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The earliest evidence of large animal fossil collecting in mainland Greece at Bronze Age Mycenae

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Fossils of large animals have long influenced social practices and ideologies in human societies, including the fantastic myths of giants, heroes, and gods in ancient Greece. It has been estimated that purposeful fossil collecting in Greece began in the Late Bronze Age. However, previous archaeological finds of fossils from mainland Greece were not well documented in secure contexts that dated this far back in time. Herein, we present a newly recognized fossilized astragalus bone recently found in the legacy collections of the archaeological site of Mycenae. It was originally recovered by excavations in the 1970s and recently reanalyzed at the Mycenae Museum. Our analysis explored the available evidence of the find location, the state of fossil preservation, and the species represented. The results suggest that a fossilized rhinoceros (*Stephanorhinus*) astragalus was collected in the past, possibly from afar. Evidence indicates it was brought to Mycenae, where it was deposited near an interesting array of artifacts in a basement storage area of the Southwest Quarter, sometime in the thirteenth century BCE. This find represents the earliest secure evidence of large animal fossil use by people in mainland Greece, dating to the Late Bronze Age.

Fossils played significant roles in past human social, ritual, and symbolic activities—notably influencing or contributing to mythical ideologies of ancient Greece. Previously, archaeological finds of questionable provenience provided a general estimate that fossil collecting for ritual use in mainland Greece originated during the Late Bronze Age[1–3]. In our recent research of legacy collections of Late Bronze Age materials stored at the Mycenae Museum, we discovered a fossilized remnant of a long-extinct animal. The fossil was initially recovered from the Southwest Quarter of the archaeological site of Mycenae during excavations that took place in the 1970s[4–6]. Here, we use contextual and zooarchaeological analysis to reconstruct the depositional and environmental history of the fossil. This find is of key importance, as it derives from a secure archaeological context and represents more chronologically reliable evidence of early fossil use in the Bronze Age than previously available in mainland Greece.

Fossils, ancient even to the prehistoric people who collected them, are not well represented in the early archaeological record of Greece. Ancient Greek literature, persistent placenames, and some iconographic sources evidence a steady interest in fossilized remains and large bones that were collected and incorporated into myths of heroes and monsters[1–3]. This practice may reflect earlier ritual use. Still, it remains unclear when collecting large fossils first began and how it was associated with Bronze Age Aegean ideologies.

Our study of the available evidence aimed to assess the species of the rediscovered fossil remain and understand its use within the wider archaeological deposit, originally excavated by G. Mylonas[6]. We analyzed the fossil morphology and dimensions to identify the species [following[7,8], see Methods]. We then situated the results within a wider regional and historical picture to elucidate the potential social, ritual, and symbolic roles the fossil played in the Late Bronze Age. Given that very limited evidence is available of fossils recovered in situ from archaeological contexts in Greece, our context-based study of the Mycenae fossil provides new insights to characterize early depositional practice with fossils and clarify the timeline of early fossil use in mainland Greece, pushing it back securely to the Late Bronze Age.

Ancient observations of fossils appear to have significantly influenced Greek myth-making. According to Mayor and Boardman[1,2], there are many instances where ancient artists and historians likely attributed symbolic or actual fossil remains to legendary monsters or heroes of impressive size. For example, Pausanias (Description of Greece, 5.13.1–7) described a large shoulder blade said to be of Pelops at Olympia, a site located near rich fossil beds. According to Pausanias, it was shipped to aid the Greeks in the legendary Trojan War, and eventually,

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displayed at the Pelopion shrine at Olympia (seventh century BCE [Before Common Era]). At the Heraion of Samos (seventh century BCE), a distal femur of a likely rhinoceros or mastodon was found that likely dated to the Miocene if originally from Samos, according to N. Solounias (personal communication in[1,3]). At Kos, a fossil molar of an elephant was recovered from the area of the Asklepion (third century BCE)[1], but was subsequently lost. At least one early Greek artistic rendering of a monster was inspired by fossils, such as the Late Corinthian column krater with the so-called monster of Troy, possibly modeled after a Samotherium fossil skull[9].

Little is known of the origins of fossil use in the Aegean region. In Cyprus, Aceramic Neolithic and Chalcolithic sites have yielded pygmy elephant and hippopotamus remains, but these may represent ancient killing or processing sites[10]. Neolithic sites in mainland Greece lack clear examples of intentional fossil use.

