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First occurrence of a fossil rhinoceros on the island of Kos (Dodecanese, Greece)

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Abstract

The Mediterranean Island of Kos, situated in the Southeastern Aegean Sea, has long attracted the interest of paleontologists. In the present study, the first records of fossil inoceroses from the island are reported. Recent field prospecting has led to the discovery of a fossiliferous site near the village of Antimacheia containing vertebrate remains, including a partial rhinocerotid nasal bone fragment attributable to the genus *Stephanorhinus*. A subsequent evaluation of a legacy museum collection from Kos also revealed a rhinocerotid astragalus morphologically and morphometrically consistent with *Stephanorhinus* cf. *etruscus*. Previous studies concur that the fossil vertebrate assemblages of Kos date to the Early Pleistocene (Villafranchian), including mammalian taxa such as *Anancus arvernensis*, *Homotherium* sp., *Hippopotamus antiquus*, *Leptobos etruscus*, *Gazella borbonica*, *Eucladoceros ctenoides*, *Croizetoceros ramosus* and *Equus stenonis*. The addition of the rhinocerotid *Stephanorhinus* cf. *etruscus* is biogeographically significant, because it complements the known Eurasian distribution of the species and offers valuable insights into the dispersal routes in the Eastern Mediterranean during the Villafranchian. These findings support the hypothesis that the island of Kos was geographically contiguous with the Anatolian Peninsula during Early Pleistocene eustatic lowstands, which created intermittent land bridges that facilitated the dispersal of Villafranchian megafauna.

Keywords Greece, Kos Island, Villafranchian, Rhinocerotidae, *Stephanorhinus*

1 Introduction

The Mediterranean Island of Kos, situated in the Southeastern Aegean Sea, has long attracted the interest of paleontologists. Over the past 150 years, researchers including M. Neumayr [1], C.I. Forsyth Major [2], A. Desio [3, 4], C. Airaghi [5], R. Willmann [6], and A.I. Avrithis & W. Fischer [7] have reported the presence of vertebrate and invertebrate fossils on the island. Recent field prospecting and Museum research have led to the discovery of the first specimens of fossil rhinoceroses from the island of Kos. The fossil record of rhinocerotids in Greece has been recently revised and updated by Giaourtsakis [8]. It is relatively rich and spans from the Middle Miocene to the Late Pleistocene, providing important insights into the temporal and spatial distribution of several lineages. Due to its geographical position at the crossroads of Europe and Asia, the Greek

rhinocerotid record can offer valuable data regarding the biogeographical dispersal of Eurasian taxa.

2 Materials and methods

The fossil rhinocerotid material from Kos Island is stored in the collections of the Museum of Geology and Paleontology of the National and Kapodistrian University of Athens (AMPG). It comprises two specimens: a fragmentary nasal bone (AMPG(V): 2601) and a nearly complete astragalus (AMPG: KO-959). The nasal bone fragment was recovered during field prospecting in 2021, which has led to the discovery of a fossiliferous site containing vertebrate remains near the village of Antimacheia. During subsequent comparative research at the AMPG, a legacy collection of fossil vertebrates from the Island of Kos was also evaluated, which included the rhinocerotid astragalus. Accompanying notes indicate that this legacy material also originates from the vicinity of Antimacheia and was likely excavated during the 1970s by the late Professor Nikolaos Symeonidis. However, a precise spatial or stratigraphic correlation between this earlier collection and the new 2021 locality cannot be confidently confirmed. The same is true for the older references that have reported the occurrence of fossil vertebrates in the wider area near the villages Antimacheia and Kardamena without precise stratigraphic data, e.g. [5, 3].

The astragalus measurements follow [9] (p. 122) and [10] (p. 129, Fig. 22). Measurements ranging between 0 and 150 mm were taken with a digital caliper to 0.1 mm and rounded to the nearest 0.5 mm. All measurements are given in millimeters (mm).

2.1 Geological setting

The fragmentarily preserved nasal bone fossil was discovered in the Early Pleistocene fluvio-lacustrine deposits of the lower part of the Tafi Formation [6] near Antimacheia village. The lithology of the fossiliferous basal bed (Fig. 1) consists of cross-bedded sands and medium-sized conglomerates with rounded clasts and weathered fragments of *Melanopsis* sp. shells indicating a fluvial environment.

