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STRATIGRAPHY OF THE PALATINE HILL (ROME, ITALY): A RECORD OF REPEATED MIDDLE PLEISTOCENE-HOLOCENE PALEOVALLEY INCISION AND INFILL

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ABSTRACT**:** The Palatine Hill in Rome (Italy) represents a key site for better understanding the Middle Pleistocene-Holocene continental deposits of the Rome basin that could be investigated by the numerous boreholes drilled during the last few decades for archeological and cultural heritage conservation. In this study, 12 cores selected for their excellent recovery rate and stratigraphic coverage are described in detail discriminating 23 lithofacies. The stratigraphic data, used in combination with the information from nearby outcrops and additional boreholes provide insights into the depositional architecture of multiple incised fluvial valley infills developed in response to sea-level fluctuations occurred between Marine Isotope Stages (MIS) 16 and 1. These infills comprise a range of fluvial deposits of the Tiber River system which interfinger with accurately dated pyroclastites from the Alban Hills and Sabatini Mts., thus providing important time constraints on the formation of paleovalleys. The paleovalleys correlated to MIS 14-13, 12-11 and 5d-1 have particularly well-preserved infills constituting useful analogues of trunk and tributary paleovalleys. Because the recognized lithofacies represents the building blocks of the lithostratigraphic, synthemic and sequence stratigraphic units currently in use at basin-scale, we believe their accurate field and core description complemented by graphical logs and photographic plates is important for identifying similar facies in future investigations on nearby paleovalley infills.

Keywords: fluvial paleovalleys, Middle Pleistocene, Holocene, Rome, facies analysis

1. INTRODUCTION

Urban geology requires thoughtful integration of geognostic data (borehole lithology, geotechnical tests, geophysics) and information from nearby outcrops, which are often sparse due to cover by man-made deposits and structures. In sedimentary successions, this requires a hierarchical approach entailing prior recognition of key stratigraphic surfaces bounding genetically-linked deposits, followed by detailed borehole lithology correlation. Implementing such an approach is particularly challenging in superimposed unconformity bounded stratigraphic units (USBU), such as multiple fluvial incised valleys lacking a robust stratigraphic reference model.

Fluvial incised valleys, or paleovalleys (*sensu* Blum et al., 2013) develop in the lower reach of fluvial systems as a result of readjustment of the equilibrium profile following base level changes driven by eustasy, tectonics or a combination of the two. During Quaternary, the dynamics governing paleovalley incision and sedimentary infill is primarily modulated by glacio-eustatic sea-level fluctuations (Wright & Marriott, 1993; Shanley & Mc Cabe, 1994; Blum et al., 2013), with formation of a basal high-relief unconformity deeply eroded into older deposits (or the bedrock) during base level falls and low-stands, and subsequent backfilling during base level rises and high-stands.

Understanding the subsurface stratigraphy of urban areas characterized by the presence of paleovalleys is made even more challenging by the poor quality and/or detail consistency of the typically available subsurface data, which are in general compiled from different sources (technical reports, geological maps, research papers) over time spans of a few to several tens of years. However, several study cases exist where physical-stratigraphy, facies analysis and sequence stratigraphy concepts are used to guide interpretation and modelling of subsurface datasets from urban areas (Ellison et al., 2004; Sarti et al., 2012; Amorosi et al., 2013; Bridgland et al., 2013; Tanabe et al., 2015; Milli et al, 2016; Van Dinter et al., 2017; Marini et al., 2018, among the others).

The present contribution reports on the sedimentary facies from Middle Pleistocene to Holocene fluvial paleovalley infills from the Palatine Hill of Rome (Italy), a world-class archeological site whose subsurface was deeply investigated over the last decades for cultural heritage preservation purposes (Cecchi, 2011). Based on detailed logging of cores from 12 boreholes with excellent recovery and stratigraphic record and ancillary observations from nearby outcrops (some of which temporary), this work intends to: i) give insights into the facies architecture of excellent examples of paleovalley infills with a well-established stratigraphic framework owing to intercalation of dated volcanics; ii) refine the existing models of subsurface geology (Moscatelli et al., 2012, 2014a, 2015; Mancini et al., 2013, 2014), and iii)

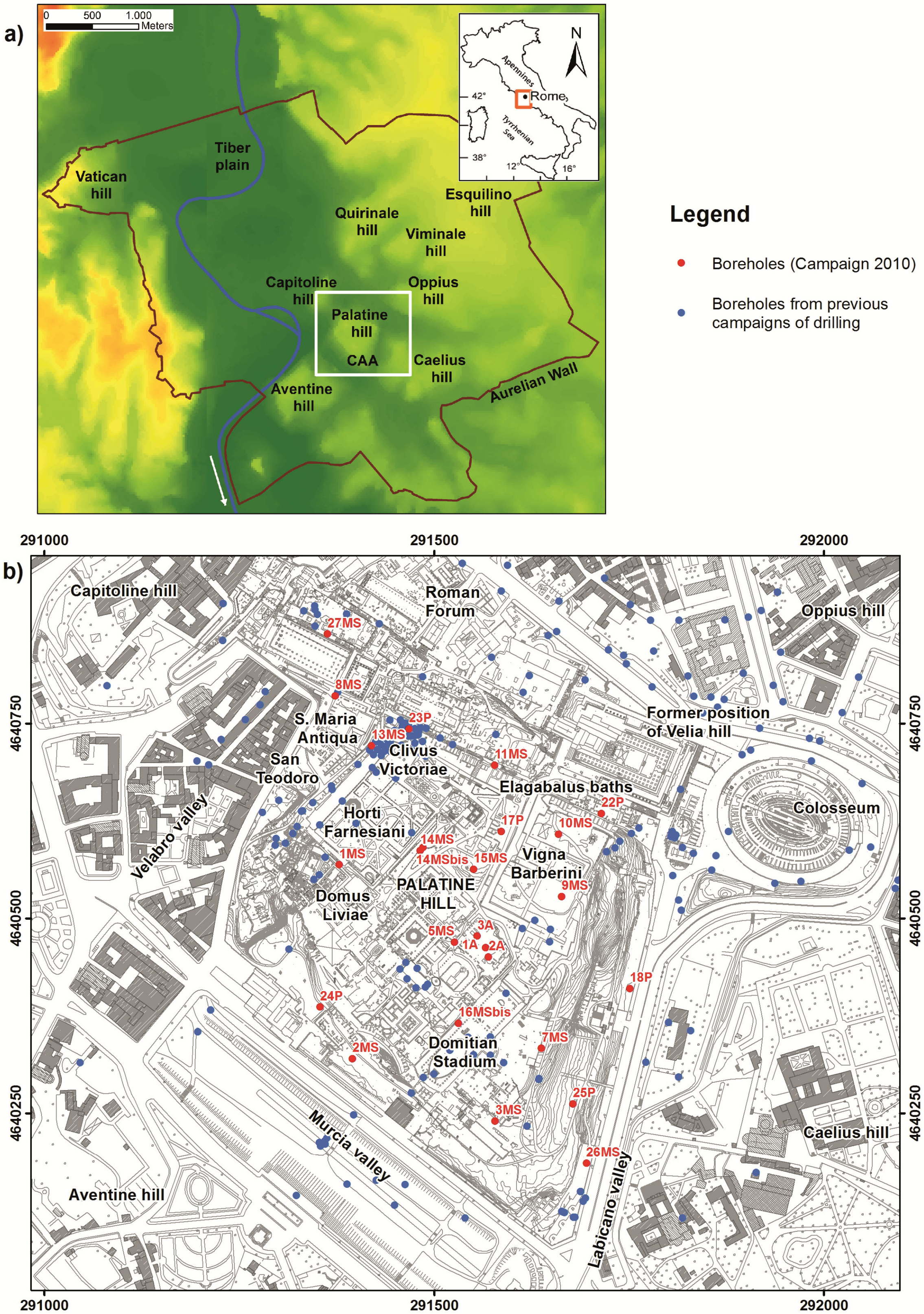

Fig. 1 - a) Location of the Palatine Hill within the historical center of Rome; the inset is referred to Fig. 1b. b) Topographic map of the Palatine and surrounding areas.

provide detailed descriptions and iconographic material useful for identifying similar facies in future investigations in nearby areas and similar deposits.

2. GEOLOGICAL AND STRATIGRAPHIC SETTING

The Palatine (Fig. 1a) is one of the world-renown "Seven Hills" of Rome, onto which the city was founded (De Angelis D'Ossat, 1956; Heiken et al., 2005; Funiciello et al., 2006). It is a 25-ha wide flat-topped hill with an elevation of ca. 50 m a.s.l. composed by a complex stack of sedimentary and pyroclastic rocks. To NW, SW and SE the Palatine is bounded by the relatively narrow Velabro, Murcia and Labicano alluvial valleys, which separate it from the Capitoline, Aventine and Caelius Hills, respectively (Fig. 1b).

Because the Palatine hosted the first settlement of ancient Rome (Brocato & Terrenato, 2016), the present-day landscape records a long-lasting history of anthropogenic modifications, witnessed by several superimposed archaeological ruins of different ages. The Palatine is bounded to NE by the Fori Imperiali-Roman Forum, a mixed natural and anthropogenically-modified depression separating the Palatine from the nearby Oppius Hill. In this specific place, the small former Velia Hill was present until the 30s of the 20th century (Fig. 1b), when it was cut away for the construction of Via dei Fori Imperiali (De Angelis D'Ossat, 1956; Palombi, 1997, 2016; Lanzini, 2008; Leone et al., 2009). The morphology of the Palatine itself was modified. Originally, it, featured two culminations to the SE and the W of the present-day hilltop referred to by historians as *Palatium* and *Germalus*, respectively (Castagnoli, 1980).

The Seven Hills are located at the periphery of the volcano-sedimentary plateau of the Alban Hills and Sabatini Mts Volcanic Districts, whose deposits were incised by the Tiber River and its tributaries (Fig. 2) (Del Monte et al., 2016). The Pliocene-Quaternary succession of the area represents part of the infill of the Rome Basin, an extensional basin developed since the earliest Pliocene as a result of back arc extension in the Tyrrhenian Sea (Patacca et al., 1990; Cavinato & De Celles, 1999; Mattei et al., 2010).

The geological bedrock of this succession consists of up to 900 m-thick Pliocene marine sediments (comprising the clayey Monte Vaticano Formation), which overlay with angular unconformity the Mesozoic-Cenozoic carbonate and siliciclastic successions of the Central Apennines (Funiciello & Parotto, 1978; Funiciello & Giordano, 2008; Giordano & Mazza, 2010). The Pliocene sediments are in turn overlain by Calabrian shallow marine sediments and by a 30-150 m -thick suite of latest Early Pleistocene-Holocene volcanic and sedimentary deposits (Conato et al., 1980; Milli, 1997; Marra et al., 1998, 2008, 2009; Giordano et al., 2003, 2006; Funiciello & Giordano, 2008, 2010; Cosentino et al., 2009; Luberti et al, 2017). This volcano -sedimentary succession recorded complex phases of syn-uplift, climate-eustatically forced and volcano-controlled basin infill, with pyroclastites and lavas sourced from the Sabatini Mts and Alban Hills Districts (Fig. 2).

A key element of the volcano-sedimentary complex is the stack of paleovalley infills (Blum et al., 2013), or fluvial incised valleys, and related interfluves resulting from cyclic, syn-uplift phases of fluvial sedimentation and erosion by the Tiber River and tributaries (Conato et al., 1980; Alvarez et al., 1996; Milli 1997; Karner & Marra, 1998; Marra et al., 1998, 2008, 2016; Milli et al., 2008, 2016; Mancini et al., 2013). At present, the Upper Pleistocene-Holocene drainage network of the Tiber River is deeply incised into older deposits as a result of the sea-level fall of Marine Isotope Stages (MIS) 5d-2 and hosts up to 65 m of Upper Pleistocene-Holocene (MIS 2-1) fluvial sediments forming the present-day fluvial plain (Bozzano et al., 2000; Milli et al., 2016). Finally, an almost continuous cover of anthropogenic deposits is present in the whole urban area, with thicknesses up to 20 m (Ciotoli et al., 2015, with references).

