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Long-lasting fault control on the Tiber River channel in Rome: did an ancestor of the Tiber Island exist in Pleistocene times?

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Abstract

In the present paper we have reconstructed the geologic substrate in the area of Rome comprised between the Capitoline Hill and the Colosseum. The analysis of the stratigraphic logs of a large number of boreholes allowed us to highlight the occurrence of a buried fluvial channel of the Paleo-Tiber River, the geometry of which mimics, almost exactly, the fluvial bend hosting the present-day Tiber Island. Several $^{40}Ar/^{39}Ar$ dates allowed at discriminating two aggradational successions filling this paleo-channel, deposited during two consecutive glacio-eustatic cycles corresponding to Glacial Termination VIII (621 ka) and VII (534 ka).

The buried paleo-channel corresponds with a partially obliterated NW-SE morpho-structural lineament affecting the present morphology, parallel to another, more marked lineament, hosting a tributary valley of the Tiber River, the Murcia Valley, 1 km to the southwest. Such lineaments match with the direction of the main Pleistocene extensional faults on the Tyrrhenian Sea margin of central Italy, which are re-activated under the present-day tectonic regime, exerting a close structural control on the drainage network of the Tiber River catchment in the area of Rome. The activity of one of these faults, running along the Murcia Valley, has been recognized to be responsible for the diversion of the Tiber course and the birth of the Tiber Island during the 6th century BCE. We conclude that a long-lasting structural control existed on this portion of the Tiber valley, which caused the repeated diversion of the river channel, around 650 ka and 550 ka, and ultimately in the 6th century BCE, creating the conditions for the origin of a fluvial island in correspondence with the fault-controlled river bend.

Keywords: Fluvial islands; Fault-control; Drainage networks; Alluvial valleys; Tiber Island

1. Introduction

Drainage network anomalies can be regarded as geomorphological indicators of active tectonics and are commonly used as a tool to infer the possible control of fault activity on the landscape, as well as, at a smaller scale, on fluvial channels (e.g. Macka, 2003; Kirby and Whittle, 2013; Baharami, 2013; Boulton et al., 2014; Calzolari et al., 2016; Pavano et al., 2016; Kent et al., 2017; Gioia et al., 2018). A close structural control on the drainage network of the Tiber River catchment in the area of Rome has been evidenced in the literature (e.g. Ciccacci et al., 1987; Caputo et al., 1993; Marra, 2001; Marra et al., 2022), while fault-control has been suggested to explain the over 2000 yr stable position of a meander of the Tiber River near the ancient roman port of Ostia (Goiran et al., 2014; Salomon et al., 2016; Marra et al., 2019), or the diversion of the Tiber channel and the origin of the Tiber Island (Marra et al., 2018, 2021).

Moderate seismicity with expected magnitude M_L <4 affects the area of Rome (Basili et al., 1996; Tertulliani and Riguzzi, 1995; Molin and Rossi, 2004; Galli and Molin 2014; Tertulliani et al., 2020), consistent with the lack of large earthquakes in the more than 2000 yr long historical record (Guidoboni et al., 2018; Rovida et al., 2020). However, the streambed directions and those of the major alluvial valleys reflect the orientation of the main NW-SE trending extensional faults and of the N-S strike-slip faults that were active during middle-upper Pleistocene (Marra et al., 2022, and ref. therein). This complex network of tectonic lineaments is presently re-activated under a faint NE-SW extensional regime (Amato and Chiarabba, 1995; Mariucci et al., 1999; Montone and Mariucci, 2016) and its deformation is associated with local moderate seismicity (Marra, 1999; Frepoli et al., 2010; Marra et al., 2022).

Regardless of the actual tectonic mechanism (sudden fault displacement vs. progressive creeping deformation) or fault behavior (seismic vs. aseismic), as discussed in detail by Marra et al. (2019, 2021), there is a clear correspondence between streambed directions and the main NW–SE and N–S faults, which is evident even in a DEM image of the greater Rome area (Fig. 1a). In particular, a marked NW-SE morpho-structural lineament coincides with the Murcia Valley, the NW continuation of which aligns with the Tiber Island. Marra et al. (2018) formulated the hypothesis that fault displacement along this structural lineament caused the diversion of the Tiber course, triggering the origin of the Tiber Island (Fig. 2). Through the study of the cores of more than 20 boreholes performed within the Sant'Omobono Project (https://sites.lsa.umich.edu/omobono/) Marra et al. (2021) recognized the vertical offset affecting a characteristic chronostratigraphic marker represented by a ca. 20 cm thick gravel layer occurring at the base of a thick succession of clayey deposits which where rapidly deposited in less than one century since the early sixth century BC. Such ca. 1.5 m offset allowed to trace the fault line crossing through the Tiber alluvial plain and bordering the Tiber Island to the NE (Fig. 1b-b′). The position of the Tiber Island is strictly constrained by the geomorphological lineament represented by the rectilinear trend of the Murcia valley, which corresponds to the fault B in Fig. 1b-b′, identified by the riverbed offset. The Authors concluded that its birth was the result of the combined effect of the fault trace to constrain the river bend, and the rapid rising of the valley floor at the end of the sixth century.

