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New finds from San Teodoro Cave: an updating of the Middle Pleistocene fossil record from Acquedolci (North Eastern Sicily)

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New finds from San Teodoro Cave: an updating of the Middle Pleistocene fossil record from Acquedolci (North Eastern Sicily)

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Abstract Excavations conducted in 2006 inside San Teodoro Cave (North Eastern Sicily) retrieved remains of *Hippopotamus pentlandi*, of a medium-sized, dwarf *Palaeoloxodon*, and of *Ursus* cf. *arctos*. The specimens were found under a blackish phosphatic crust, dated to about 120 ky. This stratigraphic position sets an important constraint on the arrival time of the ancestors of both *H. pentlandi* and *Palaeoloxodon* elephants in Sicily. The elephant has a size compatible with that of a female individual of the Puntali Cave representatives. By providing insights into its dimorphism, the finds contribute important new information on this still undescribed Sicilian dwarf elephant species. More in general, the San Teodoro elephant adds clues to the possible timing of the arrival of palaeoloxodon proboscideans in Sicily in the course of the second half of the Pleistocene. On the other hand, the presence of *Hippopotamus pentlandi* confirms that the species survived at least to the late Middle Pleistocene.

Keywords: insular endemism · Mammalia · paleobiogeography · Middle Pleisocene · Sicily

Introduction

Over the years, fossil remains of Pleistocene large mammals have been recovered from two deposits of different age at Acquedolci (North Eastern Sicily). The oldest lies at the base of the subvertical cliffs where the cave of San Teodoro is located (Fig. 1). It is a rich lacustrine deposit that provided thousands of remains of hippo (*Hippopotamus pentlandi*) and rare ones of deer (*Cervus elaphus siciliae*), wolf (*Canis lupus*), bear (*Ursus* cf. *arctos*), tortoise (*Testudo* cf. *hermanni*), and Aves (Bonfiglio 1992, 1995). The younger deposit extends into S.Teodoro Cave (Fig. 1) and yielded an extensive collection of mammalian fossils of a highly diversified assemblage of vertebrates, among which elephant (a new, still undescribed species of *Palaeoloxodon*, *sensu* Herridge 2010), wild ox (*Bos primigenius siciliae*), deer (*Cervus elaphus siciliae*), wild boar (*Sus scrofa*), wolf (*Canis lupus*), hyena (*Crocuta crocuta spelaea*), fox (*Vulpes vulpes*), equid (*Equus hydruntinus*), a number of small mammals (*Microtus (Terricola)* ex gr. *savii*, *Apodemus* cf. *sylvaticus*, *Erinaceus* cf. *europaeus* and *Crocidura* cf. *sicula*), invertebrates (molluscs) and plant remains.

This paper reports the first discovery of remains of *Hippopotamus pentlandi*, *Palaeoloxodon* sp., and *Ursus* inside San Teodoro Cave at the end of the 2006 stage of excavation. The new finds, which are stored at the Museo della Fauna of the Dipartimento di Scienze Veterinarie of Messina, provide further information that enables better understanding and interpretation of the events already outlined by Mangano and Bonfiglio (2005). They also contribute new insights into the characters and paleogeographic significance of *Hippopotamus pentlandi*.

The Lacustrine deposit: The limnic sediments are deposited on the inner margin of a wide terrace that extends from Cape Peloro, in north-eastern Sicily, to Acquedolci, at west and all the way south to Taormina, along the Ionian cost. The structure is situated between 150 and 60 m a.s.l. and is known as the "Grand replat" (Hugonie, 1979) or "Po" (Catalano and De Guidi 2003; Fig. 1, Fig. 2). This distinctive marker horizon forms a basis for regional correlation in north-eastern Sicily (Robillard 1975; Hugonie 1979; Bonfiglio 1987). The "Po" terrace is a multi-cycle marine deposit including two distinct erosional surfaces, named I (inner edge at about 130 m a.s.l) and II (inner edge at about 100 m a.s.l.). At Cape Peloro, Bonfiglio and Violanti (1983) described the sediments deposited over the erosional platform II, which lies between 100 and 80 m a.s.l., and consists of marine sands with *Persististrombus latus* (Gmelin 1791), originally known as *Strombus bubonius* Lamarck 1822. This species marks the last interglacial highstand in the Mediterranean; it has become an important stratigraphic marker of the marine isotope substage 5e (MIS 5.5 of Martinson et al. 1987), of the deep-sea $\delta^{18}O$ record.

