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Holocene aggradation history of the Murcia alluvial valley: Insights into early Rome's paleoenvironmental evolution

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ABSTRACT

Through the analysis of seven 15–30 m deep boreholes drilled in the western sector of the *Circus Maximus* we reconstruct the aggradational history of one main tributary valleys 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 base level. This would have created a dry alluvial plain, suitable for human settlement. We also find evidence for dramatic overflooding which occurred during the 6th century BCE and was 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 can be identified in mythical and ethno-historical accounts of early Rome.

Besides providing insights into the paleolandscape and anthropogenic interventions in the Murcia Valley, these previously unrecognized hydrological dynamics may attest to paleoclimatic fluctuation that have 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 anthropogenic factors could have also had a combined and cumulative effect, requiring detailed paleoenvironmental and palaeolandscape studies.

1. Introduction

Recent studies have provided detailed reconstructions 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) 13,000 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 that occurred following the Last Glacial Termination (Belluomini et al., 1986; Bellotti et al., 2007; Marra et al., 2013) that resulted in 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 of this early alluvial plain was triggered by a sea-level drop that was likely linked to 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 beginning of 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 seems to have occurred in the Archaic period, at the beginning of the 6th century BCE, when sudden and recurrent floods 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 catalysed this huge sediment accumulation, due to the activity of a fault line parallel to the Murcia Valley and crossing the Tiber Valley through the Velabrum and Forum Boarium (Fig. 1) (Marra et al., 2018, 2021). Repeated, though smaller flooding events occurred throughout the Republican period, causing a progressive aggradation of the alluvial plain, from ca. 6 m–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 anthropogenic interventions raised the ground level to prevent the continuous flooding of the ancient city.

While the above-mentioned research and interpretative efforts have focused on the Tiber valley, the same level of attention has not been paid

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to the main tributary valley of the Tiber inside the city of Rome, the Murcia valley (*Vallis Murcia*). The Murcia Valley is, however, a highly significant feature within the landscape of early Rome, being associated with some of the earliest settlement evidence and with important trade and religious activities (Brock et al., 2021). The study of the aggradation dynamics in the Murcia valley would thus provide crucial information for understanding the wider effects of Holocene sedimentary processes on Rome's palaeolandscape, and key insights into the palaeoenvironmental transformations that occurred at very beginning of the ancient city's settlement history.

In this paper, we present results from the investigation of seven borecores performed in the Murcia Valley by the Sovrintendenza Capitolina ai Beni Culturali - Roma Capitale in the years 2003–2013, and we compare the aggradational history in this tributary valley with the sedimentary succession documented for the Tiber valley.

Previous work (Carpentieri et al., 2015) interpreted these borecores using uncalibrated ^{14}C ages and did not recognize pervasive contamination of the upper portion of the sedimentary succession caused by the relapse of anthropogenic materials during drilling. Here we have carefully re-investigated the sedimentary record, re-calibrated four previous ^{14}C ages, and performed a new ^{14}C age determination on the upper portion of the alluvial deposits. We have also reviewed the archaeological material retrieved from the cores, and studied the ceramic inclusions. This allowed us to assess local responses to the main sedimentary phases that occurred during the Holocene and to provide accurate constraints for the chronology of the anthropogenic deposits.

This study presents new data on the palaeoenvironmental and paleoclimatic evolution of the region surrounding Rome during the Holocene and offers new insights into the early settlement and anthropogenic activity in the ancient city from the Late Bronze Age (ca. 3000 yr BP) to the Republican period (5th - 1st century BCE).

Our results add to, and complement, the discussion of later geomorphologic features and the anthropogenic modifications of the Murcia Valley since the Republican period discussed by Luberti et al. (2018).

2. The Murcia Valley

The Murcia Valley is a small 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 is 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). This 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). This would be further supported by new evidence for a ~1 m stratigraphic offset affecting the alluvial sediments of the Tiber River along this fault segment in the *Forum Boarium* area (Marra et al., 2021).