3. MATERIAL AND METHODS

In this work we adopt the high-rank Unconformity Bounded Stratigraphic Units (UBSU), or synthems, and the lithostratigraphic units that compose them (i.e. formations) of the Geological Map of Italy (map sheet 374 'Rome'; Funiciello & Giordano, 2008). Bounded by 5 major basal unconformities (Unconformities I to V in Fig. 3) corresponding to as many phases of fluvial erosion forced by sea level fall and low-stand (even-numbered Marine Isotopic Stages, MIS), the above mentioned synthems partly correspond to paleovalleys infills developed during phases of sea level rise and high-stand, which could be correlated with some of the high-frequency low-rank depositional sequences of the composite Ponte Galeria Sequence (Fig. 3a; Milli, 1997; Milli et al., 2008, 2016) well defined W of Rome. An additional composite surface (Surface VI in Fig. 3), locally erosive or depositional, is at the base of the anthropogenic deposits.

A sub-set of 12 (most of which double-tube cored) out of 25 continuous-core boreholes (Fig. 1) drilled in the 2010 (Cecchi, 2011) was selected for their excellent core recovery, stratigraphic record and proximity to key outcrops, and logged in detail recording all relevant sedimentologic, petrographic and pedogenetic information across most of the Middle Pleistocene-Holocene succession. This allowed the distinction of a total of 23 lithofacies (Table 1) described in detail in paragraph 4 and illustrated in Figs. 4-9 and Plate I-III. After integration with lithostratigraphy from other boreholes and ancillary observations made on nearby key outcrops, including temporary outcrops from archeological excavations and construction sites, the selected core logs were correlated across adjacent sites based on stratigraphic markers (e.g. ignimbrites, fluvial lag deposits, lignite seams, tephras) and used for facies analysis (Miall, 1996; Orton, 1996; Retallack, 2001; Amorosi, 2006).

4. RESULTS: STRATIGRAPHY AND SEDIMENTARY FACIES

The stratigraphy of the Palatine (Figs. 3b, 4) includes five of the USBU introduced by Funiciello & Giordano (2008), namely the Flaminia (LMN), Villa Glori

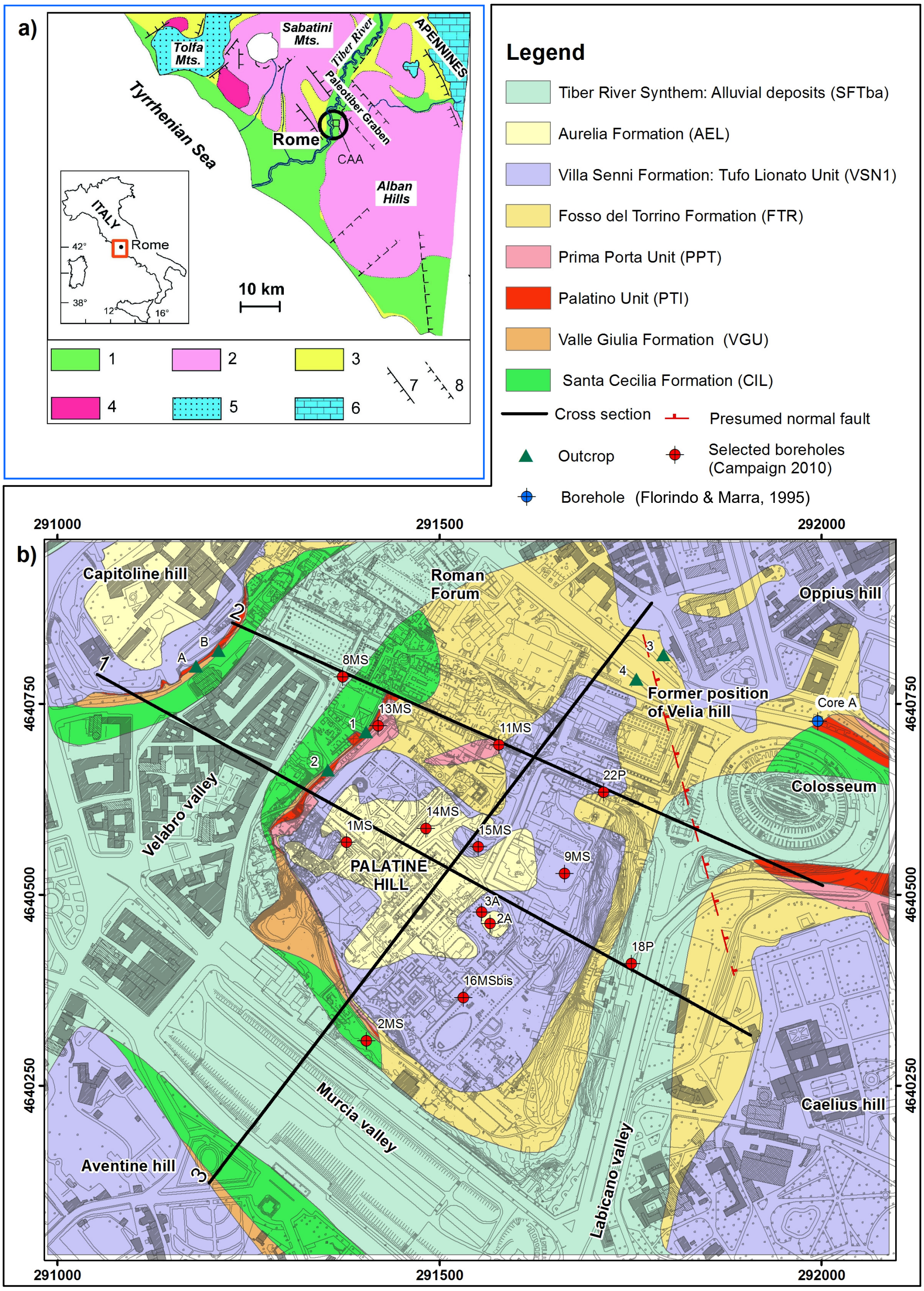

Fig. 2 - a) Simplified geological map of the Rome Basin. Legend: 1) continental and coastal deposits (late Early Pleistocene-Holocene); 2) pyroclastic deposits and lavas of the Sabatini Mts and Alban Hills Volcanic Districts (Middle-Late Pleistocene); 3) marine terrigenous clay and sands (Pliocene-Early Pleistocene); 4) lavas and lava domes of the Ceriti Mts-Tolfa Volcanic District (Pliocene); 5) marine terrigenous successions of the Liguride Units, sandstones and marlstones (Cretaceous-Paleogene); 6) limestone, marls and cherts of the pelagic Umbro-Sabina succession (Trias-Miocene); 7) normal fault; 8) buried normal fault. CAA is the Central Archeological Area of Rome. b) Geological map (modified, after Mancini et al., 2014) showing the distribution of lithostratigraphic units below the anthropogenic deposits with location of cross-sections of Fig. 4, outcrops pictured in Figs. 5 and 6, and borehole stratigraphies detailed in Figs. 7-9.

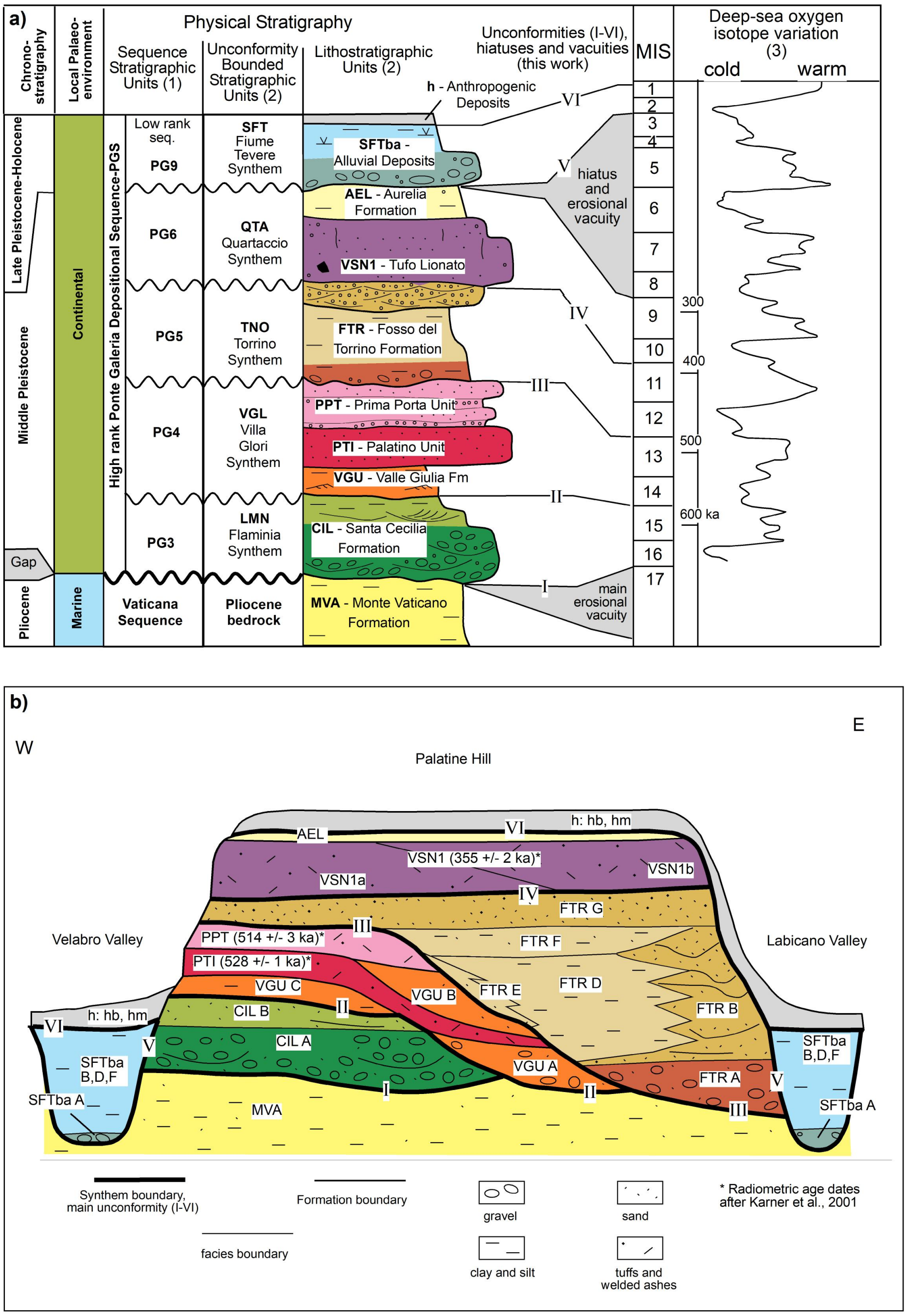

Fig. 3 - a) Chronostratigraphic reference scheme for the Palatine Hill and surrounding areas reporting correlation between (1) sequence stratigraphic units (Milli, 1997), (2) lithostratigraphic and unconformity bounded stratigraphic units (Funiciello & Giordano, 2008) and (3) marine isotope stages (MIS; after Shackleton et al., 1990). b) Simplified sketch of the stratigraphic and facies architecture of the Palatine Hill and the surrounding Labicano and Velabro Valleys (see a in this figure and text for lithostratigraphic and facies codes). In both figures, stratigraphic surfaces I to V are the unconformities bounding the synthems of Funiciello & Giordano (2008), and surface VI is at the base of the man-made deposits.