At Acquedolci, the lacustrine deposits extend over the inner margin of the "Po" terrace and overlie the erosional surface I (inner edge at about 130 m a.s.l) at the base of high, vertical limestone cliffs . The vertebrate-bearing deposits, erosional platform and beach gravels are cut by the Tyrrhenian erosional platform which extends north of the lacustrine basin and whose inner margin is situated at the altitude of 105 m a.s.l. (Bonfiglio 1992). The cliffs form the outer margin of an older terrace which is covered by coarse gravel deposits. Seven trenchs cut through the coarse gravels (Fig. 2) showed that they represent the margin of a lacustrine basin which extended at the base of the cliffs from 129 to 142 m a.s.l. (Bonfiglio 1992; Mangano and Bonfiglio 2005). The deposit is therefore 13 m thick. Large clasts, both of limestone debris of a gravity flow origin from the cliffs and of very coarse to sand-sized, rounded pebbles from the older terrace, are scattered in a fine-grained, silty matrix with variable amounts of clay. The coarser fraction prevails at the base of the cliffs.

The taphonomic signatures of the vertebrate assemblages indicate that the bone beds are not winnowed accumulations of bone debris. In contrast, they include bones shed from carcasses floating across a lake and then preserved in the silty and/or detritic sediments of the lake floor. The bones show no other signs of pre-burial modification but strong shattering due to local collapse of boulders and pebbles from the cliffs (Bonfiglio 1983, 1995).

The lacustrine deposits are Ar/Ar dated to 200±40 ky (Bada et al. 1991). The sedimentary thicknesses and implied sedimentation rates, based on oxygen isotope stratigraphy, reach up to about 150 ky.

In trench C, which is located outside the entrance of the cave, the lacustrine deposits extend up to the height of 142 m a.s.l. (Mangano and Bonfiglio 2005). They appear strongly cemented; at 136 ms a.s.l. they are overlain by a bone breccia (Fig. 3), formed for the most part of bone fragments of *Hippopotamus pentlandi* removed from the highest portion of the lacustrine deposits by the water table of the lake, which penetrated inside the cave (Mangano and Bonfiglio 2005).

San Teodoro Cave: This huge cave (about 60m long, 20m wide and up to 20m high, with a total areal coverage of over 1000 sq m) has a relatively small entrance. It includes two chambers, a large, central one and a very small, lateral one. Very small, vertical shafts pierce the cave roof, through which very small size grains (about 4-5 cm) of non-carbonate debris fall into the cave from the sedimentary cover of the terrace above it.

The cave floor rises along its major axis for about 15m from the entrance to the southern end of the main chamber (Fig. 4). A pile of fine-grain gravels, sands and silt, but also of very large carbonate boulders, accumulated at the center of the floor, sloping down laterally towards the eastern and western walls of the cave. Excavations explored the cave deposits in great detail in 1998 and 2002-2006 (Bonfiglio et al. 1999, 2001; Mangano 2011; Esu et.al. 2007 ; Bonfiglio et al. 2008).

Two trenchs (α and β) have been excavated in the eastern edge of the detrital fan (fig. 4). The comparison of altitudes of cuts and specimens required a common benchmark point (quote '0') to which all measurements could be referred; it was marked on eastern side wall of the cave. The trenches exposed fine-grained, non-carbonate gravels, sands and silt, together with carbonate blocks of different sizes fallen from the cave ceiling.

Vertebrate remains were found scattered throughout all the excavated levels. The bones, mostly in fragmental state, were not articulated. Skeletal specimens were extracted from the loose sediments by wet sieving, which permitted the recovery of a number of bones of large mammals and small vertebrates (rodents, insectivores, bats, birds, amphibians and reptiles), hyena coprolites, as well as small mollusc shells and seeds.

The taphonomic signature of the assemblage is that typical of a spotted hyena den. Numerous skeletal elements (skull, teeth, limb bones) and coprolites of *Crocuta crocuta* are associated with clear evidence of hyena damage, i.e., crushing, gnawing, chewing and digestion detected on virtually all the large mammal remains (Bonfiglio et al. 1999; Marra et al. 1999). The mollusc fauna includes land and freshwater gastropods, but also bivalves, typical of the Mediterranean-European area (Esu et al. 2007). Pollen analysis of hyena coprolites from trench α indicates a glacial landscape with low percentages of mesophilous taxa typical of of temperate refugia with Mediterranean vegetation (Yll et al. 2006).

The $^{230}Th/^{234}U$ dating of a concretion interbedded with two clayey levels in trench β to 32,000 ± 4000 (Bonfiglio et al. 2008) challenges a previous Ar/Ar dating of 455 ±90 ky obtained by Bada et al. (1991) on an elephant tooth of G.G. Gemmellaro Museum's Anca collection (Palermo). Antonioli et al. (2014) had obtained a radiocarbon date of 23-21 cal ka B.P on collagene from a metacarpal bone of *Equus hydruntinus* from level B-II of San Teodoro's trench β, which lies over the $^{230}Th/^{234}U$ dated concretion (see Fig 15 in Antonioli et al. 2014).