Fossil collecting for social and ritual use may have originated in the Late Bronze Age, yet the current evidence is unclear[1]. Fossil seashells recovered from Bronze Age contexts off the mainland likely reflect natural or accidental accumulations, such as the Gypsades cemetery at Knossos, where fossil shells in fill material likely derived from local limestone with fossil inclusions[11]. Fossil seashells were also reported from the Uluburun shipwreck (fourteenth century BCE), but little is known about them [Pulak *pers. comm.*, in[1]]. An old report also noted antlers of an extinct deer from a Minoan shrine at Knossos[12,13].

One potential example of early megafauna fossil collection in mainland Greece comes from the multiperiod site of Nichoria. The excavation report listed a fossil found on the acropolis of the site. The description reads, "Of some interest is the discovery of the distal portion of an elephant femur found in an archaeological context. The animal represented is a fossilized, extinct, probably Pliocene form that once occurred in the area ([14]pp270)." The fossil was later identified correctly by N. Solounias as the distal end of a femur of a rhinoceros or chalicothere[1]. However, the fossil provenience is questionable, potentially dating to one of several occupational phases, anywhere from the Late Bronze to the Early Iron Age[15]. A tooth of an extinct horse was also found there in a tomb, but later lost, and several fossilized seashells were recovered[1]. The lack of secure provenience information for these examples impedes further study and interpretation.

The fossil from Mycenae was recovered by Mylonas in 1974 during an excavation in the Southwest Quarter of the citadel in Building Θ (Fig. 1A), a complex with seven rooms preserved on the basement level[4–6]. The fossil came from the central Room Θ3, accessed by a side corridor, and featured an uneven steep bedrock outcropping, scant floor remains, and a low plastered corner bench. No special function was attributed to Room Θ3; both Mylonas and later Iakovidis considered Building Θ to be a domestic complex[5,6].

The Room Θ3 architecture preserved an undisturbed depositional sequence. It was destroyed and abandoned at the end of the Late Helladic (LH) IIIB2 period (ca. 1200 BCE) and a thick layer of debris from the first floor