(VGL), Torrino (TNO), Quartaccio (QTA) and Fiume Tevere (SFT) Synthems, which correspond to as many incised paleovalleys infills and stack spatially to form the volcano-sedimentary multilayer superimposed onto the Pliocene marine bedrock. This stack is covered by a thick layer of man-made deposits. In the following paragraphs, the component lithofacies (Table 1) and geometrical characters of these units, including the bedrock and the man-made cover, will be described in detail and illustrated with a rich iconographic documentation from

Depositional sequences Milli, 1997	Synthems Funiciello & Giordano, 2008	Formations Funiciello & Giordano, 2008	Lithofacies this work	Lithofacies code this work (modified after Mancini et al., 2014)
n/a	Ubiquitous units	Anthropic deposits **(h)**	Backfill material	**hb**
			Remnants of buildings	**hm**
PG 9	Fiume Tevere Synthem **(SFT)**	Alluvial deposits **(SFTba)**	Pedogenically modified mud	**SFTba F**
			Organic-rich mud	**SFTba D**
			Channel sand	**SFTba B**
			Gravel lag	**SFTba A**
PG 6	Quartaccio Synthem **(QTA)**	Aurelia Formation	Pedogenically modified mud	**AEL**
		Villa Senni Formation, Tufo Lionato **(VSN1)**	Tufo Lionato: welded and cemented ignimbrite	**VSN1 a**
			Tufo Lionato: pozolanic facies	**VSN1 b**
PG 5	Torrino Synthem **(TNO)**	Fosso del Torrino Formation **(FTR)**	Epiclastite	**FTR G**
			Well-drained floodplain mud	**FTR F**
			Colluvium	**FTR E**
			Poorly-drained floodplain mud	**FTR D**
			Channel and crevasse-splay sand	**FTR B**
			Channel gravel	**FTR A**
PG 4	Villa Glori Synthem **(VGL)**	Prima Porta Unit **(PPT)**	Green-grey, faintly laminated tuff	**PPT**
		Palatino Unit **(PTI)**	Dark grey massive tuff	**PTI**
		Valle Giulia Formation **(VGU)**	Pedogenized floodplain and channel-abandonment silt	**VGU C**
			Channel margin-levee sand	**VGU B**
			Channel gravel	**VGU A**
PG 3	Flaminia Synthem	Santa Cecilia Formation **(CIL)**	Channel sand	**CIL B**
			Channel gravel	**CIL A**
Vaticana Sequence	Pliocene marine units	Monte Vaticano Formation **(MVA)**	Offshore marine clay	**MVA**

Tab. 1 - Correlation scheme among depositional sequences, synthems, formations and lithofacies.

selected core intervals (Plates I-III) and key outcrops (Figs. 5, 6).

4.1 Pliocene marine bedrock: the Monte Vaticano Formation (MVA)

In the study area this formation does not crop out but was encountered in numerous boreholes and drilled throughout a total thickness of 500 m by the Circo Massimo well (cfr with LPa unit in Funiciello & Giordano, 2008). The formation is represented by a single lithofacies (MVA) composed of structureless blue-grey silty clay (Plate I a), with rare burrows and marine shells (*Corbula gibba*, *Venus* sp.) and with interbedded dm-thick sets of organic-rich cross laminated sands (Plate I b).

Interpretation. The clays of MVA are interpreted as the product of fall-out and, subordinately, traction plus fall-out deposition by gravity flows in outer shelf to slope offshore marine settings.

4.2 Flaminia Synthem (LMN)

Bounded below and above by Unconformities I and II (Fig. 3b), respectively, the Middle Pleistocene syn-volcanic Flaminia Synthem (Funiciello & Giordano, 2008) can be correlated with MIS 16-15 and with the PG3 depositional sequence (Milli, 1997). In the study area LMN only comprises the fluvial Santa Cecilia Formation (CIL) introduced by Marra et al. (1998) and geochronologically constrained by Karner & Marra (1998).

4.2.1 Santa Cecilia Formation (CIL)

The Santa Cecilia Formation (*cfr.* with 'Maremmano' in De Angelis D'Ossat, 1956) is up to 20 m thick in the study area and includes two lithofacies, namely channel gravel (CIL A) and sand (CIL B), occurring respectively below and above a sharp and rather

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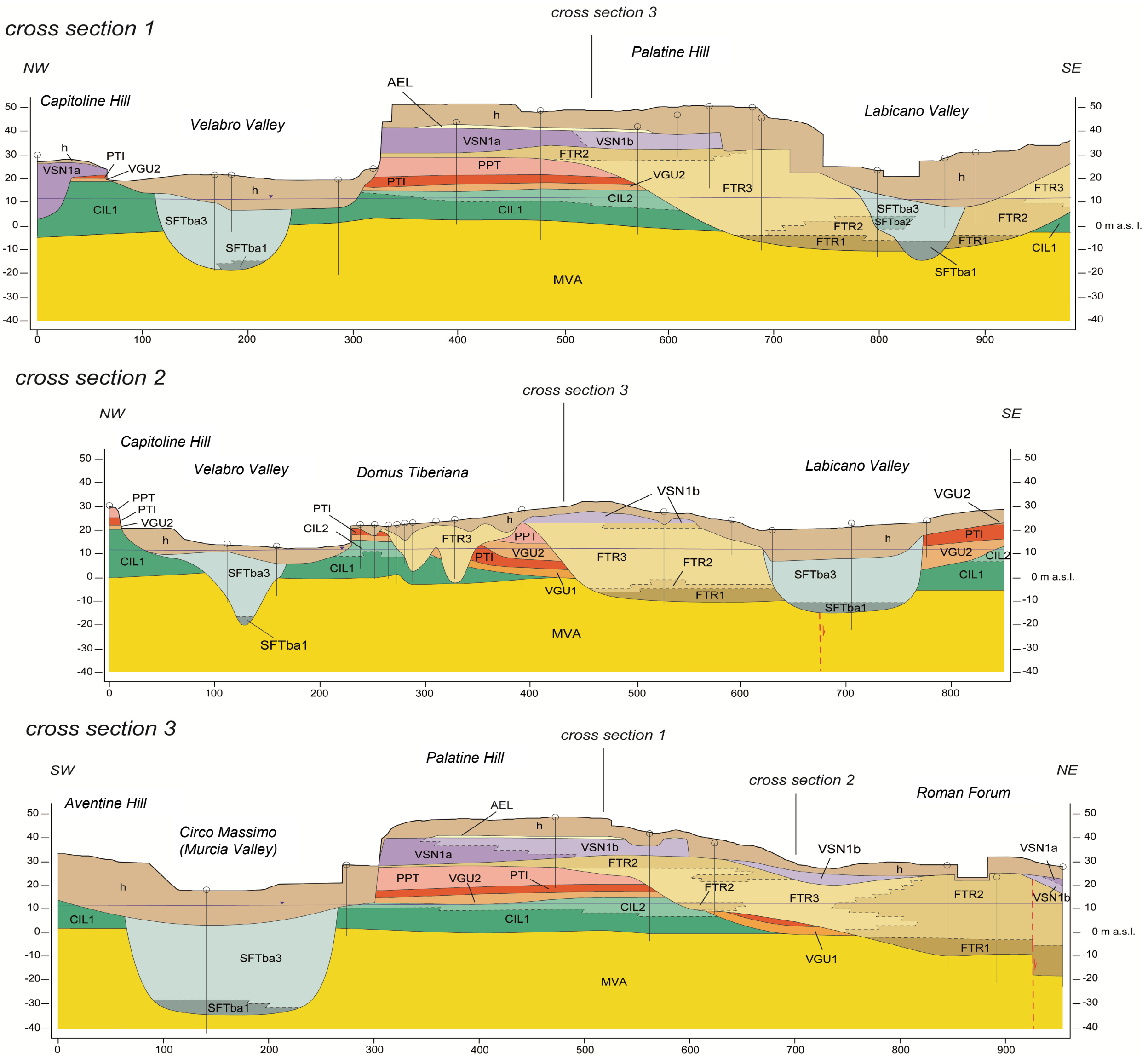
Fig. 4 - Geological cross-sections (see Fig. 2b for location) with distribution of clustered lithofacies described in the text (modified after Mancini et al., 2014). The buried normal fault on cross sections 2 and 3 is inferred from the displacement of stratigraphic horizons at the base of and within the Fosso del Torrino Fm; its activity ended before the deposition of the Villa Senni Formation (see Mancini et al., 2014, for further details).



Legend

Anthropogenic cover (h)
Sandy-pebbly backfill material (hb) and, subordinately, masonry (hm).
Maximum thickness 20 m.
Late Holocene - present day

Tiber River Synthem (SFTba) (1, 2, 3)
Poorly consolidated, fine-grained alluvial sediments
Maximum thickness 45 m.
1 - gravel lags (SFTBa A);
2 - channel sands (SFTBa B);
3 - organic-rich and pedogenically modified floodplain muds (SFTBa D and F, repsectively).
Upper Pleistocene - Holocene

Aurelia Formation (AEL)
Pedogenized mud-prone floodplain deposits
Maximum thickness 5 m.
Middle Pleistocene.

Villa Senni Formation: Tufo Lionato Mb (VSN1) (a, b)
Massive, lithoid tuff (VSN1 a);
welded scoriaceous ashes (VSN1 b).
Maximum thickness 15 m.
Middle Pleistocene.

Fosso del Torrino Formation (FTR) (1, 2, 3)
Silty, sandy and pebbly fluvial and alluvial deposits.
Maximum thickness 40 m.
1 - channel gravels (FTR A)
2 - channel and crevasse splay sands (FTR B), colluvium (FTR E) and epiclastites (FTR G)
3 - poorly- and well-drained floodplain muds (FTR D, F).
Middle Pleistocene.

Prima Porta Unit (PPT)
Layered lithoid ashy tuffs.
Maximum thickness 8 m.
Middle Pleistocene.

Palatino Unit (PTI)
Massive lithoid tuff.
Maximum thickness 6 m.
Middle Pleistocene.

Valle Giulia Formation (VGU) (1, 2)
Interbedded fluvial pebbly sands, silty sands and clays
Maximum thickness 15 m.
1 - channel gravels (VGU A);
2 - channel sands (VGU B) and floodplain muds (VGU C).
Middle Pleistocene.

Santa Cecilia Formation (CIL) (1, 2)
fluvial gravels and sands
Maximum thickness 25 m.
1 - channel gravels (CIL A)
2 - channel sands (CIL B).
Middle Pleistocene.

Monte Vaticano Formation (MVA)
Overconsolidated marine clays with sandy intercalations
Thickness greater than 500 m.
Lower Pliocene - Upper Pliocene

inferred normal fault

borehole

piezometric level

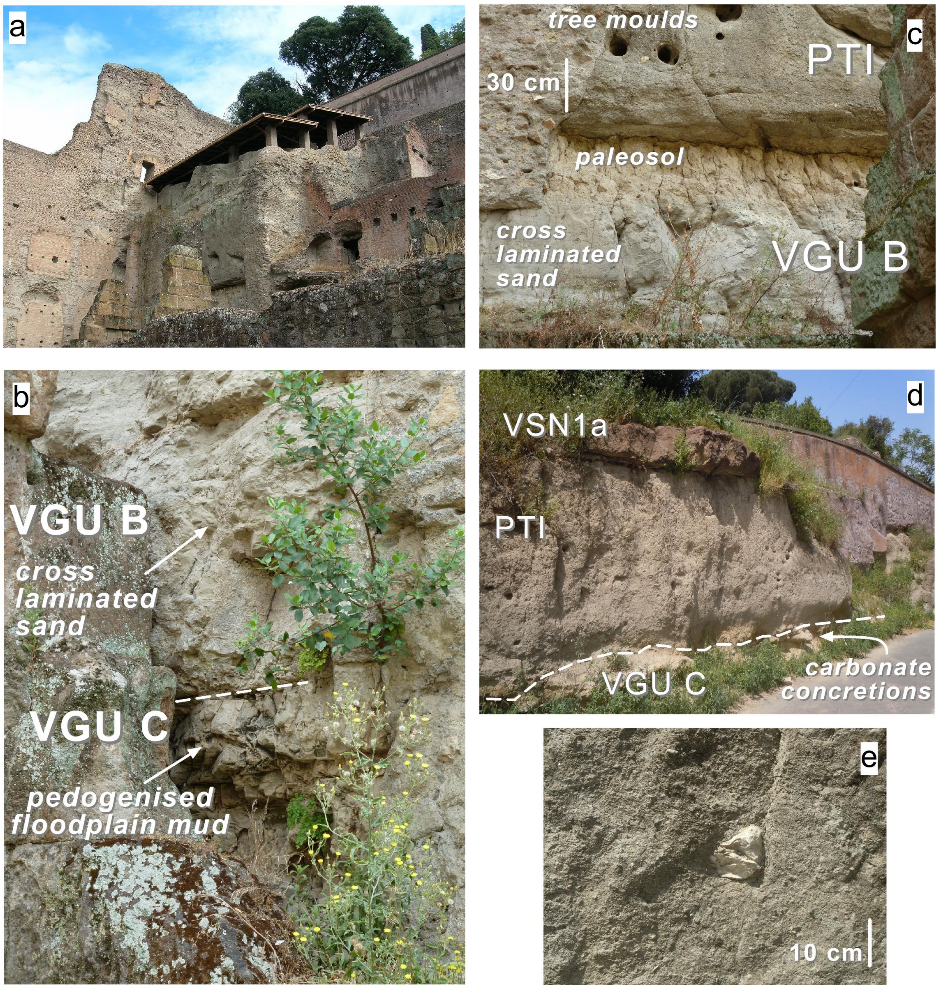


Fig. 5 - Pictures of key outcrops discussed in the text (see Fig. 2b for reference and location). a) Roman walls and foundation structures along the north-western side of the Palatine. Note how these ruins sit directly on top of outcrop 1 (see details in this figure). b) Detail of the lowermost part of outcrop 1 showing pedogenized floodplain mud (VGU C) capped by cross-laminated levee sand (VGU B) from the fluvial Valle Giulia Formation. c) Detail of outcrop 1 showing cross-laminated levee deposits with a well-developed paleosol on top (VGU B lithofacies) overlain with a sharp but non-erosive contact by the massive ignimbritic Palatino Unit (PTI). Note the presence of tree moluds in PTI, previously described by De Rita et al. (2002). d) From base to top, carbonate-rich silts and concretions (VGU C lithofacies) and the PTI and the Villa Senni Formation (VSN) ignimbrites exposed in outcrop A (Via della Consolazione, southern hillslope of the Capitoline Hill). e) Detail of the PTI ignimbrite in outcrop A showing a sub-angular, carbonate lithic fragment, most likely a xenolith (see e.g. Funiciello & Parotto, 1978).

flat intra-formational surface (Figs. 8, 9).

