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Groningen Institute of Archaeology
Poststraat 6
9712 ER Groningen
The Netherlands
gia@rug.nl

Website
https://ugp.rug.nl/Palaeohistoria

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The Middle to Late Holocene in the Agro Pontino and the Fondi basin (Lazio, Italy): A palaeogeographical overview

***W. van Gorp*[1] *& J. Sevink*[2]**

1 Groningen Institute of Archaeology, University of Groningen. 2 Institute for Biodiversity and Ecosystem Dynamics,
2 University of Amsterdam. Corresponding author: j.sevink@uva.nl

***Abstract**: The Agro Pontino, a vast plain located south of Rome (southern Lazio, Italy), has served as a valuable resource for central Italian palaeogeographical, vegetational and archaeological studies for decades. This paper reviews the regional development of the Agro Pontino and adjacent Fondi basin from the Würmian (Marine Isotope Stages 2–5d) until the end of the protohistoric, with an emphasis on the period around the Early Bronze Age (EBA) date of the Avellino eruption. Following postglacial relative sea level rise, a dissected Pleistocene landscape drowned and was filled with lagoonal, fluvial, alluvial, lacustrine and marsh deposits. In the Agro Pontino, two lakes emerged divided by an alluvial fan. The unique regionally preserved stack of Middle to Late Holocene sediments, including multiple macroscopically visible tephra layers within a depositional environment, allowed for a detailed regional palaeogeographical, tephrochronological and vegetational reconstruction. This study presents the latest palaeogeographical findings from the Agro Pontino and the Fondi basin for the Middle Holocene and the EBA, for which tephra identification and dating forms the solid basis. It contributes to the reconstruction of the Pontine plain and the Fondi basin during this period and furthers our palaeoenvironmental knowledge of the conditions for human subsistence in this region during the later phase of the EBA, around the time of the Avellino eruption (c. 1900 calBC).*

***Keywords**: Agro Pontino, Early Bronze Age, Avellino tephra, palaeogeographical overview.*

1. Introduction

1.1 General introduction

The tectonically active Italian peninsula contains some excellent examples of subsiding coastal basins with major Quaternary sedimentary archives, such as those along the Tyrrhenian coast (Nisi *et al.* 2003). These include the Arno plain (Rossi *et al.* 2011); the Garigliano basin (Belotti *et al.* 2016); the Campanian plain; and the Agro Pontino and Fondi basins (Fig. 1; Van Gorp & Sevink 2019; Van Gorp *et al.* 2020).

The Agro Pontino and Fondi basin (southern Lazio, central Italy) border the Tyrrhenian Sea and are examples of complex, small-scale, infilled basins and form the area of study for this paper. They contain a Holocene infill burying a Pleistocene landscape with dissected Middle to Late Pleistocene marine terraces formed during several marine high stands. This infill has already been extensively studied over the past decades, as it forms a rich archive of Holocene deposits (Sevink 1984, 2013; Barbieri *et al.* 1999); palaeoecological sequences (Barbieri *et al.* 1999; Eisner & Kamermans 2004; Bakels *et al.* 2015); and pre-protohistoric and historic artefacts and indicators (Loving *et al.* 1990; Voorrips *et al.* 1991; Attema 1993; Kamermans 1993; Alessandri 2009; Feiken 2014).

1.2 Regional geological setting

The Agro Pontino graben system is a more or less rectangular lowland area oriented NW–SE, bordered in the north by the Monti Lepini and in the east by the Monti Ausoni. In the south, the Monte Circeo forms a limestone promontory, which plays an important role in shaping the Holocene coastline. East of the Monti Ausoni, the triangular Fondi basin forms a second lowland area.

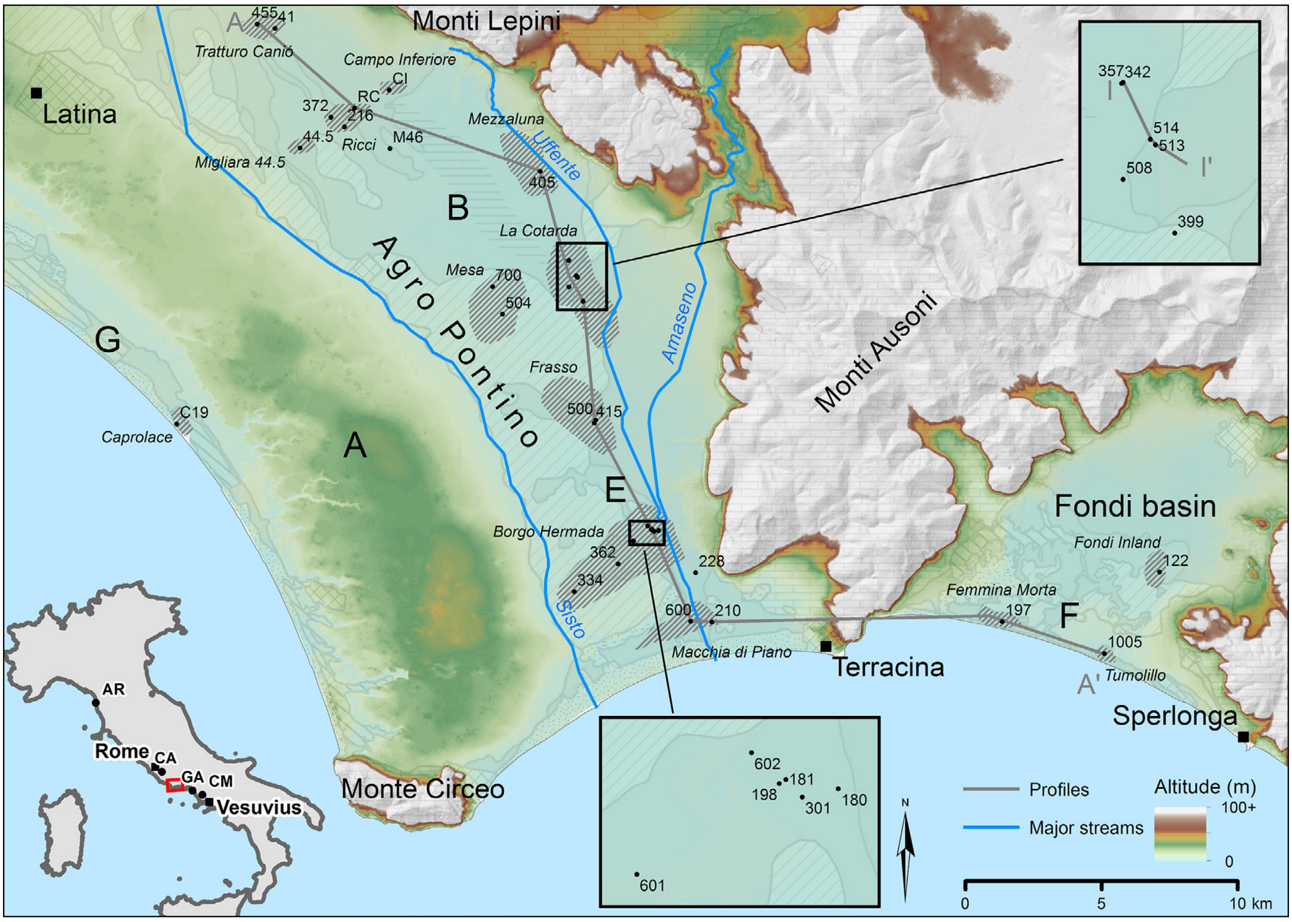

Fig. 1. Map showing sites in the Agro Pontino and Fondi basin (shaded areas, with names indicated in italics) and key coring locations (black dots) studied. Numbers refer to locations described in Table 1 (RC = Ricci; CI = Campo). A = higher complex of Pleistocene marine terraces; B = inland Agro Pontino graben; E= south-eastern Agro Pontino graben; F = coastal Fondi; G = western coastal area. Lower left inset: Map of Italy, showing study area outlined in red. CA = Colli Albani. Examples of other subsiding coastal basins indicated as follows: AR = Arno plain; GA = Garigliano basin; CM = Campanian plain.

Both basins are bordered by the Tyrrhenian Sea in the south-south-west (Fig. 1).

From south-west to north-west, the Agro Pontino can be subdivided in several zones, oriented NW–SE. In the first zone, the coastal zone in the south-west is formed by a Late Holocene beach ridge with adjacent coastal lagoons (including Lago di Caprolace) (Fig. 1). In the second zone, a plateau-like, slightly higher area is formed by a sequence of Pleistocene marine terraces formed during former sea level high stands, which have undergone mild uplift during the Pleistocene (Sevink *et al.* 1982, 1984), effectively forming the horst section of the horst–graben system. Towards the graben, this horst transitions into the lowest-lying plains (central or inland Agro Pontino) via the youngest and lowest-lying Pleistocene marine terrace, the Borgo Ermada complex, which is also widely encountered in the graben itself. This Borgo Ermada complex was dissected during the Würmian sea level low stand. Upon the Holocene sea level rise, the lower parts of this dissected landscape gradually disappeared under Holocene lacustrine, lagoonal and fluvio-deltaic deposits, and a lake formed. These 'natural' Holocene sediments have partly been covered by younger, post–Bronze Age colluvio-alluvial deposits that can be several metres thick (e.g. Sevink *et al.* 1984; Van Joolen 2003). In the north-west, in the area around Tratturo Caniò, these originate from the Monti Lepini and Colli Albani, while in the east, they mostly originate from the Amaseno River catchment. The non-covered parts of the 'natural' Holocene deposits form an undulating lowland landscape. In the lowest parts of the Agro Pontino, these lagoonal and lacustrine deposits currently lie below sea level due to post-depositional subsidence at locations where Holocene deposits are the thickest (Van Gorp *et al.* 2020).

The Fondi basin is located east of the Agro Pontino and shows a similar stratigraphy, albeit that it is fed by much smaller streams, from the surrounding limestone mountains. The most northern, inland part of the basin is entirely covered by young colluvial deposits. These deposits overly Holocene lacustrine and lagoonal sediments. South of the edge of the colluvial deposits, these lacustrine and lagoonal sediments have infilled a dissected Pleistocene plain consisting of marine terraces from

Table 1. Main relevant sites which are discussed within the context of time periods and themes.

