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A review of the Villafranchian fossiliferous sites of Latium in the framework of the geodynamic setting and paleogeographic evolution of the Tyrrhenian Sea margin of central Italy

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ABSTRACT

In the present study we provide a paleontological and chronostratigraphic review of the Villafranchian fossiliferous sites of Latium, revising the biochronologic attribution based on their framing within the geodynamic and paleogeographic evolutionary picture for this region. Aimed at this scope, we reconstruct the sedimentary and structural history of the Early Pleistocene marine basins through the review and the regional correlation of published stratigraphic sections and borehole data. Moreover, we combine the chronostratigraphic constraints provided in this study to the near-coast deposits of Gelasian-Santernian age (2.58–1.5 Ma) with the results of a recent geomorphologic study of this area, allowing us to reconstruct a suite of terraced paleo-surfaces correlated with marine isotopic stages 21 through 5. By doing so, we provide further age constraints to the sedimentary and tectonic processes acting on the Tyrrhenian Sea margin in Quaternary times, highlighting a possible different paleogeographic evolution of the southern coastal area where the Middle-Villafranchian type-section of Coste San Giacomo site is located, with respect to the northern sector.

1. Introduction

The Tyrrhenian Sea Margin of Latium (Fig. 1) is a NW-SE oriented stretch of land comprised between the coast and the Apennines mountain range, which throughout Pliocene and Early Pleistocene times hosted the marine sedimentary basins originated by extensional tectonics acting at the rear of the orogenic belt, whereas a regional uplift caused its progressive emersion since the late Early Pleistocene. A wide coastal plain developed as a consequence of a continuous SW retreat of the coastline, which eventually became a NW-SE stretching fluvial valley, following the development of a graben-like structure linked with the development of a chain of volcanic districts constituting the Roman Magmatic Province (Conticelli and Peccerilllo, 1992; Peccerillo, 2005). Parallel to the progressive continentalization, this sector was populated by terrestrial vertebrate faunas, which was previously confined into the earlier emerged portion of the Apennines range. However, due to this paleogeographic evolution, dominated by marine environment throughout Pliocene and Early Pleistocene times, Early Villaftranchian faunal remains are missing in this area, while those referred to the Middle Villafranchian are scarce and strictly confined in the inner Tyrrhenian Sea margin, at the foot of the Apennine ranges (Fig. 1). Among these, the Coste San Giacomo locality, in the southern portion of the investigated area, represents the most important fossiliferous site (Biddittu et al., 1979; Bellucci et al., 2012, 2014), being the eponymous site of the formal Faunal Unit (Gliozzi et al., 1997; Petronio et al., 2011). Other fossiliferous localities referred in literature to the Middle or even the Early Villafranchian are located in the Sabina region (Tuccimei, 1889, 1891), associated to rudite fan and slope deposits at the foot of the Sabini Mts. Finally, few Late Villafranchian fossiliferous sites occur in the south-western sector of the Tyrrhenian margin, likely because of the thick blanket of volcanic deposits that since 800 ka covered the older sedimentary successions in this area.

In the present study we provide a paleontological and chrono-stratigraphic review of the fossiliferous sites of Villafranchian age of Latium, aimed at revising their biochronologic attribution based on their framing within the geologic and paleogeographic evolution of this region. To achieve this goal, we reconstruct the sedimentary and structural history of the Early Pleistocene marine basins through the review and the regional correlation of published stratigraphic sections and borehole data. Besides providing chronostratigraphic constraints to the near-coast deposits of Gelasian-Santernian age (2.58–1.5 Ma), we integrate the pleogeographic reconstruction with results of a recent geomorphologic study of this area correlating with the marine isotopic stages (MISs) 21 through 5 a series of fluvial terraces formed through the interplay between regional uplift and glacio-eustasy (Marra et al., 2017), providing further age constraints to the sedimentary and tectonic processes acting on the Tyrrhenian sea margin in this time span.

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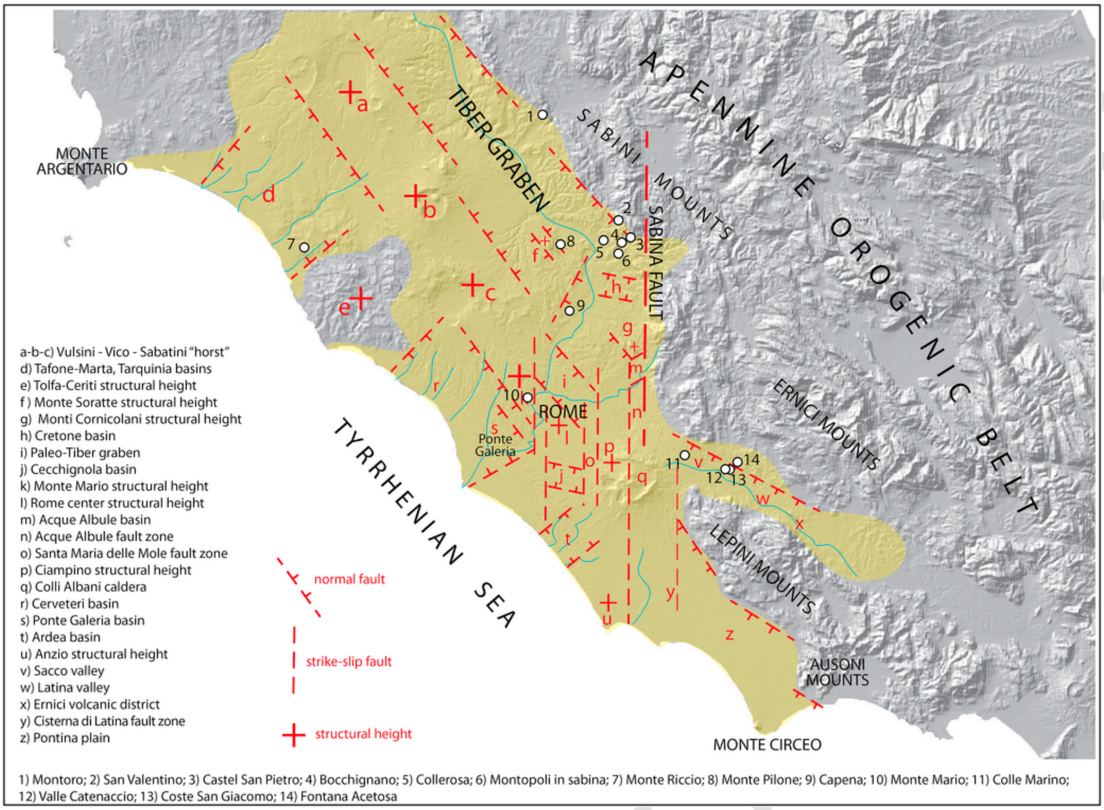

Fig. 1. Digital Elevation Map (DEM) image showing the structural setting of the area on the Tyrrhenian Sea Margin of Latium subjected to continental sedimentation since the late Santernian (shaded area), and the location of the 14 Villafranchian paleontological sites investigated in this work.

2. Geodynamic setting

The opening of the Tyrrhenian Sea was the consequence of the retreat of a subducting slab and the NE migration of an arched thrust and fold belt (Fig. 2b), originated by convergent African and Euro-Asian plate movement (Malinverno and Ryan, 1986; Patacca and Scandone, 1989). The origin and progressive NE migration of the northern Tyrrhenian Sea basins since early Oligocene times was controlled by a delamination process causing crustal thinning and astenosphere bulging, which culminated in the emplacement of intrusive granitic bodies at the center of the back-arc region, corresponding to modern Tuscan archipelago (Jolivet et al., 1998) (Fig. 2b–c). Continuous NE migration of the post-orogenic extensional domain caused the shift of the collapsing sector towards the mountain range, which was dislocated by principal NW-SE trending normal faults, bordering the incoming sedimentary basins, whose lateral continuity was interrupted by NE-SW transfer faults (Acocella and Funiciello, 2006). This migration was accompanied by parallel shifting of the volcano-tectonic processes related to uprising of magma through the crust, leading to an early, acid Pliocene volcanism (Serri et al., 1993; De Rita et al., 1994; Barberi et al., 1994), and culminating in the Middle Pleistocene high potassic volcanism of the Roman Province (Conticelli and Peccerillo, 1992; Peccerillo, 2005). In the same time span, strike-slip faulting associated with a N-S shear zone known as the Sabina Fault Zone (Alfonsi et al., 1991, Fig. 2a) affected the central Tyrrhenian margin (Faccenna et al., 1994a, 1994b; Marra, 1999, 2001; Frepoli et al., 2010).

3. The Villafranchian of central Italy

3.1. General setting

The Villafranchian Mammal Age is subdivided in three periods (early, middle and late) comprehending 8 Faunal Units (=FUs; Azzaroli, 1977; Gliozzi et al., 1997; Palombo et al., 2002; Kotsakis et al., 2003; Masini and Sala, 2007; Petronio et al., 2011) (Fig. 3). Exact chronologic boundaries among these FUs are often missing and their correlation with the mammalian standard zones (Mammiféres Néogènes et Quaternaires, MNQ) is problematic (see Palombo and Sardella, 2007), since both have regional limitation due to paleogeographic factors. In Fig. 3 we have adopted the integrated biochronologic scheme proposed in Nomade et al. (2014), while for the First Occurrences (FOs) and the Last Occurrences (LOs) of the most relevant taxa for this study we follow Kotsakis et al., 2003 and Palombo, 2014).

A marked faunal renewal characterizes the Villafranchian of Italy, with a sharp transition from species of warm temperate climate to other, more adapted species to less humid and colder climate. A brief summary of the principal biochronologic events related to the mammal species that characterized this period is reported hereby, while a detailed review is beyond the aimes of the present work, which is focussed on the paleogeographic domain represented by the coastal area of Latium.

3.1.1. Macromammals

The progressive occurrence of species fit to open spaces, including *Chasmaporthetes lunensis*, *Acinonyx pardinensis*, *Homotherium*

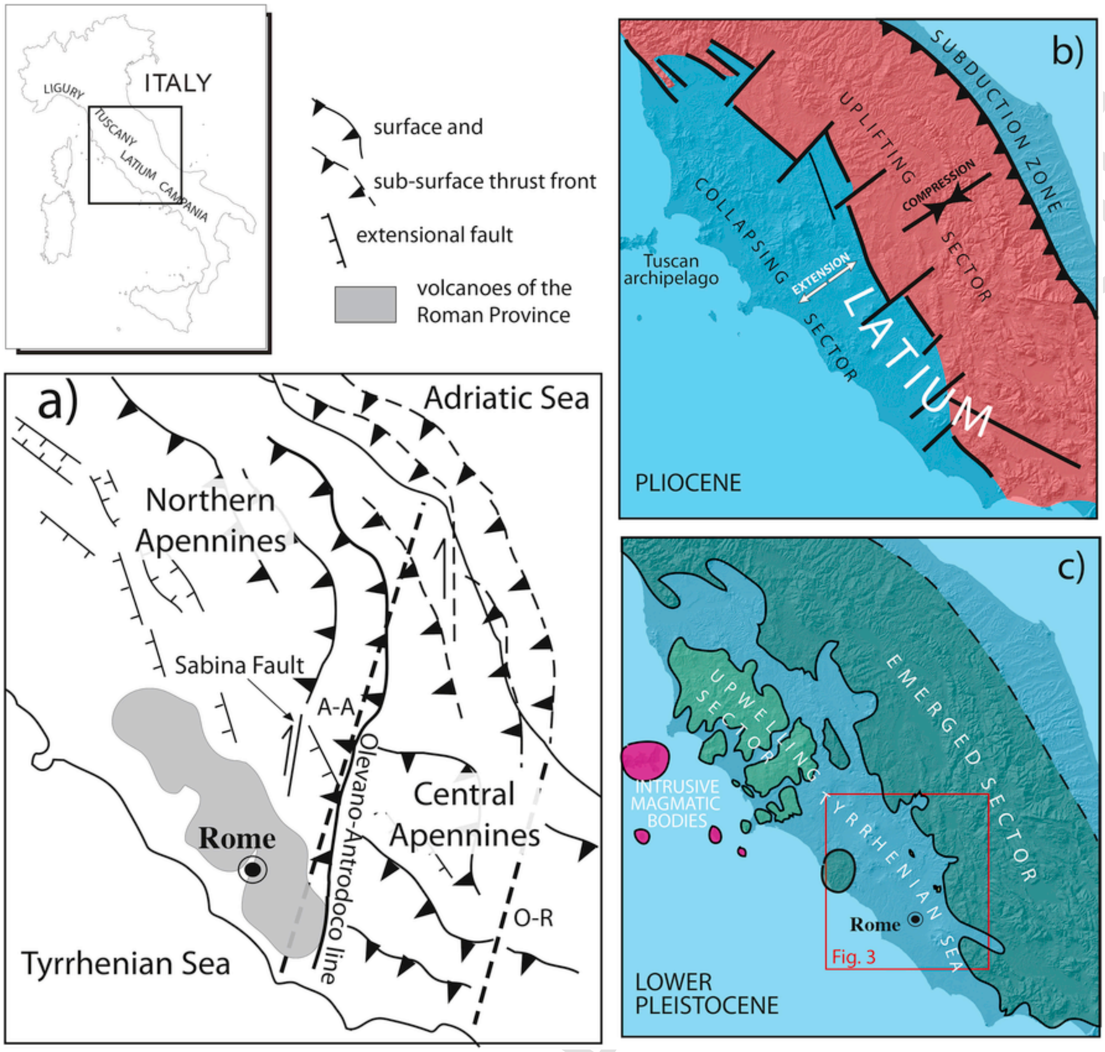

Fig. 2. Map views showing the geodynamic (a) and paleogeographic (b-b') setting, and the elements responsible for the evolution of the Tyrrhenian Sea margin of Italy during Pliocene through Pleistocene times. See text for comments.

latidens and *Ursus minimus* among the carnivores, and *Axis lyra*, *Leptobos stenometopon*, *Stephanorhinus jeanvireti* and *Mammut borsoni* among the herbivorous, besides the Pliocene survivors *Anancus arvernensis*, *Tapirus arvernensis* and *Sus minor*, characterizes the faunal renewal during the Triversa FU.