Channel gravel (CIL A)

This lithofacies is represented by well-sorted, coarse to medium-grained pebbles in a sandy matrix (Plate I c) and, subordinately, by sands forming dm-thick lenses with low (m-scale) lateral continuity. Clasts are calcareous and subordinately siliceous (up to 10-15%) and typically well-rounded with mainly blade and disc shape. The sandy matrix is fine grained and mainly composed of quartz, feldspar, calcite and, subordinately, volcanic ferro-magnesian minerals.

In the study area, CIL A forms an 8-20 m-thick wedge-shaped depositional body thickening toward the NW (Fig. 4).

Interpretation. CIL A can be interpreted as a stack of longitudinal and transversal bars and bedload sheets infilling the channels of a gravelly braided-type river. Major grain-size breaks between pebbles and sands can be interpreted as either bedset boundaries within individual bars and gravel-sand sheets or reflect auto-cyclical reorganization of the channel-network.

Channel sand (CIL B)

This facies is composed of silty fine-medium sands (Plate I d), typically of a yellow-orange hue, showing either faintly planar-parallel or ripple-drift cross lamination. The mineralogical composition of CIL B is the same as the matrix of CIL A including relatively abundant chert fragments. Locally, dm-thick, normally and inversely graded lamina-sets are observed, which suggests flow velocity fluctuations. In most localities, these sands

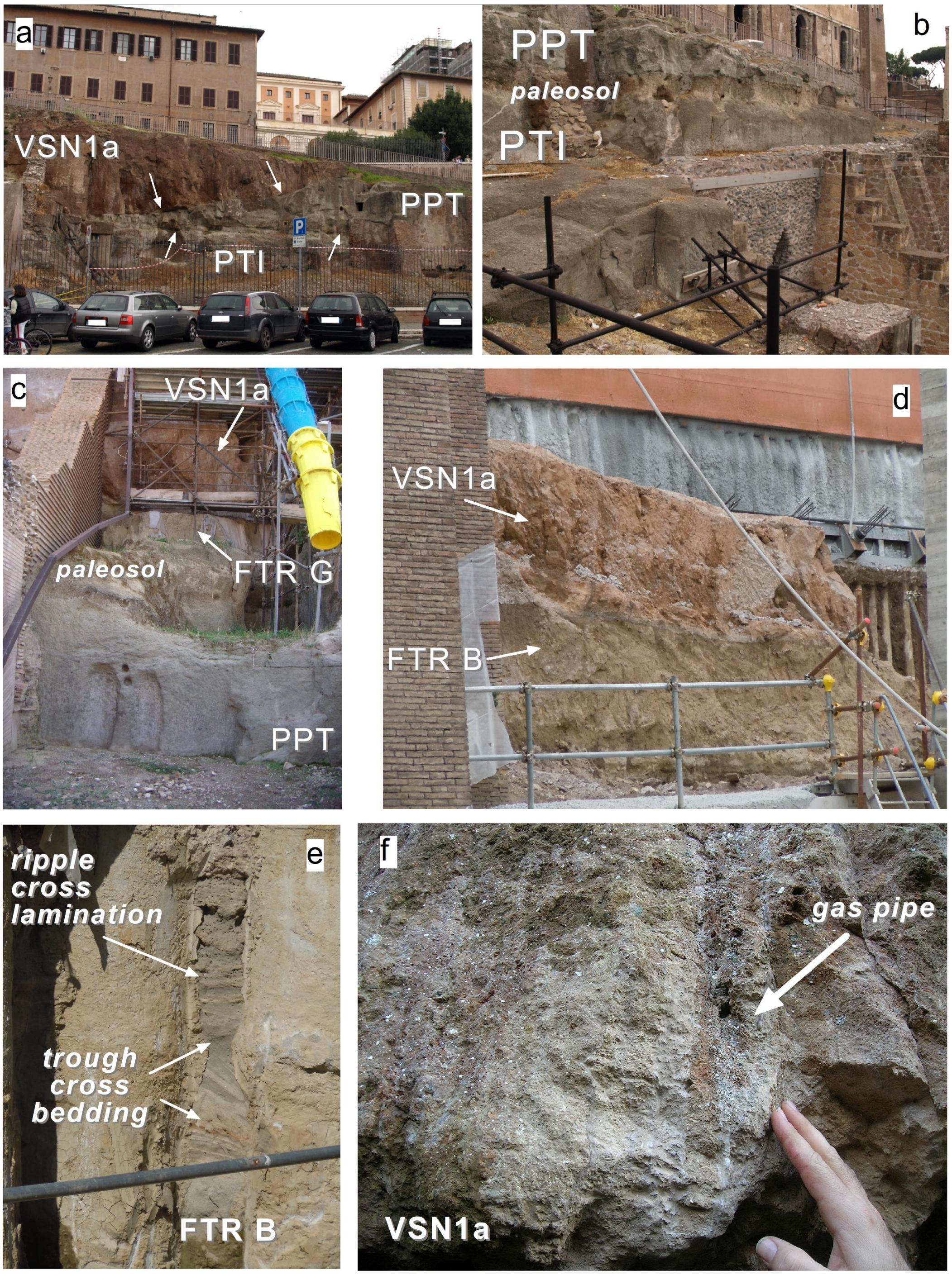


Fig. 6 - a) The superimposed Palatino Unit (PTI), Prima Porta Unit (PPT) and Villa Senni Formation - Tufo Lionato (VSN1a) pyroclastic deposits in outcrop B (Via della Consolazione). b) Detail of outcrop B showing the paleosol separating the Palatino Unit (PTI) from the Prima Porta Unit (PPT). c) Epiclastite of the Fosso del Torrino Formation (FTR G) located between the pyroclastites of the Prima Porta Unit (PPT) below and the Villa Senni Formation - Tufo Lionato (VSN1a) above in outcrop 2 (San Teodoro Church). Note the faintly laminated ashy character as well as the pedogenized top of PPT. d) Detail of outcrop 3, temporary exposed in April 2015 during the Underground Line C excavations, showing the fluvial channel sand (FTR B) of the Fosso del Torrino Formation, topped by the Villa Senni Formation - Tufo Lionato (VSN1a) ignimbrites. e) Detail of outcrop 4, temporary exposed in May 2018 during the Underground Line C excavations, showing trough-cross bedded and cross laminated sands (FTR B) of the fluvial Fosso del Torrino Formation. Outcrops 3 and 4 are remnants of the former Velia Hill, cut away in the 30s of the XX century for the construction of Via dei Fori Imperiali (De Angelis D'Ossat, 1956; Lanzini, 2008; Leone et al., 2009). f) Detail of outcrop 2 showing a columnar gas pipe from the Tufo Lionato ignimbrite (VSN1a).

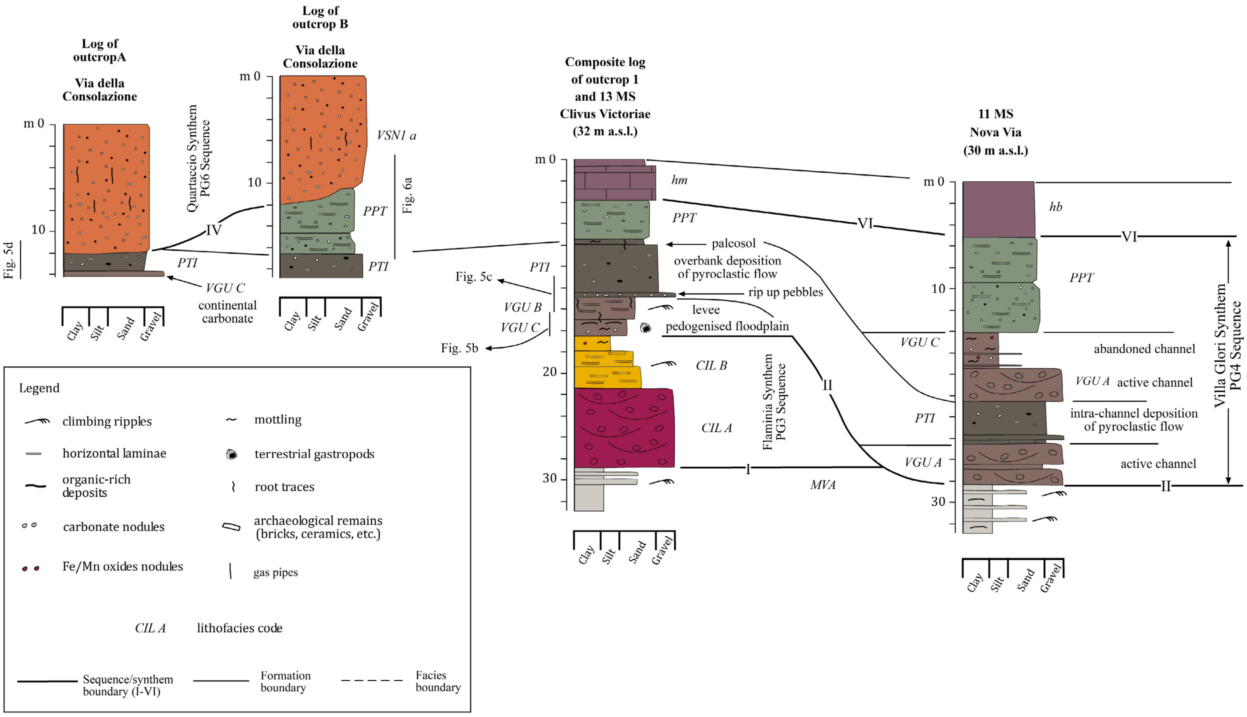


Fig. 7 - Correlated sedimentary logs from selected boreholes and key outcrops along the Velabro Valley and in the north-western Palatine (see Fig. 2b for location).

grade upward into massive sandy silt (Figs. 7-9) bearing rare root traces and mm-to-cm-scale nodules of Mn/Fe oxides. Similar fine-grained facies were reported by Florindo & Marra (1995) and Florindo et al. (2007) from the Colosseum core A (Fig. 9), which were attributed to the Brunhes magnetic chronozone. CIL B forms an up to 8 m thick tabular body with an observed minimum lateral continuity of 250 m.

Interpretation. CIL B can be interpreted as a channel-fill deposit resulting from amalgamation of subsequent bars and bedload sheets in a sand-dominated river. Root traces and nodules can be interpreted to reflect prolonged subaerial exposure and pedogenisation of bar tops. The silty deposits may be related to upper bars and/or abandoned channels.

4.3 Villa Glori Synthem (VGL)

The syn-volcanic Villa Glori Synthem (VGL; Funiciello & Giordano, 2008) is bounded below and above by Unconformities II and III (Fig. 3b) which record the sea level falls occurred between MIS 15 and MIS 14 and MIS 13 and MIS 12, respectively. As a result, there is general agreement in correlating VGL with MIS 14-13 and the PG4 depositional sequence (Milli, 1997; Funiciello & Giordano, 2008). In the study area, VGL comprises the Valle Giulia Formation (VGU), composing the most of the synthem (Figs. 3b, 7), and the Palatino (PTI) and the Prima Porta (PPT) pyroclastic units. These units collectively represent of the infill of a NW-SE trending paleovalley (Mancini et al., 2014).