Time/Theme	Coastal and landscape development	Vegetation - Climate	Tephrochronology – Toxicity	Anthropogenic influence/ suitability
T4: After AV until major anthropogenic influence	Inland lake NW (TC, RI, CI, LC, ME) Western coastal lagoon Caprolace, Fogliano,	Pollen: Ricci, Mezzaluna, Frasso,	Chronology: Borgo Hermada (BH) (AP2, ca. 1700 cal yr BC, Jung, 2017)	Caprolace, La Cotarda, Tratturo Caniò, Borgo Hermada, Maina III
T3: During and directly after AV	La Cotarda, BH coastal lagoons, Fondi Inland, Fondi coastal lagoons	Pollen: Femmina Morta, Tumolillo, Ricci, Mezzaluna, Frasso, Borgo Hermada, Fondi Inland	Chronology: TC, RI, CI, M44.5, ME, FR, BH, MP, FM, TUM, FI (AV, ca. 1909-1868 cal yr BC, Sevink et al., 2021) Toxicity: RI, ME, FR, ME, BH, FM	Tratturo Caniò, Maina III, Ricci? La Cotarda?
T2: Mid- Holocene until AV	AP Inland area, AP south-eastern area, Fondi inland, Fondi coastal lagoons BH Gully, BH Coastal lagoons, Fondi Coastal lagoons	Pollen: Ricci, Mezzaluna 3, Femmina Morta, Tumolillo	Chronology: Femmina Morta, Tumolillo (AST6, ca. 2168±118 - 2117±84 cal yr BC, Sevink *et al.*, 2020), Mezzaluna	Mesa, Ricci? Tratturo Caniò, Campo Inferiore
T1: Mid Pleistocene-Mid Holocene	AP Inland area, AP South-eastern area Ricci, La Cotarda, Amaseno outlet	Mezzaluna (4,2 ka)		

several marine high stands. At the southernmost seaward side, the current Holocene beach ridge encloses elongated coastal lagoons in which peat marshes have formed.

1.3 The Avellino tephra and the specific Early Bronze Age situation

At the end of the first decennium of this century, within the context of palaeogeographical and archaeological investigations for a PhD project at the University of Groningen (Feiken 2014), the north-western edge of the low-lying part of the Agro Pontino was cored and trenched. In 2008, a thin tephra layer was discovered within lacustrine to marshy sediments at the location known as Migliara 44.5 (Sevink 2011), while in 2009 another tephra layer was found at Campo Inferiore[1]. Both layers were identified by Sevink *et al.* (2011) as distal tephra from the EBA Avellino eruption of the Somma–Vesuvius. Since then, this tephra layer has been found at many other locations in the Agro Pontino (Sevink *et al.* 2013). Locations studied in more detail include Tratturo Caniò (Feiken *et al.* 2012) and the more southern Mezzaluna and Ricci (Bakels *et al.* 2015). Thus, the picture of a spatially preserved distal tephra within EBA lacustrine and marshy deposits started to emerge.

The Avellino (AV) tephra thereby potentially served as an excellent marker for a very specific EBA time window within these deposits. At the same time, archaeological investigation revealed that the human habitation density of the area was relatively low in the EBA and rapidly increased towards the Middle Bronze Age (Alessandri 2016; Alessandri *et al.* 2021). Moreover, from the extensive archaeological studies in the Campanian region, it appeared that the EBA population on the slopes of Mount Vesuvius had been forced to flee the effects of the Avellino eruption, after an initial, small-scale eruption had warned them of the massive eruption that would follow (Livadie *et al.* 2019).

With these ingredients, a project was started to test the hypothesis that part of this EBA population had fled towards the northern Lazio coastal basins, i.e. the Agro Pontino and the Fondi basin (Attema *et al.* 2015; Bakels *et al.* 2015). This project, The Avellino Event: Cultural and Demographic Effects of the Great Bronze Age Eruption of Mount Vesuvius, was funded by the Dutch Research Council (NWO) and included archaeological, palaeoenvironmental and palaeogeographical research conducted in the Agro Pontino and Fondi basin. In the current paper, we present the synthesis of more than four years of palaeogeographical research within the scope of this recently concluded research project.

1 Found by Carmela Anastasia at Campo Inferiore, in her exploratory excavation on behalf of the Soprintendenza archeologica per il Lazio.

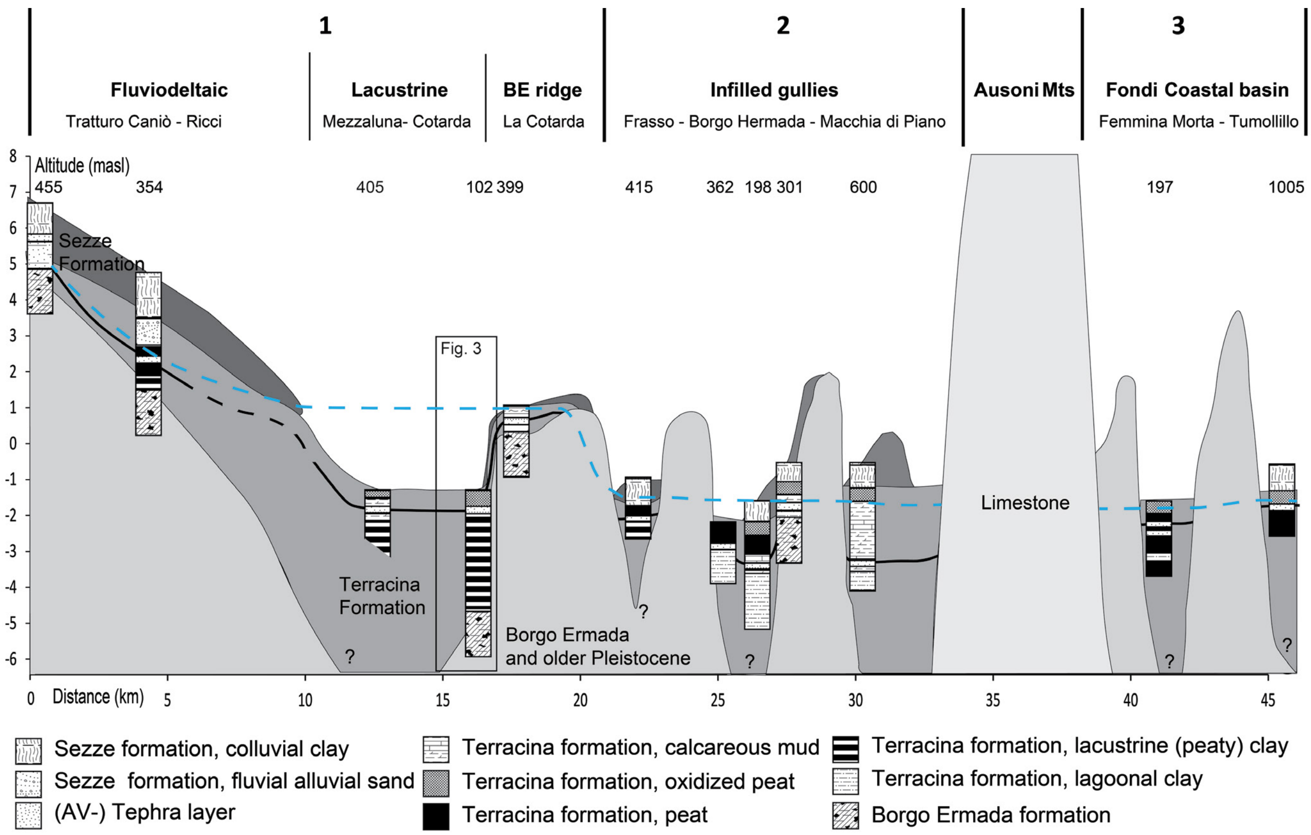

Fig. 2. Cross-section through the Agro Pontino and Fondi basin (based on Van Gorp & Sevink 2019), indicating approximate Early Bronze Age water level of lake and wetland areas (blue line). Names are mentioned once per litho-stratigraphical unit. The legend indicates the lithologies of the core profiles depicted. 1 = inland lake; 2 = south-eastern lake; 3 = Fondi basin; BE = Borgo Hermada; Mts = mountains; AV = Avellino.

2. Goals and structure

The aim of this paper is, first, to outline the significance of the newest palaeogeographical findings from the Agro Pontino and Fondi basin for the Middle Holocene and the EBA (Van Gorp & Sevink 2019; Van Gorp *et al.* 2020), founded on a solid basis of tephra identification and radiocarbon dating (Sevink *et al.* 2020, 2021), and, second, to place these findings in the context of decennia of palaeogeographical, palaeoecological and geo-archaeological research in these low-lying wetlands. We present our hitherto unpublished results within this wider context, and use them to illustrate the Holocene evolution of the area. We stress the wider implications of and potential future research for these results. The paper is structured along two main axes: A time axis, containing four relevant periods since the Middle Würmian, and a theme axis, containing the most relevant themes (Table 1). Important findings at specific locations, including some new, unpublished findings, will be discussed within this time-theme context. This will lead to a region-wide reconstruction emphasizing the vast variation that existed within this wetland landscape, as well as the important role of the AV tephra as a stratigraphic marker.

3. Observations and description of key locations

We present and summarize geo(archaeo)logical observations for three major units: the Agro Pontino inland lake, the Agro Pontino south-east lake and the Fondi basin (B, E and 'Fondi basin' in Fig. 1). Within these units, several subunits that are significant for the EBA reconstruction have been defined, and these are presented using key locations and locations within those locations. This broadly follows the 'physiographical units' defined in Van Gorp & Sevink (2018, Table 1). We additionally discuss the western coastal lagoons, as these have yielded considerable new insights into the post-EBA chronology.

3.1 *Agro Pontino inland lake*

The Agro Pontino inland lake is fed by streams discharging the northern volcanic Colli Albani, the Monti Lepini and the karstic springs at the edge of these limestone mountains. Its areas of interest are subdivided into the north-western lake edge and its adjacent fluvio-deltaic plain and southern edge, where it borders the Amaseno alluvial fan and a high part of the Pleistocene Borgo

Ermada marine terrace (Sevink *et al.* 1984; Van Gorp & Sevink 2019).

