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Holocene aggradation history of the Murcia alluvial valley: Insights on early Rome paleoenvironmental evolution

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Abstract:	Through the analysis of seven 15 to 30 m deep boreholes drilled in the western sector of the Circus Maximus we reconstruct the aggradational history of one main tributary valley of the Tiber River in Rome, the Murcia Valley (Vallis Murcia) . Consistent with recent acquisitions in the Tiber Valley, we identify a Bronze Age (4500-3000 yr BP) paleogeographic setting characterized by the lowering of the drainage network baselevel. This would have created a dry alluvial plain, suitable for anthropic frequentation. We also find the evidence for the dramatic overflooding occurred during the 6th century and responsible for the rapid rise from 2 to 6 m a.s.l. of the valley floors within the Tiber catchment basin in Rome. We suggest that these paleogeographic features could be related to mythical and ethno-historical accounts of early Rome. Besides providing insights on the paleolandscape and anthropic interventions in the Murcia Valley, these previously unrecognized hydrological dynamics may attest to paleoclimatic fluctuation occurred since 5000 yr BP. Contrary to the dry and cold conditions prevalent during the Bronze through the Iron Age, the exceptional flooding events of the archaic period suggest a shift in climatic trends. However, tectonic and anthropic factors would have also had a combined and cumulative effect, requiring future studies to untangle them.
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Dear Editor,

I would like to submit the paper entitled "Holocene aggradation history of the *Murcia* alluvial valley: insights on early Rome paleoenvironmental evolution", by Fabrizio Marra, Marialetizia Buonfiglio and Laura Motta, for possible publication in Quaternary International.

The record of environmental dynamics and human transformation of the landscape in early Rome is buried under many meters of urban buildup. This record, however, is preserved and accessible through deep coring.

In this study, we reconstruct the aggradational history of one main tributary valley of the Tiber River in heart of the city, the Murcia Valley (*Vallis Murcia)*, through the analysis of seven boreholes 15 to 30 m deep.

This work has been committed to the Istituto Nazionale di Geofisica e Vulcanologia and to the Kelsey Museum of Archaeology, University of Michigan, by the Sovrintendenza Capitolina ai Beni Culturali - Roma Capitale, which had previously sponsored a borehole campaign in the Circus Maximus in the years 2003/2013. The preliminary results of the investigations were published t in Geoarcheology (Carpentieri t al., 2015); however, this paper provided an interpretation of the stratigraphy based on four uncalibrated 14C ages which have biased the reconstruction of the aggradational history. Moreover, a deep, pervasive contamination of the historical and of the Holocene alluvial deposits by the overlaying Roman age anthropic fill due to an inaccurate coring was not recognized, affecting also the historical and archeological interpretation.

For these reasons, we have conducted a new study of the cores providing a careful sedimentological and archaeological re-analysis. Moreover, we have re-calibrated the previous 14C ages and performed a new radiocarbon age on the upper portion of the sedimentary succession, in order to provide solid geochronologic constraints.

Thanks to this novel approach, we have identified a Bronze Age (4500-3000 yr BP) paleogeographic setting characterized by a dry alluvial plain. This plain formed as a result of a significant lowering of the drainage network baselevel and was suitable for human occupation. We have also found evidence for a dramatic overflooding occurred during the 6th century and responsible for the rapid rise from 2 to 6 m a.s.l. of the valley floors within the Tiber catchment basin in Rome. We suggest that these paleogeographic features might be echoed in the mythical and ethno-historical accounts of the origins of Rome.

Besides providing insights on the paleolandscape and anthropic interventions in the *Vallis Murcia*, these previously unrecognized hydrological dynamics attest to paleoclimatic fluctuation occurred since 5000 yr BP. Contrary to the dry and cold conditions prevalent during the Bronze through the Iron Age (4500-2900 BP), the exceptional flooding events of the archaic period (6th century) suggest a shift in climatic trends. However, tectonic and anthropic factors would have also had a combined and cumulative effect, requiring further studies.

We believe that the topic treated and the data presented shed new important light on the complex interaction between human activity and climate fluctuations during the early history of Rome and may be of great interest for a broad, multi-disciplinary audience of scholars, deserving publication in Quaternary International.

While we are providing a list of potential reviewers who are expert on the geology of Rome, alluvial sedimentation and/or landscape archaeology, we gently ask to avoid, for obvious reasons, the authors of the previous paper, as well as the following persons who are competitive scholars in the field of Rome's geology and/or archaeology:

Salvatore Milli, Università La Sapienza Roma, Italy, for profesional disagreement about the interpretation of the post-glacial aggradational processes.

Albert J. Ammerman, Colgate University, USA, for conflict of interest.

Thank you for your attention,

Kind Regards,

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Holocene aggradation history of the *Murcia* alluvial valley: Insights on early Rome paleoenvironmental evolution

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Abstract

Through the analysis of seven 15 to 30 m deep boreholes drilled in the western sector of the *Circus Maximus* we reconstruct the aggradational history of one main tributary valley of the Tiber River in Rome, the Murcia Valley (*Vallis Murcia)*.

Consistent with recent acquisitions in the Tiber Valley, we identify a Bronze Age (4500-3000 yr BP) paleogeographic setting characterized by the lowering of the drainage network baselevel. This would have created a dry alluvial plain, suitable for anthropic frequentation. We also find the evidence for the dramatic overflooding occurred during the 6th century and responsible for the rapid rise from 2 to 6 m a.s.l. of the valley floors within the Tiber catchment basin in Rome. We suggest that these paleogeographic features could be related to mythical and ethno-historical accounts of early Rome.

Besides providing insights on the paleolandscape and anthropic interventions in the Murcia Valley, these previously unrecognized hydrological dynamics may attest to paleoclimatic fluctuation occurred since 5000 yr BP. Contrary to the dry and cold conditions prevalent during the Bronze through the Iron Age, the exceptional flooding events of the archaic period suggest a shift in climatic trends. However, tectonic and anthropic factors would have also had a combined and cumulative effect, requiring future studies to untangle them.

