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Research Paper

New early Pliocene Rhinocerotidae findings from Tuscany (Italy) and the Pliocene rhinocerotine record in Italy ☆

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ABSTRACT

An almost complete mandible from the Lower Pliocene deposits of Arcille (Tuscany) is described and investigated for the first time. The specimen is assigned to *Pliorhinus megarhinus*, which is documented in Italy from the latest Miocene to the mid-Pliocene. The studied specimen is larger than *Stephanorhinus etruscus* and *S. jeanvireti*, and morphologically fits *P. megarhinus* from the Early Pliocene of Montpellier (France), Vera Basin (Spain) and Val di Pugna Fangonero (Italy). This specimen represents the first stratigraphically well-documented Pliocene record of this species in Italy, the previous discoveries dating back to the 19th century or the beginning of the 20th century, hence lacking stratigraphic control. According to the obtained results, it is possible to assess the occurrence of *P. megarhinus* during the earliest Pliocene in Italy as well as to confirm the long-lasting persistence of this species, whose fossil record covers a timespan between 6.7 Ma and 3.5 Ma. During that time, *P. megarhinus* did seemingly undergo a trend of body mass reduction.

1. Introduction

Pliocene Rhinocerotidae remains are poorly documented in Western Europe with respect to older (Late Miocene) and more recent (Quaternary) record (Geraads et al., 2020). Furthermore, most of the Early Pliocene material was collected during the 19th century and lacks a firm stratigraphic control. Thus, Early Pliocene rhinocerotine record is still poorly understood and the first and last occurrences of some species (i.e., *Pliorhinus megarhinus*, *Stephanorhinus jeanvireti*), as well as their persistence over Pliocene times, are controversial and still matter of debate (Pandolfi et al., 2021a). To our knowledge, Western European Pliocene is characterized by the occurrence of four Rhinocerotidae species: *Pliorhinus megarhinus*, *Pliorhinus miguelcrusafonti*, *Stephanorhinus etruscus*, and *Stephanorhinus jeanvireti* (Guérin et al., 1969; Guérin, 1980; Pandolfi et al., 2021a; Chitoglou et al., 2023). The Early Pliocene occurrence of *Dihoplus schleiermacheri* in Spain has been recently discarded by Pandolfi et al. (2022), as is questioned that of *S. jeanvireti* in the same time interval of Italy and Spain. Furthermore, the occurrence of *P. miguelcrusafonti* has been recently reported in different Pliocene localities (Pandolfi et al., 2021a), underlying our limited knowledge of the Rhinocerotidae Pliocene records.

The discovery of a new rhinoceros specimen, an almost complete mandible, from a stratigraphically constrained outcrop at Arcille (Grosseto Province, southeastern Tuscany), allows to chronologically revise the Early Pliocene Rhinocerotidae record in Italy and briefly discuss new considerations about chronology and body size variations of the species. A better understanding of rhinoceros' diversity and occurrences during the Pliocene would lead to a better comprehension of the dispersal patterns of mammals during that time and the origin of Pleistocene species, as well as a clearer paleoenvironmental framework after the Messinian salinity crisis.

2. Geological and paleontological framework

The fossil specimen described herein was discovered in 2017 by Mr. Riccardo Chessa along a private motocross track annexed to a dormant sand quarry at a locality known as "La Castellina", in the surroundings of the Arcille village (Campagnatico Municipality). The find was suddenly reported to the local authorities, and

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subsequently recovered and prepared by personnel of the local antiquity office, namely, the "Soprintendenza Archeologia, Belle Arti e Paesaggio per le Province di Siena, Grosseto e Arezzo".

The site that yielded the specimen is located near the southwestern margin of the Baccinello-Cinigiano Basin (Fig. 1), one of the central (*sensu* Martini and Sagri, 1993) post-collisional basins of the Northern Apennines. The sedimentary infill of the Baccinello-Cinigiano Basin consists of lithologically diverse, architecturally complex Neogene–Quaternary deposits that are home to terrestrial and marine fossil assemblages spanning the Upper Miocene and the Early Pliocene (Benvenuti et al., 2015; Tinelli, 2013; Rook, 2016).

The sediments cropping out at the Arcille quarry, some 200 m North of the discovery site of the rhinoceros mandibles, comprise a ca. 30 m-thick stratigraphic section (Fig. 1) dominated by yellowish, marginal-marine sands interbedded with lenses of fluvial conglomerates and overlain by greyish, shelfal mudstones (Lorenz, 1968; Tinelli, 2013). The sands and mudstones are locally highly fossiliferous and testify to a coastal, shoreface depositional setting passing upward to a muddy offshore environment (Tinelli, 2013; Dominici and Forli, 2021). As for the deposits exposed at the nearby motocross track, they consist of yellowish sands that may be correlated lithologically with the sandy portion of the stratigraphic section of the quarry walls (i.e., units 1–4 of Tinelli, 2013), and possibly with the lower part thereof (Fig. 1).