4.3.1 Valle Giulia Formation, VGU

The fluvial Valle Giulia Formation is up to 15 m thick and includes three lithofacies, namely channel gravel (VGU A), channel margin-levee sand (VGU B) and pedogenized floodplain and channel-abandonment silt (VGU C).

Channel gravel (VGU A)

This facies consists of medium to coarse well-rounded blade-shaped pebbles (Plates I e, II a) with an abundant sandy matrix. Clast lithology includes limestone, chert and volcanic scoria, whereas the matrix is very rich in calcite, quartz, charcoal debris and volcanic ferro-magnesian minerals (clinopyroxene, biotite and magnetite), which imparts VGU A a dark hue and makes it easily distinguishable from similar lithofacies (e.g. CIL A and FTR A). Importantly, in the subsurface of the north-eastern hill slope of the Palatine, VGU A is intercalated by the pyroclastic Palatino Unit (PTI) (log 11 MS in Fig. 7).

VGU A exclusively occurs at heights below 15 m a.s.l., infilling the deeper part of Unconformity II (Figs. 3 and 4). Because of later erosion of Unconformity III, it forms depositional bodies with presumably small lateral continuity and slightly convex erosive base.

Interpretation. Channel-fill fluvial deposits, formed by amalgamation of bars and bedload sheets in a braided-type river (Fig. 7). The abundance of volcanic clasts as well as intercalation of PTI testifies syn-volcanic deposition.

Channel margin-levee sand (VGU B)

This facies is represented by light brown to pale

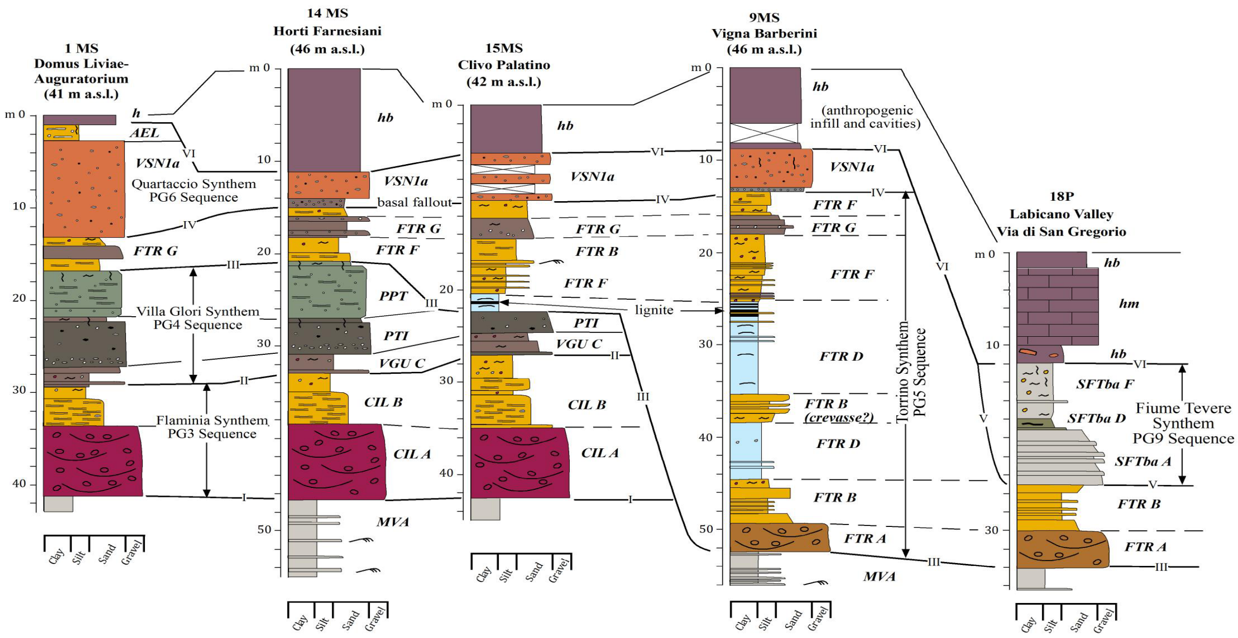


Fig. 8 - Correlated sedimentary logs from selected boreholes from central Palatine Hill (see Fig. 2b for location). Legend as in Fig. 7.

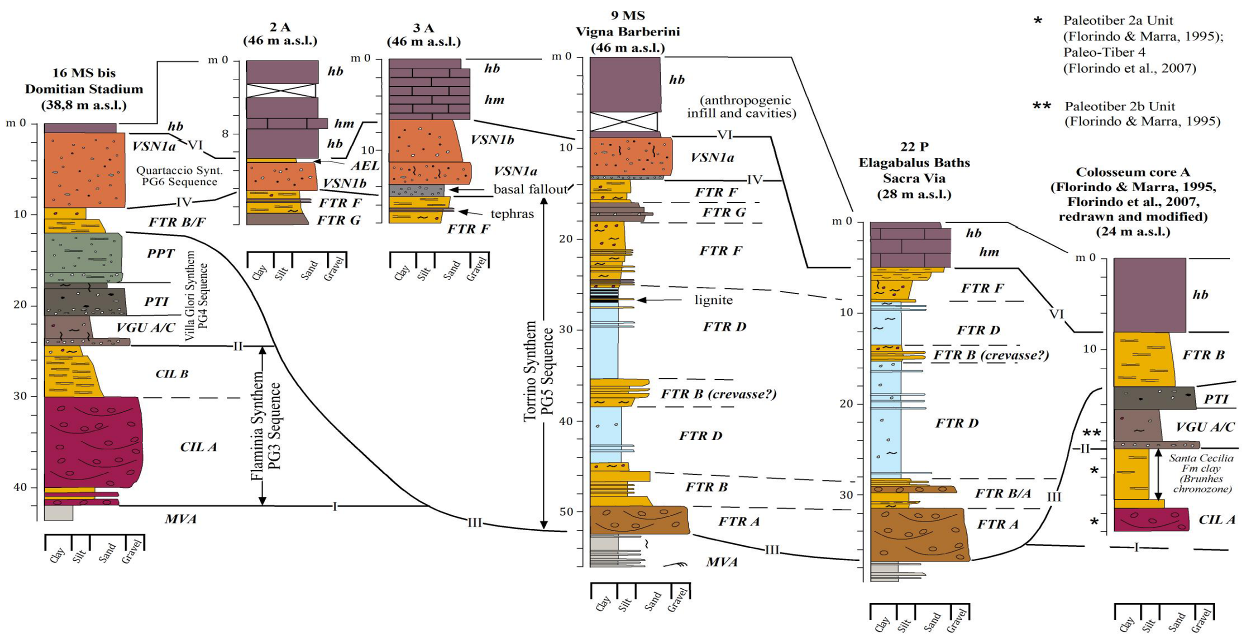


Fig. 9 -. Correlated sedimentary logs from selected boreholes in the eastern Palatine Hill and Oppius Hill (see Fig. 2b). Note the internal facies variability of the Fosso del Torrino Formation (FTR) reflecting intercalation of crevasse sandy deposits within floodplain muds. Legend as in Fig. 7.

grey, cross-laminated silty fine sand (Plates I f, II b), dominantly composed of quartz, feldspar, muscovite and volcanic ferro-magnesian minerals. VGU B form m-thick beds sets (Figs. 5 b, c), whose base is locally marked by lags of very fine to fine pebbles. On outcrop, cross bedding and ripple-drift laminations indicate paleoflow direction toward the W (Fig. 5 b, c; log 13 MS in Fig. 7). Locally, root traces and peds are present atop VGU B beds (Fig. 5 c).

VGU B was encountered at a few sites only (e.g.

Fig. 5 b, c; log 13 MS in Fig. 7) at elevation above 5 m a.s.l., suggesting it forms laterally discontinuous bodies up to 5 m thick.

Interpretation. Deposition by sand-laden waning flows in channel margin and levee settings. The levee deposits, particularly well exposed along man-made cuts on the NW flank of the Palatine Hill (Fig. 5b), can be differentiated from channel margin deposits based on vertical association with underlying floodplain deposits (i.e. lithofacies VGU C, see log 13 MS in Fig. 7) and presence of pedogenic features.

Pedogenized floodplain and channel-abandonment silt (VGU C)

VGU C consists of pale to dark grey-brown, partly calcite-cemented, massive sandy silt (Plate I e; Figs. 5 b,d), interbedded with dm-thick beds of detrital freshwater tufa and lignite. As previously described for VGU A and B, the sandy fraction is very rich in volcanic ferromagnesian minerals (clino-pyroxene and biotite). In few localities, well-developed clayey paleosols is found atop VGU C (e.g. log 13 MS, see Figs. 5 b and 7) containing: prismatic and angular blocky peds (up to 5 cm long) typical of Bt soil horizon (illuvial clay, see Retallack, 2001), dark brown cutans (Fe/Mn oxides), calcium carbonate depleted horizons, root traces and abundant shells of the terrestrial gastropod *Pomatias elegans*.

Interpretation. This facies derives from suspension and traction-fall out processes, characterized by low energy waning flows related to overbanking in floodplains (log 13 MS in Figs. 5 b and 7) and abandoned channels (log 11 MS in Fig. 7, Plate 1 e). Pedogenetic characters suggest the establishment of partly drained and oxidizing conditions. The prismatic and angular blocky peds may, in fact, reflect repeated swelling and shrinking resulting from alternation of wetting-drying conditions (Retallack, 2001). Coarsening upward facies sequences including interbedded VGU C and VGU B (e.g. log 13 MS in Fig. 7; Figs. 5 b, c) can be interpreted to reflect lateral shifts of the fluvial system axes resulting in progradation of levees onto floodplain mud (Brierly et al., 1997; Hornung & Aigner, 1999).

4.3.2 Palatino Unit (PTI)

The Palatino Unit is an ignimbrite marker-bed representing the product of a single pyroclastic flow sourced from the Alban Hills (Funiciello & Giordano, 2008). It partly corresponds to the “Cappellaccio” and “Tufo granulare” described by De Angelis D’Ossat (1956) and yielded a $^{40}Ar/^{39}Ar$ age of 528 ± 1 ka (Karner et al., 2001) and 520 ± 8 ka (Karner & Renne, 1998).

In the study area PTI crops out along the Velabro Valley (Figs. 5a; 6a, b), where intercalates into VGU fluvial deposits. It is represented by a dark grey, massive tuff (Figs. 5c-d) with a weakly pedogenized top (Fig. 6b; Plate II c), made of an ash matrix with floating crystals (leucite, biotite, clino-pyroxene), black scoriae (Plates I f, II a-c), poorly-rounded lithics (Fig. 5e) interpreted as xenoliths (Funicello & Parotto, 1978), and tree moulds (Fig. 5d). At some sites (log 13 MS in Fig. 7), the lowermost few cm of PTI contains abundant well-rounded fine pebbles of limestone and chert (Plate II b).

Though occurring at different elevations, PTI shows small thickness changes (c. 5 m) suggesting mantling of the pre-existing topography.

Interpretation. PTI character suggest deposition by a high density pyroclastic flow onto an articulated topography including interfluves. The lithic pebbles in the lowermost part of PTI (Fig. 5e) likely represents clasts ripped up from the channel floor and re-deposited in off-axes locations of the VGL valley (log 13 MS in Fig. 7). Tree moulds represent casts of burned tree trunks and branches (De Rita et al., 2002).

4.3.3 Prima Porta Unit (PPT)

The pyroclastic Prima Porta Unit crops out along the western flank of the Palatine and the south-eastern flank of the Capitoline (Figs. 6 a-c), overlaying PTI and VGU. It corresponds to the “Tufo granulare” *pro parte* in De Angelis D’Ossat (1956) and to the “Tufo Giallo di Prima Porta” in Karner et al. (2001) and Luberti et al. (2017). Sourced from the Sabatini Mts Volcanic District, this unit yielded $^{40}Ar/^{39}Ar$ radiometric ages of 514 ± 3 ka (Karner et al., 2001) and 514 ± 6 ka (Marra et al., 2014). The outcrop of PPT on the Capitoline Hill (Figs. 6 a, b) was attributed to the Fosso del Cavaliere Unit by De Rita & Fabbri (2009).