In the present paper we have reconstructed a buried fluvial channel of the Paleo-Tiber River in the center of Rome which geometry mimics, almost exactly, the fluvial bend hosting the present-day Tiber Island, occurring 1 km to the east. Thanks to the analysis of the stratigraphic logs of a large number of boreholes performed for the realization of the Metro C line and the direct observation of several borecores, Marra et al. (2024) have reconstructed the geologic substrate in the area comprised between the Capitoline Hill and the Colosseum. $^{40}Ar/^{39}Ar$ dating of 4 samples of volcanic layers and detrital sanidine strictly frame the age of the gravel layer filling the reconstructed paleo-riverbed within the interval 548±5-534±2 ka, allowing to correlate it with the basal gravel layer of the aggradational succession deposited in response to sea-level rise during termination VII at the onset of MIS 13 (Valle Giulia Formation, Marra and Rosa, 1995; Marra et al., 2017).

Here we provide a detailed reconstruction of this gravel layer, showing the occurrence of a collapsed geometry within a NW-SE elongated sector, in which the base and the top of the gravel horizon are at lower elevation than in the surrounding area. Such buried collapsed sector is interpreted as a paleo-fluvial channel (e.g. Moscatelli et al., 2012; Pagliaroli et al., 2013; Marra and Florindo, 2014; Mancini et al., 2023), corresponding with a partially obliterated NW-SE lineament affecting the present morphology, parallel to that hosting the Murcia Valley 1 km to the SE (Fig. 1b). This evidence calls for a long-lasting structural control on this portion of the Tiber valley, which caused the repeated diversion of the river channel, around 650 ka and 550 ka, and ultimately in the 6th century BCE. As in occasion of such last occurrence, it is likely that also in the past this phenomenon originated an island within the fault-controlled river bend, as discussed in this paper.

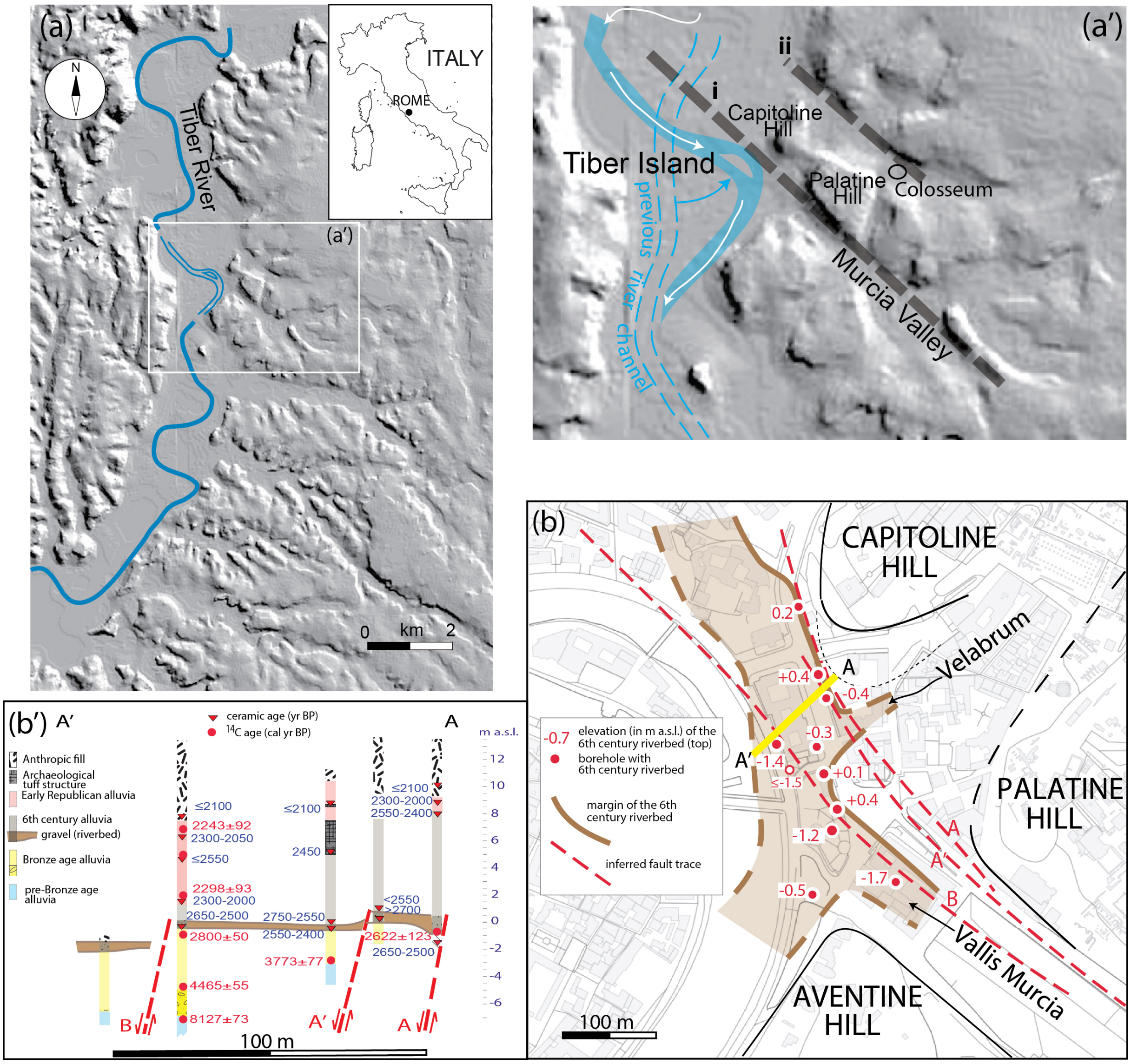

Figure 1. (a) DEM image (Tinitaly, property of INGV) of the area of Rome and detail (a′) of the investigated area, showing the marked features of the drainage network of the Tiber River. (b) Map reconstruction and cross-section (b′) of the 6th century riverbed showing the offset affecting the gravel layer dated at ~2550 yr BP (modified from Marra et al., 2021). Elevation of the boreholes is assessed with ±1 cm precision through geodetic measures performed by Marra et al. (2018, 2021).