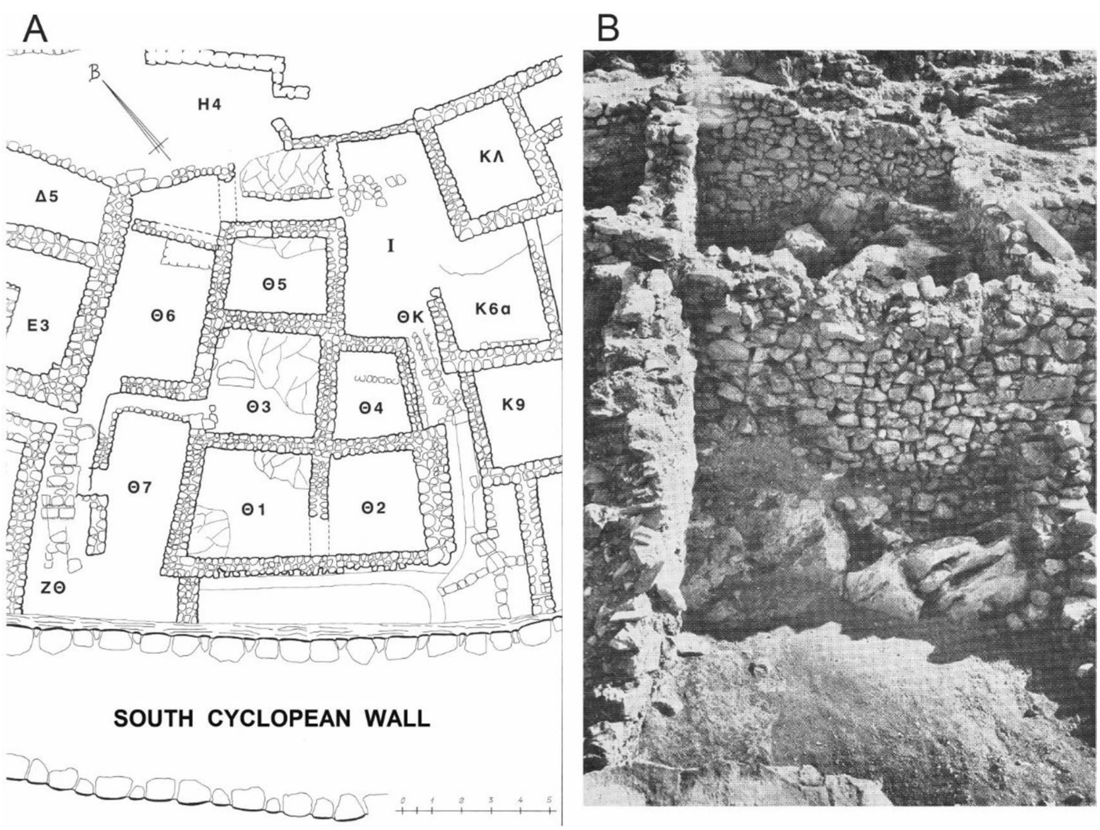

Figure 1. (**A**) Location of room in the Southwest Quarter of Mycenae and (**B**) the architecture and exposed bedrock in room Θ3 (lower half of photo), after (5): 303, plan 7, pl. 79a.

collapsed into the basement. This destruction deposit contained numerous pottery sherds and small finds, dating to the 13th cent. BCE[4,5].

In the center of Room Θ3, likely purposefully placed in a concentration in a bedrock crevice below floor level, excavators found the largest collection of cone shells (*Conus ventricosus*; n = 545) from a Late Bronze Age context in the Aegean. Many were worked and filled with lead[4,16]. There were also 12 lead objects (pellets, discoid, and conical), and pottery sherds dating up to the LH IIIA2-B1 periods (ca 1370–1230 BCE). This assemblage was interpreted as a potential gaming deposit[4].

The fossil was found in the second-deepest layer of the room deposit, higher than the crevice assemblage, and was grouped with finds recovered from the entire horizontal extent of the room (Fig. 1B). Finds included fragments of colored frescoes, blue pigment, a large lead disk, a black steatite disk, 16 clay figurine fragments, flakes of flint and obsidian, 20 conuli of colorful stone, and stone disks. Some of the artifacts were interpreted as possible markers for games, grinding surfaces to modify shells, and/or weights[4]. One pig (*Sus* sp.) tusk fragment was also noted from the room[16].

No information was published on the find-spot of the fossil, or the other finds from the same layer, relative to each other or the architectural features. The fossil was not identified as such during or after excavation. Despite the lack of specific spatial information, the artifacts and museum notes indicate that the fossil was retrieved from an undisturbed deposit. The ceramic finds from the same layer had a narrow date range from the LH IIIB2 period (ca. 1230–1200 BCE) and corresponded to a limited time frame of use for the room. The integrity of the deposit at the time of excavation is confirmed by the written description on an excavation tag surviving at the Mycenae Museum from the layer with the fossil, which we translated as: "Pottery fragments (όστρακα) of an undisturbed deposit (αδιαταράκτου επιχώσεως) from depth 1,45 from D (evidently a point from which measurements were taken) from the eastern part/sector, 8-7-74" (Fig. 2A).

Results

The fossil was originally published as (translation) "a large stone object of irregular shape, probably unfinished or broken during shaping" [Mycenae Museum BE inventory number 14242.4; Plate 86:19[5]]. Our closer examination of the shape of the preserved morphological features indicated that it was a fossilized astragalus (talus) from the left side of a two-horned rhinoceros. Meier confirmed this preliminary animal identification with Eugene Morin. Further examination by Meier noted that the superior edge of the medial trochlea, the superior-plantar border edge, and part of the dorsal surface of the lateral trochlea were not completely preserved (Fig. 2Bi-iv). The sulcus on the plantar surface and the dorsal side of the neck were partly filled by conglomerated pebbles (Fig. 2Biii). Moderate wear on the most protruding trochlear surface features had exposed lighter-colored material. This likely occurred after fossilization, possibly reflecting wear from ancient use or more recent damage.