Keywords: Murcia Valley; Alluvial valley aggradation; Rome's paleo-landscape; Holocene sea-level fluctuations; 6th century floodings

1. Introduction

Recent studies provide a detailed reconstruction of the post-glacial aggradational history of the Tiber Valley in Rome (Marra et al., 2018, 2021), highlighting the deposition of a more than 40 m thick package of fine sediments (clay, silt, and subordinated sand) 13000 through 5500 yr/BP. This aggradational phase occurred synchronously in the delta and in the area of the modern city, in response to the fast sea-level rise since the Last Glacial Termination (Belluomini et al., 1968; Bellotti et al., 2007; Marra et al., 2013) that led to a sea-level close to the present one and to the establishment of an alluvial plain at ca. 1 m a.s.l. in Rome (Marra et al., 2021). Starting after 5500 yr/BP until 4500 yr/BP, a re-incision if this early alluvial plain was triggered by a sea-level drop likely linked with regional vertical tectonic movements and/or Glacial Isostatic Adjustment (GIA) (see Marra et al., 2013 for an in depth discussion). This temporary incision was re-filled almost completely during the time span encompassing the Bronze Age through the Iron Age (i.e., 4500 - 2800 yr BP), when the alluvial plain rose again at ca. -1 m a.s.l., by 2800 yr/BP. While a stable landscape seems to have characterized the 8th and 7th centuries BCE, a dramatic paleogeographic change occurred in the Archaic period at the beginning of the 6th century BCE, when sudden and recurrent flooding of the Tiber valley caused an up to 6 m rise of the alluvial plain in less than one century (Marra et al., 2018, 2021). It has been suggested that local tectonics may have concurred to this huge sediment accumulation, due to the activity of a fault line parallel to the Murcia Valley and crossing the Tiber Valley through the Forum Boarium (Figure 1) (Marra et al., 2018, 2021). Repeated, yet less large flooding events occurred throughout the Republican period, causing continued uplift of the alluvial plain from ca. 6 m to 9 m a.s.l., by the 1st century BCE (Bersani and Bencivenga, 2001; Aldrete, 2007; Leonardi et al., 2010, Marra et al., 2018). During this time span, several anthropic interventions raised the ground level to prevent the continuous flooding of the ancient city.

In the present work, we have investigated seven borecores performed in the Murcia Valley (*Vallis Murcia*) by the Sovrintendenza Capitolina ai Beni Culturali - Roma Capitale in the years 2003 - 2013, in order to reconstruct the aggradational history in this tributary valley and to compare it with the sedimentary succession in the Tiber Valley. Previous work (Carpentieri et al., 2015) interpreted these borecores using uncalibrated ^{14}C ages and not recognizing pervasive contamination of the upper portion of the sedimentary succession due to the relapse of anthropic materials during the coring. Here we have re-calibrated previous four ^{14}C ages and carefully re-investigated the cored archaeological materials and the sedimentary deposits. Moreover, we have performed a new ^{14}C age determination on the upper portion of the alluvial deposits along with the study of the ceramics inclusions that constraint the chronology of the deposits, to assess the local response to the main sedimentary phases during the Holocene.
Besides providing new data on the paleoenvironmental and paleoclimatic evolution of this region during the Holocene, this study offers new insights on the early settlement and anthropic activity in this part of the ancient city from the Late Bronze Age (ca. 3000 yr BP) to the Republican period (5th - 1st century BCE).

2. The Murcia Valley

The Murcia Valley is a small, left tributary valley of the Tiber River in Rome (Del Monte et al., 2016) (Fig. 1). It displays a straight SE-NW trend, which reflects the main tectonic direction of the NE-SW extensional regime active on the Tyrrhenian Sea Margin of central Italy during the Pleistocene (Montone et al., 1995, Montone and Mariucci, 2016; Marra, 1999; Frepoli et al., 2010). The valley is characterized by a very limited catchment basin, which appears truncated to the SE by a ridge separating its short SE-NW course from a section of the larger Caffarella Valley aligned along the same direction (Fig. 1b). Such geometric pattern is the result of a wider tectonic control on the hydrographic network of the Tiber River (Ciccacci et al., 1987; Marra, 2001). Indeed, the Tiber Island and a 2 km-long tract of the Tiber River are aligned along the NW continuation of the Murcia Valley, suggesting the presence of a SE-NW fault line in the Tiber Valley

(Marra et al., 2018; Fig. 1c). New evidence for a ~1 m stratigraphic offset affecting the alluvial sediments of the Tiber River along this fault segment has been provided through a dedicated borecore survey in the *Forum Boarium* area (Marra et al., 2021).

3. Historical and archaeological context

The *Vallis Murcia* separated the Palatine Hill, to the north, from the Aventine Hill, to the south (Fig. 1c) and constitutes, according to the ancient authors, the southern boundary of the settlement founded by *Romulus*. At its confluence with the Tiber Valley it joins the *Velabrum* (Ammerman and Filippi, 2004; Bellotti, 2020), the terminal tract of the stream valley separating the Palatine Hill from the Capitoline Hill with a NE direction (Fig. 1c). In this area the ancient sources locate the earliest harbor of ancient Rome (Brock et al., 2021). Due to this privileged geographical position, the Murcia Valley most probably was included in the regional exchange routes since the Bronze Age, and its prehistoric frequentation is suggested by mythical accounts. In addition, several Archaic cults and ritual features are supposed to be located in the valley (Humprey 1986). However, so far, no archaeological evidence has been found to support an intensive and systematic use of the area for this period.

According to the legendary sources, the founder of Rome, *Romolus*, built here the first circus to hold the equestrian games, the *Consualia*, while the last kings, established the Roman Games and the arrangement of seats on wooden stands (Buonfiglio, 2018, and references therein). The historical sources attribute the construction of the first large masonry building of the *Circus Maximus* to *Julius Caesar* in the context of a major urban and monumentalizing intervention at the end of the Republican period (1st century BCE) (Buonfiglio, 2018, and references therein).

A discussion of the geomorphologic features and the anthropic modifications of the Murcia Valley since the Republican period can be found in Luberti et al. (2018). Here we investigate the Holocene aggradational history and the paleogeographic evolution in the Broze Age through the Republican period.

4. Materials and methods

We have investigated the chronostrarigraphic, sedimentological and archaeological features of seven borecores, 15 to 30 m deep, located in the Murcia Valley. The borecores were performed in the archaeological area of *Circus Maximus* during different drilling surveys promoted by Sovrintendenza Capitolina ai Beni Culturali - Roma Capitale in the years 2003 - 2013.

The cores were stored at the Laboratory of Geophysics of Roma Tre University and re-analyzed by the authors in 2019-2020.

To establish an archaeological chronology in the investigated stratigraphic intervals all diagnostic ceramic fragments and 9 sediment samples for sieving were collected. In addition, five organic samples (wood, charcoal, peat) have been selected for ^{14}C absolute dating.

Wet sieving of the samples was carried out in the lab with a 0.5 mesh. Alluvial deposits very rich in clay were pretreated with sodium bicarbonate and then floated. All the ceramic fragments and other anthropic inclusions visible in the sediments were collected and recorded. Ceramic dating was preferred for the anthropic fills since they usually provided abundant shards that offer a tighter chronological resolution than radiocarbon ages.

Four AMS radiocarbon analyses were performed at the Centro di Datazione e Diagnostica (CEDAD), Department of Matematics and Physics, Università del Salento, Brindisi, Italy, and the uncalibrated results were reported in (Carpentieri et al., 2015). The ages, re-calibrated according to IntCal20 (Reimer et al., 2020), are reported in this work, along with an original fifth AMS radiocarbon analysis performed at Beta Analytic Laboratories, Miami, Florida.

Calibrated dates for the five samples are listed in Table 1; full analytical data and calibration procedure are provided in Supplementary Material #1 and #2.