Another marked faunal renewal occurs during the Montopoli FU, following a global climate cooling since 2.6 Ma, causing rapid variations of the vegetal communities which are represented by dense forests during the relatively long glacials, replaced by open vegetation or more or less thickly wooded environments during the short interglacial periods (Leroy, 2007; Petronio et al., 2011). The species adapted to forest environment are replaced by taxa fit for open and arid environments coming from the East or from central Europe. The disappareance of *Tapirus* and the FO of an archaic form of *Mammuthus* (*Mammuthus meridionalis*=*Mammuthus gromovi*, see Palombo and Ferretti, 2005), along with *Equus livenzovensis*, the cervids *Eucladoceros* and *Croizetoceros*, *Gazella borbonica*, and *Stephanorhinus etruscus*, mark the passage to the Montopoli FU, at the Gauss-Matuyama paleomagnetic transition (Lindsay et al., 1980; Torre, 1987; Benvenuti et al., 1995).

The Saint Vallier FU is characterized by appearance of *Equus stenonis* and an advanced form of *M. meridionalis* (*M. meridionalis meridionalis*).

It is shortly followed, around 2.1 Ma (Bellucci et al., 2014), by the Coste San Giacomo FU, characterized by the in loco evolution of Proboscidea, Perissodactyla and cervids (*Eucladoceros tegulensis*), with the introduction of *Leptobos* ex gr. *merlai-furtivus*, *Gazellospira torticornis*, *Sus strozzii*, along with *Canis etruscus* (see Rook and Torre, 1996). The LO of *A. arvernensis* is also commonly reported within the CSG FU (Bellucci et al., 2014). However, Zanchetta and Mazza (1996) reported the occurrence of this taxon within fluvial sand and gravels at the base of *Arctica islandica*-bearing, marine sands in the lower Valdarno (Tuscany region), suggesting *Anancus* may had endured within the Olivola FU, unless the appearance of the cold guest *A. islandica* in the Tyrrhenian Sea would have occurred during the Gelasian, in contrast with the previous belief of a Calabrian age (Bonadonna, 1968).

Paleobotanical data for the Middle Villafranchian of central Italy (Pontini and Bertini, 2000) indicate a progressive transition to open, steppe-like vegetation, which favored the expansion of the prairie species, probably determining a strong impact on the vegetation, pre-

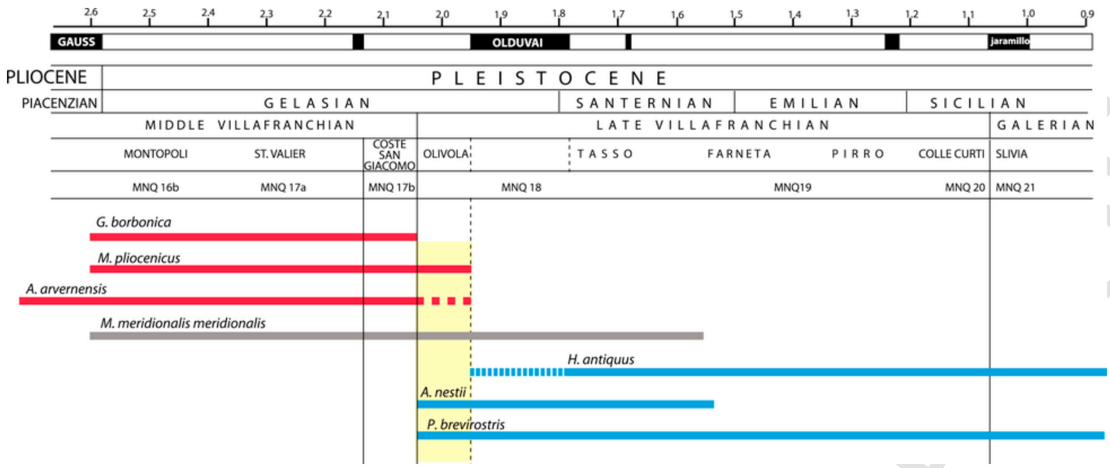

Fig. 3. A) Biochronologic scheme for the Middle and Late Villafranchian, showing the large mammal faunal units (FU) for Italy (Gliozzi et al., 1997) and the Mammifères Néogènes et Quaternaires (MNQ) calibrated biozones for French (from Nomade et al., 2014). b) Chronologic range of selected species providing constraints to the faunal assemblages discussed in this work, showing the Middle Villafranchian (red lines) and the Late Villafranchian (blue lines) markers. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

venting its "closure" during the alternating warmer, more favorable periods.

The further reduction of the forest covering during the Olivola FU is testified by appearance of *Canis arnensis* and *Lycaon falconeri*, along with the diffusion of species adapted to steppe-like or grassland environments, like the medium-large sized bovine *Leptobos etruscus*. However, persistence of the forest is also evidenced by appearance of the large-sized hyaena *Pachycrocuta brevirostris*, *Ursus etruscus*, and the two cervid species *Eucladoceros dicranios* and *Axis nestii*; whereas the occurrence of the feline *Panthera gombaszoegensis* testify also open spaces (O'Regan, 2002). In contrast, *Pliocrocuta perrieri*, and *G. borbonica* disappear.

The transition from the Olivola to the subsequent Tasso FU has been magnetostratigraphically calibrated close to the top of the Olduvai Subchron (Napoleone et al., 2003; Rook and Martínez Navarro, 2010; Rook et al., 2013). Since this moment, the progressive disappearance of the Villafranchian species, which are replaced by new ones characterizing the Middle Pleistocene, is recorded. Besides the LOs of several taxa characterizing the Middle Villafranchian, the FOs of *Equus stelhini*, *Hippopotamus antiquus*, *Leptobos vallisarni* and *Eucladoceros ctenoides* are recorded.

During the Farneta FU, the primitive megacerine *Praemegaceros obscurus* joins the Villafranchian bovid genera *Leptobos/Bison* and *Eucladoceros*. A more evolved cervid form, *Axis eurygonos*, replaces *A. nestii* (see Di Stefano and Petronio, 2002), while *M. meridionalis* is present with a specialized sub-species (*M. meridionalis vestinus,* see Gliozzi et al., 1997). Among the perissodactyla, *Equus suessenbornensis* appears (Alberdi and Palombo, 2013).

Persistence of open spaces is evidenced also in the following Pirro FU by the occurrence of the primitive bisontine form *Bison (Eobison) degiulii* (see Masini et al., 2013), and by the medium-sized equid *Equus altidens* beside the large-sized, robust *E. suessenbornensis* (see Alberdi and Palombo, 2013).

3.1.2. Micromammals

Two Mammal Ages based on the Villafranchian small mammal species, whose study has been implemented during the last decades, have been introduced: Villanyan and early Biharian (Gliozzi et al., 1997; Kotsakis et al., 2003).

The members of the family Arvicolidae are the most common during the Plio-Pleistocene in Italy and, due to the abundance of tachytelic forms, represent the systematic group upon which the micromammals biochronology is based on.

The oldest Villanyan fauna of Italy is represented by the arvicolids *Mimomys hassiacus* (= *M. haijanckensis*) and *Mimomys stehlini*, along with the extinct murid *A. alsomyoides*. A later Villanyan fauna is characterized by the marker *Mimomys polonicus*, whose occurrence is sporadic in Italy (Upper Valdarno basin, Ghinassi et al., 2005), where the Coste San Giacomo e Olivola FUs are characterized by occurrence of *Mimomys pliocaenicus* and *Apodemus dominans* (= *?Apodemus atavus*; see discussion in Knitlová. and Horáček, 2017).

The early Biharian sees the appearance of the arizodontic genus *Allophaiomys* among the arvicolids, besides several *Mimomys* species already present in the late Villanyian. The extinct murid species *A. atavus* is also present. Later on, during the Tasso FU, is the FO of *Mimomys savini*, which endured the whole Biharian. In the Farneta FU the presence in Italy of *Victoriamys chalinei* (= *Allophaiomys chalinei*, see Martin, 2012) is shortly registered, while in the Pirro FU the extant species *Apodemus flavicollis* appears (Kotsakis et al., 2003; Sala and Masini, 2007). The presence of *Allophaiomys ruffoi* is reported in both these FUs.

3.2. Villafranchian sites of Latium

The faunal assemblages recovered at the 14 fossiliferous sites attributed, according to literature, to Villafranchian age and occurring in the investigated area of the Tyrrhenian Sea margin, are reviewed in this section, while their biochronological implications are discussed in the final section. For no one of the six sites of the Sabina region (Montoro, Colle San Valentino, Castel San Pietro, Bocchignano, Collerosa and Montopoli di Sabina) any stratigraphic scheme of the deposits in which the fossils were recovered was provided in the original literature, but only their lithological description made by Tuccimei (1898, 1891, 1893) in his reports. Consequently, elevation a.s.l. of these sites is approximately reported, according to that of the toponyms on the 1:25.000 topographic maps by Istituto Geografico Militare of Italy. More recently, geology of several of these site was reported in the new 1:50.000 map of Cittaducale by ISPRA (Cosentino et al., 2012). The authors of this map assigned a Middle Villafranchian age to the deposits cropping out at the localities mentioned above based on biostratigraphy by 89, 1891, 1893), and by correlation with a few stratigraphic sections for which a Gelasian age is proposed, as opposed to the different interpretation provided in Mancini et al. (2007) (see comment and reply to Mancini et al., 2007, by Cosentino and Fubelli, 2008, and Mancini et al., 2008).

In the following sections we provide a revision of the biostratigraphy of the faunal assemblages described by 89, 1891, 1893) occurring at six sites of the Sabina region, along with those occurring at other 8 sites of Villafranchian age reported in the literature. Not all the taxa reported by Tuccimei are figured, therefore we rely on attribution made by the Author for those that cannot be re-examined, while we propose and discuss the revision of other specimens from the Sabina region, based on their illustration. We combine the revised ages for the faunal assemblages with the paleogeographic and stratigraphic reconstruction of their environments provided in this study and discussed in section 6. Our interpretation of the stratigraphy of these sites, with the exclusion of the northernmost one (Montoro), is reported in Figs. 4, 6 and 7.

3.2.1. Montoro

Ponzi (1875) recorded the presence of *Mastodon arvernensis* (recte *Anancus arvernensis*) from a yellow marl horizon near the village of Montoro (Terni, Umbria), ~300 m a.s.l.. Tuccimei (1891) confirmed the presence of *A. arvernensis* and also reported *Elephas meridionalis* (recte *Mammuthus meridionalis meridionalis*) within a sandy level occurring about 50 m above the yellow marl.

A. arvernensis is recorded during the Late Pliocene and the Early Pleistocene in Italy. The species is documented at Villafranca d'Asti, Montopoli, Coste San Giacomo and, doubtfully, at Olivola (Zanchetta and Mazza, 1996; Gliozzi et al., 1997; Palombo and Ferretti, 2005; Petronio et al., 2011; Bellucci et al., 2012), ranging the Triversa to ?Olivola FUs.