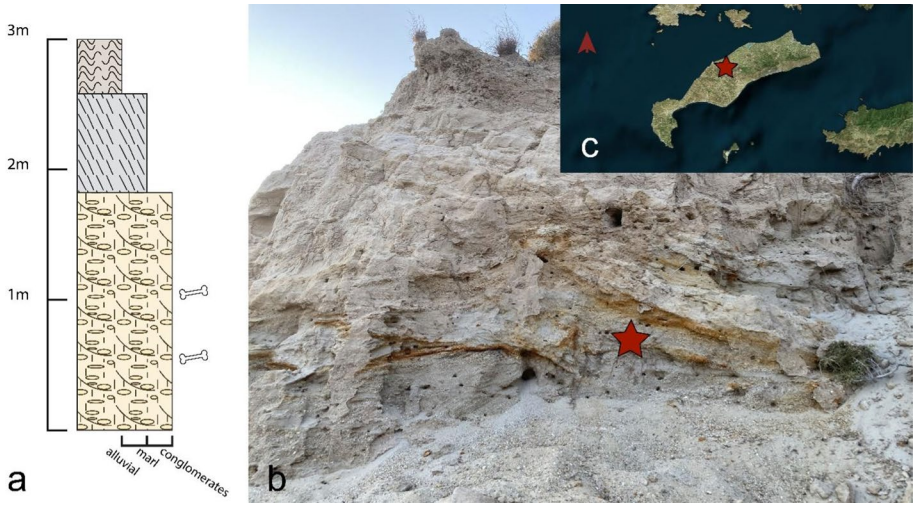

Fig. 1 **a** Stratigraphic column of the outcrop. **b** A natural section exposing the Early Pleistocene deposits of the lower Tafi Formation, Kos Island. The red star indicates the fossiliferous bed

2.2 Systematic paleontology

Class **Mammalia** Linnaeus, 1758.

Order **Perissodactyla** Owen, 1848.

Family **Rhinocerotidae** Owen, 1821.

Subfamily **Rhinocerotinae** Owen, 1821.

Tribe **Rhinocerotini** Owen, 1821.

Subtribe **Dicerorhinina** Ringström, 1924.

Genus **Stephanorhinus** Kretzoi, 1942.

Stephanorhinus cf. ***etruscus*** (Falconer *in* Ansted, 1859).

2.3 Nasal bone

In dorsal view, the nasal bone fragment AMPG(V): 2601 preserves the anterior portion of a prominent, dome-shaped nasal horn boss, marked by numerous rugose vascular impressions (Fig. 2a, c). On the ventral surface of the nasal bone, the fragmentary remains of a partially ossified nasal septum are preserved. As noted by Loose [11], the nasal septum consists of a right and left part. When the ossification occurs, two bony plates are actually formed and closely joined along the median sagittal plane (Fig. 2 insert). Due to the fracture, the outlines of these bilateral bony plates are clearly visible on the ventral side of the Kos specimen (Fig. 2c).