We have integrated the obtained chronostratigraphic dataset with three previously investigated boreholes (Marra et al. 2018; 2021), located in the Forum Boarium, at the confluence between the Murcia Valley and the Tiber valley (Figure 1c).

5. Results

5.1 Chronostratigraphic analysis

The poor quality of the drilling and the bad state of preservation of the cored sediments in the store area posed some problems for the interpretation of the anthropic material (e.g., ceramic, brick, marble, etc.) within the alluvial deposits. Indeed, the fall back in the hole of small fragments of clastic material and ceramics from the top anthropic layers is a common occurrence. Since the fragmented material accumulates at the base of the hole and it is dragged down during each maneuver, it can be a pervasive issue on the external surface of the cores, even when drilling is carried out by lowering a casing along the hole. A buffer (commonly a wet rag) is usually used at the top of the core barrel to prevent the fall back. In particular, the fall of material occurs at each stop when the core is recovered, and is more abundant following the cleaning operations of the hole between one maneuver and the next. Finally, the incoherent features of the cored sediment might cause its loss during recovery, resulting in regain maneuvers that will remix it and contaminate it with the allochthonous material retained within the coring barrel.

The awareness of these problems has allowed us to identify the portions of cores affected by contamination, as this has been recognized at the top and base of each individual core, and within sediment portions destroyed and mixed with clearly allochthonous clastic material. Furthermore, small fragments adhering to the external surface of the cores were excluded from the analysis, and only the internal, undisturbed portion of the sediment was analyzed and sampled for sieving.

5.2 Anthropic horizons

An up to 13 m-thick cover of anthropic materials, resulting from two-thousands year of history and development of a special area devoted to the celebration of equestrian games, overlay the natural ground in the investigated portion of the Murcia Valley.

Frequent small to medium-sized fragments of this rubble and occasional imperial ceramics have been found mixed within the upper portion of the underlying sedimentary deposits. However, their allochthonous nature and their elevation, between 8 and 4 m a.s.l., that is in conflict with the occurrence of an alluvial plain in Rome at ca. 8 m a.s.l. during the late Republican time (Marra et al., 2018, 2021; Ciancio Rossetto, 2002; Buonfiglio et al., 2020), strongly suggest their displacement.

5.3 Alluvial sedimentary deposits

Lateral correlation of the seven investigated cores is reported in Figure 2, while correlation with the boreholes performed in the Tiber Valley (Marra et al. 2018, 2021) is shown in Figure 3. Photographs of the cored sediments are provided in Supplementary Material #3.

^{14}C and archaeological age constraints show three chronologically distinct alluvial successions that are consistent with the stratigraphy for the Holocene alluvial deposits in the Tiber valley (Marra et al. 2021). In addition, a colluvial layer with limited extension has been recognized at the northeastern margin of the investigated portion of the Murcia Valley.

5.3.1 pre-Bronze Age alluvial succession

Dark gray, organic-rich clay with frequent peat layers and waterlogged vegetal remains in which sporadic oxidized horizons (hard grounds) occur. It is comprised between -2.5 and 2 m a.s.l. Three ^{14}C dates on peat remains constrain the portion of this alluvial succession in the interval 7335±95 - 5600±120 cal yr/BP, allowing for unambiguous correlation with the pre-Bronze Age alluvial succession defined by Marra et al. (2021) in the Tiber Valley and occurring also in the *Velabrum* (Ammermam and Filippi, 2004).

5.3.2 Bronze-Iron Age alluvial succession

Dark brown, sandy clay with abundant, fine gravel inclusion represented by well rounded, ≤1 cm-sized, pyroclastic scoriae deriving from the reworking of the volcanic deposits cropping out on the flanks of the surrounding hills. The bimodal composition and the decreasing thickness (5 to 1 m) at increasing distance from the Palatine slopes indicate that these sediments represent in part a colluvial wedge (see also Figure 3). Sieving of five sediment samples collected in this succession (Fig. 2) provided no datable organic material, nor anthropic inclusion for archaeological dating. However, the ^{14}C age constrain of 2910±130 cal yr/BP on top of this succession, at 5.5 m a.s.l., shows that it was deposited during the regressive/transgressive phase that characterized the Tiber catchment basin in the Bronze Age (Marra t al., 2013, 2018, 2021), as argued in the discussion section.

5.3.3 6th century alluvial succession and colluvial layer

Light gray, silty clay deposits, barren to the sieving analysis. This succession occurs on top of the Bronze Age alluvial/colluvial succession, filling the previous paleomorphology comprised between 2 and 5.5 m a.s.l. (Fig. 2). Moreover, it is laterally embedded with a second colluvial wedge, represented by poorly reworked volcanic materials and small glomeres of sedimentary conglomerate ("puddinga") within a silty matrix. Such deposits clearly derive from the crumbling of the volcanic and sedimentary successions exposed on the flanks of the Palatine, which experienced very limited transport and consequent reworking. Remarkably, a large block of a pyroclastic rock (Tufo Lionato pyroclastic-flow deposit; Karner et al., 2001), fallen from the overlying Palatine hill cliffs where it is largely exposed (Fig. 1c), occurs on top of this colluvium in borehole S5 (Figs. 2, 3).

The ^{14}C age constrain of 2416.5±74.5 cal yr/BP on a charcoal fragment occurring in the upper portion of the clayey succession recovered in S12, comprised between 4.5 and 8 m a.s.l. (Fig. 2), allow us to correlate its initial deposition with the dramatic overflooding events occurred during the 6th century in the Tiber Valley. The overall thickness of the alluvial succession in the Murcia Valley, spanning 2 m to 8 m a.s.l., is indeed consistent with the data in Forum Boarium, where an exceptionally high sediment accumulation in the 6th century BCE raised the alluvial plain of the Tiber River from ca. 1 m to 6/7 m a.s.l. by 2450 yr/BP. In the same area, the appearance of mortar in the anthropic fills indicates a late Republican alluvial plain at ca. 8 m (Brock et al., 2021; Marra et al., 2018, 2021) (Figure 3).

6. Discussion

6.1 The paleoenvironmental evolution of the Murcia Valley

The aggradational history of the Murcia Valley nicely complements the reconstruction of the alluvial succession in the Tiber valley, described in Marra et al. (2018, 2021) and allows for a more nuanced and detailed understanding of the paleolandscape in this area of the ancient city.

In particular, the ^{14}C constraints on the pre-Bronze Age alluvial succession provided in this study strongly support the hypothesis that up to 5500 yr/BP the Tiber basin in this area was characterized by quasi-estuarine conditions. The alluvial plain showed a very limited variation in elevation, around 1 m a.s.l., and gently progressing up to 2 m along the Murcia Valley (Figure 4a-a'). Indeed, the quick rising of the sea level in the early Holocene and the following slow down by 6000 yr/BP, attested in the coastal area (Marra 2013), created a wetland environment as indicated by the frequent peat levels in the alluvial sediments of the Tiber and those of its tributaries in Rome.