Archaic form of *M. meridionalis* is reported during the Montopoli FU (Palombo and Ferretti, 2005) at Laiatico and Montopoli. According to Gliozzi et al. (1997) the typical *M. meridionalis* occurred for the first time in Italy in the type locality of Upper Valdarno and is replaced by the more evolved form (*M. meridionalis vestinus*) since the Farneta FU to Slivia FU.

The similarities of the molars illustrated by Tuccimei (1891) with the molars of *M. meridionalis* of Upper Valdarno, exclude the identification with specimens like those of Montopoli Valdarno and Laiatico (see Palombo and Ferretti, 2005), so the attribution to Montopoli FU must be excluded for the elephant remains. Therefore, the faunal assemblage of Montoro, if considered part of the same biostratigraphic horizon, is compatible with a biochronological interval limited to the Coste San Giacomo FU, or extended to Olivola FU, depending on the biochronologic assumption regarding the LO of *A. arvernensis*. However, in case of two distinct biostratigraphic horizons, the correlation of the uppermost one, including *M. meridionaslis meridionalis*, with the Tasso FU cannot be excluded.

3.2.2. Colle San Valentino

Tuccimei (1889) recorded the presence of *Rhinocerus etruscus* (recte *Stephanorhinus etruscus*, see Pandolfi and Petronio, 2015) from the gravels and sands of Colle San Valentino, 383 m a.s.l., and Tuccimei (1898) reported also the occurrence of *Cervus pardinensis* (recte *A. nestii*) within a blue marl horizon at this locality. Re-examination of the cervid remains figured by Tuccimei (1889) allowed us

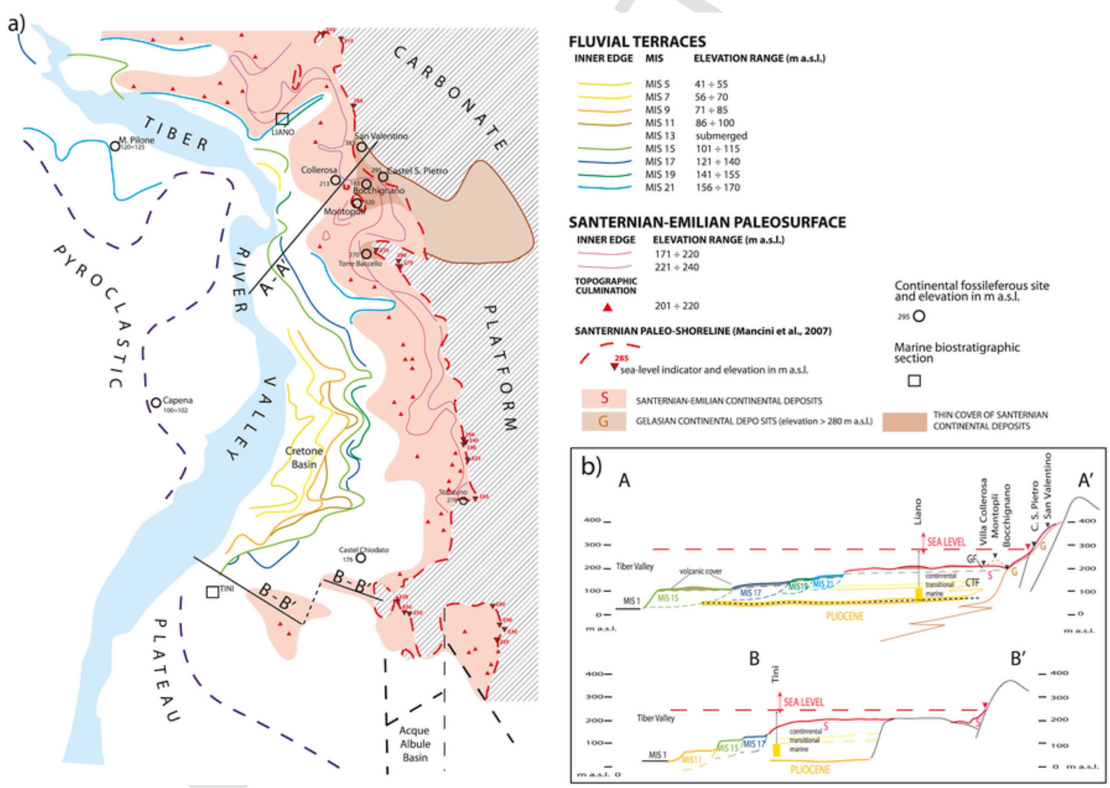

Fig. 4. A) Geomorphologic map of the Tyrrhenian Sea margin of Latium in the area adjacent to the paleo-shoreline indicators (red triangles with downward vertix) of the Santernian coastline (red dashed line, Mancini et al., 2007). A series of terraced surfaces was reconstructed from a dataset of topographic culminations: the colored lines are the inner margin of terrace (modified from Marra et al., 2017). Location of the investigated paleontological sites is shown. b) Schematic cross-sections reconstructing the geomorphologic and stratigraphic setting on the Tyrrhenian Sea margin of Latium. The location of the paleontological sites whose stratigraphy is discussed in the text is reported on the cross-section A-A' (black triangles). Paleo-batymetric data from Liano and Tini sections (Borzi et al., 1998) are also reported, showing the consistent elevation (black arrows) of the Santernian coastline (red dashed line). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

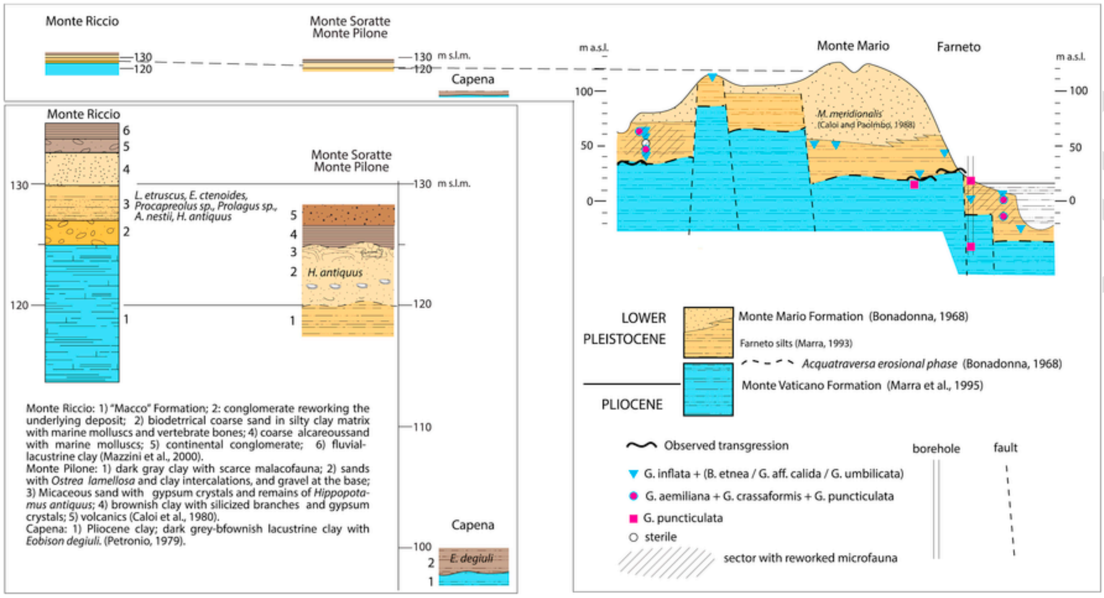

Fig. 5. Stratigraphic schemes and correlation of the fossiliferous sites hosting marine to coastal Santernian deposits in Latium.

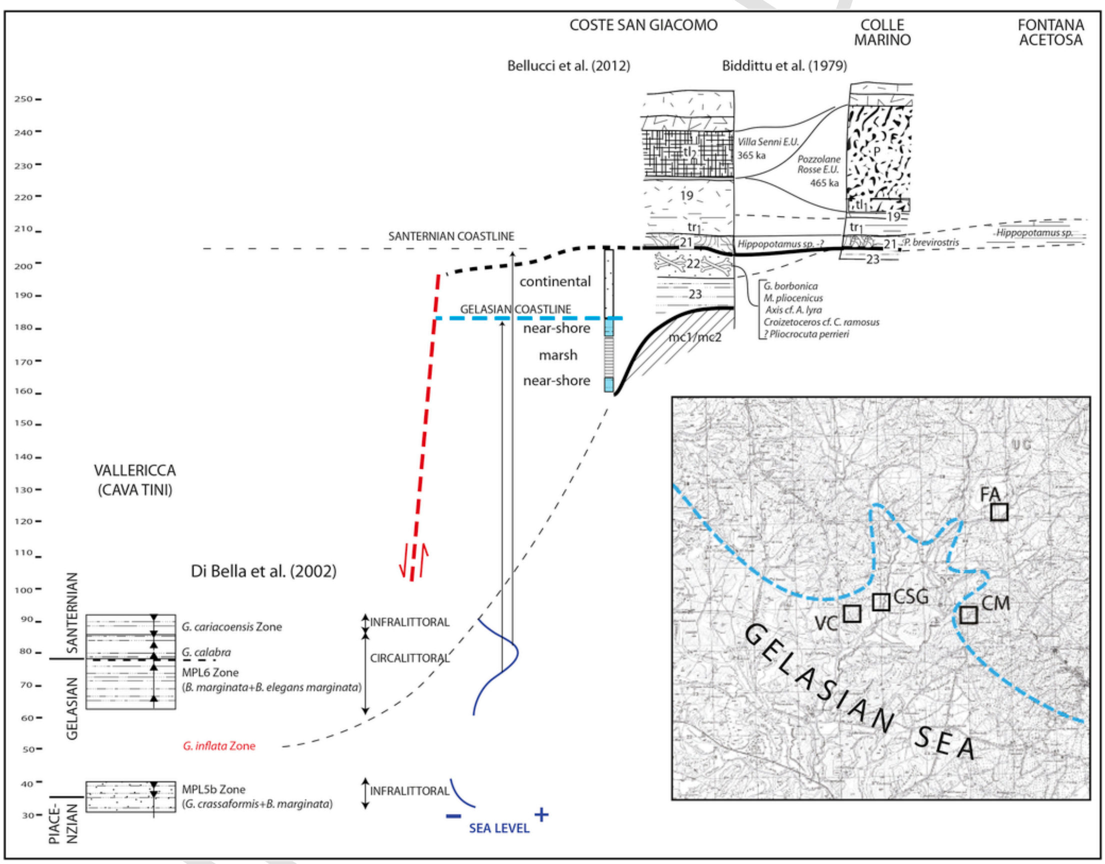

Fig. 6. The biostratigraphy at Coste San Giacomo (CSG), Colle Marino (CM) and Fontana Acetosa (FA) is re-interpreted based on outcrops stratigraphic schemes of Biddittu et al. (1979) and borehole data of Bellucci et al. (2012). Abbreviations of the stratigraphic units are the original ones; age of the pyroclastic deposits is based on our revision of the stratigraphy of Fontana Ranuccio originally reported in Bidditu et al. (1979), following updated chronostratigraphic criteria for "tl1: litoide superiore tuff" (i.e. Tufo Lionato eruption unit, 364±4 ka; Marra et al., 2009) and for "P: pozzolana" (i.e. Pozzolane Rosse Eruption Unit, 456±4 ka, Marra et al., 2009). The occurrence of Hippopotamus sp. i s interpreted as autochtonous at FA, according to a Late Villafranchian to Early Galerian age of the similar continental deposits cropping out at CM and containing remains of P. brevirostris along with lihic artifacts. In contrast, we hypothesize (see section 6.2) that the specimen recovered at CSG might come from layer 21, which Biddittu et al. (1979) correlate with the analogous layer 21 at CM, immediately above the layer (22) hosting the authochtonous Middle Villfranchian faunal assemblage.