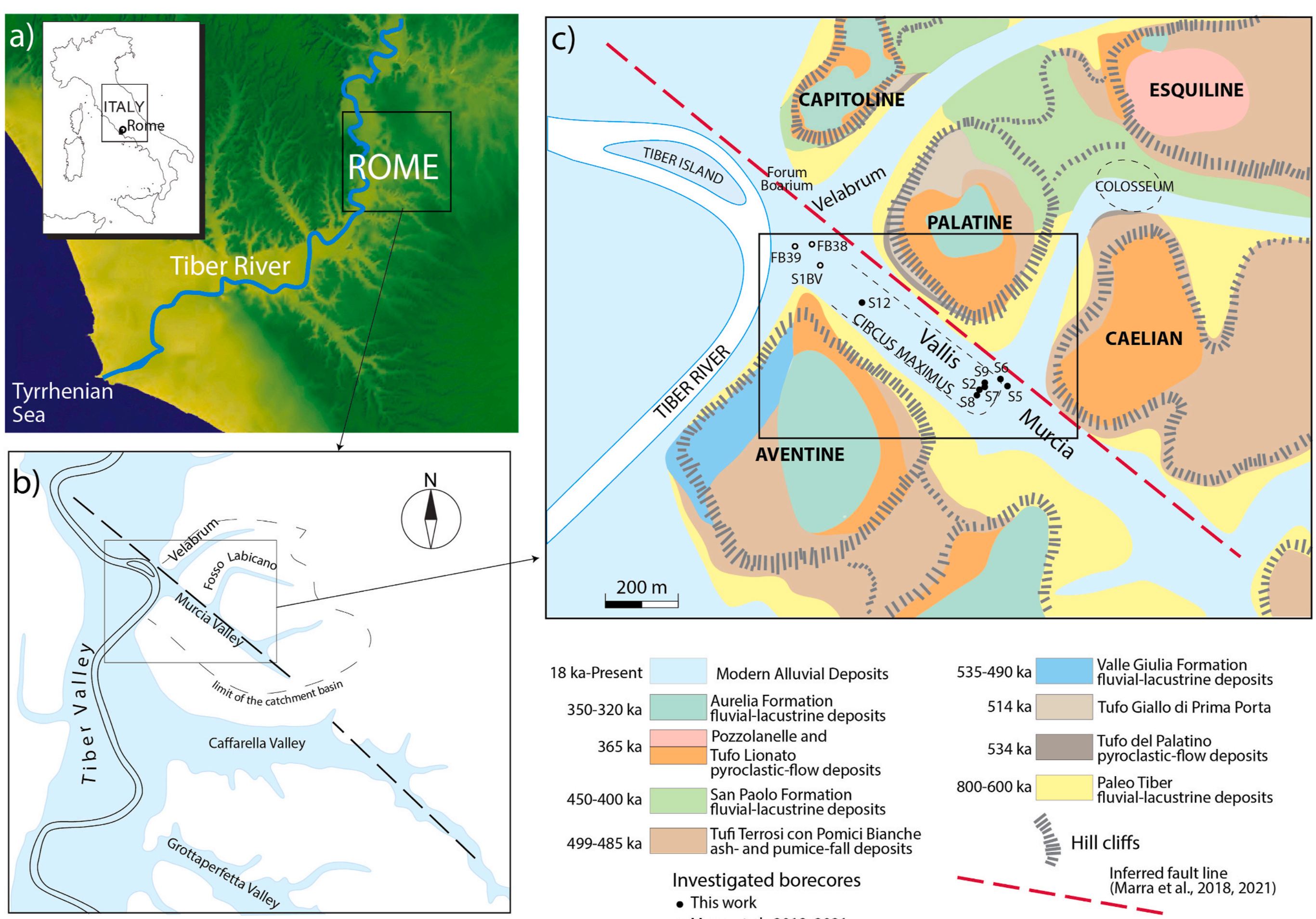

Fig. 1. a) Digital Elevation Map of the location area; b) the alluvial plain of the Tiber River and its tributary streams in Rome; c) Geological map of ancient Rome (modified from Marra and Rosa, 1995) showing the location of the boreholes used in this work.

3. Historical and archaeological context

The Murcia Valley separates 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 first fluvial harbor of ancient Rome and the oldest bridge over the Tiber River (Brock et al., 2021). Due to this privileged geographical position, the Murcia Valley was most probably involved in 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 (Humphrey, 1986). However, so far, no archaeological evidence has been found to support an intensive and systematic use of the area during this early period.

According to the legendary sources, the founder of Rome, *Romulus*, built the first circus to hold the equestrian games, the *Consualia*, in the Murcia Valley, 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).

4. Materials and methods

We investigate the chronostratigraphic, sedimentological and archaeological features of seven borecores, 15–30 m deep, located in the Murcia Valley. The borecores were obtaiuned from within the archaeological area of the *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.

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 anthropogenic material (e.g., ceramic, brick, marble, etc.) found within the alluvial deposits. The fall back of small fragments of clastic material and ceramics into the hole from the top anthropogenic layers is a common occurrence. Since fragmented material accumulates at the base of the hole and it is dragged down during each core recover, this can become a pervasive issue for the external surface of the cores, even when drilling is carried out by lowering a casing along the hole.

The awareness of these problems has allowed us to identify the portions of cores affected by contamination. This has been recognized at the top and base of each individual core, and within sediment portions disturbed 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. Photographs of the cored sediments are provided in Supplementary Material #1.

To establish an archaeological chronology for the investigated stratigraphic intervals all diagnostic ceramic fragments and 9 sediment samples for sieving were collected. In addition, five organic samples (wood, charcoal, peat) were 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 anthropogenic inclusions visible in the sediments were collected and recorded.

Four AMS radiocarbon analyses were performed at the Centro di Datazione e Diagnostica (CEDAD), Department of Mathematics and Physics, Università del Salento, Brindisi, Italy, and the uncalibrated results were published in (Carpentieri et al., 2015). The ages, 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. The full analytical data and calibration procedure are provided in Supplementary Materials #2 and #3.

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

5. Results

5.1. Chronostratigraphic analysis

Lateral correlation of the seven investigated cores is reported in Fig. 2, while correlation with the boreholes performed in the Tiber Valley (Marra et al., 2018, 2021) is shown in Fig. 3. Such correlation allows us to adopt the same chronostratigraphic units defined in Marra

Table 1
Radiocarbon ages.