Besides an abundant invertebrate oryctocoenosis, vertebrate fossils have been collected from the Arcille sands as well as from the very base of the overlying mudstone package (Merella et al., 2023). They consist of a few hundred teeth and dermal spines of sharks and rays, rarer remains of bony fishes, a few fragments of sea turtle shell, and several partial skeletons of marine mammals (Sorbi et al., 2012; Tinelli, 2013; Collareta et al., 2021a, 2023; Merella et al., 2023), including the holotype of the extinct skate *Nebriimimus wardi* and the two known specimens of the archaic monodontid whale *Casatia thermophila* (Bianucci et al., 2019; Collareta et al., 2021b; Merella et al., 2022).

Considering their marine nature, the fossiliferous sands cropping out at Arcille postdate the Messinian Salinity Crisis and ensuing Zanclean transgression (Krijgsman et al., 1999). The maximum age of the Arcille sands is in turn revealed by the planktic foraminiferal assemblage of the overlying shelfal mudstone division (Sorbi et al., 2012), which has been assigned to the Mediterranean Pliocene (MPl) zone 2 of Cita (1975). According to Violanti (2012), the bioevents that define the lower and upper boundaries of this biozone have been calibrated at 5.08 and 4.52 Ma, respectively. The whole stratigraphic succession cropping out at Arcille (Fig. 1) can be assigned to the "S2 Synthem" recognized in the Neogene depositional record of Tuscany by Dominici et al. (2018). This synthem is a large-scale sequence of Zanclean age that includes fluvial conglomerates, fluviodeltaic sandstones, and shelfal mudstones (Dominici et al., 2018). Across the Tuscan Neogene, the S2 strata sometimes overlie the lowermost Pliocene deposits of the S1 Synthem (Dominici et al., 2018) – an observation that suggests an age younger than the very base of the Zanclean for the fossiliferous sands exposed at the find locality.