2. Geologic setting

The area of Rome was characterized by marine sedimentary conditions during Pliocene through Early Pleistocene times (Marra and Rosa, 1995; Funiciello et al., 2008). These conditions were terminated by magma uprising in the underlying crust which was responsible for progressive upwelling, leading to the establishment of a Paleo-Tiber delta since ca. 800 kyr BP (Bellotti et al., 1994; Marra et al., 1998), concurrently with the start of the volcanic activity of the highly potassic "Roman Magmatic Province" (Peccerillo, 2017). A transgressive coarse gravel horizon, up to 10 m in thickness, overlies the eroded marine clay substrate in the area of Rome, while intercalations of gravel and clay layers fill a ca. 80 m deep tectonic depression ("Paleo-Tiber Graben", Marra and Rosa, 1995) to the NE of the City (Fig. 2d).

Age of these gravel horizons ranges from 1.2 to 0.6 Ma (Florindo et al., 2014; Marino et al., 2024) and their deposition at the base of coastal to continental fining upward sequences ("aggradational successions") is a marker of the Pleistocene glacial terminations (Marra et al., 2008, 2016, 2022; Giaccio et al., 2021). A thick cover of pyroclastic deposits erupted since 600 ka by the Monti Sabatini and Colli Albani volcanic districts (Fornaseri et al., 1963; De Rita et al., 1988; Funiciello et al., 2008; Marra et al., 2020, and ref. therein) emplaced above the early fluvial-to-littoral deposits of the Paleo-Tiber, forming the geologic substrate in the morphologically higher sectors, whereas they are partially eroded and intercalated with later sedimentary deposits within the paleo-incisions. During Middle-Late Pleistocene the sedimentary processes in the area of Rome were controlled by interplay among sea-level changes linked to glacio-eustatism, volcanic activity and tectonics (Luberti et al., 2017, and ref. therein). A well-defined drainage network developed in the area of Rome in consequence of the combined effect of the sea-level fluctuations and a ~50 m tectonic uplift that occurred in the last 250 kyr (Karner et al., 2001; Marra et al., 2016a), causing the alluvial valleys to display prominent and steep banks bordering the floodplains (see Fig. 1). These marked features are partially obliterated in the urban area, where more than 2,000 years of anthropic activity deeply modified the original morphology (Del Monte et al., 2016; Luberti et al., 2018), but they are clearly detectable in the DEM images of the greater area of Rome (e.g. Fig. 1a).

3. Material and methods

The analysis and stratigraphic re-interpretation of 164 borehole stratigraphies provided by Metro C and other 485 logs stored in the databank created by the PREDICT Project has been conducted for the present work, based on constraints provided by direct observation and $^{40}Ar/^{39}Ar$, paleomagnetic and micropaleontologic analyses performed on the cores of 3 boreholes drilled by the PREDICT Project in the historical center of Rome and the cores of 2 boreholes stored at Musei Capitolini (Fig. 2a) (Marra et al., 2024).

With respect to previous analysis published in Marra et al. (2024), here we have selected all the stratigraphic logs which reported the occurrence of gravel layers (black dots in Fig. 3a) and re-interpreted their chronostratigraphic attribution using the directly observed cores of four boreholes performed within the PREDICT Project (RM-BN, RM-CO, RM-QU, RM-CA) and other research projects by the INGV (ING, PR1, VVM, PSA) (Fig. 2a), in which $^{40}Ar/^{39}Ar$ dating provided geochronologic constraints to several gravel horizons, as a reference. In order to provide reliable lateral correlation and assess exact vertical offsets, only boreholes reporting ground elevation measured through geodetic surveys were considered (i.e. all the Metro C dataset and over 150 boreholes provided by private companies for which the elevation assessed with this method was reported). Elevation of the other boreholes employed in the reconstructions was assessed with ±1 m precision by reporting their location on Google Earth.

Such detailed re-analysis allowed us to refine the reconstruction of the complex morpho-stratigraphic pattern in central Rome, and to distinguish the paleo-channels of the Paleo-Tiber River in the area comprised between the Tiber Valley and the Colosseum.

4. Results

Through the analysis of 650 borehole stratigraphic logs (Fig. 2a), validated by direct observation of the cores of twelve 30 to 120 m deep boreholes performed in the last 30 years by the INGV and other public institutions (larger symbol in Fig. 2a), we have reconstructed the top surface of the Pliocene clayey marine substrate in central Rome (Fig. 2b), and that of the basal gavel horizon which transgressively overlies it in the sector located on the hydrographic left of the modern Tiber River (Fig. 2c).