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		

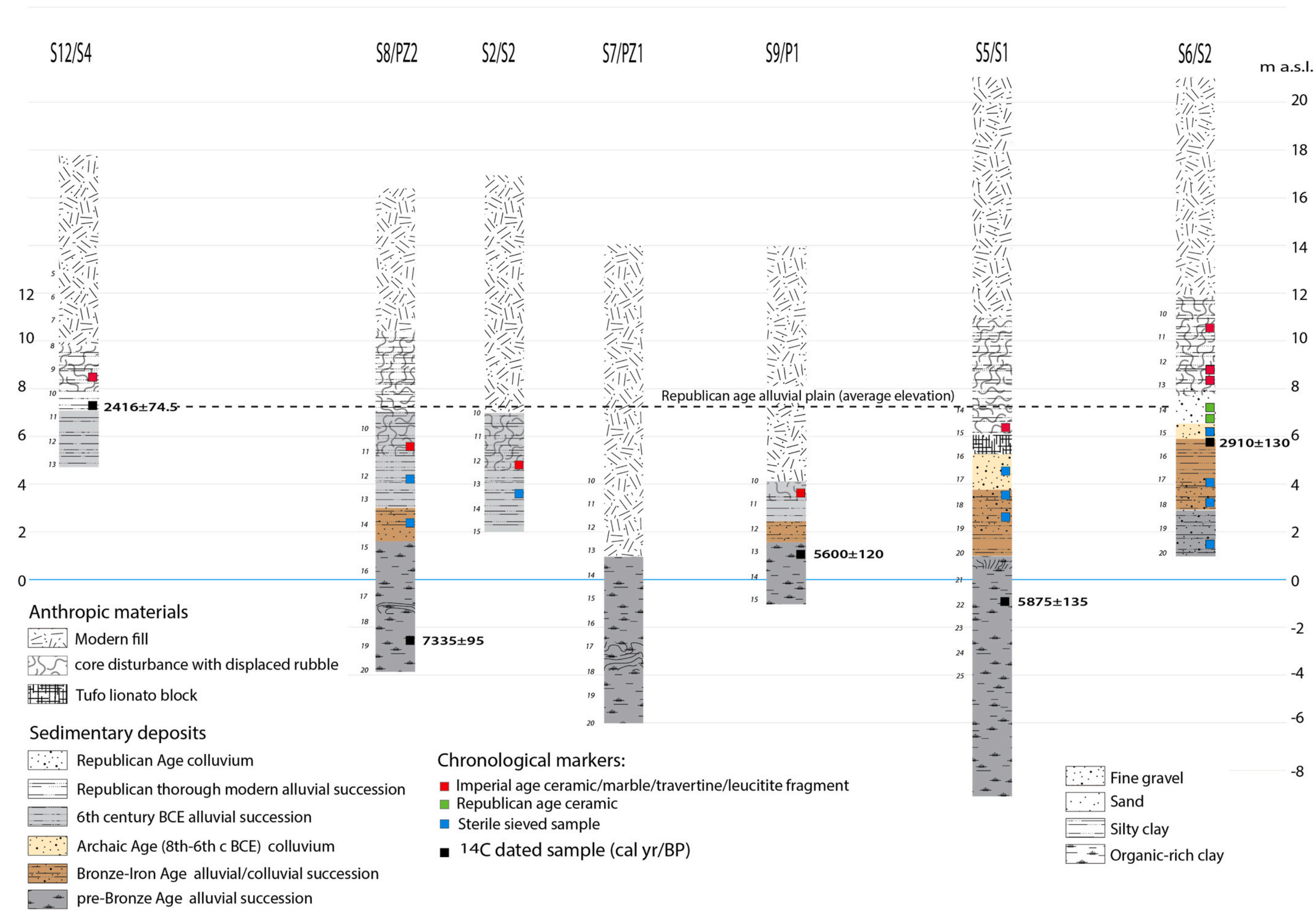

Fig. 2. Lateral stratigraphic correlation among the six investigated boreholes. See text for comments and explanation.

et al. (2021) for the alluvial deposits.

^{14}C and archaeological age constraints show that the sedimentary record of the Murcia Valley comprises three chronologically distinct alluvial successions that are described below. These successions are consistent with the stratigraphy of 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.

5.1.1. *Pre-Bronze Age alluvial succession*

Dark grey, organic-rich clay with frequent peat layers and waterlogged vegetal remains in which sporadic oxidized horizons (hard grounds) occur. It covers between −2.5 and 2 m a.s.l. This succession is micro-paleontologically barren, consistent with the anoxic environmental conditions. Three ^{14}C dates on peat remains constrain the portion of this alluvial succession to 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 which also occurs in the *Velabrum* (Ammerman and Filippi, 2004).