Our initial assessment of the sustentacular facet and trochlea shape noted similarities to published images of *Stephanorhinus* (formerly *Dicerorhinus*[17], *D.* hereafter *S.*) *kirchbergensis* [formerly "*D.*" *merckii*, in Fig. 103[7] and Table XXVII[18]]. Still, the Mycenae fossil was smaller. The trochlea were asymmetrical in size and offset laterally to the neck (Fig. 2B). The observed sustentacular facet was narrow, rounded at most margins, and slightly angled towards the broad, square ectal facet.

The facets of the plantar surface were imperfectly preserved. The distal articular surface reached the distal margin of the trochlea. The attachment surface for the lateral talocalcaneal ligament was small and rounded, particularly in comparison to larger rhinocerid astragali [see[19]]. The navicular and cuboid facets on the head of the specimen were D-shaped, slightly indented, and equivalent in depth. The navicular facet was broad. The fossil morphology supported a general taxonomic identification of some variant of *S. etruscus*.

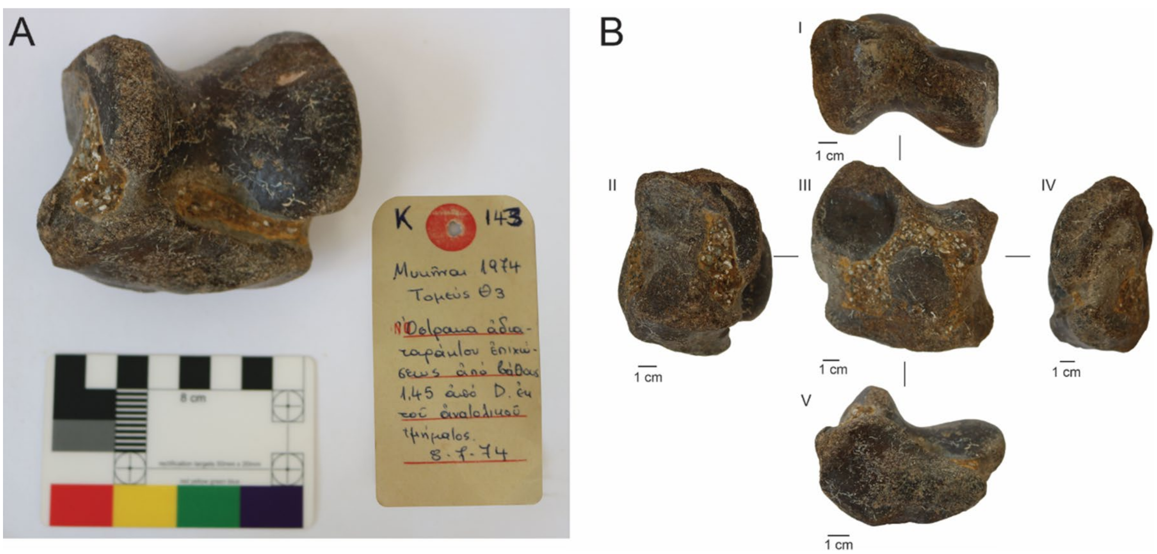

Figure 2. The rediscovered fossil astragalus from Mycenae, (**A**) posterior view with excavation tag, and (**B**) from various aspects. Photos by Meier.

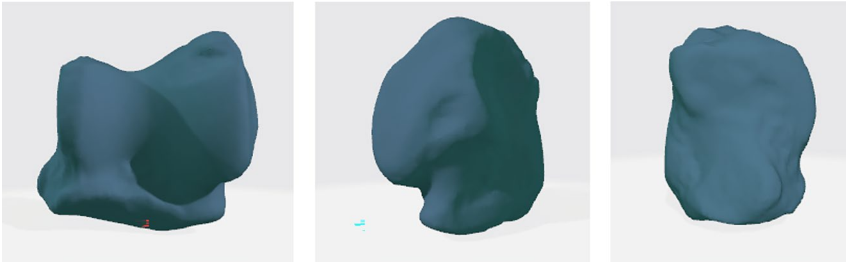

Figure 3. Fossil astragalus surface rendering model.