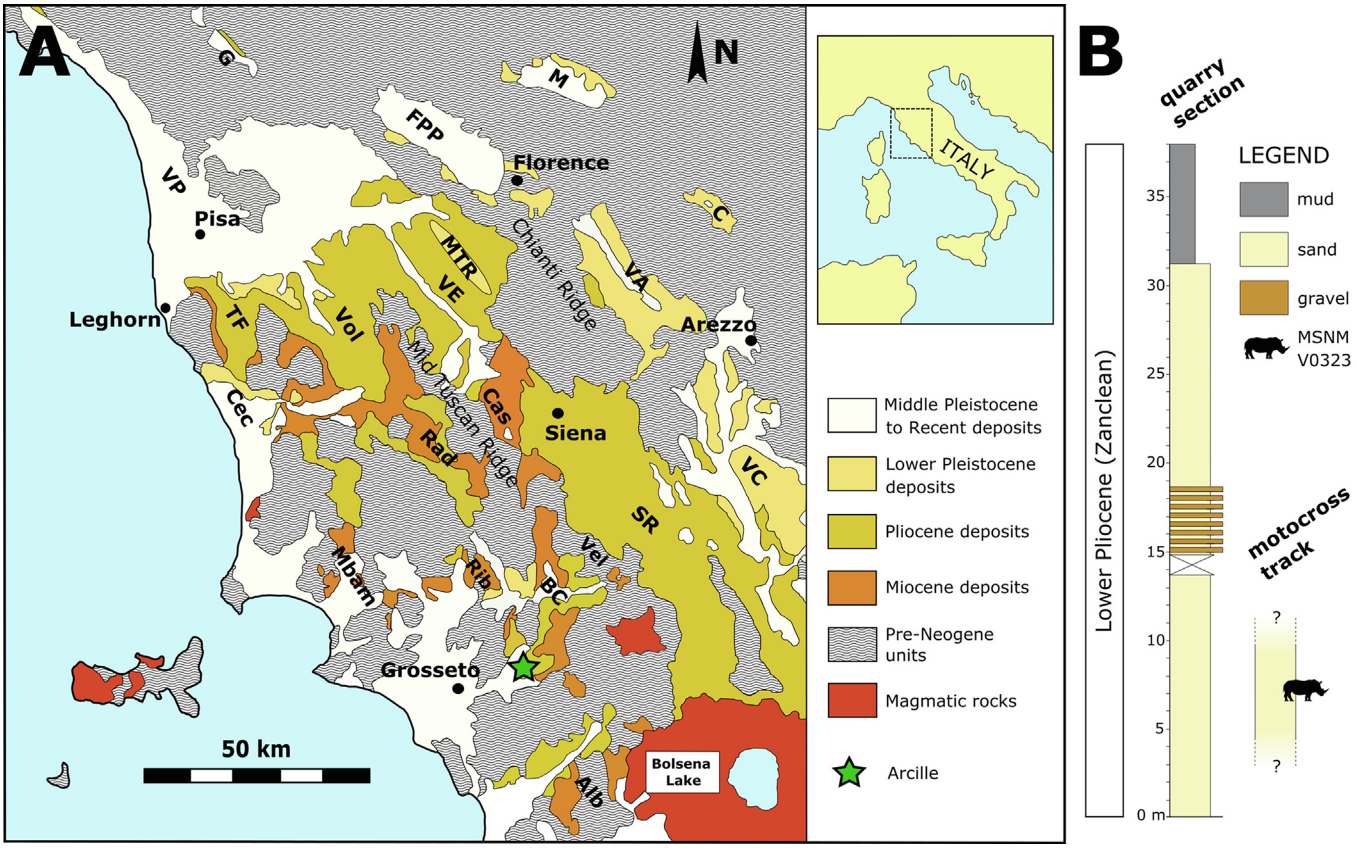

Fig. 1. Geographic and stratigraphic setting of Tuscany, Italy, with a focus on the deposits exposed at Arcille. **A.** Schematic geological map and distribution of the Miocene to Pleistocene basins of Tuscany. Abbreviations: Alb, Albegna basin; BC, Baccinello–Cinigiano basin; C, Casentino basin; Cec, Cecina basin; FPP, Firenze–Prato–Pistoia basin; G, Garfagnana basin; M, Mugello basin; Mbam, Montebamboli basin; MTR, Montespertoli–Tavernelle Ridge; Rad, Radicondoli basin; Rib, Ribolla basin; SR, Siena–Radicofani basin; TF, Tora–Fine basin; VA, upper Valdarno basin; VC, Valdichiana basin; VE, Valdelsa–lower Valdarno basin; Vel, Velona basin; Vol, Volterra basin. The green star indicates the location of the study area (Arcille, indicated by a green star). Modified from Benvenuti et al. (2014). **B.** Schematic stratigraphic log of the Lower Pliocene deposits exposed at Arcille, showing the approximate stratigraphic position of the sandy division that yielded the rhinocerotid specimen MSNM-V0323, based on lithological correlations with the succession exposed at the nearby quarry walls (modified from Bianucci et al., 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Material and methods

The studied material is stored at Museo di Storia Naturale della Maremma in Grosseto. The dental nomenclature used in this paper follows Pandolfi et al. (2021a). The morphometric methodology follows Guérin (1980: pp. 66, 71) and Lacombat (2006: fig. 43). The measurements of the considered specimens are reported in Tables S1 and S2 (Appendix A). The studied specimen was acquired using a structured blue led light 3D Scanner Artec Space Spider. A downloadable 3D model is available as a supplementary resource file (Appendix A).

Body mass of *P. megarhinus* specimens is here calculated considering the m1, following the formula m = exp(1.5133 × ln(L × W) + 3.6515), proposed for Perissodactyla (Legendre, 1989). The body mass (m) is in gram, and L and W are length and width of m1 in mm, respectively (Table S2; Appendix A). However, it should be noted that m1 is the first permanent tooth to erupt and its dimensions are affected by wear, diminishing in length through time life. Accordingly, body mass calculated for old individuals can be underestimated.

The description of enamel hypoplasia (EH) follows Hullot and Antoine (2022). EH can be present in several forms, including: pits – which can be single, multiple, shallow, deep, randomly dispersed, or arranged in a series across the tooth crown; grooves – which can be single, multiple, narrow, or wide; partial or complete absence of enamel over a substantial portion of the dentin. Such variations can affect numerous or only a few teeth in the same individual (Szpringer-Nodziak and Wochna-Sobańska, 2015). EH has been identified in the teeth of various fossil rhinoceros species (Mead, 1999; Bacon et al., 2018; Böhmer and Rössner, 2018; Hullot and Antoine, 2022; Hullot et al., 2023).

Anatomical abbreviations: i, lower incisor; m, lower molar; p, lower premolar.

Morphometric abbreviations: Lp, length of the premolar row, buccal side; Lm, length of the molar row, buccal side; Ltb, length of the tooth row, buccal side.

Institutional abbreviations: MGUV, Museu de Geologia de la Universitat de València, Valencia, Spain; MSNAF, Museo di Storia Naturale, Accademia dei Fisiocritici, Siena, Italy; MSNM, Maremma Natural History Museum, Grosseto, Italy; NHMUK, Natural History Museum, London, UK; NMB, Naturhistorisches Museum, Basel, Switzerland.