5.1.2. *Bronze-Iron Age alluvial succession*

Dark brown, sandy clay with abundant, fine gravel inclusions 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 (5–1 m) at increasing distance from the Palatine slopes indicate that these sediments represent, in part, a colluvial wedge (see also boreholes S5/S1 and S6/S2 in Fig. 3). Sieving of five sediment samples collected in this succession (Fig. 2) provided no datable organic material, nor anthropogenic inclusions for archaeological dating. The only exception is the ^{14}C age of 2910 ± 130 cal yr/BP on top of this succession, at 5.5 m a.s.l.

5.1.3. *6th century BCE alluvial succession and colluvial layer*

Light grey, silty clay deposits, found to be barren following sieving. This succession occurs on top of the Bronze Age alluvial/colluvial succession, filling the previous paleomorphology covering between 2 and 5.5 m a.s.l. (Fig. 2). Moreover, it is laterally embedded with a second colluvial wedge (see also boreholes S5/S1 and S6/S2 in Fig. 3), represented by poorly reworked volcanic materials and small glomeras 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 and 3).

The ^{14}C age of 2416 ± 74.5 cal yr/BP measured on a charcoal fragment occurring in the upper portion of the clayey succession recovered in S12 at 7.5 m a.s.l. (Fig. 2) allows us to correlate its initial deposition with the dramatic overflooding events which occurred during the 6th century in the Tiber Valley. The overall thickness of the alluvial succession in the Murcia Valley, spanning 2 m–7.5 m a.s.l., is indeed consistent with the data in the Velabrum and Forum Boarium, where an exceptionally high sediment accumulation in the 6th century BCE raised