Both these surfaces are affected by an elliptical depressed sector comprised between the Capitoline Hill and the Colosseum, more marked at the top of the Pliocene substrate, where it is 15 m lower than in the surrounding, flat area (Fig. 2b). Similarly, the top of the gravel horizon reaches down to −5 m a.s.l. in this small area, as opposed to a relatively flat surrounding area at +5 m a.s.l. (Fig. 2c). The NW-SE elongation of the lowered sector, parallel to the Murcia Valley located to the SW, and its correspondence with a morphologically depressed sector which characterizes the present-day topography (Fig. 1b), clearly indicate that it represents the buried evidence of a fluvial paleo-valley. However, the closed feature and the depth of this depression are not compatible with a fluvial channel, as discussed in the next section, and calls for a tectonic collapse. Indeed, both these valleys match marked NW-SE morpho-structural lineaments (i and ii in Fig. 1a′), evidencing a structural control on their flow direction and suggesting that the observed buried depressed sector was originated by progressive tectonic deformation, due to repeated displacement along the fault a shown in Fig. 2b. The persistence of a structurally-controlled paleo-channel

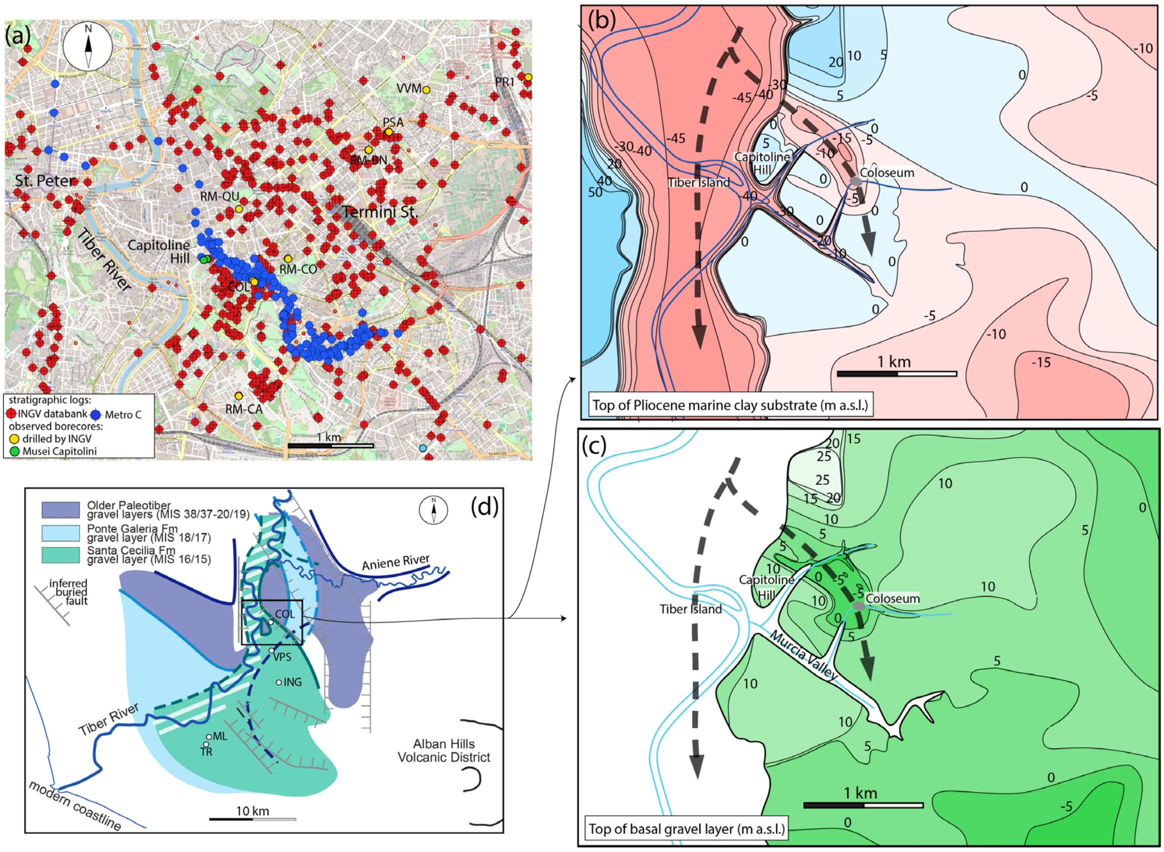

Figure 2. (a) Satellite image of central Rome showing the location of the boreholes used in the present study. (b) Isobath map of the top surface of the Pliocene marine clay substrate. (c) Isobath map of the top surface of the gravel horizon overlying the Pliocene substrate. Thick dashed black lines show the fluvial channels of the Plaeo-Tiber River. (d) Paleogeography of the Paleo-Tiber delta and distribution of the basal gravel layer of the aggradational successions deposited in the interval 1300-600 ka (from data in Marra and Florindo, 2014; Florindo et al., 2024). Only one NW-SE trending fault was previously hypothesized in historical center of Rome, northeast of the Colosseum, based on a lesser number of borehole data with respect to the more detailed reconstruction performed in the present work (see Fig. 3).

