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VERTEBRATE TRACKS IN LATE PLEISTOCENE–EARLY HOLOCENE (?) CARBONATE AEOLIANITES, PAPHOS, CYPRUS

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Abstract: In 2005, numerous vertebrate tracks were discovered in carbonate aeolianites in and around the town of Paphos, in the southwestern part of Cyprus. The main track-bearing exposure is located in a protected archaeological site near the Agia Solomoni Church inside the city of Paphos, where cross-sections through tracks are abundant in vertical exposures of the aeolianite along Apostolou Pavlou Avenue. Some exposures show as many as 10 tracks per m^2 of vertical exposure. Several additional tracks were found in the extensive subterranean tomb complex, the Tombs of the Kings, just outside Paphos. The aeolian deposit was formed when westerly to southwesterly winds drove fine- to medium-grained calcareous sand onshore from the beach. This generated low coastal dunes, represented by 1–2-m-thick, cross-bedded sets made up of grainflow and wind-ripple strata, and sand sheets composed entirely of wind-ripple strata. The sediment does not yet have an absolute date, but is considered to be of Late Pleistocene to Early Holocene age, as are many other coastal aeolianites in the Mediterranean area. The Late Pleistocene endemic fauna in Cyprus was limited to the dwarf hippopotamus *Phanourios minor* Desmarest, 1822, the dwarf elephant *Elephas cypriotes* Bate, 1902, a small carnivore *Genetta plesictoides* Bate, 1903, and (possibly) humans. The exposed tracks are 5–15 cm in diameter, with a few tracks up to 23 cm in size. This range of size correlates well with the estimated foot size of dwarf hippopotami and dwarf elephants. This low-diversity, endemic island fauna provides a unique opportunity to correlate tracks with trackmakers.

Key words: Cyprus, aeolian, footprints, probocideans, hippopotamus, insular dwarfism, track preservation.

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INTRODUCTION

Carbonate aeolianites are known from a number of areas in the Mediterranean region. Many of these Late Pleistocene and Holocene aeolianites contain vertebrate tracks. Important sites comprise localities on Mallorca, Sardinia, and Rhodes. Well exposed outcrops of Middle and Late Pleistocene aeolianites have been known on Mallorca since the classical works of Butzer and Cuerda (1962). Work by Clemmensen *et al.* (1997), Clemmensen *et al.* (2001), Fornós *et al.* (2002, 2009), Nielsen *et al.* (2004), has shown that the aeolian deposits formed in a variety of coastal-plain settings, including cliff-front and distal alluvial-fan environments; locally extensive cliff-top aeolian systems were also developed by dunes that migrated far inland. Many of the aeolianites contain tracks and trackways of the ruminant goat *Myotragus balearicus* Bate, 1909 (Fornós *et al.*, 2002). Tracks are seen on bedding planes and as small-scale deformation structures in vertical sections. Aeolianites also crop out abundantly along the shores of western and northwestern Sardinia. These aeolianites are primarily of Middle and Late Pleistocene age (Andreucci *et al.*, 2010ab; Pascucci *et al.*, 2014), but rather loosely cemented carbonate aeolianites of Holocene age are present locally (Andreucci *et al.*, 2014). Most of the aolianites formed on coastal plains, backed by cliffs or low hills, or in front of valley-heads. Rare tracks and trackways of "*Praemegaceros" cazioti* Depéret, 1897, (Artiodactyla, Cervidada) are seen (Fanelli *et al.*, 2007). On Rhodes, track-bearing aeolianites of Late Pleistocene to Holocene age were described by Milàn *et al.* (2007). The ae-