Remains of *Hippopotamus pentlandi*, *Palaeoloxodon* sp. and *Ursus* cf. *arctos* (Fig. 5) were encountered in the eastern part trench β (depth coordinates -0,30 – 0,40). The specimens were lying under 3-4 cm of blackish, phosphatic crust (G. Vita, personal comunication). The fossils are stored in the Museum of the Fauna of the Annunziata Academic Centre of the University of Messina and have the inventory numbers from 1039 to 1043, respectively.

The fossil remains

The bones of *Hippopotamus pentlandi* include the dorso-medial half of a right trapezoid bone and the proximal half of a third right metacarpal bone (inventory numbers 1039, 1040, respectively). The former is triangular-shaped proximo-distally, with a concave surface for the scaphoid, a somewhat convex articular facet, distally, for the II metacarpal and a flatter one, laterally, for the magnum.

The proximal epiphysis of the third right metacarpal bone is incomplete, with the palmar end broken off. The specimen is quite more slender than it is in *Hippopotamus antiquus*. Proximally, the proximal end is triangular-shaped, with its typically raised lateral portion, which however, is weaker and less prominent in the third metacarpals of *H. antiquus*. The epiphysis is morphologically and proportionally similar to those of *H. amphibius* and is much narrower, latero-medially, than those of *H. antiquus*. Laterally, the proximal articular facets for the IV metacarpal is broad and roundish; the one for the uncinatum is not preserved. Medially, the two facets for the II metacarpal bone are roughly sub-triangular and differ in size, with the dorsal one being larger than the palmar one. Metrically, the proximal epiphysis and its articualr surface are, 52,5 and 45,6 mm wide, respectively.

The elephant is represented by an adult left humerus and a fragmental, juvenile fibula (inventory numbers 1041, 1042). Both bones are incomplete. In the humerus, the lateral half of the proximal epiphysis, the lateral portion of the proximal end of the diaphysis and large sections of the lateral and caudal parts of the distal epiphysis are not preserved. The rounded caput humeri is situated in the caudo-medial portion of the epiphysis. What remains of the neck is slightly constricted and separates the head and diaphysis indistinctly. Only the basal stump of the major tubercle is preserved, situated laterally to the head. The diaphysis is distinctly arcuate, with medial concavity. The crest of the major tubercle is elongated cranially; it is prominent proximally and vanishes towards the middle of the diaphysis. The crest of minor tubercle appears as a rough line on the mediocaudal surface; it ends in a slightly elongated and elevated teres major tuberosity. On the lateral side of the diaphysis, about halfway along its length, is the prominent deltoid tuberosity, in the form of a robust, elongated prominence. The musculospiral groove is deep. The lateral epicondyle must have been fairly massive, judging by what remains of it. The distal end of the bone shows what was probably a broad, shallow sagittal groove. Caudally the two epicondyles are broken. The olecranon fossa is wide and somewhat shallow. Following Herridge's (2010) measurement protocols, the diaphysis length (DL) measures 403 mm, the maximum diaphyseal width (DeltML) 99 mm, the minimum ML width (MinML) 63 mm, the minimum anteroposterior width (MInAP) 60 mm. and the head anteroposterior diameter (Head AP) is 114 mm.

The juvenile fibula is represented only by the distal 1/3 of the diaphysis. The distal epiphysis is unfused and not preserved. Distally, in lateral view, the cortical surface of the bone shows a cluster of corrosion pits (Fig. 5).

The second phalanx of *Ursus* (inventory number 1043) shows signs of gastric digestion (corrosion). It is short and robust, somewhat flattened dorso-ventrally, and wider latero-medially at the proximal end than at the distal one in dorsal and ventral view. The prominence on the dorsal margin of the proximal epiphysis is eroded. Proximally, the proximal articular surface shows a roughly semicircular outline. Dorsally and ventrally, the distal articular surface shows a slightly concave margin. The dorsal face of the distal epiphysis shows two deep, symmetrical fossae for the extensor digitorum tendons.

Discussion

The fossiliferous deposits in San Teodoro Cave are situated at the same altitude of the zero benchmark which is at about 153 ms a.s.l. Outside the cave the deposits slope down to the minimum altitude of 130 m a.s.l..The lacustrine deposits therefore reached a total thickness of about 23 m, when all the cave was flooded by the lake water. The present, very small cave entrance (Fig. 6) was perhaps modified and reduced by a tectonic collapse of a portion of the cave; a block of limestone, probably detached from the rock wall overhanging the entrance lies on top of the lacustrine deposits at 142 m a.s.l.. The lacustrine deposits inside the cave were probably truncated by an erosive episode related to the regional low-stand due to the late Middle Pleistocene uplift of North Eastern Sicily. This erosional phase gave origin to the bone breccia (Fig. 3) largely formed by bone fragments of *Hippopotamus pentlandi*. The 200±40 ky or about 150 ky age of the lacustrine deposits and the 32,000 ± 4000 a of the trench β concretion give an interval of about 120 ky for the blackish phosphatic crust.