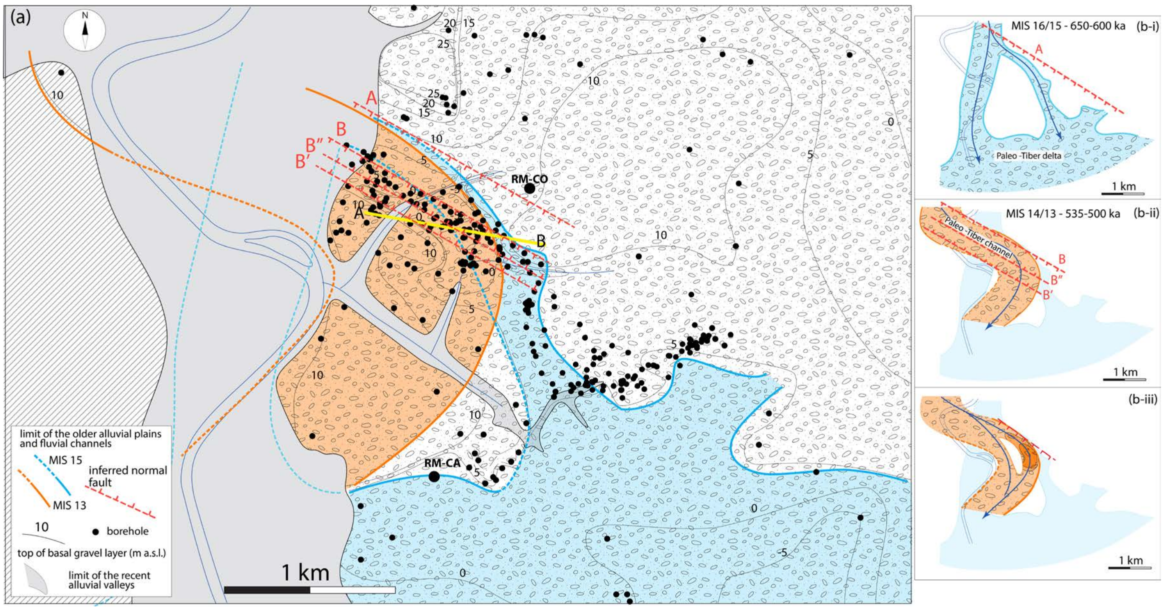

Figure 3. (a) Isobath map (in m a.s.l.) of the top surface of the gravel horizon and (b-i) Reconstruction of the Paleo-Tiber mouth at 650 ka; (b-ii-iii) Reconstruction of the river bend at 550 ka and of the fault process which caused the collapse of the gravel layer and the possible origin of a fluvial island (see text for comments and explanation).

is supported by geochronologic and stratigraphic constraints to the sedimentary deposits, which evidence the presence within the depressed sector of three erosionally embedded aggradational successions, correlating with MIS 15, MIS 13, and MIS 11 (Figs. 3 and 4), as also discussed in the next section.

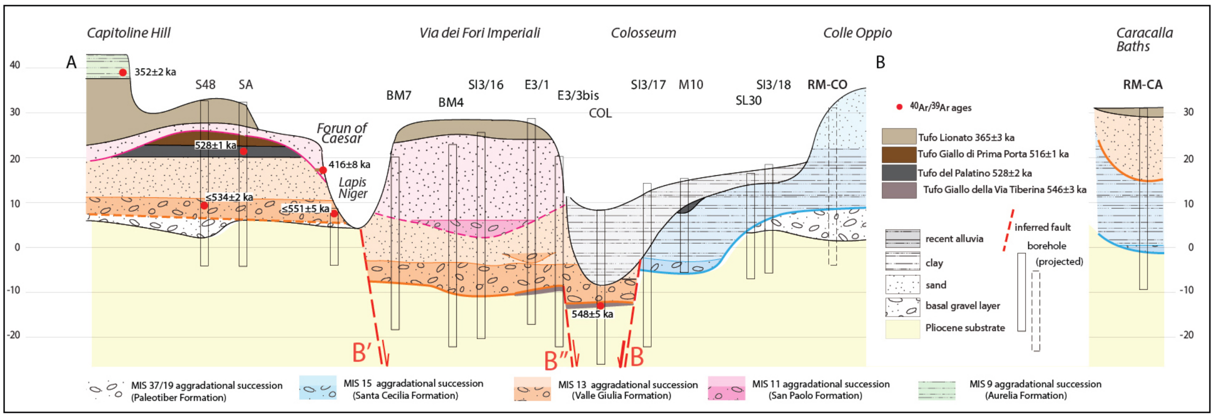

Figure 4. Cross-section (see track of porofile A-B in Fig. 3a) showing the complex pattern of embedded aggradational successions filling the paleo-incisions excavated during periods of sea-level falls 650 through 350 ka, reconstructed based on borehole data and geochronologic constraints.

5. Discussion

5.1 Age of the fluvial channels

Some crucial direct observations allowed us to recognize the occurrence of three distinct aggradational successions embedded with each other within the abandoned channel of the Paleo-Tiber, and to correlate them with MIS 15, MIS 13, and MIS 11. In particular, the basal gravel layer of a channeled MIS 15 aggradational succession, characterized by a distinctive section of “blue clays” (i.e. homogeneous grey clay with diffused veils of organic matter), has been geochronologically and paleomagnetically correlated through the Colosseum (Borehole M10, Florindo and Marra, 1995) and southern Rome (borehole ING, Florindo et al., 2007) (Marra and Florindo, 2014, Fig. 2d). Within the investigated sector (between boreholes M10 and RM-CA) elevation of the MIS 15 gravel layer displays sub-horizontal attitude between 0 and −5 m a.s.l. (Fig. 3a).