In the study area, PPT is represented by green-grey tuffs composed of well-sorted, fine ashes (Plate II c; Figs. 6 a-c) with faint planar-parallel lamination, containing scattered sub-centimetric pumice. The top of the unit is marked by a yellowish clayey paleosol with root traces. The unit is composed of two superimposed laterally continuous bodies, each up to 4 m thick, separated by a planar amalgamation surface. Observed thickness changes of PPT are very small, suggesting tabular geometry over short lengths.

Interpretation. PPT can be interpreted as the distal product of two pyroclastic flows, originated from highly fragmented magma of phreato-magmatic origin. Planar-parallel lamination testifies deposition under upper regime conditions by low-density flows.

4.4 Torrino Synthem (TNO)

The Torrino Synthem (Funiciello & Giordano, 2008) is correlated with MIS 12-11 and PG5 depositional sequence (Milli, 1997), and is bounded at the base by the high relief Unconformity III. In the study area TNO comprises only the Fosso del Torrino Formation (FTR) and represents the infill of a NW-SE (north-eastern hillslope of Palatine and Fori Imperiali) to N-S (eastern hillslope of Palatine and Labicano Valley) (Figs. 2 and 10) directed paleovalley (Mancini et al., 2013, 2014; Moscatelli et al., 2015).

4.4.1 Fosso del Torrino Formation (FTR)

The Fosso del Torrino Formation (FTR) is up to 40 m thick and comprises several facies including channel gravel (FTR A) and sand (FTR B), poorly and well-drained floodplain mud (FTR D and F, respectively), buried colluvia (FTR E) and epiclastites (FTR G). This formation partly corresponds to the San Cosimato Formation (Conato et al., 1980) and to the San Paolo Formation, with the latter reported from the subsoil of the nearby Quirinale (Marra & Rosa, 1995) and Capitoline Hills (Corazza et al., 2004). It is noteworthy that the

Plate I

Examples of lithofacies from selected cores (bottoms and tops in the lower left and upper right, respectively; core box is 1 m-long), with main facies boundaries marked in red. a) Over-consolidated marine clay of The Monte Vaticano Formation (MVA; Pliocene) overlain by fluvial channel gravel (FTR A) of Fosso del Torrino Formation (Middle Pleistocene) in borehole 22 P (depth interval 40-35 m); b) dm-thick cross laminated sands intercalating the clays of MVA (detail from core of borehole 8 MS). Santa Cecilia Formation (Middle Pleistocene): c) channel gravel (CIL A) from borehole 2 MS (depth interval 15-10 m) and d) cross-laminated channel sand (CIL B) from borehole 16 MS (depth interval 30-25 m). e) The Valle Giulia Formation (Middle Pleistocene) in borehole 11 MS (dept interval 20-15 m): channel gravel (VGU A) passing upward to channel-abandonment fines of VGU C. Note the dark-grey hue of the VGU A sandy matrix, rich in ferro-magnesian minerals; f) channel sand of the Santa Cecilia Formation (CIL B), overlain by grey overbank sand of VGU B lithofacies and by structureless ignimbrite of the Palatino Unit (PTI; Middle Pleistocene) from borehole 1 MS (depth-interval 30-25 m).

sand of FTR B represents the matrix of a vertebrate fossil assemblage (including *Elephas antiquus*, *Bos primigenius*, *Cervus elaphus*, *Hippopotamus amphibious*) unearthed during the excavation of Via dei Fori Imperiali (De Angelis D'Ossat, 1956).

Channel gravel (FTR A)

This facies is represented by poorly sorted, coarse -medium gravels in an abundant sandy matrix (Plates I a and II d), frequently intercalated with dm-thick beds of beige cross-laminated sands. Clasts are carbonate, chert and tuff lithics, generally well-rounded and blade-shaped. The sandy-silty matrix, reddish to dark grey in colour, is very rich in volcanic ferro-magnesian minerals and chert.

FTR A occurs at elevations below -2 m a.s.l., infilling the deepest part of Unconformity III and forming a flat-topped channel-fill body up to 10 m-thick and at least 200 m-wide across.

Interpretation. FTR A represents a stack of longitudinal bars and bedload sheets infilling the channels of a gravelly-sandy braided river.

Channel and crevasse-splay sand (FTR B)

FTR B is represented by yellow to light brown cross-laminated and through-cross bedded sands with quartz, feldspar and muscovite and volcanic ferro-magnesian minerals (augite, biotite, magnetite), interbedded with dm-thick beds of silt (Plate II d; Fig. 6d-e). Sand and silt are vertically arranged to form meter-thick bed-sets with alternated fining- and coarsening-upward patterns (e.g. logs 9 MS, 18 MS and 22 MS on Figs. 8 and 9); the coarsening-upward pattern typifies those FTR B bed-sets interbedded as isolated lenses within floodplain mud (FTR D, see below), in the subsurface of the eastern Palatine. Apart from these lenses, FTR B forms a main depositional body up to 30 m thick, which can be tracked from N to S for at least 500 m where the base of FTR is most deeply incised (Roman Forum and Labicano Valley, Fig. 4). Toward the W, FTR B interfingers with mud-prone floodplain deposits (FTR D).

Interpretation. Bedding pattern, sedimentary structures and large-scale geometry suggest that the main depositional body of FTR B might represent the result of a multistorey-multilateral stack within a fluvial channel-belt, composed of sandy bed-load sheets and bars referred to a mixed bed/suspended-load meandering fluvial system. Lenticular FTR B bed-sets within floodplain muds are interpreted as crevasse splay deposits (Basilici, 2000).

Poorly-drained floodplain mud (FTR D)

This lithofacies is represented by blue-grey to turquoise structureless clay (Plate II e, f), locally interlayered with cm-thick beds of muscovite-rich very fine silty sands with faint planar-parallel lamination. Pale grey to yellowish mottles and white-yellow small micritic carbonate nodules (Plate II e) are commonly observed in the clays, especially in the lower part of FTR D (logs 22 P and 9 MS; Fig. 9). Plant debris is scattered throughout the upper part of FTR D but is particularly abundant at about 20 m a.s.l., forming laterally continuous lignite seams traceable across adjacent boreholes (Fig. 8; Plate II f).

This lithofacies is up to 25 m thick and can be traced laterally for at least 300 m in the subsoil of the eastern portion of the Palatine, before it passes laterally to FTR B north- and east-ward.

Interpretation. Lateral association with channel facies suggests that FTR D represents the product of suspension fall-out and, subordinately, traction-fall out deposition by repeated overbanking in a floodplain environment (Davies & Gibling, 2003; North & Davidson, 2012). Structureless mud may represent the deposit of either a shallow flood-basin ponds or distal floodplain setting (*cfr* with Fm lithofacies of Miall, 1996), whereas thin sand/mud alternations might reflect weak tractional waning flows in more proximal setting (*cfr* facies Fl by Miall, 1996, and lithofacies association SL by Ghinassi et al., 2005). The abundance and preservation of plant fragments suggests waterlogged conditions typical of poorly drained floodplain, which might have favoured lignite seams formation via accumulation of reotrophic peat in low-lying swamps (Mc Cabe, 1984; Fielding, 1985). Conversely, mottles and carbonate nodules are pedogenic hydromorphic features (gleying) best interpreted to reflect ground-water oscillations (Kraus & Aslan, 1993) in a partially waterlogged environment.

Colluvium (FTR E)

This facies consists of yellow-brown to grey, poorly sorted and massive silt and fine sand with abundant tuff fragments and ferro-magnesian minerals. It fills two SW-NE trending gullies underneath the *Domus Tiberiana* (Fig. 4) cutting older pyroclastic rocks.

Interpretation. FTR E is interpreted as the deposit of multiple gravity-driven mass flows along the flanks of local gullies.

Well-drained floodplain mud (FTR F)

This facies is composed of pale yellow to brown, structureless silty clay with cm-scale sub-spherical iron oxides mottles, calcium carbonate concretions and root traces, intercalated with planar-parallel laminated silts and sands with a typical yellow-reddish hue (Plates II f, III a-d). Particularly noteworthy are two cm-thick tephra occurring in the uppermost part of FTR F (logs 2 A and 3 A in Fig. 9; Plate III b).

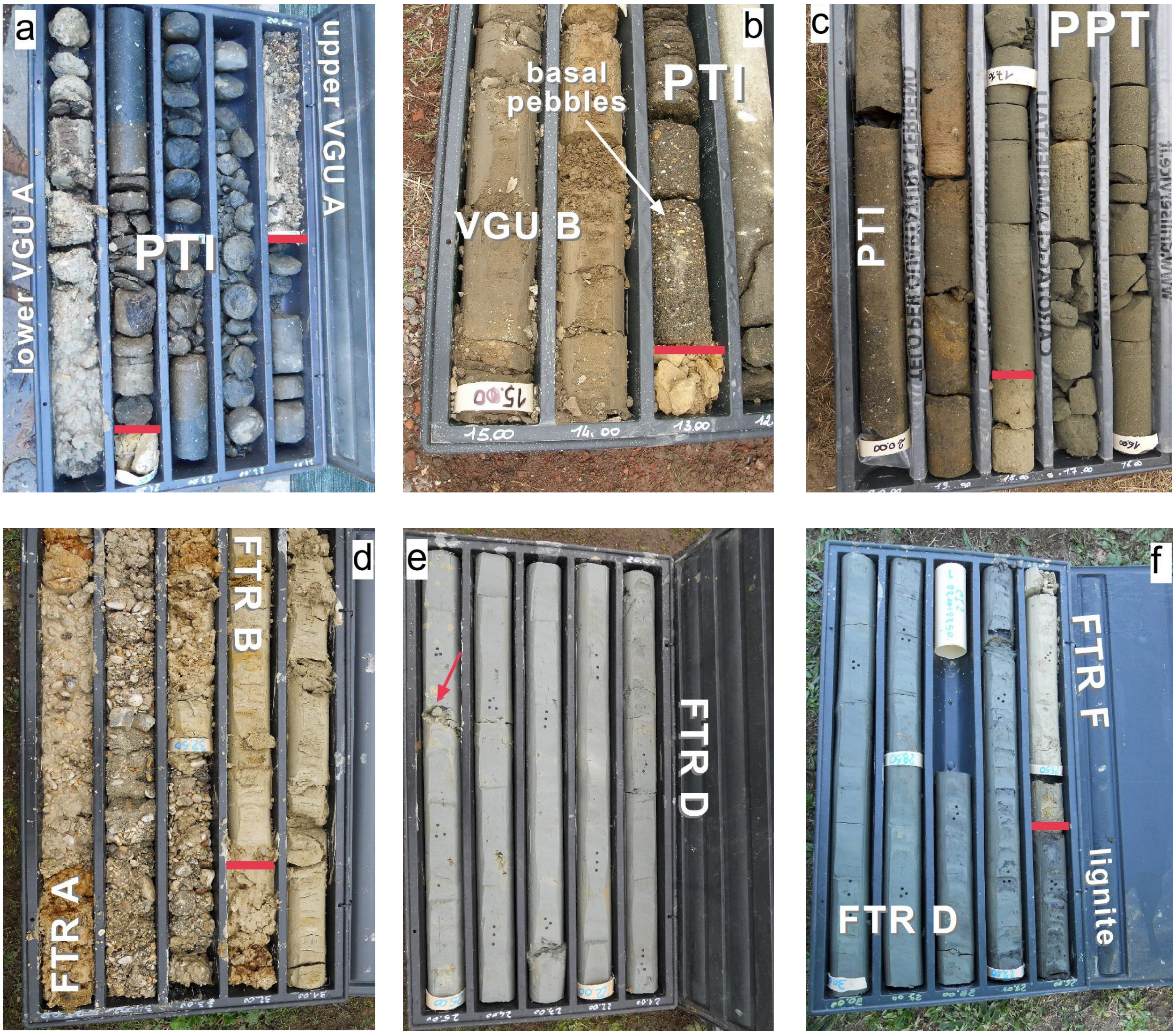
Interpretation. As previously discussed for similar mud-prone facies, FTR F reflects floodplain deposition. Widespread oxidation and pedogenic elements, such as mottles, glaebules and root traces (Davis & Gibling, 2003) would testify more drained conditions compared to the underlaying FTR D.