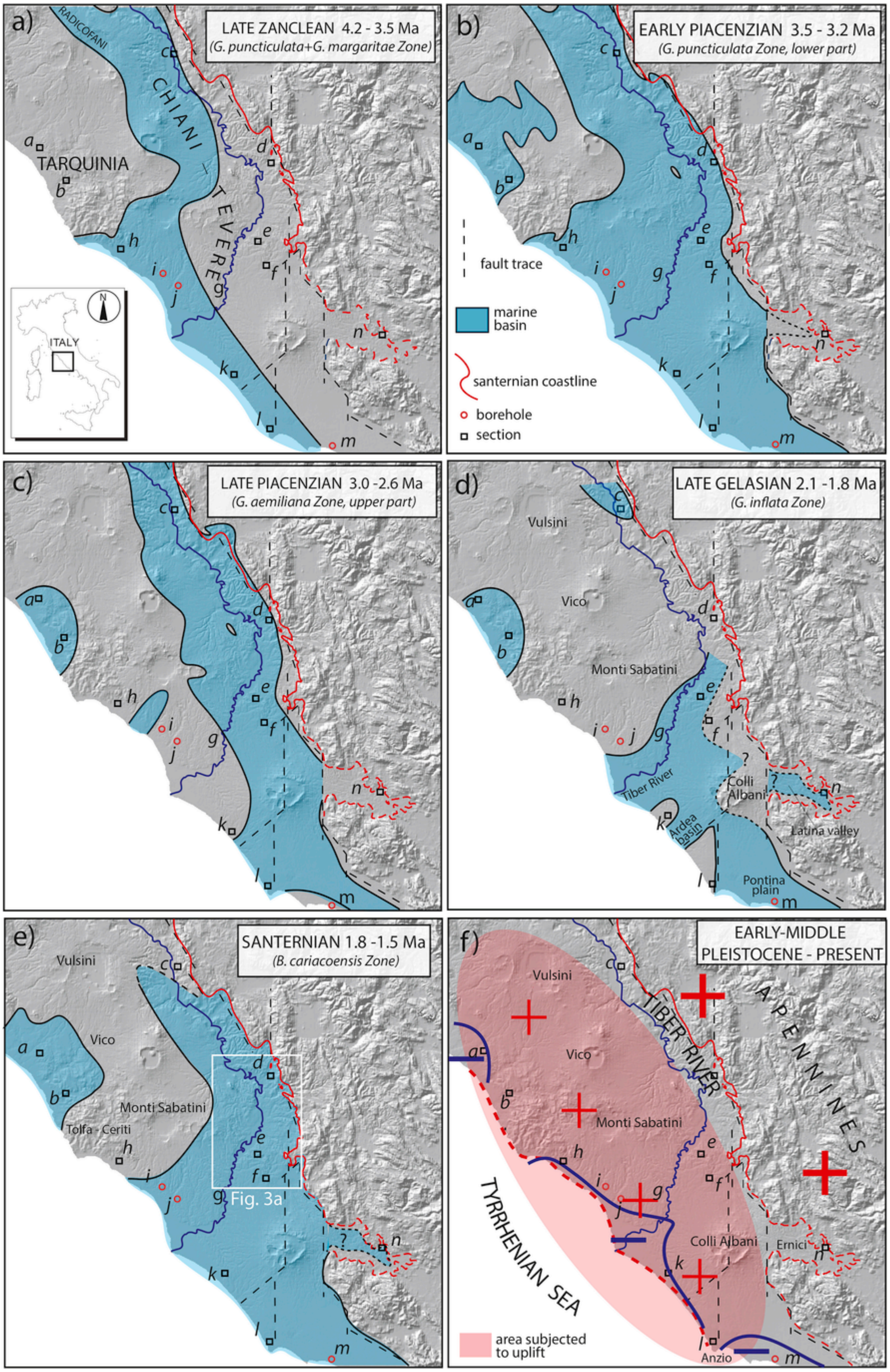
a)
LATE ZANCLEAN 4.2 - 3.5 Ma
(G. puncticulata+G. margaritae Zone)
RADICOFANI
CHIANI
TEVERE
TARQUINIA
ITALY
N
b)
EARLY PIACENZIAN 3.5 - 3.2 Ma
(G. puncticulata Zone, lower part)
fault trace
marine basin
santernian coastline
borehole
section
c)
LATE PIACENZIAN 3.0 -2.6 Ma
(G. aemiliana Zone, upper part)
d)
LATE GELASIAN 2.1 -1.8 Ma
(G. inflata Zone)
Vulsini
Vico
Monti Sabatini
Tiber River
Colli Albani
Ardea basin
Latina valley
Pontina plain
e)
SANTERNIAN 1.8 -1.5 Ma
(B. cariacoensis Zone)
Tolfa - Ceriti
Fig. 3a
f)
EARLY-MIDDLE PLEISTOCENE - PRESENT
TIBER RIVER
APENNINES
TYRRHENIAN SEA
Ernici
Anzio
area subjected to uplift

Fig. 7. Paleogeographic evolution of the Tyrrhenian Sea Margin of Latium and extension of the marine basins at different ages, based on biostratigraphic, biochronologic and paleo-batymetric data from published sedimentary sections and borehole data. a: Tarquinia basin (Barberi et al., 1994; Carboni and Palagi, 1997, 1998); b: Monte Riccio (Mazzini et al., 2000); c: Lugnano, d: Liano (Borzi et al., 1998); e: Tini-Vallericca (Carboni and Conti, 1977; Arias et al., 1990; Borzi et al., 1998); f: Marco Simone (Carboni, 1975; Arias et al., 1976); g: Monte Mario - Rome (Bonadonna, 1968; Marra et al., 1995; Bergamin et al., 2000; Cosentino et al., 2009); h: Tolfa-Ceriti (De Rita et al., 1994); i–j: Roma 1 and Roma 2 well logs (Conforto, 1962); k: Pomezia (Malatesta and Zarlenga, 1985), i: Anzio (Carboni and Di Bella, 1997), m: Fogliano well (Lombardi, 1968), n: Coste San Giacomo (Bellucci et al., 2012, 2014). The Santernian pale-shoreline from Mancini et al. (2007) is reported with the red line, whereas its hypothetical continuation to the south is tentatively traced (dashed red line). See text for comments. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

at re-determining them as *A. nestii*, according to the evolved morphology of the antlers displayng the attack of the first tine very close to the beam (see Di Stefano and Petronio, 1998, 2002). *A. nestii* occurs in the Olivola and Tasso FUs, while *S. etruscus* has a wide range encompassing Montopoli through Slivia FU (Pandolfi and Marra, 2015).

3.2.3. Castel San Pietro

Mammal remains from the lignite mine of Castel San Pietro, 295 m a.s.l., have been collected since the end of the 1800. Tuccimei (1889) reported the presence of *Rhinoceros etruscus* (recte *Stephanorhinus etruscus*) and *Castor fiber*. The latter species was described and illustrated by Tuccimei (1889, 1891) and revised by Barisone et al. (2006) who assigned dubitatively the specimens of Castel San Pietro to the subspecies *C. fiber plicidens*. However, the importance assigned by Tuccimei (1889, 1891) to the beaver as a Villafranchian biochronological marker is now discarded. Remains of *Bos* sp. (recte ?*Leptobos* sp.) and *Cervus* sp. (recte undetermined Cervidae) (see Petronio et al., 2002) were also reported by Tuccimei (1889). In addition, scanty and fragmentary remains of *Hippopotamus* were recorded from the surroundings of Castel San Pietro by Meli (1882) and Tuccimei (1891), but it is unclear if they have been collected from the lignite mine, from which Maxia (1949) recorded also the occurrence of *A. arvernensis* and *S. etruscus*. The occurrence of *H. antiquus* spans the Tasso to at least Isernia FUs (Azzaroli, 1977; Gliozzi et al., 1997; Palombo et al., 2002; Petronio et al., 2011; Pandolfi and Petronio, 2015). Bellucci et al. (2014) have extended its occurrence as back as to the Coste San Giacomo FU, although it has never been documented *in stratum* earlier than the Tasso FU (Palombo, 2014).

Therefore, fossils recovered at Castel San Pietro, including *A. avernensis* and *H. antiquus*, suggest the occurrence of two distinct faunal assemblages corresponding to the Coste San Giacomo/Olivola and Tasso FUs, also according to the pollen and macromammal record within the lignitic clays indicating a Middle to early Late Villafranchian age for the deposit (Pandolfi et al., 2017).

3.2.4. Bocchignano

Tuccimei (1889) reported the presence of *Hippopotamus major* and *Rhinoceros etruscus* within fossiliferous levels above the conglomerates outcropping at Bocchignano, 183 m a.s.l.. Later Tuccimei (1891) also recorded the presence of *Cervus etueriarum* from the marl deposits of Bocchignano. *Equus stenonis* was reported by Tuccimei (1891) from the same locality and *Arvicola amphibious* was described by Tuccimei (1893).

However, re-examination of the cervid remains figured by Tuccimei (1889) allowed us at re-determining them as *Axis* sp.. Teeth of rhinoceros were figured by Tuccimei (1889) but an attribution to the Etruscan rhino is difficult to confirm. The horse is represented only by a damaged deciduous tooth which prevents any systematic attribution at specific level.

The two mandibular fragments of an arvicolid, described and figured by Tuccimei (1893), bearing respectively m1-m2 and m1 indicates the presence of a “mimoyan island” in the first lower molar of the specimen n.1. The presence of these character make certain the attribution to the genus *Mimomys*. Kotsakis (1988) has suggested an attribution to *M. polonicus* or *M. pliocaenicus*. The first species is characteristic of Middle Villanyian (corresponding to MN 16b zone - Montopoli FU), while *M. pliocaenicus* characterize the Late Villanyian (zone MN 17 – Saint Vallier, Coste San Giacomo and Olivola FU's) (Sala et al., 1994; Girotti et al., 2003; Ghinassi et al., 2005; Bona et al., 2015).

Therefore, two distinct faunal assemblages are recognized in Bocchignano, based on the occurrence of *Mimomys* and *H. antiquus*. An oldest one, spanning Saint Vallier through Olivola FUs, and a youngest one, attributable to the Tasso FU.

3.2.5. Collerosa

Tuccimei (1889) reported the finding of remains of *Rhinoceros etruscus* (recte *Stephanorhinus etruscus*) within a lacustrine deposit in the Collerosa locality, 213 m a.s.l.. The large biochronological range of this taxon, encompassing Montopli through Slivia FUs, does not provide any useful age constraint to Collerosa.

3.2.6. Montopoli di Sabina

Within a gravel layer cropping out close to the village of Montopoli di Sabina, 320 m a.s.l., Tuccimei (1898) reported the finding of a tusk fragment of *Elephas* cf. *meridionalis* (recte *Mammuthus* cf. *meridionalis*) from a gravel deposit. From the locality of Moronte, near Montopoli di Sabina, *Cervus etueriarum* was recorded by Tuccimei (1898) from a marl deposit.

Also in this case, the cervid remain figured in Tuccimei (1898) is re-determined here in *A. nestii*, due to the morphology of the antlers, characterized by an arched and long span between the first two tines (Di Stefano and Petronio, 1998, 2002).

Therefore, the faunal remains recovered at Montopoli di Sabina have a common biochronological interval within the Olivola and Tasso FUs.

3.2.7. Monte Riccio

Within a biodetritical deposit of coastal environment cropping out 127 m a.s.l. at Monte Riccio locality (Fig. 5) the following taxa have been found (Mazzini et al., 2000): *Prolagus* sp., *Mammuthus* cf. *meridionalis*, *Sus strozzii*, *Hippopotamus antiquus*, *Leptobos* cf. *L. etruscus*, *Procapreolus* sp., *Eucladoceros ctenoides*, *Axis nestii*, *Stephanorhinus* cf. *S. etruscus*, *Equus stenonis*, *Vulpes* cf. *V. alopecoides*, *Canis etruscus* and *Megantereon cultridens*.

The fossiliferous deposit has a transgressive contact above the local “Macco” Formation (Conti et al., 1983, and references therein), and laterally correlates *Bulimina etnea* bearing, marine shallow water deposits occurringt in this area (Mazzini et al., 2000; Conato and Dai Pra, 1980; Carboni and Palagi, 1997, 1998). It is unconformably followed by conglomeratic lenses passing upwards to coarse sand and to more continental clastic deposits. The stratigraphic scheme of this site is reported in Fig. 5, showing correlation with the other sites located in the sector comprised between the present coast and the Apennine margin, including Monte Pilone, Capena and Monte Mario.

The mammal fauna of Monte Riccio is referable to the Tasso FU (Mazzini et al., 2000; Petronio et al., 2011), due to the presence of several species having the LO within this FU such as *L. etruscus*, *E.*

ctenoides, *Procapreolus* sp., *Prolagus* sp., and *A. nestii*, in association with *H. antiquus*, which is not reported earlier. More recently, Croitor (2012) has attributed the cervid remains of Monte Riccio to *Praeelaphus lyra (=A. lyra)*, based on the shape of the pedicicles approaching that of the holotype of *P. lyra* from the Lower Valdarno, suggesting the inclusion in the Olivola FU for the faunal assemblage of Monte Riccio. However, in our opinion this attributiion is not compatible with the occurrence of *H. antiquus*, as well as with the Santernian age of the transgressive succession, accounted by the occurrence of *B. etnea* in the corresponding marine deposits of this area (Carboni and Palagi, 1997, 1998). For this reason we remain conservative on the chronological attribution to Tasso FU, even though inclusion in the Olivola FU would not be in contrast with the occurrence of a transgression during the latest part of the Gelasian (i.e. Olivola FU) and culminating in the Santernian (Tasso FU), as discussed for the faunal assemblages of the Sabina region, which are attributed to both these FUs.