4. Systematic paleontology

Order Perissodactyla Owen, 1848.
Family Rhinocerotidae Gray, 1821.
Subfamily Rhinocerotinae Gray, 1821.
Tribe Rhinocerotini Gray, 1821.
Subtribe Rhinocerotina Gray, 1821.
Genus ***Pliorhinus*** Pandolfi et al., 2021

Type species: *Pliorhinus megarhinus* (de Christol, 1834) from the Pliocene of Montpellier, France.

Other species: *Pliorhinus miguelcrusafonti* (Guérin and Santafé-Llopis, 1978).

Pliorhinus megarhinus (de Christol, 1834)
Fig. 2

Material: An almost complete mandible with the right and left molar rows and p4s housed at MSNM with inventory number V0323.

Description: The specimen MSNM-V0323 is a fragmentary mandible of an adult individual (m3 erupted and in wear; Fig. 2). The right side of the mandible (Fig. 2(B)), in buccal view, displays a right distal border below the molar row and the horizontal ramus upraises at the level of p4. In the left side view (Fig. 2(C)), the anterior border of the vertical ramus forms an obtuse angle with the proximal border of the horizontal ramus. Two mental foramina are located at the level of p2. The posterior border of the symphysis, in the proximal view, ends at the level of the anterior root of p3. The incisor corpus is not completely preserved, but, in the anterior view, it displays two circular foramina probably connected with the presence of two small-sized i2s.

A mesial-buccalcingulum is present on m1, m2 and m3 whilst it is absent on p4 (Fig. 2(D, E)). Enamel hypoplasia occurs on the buccal side of m2s and p4s (Fig. 2(D)). EH exhibits enamel pits which are closely arranged, forming an irregular line, as well as multiple pits scattered across the buccal surfaces of m2s and p4s. A slight distal cingulum is visible on m2s and m3s. Lingual cingula are absent. The anterior and posterior lingual valleys are broad V-shaped on m3s and narrow V-shaped on p4s. The buccal groove is opened and shallow and reaches the neck on all the molars and right p4 (Fig. 2(E)). In occlusal view, the paralophid reaches the lingual rim. In the same view, the trigonid forms an obtuse dihedron.

Remarks: The studied mandible MSNM-V0323 differs from *Pliorhinus miguelcrusafonti* in having a wider coronoid incisure. Teeth on the studied specimen can be distinguished from those of *P. miguelcrusafonti* in having broad lingual valleys, shallow buccal groove at the base of the tooth, and a faint mesial-buccal cingulum. *Stephanorhinus etruscus* is characterized by smaller size, ca. 15% considering the mean length of the lower tooth row (Table S1; Appendix A), with respect to the studied material; the mandible of the Etruscan rhinoceros is shorter, with a more acute angle between the anterior border of the ascending ramus and the horizontal ramus. Further, the lower teeth of *S. etruscus* display opened and shallow buccal groove, and V-shaped lingual valleys. In respect to the studied specimen, *S. jeanvireti* has a more acute angle between the anterior border of the ascending ramus and the horizontal ramus, narrower lingual valleys on the molars, deeper vestibular groove and a shorter metalophid. The tooth morphology of the studied molars resembles those from Vera Basin (MN14, Spain; MGUV) and from Montpellier (MN14, France; NMB, NHMUK) assigned to *Pliorhinus megarhinus* in having a faint mesial-buccal cingulum, a distal cingulum, broad lingual valleys. The morphology of the mandible from Arcille share with those of *P. megarhinus* from Montpellier an obtuse angle between the anterior border of the ascending ramus and the horizontal ramus and a broad coronoid incisure. The length of the molar row and the measurements of the single molars fall within the known range size of *P. megarhinus* (Table S1; Appendix A), being generally larger than other Pliocene European species.

5. Discussion

5.1. Chronology of Pliorhinus megarhinus *in the Italian Peninsula*

According to Pandolfi (2013) and Pandolfi and Rook (2017), *Pliorhinus megarhinus* (= '*Dihoplus*' *megarhinus* in previous papers) occurs in Italy during the latest Miocene, being documented by cranial and postcranial remains at Baccinello V3 and Cava Monticino (Fig. 3), both referable to the MN13. These records suggest a dispersal pattern of *P. megarhinus* from East, in particular from the northern Parathethys area (i.e., Hungary), together with other taxa such as *Hippotherium* and *Procapreolus*, well-documented in Hungary and Italy during the end of MN12 and MN13 (Bernor et al., 2011; Pandolfi et al., 2021b). *Pliorhinus megarhinus* persisted in the Italian Peninsula through the Pliocene (Table 1),