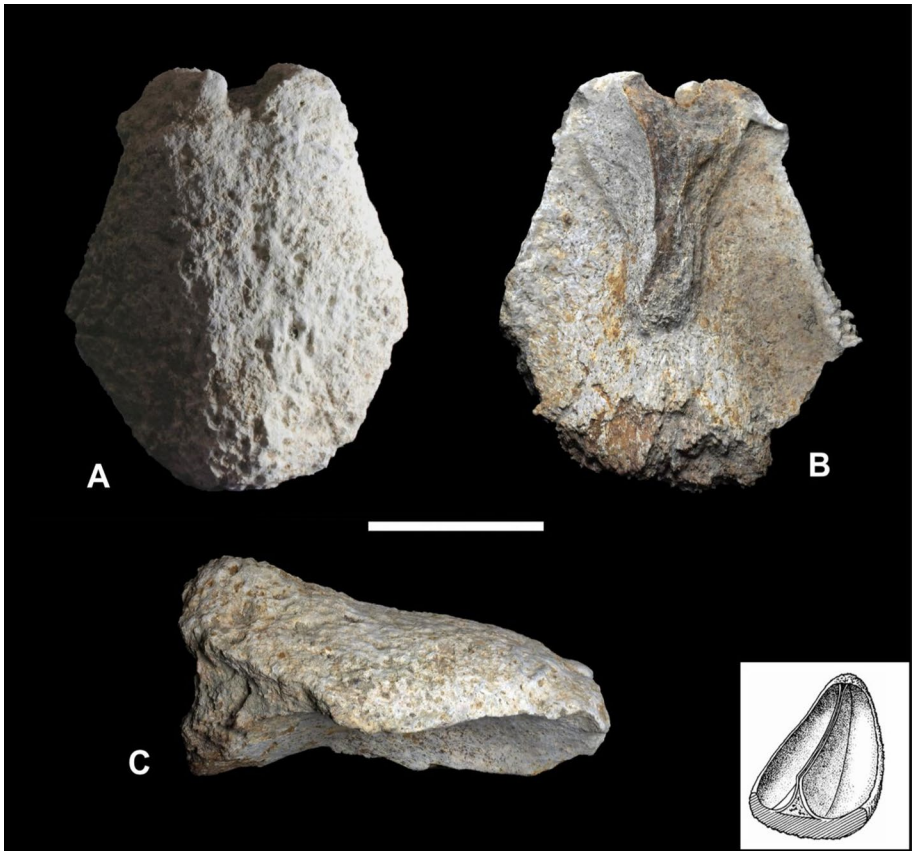

Fig. 2 *Stephanorhinus* cf. *etruscus* from the Aegean Island of Kos, Greece. Nasal bone fragment AMPG(V): 2601 in **a** dorsal, **b** ventral and **c** lateral view. Scalebar: 5 cm. Schematic figure of bilateral bony plates forming the ossified nasal septum (after [11]; released under the CC-BY 4.0 License)

Comparison and Remarks: The presence of a partially ossified nasal septum clearly supports the attribution of the specimen to the dicerorhine genus *Stephanorhinus*. Nevertheless, the incomplete state of preservation is insufficient for more specific comparisons.

2.4 Astragalus

The specimen AMPG: KO-959 is a moderately well-preserved left astragalus (Fig. 3). Some parts of the bone are incompletely preserved due to abrasion and surface loss. This condition has resulted in the exposure of the cortical bone layer across several areas, exhibiting a somewhat porous texture. This apparent porous texture may reflect either the naturally thinner cortex of a juvenile individual, or abrasive post-mortem damage that has exposed the underlying porous cancellous bone of an adult. The preserved dorsal remnant of the medial tubercle, as well as the preserved solid portion of the distal articular facets for the navicular and the cuboid, are indicative of an adult or subadult individual. In addition, some surface pits may represent predator bite marks. In dorsal view, the trochlea is asymmetrical, with the lateral lip being more massive than the medial one. The talar neck is relatively high, and the depression beneath the midpoint of the trochlea is well-expressed. Neither the medial nor the lateral lip of the trochlea extends significantly towards or contacts the distal articular facets for the navicular and cuboid bones, respectively. In particular, the distal margin of the lateral lip of the trochlea is clearly separated from the talar neck, and its minimum distance is ca. 17 mm from the dorsal border of the cuboid facet. The same is true for the middle portion of the distal trochlear margin, which retains a minimum distance of ca. 18 mm with respect to the dorsal border of the navicular facet. The distal border of the medial trochlear lip blends gently with the trochlear neck but still preserves a minimum distance of approximately 8 mm from the dorsal border of the navicular facet.

In distal view, the plantar half of the navicular and cuboid articular facets are not preserved. The remaining dorsal portion exhibits the typical rhinocerotid morphology, characterized by a saddle-shaped navicular facet (slightly concave transversely and convex dorso-plantarly) and by a comparatively smaller and flattened cuboid facet. On

Fig. 3 *Stephanorhinus* cf. *etruscus* from the Aegean Island of Kos, Greece. Astragalus AMPG: KO-959 in **a** dorsal and **b** plantar view. Scalebar: 3 cm

the medial side of the bone, both the trochlear articular surface that corresponds to the medial malleolus of the tibia, as well as the distal medial tubercle are poorly preserved. Similarly, on the lateral side, the articular stripe of the trochlea that articulates with the lateral malleolus of the fibula has suffered significant abrasion. The attachment surface for the lateral talocalcaneal ligament is partially preserved; it is relatively small, rounded, and slightly depressed. In plantar view, the ectal calcaneal facet is notably concave and features a small, low and wide distal extension. The talar sulcus is deep, clearly separating the ectal from the sustentacular calcaneal facet. Only a small proximal portion of the sustentacular calcaneal facet is preserved, while the area corresponding to the distal calcaneal facet is completely abraded.