3.1.1 Inland north-western lake edge and fluvio-deltaic area: Tratturo Caniò, Ricci and Campo Inferiore

At the north-western lake edge and its interlacing fluvio-deltaic area lie Tratturo Caniò, Ricci and Campo Inferiore (see Fig. 1 for all numerical identifiers and names mentioned in the text). The archaeological site of Tratturo Caniò is located on a fluvial stream levee, where clayey colluvial strata overlie dense fluvial clays. These strata interfinger with coarser stream deposits (Feiken *et al.* 2012). Within the lower, dense clays, the Avellino tephra is present at an altitude of more than 5.5 m asl. Archaeological indicators, such as charcoal and bones, have been found at the same level or below the Avellino tephra, not only at the site of Tratturo Caniò (455) itself, but also at site 41 (Maina III). Towards the south-east, these tephra-bearing deposits are also found at Ricci, at an altitude of 2 to 3 m asl, again in association with stream deposits and archaeological indicators (Bakels *et al.* 2015). These indicators are reported from stratigraphic positions below the AV tephra and comprise a piece of human bone and ceramics (Bakels *et al.* 2015). At both locations, the dense clays are overlain by thick (>1 m) colluvial strata, leading to (limited) compaction, as the non-compactable Pleistocene surface is found within the first metre of deposits below the AV ash layer. Ricci marks the transition from a fluvial to a lacustrine setting (Bakels *et al.* 2015; Van Gorp *et al.* 2020), as also reconstructed for the EBA by Feiken (2014). This fluvio-deltaic unit rests on a Pleistocene subsurface within 1 m below the AV tephra. At Ricci, a Middle Pleistocene fluvially reworked lithoid tuff lies on top of older Pleistocene deposits (Sevink *et al.* 2018). South-west of Ricci, lateral to the Ricci stream direction, the tephra is encountered within pyritic clays originally deposited in a flood basin–to-lake setting, at sites 216 and 372. Even more to the west, the site of Migliara 44.5 also bears the tephra, within finely laminated pyritic clays (Sevink *et al.* 2011), and here these clays were deposited in distal, tranquil conditions. The genesis of these pyritic clays can be linked to the composition of the waters that ran into the plain and were fed by springs at the mountain front. These waters, such as the Laghi di Vescovo, were – and still are – high in sulfur, which, in such distal, tranquil conditions with stagnant waters may easily lead to accumulation of pyrite. In such an anoxic environment, the sulphur compounds are reduced to sulphide (S^{2-}), which together with reduced iron (Fe^{2+}) precipitates as highly insoluble FeS_2 (pyrite). The phenomenon is well known from coastal areas where sulphide comes from sea water–containing sulphate (SO_4^{2-}) that is reduced, but also from the type of tranquil flood basin–to-lake setting described here (see Sevink 2020).

To the north-east of Ricci, the tephra at the site of Campo Inferiore is present in fine, lacustrine clays. The altitude of the tephra layer decreases from west to east, and there is a gradient from anaerobic conditions (pyritic clays) to aerobic conditions (Ca-rich lacustrine clays and peat) (Bakels *et al.* 2015; Van Gorp & Sevink 2019). The difference in altitude makes it difficult to attribute all these locations to one and the same lake or lake edge. Rather, multiple streams and floodplain basins existed, where the anaerobic marsh–floodplain setting north-east of the main stream has been fed by karstic springs that lie north-west of Trattura Caniò, while the Ca-rich clays south-east may also have been fed by local springs that lie along the Monti Lepini edge. The advance of the alluvial deposits of the Ricci stream burying the peaty strata here occurred concurrent with or just after the AV tephra deposition, while the advance of the adjacent fan covering the Campo Inferiore clays to its current shape occurred in the 1000 years hereafter (Attema & Delvigne 2000). Pollen analysis at Ricci indicates the disappearance of alder carr some time before the AV tephra deposition, driven by waterlogging of the area. As this is a disturbance of the natural succession, Bakels *et al.* (2015) interpreted it as probably due to increasing human influence in the area before the AV event.

3.1.2 The north-eastern central inland lake and south-western-southern inland lake edge

These two units form two elongated areas in a NW–SE direction, more or less parallel to the graben. The north-eastern central inland lake is the continuation of the aerobic lacustrine clays at Campo Inferiore and runs via Mezzaluna towards La Cotarda Northwest. The south-western-southern lake edge is the downstream continuation of anoxic marshy conditions at Migliara 44.5 and Ricci 372 and runs via Mesa towards La Cotarda Southeast (Fig. 1).

3.1.3 The east-central part of the inland lake: Mezzaluna and La Cotarda Northwest

The east-central part of the inland lake contains a thick Holocene infill (Serva & Brunamonte 2007). A deep, infilled gully can be traced from the small alluvial fan north of Mezzaluna towards the northern part of La Cotarda, right into the Amaseno valley. This gully is filled with metres-thick stratified fluvial and fluvio-lacustrine sands, clays and peats, sometimes containing reworked peat. The fluvial sandy clays are found nearest to the Amaseno River (at locations 513 and 514; Fig. 3, Appendix A), and the fine to laminated clays and

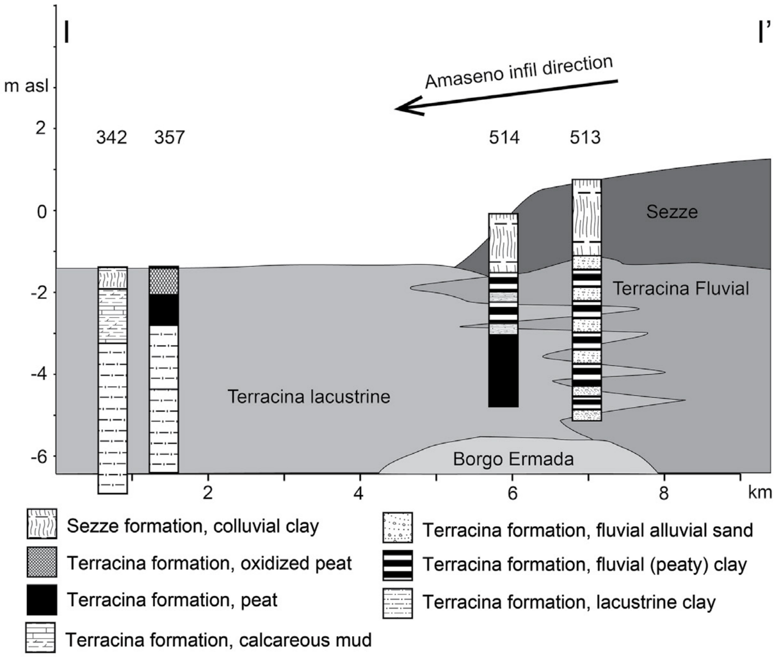

Fig. 3. Cros-section at La Cotarda, showing direction of infill of Amaseno River, with coarser fluvial deposits interfingering with finer, distal and lacustrine/marshy deposits. Note that, unlike in Fig. 2, the Terracina deposits are subdivided into lacustrine and fluvial.

peat are found farther north-west, towards the centre of the inland Agro Pontino (342, 257; Fig. 3). This distribution demonstrates that the sediment originates from the Amaseno River, which largely filled the original Pleistocene valley. Around and on top of this deep gully fill, peats and calcareous muds (gyttja) occur, such as at the location Mezzaluna (Barbieri 1999; Eisner & Kamermans 2004). The calcareous muds are formed in water from karstic springs at the border of the graben and the Monti Lepini (see Sevink *et al.* 2013; Feiken 2014). AV tephra is found in peats near the lake edges (location 1015, and in gyttja at 405, or Mezzaluna 3) (Sevink *et al.* 2013; Bakels *et al.* 2015). At this latter site, peat tops an approximately 40 cm thick calcareous mud, which contains the AV tephra halfway. Below this calcareous mud, peat also occurs. Palaeoecological analysis indicates an initial sequence of alder carr, similar to the situation at Ricci (section, 3.1.1; Bakels *et al.* 2015), followed by a freshwater lake setting. The occurrence of both peaty strata and lake muds indicates a diverse marsh landscape with both open water and vegetated areas. In all cases, the top 30-50 cm of peat is highly oxidized. At all locations in the inland lake area with thick peaty strata, AV tephra occurs around −1.5 to −2 m asl and this altitude is the combined effect of its deposition on a lake bottom and significant post-depositional subsidence (Van Gorp *et al.* 2020). Toxicity analysis of the tephra and its adjacent sediment indicates high levels of F in the AV layer. In a Ca-rich environment, F from the ash fallout would indeed become immobilized as CaF_2. In other, non-Ca-rich environments, such as the anoxic clays and the peat areas, F would have been mobile and thus may have had a harmful, toxic effect on the environment after ash deposition (Sevink *et al.* 2021).

3.1.4 The south-eastern and southern parts of the inland lake edge: Mesa and La Cotarda Southeast

The south-western and southern parts of the inland lake edge are formed by a gently sloping Pleistocene marine terrace forming part of the Borgo ermada level. Its surface gently dips underneath younger Holocene strata and has some larger, elongated depressions. These are old, filled-in fluvial incisions that start from the adjacent, western higher Pleistocene ridge and run towards the north, where they join the central river, draining the interior graben. The Mesa area was extensively studied within the Pontine Region Project, the results of which were published by Tol *et al.* (2020). Summary results of the study of the soils and sediments by Sevink, reported in Tol *et al.* (2020), are presented here, combined with further observations on adjacent parts of the area studied within the scope of the AV project.

In the Mesa area, the lagoonal clays of the Borgo Ermada surface are covered by a thin layer of Holocene clay, which is generally less than 50 cm thick and more or less mixed with the underlying Pleistocene clay as a result of deep ploughing. The quite level and gently dipping surface is marked by small, either straight or oval, 'ditches', and by small depressions. These ditches and depressions are filled with more or less peaty and pyritic sediment containing the AV tephra layer, which was deposited at a relatively late stage of the infilling. The AV tephra is encountered at around 0.5 to 1 m asl. The fills are preserved wherever they are deep enough to not be affected by deep ploughing and may extend to more than 1 m below the ground surface. In the elongated depression, a much thicker fill of Holocene grey clays is