The two hippopotamus remains with the morphological features and sizes typical of equivalent bones of *Hippopotamus pentlandi* confirm the presence of this species in Sicily in the late Middle Pleistocene. Even more significant is the occurrence of the elephant. Metrically, the humerus is larger than the small-sized dwarf elephants from Spinagallo Cave and the medium-sized ones from Luparello Cave, and smaller than the medium-sized elephants from Puntali Cave, which Herridge (2010) attributed to male individuals. It falls in the fields of variation of male specimens of the medium-sized dwarf elephant *Palaeoloxodon tiliensis* from Charkadio Cave, Tilos. These observations lead to two possible options for the taxonomic identification of the San Teodoro humerus: 1) it signals a broader geographical distribution of *P. tiliensis* than previously believed; 2) it was a female of the Puntali Cave elephant. The former alternative is hardly imaginable, because *P. tiliensis* was never reported outside Tilos. The much more credible second option would make an important contribution to our knowledge, providing new insight into the dimorphism of this still undescribed Sicilian dwarf elephant species.

The new fossils from San Teodoro Cave indicate that the cave deposits are stratigraphically near the hippopotamus-bearing deposits of San Ciro Cave (Scinà 1831) and Puntali Cave, where Petronio (1995) recovered numerous remains of *H. pentlandi* under the celebrated elephant bone-bed. The new data from San Teodoro confirm that numerous caves of the carbonatic massifs were flooded by lakes during the Middle Pleistocene, when elephants were starting to include Sicily in their geographical distribution.

Conclusion

Acquedolci is celebrated for its highly fossiliferous lacustrine deposits, which were also discovered inside San Teodoro Cave. New finds from the cave, found under an around 120-ky-old phosphatic crust, yield very significant new information in the timing of arrival of faunal communities in Sicily in the course of the second half of the Pleistocene. *Hippopotamus pentlandi* is assumed to have derived from *H. amphibius* already during the late Middle Pleistocene (Accordi 1955; Caloi and Palombo 1983). The presence of *H. pentlandi* earlier than the time set by San Teodoro's phosphatic crust provides an important time constraint on the arrival of the ancestors of *H. pentlandi*. Considering the greatest Middle Pleistocene sea-level excursions (134 m to 122±9 m below present sea level - BPSL in MIS 10; 120±8m BPSL in MIS 8; 125±6 m BPSL in MIS 6: Murray-Wallace and Woodroffe 2014), and the absence of any sign of *H. amphibius* from Europe before the late Middle Pleistocene, the ancestor of *H. pentlandi* may have reached Sicily at the time of the MIS 6 or MIS 8 sea-level lowstands, which means around 250 Ma or 150 Ma BP.

The Middle Pleistocene sea-level excursions also set important time constraints on the timing of arrival of ancestral *Palaeoloxodon* in Sicily. In contrast to *Hippopotamus ampibius*, *Palaeoloxodon* elephants distributed into Europe already since the earliest Middle Pleistocene and likely reached Sicily long before hippopotamuses. Besides the time periods listed above, other possible ones for the arrival of elephants in Sicily may include MIS 12, ~440 ka, when the sea-level dropped to 139±11 m BPSL, or MIS 10, when the sea-level lowered to 134 m - 122±9 m BPSL. Pinpointing when palaeloxodons distributed into Sicily would be an interesting addition to our knowledge of how rapidly these formidable pachyderms responded to new environmental challenges. in any case, by further enriching the already long list of dwarf elephants endemic to the Mediterranean islands, the San Teodoro find confirms that *Palaeoloxodon* elephants had pronounced tendency to endemize in restricted, insular circumstance.

Ethical statement/conflict of interest

In my name and on behalf of my co-authors as corresponding author, I certify that **ALL** of the following statements are correct.

The manuscript entitled "New finds from San Teodoro Cave: a modified picture of the Middle Pleistocene fossil record from Acquedolci (North Eastern Sicily)" represents valid work; neither this manuscript nor one with substantially similar content under my authorship has been published or is being considered for publication elsewhere.

I certify that every author of the manuscript has made substantial contributions to **ALL** of the following aspects of the work:

- Conception and planning of the analysis and interpretation of the data that led to the manuscript; ***AND***
- Drafting of the manuscript; ***AND***
- Approval of the final submitted version of the manuscript.

I certify that my co-authors and I fulfill **ALL** of the above criteria for authorship.

In my name and on behalf of my co-authors as corresponding author, I certify that we have all participated sufficiently in the work to take public responsibility for the entire content of the manuscript.

In my name and on behalf of my co-authors as corresponding author, I certify that all financial and material support for the conduct of this study and preparation of this manuscript is clearly described in the Acknowledgements section of the manuscript.

In my name and on behalf of my co-authors as corresponding author, I certify that we have had no relationships with entities that have a financial interest in the subject matter discussed in this manuscript.