However, the continued lowering of the baselevel of the Tiber River that occurred 5500 through 4500 yr/BP (Marra et al., 2013, 2018) affected this paleo-environment in a matter of a few centuries. Independent from its causes, and without implying a corresponding sea-level drop (as discussed in depth in Marra et al., 2013, 2018), this phenomenon triggered a re-incision of the former alluvial plain down to -10 m a.s.l. (Figure 4b) and the disappearance of the marshy estuarine conditions.

As opposed to the Tiber valley, the relatively short duration of this base-level lowering since 4500 yr/BP caused very limited erosion in the tributary valleys, as suggested by the borecores data from the higher portion of the Murcia Valley, where this re-incision is missing (Figure 4b-b'). Indeed, the erosional process triggerred by the lowering of the baselevel has a retrograde character, progressing from the coast to the inland and it requires some time to affect the higher portions of the drainage network.

The progressive recovering of the base-level since 4000 yr/BP caused the re-fill of the previously incised paleomorphology within the Tiber valley, where a novel alluvial plain established at 1 to 3 m a.s.l. by 2800 yr/BP (Marra et al., 2021) (Figure 4c).

In contrast, our reconstruction highlights how very limited sedimentation occurred throughout this long time span within the Murcia Valley, where the deposits ranging 5600 - 2900 yr/BP are represented mainly by a colluvial wedge emplaced at the foot of the Palatine slope. Only a <2 m horizon of brown sandy clay deposits is tentatively attributed to the Bronze-Iron Age alluvial succession (Figure 4b'/c').

Therefore, since the Early Bronze Age, throughout the Iron Age and up to the beginning of the Archaic period, the Murcia Valley formed a sort of highland, suspended above the Tiber Valley, unaffected by the major hydrographic processes acting there. The Murcia Valley must have been a dryland crossed by an incised, small creek most of the year, and affected by limited colluvial/alluvial phenomena during seasonal rainstorms. However, since the 6th century, in connection with the massive overflooding phenomenon occurring in the Tiber Valley, large alluvia must have affected also the Murcia Valley, rising of the alluvial plain to reach up ~7.5 m a.s.l. at the end of the 5th century (Figure 4d-d'). Such estimation is in substantial agreement with previous archaeological data (Ciancio Rossetto, 2002; Buonfiglio, 2014, 2018; Buonfiglio et al., 2020), which accounted for a natural ground below the anthropic covers at 6/7 m and a ground level at ca. 9 m at the end of the Republican Age.

6.2 Relationships among sea level, tectonics and sedimentation rates

The radiocarbon age constraints to the sediment aggradation in the Murcia Valley are plotted against elevation in Figure 5. In evaluating the sedimentation rates, it is important to note that that each dated organic material occurred above one isochrone paleosurface of a continental, fluvial environment characterized by varying elevation possibly in the order of several meters. Therefore, difference in elevation between two successive dated samples not necessarily reflects the average sediment accumulation in the time interval. This is even more relevant when the dated samples are not on the same vertical, but are collected in different boreholes, located several meters apart. In addition, the age of the samples should be considered a *terminus post quem* (i.e., maximum age) for sediment emplacement, since the dated material might be reworked and resedimented. Following these considerations, the curve of sediment aggradation in Figure 5 should be regarded as indicative of the overall aggradational trend.

Consistent with the known aggradational history of the Tiber River, a sharp decrease in sedimentation rate is evidenced after 5600 yr/BP in Figure 5, while the anomalous low rate between 7335 and 5875 yr/BP is likely due to reworking of the lowest age constraint, overestimating the actual sediment age. On the other hand, it is very likely that the trend of the curve between 5600 and 2900 yr/BP overestimates the actual sedimentation rate, since not only should the age of 2900 yr/BP be considered only a maximum age, but also it occurs on top of a colluvial wedge that overlies the coeval alluvial plain by several meters.

Therefore, we hypothesize a more plausible sediment aggradation curve in this time span, represented by the tentative thin dashed red line in Figure 5, which should better reflects the intervening erosional phase as well as the following scanty sedimentation affecting the Murcia Valley (Fig. 4 b'-c').

In order to compare this datum, we have reported in Figure 5 the elevation range of a supposedly Bronze Age (3175- 2897 cal yr/BP) alluvial plain occurring at Sant'Omobono in *Forum Boarium* (a'), and an almost coeval alluvial plain (a) recovered at much lower elevation on the eastern margin of the river valley (Marra et al., 2021). According to the Authors, this remarkable difference in elevation in a short spatial distance highlights a tectonic displacement occurred since ca. 3000 yr/BP along a fault segment bordering the foot of the Capitoline Hill (see Fig. 4 c). Based on data from Sant'Omobono, a conservative elevation of 3 m a.s.l. for a ca. 2900 yr/BP alluvial plain can be assumed (Fig. 5), which matches well the inferred curve of the sedimentation rate in the Murcia Valley, as well as the elevation of the 2900 yr/BP alluvial plain at the foot of the colluvial wedge in this valley (Fig. 4 b'/c').

It must be remarked that the up to 5 m, possible offset inferred for the fault in Figure 3 and 4 has been interpreted as a cumulative effect of a deformation persisted at least four centuries, spanning ~3000 to 2600 yr/BP (Marra et al., 2021). These authors also suggested for this fault a mainly creeping behavior, which is generally associated with cumulative aseismic deformation interpunctuated by seismic release during the long-term evolution of the fault surface (e.g., Kaduri et al., 2017).

Finally, a sharp increase in sedimentation rate in the Murcia Valley is well constrained by the 2416±74 yr/BP date at 7.3 m a.s.l. at the top of the 6th century alluvial succession in core S12 (Fig. 5). Remarkably, this datum fits exactly on the sub-vertical sediment aggradation curve reconstructed for this section of the Tiber valley by Marra et al. (2018, 2021). The ^{14}C and archaeological age constraints on the 6th century riverbed layer (b in Fig. 5; see core FB39 in Fig. 3 and 4d') and on the highest portion of the 6th century alluvial succession (b' in Fig. 5; see core S1BV in Fig. 3 and 4d) are reported with a dashed black line in Fig. 5.

Further investigation is needed to explore the causes of this dramatic increase in sediment accumulation, which uplifted the level of the alluvial plain from ca. 1 m to 6 m within the 6th century (Figure 3 and 4d-d'). The combined effect of multiple factors might be suggested, including tectonics, climate and anthropic activity (Brock et al., 2021, Marra et al., 2018, 2021).

7. Conclusions and final remarks

The results of the analyses carried out in the Murcia Valley allow us to investigate and reassess some of the most ancient phases of occupation in this area of ancient Rome. The geologic and sedimentary processes that in the last millennia have affected the Tiber and its tributaries have determined important changes in the geomorphology of the valley floors. Indeed, many anthropic interventions and settlement choices that have characterized the history of Rome can be read through the lens of continuous reclaiming efforts to create new urban spaces. Through time, the different levels of the Tiber River have determined the elevation of the valley floor. Notably, this study shows that the Murcia Valley, location of the later *Circus Maximus*, was suitable for anthropic use since the Bronze Age. This area constituted a large plateau above the Tiber valley, a condition that would have favored traffic, trade and meeting venues.