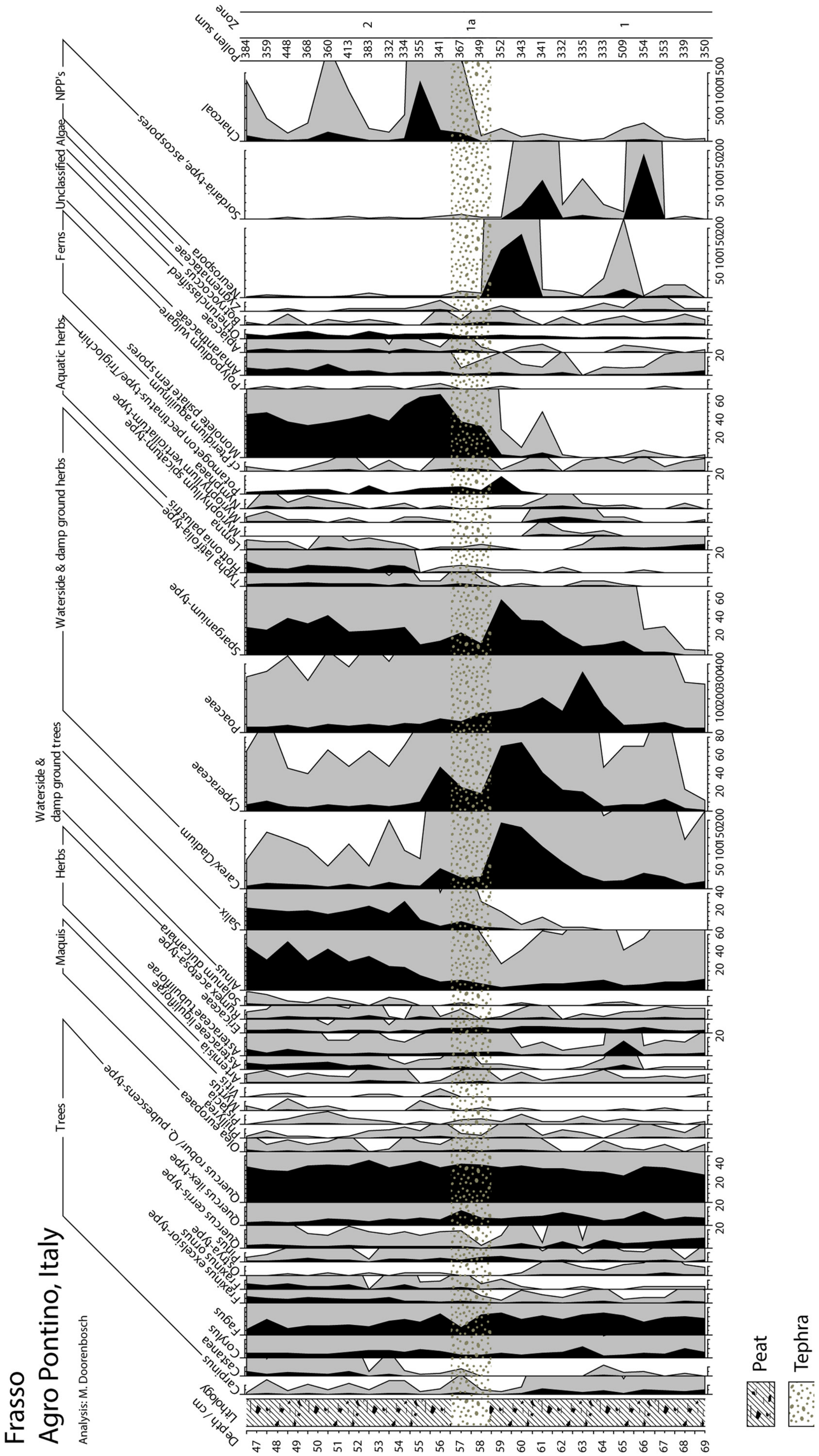

Fig. 4. Frasso pollen diagram (analysis Doorenbosch 2022, reproduced from van Gorp et al. 2019).

present, grading upward into pyritic clays also holding the AV tephra layer and grading laterally into the ditch fills described above. Due to later subsidence, largely resulting from the Bonifica, the AV layer in this type of fill is encountered at a lower altitude (see Van Gorp *et al.* 2020). An additional phenomenon linked to this drainage is the widespread oxidation of the pyritic sediment, leading to the massive formation of 'burnt clay' (Sevink 2020), which is characteristic for the Mesa area and testifies to the pronounced anoxic conditions at the lake edge at the time of deposition of the Avellino tephra.

Quite evidently, both the rectilinear ditches (one of which is more than 1 km long) and the oval ditches must be anthropogenic in origin and, given the presence in these ditches of AV tephra, must date from before this EBA eruption. That these ditches were filled testifies to a rise of the water table before the deposition of the AV tephra, and thus to a large lateral extension of the lake edge to around 0.5–1 m asl. (e.g. see Van Gorp *et al.* 2020). Together with Ricci and Mezzaluna (Sevink *et al.* 2013; Bakels *et al.* 2015), a consistent image appears of lake-wide rewetting some time before the AV tephra deposition.

The current difference in altitude of up to 2 m between locations underlain by a thin or locations underlain by thick Holocene strata reflect not only differential post-depositional subsidence (Van Gorp & Sevink 2019), but also, in part, some recent oxidation of the (peaty) topsoil (Van Gorp *et al.* 2020). At the locations of Mesa and La Cotarda, the subsidence has been limited due to the shallow presence of underlying non-compactable Pleistocene substrate. Therefore, the AV tephra–bearing lacustrine deposits at these locations give a more reliable indication of the EBA lake level (Van Gorp *et al.* 2020). Additionally, Mesa and especially La Cotarda Southeast (site 399) are part of the lake edge at the outlet, or downstream side, of the inland lake. The AV tephra altitude at these locations therefore eliminates potential floodplain or marsh gradients, which may explain the somewhat higher altitude of floodplain and lake sediments at the north-western edge of the inland lake. The reconstructed inland EBA lake level of van Gorp *et al.* (2020) can be seen as the maximum lake level, associated with the maximum lake extent.

The location Cotarda Southeast (399) lies on the eastern extension of the low Pleistocene marine terrace upon which Mesa also lies, at an approximately similar altitude (see Fig. 1). The northern extension of this terrace towards the rim of the Monti Lepini is dissected by a steep major gully draining the inland area into the Amaseno basin. This steep gully was formed relatively late, as a response to sudden drop in sea level, from −40 to −125 m asl, during the Last Glacial Maximum (LGM) (Sevink *et al.* 2018). The presence of a thick petrocalcic horizon in the top of the Pleistocene terrace probably prevented a farther widening of this gully. Corings in the gully indicate the continuation of >6 m deep layered clayey and peaty fluvio-lacustrine strata, covered with younger colluvial deposits belonging to the now visible Amaseno fan. As discharge from the Amaseno is the only local source of these sandy deposits – because it is eroding older Pleistocene beach, dune and more upstream volcaniclastic deposits – these sands must originate from the Amaseno and thus evidence late Early to Middle Holocene aggradation of an initial alluvial fan into the central part of the graben. A NW–SE section through this gully, demonstrating the change in the composition of its fill, is presented in Fig. 3. Key coring lithostratigraphy is presented in Appendix A. It should be stressed that altitudes indicated are very much affected by post-depositional subsidence of the peats; the sandy deposits were far less affected by subsidence.

Slightly south-east of this infilled valley, a thin Holocene layer of pyritic clays and peats occurs on top of the Pleistocene terrace, locally with calcareous mud and shell layers. The pyritic clays contain the AV tephra, as is observed at location 399, demonstrating that the drainage through this gully remained active till after the deposition of the AV tephra, only to be fully blocked by the build-up of the Amaseno fan later on. An indication for the timing of this blocking is the presence, on top of this thin pyritic clay layer, of an archaeological stratum containing Late to Final Bronze Age artefacts, which in turn is covered by a thin layer of Amaseno sediment, thus indicating that drainage stopped at the transition to the Iron Age (location Casale Mazzocchio; for details, see Sevink *et al.* 2022).

3.2 *South-eastern lake*

The south-eastern lake is formed by the area downstream of La Cotarda. Currently, the central axis of this lake, formed by the Amaseno palaeovalley, is buried under thick alluvial and colluvial deposits. Timing of this build-up shows its gradual post–Bronze Age expansion to the south (Van Joolen 2003). The toe of the fan was still far more north during or just before the EBA (Van Joolen 2003; Van Gorp *et al.* 2020). Infillings of the main Amaseno axis show that a stack of fluvio-lacustrine/floodplain deposits, consisting of dark peaty clay with reworked peat, underlie the most recent alluvium and colluvium. These sediments are underlain by marine lagoonal sediments such as found at location 210. The western tributary valleys show an aggradation subsequently of lagoonal, lacustrine and marsh sediments.

3.2.1 Frasso gully

The downstream part of the Frasso gully contains an aggradational sequence of sediments, namely shell-rich marine lagoonal clays, overlain by peat, gyttja and again peat. AV tephra has been found in the upper peat layer. Palaeoecological analysis of this upper layer shows already existing swamp conditions and a general drying trend, where aquatic and marsh vegetation are succeeded by alder carr (Fig. 4; van Gorp *et al.* 2019; for a full presentation and description, see Doorenbosh 2022). There is no apparent influence of the AV tephra on this succession.

3.2.2 Borgo Hermada gully

The Borgo Hermada gully has been described by Van Gorp & Sevink (2019) and Van Gorp *et al.* (2020). It contains an aggradation sequence like Frasso, with marine lagoonal clays overlain by freshwater and marshy deposits. Throughout this gully, the AV tephra can be found. In the western, upstream part, it is present in the upper 1 m of peats and clayey peats, which are sometimes pyritic. Moving downstream, the tephra is found at lower and sometimes deeper positions, at the transition from marine deposits to overlying peats (BH 362) and, near its outlet into the Amaseno, within calcareous muds. Although tephra altitude dips towards the Amaseno River, the tephra consistently occurs just above the transition from marine to freshwater deposits, ranging from a location at the interface to one 20 cm above (Van Gorp & Sevink 2019). Analysis of different tephra sites directly on top of a stable Pleistocene subsurface led to reconstruction of the EBA lower lake level between −1.3 and −1.5 m asl. Because AV tephra occurs just above the marine–freshwater boundary, this level is interpreted as an EBA relative sea level by Van Gorp *et al.* (2020). Within this gully, the time at which the freshwater environment changed into a (finally carr) peat varied depending on the position within this gully. This is confirmed by two palynological analyses (BH192 and 362) and resembles the pollen data from Frasso 500 (Fig. 4; Doorenbosch 2022). Tephra toxicity analysis of the calcareous mud environment of BH 192 (sample 601) shows a high spike of F in the tephra layer, as is the case at Mezzaluna. This spike is less prominent in the BH 362 core, indicating the indeed higher mobility and thus potential toxicity of F in those environments (Sevink *et al.* 2021). At some locations in the lower Borgo Hermada gully, a second, very thin tephra layer has been encountered a few tens of centimetres above the AV tephra. This layer has been identified as the Monte Somma–Vesuvian AP2 tephra, while the lower, much thicker and widely traceable tephra layer clearly has the Avellino eruption as its origin (sample 198-L; Sevink *et al.* 2020).

3.2.3 Macchia di Piano

The near-coastal lagoon of Macchia di Piano is situated along the most recent Holocene beach ridge. It again shows the transition of marine, lagoonal clays, in this case with many broken shells, into overlying freshwater calcareous muds, which in turn are overlain by peats. Here these peats are highly oxidized or removed and overlain by colluvial clay. Within the thick calcareous mud layer, the Avellino tephra is found, which again dips towards the Amaseno River axis, similar to the situation in the Borgo Hermada gully. Malacological analysis of core 600 (see Fig. 1) confirms the transition from a marine environment with moving water via a brackish lagoonal environment with e.g. *Cerastoderma glaucum* into tranquil conditions of the tephra-bearing calcareous muds (Appendix B).