In contrast, within the NW-SE elongated depressed sector, the age of the gravel layer is well-constrained to the period of sea-level rise at the onset of MIS 13. This is supported by the ^{40}Ar/^{39}Ar ages, including 548±5 ka (Karner and Renne, 1998) from the distal pyroclastic-flow deposit of Tufo Giallo della Tiberina (546±3 ka, Marra et al., 2014), which is located at the base of the layer in borehole COL, and 533±4 ka from detrital sanidine (i.e. reworked) extracted from a sample at the top of the gravel layer in borehole S48, providing a maximum age to the deposit (Fig. 4). Consistently, the gravel layer below the Colosseum was originally attributed (Bozzano et al., 1995) to the MIS 13 aggradational succession (Valle Giulia Formation). In contrast, later works (Moscatelli et al., 2012; Pagliaroli et al., 2013; Mancini et al., 2014, 2023, and ref. therein), have interpreted the sedimentary succession filling the paleovalley as hosting the MIS 11 aggradational succession (San Paolo Formation, Marra and Rosa, 1995) relying on the age of 416±8 ka (Karner and Renne, 1998) of a pumice fallout layer intercalated within the sedimentary deposits of the San Paolo Formation cropping out at Forum of Caesar (Karner and Marra, 1998) (Fig. 4). However, the ^{40}Ar/^{39}Ar ages provided in the present work, combined with the stratigraphic reconstruction in this sector realized with the Metro C boreholes and those performed by INGV, confirm previous attribution to MIS 13 and show that the fluvial-lacustrine deposits of the San Paolo Formation occur on top of the partially eroded MIS 13 aggradational succession (see cross-section in Fig. 4). The contact between these aggradational cycle is only tentatively assessed (dashed magenta line in Fig. 4), based on the occurrence of a possible basal gavel layer of the San Paolo Formation. However, it is not excluded that this lens of gravel is part of the Valle Giulia Formation, resulting from the eastward and downward migration of the fluvial channel originated by sin-sedimentary fault displacement (see Fig. 5).

5.2 Structural control on the fluvial channels

The strongly anomalous low elevation of the top of the Plio-Pleistocene substrate underlying the MIS 13 gravel in the area corresponding the paleo-channel, which is more than 15 m lower than the average elevation displayed throughout the surrounding area (Fig. 3a), couldn't be originated by regular fluvial erosion near the coast. Indeed, it is too deep to be explained with over-excavation of the fluvial channel at a river bend or meander (e.g. Ferguson et al., 2003; Blanckaert, 2011). Moreover, the occurrence of a several hundred meters thick clay succession (Signorini, 1939) excludes the presence of sinkhole processes.

Besides the close match with a NW-SE morpho-structural lineament visible in the DEM, cross-section A-B in Fig. 4 clearly shows that this feature is originated by fault displacement. Several boreholes at the Capitoline Hill, including the directly observed S48 and SA borecores, show that the basal gravel layer of the MIS 13 aggradational succession has a tabular trend, with the top around 10 m a.s.l., while a number of Metro C boreholes along Via dei Fori Imperiali (BM7, BM4, SE/13, E3/3bis) highlight the sudden 15 m drop of this stratigraphic horizon, which is here interpreted as a tectonic depression ("graben") originated by two antithetic NW-SE, extensional faults (Fig. 3a). Notably, the preservation below the gravel layer of the pyroclastic-flow deposit of Tufo Giallo della Via Tiberina, as observed in boreholes E3/3bis and COL, excludes that the deepening of the base of this layer may be due to erosion at a river bend (Fig. 4).

While such large vertical displacement is likely the result of a long-lasting deformation process since 550 ka, other elements may suggest that it was a fast collapse occurred during glacial termination VIII, concurrently with the last stages of gravel accumulation. Indeed, the occurrence of two gravel lenses above the basal gravel horizon within the tectonically lowered sector can be interpreted as the result of progressive upward migration of the riverbed during the tectonic collapse. The coarser grainsize of the sedimentary deposits overlying the gravel in the depressed sector (medium to coarse sand, with subordinated clayey sand intercalations), as opposed to the prevalently sandy clay section occurring at the Capitoline Hill, also may be regarded as deposited during a period of high water transport capacity (concurrently with gravel) within a quickly subsiding channel. However, it may also reflect a lateral variation in grainsize due to the higher water velocity in the external sector of the river bend (e.g. Ferguson et al., 2003). A fact that may also explain the occurrence of small gravel lenses, reflecting the position of the riverbed, within the fine-grained sedimentary succession in this sector, and its persistence (in space and time) further proves the fault-controlled sedimentary process.

5.3 Seismotectonic implications

Understanding the tectonic style associated with the activity of these faults goes beyond the scopes of the present work; however, because this issue has implications for the seismic hazard in the City of Rome, it deserves to be briefly discussed.

A cumulated tectonic deformation during the last 550 ka to explain the observed 15 m collapse of the Pliocene substrate is in line with regular fault slip rates, which in the nearby central Apennines region is estimated to range between 0.08-1.48 mm/yr (Carafa et al., 2022, and ref. therein). Assuming a continued deformation process during the last 550 ky would imply a very modest slip rate of 0.027 mm/yr, consistent with the smaller extensional rates active on the Tyrrhenian Sea margin where Rome is located (e.g. Montone and Mariucci, 2016). However, the activity of the NW-SE faults bordering the collapsed sector should be considered to have occurred in a more limited, younger time span, as the abandonment of the paleovalley and the successive SW migration in the Murcia Valley of the tectonic deformation suggests. Indeed, the abandonment of the valley crossing between the Colosseum and the Capitoline Hill must postdate MIS 11, at the least (400 ka). In the Murcia Valley, a much younger activity is inferred for the faults responsible for the birth of the Tiber Island. Here, a throw of 1-1.5 m affects the 2.55 ka Tiber riverbed gravel layer at the base of the 6th century alluvial succession (Marra et al., 2021). Such offset may be considered as a relatively sudden event, as also suggested by observation in thin section of microfaulting affecting the 6th century alluvial sediments with dip-slip, millimiter offsets (Brock et al., 2024). Such feature suggests a rigid behavior, as opposed to progressive, slow deformation.