It is possible that the ancient sources echoed this landscape and its use through the memory of legendary events connected to the festival in honor of the god *Conso* (*Consualia*). Included in the celebrations were horse races, considered the forerunners of the games performed in the *Circus Maximus* (Buonfiglio, 2018, and references therein).

While up to the end of the Iron Age, the level of the Tiber would have been 1-2 m above sea level (Marra et al., 2018, 2021; Belotti, 2020), the dramatic alluvial events of the 6th century B.C. resulted in a rapid rise of the valley floor at least up to 6 m a.sl.. The fast accumulation of sediment would have covered the oldest anthropic evidence. These important hydrogeological processes that affected the main river valley and its tributaries can be related to the archeological and historical evidence for a reorganization of the settlement's drain system. The historical sources attribute to the last kings, the Tarquins, a network of *cloacae* that converged in the *Cloaca Maxima*, including a *Cloaca Circi* (Bianchi 2020; Buonfiglio 2014, Buonfiglio et alii 2020, and references therein). These works made it possible to drain the valley floor after each flood and were followed by rapid urban growth.

With its own *cloaca* the Murcia Valley became again accessible, on a new and higher level. Likely other infrastructures were also built in this period in addition to the drain including the wooden stands erected to attend the games and described by the ancient authors (Buonfiglio, 2018, and references therein). From this moment on, the Murcia Valley became the privileged site for the horse races organized for the most important religious and civic festivals in Rome. However, the valley was not exempted from the effects of exceptional floodings. This resulted in a further ca. 1 m increase in elevation of the valley floor during the Republican period (see Aldrete 2007, table 1.1. p. 15. for the floods recorded in the historical records). Consistent with an average elevation of 6-8 m a.s.l. in the *Forum Boarium* (Brock et al., 2021; Marra et al., 2021), the data presented in this paper account for an elevation of ca. 7.5 m of the Murcia Valley at the end of the 5^{th} century BCE. In the following centuries an additional couple of meter of alluvial sediments are deposited in the valley. The construction of the first masonry structure for the *Circus* by Caesar and Augustus during the last decades of the 1^{st} century BCE, involved a new rise of the valley floor with the inclusion of artificial levelling. The new track sat at ca. 9 m a.s.l., a level that provided good shelter from seasonal floods (Aldrete 2007; Buonfiglio 2018).

From this moment on the aggradation history of the Murcia Valley becomes a story of anthropic fills, dumps and modern rubble that starts in Imperial time at ca 9 m a.s.l. and continues for two thousand years.

The present study offers some more general considerations.

It confirms the occurrence of a significant baselevel lowering in the Tiber River drainage network between 5000 and 3000 yr BP, which in the Murcia Valley corrsponds to a drastic reduction of the sedimentation rate, accounting for a strong climatic reversal (e.g., Magny et al., 2011) to which a sea-level fluctuation is possibly associated (see Marra et al., 2013, for a discussion).

The rapid sediment accumulation observed in the Tiber Valley, in particular in the Forum Boarium, during the 6th century also occurred in the Murcia Valley. It has been suggested for the Forum Boarium that fault displacement might have increased accommodation space for the alluvial deposits (Marra et al. 2021). However, there is no evidence in the Murcia Valley for the same kind of displacement and, indeed, the thickness of the deposits is less remarkable. Thus, the 6th century overflooding phenomenon must have had a wider, regional trigger responsible for outstanding changes in the hydrologic regime and sediment input. Possible causes may rely both on climate and anthropic (e.g., deforestation) factors. Further investigations are needed to clarify the origin of these significant hydrologic changes in the Tiber River catchment basin.

Autor contributions

F. Marra: designed the geological study, performed the stratigraphic analysis, wrote the paper. M. Buonfiglio: performed the archaeological study, contributed to the writing of the paper. L. Motta: performed the archaeological investigation, contributed to the writing of the paper.

Data availability

^{14}C full analytical data are available in Supplementary Data File #1.

Declaration of competing interest

The authors declare no conflicts of interest.

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FIGURE CAPTIONS

Figure 1 - a) Digital Elevation Map of the location area; b) the alluvial plain of the Tiber River and its tributary streams in Rome; c) Geological map of ancient Rome (modified from Marra and Rosa, 1995) showing the location of the boreholes used in this work.

Figure 2 - Lateral stratigraphic correlation among the six investigated boreholes. See text for comments and explanation.

Figure 3 - Google image showing the location of the boreholes investigated in the present study to reconstruct the sediment aggradation in the Murcia Valley. Geologic cross-section of the valley along A-A' line (boreholes S5/S1 and FB38 are projected out of line in order to highlight the morpho-structural setting); see text for comments and explanation.

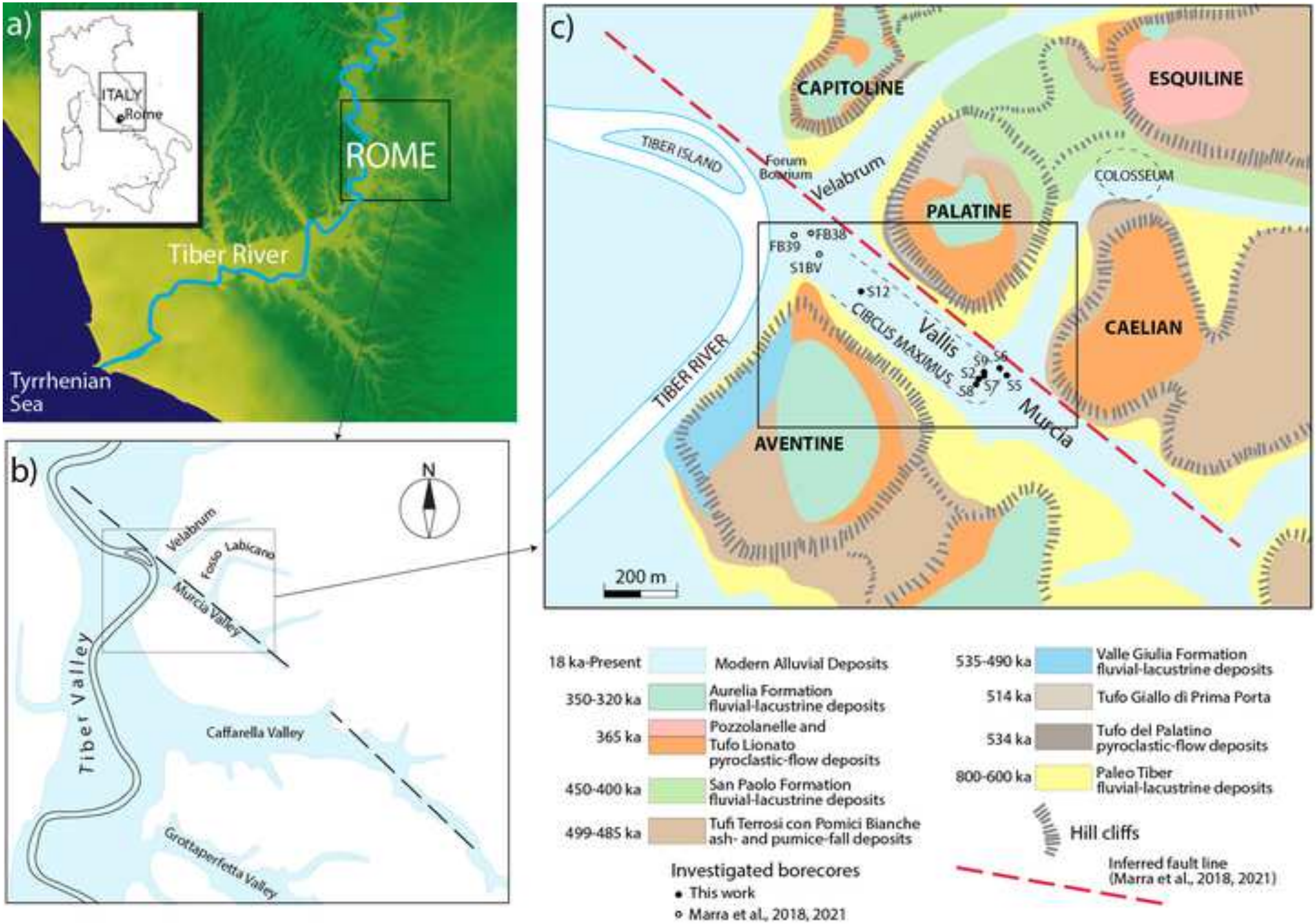
Figure 4 - Reconstruction of the aggradational history and paleoenvironmental evolution in the Tiber and Murcia valleys between 12000BP and 2400 BP. Inserts a-d: above, plan (red dashes indicate the lowered sector along the fault lines); below, cross section of the Tiber Valley B-B’, cross-section of the Murcia Valley C-C’. Inserts a’-d’: reconstruction along cross section A-A’ (see fig. 3).