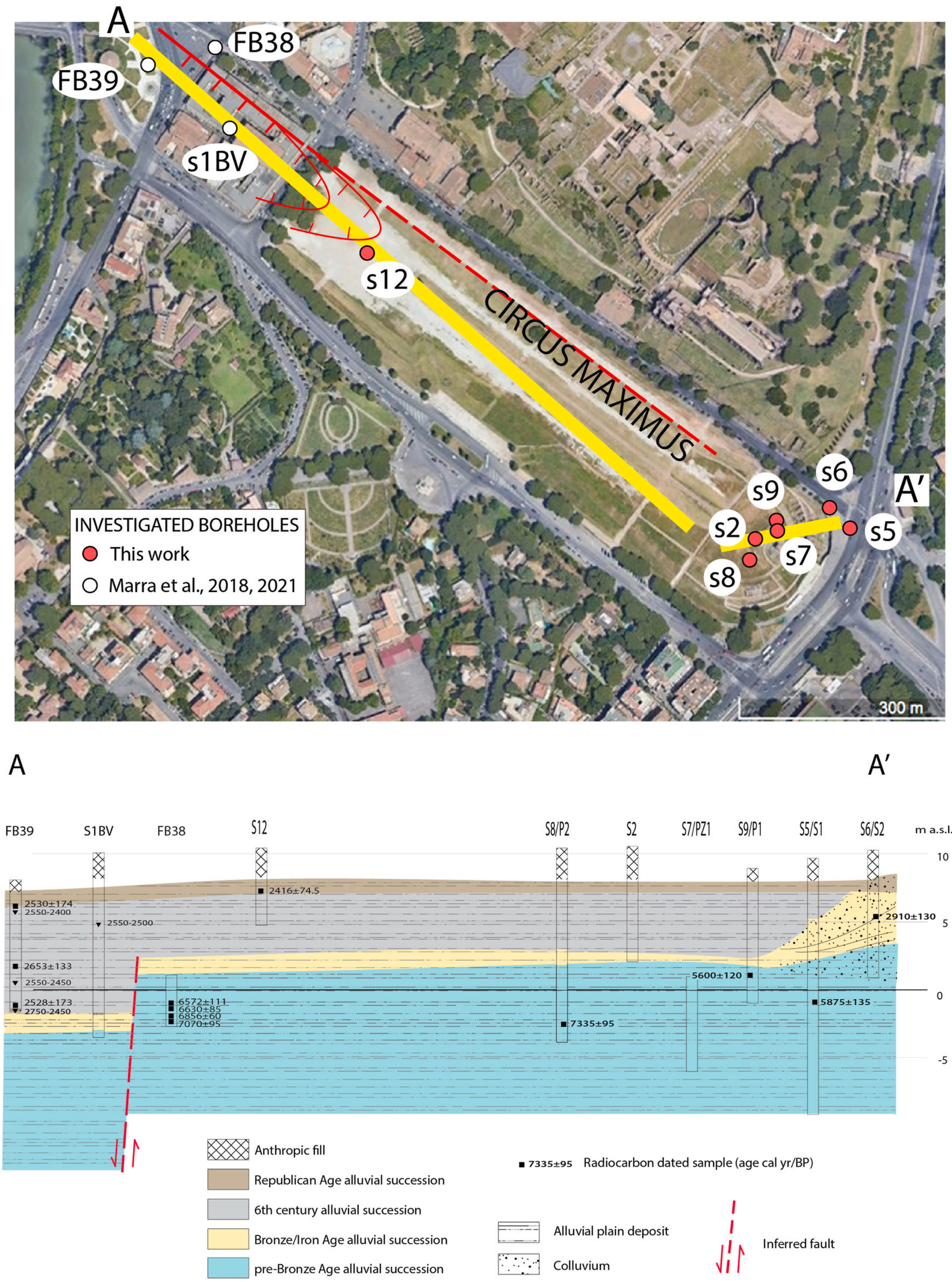

Fig. 3. Google image showing the location of the boreholes investigated in the present study to reconstruct the sediment aggradation in the Murcia Valley. Geologic cross-section of the valley along A-A′ line (boreholes S5/S1 and FB38 are projected out of line in order to highlight the morpho-structural setting); see text for comments and explanation. The fault line hypothesized in Marra et al. (2018, 2021) is shown (dashed red line); perpendicular slashes indicate the active fault segments, bending fault splays border the lowered sector to the NE. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the alluvial plain of the Tiber River from ca. 1 m to 6/7 m a.s.l. by ~2450 yr/BP. Based on this ^{14}C age and the occurrence of 4th-3rd century BCE ceramics around 7.5 m a.s.l. in borehole S2/S6 (Fig. 2), we have assessed an average elevation for the alluvial plain in the Murcia Valley during the early Republican age (dashed black line in Fig. 2). Consistent with this, in the Velabrum area the appearance of mortar in the anthropogenic fills indicates a late Republican alluvial plain at ca. 7/8 m (Brock et al., 2021; Marra et al., 2018, 2021) (Fig. 3).

5.1.4. Anthropogenic horizons

An up to 13 m-thick cover of anthropogenic materials, resulting from two-thousand years of history and urban development of this special area devoted to the celebration of equestrian games, overlays the natural ground in the investigated portion of the Murcia Valley.

The lower portion of this sequence is characterized by anthropogenic fills typically associated with big urban projects of the Imperial period. They comprise dumps of building material, tiles, ceramic fragments, animal bones and other domestic waste, and they can be related to the several phases of remodeling and reconstruction of the *Circus Maximus* between the beginning of the 1st and the 2nd century CE.

Frequent small to medium-sized fragments of this rubble and occasional imperial ceramics have been found mixed within the upper portion of the underlying alluvial sedimentary deposits. However, their allochthonous nature in the alluvial matrix and their elevation, between 4 and 8 m a.s.l., strongly suggests that their displacement is due to the drilling technical problems discussed above.

6. Discussion

6.1. The paleoenvironmental evolution of the Murcia Valley

Our observations of 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 palaeolandscape in this area of the ancient city of Rome.

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 was characterized by quasi-estuarine conditions in this area. The alluvial plain showed very limited variation in elevation, around 1 m a.s.l., and gently progressing up to 2 m along the Murcia Valley (Fig. 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 et al.,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.

Between 5500 and 4500 yr/BP this paleoenvironment was affected by the continued lowering of the base level of the Tiber River in a matter of a few centuries (Marra et al., 2013, 2018). 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. (Fig. 4b) and the disappearance of the marshy estuarine conditions in the Tiber Valley. While this process is clearly recorded in the Tiber valley, evidence for the re-incision is missing in borecore data from the higher portion of the Murcia Valley (Fig. 4b-b'). This suggests that the relatively short duration of this base level lowering since 4500 yr/BP caused very limited erosion in the tributary valleys. Indeed, the erosional process triggered by the lowering of the base level has a retrograde character, progressing from the coast inland, with considerable time being required until it impacted the higher portions of the drainage network.

The progressive recovery of the base level since 4000 yr/BP caused the re-infill of the previously incised palaeomorphology within the Tiber valley, where a novel alluvial plain was established at 1–3 m a.s.l. by 2800 yr/BP (Marra et al., 2021) (Fig. 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 (Fig. 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, not impacted 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 would have also impacted the Murcia Valley, where we have evidence for the rising of the alluvial plain up to ~7.5 m a.s.l. in the mid Republican period (Fig. 4d-d').

Such an 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 covering anthropogenic material at 6/7 m and a ground level at ca. 9 m at the end of the Republican Age.

6.2. Relationships between sea level, tectonics and sedimentation rates

The radiocarbon age constraints for the sediment aggradation in the Murcia Valley are plotted against their elevation in Fig. 5. For comparative purposes we have also reported the curve of sea-level rise for the central Tyrrhenian Sea according to Vacchi et al. (2016).

In evaluating the sedimentation rates, it is important to consider that the difference in elevation between two successive dated samples does not necessarily reflect the average sediment accumulation in the time interval. This is mainly due to the fact that the dated samples are not on the same vertical, but occur above the paleosurface of a fluvial environment characterized by varying elevation, possibly in the order of several meters. In addition, the age of the samples should be considered a *terminus post quem* (i.e., maximum age) for sediment emplacement, since the dated organic remains might be reworked and re-sedimented material. Following these considerations, the curve of sediment aggradation in Fig. 5 should be regarded as indicative of the average, overall aggradational trend.

It is important to note that the relationship between the global sea-level curve and the curve of sediment aggradation in a tributary valley far from the coast is not straightforward and the only requisite is that the second curve must overly the first one. Regarding the relationships between the sea-level curve and the aggradation within the main Tiber Valley, this subject has been thoroughly discussed already in Marra et al. (2013, 2018), and is not replicated here.