Further tests of the Mycenae fossil species compared measurements of its dimensions to averaged measurements of published fossil rhinoceros astragali[7]. The Mycenae fossil plotted within the PC1 and PC2 ranges for *S. hundsheimensis* [formerly *D. etruscus brachycephalus* in[7]] (Fig. 4A, Supplementary Tables S1-3). This exploratory analysis appeared to accurately predict species, as published values of a recently identified astragalus fossil from Petralona[8], identified as *D.* (now *S.*) *hemithoecus*, plotted near the average for *hemithoecus*. Yet, a published

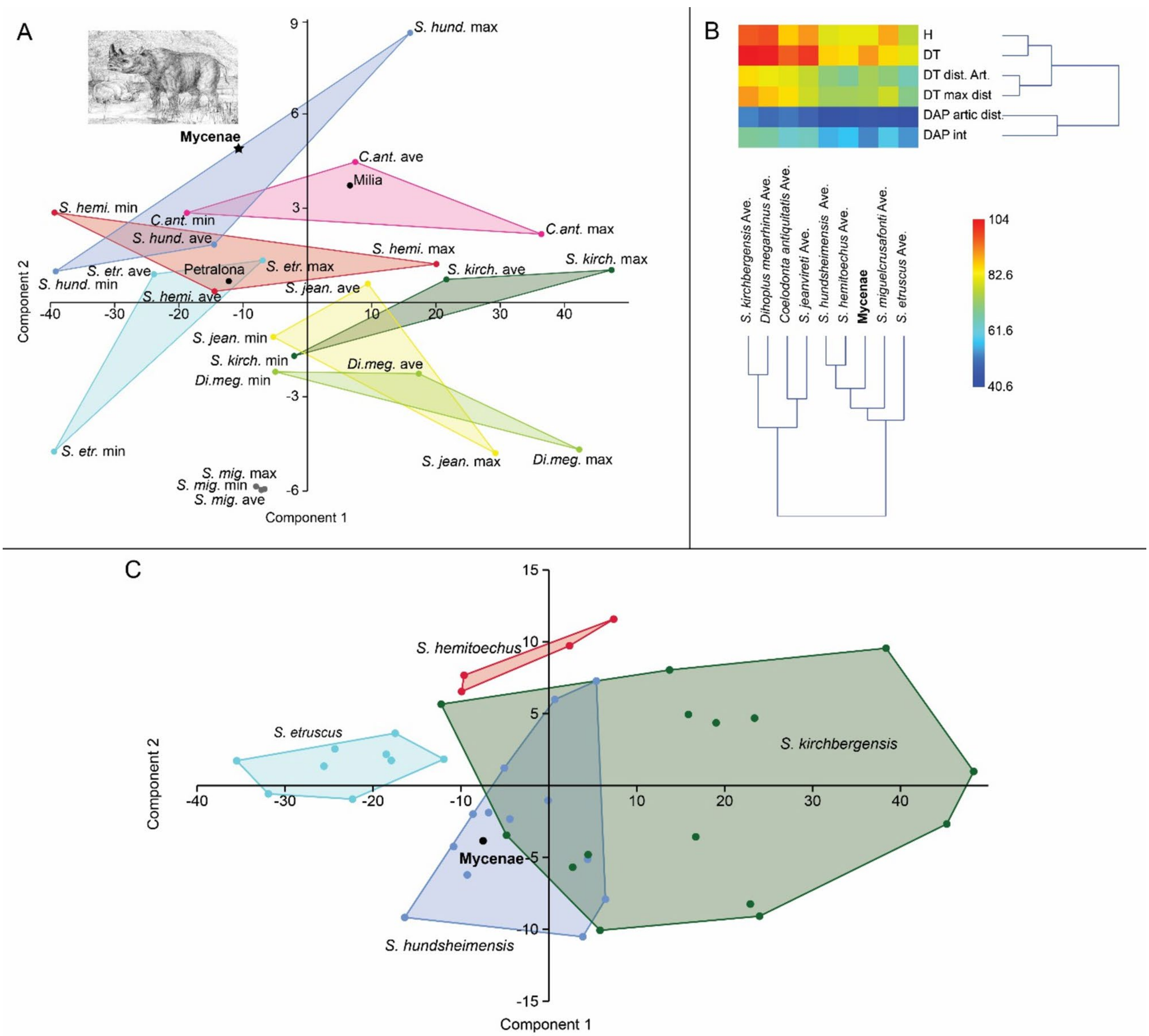

Figure 4. Results of (**A**) PCA and (**B**) two-way cluster analysis with (6) and PCA with (18). Rhinoceros drawing by Puech (with permission from the Institut de Paléontologie Humaine, Paris).