In faith,

Paul Mazza

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Figure captions

Fig. 1 San Teodoro Cave. **a** Location of the site in Sicily. **b** Location of the two deposits of different age at Acquedolci. The oldest lies at the base of the subvertical cliffs (arrow), the youngest extend inside San Teodoro Cave (cave opening in the square)

Fig. 2 Trenches. Location of the seven trenches dug in the detrital fan that is outspread outside San Teodoro Cave; trench C extends outside the cave opening

Fig. 3 Trench details. **a** Profile of San Teodoro Cave's floor from the entrance (sq. 1) to the inner of the cave and location of the excavated trenches with correlation of the stratigraphic units. The cross indicates the landmark (quote '0'). The numbers indicate the distance (m) from the entrance. C = unit C; R = recent level. **b** Bone breccia, largely formed by bone fragments of *Hippopotamus pentlandi* removed from the highest portion of the lacustrine deposits and accumulated by the water table of the lake, which penetrated inside the cave

Fig. 4 Inner part of San Teodoro Cave. **a** The floor rises for about 15m along its major axis from the entrance to the southern end of the main chamber. **b** the left humerus of *Palaeoloxodon* sp. *sensu* Herridge (2010) as it was found in the blackish phosphatic crust. The arrow shows the location of the square in which the remains of *Palaeoloxodon* sp., *Ursus* cf. *arctos* and *Hippopotamus pentlandi* were found

Fig. 5 New fossil finds. **a** *Palaeoloxodon* sp. *sensu* Herridge (2010), left humerus: 1., cranial view; 2. lateral view; 3. caudal view; 4. medial view. **b** *Palaeoloxodon* sp. *sensu* Herridge (2010), left fibula, lateral view. **c** *Hippopotamus pentlandi*, third right metacarpal bone: 1, lateral view; 2, dorsal view; 3, proximal view; 4, medial view. **d** right trapezoid bone: proximal view. E, *Ursus* cf. *arctos*, second phalanx: 1, dorsal view; 2, proximal view. Bar scale 10 cm for a-c; 1 cm for d-e

Fig. 6. San Teodoro Cave entrance.