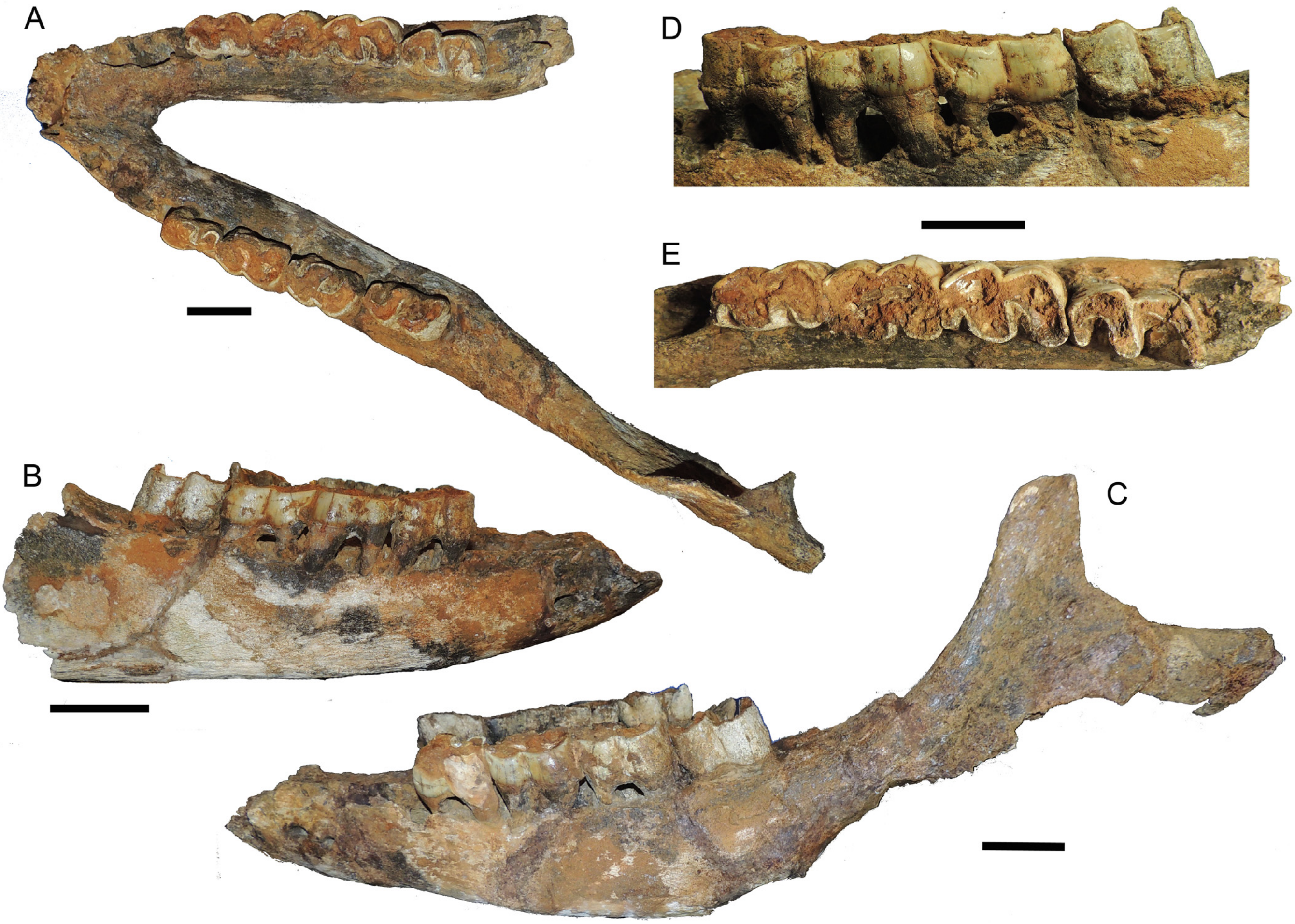

Fig. 2. *Pliorhinus megarhinus* mandible with the right and left molar rows and p4s, MSNM-V0323. **A.** Dorsal view. **B.** Right side view. **C.** Left side view. **D.** Buccal view of the right tooth-row. **E.** Occlusal view of the right tooth-row. Scale bars: 5 cm.