Figure 5 - Sedimentation rates in the Murcia Valley reconstructed in this study (red lines) compared with those in the Tiber Valley (black dashed line). The dashed red lines accounts for a more smoothed aggradational trend; see text for comments and explanation.

Table 1 - Radiocarbon ages

Figure

Click here to access/download;Figure;Fig. 1.jpg



Figure

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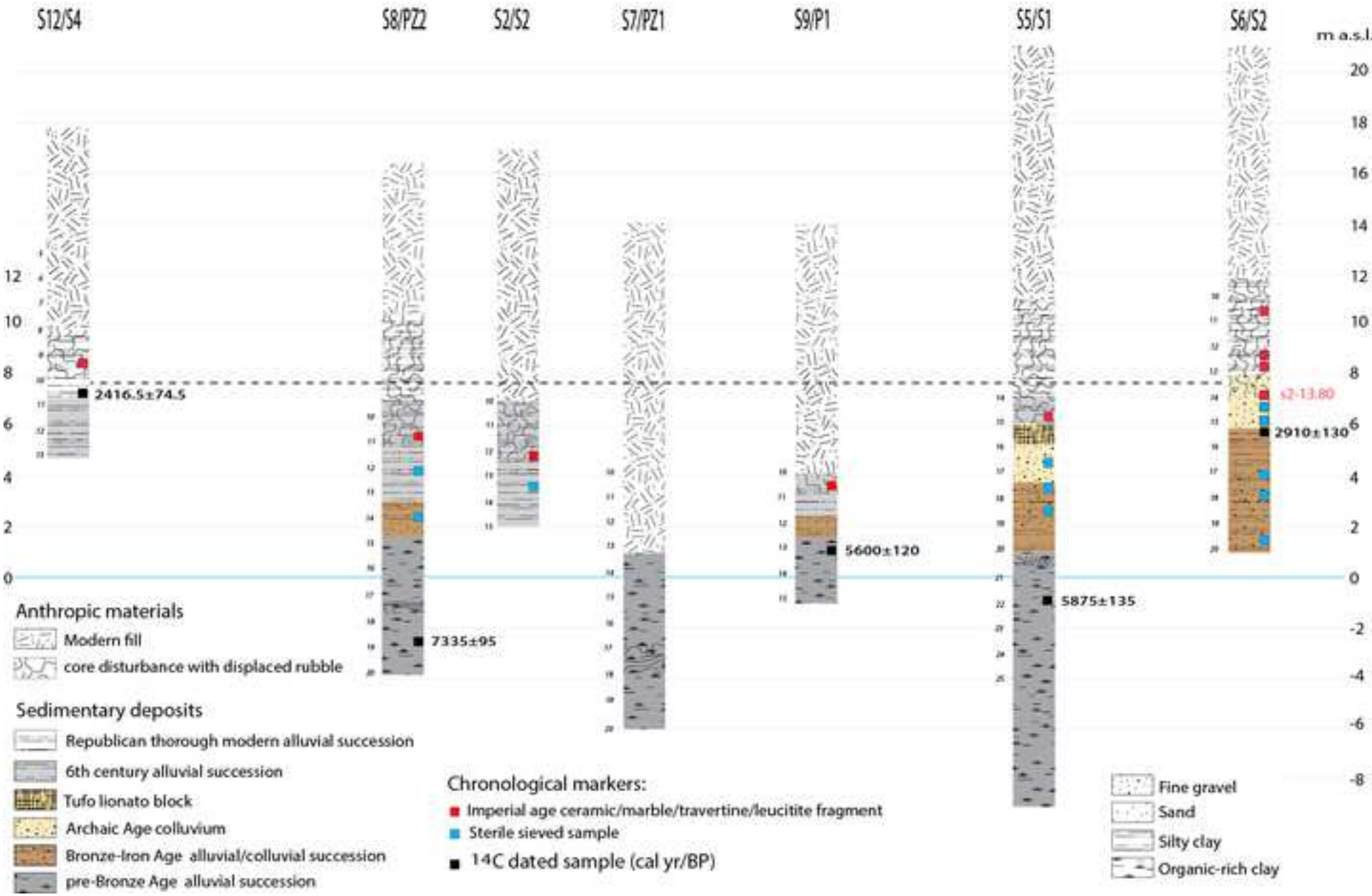
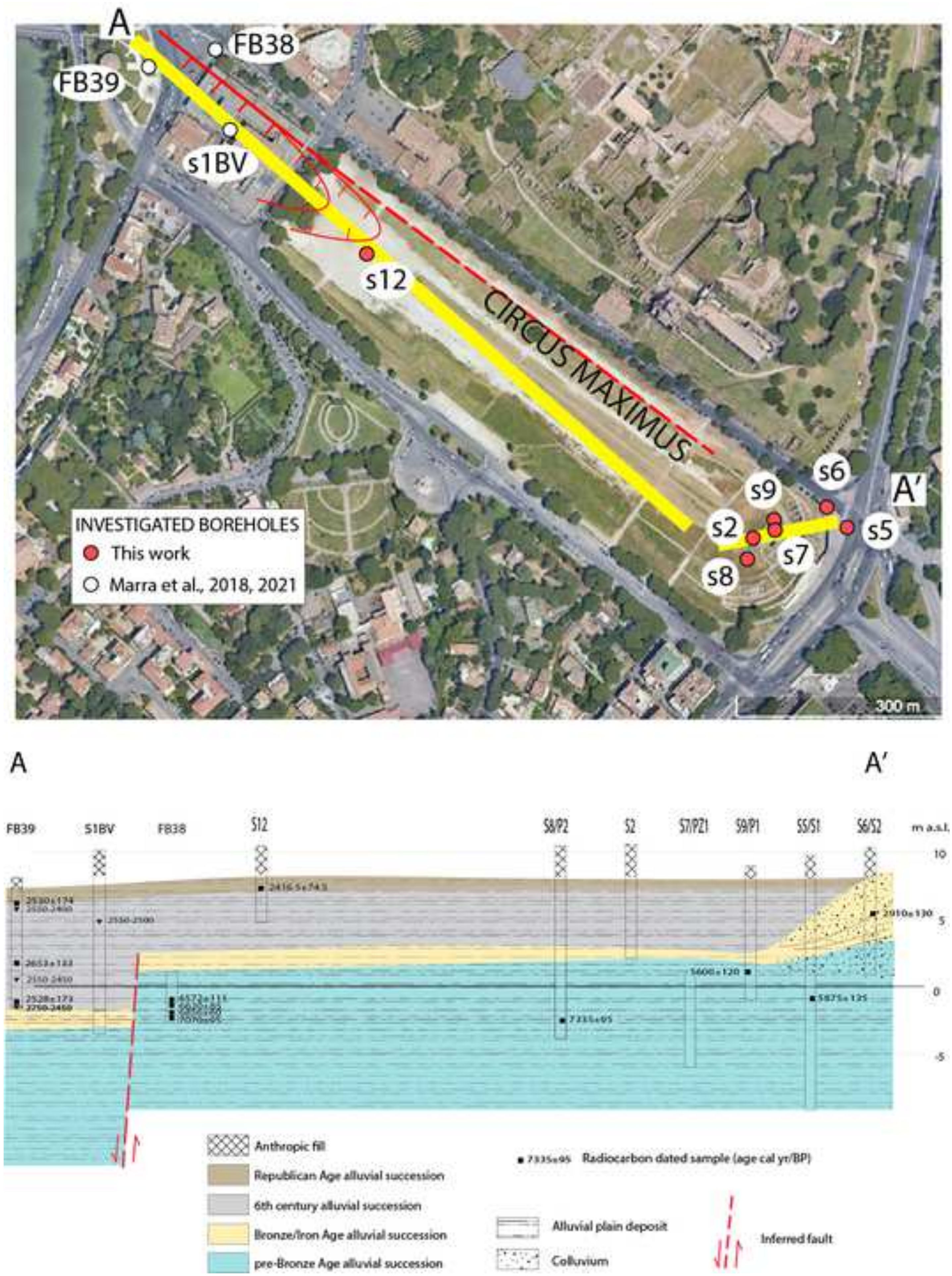
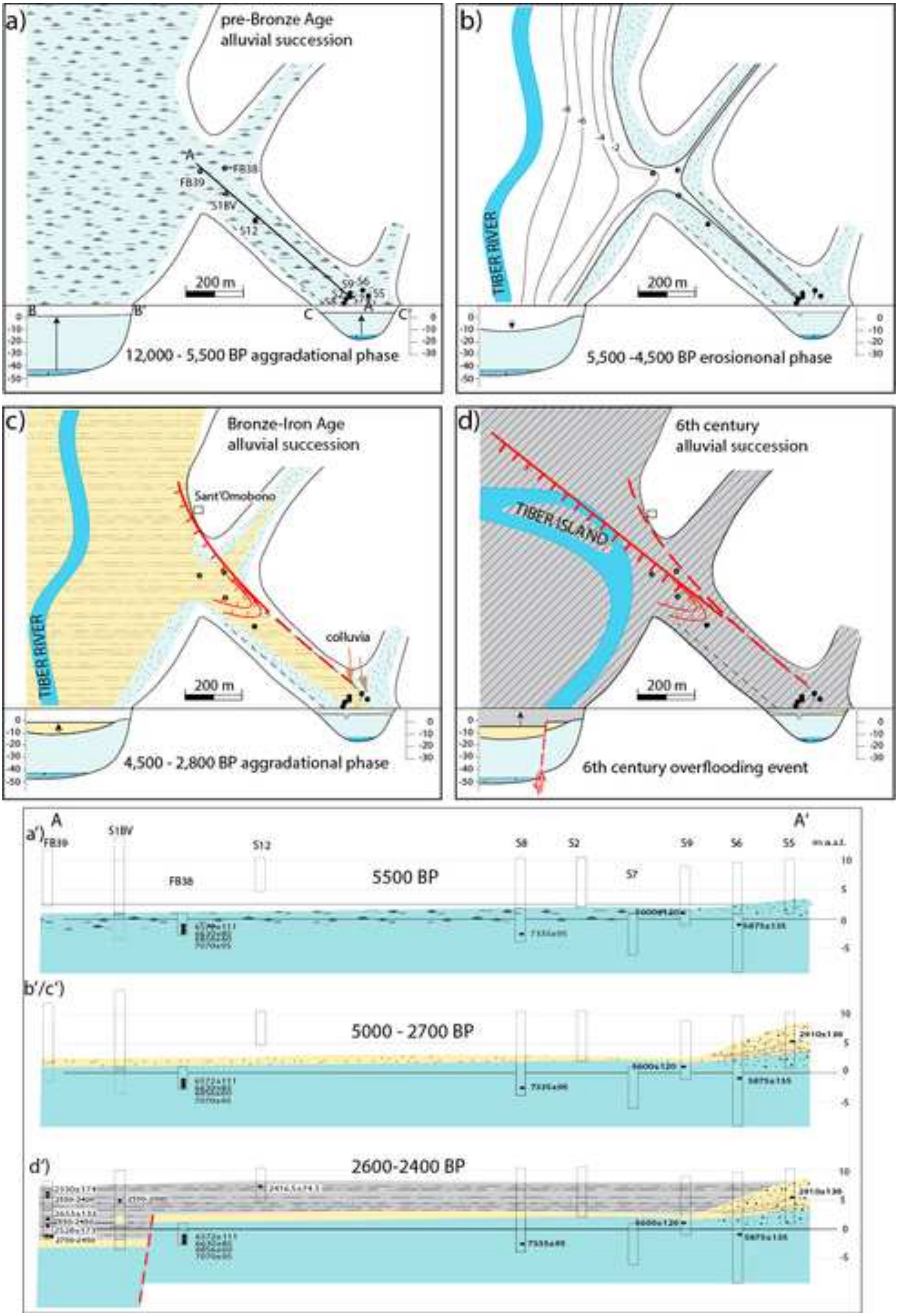