specimen from Milia[20], identified as *S. jeanvireti*, plotted within the *Coelodonta antiquitatis* range, reflecting either an updated species identification or unclear test loadings. Even so, two-way cluster analysis of the same data grouped the Mycenae fossil in a sub-clade with average values for *S. hundsheimensis* and *S. hemitoechus*, with the most variation in measurements DT (maximum transverse diameter perpendicular to the vertical axis) and H (maximum height), Fig. 4B). Another test utilized raw values for a different set of measurements taken from a selection of rhinoceros astragali fossils[17]. Once again, the Mycenae astragalus plotted within the convex hull PC1 and PC2 ranges of *S. hundsheimensis* (Figs. 3, 4C, Supplementary Tables S4-6).

Discussion

The results indicate the Mycenae astragalus was most likely from a *Stephanorhinus hundsheimensis*, or a variant species of an *S. etruscus* rhinoceros. Current paleontological research largely accepts that several likely intermediate forms existed between *S. etruscus* and *hundsheimensis*, while *hemitoechus* was a more derived species and *hundsheimensis* developed later (Middle Pleistocene)[17,21]. Paleontologists have documented fossil localities of rhinoceros species across mainland Greece, including rich deposits at Pikermi and Megalopolis[21]. Our species results reject a Miocene source, such as those in the eastern mainland or on Samos. Major localities in the Peloponnese region have yielded Early–Middle Pleistocene rhinoceros fossils, including Karnezeika (*Stephanorhinus* sp.), located in the Argolid near Mycenae and the Mycenaean sites of Tiryns, Dendra, and Midea[22]. Additional locales along a route from Mycenae to Pylos or Kalamata include Megalopolis, with remains of *Stephanorhinus* sp. and *etruscus*, Marathousa with *S. etruscus*, and Kyparíssia with *Stephanorhinus* sp.[21,23,24]. A radial-carpal bone from Kyparíssia did fall within the size range of *hundsheimensis*[23]. Still, remains of *hundsheimensis*, the likely species of the Mycenae fossil, were most securely identified in the north of Greece at the localities of Platanochori-1 and Apollonia (Early Pleistocene)[25].

Therefore, our results and the current paleontological evidence suggest one of the following scenarios. The Mycenae fossil came from the north of Greece, where *hundsheimensis* was identified, possibly arriving through distant trade. Alternatively, it was sourced nearby and would suggest that *hundsheimensis* was present in the Peloponnese[20]. Given the far- reaching trade interactions of the Mycenaeans, it could also be from a more distant locality, such as the Denizli Basin in Turkey where *hundsheimensis* mandibles were recently discovered[25].

The lack of detailed excavation records limits context-based interpretations of fossil use at Mycenae. It came from a domestic/residential area of the citadel, and this function was similar for all rooms of Building Θ. The basement room Θ3 had indirect access, limited lighting, prominent steep bedrock outcropping and a low corner bench, all features pertaining to a storeroom. Its fill material included mostly tableware pottery, a large variety of small finds, and the astragalus fossil. A large transport stirrup jar, a jug, and a tripod stone mortar were on the floor. The shell and lead assemblage were in the bedrock crevice. The lack of raw or waste materials and tools precludes craft activities. Thus, the room does not appear to reflect any specific function other than an auxiliary space possibly used for storing or hiding objects, including the fossil and reflecting domestic, elite, and/or ritual activities.

There are many possible interpretations for the social, ritual, and symbolic roles of the Mycenae fossil that center on its exotic nature. One of us (VP) considered the fossil as a possible part of the gaming assemblage, since astragali were often used as dice or for divination [e.g.[26]]. It might also represent a "zoomorphic weight"; it weighs 501 g, corresponding exactly to the ancient weight unit of one mina, and other weights were recovered from the same level[4]. It could also reflect a contagious magic object that brought luck, religious, and/or mythical essence to a user or situation[27]. This supernatural quality could have been linked to a giant mythical being, much like later associations of fossils with heroes and monsters in Greek historical times[1,2]. The Mycenae fossil, recognizable as a very large astragalus, could have contributed to the formation of a local myth, like that of the Cyclopes, the giants of later Greek mythology that were used to explain the massive Mycenae fortifications.