However, such large displacements are generally associated with big earthquakes (e.g. M≥6.5, Wells and Coppersmith, 1994), while historical and instrumental records indicate a maximum expected magnitude ML = 5.6 for the City of Rome (Tertulliani and Riguzzi, 1995; Guidobobni et al., 1997; Molin and Rossi, 2004; Rovida et al., 2020).

Unless a recurrence time >2000 years is hypothesized, an aseismic, creeping behavior (e.g. Kaduri et al., 2017) should be assumed as the faulting mechanism in Rome, which may be regarded as consistent with the vertical tectonics acting in this region during the last 300 ka (Karner et al., 2001), that resulted in ca. 50 m uplift of the Tyrrhenian Sea margin in Central Italy (Marra et al., 2016a). Under such conditions, aseismic re-activation of small segments of pre-existing fault lines cannot be excluded, also triggered by strong earthquakes occurring in the nearby Apennine region.

5.4 Origin of the Tiber islands 650 ka through the Present

Fluvial islands are commonly ephemeral objects, rapidly shaped and destroyed by seasonal hydrologic regimes. Cases of prolonged stability have been discussed in the specialized literature and sometimes related to rapid vegetation colonization (e.g. Winterberger et al., 2016, and ref. therein).

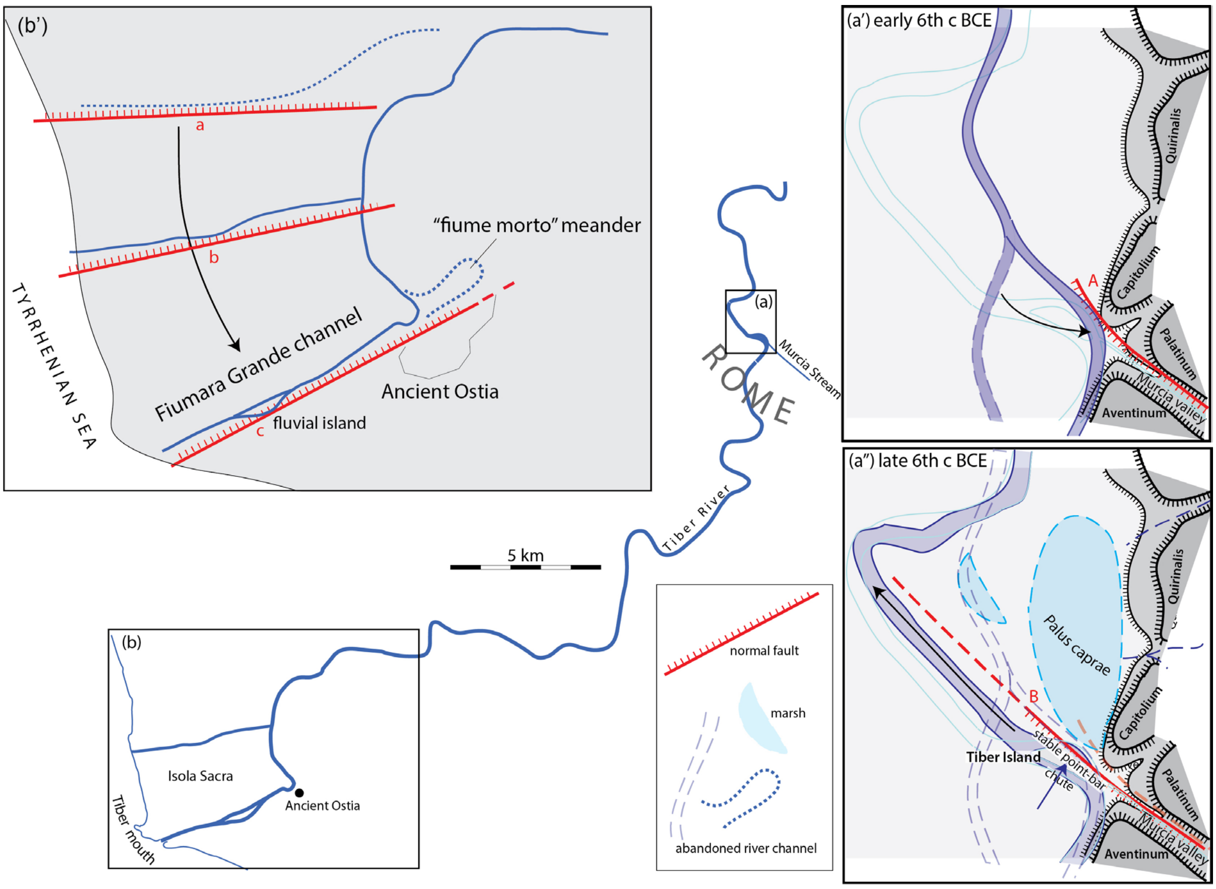

Figure 5. Location of the two fluvial islands (a) Tiber Island, (b) Fiumara Grande island, occurring along the terminal tract of the Tiber River. Insets (a′-a″) and (b′) show the tectonic processes suggested to be at the base of the birth of these fluvial islands (see text for comment and explanation).