Fig. 1

a

b

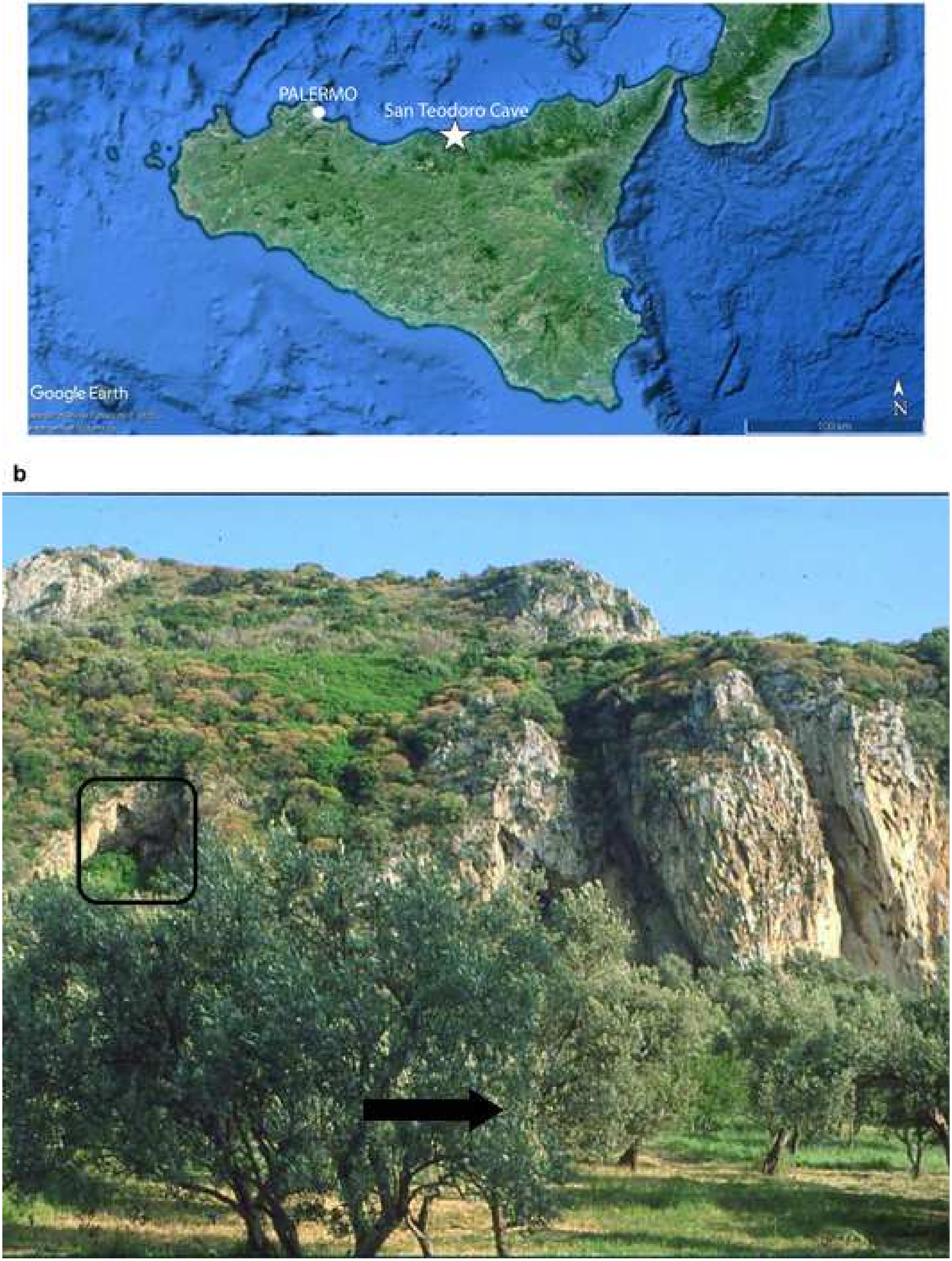

Fig. 2

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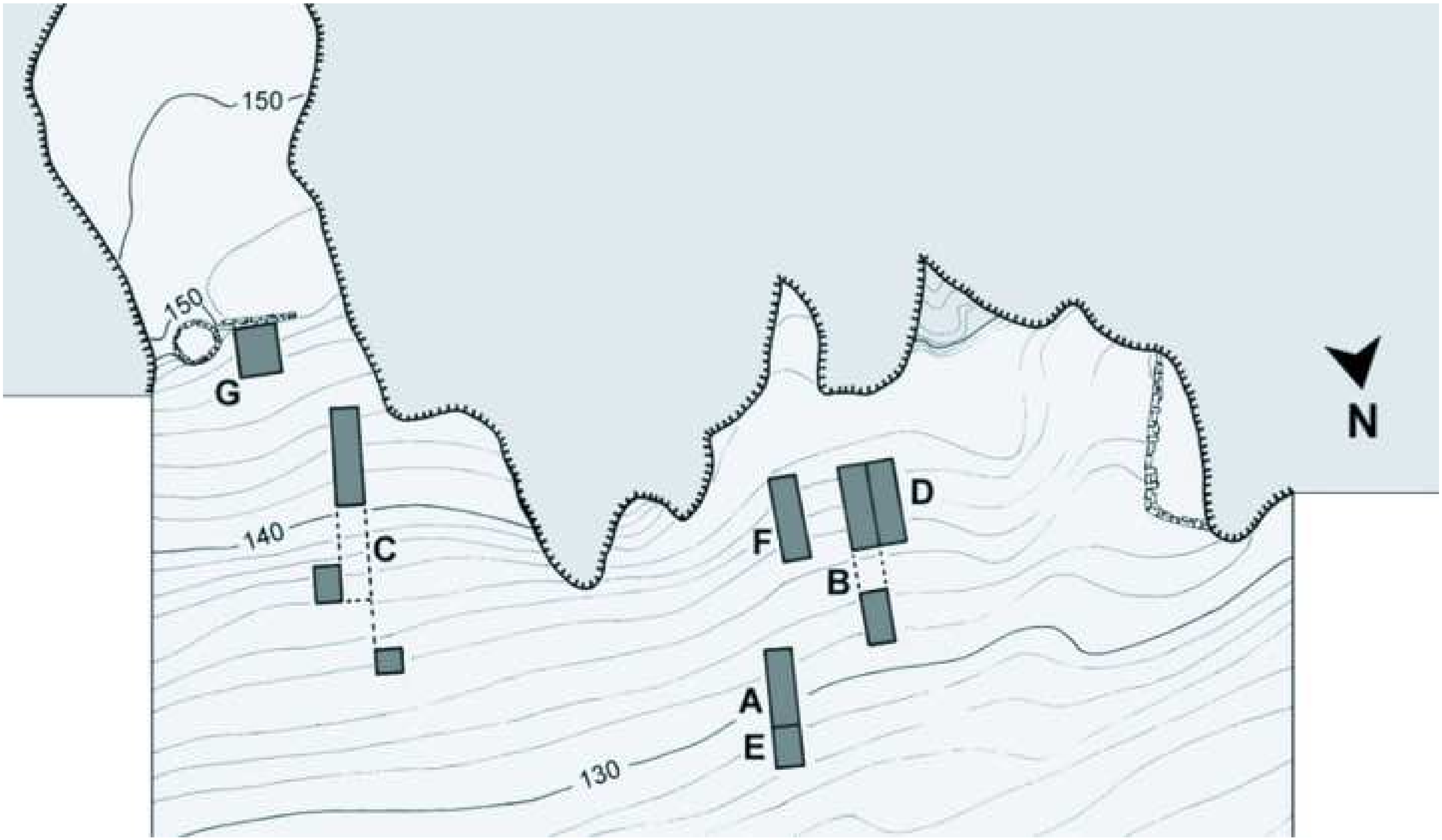