Epiclastite (FTR G)

This is a crudely stratified heterometric deposit with coarse-tail normal grading, composed of coarse sand and very fine poorly rounded pebbles (Fig. 6c; Plate III a) in a silty matrix with a dark yellow to brown hue. Clast composition comprises abundant pyroclastic material with ferro-magnesian juvenile crystals and a range of juvenile to accidental lapilli, including fragmented clasts of violaceous-reddish un-welded ash (pozzolan), chert and carbonate. FTR G intercalates to FTR F facies (Figs 8 and 9) forming an up to 4.5 m thick body with a sharp, but not erosive base and a pedogenically modified top, which contains root traces, mottles and terrestrial gastropods (*Vallonia* sp.).

Interpretation. The features of FTR G, along with its

Plate II



Examples of lithofacies from selected cores (bottoms and tops in the lower left and upper right, respectively; core box is 1 m-long), with main facies boundaries marked in red. a) The Palatino Unit (PTI) ignimbrite interbedded to the fluvial channel gravels of the Valle Giulia Formation (VGU A) from borehole 11 MS (depth interval 25-20 m). b) Very fine-to-fine limestone well-rounded pebbles embedded within the lowermost part of the Palatino Unit (PTI) and the overlaying ripple-drift laminated levee sand (VGU B) of the Valle Giulia Formation from borehole 13 MS (depth interval 13-15 m). These pebbles occur mostly in off-valley axis settings and are interpreted to reflect entrainment of fluvial deposits by the PTI pyroclastic flow from the substrate. c) Green-grey, faintly laminated pyroclastic deposit of the Prima Porta Unit (PPT; Middle Pleistocene), overlaying the dark-grey PTI ignimbrite in borehole 16 MS (depth interval 20-15 m). Fosso del Torrino Formation (Middle Pleistocene): d) channel gravel (FTR A) with heterometric pebbles in an abundant sandy matrix overlain by cross-laminated fluvial sand of FTR B lithofacies from borehole 22 P (depth 35-30 m); e) pale grey, structureless, silty clay with sparse carbonate nodule (red arrow) interpretable as poorly drained floodplain deposit (FTR D) from borehole 22 P (depth interval 25-20 m); f) blue-grey, structureless, organic-rich clay with a lignite seam on the top interpretable as the deposit of poorly drained flooplain (FTR D) followed upward by yellowish clayey deposits of a well-drained floodplain (FTR F) in borehole 9 MS (depth interval 30-25 m).

association with FTR F, suggest deposition by massive, hyper-concentrated and out-of-channel flows (North & Davidson, 2012) in floodplain environment. The clast composition, dominated by volcanic particles, suggests a syn- to slightly post-eruptive epiclastic origin, as well as *en-route* entrainment of fluvial pebbles from the substrate.

4.5 Quartaccio Synthem (QTA)

The Quartaccio Synthem (Funiciello & Giordano, 2008) is correlated with MIS 10-9 and the PG6 depositional sequence (Milli, 1997). In the study area it corresponds to the pyroclastic Villa Senni Formation - Tufo Lionato ignimbrite (VSN1) and to the overlaying fluvial Aurelia Formation (AEL). The Quartaccio Synthem is bounded at the base by the IV Unconformity, recording the sea level fall occurred between MIS 11 and MIS 10. This surface, corresponding to the base of the Villa Senni Formation - Tufo Lionato ignimbrite (VSN1), is flat on top of the Palatine Hill and deeply incised in the nearby Capitoline Hill.

4.5.1 Villa Senni Formation, Tufo Lionato (VSN1)

The Tufo Lionato is an ignimbrite sourced from the Alban Hills (De Rita et al., 1995; Watkins et al., 2002; Giordano et al., 2006; Giordano and the CARG team, 2010) which belongs to the Villa Senni Formation and was $^{40}Ar/^{39}Ar$ dated to 355 ± 2 ka using samples from the Palatine outcrops (Karner & Renne, 1998; Karner et al., 2001). Well-exposed along the Velabro Valley (Figs. 6 a, c), VSN1 is a dark red-orange, massive tuff (Figs. 7 -9; Plate III c;) with an ash matrix and sparse crystals (leucite, biotite, clino-pyroxene), lithics (small and rare limestone clasts), and grey to black scoriae, and locally with columnar gas escape pipes up to 40-50 cm long and a few centimeters wide (Fig. 6 f). The deposit may be either welded (VSN 1a) as a result of cementation by zeolite minerals or un-welded (VSN 1b), consisting of scoriaceous reddish to dark grey pozzolan (Plate III d). Locally, an up to 50 cm thick bed of lapilli occurs below the tuff suggesting that the ignimbrite was preceded by the fall-out of lapilli (Plate III c; logs 14 MS, 9 MS and 3 A, in Figs. 8 and 9). Tabular with flat base and mean thickness of c. 10 m on the Palatine Hill top and the orographic left of the Velabro Valley, the VSN1 rapidly thickens to up to 45 m in the subsurface of the Capitoline Hill (Alvarez et al., 1996; Corazza et al., 2004) suggesting it partially fills a NE-SW trending incised valley (see also cross section 1 on Fig. 4; Fig. 7).

Interpretation. Deposition of a large volume, very hot and dense pyroclastic flow, infilling the pre-existing topography. Large-scale geometry suggests the presence of a fluvial paleovalley, located NW of the Capitoline Hill, related to the Quartaccio Synthem (Fig. 10) and flanked by to the southeast by an interfluve (the present-day Palatine Hill) superelevated by at least 20 m above the valley floor.

4.5.2 Aurelia Formation (AEL)

In the study area this unit (cfr. with the *Formazione Fluvio-Lacustre* of De Angelis D'Ossat, 1956) crops out limitedly to the Palatino and Capitolino hilltop and is represented by a few metres of pale yellow clayey silt with a range of pedogenic features. These include mottles, orange-red Fe^{3+} oxides cutans, sparse sub-spheroidal carbonate nodules, root traces and $CaCO_3$-depleted horizons (Plate III d).

Interpretation. AEL sediments exposed on the Palatine hilltop might represent floodplain mud-prone deposits which have undergone intense pedogenization and illuvial clay enrichment under highly oxidizing conditions.

4.6 Fiume Tevere Synthem (SFT)

The post-volcanic Fiume Tevere Synthem (Funiciello & Giordano, 2008) is correlated with MIS 5d-1 and the PG9 depositional sequence (Milli, 1997; Tiber Depositional Sequence of Milli et al., 2016). It comprises only the Alluvial deposits (SFTba) *sensu* Funiciello & Giordano (2008), and is bounded at the base by the deeply incised V Unconformity, recording the last glacio-eustatic sea level fall (MIS 5d- MIS 2).

In the study area, the Alluvial deposits (SFTba) mainly consists of poorly consolidated fine-grained sediments forming the Upper Pleistocene-Holocene (MIS 2-1) infill of the left-bank tributary valleys of the Tiber River, namely the Velabro, Murcia and Labicano valleys (Bozzano et al., 1995; Ammerman et al., 2000; Campolunghi et al., 2007; Carpentieri et al., 2015; Marra et al., 2018).

Gravel lag (SFTba A)

This facies is represented by sub-angular to well-rounded very fine to medium pebbles (Plate III e) of limestone, chert and tuff in an abundant dark grey silty sandy matrix rich in ferro-magnesian minerals and plant fragments.

Interpretation. SFTba A forms a coarse basal lag up to about 5 m thick infilling the lower part of the Tiber tributary paleovalleys. It represents an early-stage deposit resulting from local erosion and deposition of older gravelly-sandy deposits (e.g. CIL A-B, VGU A-B and FTR A-B) cut by Unconformity V.

Channel sand (SFTba B)

This facies is comprised of grey to brown, fine-medium silty sands, with quartz, feldspar, muscovite, ferro-magnesian minerals of volcanic origin and scattered peat fragments. SFTba B forms lens-shaped bodies up to 8-10 m thick and less than 100 m wide, which pass laterally to mud-prone deposits of facies SFTba D-F (see below).

Interpretation. SFTba B can be interpreted as a channel-fill deposit of streams with a sandy bed-load.

Organic-rich mud (SFTba D)

This facies represents most of the infill of SFT paleovalleys reaching thickness up to 35 m (e.g. Murcia Valley, Fig. 4). It is composed of dark grey, structureless silty clay (Plate III f), typically plastic and poorly consolidated, interbedded with cm-thick beds of sand compositionally similar to SFTba B. The dark grey hue is imparted by the abundance of plant fragments, which in some cases can be concentrated to form dm-thick peat layers.

Interpretation. SFTba D reflects fall-out and, subordinately, traction-fall deposition by fluvial overbanking in an undrained floodplain environment with ponds and

Plate III

Examples of lithofacies from selected cores (bottoms and tops in the lower left and upper right, respectively; core box is 1 m-long), with main facies boundaries marked in red. a) The Fosso del Torrino Formation (Middle Pleistocene): pale yellow, faintly laminated sandy silt (FTR F) interpreted as a well-drained floodplain deposit, interbedded with grey-brown, reworked coarse pyroclastic sand (FTR G) (borehole 9 MS, depth interval 20-15 m). b) Detail of a tephra layer from FTR F (borehole 3 A; depth 16.40 m). c) Villa Senni Formation - Tufo Lionato (Middle Pleistocene): orange-red massive ignimbrite (VSN 1a) with a 40 cm thick basal fallout deposit, composed of dark grey lapilli and coarse ashes. VSN 1a covers overbank silt (FTR F) of the Fosso Torrino Formation (borehole 9 MS; depth interval 15-10 m); d) Villa Senni Formation - Tufo Lionato: reddish pozolan (VSN 1b) overlaying FTR F. VSN 1b is in turn overlain by yellowish, intensely pedogenized clay of the Aurelia Formation (AEL; Middle Pleistocene) and by anthropogenic landfill material (h) (borehole 2 A; dept interval 15-10 m). e) Fiume Tevere Synthem - Alluvial deposits (Late Pleistocene-Holocene): dark brown-grey, sandy rich, very fine to fine pebbles of SFTba A overlaying the sand of the Fosso del Torrino Formation (FTR B) in borehole 18 P (depth interval 25-20 m); f) Fiume Tevere Synthem - Alluvial deposits: grey, organic-rich, poorly drained floodplain mud (SFTba D lithofacies), overlain by pale brown, pedogenized sandy silt (SFTba F) in borehole 18 P (depth interval 20-15 m).

marshes.

Pedogenically modified mud (SFTba F)

This facies can be differentiated by SFTba D based on its stiffness, its reddish to dark brown-hue and mottled texture reflecting oxidization of abundant plant fragments (Plate III f). At some sites, scattered fine-pebble sized clasts of limestone and brick fragments are found embedded within the topmost part of SFTba F, witnessing man-made excavation and dumping of landfill materials, likely from Roman times.

Interpretation. SFTba F is widespread within SFT paleovalleys, forming a laterally continuous body up to 7 m thick overlaying SFTba D. It can be interpreted to reflect overbank deposition in a drained floodplain environment subject to intense root mottling and pedogenization.

4.7 Anthropogenic cover (h)

This unit is represented by an almost continuous layer of backfill material (lithofacies hb), and remnants of buildings (lithofacies hm) from the Roman age, reaching maximum thickness of 15-20 m. The backfill (hb) is constituted by sand-pebble sized clasts in a silty-clayey matrix of pozzolanic composition, while masonry (hm) is mainly composed by hard concrete and rocky blocks (travertine, lava rocks, marble, etc.). The anthropogenic layer mantles the pre-existing morphology and reaches its maximum thickness in correspondence of buried valleys (Moscatelli et al., 2014b).

5. DISCUSSION

Owing to the availability of numerous subsoil investigations carried out over the last few decades mostly for archeological, geotechnical and cultural heritage preservation purposes (De Angelis D'Ossat, 1956; Alvarez et al., 1996; Corazza et al., 2004; Cecchi, 2011; Moscatelli et al., 2012; Calabresi et al., 2013; Mancini et al., 2014), the Palatine Hill represents a key site for unfolding the stratigraphic architecture of the volcano-sedimentary succession of the Rome Basin (Conato et al., 1980; Milli, 1997; Karner & Marra, 1998; Marra et al., 1998, 2008, 2016; Giordano et al., 2003; Milli et al., 2008; Marra & Florindo, 2014; Luberti et al., 2017, among the others). Based on a few classical and well-studied outcrops (Figs. 5 and 6 a, b; see also Marra & Rosa, 1995; Corazza et al., 2004; De Rita et al., 2002; De Rita & Fabbri, 2009), temporary outcrops from archeological excavation and construction sites (Figs. 6 c-e) and selected boreholes recently drilled in the study area (Figs. 7-9), this contribution is aimed at describing the sedimentary facies making up the infills of multiple incised paleovalleys (*sensu* Blum et al., 2013) of the Tiber River, developed in response to the Middle Pleistocene to Holocene high-frequency sea level fluctuations affecting the Rome Basin. The following discussion aims to: 1) show the significance of the Palatine Hill case study as a depositional analogue for paleovalley development, and 2) comment best practices in geology of urban areas.