Only two fluvial islands occur along the 40 km long terminal tract of the Tiber River: the Tiber Island in central Rome, and one unnamed island in the Fiumara Grande river branch that reaches the sea, southwest of the ancient Roman harbor of Ostia (Figs. 5a and b, respectively). While the mechanism of formation of a fluvial island as the evolution of a point bar in correspondence with a river bend (see Fig. 5a′-a″) is well-known in the literature (e.g. Bridge and Jarvis, 1982), we remark on the peculiar position and stability of the Tiber channel where the two fluvial islands are located. Indeed, both these islands occur in correspondence with rectilinear stretches of the Tiber channel, which are parallel to the direction of the main NW-SE and NE-SW extensional faults that were active on the Tyrrhenian Sea margin in Pleistocene times (Acocella and Funiciello, 2006, and ref. therein). Moreover, the

Fiumara Grande island is not located on a river bend but along a straight NE-SW trending channel, which continues from a recently abandoned meander ("Fiume morto", Fig. 5b′). This meander, also narrowly NE-SW elongated, has exhibited an anomalous stability lasting over 2000 years, as noted from historical sources and archaeological data attesting its existence in ancient Roman times (Goiran et al., 2014; Salomon et al., 2016). The strict structural control by a NE-SW trending fault on the meander and on the origin of the fluvial island occurring along the associated fluvial channel has been suggested in Marra et al. (2019). These authors interpreted the hydrographic pattern in the area outlined in Fig. 5b′ as resulting from the structural control on three parallel (paleo)channels, progressively originated through time by the southward migration and counterclockwise rotation of the normal faults (a, b, c in Fig. 5b′) of the Tiber delta half-graben (Ciotoli et al., 2013, 2015).

A similar hydromorphologic framework occurs in central Rome, where the Tiber Island is located between two NW-SE elongated fluvial channels flowing in the Tiber and the Murcia valleys (Fig. 5b), the direction of which match that of the major extensional faults operating an evident structural control on the major stream valleys in Rome (Fig. 1a).

The reconstruction of sediment-aggradation phases in the Tiber valley has evidenced a sudden shift of the riverbed from the center of the alluvial valley to the foot of the Capitoline Hill occurred between the 8th and the beginning of the 6th century BCE, which Marra et al. (2021) hypothesized to have been triggered by displacement on a first fault segment (A in Fig. 5a′). Activation of a second fault segment (B in Fig. 5a′) would have been responsible for a further diversion of the river course and for the stability of the riverbed throughout the overflooding phase occurred during the 6th century BCE, leading to the birth of the Tiber Island in consequence of the evolution of a point bar (Fig. 5a").

The framework of hydrographic and morpho-structural factors that lead to the origin of the Tiber Island is remarkably similar to that reconstructed for the paleo-channels of the Tiber rivers in the very same area 650 and 550 ka (Fig. 3a).

In the case of the 650 ka Paleo-Tiber (Fig. 3b-i), a secondary fluvial channel is recognized at the southwestern margin of the morphologically high central sector in Rome, in correspondence of the previously mentioned NW-SE morpho-structural lineament (Fig. 1a′). The minor character of this paleo-channel with respect to a major fluvial channel corresponding with that of the modern Tiber is inferred from its reduced width, which couldn't allow for transportation of the huge amount of gravel emplaced in the Paleo-Tiber delta 650 ka (see also Fig. 2d). Notably, this paleogeographic reconstruction mirrors that at the present Tiber mouth, with a large fluvial island ("Isola Sacra", Fig. 5b) comprised between two fault-controlled fluvial branches. Indeed, the 650 ka coastline and the Paleo-Tiber delta were located more inland, in the present historical center of Rome (Fig. 3b-i).

A different paleogeographic situation, much more similar to the present-day, is outlined at 550 ka due to the intervening significant progradation of the Paleo-Tiber mouth linked with regional uplift (Karner et al., 2001). The large number of investigated boreholes allows at reconstructing a fluvial paleo-channel which mimics the present Tiber River bend in correspondence of which the Tiber Island is located. The large width of this paleo-channel reflects a closer position of the paleo-coast and the consequent widening of the paleo-channel, as well as the fact that the gravel emplaced during a phase of lateral migration of the riverbed in a braided-channel environment, during the last stages of the MIS 14 sea-level low-stand. Only during the successive sea-level rise following glacial termination VII (534 ka, Lisiecki and Rasymo, 2005) a narrow river channel established and the conditions to create a relatively stable fluvial island became possible. In our reconstruction, the position of such river channel in the sector between the Capitoline Hill and the Colosseum was strictly forced by a new set of extensional faults (B, B′ in Fig. 3b-ii), creating a river bend and the condition for the migration of a point-bar, similarly as reconstructed for the Tiber channel during the 6th BCE which lead to the birth of the Tiber Island. It is therefore possible to imagine that an ancestor of the modern Tiber Island existed at this stage of the landscape evolution, around 550 ka (Fig. 3b-iii).

6. Conclusions

A persistent structural control on the Tiber River channel in central Rome, constraining the position of a river bend in the same area 650 ka through the present, has been evidenced through the analysis of a large number of borehole stratigraphic logs, borecores, and $^{40}Ar/^{39}Ar$ dating of the sedimentary deposits.

Such tectonic control is the result of the activity of a set of NW-SE trending normal faults, consistent with the extensional regime acting on the Tyrrhenian Sea Margin of central Italy throughout the Pleistocene. Such faults are associated with a set of parallel structural lineaments, controlling the geometry of the stream valleys in the area of Rome, one of the most prominent one coinciding with the Murcia Valley, which has been recognized responsible for the diversion of the Tiber course and the origin of the Tiber Island during the 6th century BCE.

Here we have shown that the activity of a NW-SE parallel fault, located 1 km to the NE, is the likely responsible for the presence of a river bend in this sector already since 650 and 550 ka, during two consecutive post-glacial aggradation cycles of the Paleo-Tiber River. We conclude that the presence in this tract of the river of a fluvial island may have been a persistent feature which characterized the local landscape well before the foundation of Rome.

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