Fig. 3

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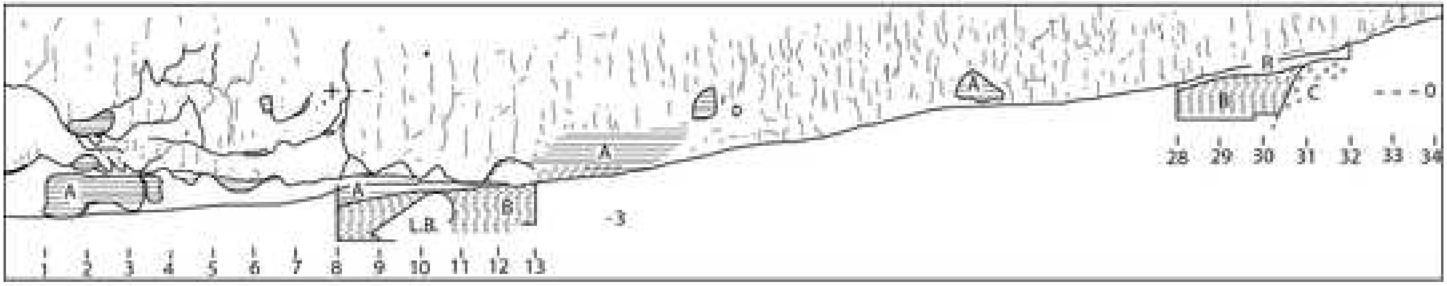
a



