino eruption of Somma-Vesuvius (3.9 ka BP). Part I:

Stratigraphy, compositional variability and eruptive dynamics. *Bulletin of Volcanology*, *72*(5)539–558.

Tagliamonte, G. (1996). *I Sanniti: Caudini, Irpini, Pentri, Carricini, Frentani*. Milano: Longanesi Editore.

Tomay, L. (2005). Benevento. Interventi di archeologia urbana, in "Notiziario della Soprintendenza per i Beni Archeologici di Salerno, Avellino e Benevento", *2005*(1), 34–38.

Tomay, L. (2009). Benevento longobarda: Dinamiche insediative e processi di trasformazione. In G. D'Henry & C. Lambert (Eds.), *Il popolo dei longobardi meridionali (570-1076): Testimonianze storiche e monumentali* (pp. 119–151). Salerno: Gruppo Archeologico Salernitano.

Tomay, L. (2013). Tutela, ricerca e pianificazione urbana. Nuove acquisizioni e strumenti per la conoscenza e la gestione del patrimonio archeologico beneventano. In P. Caruso (Ed.), *Antiqva Beneventana. La storia della città romana attraverso la documentazione epigrafica* (pp. 13–34). Benevento: La Provincia Sannita Editore.

Tucker, M. E. (2011). *Sedimentary rocks in the field: A practical guide* (4th ed.). Chichester, England: John Wiley and Sons Ltd.

Vecchio, G., Castaldo, N., Pappalardo, M. T., Pizzano, N., Livadie, C. A., Amato, L., & Di Vito, M. A. (2007). Napoli—L'insediamento protoappenninico di Fuorigrotta-Piazzale Tecchio. Rivista di Scienze Preistoriche. *spec. Relazioni XL Riunione Scientifica Istituto Italiano di Preistoria e Protostoria*, *2005*, 961–964.

Verhagen, P., & Witley, T. G. (2011). Integrating archaeological theory and predictive modeling: A live report from the scene. *Journal of Archaeological Method and Theory*, *7*, 135–158.

How to cite this article: Amato V, Ciarcia S, Rossi A, Santoriello A. The urban geoarchaeology of Benevento, southern Italy: Evaluating archaeological potential. *Geoarchaeology*. 2018;33:100–111. https://doi.org/10.1002/gea.21658