Comparison and Remarks: The astragalus from Kos stands out for its relatively compact size and slender proportions. When compared with the other *Stephanorhinus* samples (Table 1), it falls well within the range of the typical Villafranchian *S. etruscus* and close to its mean values as reported by both [9] and [10]. The primarily Late Pliocene *S. jeanvireti* and the Middle-Late Pleistocene *S. kirchbergensis* are markedly larger and significantly more robust; the Kos astragalus remains well below their reported minimum values [9, 10]. The dimensions of the Kos astragalus are also smaller with respect to the values of the Early-Middle Pleistocene *S. hundsheimensis* reported by [9]. There is some overlapping with the lower range of the values reported by [10], who included a larger sample but utilized a somewhat different concept for this species with respect to subsequent authors (e.g. compare discussion in [9, 12]). Apart from the apparent larger size, the dorsal articular surface of *S. hundsheimensis* astragalus becomes proportionally broader transversally [9]. There is also some overlapping between the astragalus from Kos and the lower range of the values reported for the Middle-Late Pleistocene *S. hemitoechus* (Table 1). However, in dorsal view, the trochlea of the astragalus of *S. hemitoechus* is broader latero-medially, and its lateral lip is somewhat less steep [9]. In addition, the talar neck of *S. hemitoechus* appears generally shorter and the distal border of the trochlea may come very close to the distal articular surfaces for the navicular and the cuboid. Despite its moderate state of preservation, the available morphological and morphometrical properties of the Kos astragalus exhibit clear affinities with the typical Villafranchian *S. etruscus*. However, due to the limited available material, we shall preliminarily retain the determination as *Stephanorhinus* cf. *etruscus* for the Kos rhinocerotid.

Table 1 Comparative measurements (in mm) between the astragalus AMPG: KO-959 from the Aegean Island of Kos and relevant Plio-Pleistocene *Stephanorhinus* species

	KOS	***S. etruscus***		***S. hundsheimensis***		***S. hemitoechus***		***S. kirchbergensis***		***S. jeanvireti***
	AMPG KO-959	**Guérin (1980)**	**Fortelius et al. (1992)**	**Guérin (1980)**	**Fortelius et al. (1992)**	**Guérin (1980)**	**Fortelius et al. (1992)**	**Guérin(1980)**	**Fortelius et al. (1992)**	**Guérin (1980)**
LL	ca. 76	71–84	69–75	67–89	79–92	72–94	71–78	85–105	81–105	87–104
ML	ca. 72	-	65–74	-	73–81	-	76–80	-	76–95	-
B	ca. 78	73–88	75–86	76–107	80–96	73–95	74–96	93–113	93–108	92–108
BDa	ca. 67	57–75	58–70	60–85	71–80	61–80	67–75	74–93	78–96	70–85

Measuring protocol and abbreviations after Fortelius et al. [9]: LL: lateral length; ML: medial length; B: greatest breadth; BDa: breadth of the distal articular surface. Measurements are given in milimeters (mm)

Fig. 4 Pliocene and Pleistocene distribution of the family Rhinocerotidae in Greece, including the most significant localities. Modified from [8]. A double asterisk (**) following a locality name indicates a cf. determination

3 Discussion and conclusions

The Early Pleistocene vertebrate material described herein represents the first occurrence of fossil rhinoceroses on the Island of Kos. The rhinocerotid fossil record of Greece has been recently revised and updated [8]. Despite the numerous localities, the Pliocene and Pleistocene record (Fig. 4) remains relatively sparse and fragmentarily preserved, when compared to the rich and diverse Late Miocene record known from the classical localities of Pikermi, Samos, and the Axios Valley [8]. The end of the Miocene was marked by a major faunal turnover caused by the environmental impacts of the Messinian Salinity Crisis, during which the Mediterranean Sea underwent a cycle of significant desiccation. Following the subsequent Zanclean flood, regional environmental conditions shifted toward more temperate and forested habitats. The Early Pliocene rhinocerotid record remains notably limited in Greece [8]. In the Late Pliocene, however, *Stephanorhinus jeanvireti* is well-documented with ample material from the fossiliferous localities of Milia and Angelochori [13, 8]. The typical Villafranchian species *Stephanorhinus etruscus* has been reported with varying degrees of certainty from several, primarily Early Pleistocene, sites [8, 14, 15, 16]. It was subsequently replaced by *Stephanorhinus hemitoechus*, which is documented from a few Middle-Late Pleistocene localities, such as the renowned Petralona Cave [17]. Finally, the occurrence of the

woolly rhinoceros *Coelodonta antiquitatis* is restricted to a single Late Pleistocene locality in Northern Greece [8, 18], affirming its scarcity at low latitudes.