Consistent with the known aggradational history of the Tiber River, a sharp decrease in sedimentation rate is apparent after 5600 yr/BP in Fig. 5, while the anomalously low rate between 7335 and 5875 yr/BP may be due to reworking of the lowest age constraint, overestimating the actual sediment age. It is very likely that the trend of the curve between 5600 and 2900 yr/BP also overestimates the actual sedimentation rate, since not only should the age of 2900 yr/BP be considered only a maximum age but it also occurs on top of a colluvial wedge that overlies the coeval alluvial plain by several meters (see Fig. 3).

Therefore, we hypothesize for this time span a more plausible sediment aggradation curve, based on data from the Tiber Valley (Marra et al., 2013, 2018, 2021), represented by the tentative thin dashed red line in Fig. 5, which should better reflect the intervening erosional phase as well as the following scanty sedimentation affecting the Murcia Valley (Fig. 4 b'-c').

On the other hand, a sharp increase in sedimentation rate in the Murcia Valley is well constrained by the 2416 ± 74 yr/BP date at 7.5 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 (a in Fig. 5; see core FB39 in Figs. 3 and 4d') and on the highest portion of the 6th century alluvial succession (a' in Fig. 5; see core S1BV in Figs. 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–6 m within the 6th century BCE in the Tiber

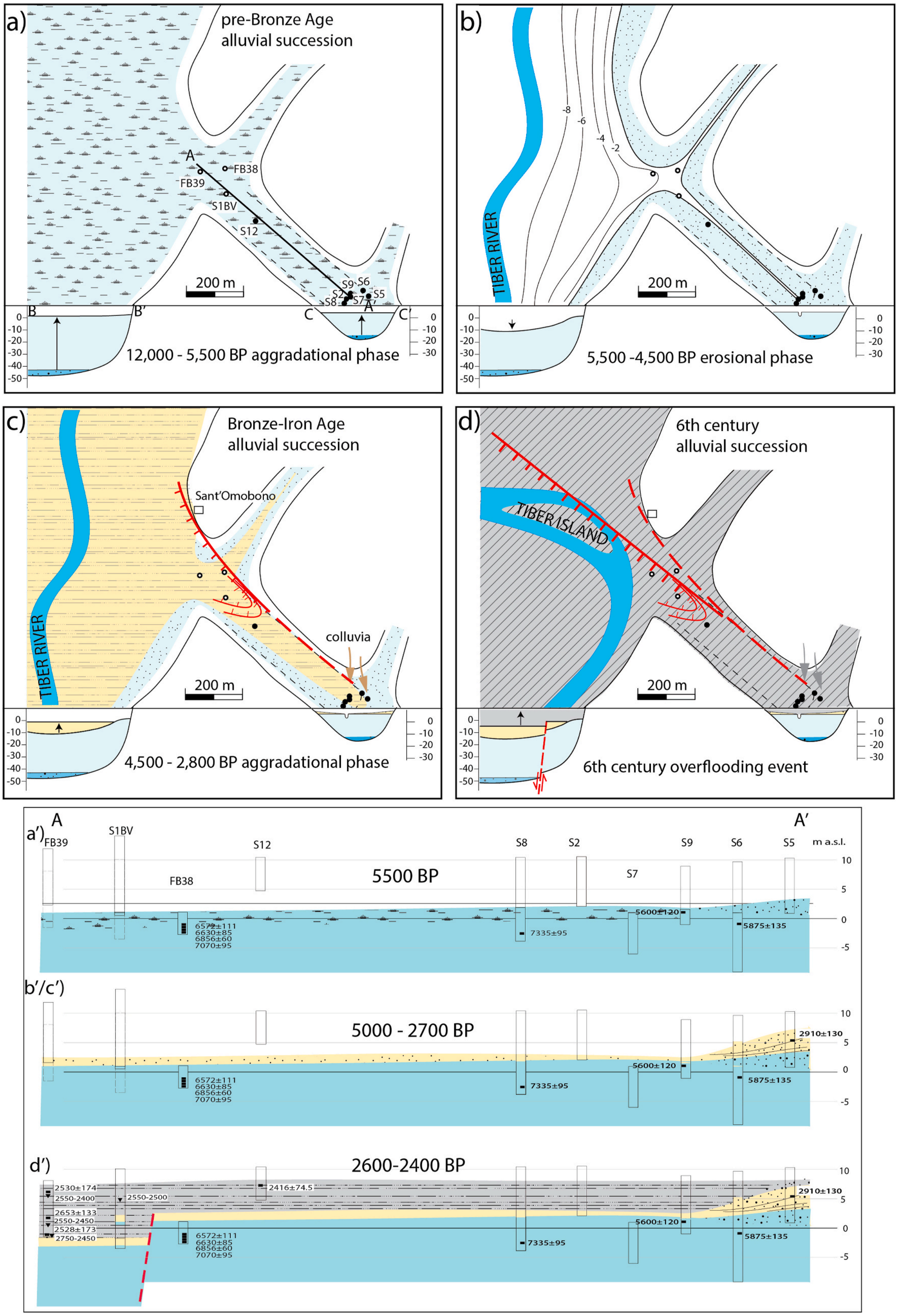

Fig. 4. Reconstruction of the aggradational history and paleoenvironmental evolution in the Tiber and Murcia valleys between 12000BP and 2400 BP. Inserts a–d: above, plan; perpendicular slashes indicate the active fault segments reported in Marra et al. (2021), bending fault splays accounting for the lack of fault displacement in the Murcia Valley border the lowered sector to the NE; 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).