3.2.8. Monte Pilone

At the foothill of Monte Soratte, in Monte Pilone locality, an almost complete skeleton of *Hippopotamus antiquus* in anatomical connection was recovered, within a littoral sand deposit (Caloi et al., 1980) overlying marine clay deposits at elevation of 125 m a.s.l. (Fig. 5). A fragmentary horn re-determined in the present study as *Bison (Eobison) degiulii* was also found in the same deposit. This latter taxon provide a biochronological indication spanning Pirro through Colle Curti FUs. Recently, Marra et al. (2014) have tentatively extended the LO of this taxon to the Slivia FU due to the presence of remains of *Bison* aff. *degiulii* in the MIS 19 fluvial deposits of Cava Redicicoli.

3.2.9. Capena

Several remains of artiodactyls including two almost complete skeletons of Cervidae in anatomical connection along with remains of *Bison (Eobison) degiulii* were recovered in the clayey deposits of a lacustrine basin exposed by excavation for the high velocity railways near the village of Capena, ∼100 m a.s.l. (Petronio, 1979; Masini, 1989; Masini et al., 2013). The continental deposit rested in angular unconformity on marine clay with Early Pleistocene microfauna (*Bulimina fusiformis marginata*) and was previously attributed to the Late Villafranchian (Pirro FU; Gliozzi et al., 1997) based on the presence of *B. degiulii*.

3.2.10. Monte Mario

A molar attributed to *Mammuthus meridionalis* (see Caloi and Palombo, 1988) was recovered from the sands and clays of the Monte Mario Formation referred to the middle Santernian (Cosentino et al., 2009), in Rome (Fig. 5). Exact location and elevation a.s.l. of the finding was not reported. The morphological features of this remain are similar to those of *M. meridionalis meridionalis*, a form typically diffused in the faunal assemblages from the Coste S. Giacomo to the Olivola and Tasso FU.

3.2.11. Colle Marino

Stratigraphic scheme by Biddittu et al. (1979) for Colle Marino is reported in Fig. 6. The only species reported at this locality by Segre Naldini et al. (2009) is *Pachycrocuta brevirostris*, which indicates a Late Villafranchian to Galerian age due to its occurrence since the Olivola throughout Slivia FUs. Moreover, in the same layer a lithic assemblage comprising mono and bifacial choppers, polyhedrons, flake and pebble scrapers is described by Biddittu et al. (1979), who suggest resemblance with the oldowan industry of the lower levels of Olduvai reviewed by Leakey (1971). Indeed, Biddittu et al. (1979) correlate the silty clay horizon with carbonatic concretions hosting the lithic industry and the fossil remain (layer 21 in Fig. 6), croping out at ∼205 m a.s.l., with an equivalent horizon, occurring at the same elevation and immediately overlying the fossiliferous layer of Coste San Giacomo, which is attributed to the Middle Villafranchian, suggesting a rather old age for it.

3.2.12. Fontana Acetosa

In a continental clayey sand deposit at the Fontana Acetosa site, for which no other stratigraphic indication is provided in the literature, Palombo et al., 2002 reported the following faunal list: ?*Canis arnensis*, ?*Canis etruscus*, cf *Ursus etruscus*, ?*Pachycrocuta brevirostris*, *Megantereon* cf. *M. cultridens*, *Mammuthus* (*Archidiscodon*) *meridionalis*, *Equus* cf. *E. stenonis*, *Stephanorhinus* sp., *Sus* cf. *S. strozzii*, *Hippopotamus* ex gr. *H. antiquus*, *Pseudodama nestii* (recte *Axis nestii*), *Eucladoceros dicranios*, *Leptobos* sp., Cervini indet. After a first revision provided by Segre Naldini et al. (2009), Bellucci et al. (2012) reported the following faunal list: *Mammuthus meridionalis*, *Hippopotamus* sp., *Stephanorhinus etruscus*, *Leptobos* sp., *Sus strozzii*, *Equus stenonis*, *Eucladoceros* sp., "*Cervus philisi*", *Megantereon cultridens*, *Pachycrocuta* sp., *Canis* sp., *Lepus* sp., and *Testudo* sp.

The fossils of this locality are no more accessible, preventing the possibly discriminating identification of *A. nestii* vs. *A. lyra*; however, a biochronological range restricted to Tasso FU is suggested by the taxa with secure attribution reported above. In Fig. 6 we have tentatively correlated the sedimentary deposit of Fontana Acetosa with that hosting the lithic industry and the fossil remains in Colle Marino (see discussions).

3.2.13. Coste San Giacomo

The faunal assemblage of Coste San Giacomo (hereby CSG) (see Fig. 6 for site stratigraphy) is known since the end of the 70s (Biddittu et al., 1979; Cassoli and Segre Naldini, 1984) and it has been re-proposed and re-determined, repeatedly (Segre, 2004; Petronio et al., 2005, 2011; Segre Naldini et al., 2009). It constitutes the local fauna for the homonimous FU of Middle Villafranchian (see Gliozzi et al., 1997; Petronio et al., 2011). Following new investigations at the site, Bellucci et al. (2012, 2014) provided the following updated list of large mammal taxa: *A. arvernensis*, *M. meridionalis*, *Stephanorhinus* sp., *E. stenonis*, *Eucladoceros* sp., *Axis* cf. *A. lyra*, *Croizetoceros* cf. *C. ramosus*, *Leptobos* sp., *Gallogoral meneghini*, *Gazella borbonica*, *Gazellospira torticornis*, *S. strozzii*, *Hippopotamus* sp., ? *Pliocrocuta perrieri*, *Ursus* cf. *U. etruscus*, *Canis* sp., *Vulpes* cf. *V. alopecoides*, *Homotherium* sp., *Macaca sylvanus*. Excluding those covering a wide biochronological range or not securely determined, all of the remaining taxa are present both in the CSG and Olivola FUs, with the exception of *G. borbonica* which has its LO in the earliest FU (see also Cregut Bonnrue, 2007). Regarding the finding of *Hippopotamus* sp., according to Bellucci et al. (2012, 2014) it evidences the occurrence of this taxon since the Middle Villafranchian. However, the occurrence of *H. antiquus* in several country of Mediterranean basin has not been reported prior to 1.6 Ma (Petronio, 1995; Bar-Yosef and Belmaker, 2011; Mazza and Bertini, 2013; and references therein). The Villafranchian deposits of peninsular Italy, including those occurring at Montopoli, Quercia, Olivola, Argille di Figline, Matassino, Casa Frata, and Sabbie del Tasso, yielded an almost continuous biochronologic succession, with a short lacuna in the Middle Villafranchian, in which *Hippopotamus* is present only within the Sabbie del Tasso (Tasso FU) (Azzaroli, 1977; Gliozzi et al., 1997; Palombo et al., 2002; Petronio et al., 2011).

Therefore, the occurrence of this taxon in the CSG FU is strongly questionable (Palombo, 2014).

A rich fauna of small mammals (Soricidae, Talpidae, Ochotonidae, Sciuridae, Castoridae, Arvicolidae, Muridae, Hystricidae) was also collected in CSG and has been studied recently by Bona et al. (2015). The following species have been described: *Beremendia fissidens*, *Sorex* cf. *S. minutus*, Soricinae indet., *Talpa minor*, *Galemys kormosi*, *Prolagus italicus*, *Sciurus* cf. *S. warthae*, *Castor fiber*, *Mimomys pliocaenicus*, *Mimomys* gr. *tigliensis*/*tornensis*, *Apodemus* sp., *Hystrix refossa*. The fauna is typical of a Late Villanyian age (MN 17). According to Bona et al. (2015) *M. pliocaenicus* of this locality is comparable with *Mimomys* cf. *pliocaenicus* from Rivoli Veronese (Veneto, Northern Italy), site referred to CSG FU (Gliozzi et al., 1997; Kotsakis et al., 2003; Sala and Masini, 2007).

The last occurrences of *G. borbonica* in Western Europe are reported in the Saint Vallier FU (Crégut-Bonnoure, 2007), while it persisted until the CSG FU in peninsular Italy (Bellucci and Sardella, 2015); combined with the poorly evolved feature of the specimens of *M. pliocaenicus* recovered at CSG, this fact provides an upper biochronologic constrain within the CSG FU, whereas the occurrence of several taxa having the FO within this FU, including *G. meneghini*, *G. torticornis*, *S. strozzii*, excludes an older age for the faunal assemblage.

3.2.14. Valle Catenaccio

This site is located about 500 m southwest of CSG (Bellucci et al., 2012), however no stratigraphic or lithologic description exists for it in the literature. The faunal list from this site provided by Palombo et al. (2002) was revised by Segre Naldini et al. (2009) who reported: *Mammuthus (Archidiscodon) meridionalis*, *Stephanorhinus etruscus*, *Equus stenonis*, *Gazella borbonica*, *Pseudodama lyra* (recte *Axis lyra*), *Eucladoceros senezensis*, *Acinonyx* cf. *pardinensis*, *Pachycrocuta* sp., *Testudo* sp., *Emys* sp.

The presence of *G. borbonica* (and *A. lyra,* if correctly identified) restrict the interval of this faunal assemblage to Montopoli and CSG FUs.

4. The Plio-Pleistocene marine basins

Marine ingression affected the Tyrrhenian Sea margin of Central Italy since Messinian times (Patacca et al., 1990), while in southern Tuscany and Latium the earliest ingressive deposits are represented by Pliocene clays of the *Globoratalia margaritae* biozone (Barberi et al., 1994). We have reconstructed in detail the progressive evolution of the marine basins in this region through a review of the extant literature, which reports a fragmented picture based on a series of specific studies on local successions (reported with the letters *a* through *m* in Fig. 7a), and we provide a revision in the light of a broader paleogeographic framework. As a biochronological reference we use an updated foraminiferal biostratigraphy defined in Violanti (2012) and absolute ages for planes based on Gradstein et al. (2004), whereas for the Plio-Pleistocene chronostratigraphy we refer to Gibbard et al. (2009).

Four main sedimentary basins are traditionally recognized in Tuscany and Latium (Barberi et al., 1994): Albegna and Tarquina, along the present coast, and Radicofani and Chiani-Tevere, on the inland. Among these, the only one relevant for the paleogeography of the investigated area is the Chiani-Tevere basin (Fig. 7a), whose biostratigraphic and bathymetryc features are described in the following section.

4.1. Chiani-Tevere Basin

In this sector, closer to the orogenic belt, marine ingression occurred during the *G. margaritae* + *G. puncticulata* Zone (Fig. 7a; Barberi et al., 1994), and was characterized by a discontinuous hiatus at the transition between the *G. puncticulata* through *G. aemiliana* biozones (Fig. 7b and c), and by a more widespread emersion encompassing the *G. inflata* Zone (Fig. 7d; Ambrosetti et al., 1987; Di Bella et al., 2000–2002). A new ingression since the Santernian is observed throughout the southern Chiani-Tevere Basin and the Pontina Plain (Fig. 7e), leading to the deposition of the Chiani-Tevere Formation (Mancini et al., 2004, 2007).