but most of the Italian Pliocene remains of this species were collected during the 19th or early 20th centuries, without a firm stratigraphic control, making difficult to chronologically define the lifetime span of the species. An attempt to provide a stratigraphic and chronological framework of Pliocene specimens was conducted by Bianucci et al. (2001) with respect to the mammal remains from Val di Pugna-Fangonero. The integrated biostratigraphic analysis of the planktonic foraminifers and calcareous nannoplankton indicates that the sediments deposited at the transition from the Zone MPL3 to MPL4 of the planktonic foraminifer scale correlate with the MNN14-15 Zone of the calcareous nannoplankton scale (between ca. 3.9 and 4.1 Ma; Fig. 3). Bianucci et al. (2001) suggested to refer the rhinoceros remains from Val di Pugna-Fangonero to as *S. jeanvireti*, contrary to Guérin (1980) and, later, Pandolfi (2013) who instead referred to these specimens as belonging to '*Dihoplus*' *megarhinus*. According to Bianucci et al. (2001), the mandible form Val di Pugna-Fangonero (housed at MSNAF) can be assigned to *S. jeanvireti* since the horizontal rami are less massive proximal-distally compared to *P. megarhinus* and the incisor corpus bears only two anterior alveoli instead of the four of *P. megarhinus*. However, the height of the horizontal rami falls within the range of variability of *P. megarhinus* given by Guérin (1980) and the toothrow is longer than that of *S. jeanvireti*. The morphology of the lower teeth allows to exclude an assignment to *P. miguelcrusafonti* and fits instead with an attribution to *P. megarhinus*. The latter species can show four alveoli, with those for i2s larger than those for i1s; however, i2's alveoli in *P. megarhinus* bear small and rounded incisors similarly to the specimen from Val di Pugna-Fangonero. The latest record of *P. megarhinus* could be placed at the earliest Piacenzian, this species being represented by an almost complete skeleton from the marine deposits of Monte Giogo, probably dated between 3.57 Ma and 3.10 Ma (if we consider the specimen as collected from the same levels that yielded cetaceans, i.e., Montezago Unit; Freschi et al., 2019). Rhinocerotidae records younger than 3.5 Ma suggest the extinction of *P. megarhinus* and the arrival in Italy of *S. jeanvireti* at first, and *S. etruscus* subsequently (the isolated remains from Villafranca d'Asti housed at NMB come from an undefined stratigraphic level, and an attribution to an age younger than the early Villafranchian cannot be excluded; Cirilli et al., 2020; Table 1). However, the occurrence of *P. miguelcrusafonti*, which characterized some Upper Pliocene localities ranging from Georgia (Caucasus) to Iberian Peninsula (Pandolfi et al., 2021a), cannot be ruled out, pending a revision of some Pliocene specimens dubitatively assigned to *Stephanorhinus* sp. (e.g., from Lucardo, Tuscany) or to an evolved form of *P. megarhinus* (e.g., San Regolo, Palaia, in the lower Val d'Arno Valley, Tuscany). Unfortunately, most of the latter records lack a firm stratigraphic control and the age can be only approximated considering the Pliocene outcropping nearby the named locality.