3.3 Fondi basin

The Fondi basin is divided in an inland part and a near-coastal basin. In the inland part, incisions in the Pleistocene marine terraces became filled in with Holocene deposits with relative sea level rise. The central part currently forms Lake Fondi, while the most upstream parts of these gullies now form infilled depressions. The local aspects of these locations are summarized below. Regionally, palaeoecological evidence from three locations (coastal Femmina Morta 197 and Tumolillo 1005, and inland Fondi 122) indicates a low human impact. A recovery from cool and dry conditions since the 4.2 ka event is suggested by the lowest part of the pollen diagram from Tumollillo (Doorenbosch 2022).

3.3.1 Fondi coastal area: Femmina Morta and Tumolillo

In the coastal Fondi area, a peat marsh existed. The locations Femmina Morta 197 and Tumolillo 1005 (TUM2 in Doorenbosch 2022) display >1 m of peats underlain by marine clays, with sandy incursions. Within this peat, two tephra layers have been encountered, approximately 20 cm apart. At Femmina Morta, where these two tephra layers were first discovered, dating verified they are both EBA in age (Doorenbosch & Field 2019; Doorenbosch 2022). Subsequent dating analysis and geochemical characterisation of both locations confirmed the upper tephra to be the Avellino tephra and the lower to be related to the Astroni 6 eruption, which is of Phlegrean origin. The latter falls into the period 3978-4297 calBP (Smith *et al.* 2011), which is confirmed by dates obtained on samples taken above and below the Lower Tumolillo tephra (4007-4149 calBP; Sevink *et al.* 2020). Palaeoecological results show the existence of a shallow lake with an adjacent reed swamp during both tephra falls. Also here, no significant impact of tephra on human presence is found. At Tumolillo, indications for groundwater fluctuations are present and a succession into alder carr initiated after the AV tephra was deposited.

3.3.2 Inland Fondi: locations 121 and 122

At inland Fondi, the edge of the colluvial fan north of Lake Fondi has been extensively cored. A sequence of

Table 2. Time-theme table with major characteristics and events for each landscape unit.

Time\Theme	Coastal and landscape development	Vegetation - Climate	Tephrochronology – Toxicity	Anthropogenic influence/ suitability
T4: After AV until major anthropogenic influence	AP Inland: NW area development and expansion of alluvial fan. Central area (limited) peat growth. SE area Amaseno fan expands. AP Southeast: Amaseno expands, terrestrialization continues, thick peat growth in BH Fondi: Rather stable. Indications of terrestrialization. Inland colluvial fan expansion. Western coastal: Beach ridge development, Caprolace still saltwater environment.	AP Inland: Transition from lake to peat marsh and Alder carr. AP Southeast: Transition from lake to peat marsh and alder carr.	Toxicity: F is present in its immobilized form in Ca-rich deposits. May have (temporarily) reached toxic levels in shallow anoxic environments.	AP Inland: Tratturo Caniò site shows EBA-RBA and via Early Iron Age into Republican chronology. Adjacent Maina III shows potentially similar chronology. La Cotarda: FBA site Borgo Hermada: MBA Site Caprolace: Salt production, activity since MBA
T3: During and directly after AV	AP Inland: Maximum lake extent, AV tephra deposited in different lake-marsh settings. Amaseno fan pushes lake outlet to south near La Cotarda. Lake level stabilizes and eventually falls. AP Southeast: AV tephra deposited in a diachronically terrestrializing lake/marsh (Frasso, Borgo Hermada). Fondi Coastal: Stable wetland-marsh conditions. Inland Fondi: Peat marsh.	Regional: Ongoing decline of evergreen pollen (drought stress). AP inland: Wet conditions, Chara.	Chronology: Borgo Hermada (AP2, AV), all others (AV) Toxicity: Ricci, Mesa, Frasso, Mezzaluna, Borgo Hermada, Femmina Morta.	Inland AP: Tratturo Caniò shows EBA activity some time after AV. Ricci around or just after AV. Tratturo Caniò, Maina III, Ricci? La Cotarda?
T2: Mid- Holocene until AV	AP Inland: Amaseno blocks main drainage axis of inland basin, submergence of marsh area, existence of Ca-rich (east) and Ca-poor (west) lakes. AP Southeast: Beach ridge development, Amaseno aggradation. Transition from brackish marine to freshwater lake-marsh in tributary gullies. Fondi: Transition from marine to freshwater swamp in coastal lagoon following beach ridge development. Inland Fondi: Transition of freshwater lake into peat marsh.	Regional: Optimum of wet-warm conditions is reached. AP inland: Submergence of lake/marsh. AP southeast: Ongoing terrestrialization. Fondi: Groundwater-driven marshland. Local groundwater fluctuation.	Fondi coastal: Deposition of Lower tephra, Astroni 6 (4000- 4200 ka BP).	Copper Age findings at La Sassa Cave.
T1: Mid Pleistocene-Mid Holocene	AP inland: LGM partial dissection of Pleistocene terrace Holocene infilling as Amaseno starts aggrading and blocking AP inland basin. AP Southeast: Pleistocene major Amaseno valley in which Holocene marine-brackish lagoon forms Fondi: Dissection of Pleistocene terraces, subsequent Holocene aggradation. Coastal marshes still marine, inland lacustrine.		AP Inland: Mid-Pleistocene lithoid tuff: Albano 5-7 (30-36 ka BP)	AP Inland: Flints at Pleistocene surface
Time/Theme	**Coastal and landscape development**	**Vegetation - Climate**	**Tephrochronology – Toxicity**	**Anthropogenic influence/ suitability**

lacustrine clays is overlain by calcareous mud and peat. However, the Avellino ash has not been encountered. In the smaller infilled gully heads east of Lake Fondi, calcareous muds and peats overlie lagoonal deposits or directly overlie deposits forming part of the Pleistocene marine terrace. Here, the upper 1 m of peat contains the AV tephra, geochemically characterized as such from pumice found at coring location 122, while concordant radiocarbon dates from above and below the ash have been obtained (Sevink *et al.* 2021). Palaeoecological core Fondi 122 shows only a mild hint of succession into alder carr after the AV deposition (Doorenbosch 2022).

3.4 Western coastal lagoon

The coastal lagoons west of the large, NW–SE-oriented Pleistocene marine terraces have been investigated by Sevink *et al.* (1982, 1984), but these studies did not provide detailed information on their palaeogeography. Van Joolen (2003) studied a core from near Lago di Fogliano, aiming to reconstruct the vegetational history of this lake. Though Van Joolen (2003, 160-71) found a gradual decrease in aquatic species, it is not clear whether this is linked to the build-up of a coastal beach ridge and lagoon system and the closure of this beach ridge, as was the case in the south-eastern lake area. Moreover, this transition is described as gradual and taking place in the period between "some 3400 years BP (1940-1455 cal BC) and about 2400 years BP (761-209 cal BC)".

More precise information comes from the more recent study of the Middle Bronze Age (MBA) salt production site at the slightly more southern Lake Caprolace. This study was conducted within the scope of the Avellino Event project and published by Alessandri *et al.* (2019), who concluded that around 1500 calBCE the lagoon at Caprolace still was in open connection with the sea and thus was saline and that its water level probably rose to a higher level later. The authors based their conclusion on diatom analyses and radiocarbon dating of a peat section from a former small salt marsh at this site. These observations imply that by that time in this western coastal area, there is still no well-developed coastal dune system of the kind present today.

4. Discussion: Time–theme development of all landscape units

The discussion below amalgamates all findings of the various themes along the time axis (Table 2), based on the results presented above.

4.1 Middle Pleistocene to Middle Holocene evolution

In the Middle Würmian, the stable, slightly undulating Pleistocene lagoonal flat at the north-western side of the central Agro Pontino was not yet seriously fluvially dissected and was partly covered by a lithoid tuff, as observed near Ricci (Sevink *et al.* 2018). As a response to the low relative sea level of *c.* −120 m during the LGM (20-25 ka BP; Lambeck *et al.* 2014), Pleistocene marine terraces and beach ridges, including the Late Eemian–Early Würmian deposits forming part of the Borgo Ermada level, became fluvially dissected. In the Agro Pontino, the main discharge axes were formed by the eastern Amaseno palaeovalley and a major valley fed by the northern, volcanic Alban hills and the limestone mountains discharging into the central Agro Pontino.

The subsequent Late Pleistocene and Holocene relative sea level rise caused infilling of the major valleys, leading to a fluvio-lacustrine environment in the inland lake and a lagoonal environment, transitioning into a fluvio-lacustrine environment in the south-eastern Agro Pontino (Sevink *et al.* 1984; Van Joolen 2003). The Holocene marine ingression did thus not reach the inland Agro Pontino, but its indirect effects did. The gradient of the Amaseno River, upon leaving the Monti Lepini, was determined by the marine base level, the rapid rise of which caused aggradation near its mountain outlet, in the form of a deltaic fan. This even led to aggradation into the inland Agro Pontino, as observed at La Cotarda. This aggradation thus limited the discharge from the inland Agro Pontino and induced the development of an inland lake. Further downstream, the decreasing relative sea level rise and its associated beach ridge formation caused marine influence to cease and caused the Holocene Amaseno valley to become filled in with fluvio-lacustrine materials. During this build-up, tributary valleys, such as those of Frasso and Borgo Hermada, also became blocked and subsequently transformed from brackish marine into shallow freshwater lakes (Fig. 5; van Gorp *et al.* 2020), with reed swamps at their edges. A similar transition can be observed in the coastal parts of the Fondi basin. In the more inland Fondi basin, lacustrine conditions were already occurring somewhat earlier.