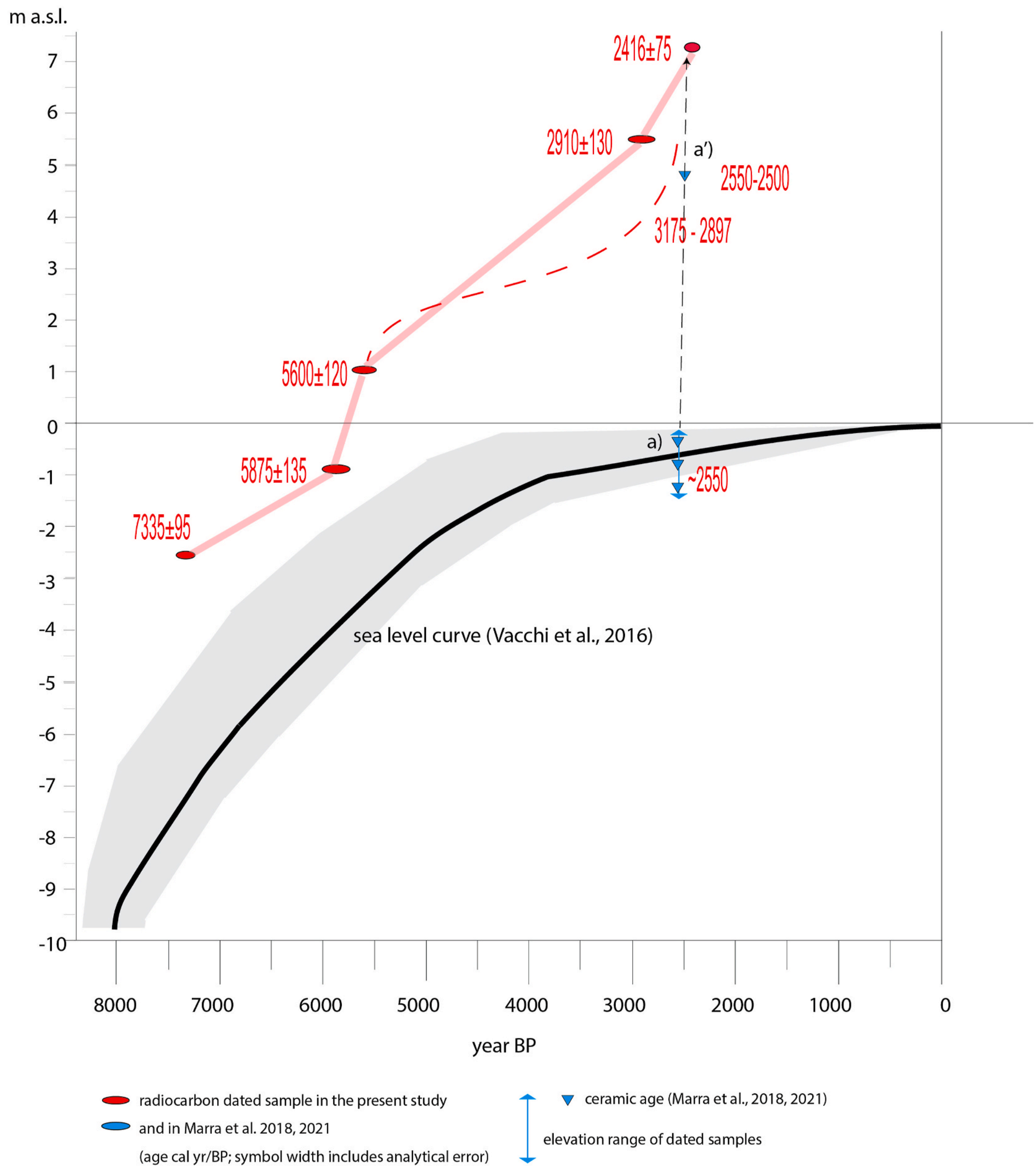

Fig. 5. Sedimentation rates in the Murcia Valley reconstructed in this study (red lines) compared with those in the Tiber Valley (black dashed line). Note the sub-vertical trend of the black line (a-a') that accounts for the sudden increase in the elevation of the alluvial plain in the Tiber Valley as a result of the dramatic flooding events during the 6th century BCE (ca. 6500 yr BP). The dashed red line accounts for a more smoothed aggradational trend and a similar sudden increase during the 6th century in the Murcia Valley; see text for comments and explanation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Valley (Figs. 3 and 4d-d'). The combined effect of multiple factors has been suggested, including tectonics, climate and anthropogenic activity (Brock et al., 2021; Marra et al., 2018, 2021).