A
FB38
FB39
s1BV
s12
CIRCUS MAXIMUS
s6
s9
A′
s2
s5
s7
s8
INVESTIGATED BOREHOLES
This work
Marra et al., 2018, 2021
300 m
A
A′
FB39
S1BV
FB38
S12
S8/P2
S2
S7/PZ1
S9/P1
S5/S1
S6/S2
m a.s.l.
10
5
0
-5
2416.5±74.5
2910±130
5600±120
5875±125
7335±95
Anthropic fill
Republican Age alluvial succession
6th century alluvial succession
Bronze/Iron Age alluvial succession
pre-Bronze Age alluvial succession
7335±95 Radiocarbon dated sample (age cal yr/BP)
Alluvial plain deposit
Colluvium
Inferred fault

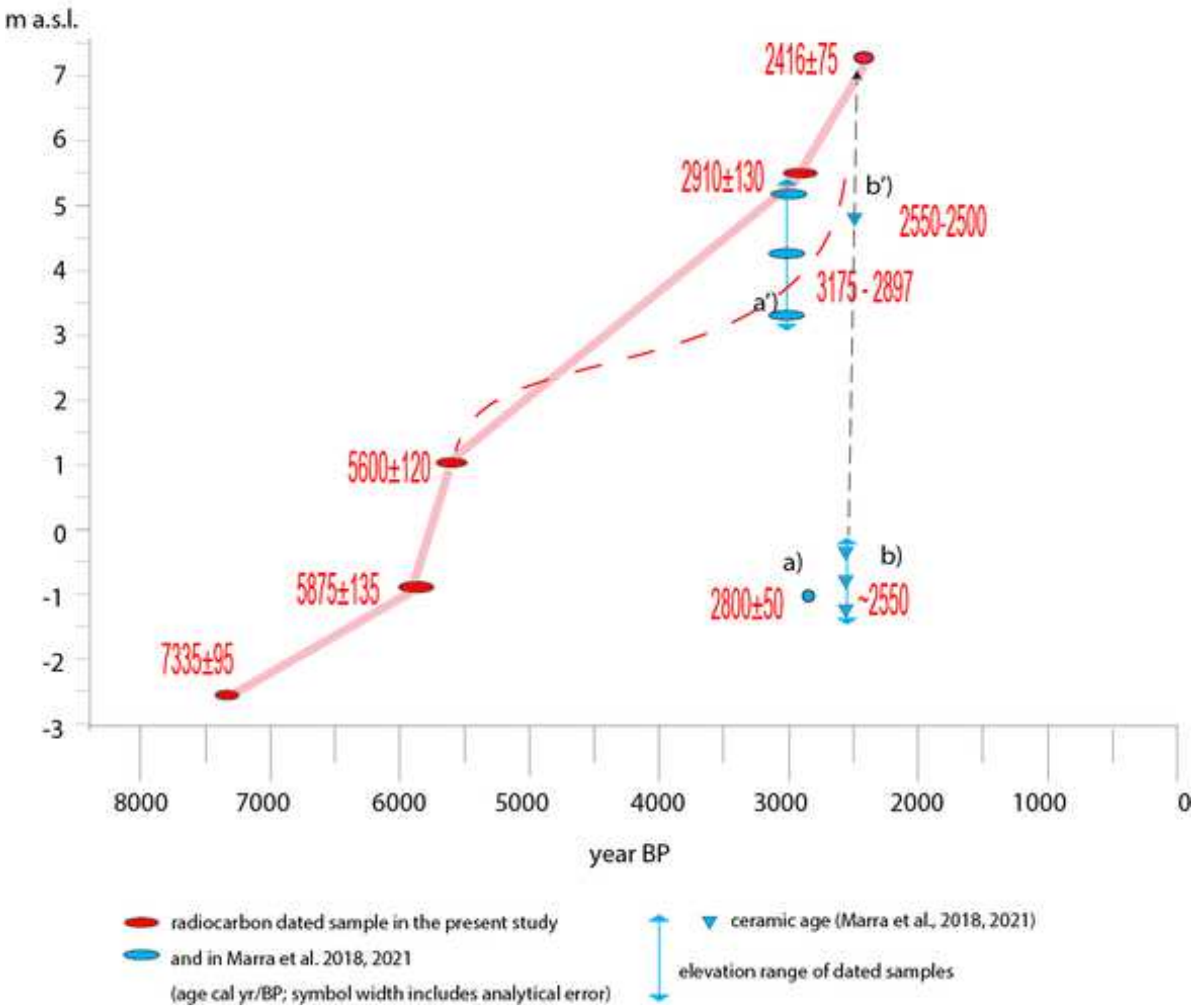
Figure

Click here to access/download;Figure;Fig. 4 Vallis Murcia_rev.jpg



Figure

Click here to access/download;Figure;Fig. 5.jpg



SAMPLE S12-10.30
Radiocarbon Age BP 2380 +/- 30
Probability distribution

68.3 (1 sigma)	cal BC 510- 507	0.016
	480- 398	0.984
95.4 (2 sigma)	cal BC 716- 710	0.011
	660- 655	0.012
	542- 393	0.977

Median probability: -454
Calibrated age BP: 2416±74.5

SAMPLE S9-13.2
Radiocarbon Age BP 4876 +/- 45
Probability distribution

68.3 (1 sigma)	cal BC 3707- 3669	0.478
	3661- 3632	0.474
	3550- 3544	0.049
95.4 (2 sigma)	cal BC 3772- 3623	0.866
	3582- 3531	0.134

Median probability: -3660
Calibrated age BP: 5600±120

SAMPLE S8-18.8
Radiocarbon Age BP 6382 +/- 45
Probability distribution

68.3 (1 sigma)	cal BC 5468- 5442	0.219
	5382- 5310	0.781
95.4 (2 sigma)	cal BC 5473- 5423	0.223
	5420- 5301	0.690
	5254- 5223	0.087

Median probability: -5358
Calibrated age BP: 7335±95

SAMPE S5-21.9
Radiocarbon Age BP 5159 +/- 50
Probability distribution

68.3 (1 sigma)	cal BC 4043- 4012	0.256
	3999- 3945	0.597
	3855- 3844	0.057
	3835- 3818	0.090
95.4 (2 sigma)	cal BC 4158- 4139	0.019
	4053- 3895	0.745
	3881- 3799	0.236

Median probability: -3970
Calibrated age BP: 5875±135

SAMPLE S6-15.5
Radiocarbon Age BP 2809 +/- 45
Probability distribution

68.3 (1 sigma)	cal BC 1015- 902	1.000
95.4 (2 sigma)	cal BC 1108- 1094	0.017
	1082- 1067	0.020
	1057- 833	0.963

Median probability: -964
Calibrated age BP: 2910±130

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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We the authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.
We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.
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Sincerely,

On behalf of all authors

Fabrizio Marra

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