4.2 Middle Holocene (4.2 ka BP) until Avellino eruption

It is particularly to enable study of the period from the Middle Holocene (4.2 ka BP) to the Avellino eruption that the peat cores were taken. They include and cover the period around the AV tephra, with the aim to register any EBA human influence and to understand the influence of the tephra on the local and regional environment. A major observation is a lack of palaeoenvironmental evidence for intensive human occupation of the area before, during and directly after the AV eruption (Doorenbosch & Field 2018; Doorenbosch 2022). Regional pollen in the cores of Doorenbosch 2022 show a rather stable landscape, with temperate forest on higher grounds, changing into evergreen forest and Mediterranean forest and shrublands on lower grounds. Few indications for recovery from the cold

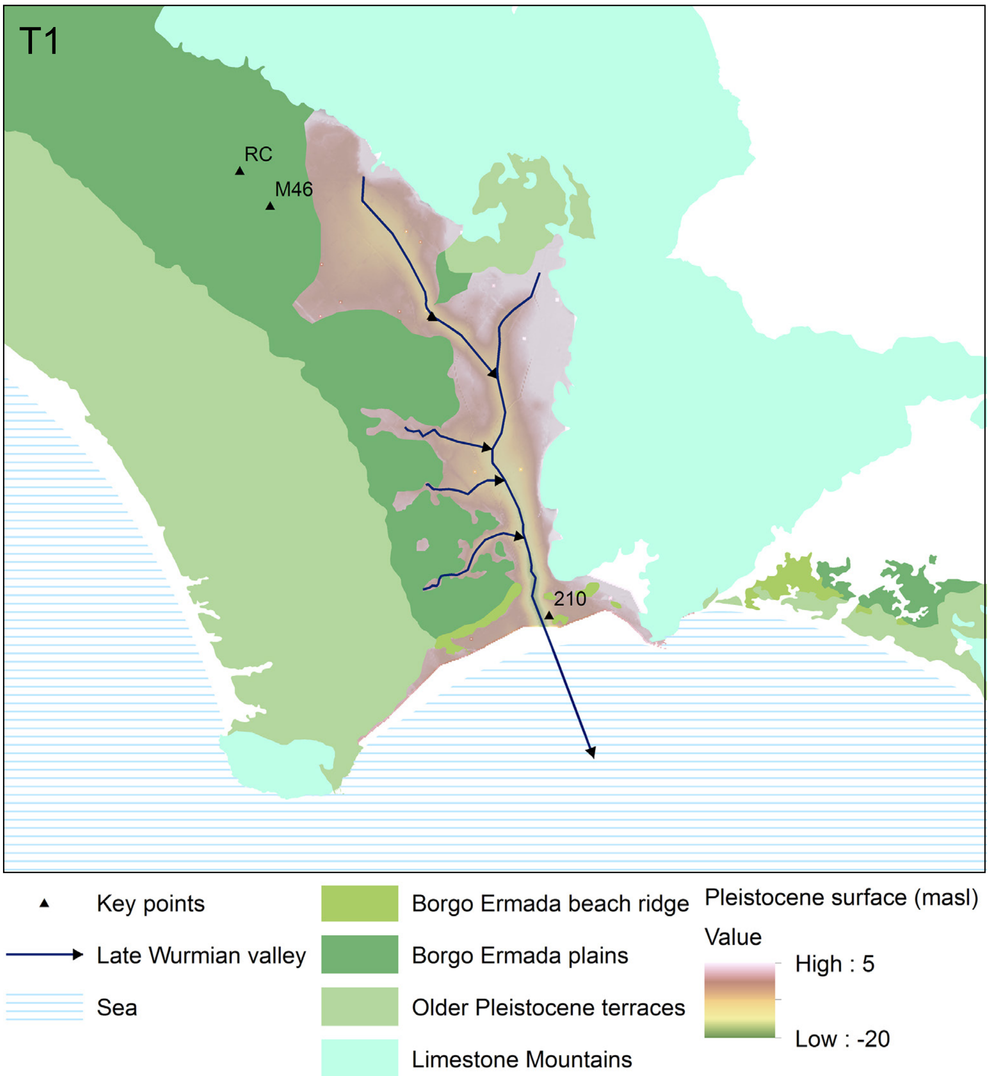

Fig. 5a. Palaeogeography of the Agro Pontino–Fondi area for time period 1 (see Table 2).

and dry conditions of the 4.2 ka event exist. Local pollen and macro-fossil assemblages all reflect moist and wet site conditions, which are responsible for the peat growth. Temporal variations in these assemblages differ between the inland Agro Pontino, the south-eastern Agro Pontino and the Fondi basin, indicating that they reflect local or subregional variations in the conditions within each of the zones discussed below.

4.2.1 Inland lake

Before 4 ka BP, the rising level of the Amaseno River led to a build-up of alluvial deposits in the eastern part of the Agro Pontino. The presence of a Pleistocene ridge south of the major drainage axis coming from the central Agro Pontino into the Amaseno valley caused the outlet of this drainage axis into the Amaseno valley to serve as the base level for the central part of the Agro Pontino (Van Gorp & Sevink 2019), which eventually rose to around 1 m asl. A rather confined palaeovalley near La Cotarda, filled with >6 m of Holocene clay and peaty clay and, more proximal to the Amaseno valley, with intercalated sandy, clayey and peaty layers, testifies to the infilling of the central Agro Pontino valley as a response to Amaseno alluvial build-up (Fig. 3). Other than in the south-western Agro Pontino, marine shells are absent in the upper few metres, and the entire infill can be seen as a fluvio-lacustrine deposit with a central clayey valley fill and distal clayey and peaty deposits. In the upper metre of peats adjacent to this infill, the Avellino tephra is present within pyritic clays, peat or gyttja.

Overall, an image arises of a large area with marshy conditions, which experiences net aggradation/accretion of clayey and peaty materials. Then, the inland lake area further submerges, driven by blockage of the main valley axis by Amaseno fan build-up. This leads to shallow lacustrine and marsh conditions with a Ca-rich

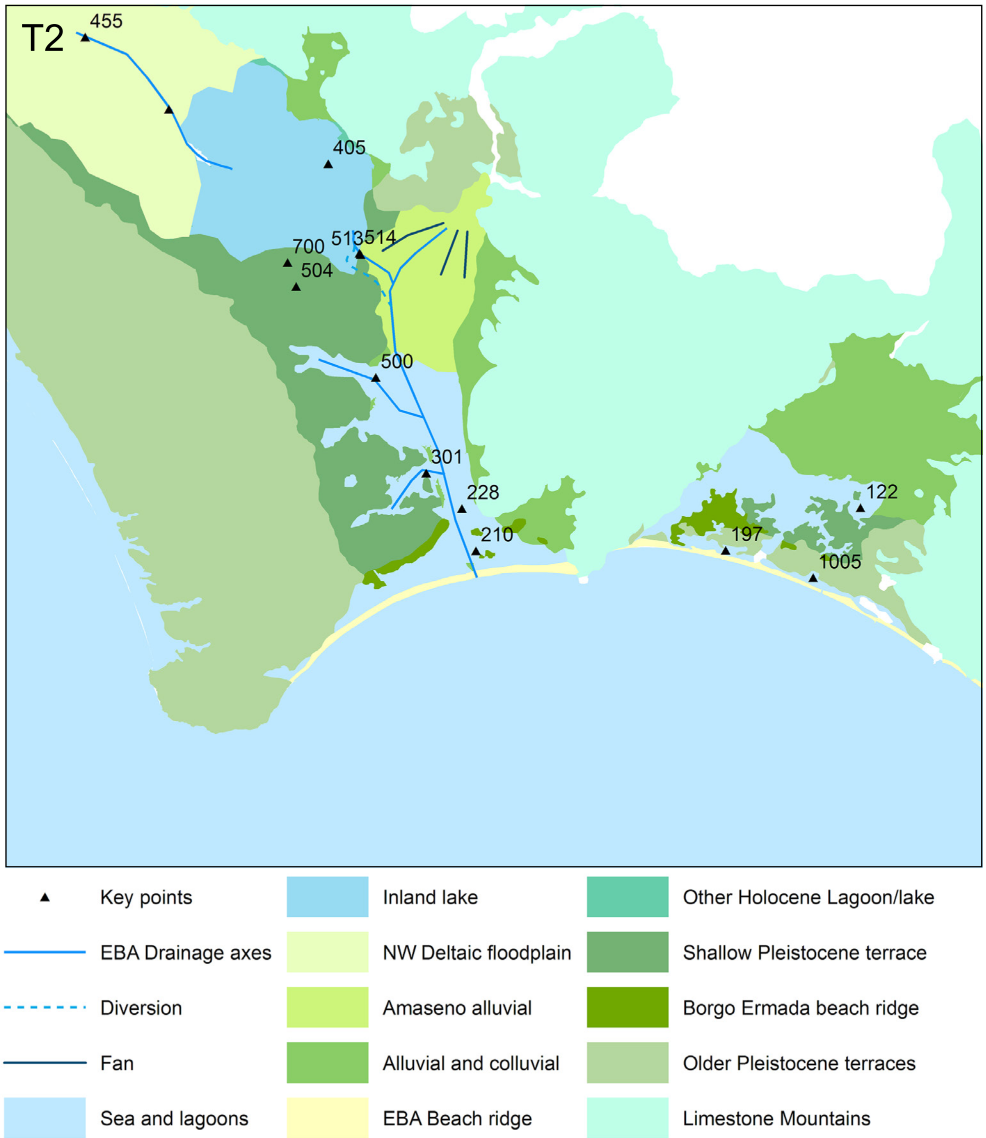

Fig. 5b. Palaeogeography of the Agro Pontino–Fondi area for time period 2 (see Table 2).

north-eastern part (Mezzaluna) and an anoxic environment at the south-western lake edge (Mesa, La Cotarda). The first indications of rectangular ditches near Mesa and other locations on the south-western lake edge stem from this pre-AV time and may reflect early attempts at drainage of a submerging environment (Tol *et al.* 2020). These attempts ultimately were in vain, since the water table continued to rise because of the further aggradation of the Amaseno River. This rising water table may also have led to the disappearance of alder carr at upstream Ricci (Bakels *et al.* 2015), where backwater conditions may have occurred under this wetter regime. This explanation is an alternative for that proposed by Bakels *et al.* (2015), who assumed that human intervention was the cause. At the same time, the more upstream fluvio-deltaic landscape continued to serve as a suitable environment for settlement, illustrated by the pre-AV archaeological finds at the lake edge environment at Campo Inferiore (Sevink *et al.* 2013; Bakels *et al.* 2015).

4.2.2 South-eastern lake

At the beginning of the Middle Holocene, this area still was a brackish lagoon with adjacent wetland. In this lagoon, the major Amaseno axis deposited its sediment. In the most south-eastern tributary gullies, shores existed where wave action was important, resulting in coarse sandy deposits. The deepest and most downstream parts of these gullies display a transition to a shallow freshwater environment. At its edges and in its more upstream parts, a narrow rim with marshy conditions already existed. Likewise, the more upstream Frasso infilling already was a freshwater swamp before the deposition of the AV tephra (Fig. 4; Doorenbosch 2022).