In particular, within the Aegean region, fossil rhinoceroses from the Pliocene and Pleistocene are exceptionally rare, with only two occurrences previously reported from Rhodes and Lesvos Islands (Fig. 4). The Rhodes record was discovered in the Apolakkia locality, dated to the Early Pliocene (Ruscinian, zone MN15), and was reported as Rhinocerotidae indet [19]. The material from Lesvos originates from the Vatera DS locality, dated to the Early Pleistocene (Middle Villafranchian, zone MN17), and was identified as *Stephanorhinus* cf. *etruscus* [20]. In mainland Greece, the presence of *Stephanorhinus etruscus* has been reported with more or less (cf.) certainty from several sites (Fig. 4, compare also [8, 14, 15]). In fact, some of these occurrences may represent *Stephanorhinus hundsheimensis*, as suggested by [16]. In Anatolia, the only known record of *Stephanorhinus* is the occurrence of *Stephanorhinus hundsheimensis* from the late Early Pleistocene deposits of the Denizli Basin [21]. The Villafranchian is a period where the genus *Stephanorhinus* was widely distributed in Eurasia, represented by multiple species that adapted to significant climatic and paleoenvironmental changes [22, 23].

Previous studies concur that the fossil vertebrate assemblages of Kos date to the Early Pleistocene (Villafranchian), including taxa such as *Anancus arvernensis*, *Homotherium* sp., *Hippopotamus antiquus*, *Leptobos etruscus*, *Gazella borbonica*, *Eucladoceros ctenoides*, *Croizetoceros ramosus and Equus stenonis* [2, 3, 4, 5, 24, 25, 26]. The addition of the rhinocerotid *Stephanorhinus* cf. *etruscus* is biogeographically significant, because it extends the known Eurasian distribution of the genus, and potentially of the species, and offers valuable insights into faunal dispersals in the Eastern Mediterranean during the Villafranchian. The presence of a balanced Early Pleistocene terrestrial mammal fauna on the island of Kos provides strong evidence for a former land connection with the Anatolian mainland. This was further supported by the recent discovery of a trionychid turtle in lacustrine sediments of the same formation [27]. The occurrence of large-bodied taxa with limited swimming capabilities, clearly implies that the fauna has reached the island of Kos through natural dispersal mechanisms during periods of lowered sea level that exposed land bridges across the eastern Aegean [28, 29]. These dispersal patterns are consistent with glacio-eustatic fluctuations that temporarily unified insular and continental biogeographic zones, facilitating faunal exchange across what is now the southeastern Aegean archipelago.

Acknowledgements
We are grateful to E. Koskeridou and S. Roussiakis for their assistance during the study and analysis of the material at the collections of the Museum of Geology and Paleontology in Athens. We are greatly indebted to R. Sabin and R. Pappa for facilitating comparative studies at the collections of the Natural History Museum of London. I.G. received support from the SYNTHESYS+ Project (http://www.synthesys.info/), which is financed by the European Community Research Infrastructure Action under the H2020 Integrating Activities Program, Project number 823827.

Author contributions
A.I.A. and I.X.G. conceptualized and designed equally the study and wrote and approved the manuscript. A.I.A. discovered the locality and recovered the nasal specimen. I.X.G. evaluated the legacy collection from Kos at the AMPG and identified the astragalus.

Funding
I.X.G. received support from the SYNTHESYS+ Project (http://www.synthesys.info/), which is financed by the European Community Research Infrastructure Action under the H2020 Integrating Activities Program, Project number 823827, to conduct relevant comparative studies at the collections of the Natural History Museum of London.

Data availability
All data generated or analysed during this study are included in this published article. The fossil specimens described in this study are deposited in the collections of the Museum of Geology and Paleontology of the National and Kapodistrian University of Athens, Greece, where they are available for examination upon reasonable request.

Declarations

Ethics approval and consent to participate
This study is based exclusively on geological and paleontological material and did not involve human participants, live animals, or sensitive personal data. Ethics approval and consent to participate were therefore not applicable.

Consent for publication
This manuscript does not contain any individual person's data in any form. Consent for publication is not applicable.

Competing interests
The authors declare no competing interests.

Received: 10 December 2025 / Accepted: 21 July 2026
Published online: 29 July 2026

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