Mycenaeans certainly encountered bones on a regular basis, as food rubbish that was often not relegated to discrete dumps[16,28], and bone was a common raw material for crafting objects [e.g.[29]]. Thus, Mycenaeans could have recognized the fossil as a body part of notable distinction in size and weight from their local fauna. We speculate that they could have noted its similarity to a horse astragalus and perhaps associated it with horse symbolism, such as elite status, warfare or hunting, and/or a horse "mistress" or deity [see tablet PY Ea 59[30]].

Mycenae's residents also likely recognized that the fossil was old, since they often handled fresh and dry bones in funerary, dietary, and production practices. Therefore, it may have been treated like an heirloom with special importance related to its antiquity. Many artifacts recovered from contexts later than their creation evidence the importance of heirlooms at Mycenaean sites. At Mycenae, the Early Cycladic (3rd millennium BCE) marble pyxis deposited in Grave Circle B tomb Nu is a notable example[31], as are the 14th cent. BCE Egyptian faience plaques and monkey figurine, retrieved from 13th cent. contexts in the citadel[32].

Heirlooms and exotica were valued in ritual practice at the time the room deposit was formed[33] and their significance increased by the 12th century BCE[34]. The exotic nature of the fossil could have signified a link to another place, or simply denoted its special status as an heirloom from afar. Future exploration of the fossil's origin through compositional analysis may clarify its provenience. Still, this precise information may already have been lost by the time it arrived at Mycenae and may not have contributed to the meaning of fossil use.

Discovery of the fossil from a secure archaeological context confirms that collecting in mainland Greece extends back to the Late Bronze Age. Wider potential evidence suggests that this was likely not a one-off practice unique to Mycenae and hints at a shared practice of ancient animal part use in deposits laden with symbolism—one that may have been the harbinger for later Greek myths. Bronze Age examples of symbolic fossil use were found across the Mediterranean at archaeological sites in Egypt and Cyprus[1,10]. In Turkey, a fossil vertebra noted by Schliemann at Troy (estimated thirteenth century BCE), was from a Miocene cetacean[1]. Even though these cultures interacted in one of the earliest globalized economic systems that drove innovation in the Late Bronze

Age[35], the evidence for fossil collecting suggests a sustained fascination with the past. Further context-based studies of legacy collections are undoubtedly needed to understand early fossil collecting and how it relates to myths that are still popular today.

Methods

We measured the specimen and observed the shape of the preserved features from different aspects in the Mycenae Museum. A digital surface model was created with EinScan-SP technology that aligned and meshed two groups of point clouds. This facilitated detailed inspection of the surface topography through the exclusion of mineral colors to better assess surface preservation. The model allowed for replicable measurement of bone dimensions used by paleontologists and zooarchaeologists, who employ different standards.

We explored potential species identifications through tests that compared the Mycenae fossil dimensions to two sets of measurements from previously identified fossil rhinoceros astragali across Europe. The first set of measurements comprises summaries of the average, maximum, and minimum values of several dimensions. These summary statistical values are commonly referenced by paleontologists[7]. The second set of measurements was collected more recently and represented raw values from individual specimens[17]. The dimensions of the Mycenae astragalus were measured by hand and on the digital model (Fig. 3). Comparisons were explored through PCA tests (Supplementary Tables S1-6).

Data availability

Data is provided within the manuscript or supplementary information files.

Received: 25 March 2024; Accepted: 29 July 2024
Published online: 19 August 2024

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Acknowledgements

We are grateful to Dr. Alkestis Papadimitriou, Head of the Ephorate of Antiquities of Argolis, Ms. Vassiliki Papamichalopoulou, Mr. Nikos Katsoulieris, and all employees at the Mycenae Archaeological Museum, the Archaeological Society at Athens, and the Nemea Center for Classical Archaeology, UC Berkeley. This research was funded by the AIA Richard C. MacDonald Iliad Endowment for Archaeological Research (JSM). Thanks to Eugene Morin, Gordon Rakita and David Reese for help and suggestions.

Author contributions

J.S.M. and V.P. designed the research; J.S.M., V.P., and K.S. performed the research; J.S.M. and V.P. analyzed the data; J.S.M., V.P. and K.S. wrote the manuscript. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-024-68778-w.

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