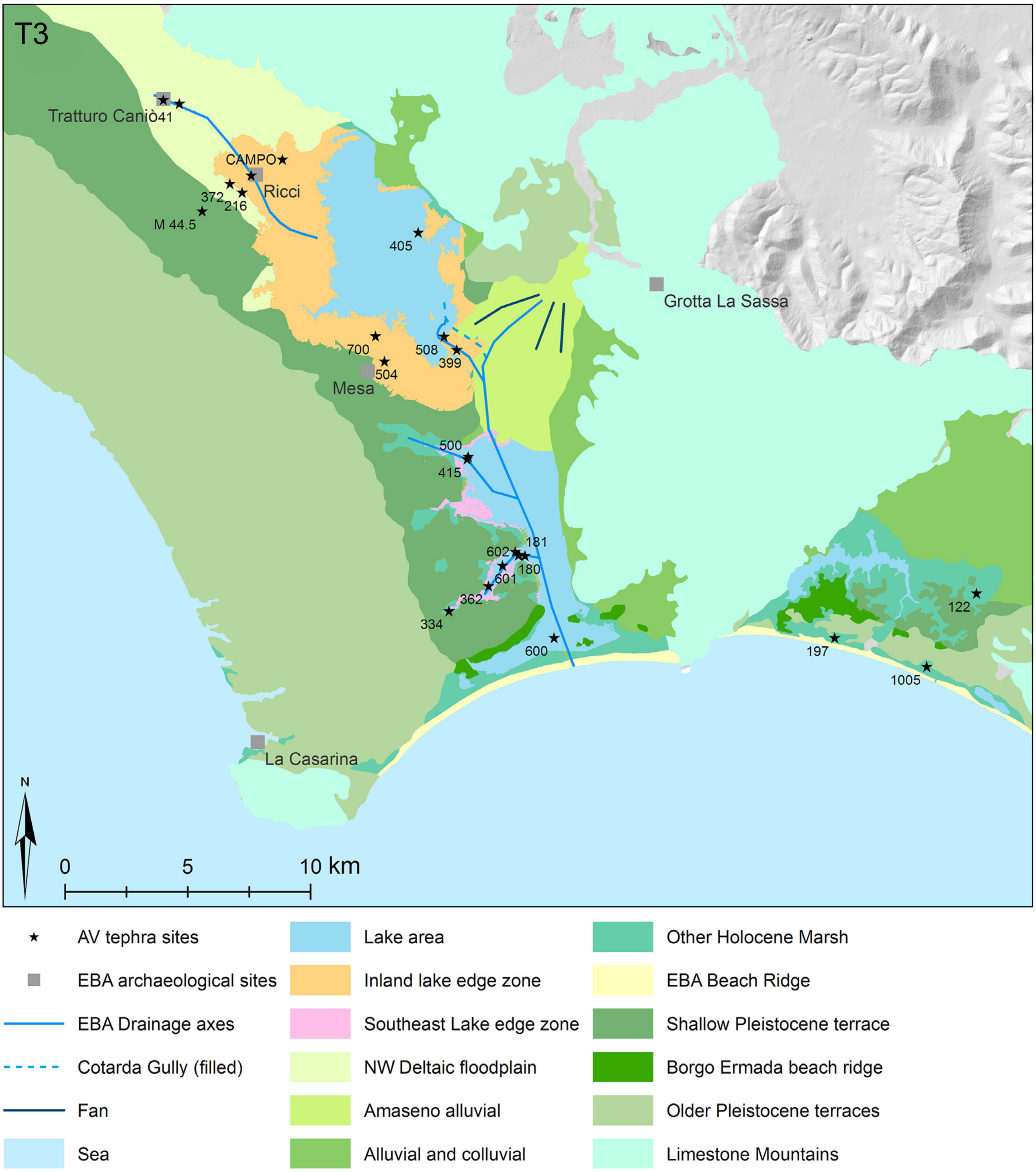

Fig. 5c. Palaeogeography of the Agro Pontino–Fondi area for time period 3 (see Table 2).

4.2.3 Fondi basin and western coastal Agro Pontino zone

In the mid-Holocene Fondi basin, prior to tephra deposition, the sequences show a similar transition from marine to freshwater or marsh conditions. The marine deposits of inland locations contain more lagoonal clays, while the coastal lagoon shows a higher contribution of marine sands below the tephra-bearing peats. Transition to a coastal marsh occurs at the beginning of the Middle Holocene, at least sometime before deposition of the lower Astroni tephra and thus at or just after the 4.2 ka climatic event. These coastal marshes consisted of freshwater reed swamps with adjacent alder carr throughout the EBA timespan of the profiles. The western, Femmina Morta area exhibits more stable local groundwater regimes than the more variable eastern, Tumolillo site. This reflects a different freshwater supply regime.

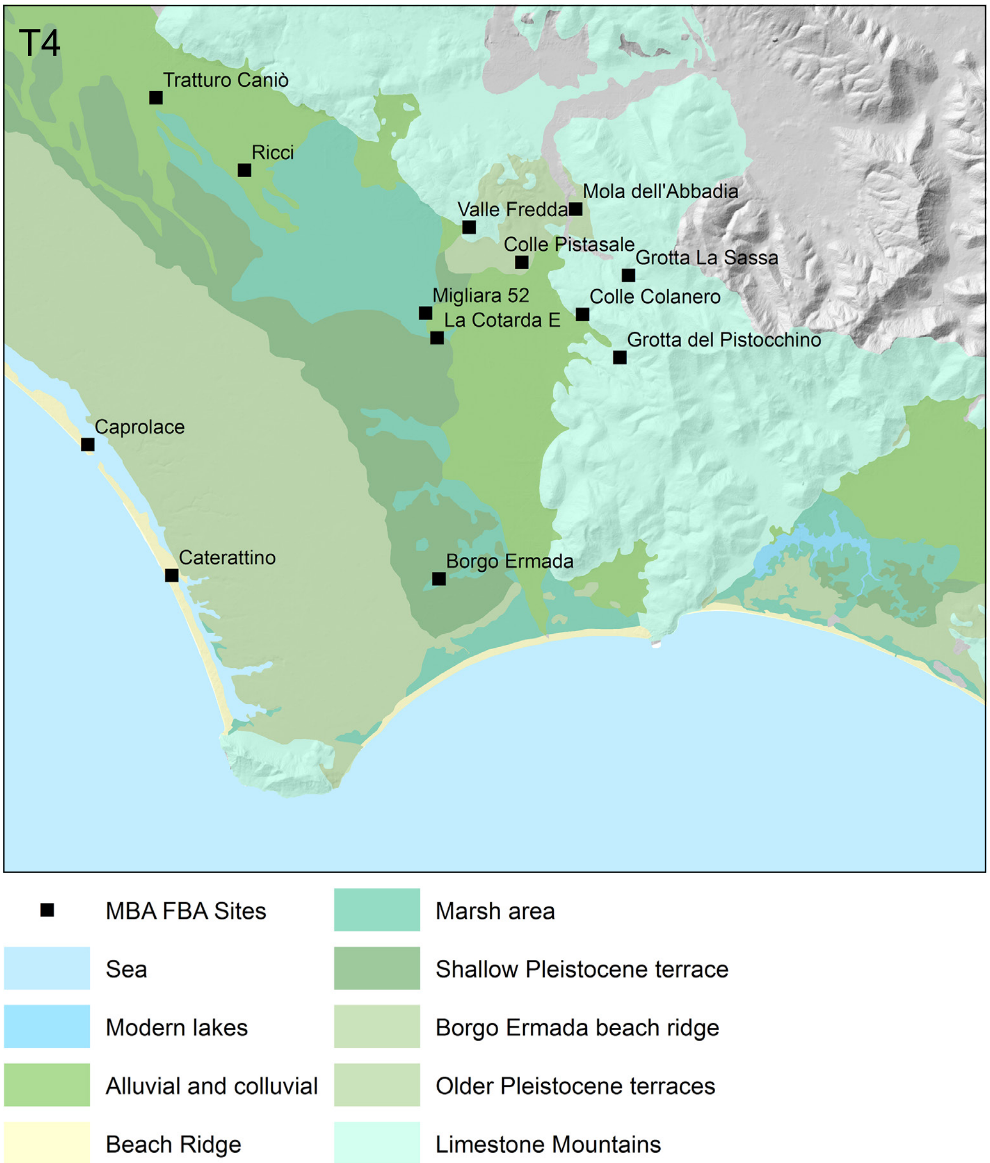

Fig. 5d. Palaeogeography of the Agro Pontino–Fondi area for time period 4 (see Table 2).

4.3 *At and immediately after AV tephra deposition*

It is within these generally wetter conditions that the Avellino volcanic eruption deposited its distal tephra over the entire Agro Pontino and Fondi basin. Its downfall certainly had some local effect on vegetation (Sevink *et al.* 2021; Doorenbosch 2022), but no regional effects have been observed in either the palaeoecological records, the natural vegetation, or the vegetation indicative of human activity (Doorenbosch 2022). However, the levels of toxic substances from the tephra, released into the marshes and topsoils, must have been above toxic thresholds for some time, as Sevink *et al.* (2021) demonstrate for F. These levels may have had a negative effect on the suitability for human land use of an already hostile environment, and more particularly on marshes and shallow lakes, thereby contributing to the low population density in the lower, poorly drained plains.

4.3.1 Agro Pontino inland lake at and immediately after AV tephra deposition

Regionally, rather stable forest conditions existed and remained after AV tephra deposition (Doorenbosch 2022). The AV tephra was deposited and preserved in peat marshes, Ca-rich lakes and streams, as well as anoxic, shallow waters while water levels were still slowly rising. The fresh volcanic deposits introduced toxic material, such as F, into the system; however no impact is seen in the form of changes in vegetation composition at the sites of Ricci, Mezzaluna and Migliara 44.5. The impact on vegetation growth is variable (Sevink *et al.* 2021). Ca-rich Mezzaluna, and also Ricci, do not show any response, while accumulation of organic matter in the sulphuric marsh at Migliara 44.5 stagnated. For an in-depth elaboration of these potential tephra impacts, we refer the reader to Sevink *et al.* (2021). At the south-eastern lake edge locations of Mesa and La Cotarda, sediment infill under anoxic conditions continued for some time after the AV tephra deposition. At Mesa, peaty and anoxic clay fills the previously mentioned elongated, shallow depressions, while at La Cotarda, the ridge of Pleistocene Borgo Ermada origin that separates the inland lake from the south-western lake shows limited accumulation of anoxic clays. The ongoing advance of the Amaseno fan did not reach this part of the shallow ridge, either at this time or in subsequent times.

4.3.2 Agro Pontino south-eastern lake at and immediately after the AV tephra deposition

Influenced by the aggrading main Amaseno drainage axis, the south-eastern lake edges, including the Frasso, Borgo Hermada and Macchia di Piano incisions, continued to show a gradient from marshy edges into brackish to freshwater, Ca-rich, shallow lakes. Because sea level rise slowed down, the marshy lake margins stabilized within or shortly after this period, while calcareous muds continued to form within the lake's slightly deeper parts.

4.3.3 Fondi basin at and immediately after AV tephra deposition

Freshwater reed swamps with adjacent alder carr continuously occurred during this period, at both in Inland and Coastal Fondi. Pollen data demonstrates that the impact of the AV tephra on this environment is largely absent for Femmina Morta, Tumolillo and Inland Fondi, albeit that local vegetation was briefly disturbed at Femmina Morta (Doorenbosch & Field 2018). Post-tephra peat accumulation appears to have been temporarily disturbed at Femmina Morta and Inland Fondi (Sevink *et al.* 2021).