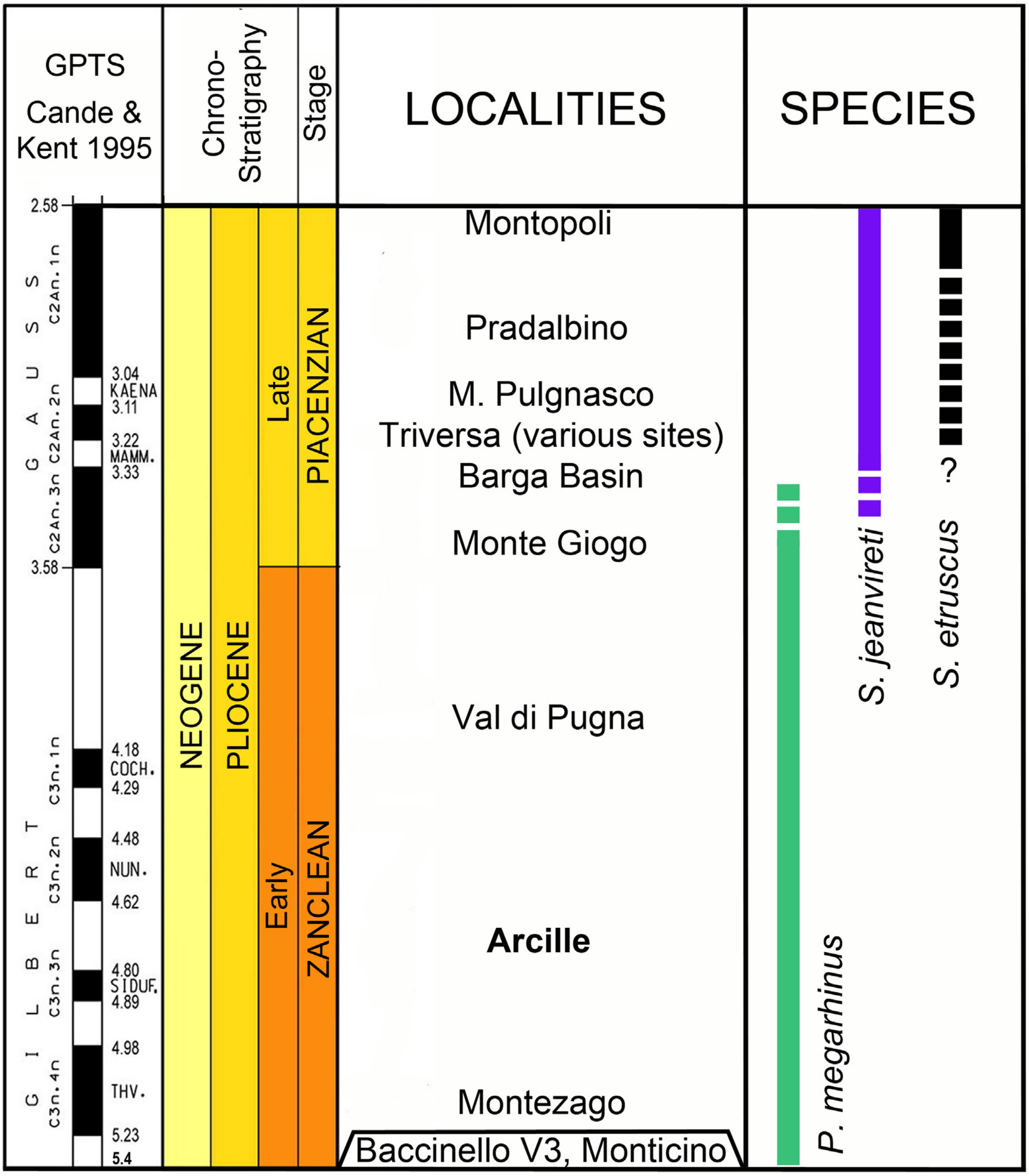

Fig. 3. New biochronological scheme for the Italian Pliocene rhinocerotines and chronological position of selected localities discussed in the text.

According to the reported Italian occurrences of *P. megarhinus*, the species spanned in the country from 6.7 Ma (Baccinello V3) to ca. 3.5 Ma (Monte Giogo). The occurrence of the species at Arcille provides the evidence of a long and continuous persistence of *P. megarhinus* over the Early Pliocene, suggesting it was the sole rhinoceros species in Italy at that time (Fig. 3).

Based on current evidence, the extinction of *P. megarhinus* approximates the Zanclean-Piacenzian boundary. This transition is characterized by a cooling event (Lourens et al., 1996, 2004) with a decrease of subtropical trees and an increase of warm-temperate and cool-temperate trees as well as herbs (Suc et al., 1995; Bertini, 2010), with a cold culmination at 3.5–3.3 Ma, followed by the "mid-Pliocene" warm interval between 3.2 and 2.8 Ma. A possible relation between the extinction of *P. megarhinus* and this cooling event, followed by the arrival of *Stephanorhinus*, remains to be investigated.

5.2. Body size variations and enamel hypoplasia

Some attempts to identify morphometric variations in Pliocene rhinoceros species were provided by Guérin (1980). This author, considering the then-available specimens of *P. megarhinus*, detected a reduction of length and width on upper teeth, a weak reduction in size of lower teeth, an increase of hypsodonty and a reduction in length of long bones and size of carpals. However, extant rhinoceros species can be affected by a certain variability of size due to sexual dimorphism, sexual maturity and availability of resources, resulting in morphological and morphometric differences of some features such as shape and size of nasal bones, shape of occipital face, shape and size of zygomatic arches, and length of some long bones (Groves, 1982; Pandolfi, 2022). Studies on fossil rhinoceroses showed that length of lower premolars and molars, and m1 occlusal surface areas, are not statistically different

Table 1
Selected occurrences of Pliocene Rhinocerotidae in the Italian Peninsula.

Site	Species	Age	References	Note
Baccinello V3	*P. megarhinus*	6.7–5.4 Ma	Pandolfi and Rook (2017)	
Cava Monticino	*P. megarhinus*	6–5.4 Ma	Pandolfi and Rook (2017)	
Montezago	*P. megarhinus*	5.33–4.53 Ma	Freschi et al. (2019)	lower unit?
Arcille	*P. megarhinus*	5.08–4.52 Ma	this work	
Val di Pugna	*P. megarhinus*	4.1–3.9 Ma	Bianucci et al. (2001), Pandolfi (2013)	
Monte Giogo	*P. megarhinus*	3.57–3.10 Ma	Pandolfi (2013)	supposed Montezago Unit basing on the presence of blue clay levels.
Villafranca d'Asti	*S. jeanvireti*	3.2–2.6 Ma	Cirilli et al. (2020)	San Martino Unit
Roatto	*S. jeanvireti*	3.2–2.6 Ma	Cirilli et al. (2020)	San Martino Unit
Monte Pulgnasco	*S. jeanvireti*	3.10–3.05 Ma	Pandolfi (2013)	
Pradalbino	*S. jeanvireti*	3.10–2.58 Ma	Pandolfi (2013)	
Montopoli	*S. jeanvireti*, *S. etruscus*	ca. 2.58 Ma	Pandolfi (2013), Cirilli et al. (2020)	