In particular, the biostratigraphy of the Liano section, in the central-northern sector of the investigated area (*d* in Fig. 7), provides important bathymetric constraints to the Santernian basin. In contrast with the northern section of Lugnano (*c* in Fig. 7), where Santernian deposits are lacking while there is no hiatus during the Gelasian, circa-littoral sediments of the *B. etnea* biozone occur at Liano 100 through 120 m a.s.l., above a hiatus including the upper part of the *B. marginata* zone and the whole *G. inflata* zone (Fig. 8; Borzi et al., 1998). Santernian deposits with *B. etna* (Farneto silts, Marra, 1993; Marra et al., 1995; see Fig. 5) are also found at 125 m a.s.l. on the Monte Mario structural height in Rome (*g* in Fig. 7), but characterized by a slightly shallower bathymetry (outer infralittoral-inner cir-

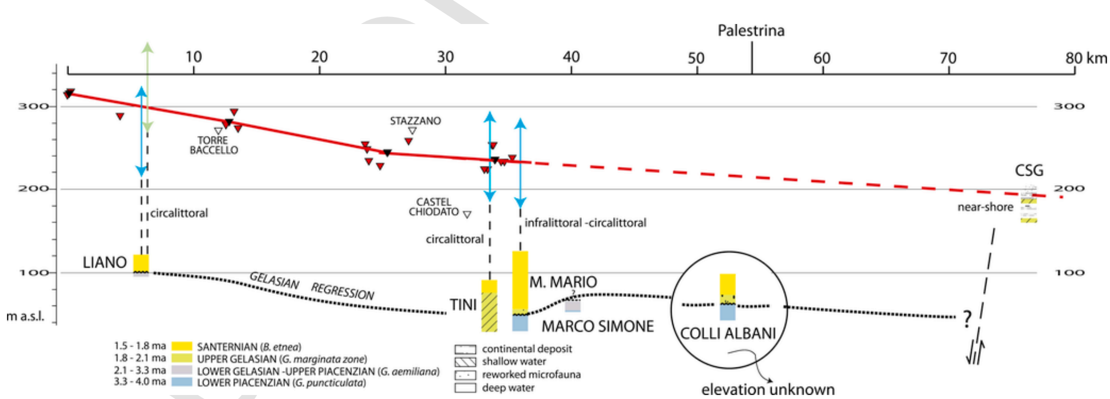

Fig. 8. Cross-section along the paleo-shoreline reconstructed in Manicini et al. (2007) (solid red line) and its hypothetical southeastern continuation, assuming a constant trend (thick dashed line) evaluated from the average elevation (black triangles) of the first three clusters of indicators (red triangles), and assuming a variation of inclination (thin dashed line) based on the trend depicted by the last two clusters (see test for detail). Biostratigraphic and paleo-batymetric data from the most proximal sedimentary sections of Liano, Tini, Marco Simone and Coste San Giacomo (CSG) are projected along the profile, along with data from the area of Rome (Monte Mario and Colli Albani). See text for comments. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

calittoral environment, Cosentino et al., 2009). Here, the ingressive deposits comprehend the upper portion of the *G. inflata* biozone, and overlay sediments of the *G. puncticulata* zone (Marra et al., 1995; Cosentino et al., 2009), evidencing a hiatus affecting the *G. aemiliana* zone. However, abundant reworked specimens of this foraminifer and of *G. puncticulata* occur within the ingressive sediments (Marra et al., 1995; see Fig. 5), in consequence of the fact that the Rome's area was located at the southeastern margin of a wide uplifting sector, corresponding to the volcanic area comprehending the Vulsini, Vico and Monti Sabatini districts, that was affected by a significant hiatus during the Gelasian (Fig. 8d; Barberi et al., 1994). The Gelasian regressive phase is probably marked by a hiatus also at Marco Simone quarry (*f* in Fig. 7; Carboni, 1975; Arias et al., 1976), where only the deposits of the *G. crassaformis* biozone are present (Fig. 8). No hiatus occurs instead at the near Valericca-Tini section (*e* in Fig. 7), where the Santernian deposits are in continuity with those of the *B. marginata* zone (*G. inflata* is missing in Vallericca; Borzi et al., 1998; see Fig. 6), evidencing a similar chronology of the ingression with respect to Rome, with sediments of the upper Gelasian at the base of those with *B. etnea*. Also in Vallericca a circa-littoral environment characterizes the Santernian deposits, occurring up to 90 m a.s.l.: in particular, the maximum inferred depth of the marine basin is observed in correspondence of earliest Santernian deposit with *Bulimina* aff. *etnea* (Carboni and Conti, 1977).

A similar bathymetric evolution, with a regressive phase during the *G. inflata* zone and a successive new marked ingression during the Santernian is inferred to occur in the Colli Albani area (Fig. 8), based on the analysis of the lithic inclusions in the products of the phreaotomagmatic activity (Funiciello and Parotto, 1978). The marine clay fragments contained in the hydromagmatic surge deposits of Prata Porci crater revealed a rich microfauna (Plancton/Benthos 80%) of the *G. puncticulata* - *G. crassaformis* biozone and a scanty (20%) microfauna of the *G. inflata* zone, with evidence of reworking, along with an abundant Early Pleistocene (i.e.: Santernian) microfauna (Funiciello and Parotto, 1978).

5. Paleogeographic evolution

The paleogeographic reconstruction provided in Fig. 7 accounts for a first large ingressive phase, characterized by the NE migration of the marine basin driven by the NW-SE extensional faults at the margin of the Apennine's orogen, culminating during the Early Piacenzian (Fig. 7a and b). The progressive upwelling of the NW coastal sector occurs since the Late Piacenzian (Fig. 7c) and propagates SE during the Gelasian (Fig. 7d), driven by uprising of magma in the lower crust, heralding the origin of the volcanic districts of the Roman Province (Serri et al., 1993; Barberi et al., 1994).

A widespread regressive phase characterizes the Late Gelasian, when small sedimentary basins are confined along the southwestern Tyrrhenian margin, within two half-graben structures, corresponding to the Tiber (Ciotoli et al., 2015) and to the Ardea (Faccenna et al., 1994c) basins, and in the Pontina plain (Lombardi, 1968) (Fig. 7d). In this framework, the attribution to the Gelasian of the transgressive deposit characterized by near-shore facies recovered in borehole at Coste San Giacomo in the Latina Valley (Bellucci et al., 2014; *n* in Fig. 7) seems in contrast with the Early Pleistocene paleogeography of this region and the bathymetry of the marine basins inferred from biostratigraphic data discussed above (Fig. 7d). The age of the CSG deposit has great relevance since a rich and diverse vertebrate fauna recovered at this site constitutes the faunal assemblage for the homonymous Middle Villafranchian Faunal Unit (Bellucci et al., 2012, and references therein). Its chronostratigraphic position will be discussed in detail in the following sections.

A new, large ingressive phase occurs since the Santernian in the whole region, with the exception of the Tolfa-Ceriti (De Rita et al., 1994) and of the Vulsini - Monti Sabatini (Buonasorte et al., 1999; Barberi et al., 1994) structural heights, as testified by ubiquitous infralittoral to circalittoral successions characterized by the presence of *B. enea* or equivalent Calabrian markers recorded in several drillings and outcrops along the coast, including the Roma 1 and Roma 2 boreholes (*i, j* in Fig. 7; Conforto, 1962), Pomezia (*k*; Malatesta and Zarlenga, 1985), Anzio (*i*; Carboni and Di Bella, 1997), and the Fogliano well (*m*; Lombardi, 1968), in the Rome's area (*g*, Marra et al., 1995; Bergamin et al., 2000), and close to the Apennine (Liano and Tini sections, *d* and *e* in Fig. 7; Borzi et al., 1998).

The biostratigraphic and bathymetric features outlined at key sections among those described above are summarized in the cross-section of Fig. 8, representing a transect parallel to the paleo-shoreline (Mancini et al., 2007), located along the margin of the Apennine's relief.

5.1. The Gelasian-Santernian coastline

A series of paleo-shorelines extending for about 100 km along the western margin of Central Apennines was reconstructed correlating a series of geologic and stratigraphic indicators by Mancini et al. (2007). These authors recognized a youngest and uppermost paleo-shoreline with decreasing altitude from ca. 480 m a.s.l. in the NW area to ca. 220 to the SE (red solid line in Fig. 7), consistent with a differential uplift characterizing the Tuscany region with respect to Latium due to the development of the Plio-Pleistocene magmatism in central Italy (Serri et al., 1993; Barberi et al., 1994). A Santernian age was attributed to this paleo-shoreline based on measurements of $^{87}Sr/^{86}Sr$ ratio on corals and mollusk shells collected from the nearshore deposits (Mancini et al., 2004, 2007). These authors also correlated with this paleo-shoreline the deposits of a 3rd order sequence composed of: i) a transgressive member including marine shelf, near-shore and deltaic sediments (Chiani-Tevere Formation, CTF; Mancini et al., 2004), 2.1 to 1.5 Myr old (late Gelasian-Santernian); ii) fluvial and lacustrine deposits filling the intramountain basins at the rear of the paleo-shoreline and laterally contiguous to the CTF; iii) a regressive member including fluvial-lacustrine carbonate and terrigenous sediments (Giove Formation, GF; Mancini et al., 2004), referred to the Emilian sub-stage (1.5–1.2 Ma).

The Santernian age of the paleo-shoreline was questioned by Cosentino and Fubelli (2008) based on the supposed Middle Villafranchian age of a series of the continental deposit cropping out in the vicinity of this paleoshoreline, around 270 m a.s.l., in the Sabina region (Bocchignano, Castel San Pietro, Torre Baccelli, Stazzano, Figs. 1 and 3), which according to the authors evidenced a Gelasian age for it. Cosentino and Fubelli (2008) also argued about the Gelasian age of the southernmost portion of the paleoshoreline, occurring 170 m a.s.l., based on the presence of *Amphistegina* spp. in the nerarshore deposits of Castel Chiodato and Molino del Moro. However, also according to reply by Mancini et al. (2008), these latter paleo-shoreline indicators are well below those correlated with the Santernian paleoshoreline in this area, occurring at 220 m a.s.l. (see Fig. 8), and may as well represent the actual Gelasian paleo-shoreline which, consistent with the paleogeographic conditions outlined in the previous paragraph, should be at lower elevation based on the more limited extension of the Gelasian marine basins in this region (Fig. 7d). Moreover, the objection about the supposed Middle Villafranchian age of the continental deposits in the Sabina region is quite weak, as observed by Mancini et al. (2008) who pointed out the contradictory biochronological evidence at some of these sites, and as confirmed in the present study for Castel San Pietro and Bocchignano, where the occurrence of both CSG and Tasso FUs is evidenced. In the present study we discuss the fact that the occurrence of such deposits is not conflicting with a maximum sea-level reached during the Santernian, as explained in detail in the next sections. Moreover, we note that occurrence of a Gelasian shoreline above 268 m a.s.l. in Stazzano is not consistent with the datum of a coeval, according to Cosentino and Fubelli (2008) shoreline 170 m a.s.l. in Castel Chiodato few kms to the west (Fig. 8).

In contrast, the cross-section of Fig. 8 shows a good consistency between the bathymetric indications provided by the biostratigraphy of Liano, Tini and Monte Mario sections and the occurrence of a Santernian maximum sea-level matching elevation of the paleo-shoreline indicators reported in Mancini et al. (2007), ranging 320 - 220 m a.s.l.. Indeed, circalittoral clay sediments with *B. etnea* and *G. calabra* occur up to 120 and 90 m a.s.l. in Liano and Tini, respectively (Borzi et al., 1998; Di Bella et al., 2000–2002), whereas an infralittoral to circalittoral environment is associated with the Farneto silts at Monte Mario (Cosentino et al., 2009), reaching up to 125 m a.s.l. (Marra et al., 1995). Even assuming a conservative estimation for this region for the circalittoral environment at 100–200 m depth (L. Di Bella, pers. com.; blue arrows in Fig. 8), with respect to the canonical range spanning 150–250 m (Peres, 1982; green arrows in Fig. 8), and at 50–100 m depth for the shallower environment of the Farneto silts, the corresponding altitude intervals account for consistent elevation of the Santernian shoreline and the corresponding bathymetric feature of the marine basins at this age.

Fig. 8 also shows a marked hiatus corresponding to the upper Gelasian (*G. inflata* biozone, 2.1–1.8 Ma) followed by the Santernian ingression at Liano and Monte Mario, whereas at Vallericca the Tini section testifies an early ingression during the late Gelasian, culminating in the Santernian ingressive phase. Therefore, the Gelasian sea-level in this region was markedly lower than in the Santernian, conflicting with the hypothesis that the paleo-shoreline indicators between 270 and 220 m a.s.l. may correspond to the maximum sea-level reached around 2.1 Ma.

The lack of paleo-shore indicators south of Bagni Albule (Figs. 4 and 8) is interpretable as due to the presence of a thick cover of volcanic products erupted by the Colli Albani district since 608 ka (Marra et al., 2009). Indeed, the pyroclastic plateau reaches over 350 m a.s.l. close to the Apennine's range east of Rome, well above the inferred elevation of the Santernian coastline, and it keeps above 200 m a.s.l. in the Latina Valley where the CSG site is located. We have reported the inferred position of the Santernian coastline by projecting its assumed elevation against the carbonate structures forming the flanks of the Apennine's range in southern Latium (dashed red line in Fig. 7). According to this paleogeographic reconstruction and to the biostratigraphic and bathymetric indicators illustrated above, the Latina valley would have represented an eastward gulf in which a maximum sea-level was achieved during the Santernian (Fig. 7e). However, coupled magnetostratigraphic and biostratigraphic data indicates a Late Gelasian age for the near-shore deposits recovered in borehole at CSG below continental deposits of Middle Villafranchian age (Bellucci et al., 2014), suggesting an early marine ingression in the Latina valley since this time (Fig. 7d), followed by a regressive phase during Santernian, based on the lack of outcropping marine deposits of this age.