4.4 Late Holocene until major anthropogenic influence

In the pollen records, a regional cooling trend can be observed between 1900 and 1500 BCE. Sea level rise had become minimal, and lagoons transformed into coastal freshwater lakes with an ongoing hydrosere succession showing local differences in expression and timing.

4.4.1 Agro Pontino inland area

Sometime after AV tephra deposition, aggradation stopped. At the site of La Cotarda Southeast, the Amaseno fan continued to advance south, leading to southward migration of the lake outlet as well, creating a spill-over area between the inland lake and the south-eastern lake. The very shallow stream deposits in the southern part of the La Cotarda Southeast site evidence this event. This spill-over caused stabilization of the lake level and subsequent drying out of some of the higher lake edge areas. It is not entirely clear when exactly this drying out started, but the location of La Cotarda Southeast (399) was dry ground at least during the Late-Final Bronze Age and has not been covered by significant younger colluvial fan deposits. In the north-western fluvio-deltaic area, expansion of alluvial deposits on top of AV tephra-bearing peaty and clayey material occurred during or shortly after the EBA, by materials originating from the Alban hills near Campo Inferiore (Attema & Delvigne 2000) and Tratturo Caniò (Feiken *et al.* 2012).

4.4.2 Agro Pontino south-eastern area

The main drainage axis of the Amaseno River continued to build up sediment, which became colluvial in nature due to intensified land use in the upstream hills. In the deepest parts of the Ca-rich lakes, this led to further active, Ca-rich lakes, which transformed into peat marshes and, finally, alder carr, showing a hydrosere succession due to groundwater level stabilisation (van Gorp *et al.* 2019; Doorenbosch 2022).

4.4.3 Fondi

Inland, colluvial fans built up over lacustrine and lagoonal sediments. Locally, peat marshes continued to exist, which later dried out. Peat marshes in the coastal basins showed relatively little disturbance.

4.4.4 Western coastal Agro Pontino zone

The beach ridge of the western coastal Agro Pontino zone developed sometime after the EBA. Research carried out within the scope of the Avellino Event project at Caprolace has revealed that this beach ridge was closed after the AV eruption. Caprolace island developed several stages of habitation, ranging in time from the MBA to Roman Republican times, and included an MBA salt production site (Alessandri *et al.* 2019). Pollen and diatom analysis support the presence of salt water during the MBA and indicate an open connection with the sea. No evidence of earlier human activity or of EBA tephra layers has been found. This is in line with the then-still-active, open marine environment in the western coastal area.

5. Conclusion and wider implications

The set of diverse findings from different landscape units not only illustrates the wealth of mostly Holocene information that these sediment archives hold, but also its diversity and significance for different palaeogeographical themes. The AV tephra forms a high-resolution chronological marker that allows the reconstruction of environmental conditions during the EBA for all those themes. We believe that our multidisciplinary approach is fundamental to understand such a diverse landscape and to appreciate its complexity, something that is enhanced by the regional nature of all of our data, with many cores telling different, sometimes contradictory stories for different landscape units within the same basin. In tandem with the vegetation reconstruction of the Agro Pontino and Fondi plain before and after the Bronze Age eruption of Somma–Vesuvius by Doorenbosch and Field (Doorenbosch & Field 2018; Doorenbosch 2022), our reconstructions have greatly increased our insight into the living conditions for human presence in this region.

Palaeogeographically, the areas around the EBA lakes can be divided in a north-western delta–floodplain–levee landscape with an adjacent, low-gradient lake edge formed by a Pleistocene ridge. Under the influence of alluvial fan build-up of the Amaseno River, this north-western lake had a southward-migrating spillover into an undulating dissected plain to the south-east. Although the different landscape units certainly contained potential for human habitation, as habitation from the MBA and onwards demonstrates, indicators of EBA human activity are sparse at most, and are largely limited to the north-western deltaic region, where fluvial levees seemed to be the most viable locations for habitation. However, we note that data are still of low density and that investigation of lake edge areas, such as that near Mesa, is ongoing, and that more such indicators may be found in future.

The unique regionally preserved stack of Middle to Late Holocene sediments, including multiple macroscopically visible tephra layers within a depositional environment, allowed for a detailed regional palaeogeographical and vegetational reconstruction, aided by excellent relative to absolute chronology from these tephra layers. The promising results for the continuous sedimentary records covering the pre- and post-Avellino eruption records advocate a more detailed investigation of these records, as they may hold valuable climatic and tephrochronological information, such as crypto-tephras. Insights in the landscape configuration revealed the suitability for human communities attempting to live in this region. Aside from potentially toxic levels of F in Ca-low environments, our research did not reveal major effects of the Avellino eruption on living conditions and human presence.

6. Acknowledgements

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APPENDIX A. COTARDA CORINGS

Coring nr	Layer nr	Top	Bottom	Lithostratigraphy	Field Remarks
357	1	0	55	Terracina formation, peat, oxidized peat	oxidized peat with shells and iron mottling
357	2	55	60	Terracina formation, peat, oxidized peat	less oxidized peat with brown spots, shells and iron mottling
357	3	60	70	Terracina formation, peat	woody peat with yellow mottling, shells and iron mottling
357	4	70	120	Terracina formation, peat	woody peat with yellow spots
357	5	120	122	Terracina formation, peat	shell bank in woody peat
357	6	122	130	Terracina formation, peat	woody peat
357	7	130	133	Terracina formation, Lacustrine clay	clay layer with small sand band underneath
357	8	133	150	Terracina formation, peat	woody peat with shells
357	9	150	170	Terracina formation, Lacustrine clay	peatey clay with some shells and wood
357	10	170	220	Terracina formation, Lacustrine clay	humic clay with shells
357	11	220	500	Terracina formation, Lacustrine clay	dark grey clay
342	1	0	50	Brought up materials	topsoil, shells, reworked
342	2	50	135	Terracina formation, Calcareous muds (Gyttja)	peat, gyttja, shell fragments, black/brown/ yellowish, plant remains. Shell layer at 115cm
342	3	135	200	Terracina formation, Calcareous muds (Gyttja)	See above + more shell layers
342	4	200	580	Terracina formation, Lacustrine clay	Unripened clay, layered
513	1	0	100	Sezze formation, Colluvial-alluvial deposits	Red brown clay
513	2	100	200	Sezze formation, Colluvial-alluvial deposits	Red brown sandy clay
513	3	200	300	Terracina formation, Fluvial deposits, Fluvial channel deposits	Red brown clayey sand
513	4	300	400	Terracina formation, Fluvial deposits, Fluvial channel deposits	Greyish clayey sand, micas (from Amaseno)
513	5	400	420	Terracina formation, Fluvial deposits, Fluvial channel deposits	Gravelly sandy layer with peat layers
513	6	420	500	Terracina formation, Fluvial deposits, Fluvial channel deposits	Alternating clayey sand with peat
513	7	500	510	Terracina formation, peat	Wood peat, Quercus fruit capsula+acorn
513	8	510	600	Terracina formation, Fluvial deposits, Fluvial channel deposits	Clay, sandy clay, peat layers
514	1	0	30	Sezze formation, Colluvial-alluvial deposits	Black dark clay
514	2	30	150	Sezze formation, Colluvial-alluvial deposits	Brown colluvial clay
514	3	150	200	Terracina formation, Fluvial deposits, Fluvial channel deposits	Laminated plastic clay with peat layers
514	4	200	230	Terracina formation, Calcareous muds (Gyttja)	Peat, Gyttja, shells
514	5	230	280	Terracina formation, Fluvial deposits, Fluvial channel deposits	Clay, plastic, laminated
514	6	280	300	Terracina formation, Calcareous muds (Gyttja)	Peat, Gyttja
514	7	300	480	Terracina formation, peat	Peat, Monacods, reedsteems
514	8	480	500	Terracina formation, peat	Wood peat with tree leaves

APPENDIX B. ITALIE, AGRO PONTINO. MACCHIA DI PIANO, PORTO BADINO. CORE NR. 600

depth in cm below surface	**207-209**	**209-210**	**210-212**	**212-220**	**220-228**	**228-232**
soil	gyttja	gyttja+volcanic ash	gyttja	gyttja	gyttja	sand+clay
volume in cm³	some	some	some	50	50	50
sand	-	x	-	-	-	xxx
mica / glimmer	-	x	-	-	-	-
small root (recent)	x	x	x	x	x	x
plants						
Chara sp. - oögonium	xx	xx	xx	xxx	xxx	xx
Chara sp. - stemfragment	xxx	xxx	xxx	xxxx	xxxx	xx
Typha sp.	-	-	-	1	-	-
Cladium mariscus	-	-	-	-	1	-
Schoenoplectus cf tabernaemontani	-	-	-	-	-	1
Najas marina	-	-	-	-	-	1
Najas cf flexilis	-	-	-	-	-	1
animals						
Bryozoa - statoblast	x	-	x	x	x	-
Nereis sp. - jaw	-	-	-	-	-	2
Foraminifera	-	-	-	-	1	xxx
Ostracoda	-	-	-	-	x	xxx
Mollusca - freshwater						
Bithynia tentaculata - shell	8	2 cf	3	xx	xx	xx
Bithynia tentaculata - operculum	12	2	2	xx	xx	xx
Bithynia leachii - shell	-	x	-	xx	x	xx
Bithynia leachii - operculum	-	-	-	xx	x	xx
Valvata piscinalis	-	-	-	-	5	xx
Radix ovata	-	-	-	2	-	3
Gyraulus crista	-	-	-	-	4	1
Pisidium sp./Sphaerium sp.	-	-	-	-	1	1
Theodoxus fluviatilis	-	-	-	-	1	5
Mollusca - brackish water						
Cerastoderma glaucum	-	-	-	-	1	xxx
Ecrobia ventrosa	-	-	-	-	-	xx
Mollusca - marine						
Hydrobiidae	-	-	1	-	x	xxx
Rissoa sp.	-	-	-	-	1	x
Cerithium sp.	-	-	-	-	-	x
Macoma/Abra/Angulus/Tellina/etc.	-	-	-	1	x	-
Mytiliidae	-	-	-	-	1	x
Corbula gibba	-	-	-	-	-	x
cf Venerupis	-	-	-	-	-	x
Cerastoderma cf edule	-	-	-	-	-	x
dif. sp.	-	-	-	-	-	xx

analyse: W.J. Kuijper, nov. 2017

x = enkele, xx = tientallen, xxx = honderden, xxxx = duizenden