5.1 The Palatine Hill as an analogue for paleovalley development

The paleovalley infills preserved in the subsurface of the Palatine Hill and surrounding areas correspond to some of the synthems introduced by Funicello & Giordano (2008), namely, from older to younger the Flaminia (LMN), Villa Glori (VGL), Torrino (TNO), Quartaccio (QTA) and Fiume Tevere (SFT) Synthems.

In the study area, the Flaminia Synthem (LMN; MIS 16-15) is characterized by a rather flat basal unconformity (Unconformity I), tabular geometry and a fining-upward infill represented by the fluvial Santa Cecilia Formation, made of channel gravel (CIL A) and sand (CIL B) and deposited by a braided river with a coarse bed load. Along with the underlying marine sediment of the Monte Vaticano Formation (MVA), the Flaminia Synthem represents the substrate into which younger paleovalleys developed. Basing on its almost tabular geometry and stacking of facies, the Santa Cecilia Formation (CIL) can be interpreted as a "stacked channel sheet with smooth or near-smooth basal unconformity", following the valley architectures classification by Holbrook (2001). To the east of the study area, however, the CIL thickness increases rapidly and its top deepens, suggesting syn- to post- depositional extensional tectonics controlling locally the basin infill (Funicello & Giordano, 2008).

The Villa Glori (VGL) and Torrino (TNO) Synthems are by far the best-preserved paleovalley infills documented in the Palatine Hill subsurface. These show a NW-SE to N-S trend (Fig. 10), high-relief basal unconformities (Unconformities II and III) and a common facies motif with a lower gravelly facies grading upward into a suite of channelized sands, channel abandonment fines and floodplain muds. This facies architecture that indicates valley incision was followed by the establishment of an entrenched gravelly braided fluvial system, evolving upward into a mixed, sandy-muddy suspended-load and bed-load river (i.e. channel-levee sands and silt) with laterally continuous and well-developed floodplains (i.e. mud-prone facies).

Notably, tough partly cannibalized by the younger TNO, VGL (MIS 14-13) represents a particularly valuable example for constraining the likely morphology of the studied paleovalleys, in that its fluvial infill (the Valle Giulia Fm. VGU) is intercalated by ignimbrites from large volume catastrophic pyroclastic flows (the Palatino and Prima Porta Units, PTI and PPT) capable of blanking the topography and providing a snapshot of relative location of coeval depositional elements. In fact, for example, the PTI ignimbrite covered both the active channel and levee-floodplain belt (logs MS 13 and MS 11, in Fig. 7), and was later incised by the re-established active fluvial channel, represented by facies VGU A above PTI (Fig. 7).

A full record of paleovalley morphology and infill development is provided by TNO (MIS 12-11). The excellent preservation of the dominantly fluvial Fosso del Torrino Fm. (FTR) allows confidently tracking: 1) the stratigraphic replacement of a lower gravel-prone early stage-fill (FTR A) by a sandy multi-storey channel belt fill (i.e. the main depositional body of facies FTR B) along the paleovalley axis (Fig. 10); 2) the evolving relation-

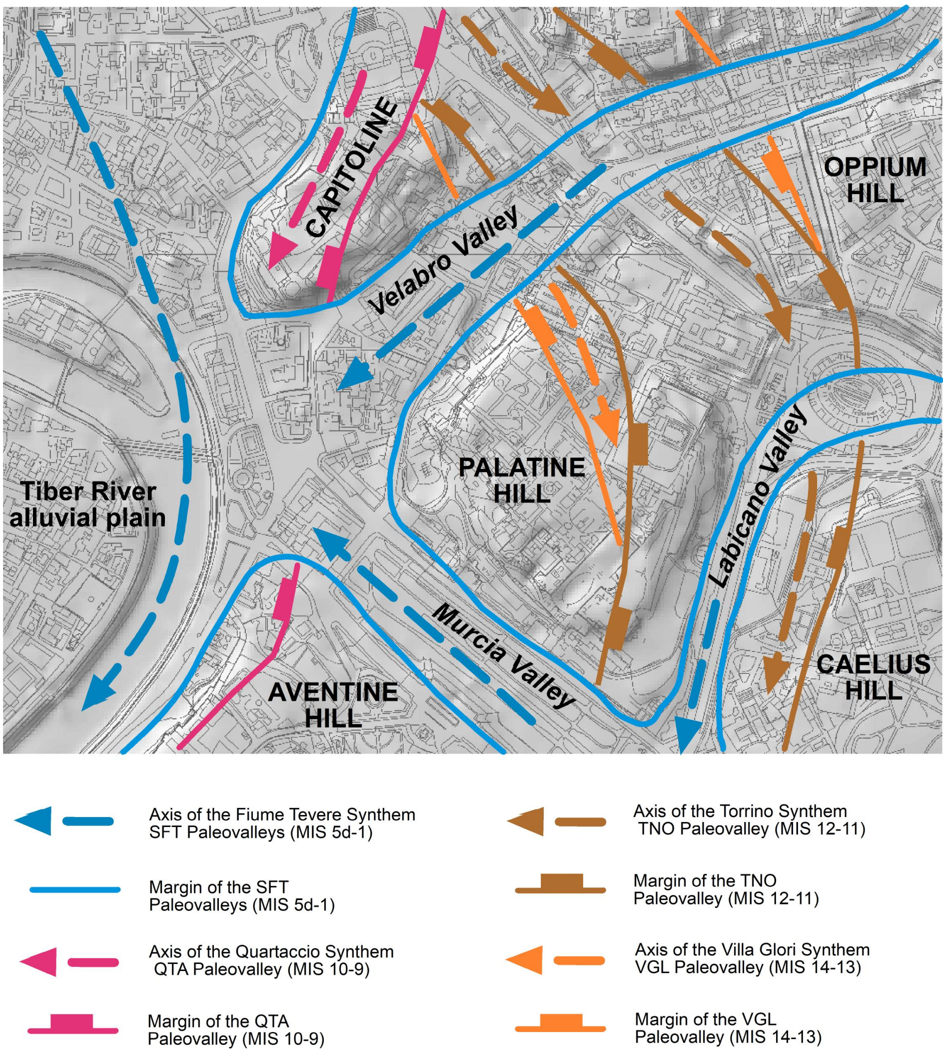


Fig. 10 - Paleogeographic sketch map of the Palatine area showing axes and margins of the main buried paleovalleys (modified and adapted after Alvarez et al., 1996, and Mancini et al., 2014).

ship between the active channel belt and coeval floodplains.

Regarding the latter aspect, it can be noted how, over most of the paleovalley infill thickness, floodplain muds are intercalated with hydromorphic paleosols suggesting waterlogged conditions (FTR D), whereas in the uppermost FTR they contain oxidized paleosols (FTR F). This stratigraphic and pedogenetic change from poorly- to well-drained floodplains may be interpreted as a progressive lowering of the groundwater table, which can be explained by incipient channel re-incision of floodplain under a general decrease of rate of floodplain accommodation (Wright & Marriot, 1993; Miall, 2014).

Moreover, in the uppermost FTR the widespread presence of out-of-channel epiclastites (FTR G) and tephra testifies active syn-volcanic alluvial sedimentation. The tephra horizons preserved within the upper floodplain deposits (Plate III b; Fig. 9) might correlate to the tephra reported by Marra et al. (2016) as part of the San Paolo Fm. (i.e. Fosso del Torrino Fm.) from the subsurface of the nearby Capitoline Hill. A sanidine sample (SPQR-51sample) from the Capitoline tephra was $^{40}Ar/^{39}Ar$ dated 416 ± 11 ka (Karner & Renne, 1998; Karner et al., 2001) suggesting a correlation with the Vico α horizon sourced from the Vico Volcanic District of northern Latium (Luberti et al., 2017) and thus providing important constrain on timing of development of the FTR paleovalley infill.

The study area provides only a partial view of the Quartaccio Synthem (QTA, MIS 10-9; Fig. 10). Nonetheless, the geometry and facies character of the pyroclastic Villa Senni Formation-Tufo Lionato (VSN1) and the Aurelia Formation (AEL) agree with a river system, and the corresponding paleovalley, located to the NW of the Capitoline Hill (Alvarez et al., 1996; Corazza et al., 2004), which delivered fines to a left-bank floodplain (i.e. AEL) occupying the Palatine Hill area. If the likely location of the paleovalleys documented in the subsurface of the Palatine Hill and surrounding areas is compared (Fig. 10), a progressive westward shift of the river system is apparent starting from TNO to QTA which may reflect the interplay of the long-term regional tectonic uplift of the western periphery of the Central Apennines (Milli, 1997; Giordano et al., 2003; Marra et al., 2008; Milli et al., 2008; Mancini et al., 2013) and the input of volcanic products from the Alban Hills in subtracting accommodation space to the Tiber River fluvial system.

One last observation can be made about the significance of the Fiume Tevere Synthem (SFT; MIS 5d-1) present in the study area, representing the infills of the left-bank Velabro and Murcia tributary paleovalleys of the Tiber River. Compared to previously addressed examples, which refer to the ancient main trunk paleovalleys (VGL, TNO, QTA), the Velabro and Murcia paleovalley infills are initiated by coarse and poorly organized lags deposited by gravitative processes (facies SFTba A), contain a much greater proportion of pedogenized, organic-rich fines (SFTba D-F) and appear to be deficient of channel sand (SFTba B). This contrasting architecture of tributary vs. trunk paleovalley of the Tiber, much richer in channel-belt deposits (see also Milli et al., 2016), can be interpreted to reflect the fact that the higher rate of aggradation of the Tiber River valley with respect to surrounding areas might have resulted in "passive" backfilling of lateral valleys.

5.2 Methodological remarks on urban geosciences

Finally two aspects concerning the best practice on urban geosciences can be considered, which derive from the present research: 1) the extensive use of photographic illustration for core facies analysis; 2) the documentation of temporary outcrops.

On the first aspect, the photographic depiction of cores is well recommended for describing facies of Quaternary units within fluvial and urban contexts (Amorosi 2006; Sarti et al., 2012), and can significantly contribute to solve potential gaps of knowledge on local stratigraphy. However, within the rich scientific literature on the Rome Basin stratigraphy (Luberti et al., 2017, with references) only few examples do exist of core data reported through photographic pictures (Marra & Florindo, 2014; Martino et al., 2015; Milli et al., 2016). In our opinion, the core data here illustrated (Plates I-III) can be potentially used as useful reference and comparison material for subsoil reconstructions of nearby areas.

The occurrence of temporary shortly-exposed outcrops, related to in-progress city works such as subway construction and archeological excavations, is well documented in this article (Figs. 6 c-e). Their observation, description and correlation with other field and subsoil data should be emphasized. In fact, the integration of temporary outcrops with other data can be useful for anchoring unsolved stratigraphic reconstructions in densely urbanized contexts, where the widespread presence of pervious surfaces usually impedes the observation of natural outcrops, and where available cores may be insufficient, in some cases, to provide a complete picture of the subsoil. This is particularly true in the ancient historical center of Rome, where the anthropogenic modifications and a thick layer of anthropic backfill (Moscatelli et al., 2014 b; Ciotoli et al., 2015) often prevents detailed palaeo-environmental reconstructions based only on the terrain morphology observation.

6. CONCLUSION

The facies analysis of core and outcrop data has allowed to reconstruct with great detail the stratigraphic architecture of the Palatine Hill. This architecture is represented by a series of nested paleovalley infills related to the Tiber River system and encompassing Middle Pleistocene to Holocene intervals (MIS 16-9 and MIS 2-1 intervals) of fluvial sedimentation and distal pyroclastic deposition. The paleogeography of the most relevant paleo-valleys, as reconstructed from the present study, can be related to external forcing as uplift, pyroclastic supply and fluvial response to glacio-eustatic changes, as well as to internal reorganization of the fluvial system, which deserve to be investigated on a wider area. Nevertheless, thanks to its well detailed stratigraphic reconstruction the Palatine can be considered a key area for better understanding trends, characters and continuity of fluvial paleo-valleys within the whole Rome Basin.

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