To assess this issue, in Fig. 8 the Santernian paleo-shoreline is tentatively extended southward. In the hypothesis of a decreasing inclination based on the average elevation values in its terminal portion (black triangles in Fig. 8) it would meet elevation of the CSG section at 200 m a.s.l (dashed red line). However, the occurrence of Late Gelasian coastal deposits and the lack of Santernian marine deposits above them implies a change of the paleogeographic conditions with respect to Liano and Tini sections, which may be accounted by fault displacement, as hypothesized in Fig. 8, linked with the extensional tectonic phase triggering the Santernian ingression.

We will give reason of this hypothesis in the following sections, proposing a step-by-step evolution for the coastal area of Latium where the Villafranchian fossiliferous sites are located.

6. Discussion

6.1. Biochronological and chronostratigraphical reconstruction

Based on the occurrences so far documented in central Italy, the faunal assemblages occurring at all the investigated sites of Latium can be comprised within a time interval constrained by the CSG and the Tasso FUs, in which the lower boundary (oldest occurrence) is given by *G. borbonica* and the upper boundary by *H. antiquus* (Fig. 3). Indeed, the first species has never been found later than the CSG FU, whereas the FO of the latter one is in the sand deposits of the Tasso FU, and its extension to previous FUs in not supported by in stratum occurrences (Palombo, 2014). However, based on the supposed occurrence at the site of CSG, Bellucci et al. (2014) have pre-dated the FO of *H. antiquus* within the CSG FU. If we admit such an older age for this taxon, then the upper boundary of the faunal assemblages recovered at the abovementioned sites is represented by occurrences of *A. nestii* and *P. brevirostris*, both in the Olivola FU, which cannot occur in the same deposits with *G. borbonica*. Indeed, if we exclude this latter taxon, the entire list of taxa occurring at all the investigated sites of the Tyrrhenian Sea margin may be regarded as a single faunal assemblage of Late Villafranchian age, compatible with the Olivola FU (yellow shaded interval in Fig. 3). Remarkably, *G. borbonica* has not been reported at the sites of the Sabina region located along the Santernian paleo-shoreline, consistent with an age <2.0 Ma and the attribution to the Olivola-Tasso FUs for the continental deposits associated with this paleogeographic boundary (Table 1). In any case, the occurrence of two distinct faunal assemblages related to diachronic deposits (i.e. CSG and Tasso FUs), like that documented in Castel San Pietro (Table 1), is not conflicting with a Santernian age for the maximum sea-level and the corresponding shoreline at 300 - 270 m a.s.l. in the Sabina region, as shown in the cross-sections of Fig. 9 in which a possible evolutionary scenario is reconstructed, based on biostratigraphic and chronostratigraphic data illustrated in the previous sections.

6.2. Late Gelasian regression

Cross-section of Fig. 9a shows the paleogeography during the Late Gelasian, around 2.1 Ma, when the regressive phase had reached its maximum and the sea-level fell below 100 m a.s.l. (red dashed line in Fig. 9a), as evidenced by the sedimentary hiatus corresponding to the *G. inflata* zone at the Liano section (Borzi et al., 1998). Consistently, continental deposits of Gelasian age, hosting fossil remains of taxa pertaining to the CSG FU (CSG, in Fig. 9a), are emplaced during the whole regressive phase at the foot of the Apennine's margin, in the transitional sector between the mountain range and the coast. Brackish deposits cropping out several meters below the lacustrine horizon with Late Pliocene pollen record (corresponding to the Fosso Bianco record, spanning approximately 2.55–2.15 Ma; Pontini and Bertini, 2000; Bertini, 2000) occurring 270 m a.s.l. at Torre Baccello

Table 1
Interpreted chronostratigraphy of the investigated fossiliferous sections. Two FUs are reported for sites were incompatible faunal assemblages occur, implying the presence of distinct biostratigraphic levels. The biochronological interval common to all the recovered taxa is reported in all other cases, assuming the presence of a single biostratigraphic level. See text for comments and explanations.

Coste San Giacomo	Coste San Giacomo	MIDDLE VILLAFRANCHIAN
Valle Catenaccio	Coste San Giacomo	
Castel San Pietro	Coste San Giacomo-Olivola	MIDDLE-LATE VILLAFRANCHIAN
	Tasso	LATE VILLAFRANCHIAN
Montoro	Coste San Giacomo-Olivola	MIDDLE-LATE VILLAFRANCHIAN
	Tasso	LATE VILLAFRANCHIAN
Bocchignano	Olivola	LATE VILLAFRANCHIAN
	Tasso	
Colle San Valentino	Olivola - Tasso	
Montopoli di Sabina	Olivola - Tasso	
Collerosa	Tasso	
Fontana Acetosa	Tasso	
Monte Riccio	Tasso	
Monte Mario	Tasso	
Monte Pilone	Pirro (-Slivia?)	
Capena	Pirro (-Slivia?)	EARLY GALERIAN ?
Colle Marino	Olivola-Slivia	EARLY GALERIAN ?

(Cosentino and Fubelli, 2008), may be interpreted as witnessing an older coastline, corresponding to the maximum sea-level (thinner red dashed line) reached before the beginning of the regressive phase during the early Gelasian, 2.5–2.3 Ma. Indeed, a Late Gelasian coastline close to 270 m a.s.l. would be incompatible with biostratigraphic and bathymetric data recorded at Liano.

6.3. Santernian ingression

A new ingressive phase affecting the marine basins adjacent to the Apennine's margin starts since 2.1 Ma, corresponding to the upper part of the *B. marginata* zone, and the maximum sea-level is reached at the beginning of the Santernian, around 1.8 Ma, as evidenced by biostratigraphy of the Liano and Tini sections (Fig. 9b). Bathymetric features of the Santernian deposits at these sections, corresponding to circalittoral environments, are consistent with a paleoshoreline ranging 310-250 m in this sector of the Tyrrhenian margin. Continental deposits hosting fossil remains of the Olivola and Tasso FUs (OL-TA in Fig. 9b) are emplaced in the interval 2.05–1.7 Ma in the transitional sector comprised between the Apennine's chain and the uprising Santernian coast. During this time span this sector is characterized by a foothill landscape in which conglomerate deposits interfingers with fluvial and lacustrine deposits in fan-delta environments. Consequently, the resulting stratigraphic setting is characterized by frequent vertical and lateral contact between deposit with age corresponding to the CSG and the Olivola-Tasso FUs. It is not surprising that faunal assemblages attributable to these FUs occur at the same location, as in the case of Castel San Pietro and, possibly, Bocchignano.

Cross-section of Fig. 9c shows a possible stratigraphic setting of this sector associated with the present-day morphology and the location of the fossiliferous sites, demonstrating that the occurrence of the taxa reported in Section 3.2 at each one of these locations, is compatible with the reconstructed paleogeographic evolution and a maximum sea-level reached during the Santernian, as a consequence of the hypotheses made above.

6.4. Late Santernian regression

A marked regressive phase that will lead to the complete emersion of the Chiani-Tevere basin must have started already during the Santernian, as suggested by the occurrence of *M. meridionalis meridionalis* (see Caloi and Paolmbo, 1988) in the sand deposits of Monte Mario, few meters above the Farneto silts. This taxon did not persist after the Tasso FU and its presence within the coastal sediments of Monte Mario implies a rapid sea-level drop in the time span between 1.8 and ~1.5 Ma (the lower boundary of the Tasso FUs is not dated). Similarly, at Monte Riccio the regressive deposits (biodetritical coarse sand) include a faunal assemblage of the Tasso FU (Mazzini et al., 2000). These coastal deposits occur 125 m a.s.l. (See Fig. 4), at the same elevation of similar shallow-water deposits (intercalating gravel layers) that at the Liano section overly the circalittoral Santernian deposits (Fig. 9e). Unless significant tectonic dislocation between these two sections, the occurrence of an approximately 120 m sea-level drop (from 270 to ca. 150) by approximately 1.5 Ma is inferred, when a water depth of ~25 m is assumed for the coastal environment at Monte Riccio.

According to the estimated amplitude of this sea-level drop, littoral deposits of Monte Pilone, also occurring around 125 m a.s.l. (Fig. 4), can be dated around 1.5–1.3 Ma due to the occurrence of remains of *B. degiulii* which has the FO within the Pirro FU. An even lower sea-level fall by this time is inferred at Capena site, where continental deposits occurring at circa 100 m a.s.l. also yielded *B. degiulii*. However, occurrence of *B. degiulii* might be tentatively extended to the Slivia FU based on the presence of *Eeobison* aff. *degiulii* in the gravel beds of Cava Redicicoli, which have been correlated to the Ponte Galeria 1 Formation deposited during MIS 19, around 800 ka (Marra et al., 2014a). Therefore, this further sea-level fall may not have occurred until the beginning of the large glacio-eustatic cycles since MIS 22/21.

Independent from the causes of the rapid sea-level fall at the end of the Santernian (see Marra et al., 2017 for a discussion), a rather stable tectonic regime, as provided by a maximum sea level never above ~150 m, is assumed in the interval 1.5–0.9 Ma, in order to fit elevation of the paleo-surfaces correlating MIS 21 through MIS 5 reconstructed in Marra et al. (2017), and according to the age within the Pirro FU for the littoral deposits of Monte Pilone. Based on these data, a significant new uplift is observed only since 870 ka, coincident with the initial magmatic impulse (Fig. 10), in agreement with the more reliable hypotheses on the genesis of the Middle Pleistocene magmatism in the Roman Region and the related uplift, which are interpreted as the combined result of a slab detachment and its metasomatization since around 0.8 Ma (Conticelli and Peccerillo, 1992; Serri et al., 1993; Wortel and Spakman, 2000; Peccerillo and Frezotti, 2015).

6.5. Paleogeographic and structural evolution of the Latina Valley

If we exclude a Santernian age for the fossiliferous deposit of CSG, the combination of the paleogeographic and tectonic elements illustrated in Fig. 11 must be assumed, in order to correlate the Gelasian ingressive deposits of CSG with the coeval sedimentary hiatus occurring at the Liano section. Cross-section of Fig. 11a' summarizes the paleogeographic conditions illustrated in Fig. 11a, inferred from biostratigraphic and paleo-bathymetric data recorded at Liano, Tini, Monte Mario (MM), Marco Simone (MS), Colli Albani (CA; lithic inclusions in the phreatomagmatic products of Prata Porci) and CSG (CSG). In this early phase, tectonic subsidence triggers a Late