b

Fig. 4

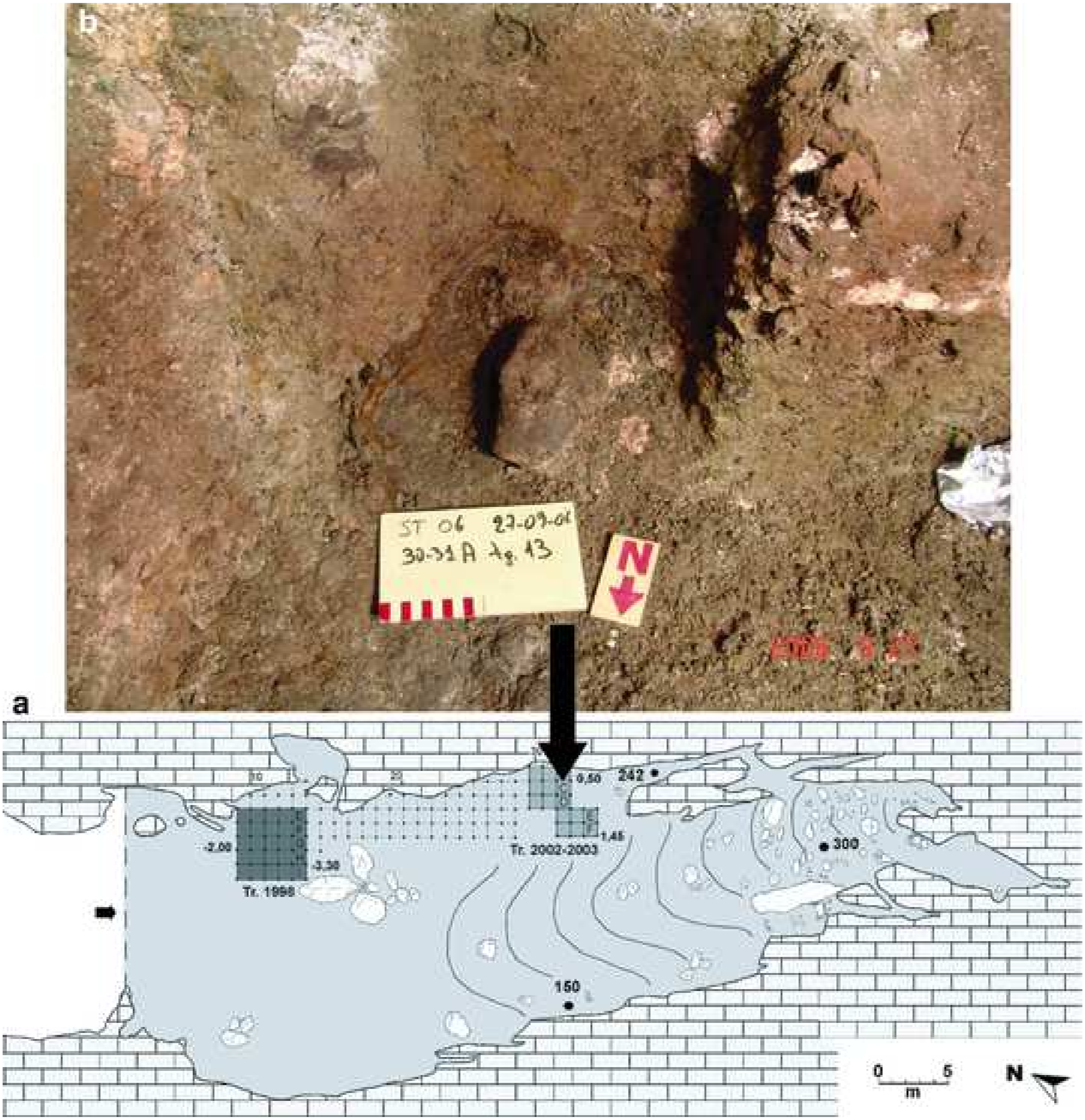


Fig. 5

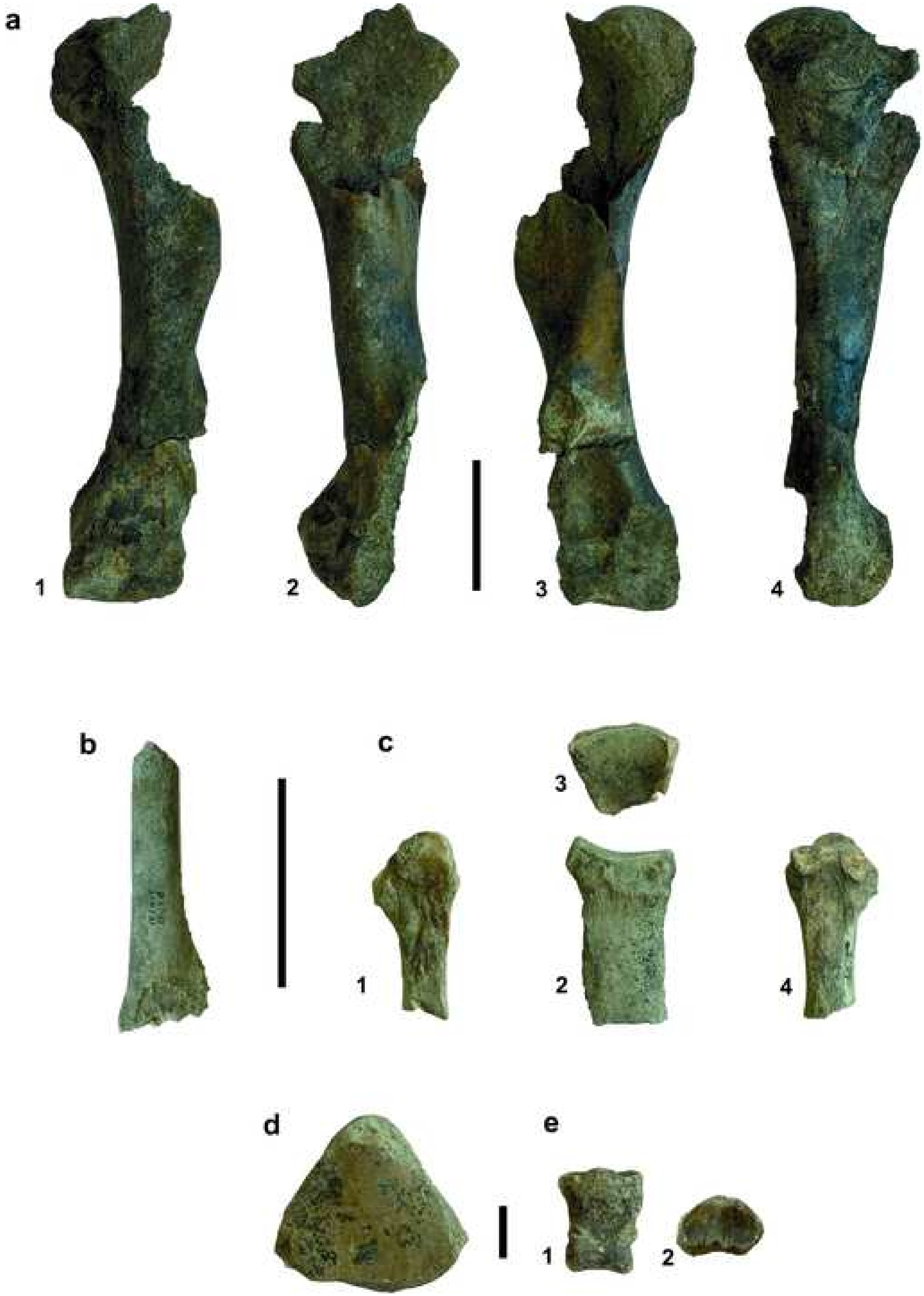


Fig. 6

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Cover letter