between males and females (Mead, 2000), suggesting they can be reliably used for estimation in body size variations. Applying the formula proposed by Legendre (1989), the individual from Arcille varies between 2957 and 3223 kg (Table S2; Appendix A). These values are larger than those obtained from Val di Pugna, between 2079 and 2333 kg. The Arcille' values are also larger than those obtained for *S. jeanvireti* from Monte San Pietro and Monte Pulgnasco, 2448 kg and 2112–2127 kg, respectively. The body mass of the Arcille rhinoceros falls within the range estimated for the individuals from Saint-Laurent-des-Arbres, between 2512 kg and 3584 kg. Accordingly, *P. megarhinus* seems to be represented by large-size individuals during the early Zanclean and relatively smaller individuals towards the end of the Zanclean.

Furthermore, looking at the premolar and molar lengths, it is possible to detect how the ranges of the specimens from the early Zanclean of Montpellier (Lp = 101–119 mm; Lm = 131–158.09 mm; Ltb = 230–276 mm) and Saint-Laurent-des-Arbres (Lp = ca. 107–139 mm; Lm = 140–152 mm; Ltb = ca. 248–285 mm) are similar to those from Arcille (Lp = ca. 113.6-ca. 123.5 mm; Lm = 153.6–157.7 mm; Ltb = ca. 264-ca. 275 mm), and are a little bit larger than those from the late Zanclean localities (i.e., Val di Pugna: Lp = ca. 110.7 mm; Lm = ca. 139 mm; Ltb = ca. 244.65 mm; Monte Giogo: Lp = 107–110 mm; Lm = 130–133 mm; Ltb = 242–251 mm; Fratesti: Lp = 107 mm; Lm = 142 mm; Ltb = 248 mm). However, the available sample size is too small to statistically test differences among *P. megarhinus* populations through time, and a more comprehensive sample is needed to validate these variations.

The hypoplasia was detected on the visible enamel surface of m2 and p4. It is possible that it may exist on other teeth beneath sediment or cement, but it cannot be detected by μCT methods (Hullot and Antoine, 2022). The observed EH on m2 and p4 more likely reflects physiological stress associated with separation of the calf from the adult (Mead, 1999). Following the tooth eruption sequence reported for *Ceratotherium simum* (Hillman-Smith et al., 1986), it can be estimated that the recorded EH occurred approximately between the 4 and 7 years of the rhinoceros's life (eruption of p4 and m2), when the animal was adolescent and independent from mother. A similar age can be also estimated considering the extant *D. bicornis*; in this species, the second molar starts to erupt at ca. 4 years, and the premolars erupt in sequence between 5 and 8 years (Goddard, 1970).

6. Conclusions

The rhinoceros mandible MSNM-V0323 collected from the Lower Pliocene deposits of Arcille is here assigned to *Pliorhinus megarhinus*. The morphology and the morphometry of the specimen allow to distinguish it from *Stephanorhinus* species and from the Late Pliocene *P. miguelcrusafonti*. Similarities in morphology and morphometry with earliest Pliocene specimens of *P. megarhinus* from Montpellier, Vera Basin and Saint-Laurent-des-Arbres are here detected for the specimen from Arcille. Thus far, *P. megarhinus* represents the unique rhinoceros species spanning from 6.7 Ma to 3.5 Ma in the Italian Peninsula. A preliminary investigation of body mass variation calculated on the considered specimens would suggest a decrease in size of *P. megarhinus* from the earliest Pliocene to the end of the Zanclean. Late representatives of the species approximate the Zanclean-Piancenzian transition and could be affected by the cooling event at 4–3.3 Ma that led them to a possible extinction. The latter hypothesis needs to be tested with detailed analyses and could help understanding the replacement of *Pliorhinus megarhinus* by *Stephanorhinus* species that occurred during the Late Pliocene.

Data availability

Data and material are available within the cited collections and institutions.

CRediT authorship contribution statement

Luca Pandolfi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Alberto Collareta:** Investigation, Supervision, Validation, Software, Methodology, Writing – original draft, Writing – review & editing. **Dariusz Nowakowski:** Investigation, Methodology, Writing – review & editing. **Giovanni Bianucci:** Supervision, Resources, Writing – review & editing. **Lorenzo Rook:** Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

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

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Appendix A. Supplementary information

Supplementary information (including Tables S1 and S2 as well as a 3D model [.ply format] of the Arcille rhinoceros mandible MSNM-V0323) associated with this article can be found, in the online version, at: https://doi.org/10.1016/j.geobios.2023.12.012.

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