Here it is important to note that no direct influence of the fault activity evidenced in the Tiber plain has been detected in the Murcia Valley. This suggests that although the fault segment moved for a limited extension across the Velabrum and the Forum Boarium in the 6th century, it did not activate to the NE along the Murcia Valley (Figs. 3 and 4; see the fault splays bordering the tectonically lowered sector to the NE).

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 geological and sedimentary processes that have affected the Tiber and its tributaries over the last few millennia have determined important changes in the geomorphology of the valley floors. Indeed, many anthropogenic 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. Notably, this study shows that the Murcia Valley, later occupied by the *Circus Maximus*, was suitable for human settlement since the Bronze Age. This area constituted a large plateau above the Tiber valley, a condition that would have favoured traffic, trade and meeting venues.

It is possible that the ancient writers echoed this landscape, and its progressively more intensive use, through the memory of legendary events and rituals attributed to the first mythical king, Romulus. According to the literary sources, the Murcia valley was the location of the earliest cult activities suggesting that it was a dry and accessible area. The festival in honour of the god *Conso* (*Consualia*) took place in the valley and horse races, considered the forerunners of the games performed in the later *Circus Maximus,* were included in the celebrations

(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; Bellotti, 2020), the dramatic alluvial episodes of the 6th century B.C. resulted in a rapid rise of the valley floor up to at least up to 6 m a.s.l. These important geomorphological changes and fast accumulation of sediments, that affected the main river valley and its tributaries, would have also affected the accessibility of the Murcia Valley. It is tempting to see these events in relation to the important urban infrastructure work sponsored in the valley floors by the last kings of Rome, at the end of the 6th century BCE. In particular, these hydrogeological processes could have been the reason for the reorganization of the settlement's drain system to reclaim public spaces mentioned in the ancient sources.

The ethno-historical accounts attribute major water management efforts and the building of a network of *cloacae* that converged in the *Cloaca Maxima*, including a *Cloaca Circi* in the Murcia valley, to the Tarquins (Bianchi, 2020; Buonfiglio, 2014, Buonfiglio et al., 2020, and references therein). There is no archaeological evidence for the *Cloaca Circi* and it is unknown where it would have connected and discharged into the *Cloaca Maxima*. However, with its own *cloaca* to drain the valley floor after each flood, the Murcia Valley would have become accessible again, on a new and higher level. The reclamation work was likely accompanied by other infrastructure that was also built in this period, such as the wooden stands erected to attend the games described by the ancient authors (Buonfiglio, 2018, and references therein). From this moment on, the Murcia Valley became the privileged and permanent 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 5th century BCE. In the following centuries an additional couple of metres 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 1st 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), but still necessitated a drainage ditch around the structure to keep it dry.

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

The present study offers some additional and more general considerations.

It confirms the occurrence of a significant base-level lowering in the Tiber River drainage network between 5000 and 3000 yr BP, which in the Murcia Valley corresponds to a drastic reduction of the sedimentation rate, likely linked to a strong climatic reversal (e.g., Magny et al., 2011) with 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 hydrological regime and sediment input. Possible causes may rely on both climate and anthropogenic (e.g., deforestation) factors. A low rainfall phase, with higher summer temperatures and cooler winters corresponds to the Bronze Age in Central Italy (Sadori et al., 2011; Goudeau et al., 2015), and it is followed by a period with a marked increase in precipitation 2700-2300 yr BP (Magny et al., 2013) that could be related to the unusual flooding event in the Forum Boarium.

In contrast, the flood clusters with overlapping periods at 2300-2100 yr BP and 2350-1850 yr BP in peninsular Italy suggested by Benito et al. (2015), are not consistent with the sedimentary record of the Tiber and Murcia valleys.

In addition, palynological data from several lakes in central Italy indicate that multiple cycles of forest reduction and re-growth coincide with the expansion of human settlements, at 3800–3600 and 3000-2800 yr BP, and at 2900-2800 yr BP (Sadori et al., 2011; Mercuri et al., 2002). A parallel marked increase in cultivated trees after 2800 yr BP suggests large-scale human-induced vegetation change (Follieri et al., 1988).

In light of these considerations, Marra et al. (2018) suggested that this chronologically broad and contrasting evidence for changes in vegetation cover and precipitation patterns could not by itself account for the shift in the river hydrology that triggered the sudden and unprecedented accumulation of alluvial deposits in the 6th century BCE.

Further investigations are in progress, in order to clarify the origin of these significant hydrological changes in the Tiber River catchment basin.

Data availability

^{14}C full analytical data are available in Supplementary Data Files #2 and #3.

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CRediT authorship contribution statement

Fabrizio Marra: Formal analysis, Writing – original draft, designed the geological study, performed the stratigraphic analysis, and wrote the paper. **Marialetizia Buonfiglio:** Investigation, Writing – original draft, undertook the geo-archaeological investigations, contributed to the writing of the paper. **Laura Motta:** Formal analysis, Writing – original draft, designed and performed data collection and analysis, contributed to the stratigraphic analysis, performed the archaeological study, contributed to the writing and edited the paper.

Declaration of competing interest

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.

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Appendix A. Supplementary data

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