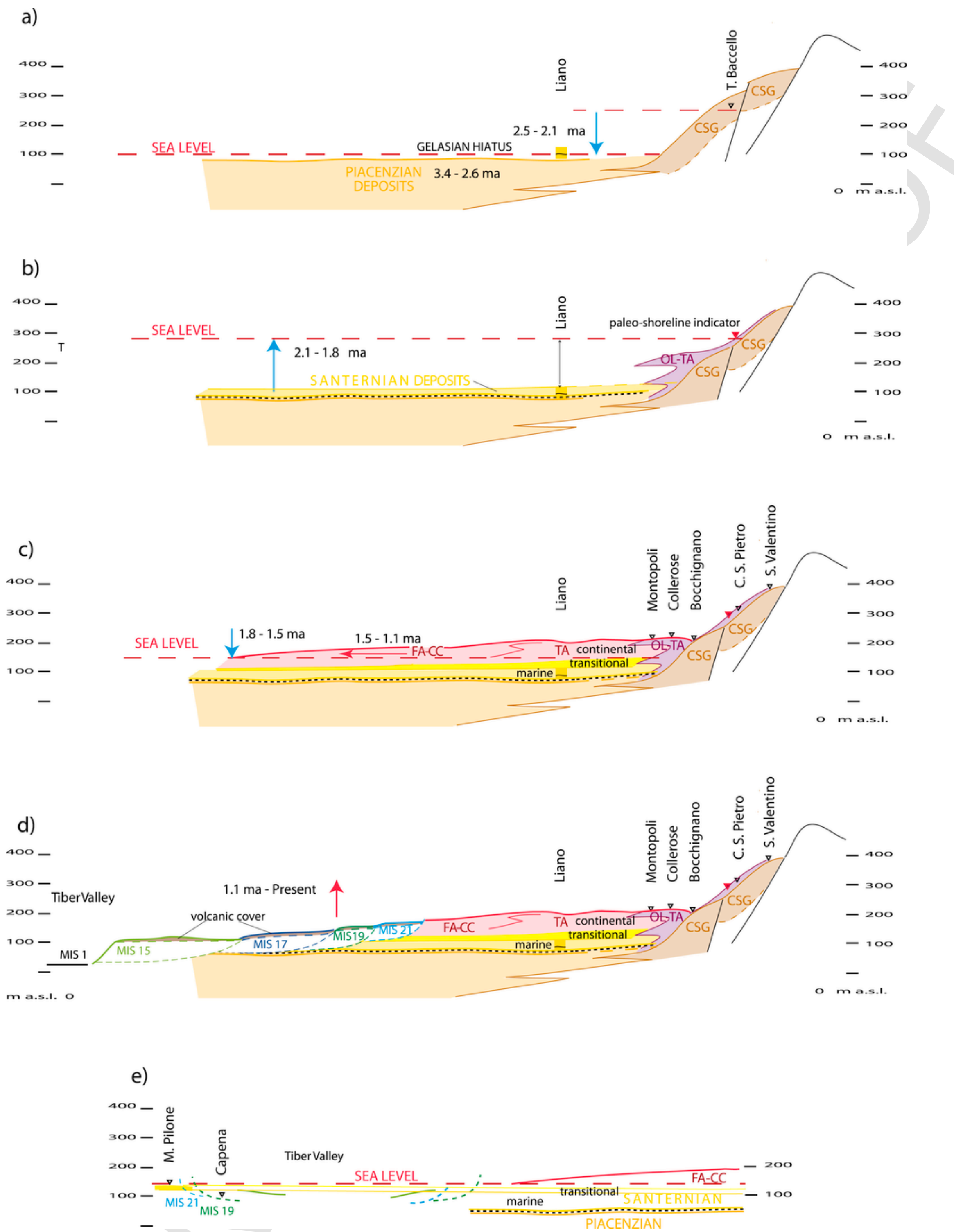

Fig. 9. The present-day stratigraphic setting at the paleontological sites of the Sabina Region is assessed by reconstructing the paleogeographic conditions at different ages (a-b-c-d) along the cross-section A-A′ of Fig. 4, perpendicular to the Apennine's margin and to the ancient coastline. See text for detailed explanation. e) Composite cross-section in which the Monte Pilone and Capena sites are projected along the previous profile, to show their elevation with respect to the paleosurfaces correlated with MIS 19 through MIS 15. The continental deposit of Capena are well below the sea-level indicator represented by the littoral sand deposit of Monte Pilone, evidencing diachronocity between these two sites, and a younger age for Capena.

Gelasian ingression originating a shallow, fragmented marine basin in the southeastern, outward Tyrrhenian margin, and two sea lochs entering inside the Tiber and the Latina valleys. Increased tectonic subsidence since the Santernian (b-b') causes differential collapses through the Tyrrhenian margin and the deepening of the marine basins, while the Latina Valley is isolated due to the vertical displace-

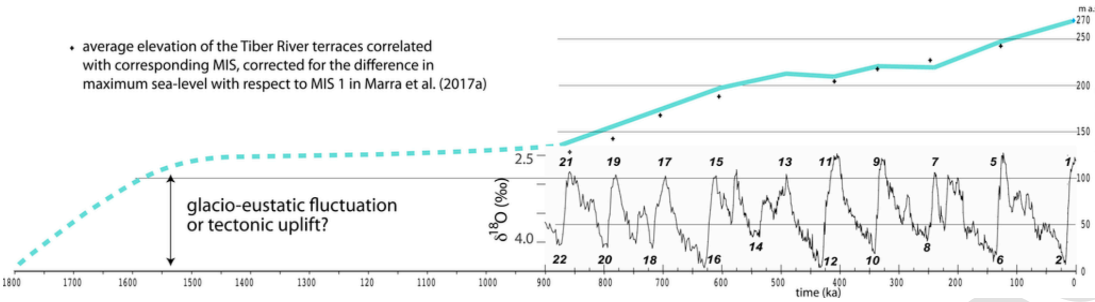

Fig. 10. The uplift affecting the investigated area since 900 ka (green solid line) is assessed based on elevation of the terraced surfaces correlated with the MISs (black crosses) corrected for the different sea-level with respect to present day at each interglacial (modified from Marra et al., 2017). The lack of significant uplift in the time span 1.7– 0.9 Ma is assessed considering biostratigraphic data from Monte Mario and Monte Riccio (see text), suggesting a sea-level fall of ca. 120 by 1.7 Ma (dashed curve). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

ment along the Cisterna di Latina fault zone (CLFZ), originating a threshold preventing further sea ingression. A 250 m tectonic displacement is inferred to occur along the main border faults of the Apennine range, along the northern Tiber Valley in the Chiani-Tevere Basin (CTB), and a lesser displacement in the order of 200 in the outward Rome's basin (RMB), in order to fit a depth consistent with the bathymetric indications at the different sections and a maximum sea-level at lower elevation with respect to CSG, and consistent with the intervening uplift since 1.8 Ma, accounting for the present day elevation of the paleo-shoreline (Fig. 11c).

Such tectonic activity of the border, extensional faults of the SW Apennine margin is consistent with the emplacement, all along the coastal sector, of a large suite of continental deposits of delta-fan to alluvial plain environments, in the time span corresponding to the Olivola and Tasso FUs. Also, the N-S boundary hindering propagation into the Latina Valley of the magmatic uplift since 0.9 Ma, and the consequent tectonic inversion, would give reason for the reversal of the hydrographic network in this area, accounting for the present southeastward course of the Sacco and Liri rivers, flowing through Campania-Latium boundary into the southern Tyrrhenian Sea, instead of meeting the Aniene and Tiber valleys.

7. Conclusions

Biostratigraphic data from the sections along the Apennine's margin of Umbria and northern Latium indicate that an ingressive cycle started in the Late Gelasian (2.1 Ma) and that the maximum depth of the basins was reached in the early Santernian (1.8 Ma). A rapid sea-level fall in the order of 120 m was achieved not much later, at the end of the Santernian (~1.5 Ma), as documented by the occurrence of near-shore deposits hosting faunal assemblages of the Tasso FU, either close to the modern coast (Monte Riccio) and mid-way to the Apennine (Monte Mario). Relatively stable paleogeographic conditions are inferred during the following 100 ka, consistent with the lack of significant uplift in the interval 1.6–0.9 Ma. After this time, two pulses of uplift are recognized 0.9 through 0.5 Ma, and 0.25 Ma through the Present, according to the occurrence of two major volcanic phases in this area.

In this framework, the paleo-shoreline indicators occurring 310 to 270 m a.s.l. in the Sabina Region, close to the Montoro through Montopoli di Sabina localities, are compatible with a late Gelasian - early Santernian age. The continental deposits occurring at these localities and the hosted faunal remains are emplaced during the late stages of the ingressive phase culminating around 1.8 Ma, and during the following regression along the margin of the Apennine's range, in the transitional sector to the coast. Consistent with these considerations, we attribute most of the continental deposits occurring at the sites of Montoro, Colle San Valentino, Castel San Pietro, Bocchignano, Collerosa and Montopoli di Sabina to the Late Villafranchian, based on the compatibility of the recovered faunal assemblages with the Olivola and Tasso FUs (Table 1). Moreover, continental Gelasian deposits are recognized at the sites of Castel San Pietro and, possibly, of Bocchignano in close stratigraphic relationship with the analogous Santernian deposits. An age constrained within the Tasso FU is attributed instead to the deposit and the hosted fossils of Monte Riccio and Monte Mario sites, while those of Monte Pilone and Capena have a biochronologic constraint (*B. degiulii*) within the Pirro FU. However, based on the environmental feature and absolute elevation of the Capena deposits, combined to a possible persistence of *B. degiulii*, a later age for this site cannot be excluded (Table 1). The Colle Marino site, in the northern sector of the Latina Valley, fits well in this paleogeographic picture, based on its biochronologic constraint (*P. brevirostris*) spanning the Olivola through Slivia FUs. In contrast, an early Gelasian ingression at CSG and Valle Catenaccio sites in the Latina Valley is followed in the early Santernian by an upwelling of this area located at the footwall of the Cisterna di Latina Fault Zone. In this sector, a marked displacement along a segment of the regional N-S tectonic lineament originates a threshold separating the Latina Valley from the subsiding area of the Tyrrhenian margin.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.quascirev.2018.05.011.

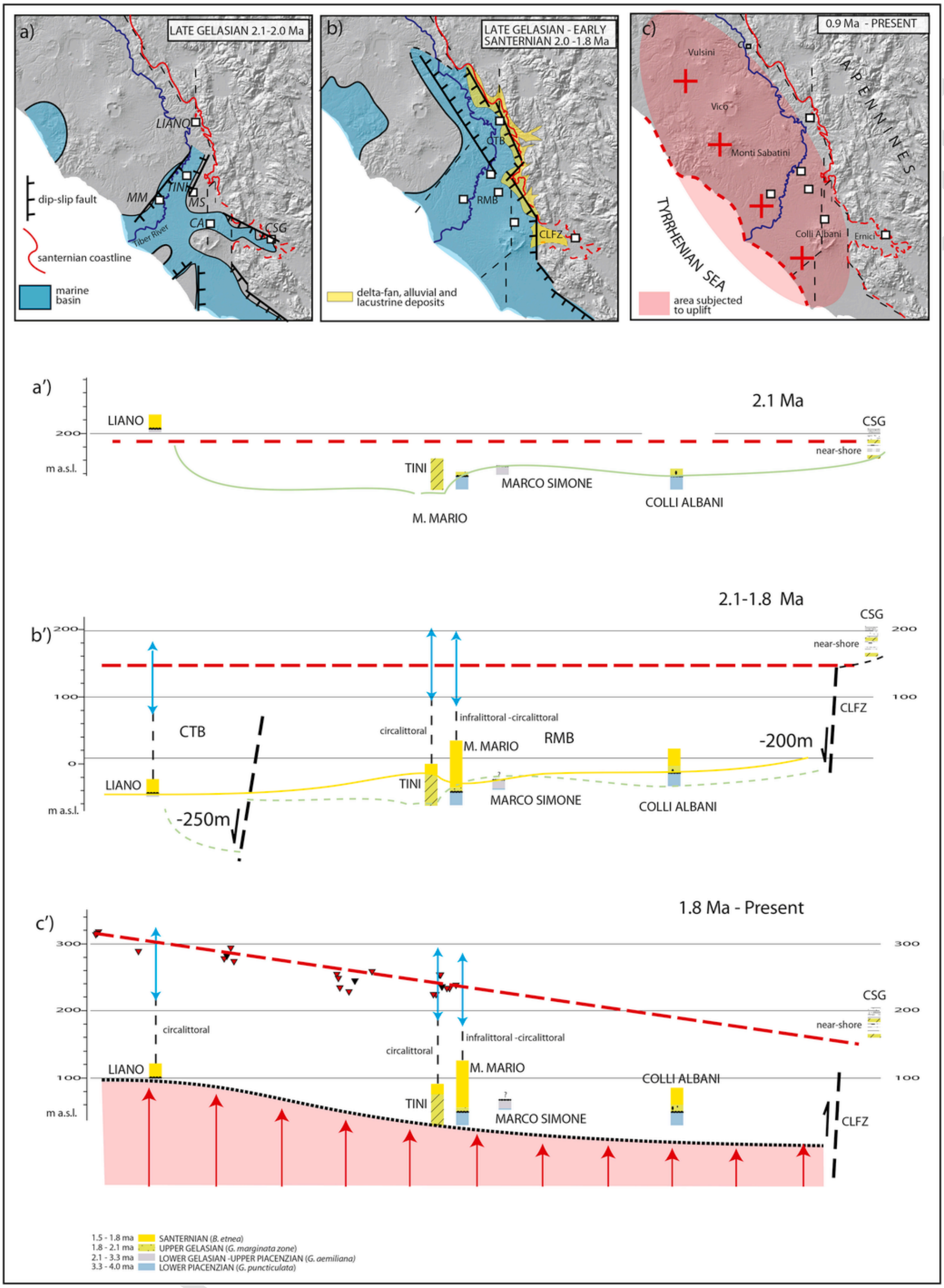

Fig. 11. Hypothetical paleogeographic evolution of the Tyrrhenian sea basins, accounting for an early ingression occurring synchronously along the Apennine's margin in the late Gelasian (a-a'). Successively, the Latina Valley basin is isolated by a threshold originated by dip-slip displacement along a segment of the Cisterna di Latina Fault Zone (CLFZ), while differential tectonic subsidence occurring in the Chiani-Tevere basin (CTB) and in the Rome's area marine basins (RMB) accounts for the deepening of these sedimentary basins in Santernian times (b-b'). Since 0.9 Ma a differential magmatic uplift (c-c') causes the elevation gain of the paleo-shoreline indicators observed at Present time.

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