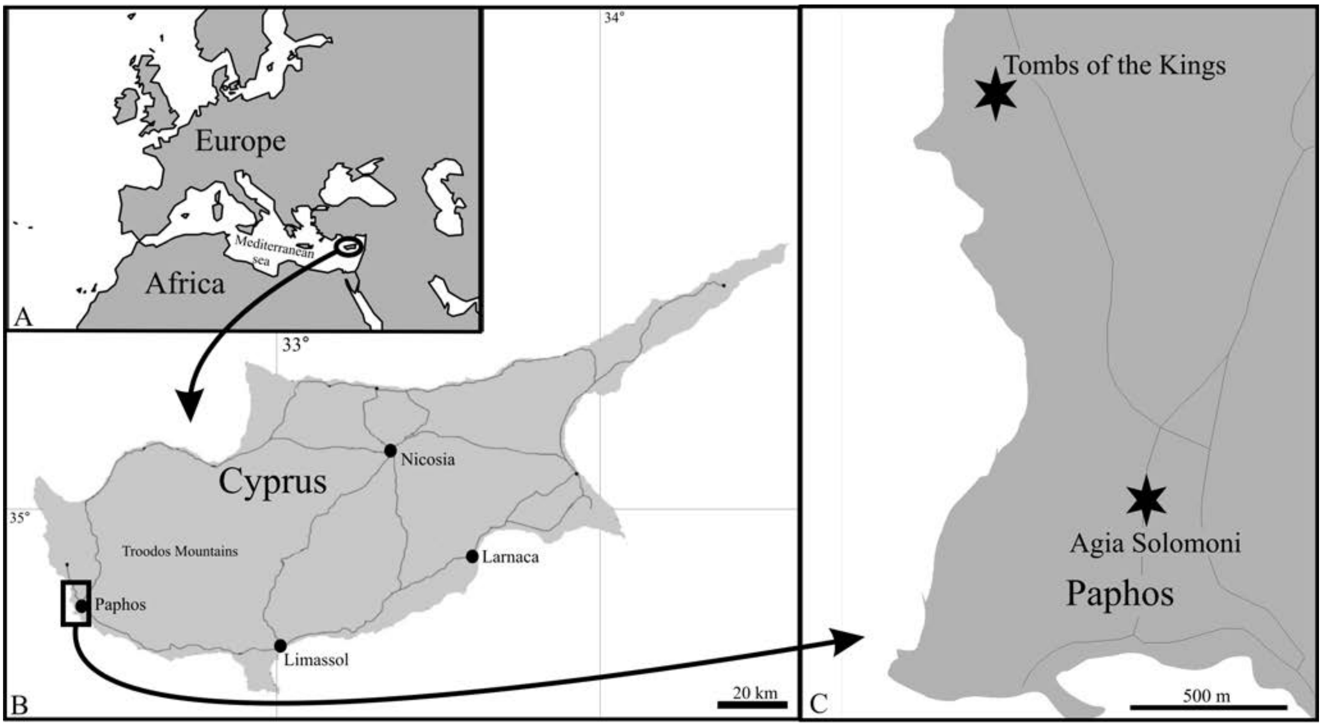

Fig. 1. Location map. **A.** The Island of Cyprus is located in the eastern part of the Mediterranean Sea, just south of Turkey. **B.** Map of Cyprus. Paphos is located on the southwestern end of Cyprus. **C.** City map of Paphos with the two track-bearing localities indicated.

olian deposits of Rhodes form a local sand-ramp accumulation and contain ichnological evidence of a diverse vertebrate fauna, comprising footprints made by medium-sized endemic elephants, artiodactyls and camels.

In 2005, numerous tracks were discovered by Theodorou (Project UOA Research account 7093 and 3370) in aeolianites in and around the town of Paphos in the southwestern part of Cyprus (Theodorou *et al*., 2005). The main track-bearing exposure is located in the protected archaeological site near the Agia Solomoni Church, inside the city of Paphos (Fig. 1), where cross-sections through tracks are abundant in the vertical exposures of the aeolianite. Some exposures show as many as 10 tracks per m^2 in exposed vertical sections of the aeolianite. Several additional tracks were found in the extensive subterranean tomb complex, the Tombs of the Kings, just outside Paphos (Fig. 1). The aim of this study is to present a preliminary description of the abundant vertebrate tracks found in the aeolianites in the area in around Paphos, southwestern Cyprus and to link them to potential trackmakers.

TRACK TERMINOLOGY

Fossil and subfossil animal tracks are most easily recognized, where they are exposed on bedding planes representing the original tracking surface. But, as tracks are three-dimensional, structures that commonly deform the original sedimentary fabric to considerable depths below the original tracking surface, it is possible to recognize tracks in vertical sections or random erosional cuts through bedding (Loope, 1986; Allen, 1989, 1997; Lea, 1996; Fornós *et al.*, 2002). The original sedimentary surface where the animal trod is termed the "tracking surface" *sensu* Fornós *et al.* (2002), and the animal responsible for the track is the trackmaker. The direct impression of the trackmaker's foot into the tracking surface is termed the "true track" (Lockley, 1991). The force of the trackmaker's foot not only deforms the tracking surface, but is transferred radially outward into the surrounding sediment, causing deformation of the subjacent layers as well (Allen, 1989, 1997). The deformation structures in the layers subjacent to the true track at the tracking surface are termed "undertracks" (Lockley, 1991). Undertracks preserve less detail than true tracks; they become successively shallower and wider and preserve successively fewer anatomical features downward (Manning, 2004; Milàn and Bromley, 2006, 2008; Jackson *et al.*, 2010). The radial pressure of the foot further creates a "marginal ridge" of displaced sediment around the tracks.

In tracking substrates of a consistency that allow the trackmaker's foot to penetrate the surface and sink down into the substrate, the foot can create vertical or inclined walls from the bottom of the true track to the tracking surface, termed trackwalls (Brown, 1999) or shafts (Allen, 1997). When the trackwalls are inclined, the track at the surface appears wider than the true track at the bottom of the track and is termed the "overall track" (Brown, 1999). When tracks are emplaced in dry, loose sediments, the trackwalls collapse on removal of the foot, thus destroying the shape of the true track; in extreme cases, only a bowl-shaped depression on the sediment surface is left. If the track subsequently is covered by several thinner layers of sediment, the layers will drape the contours of the track and

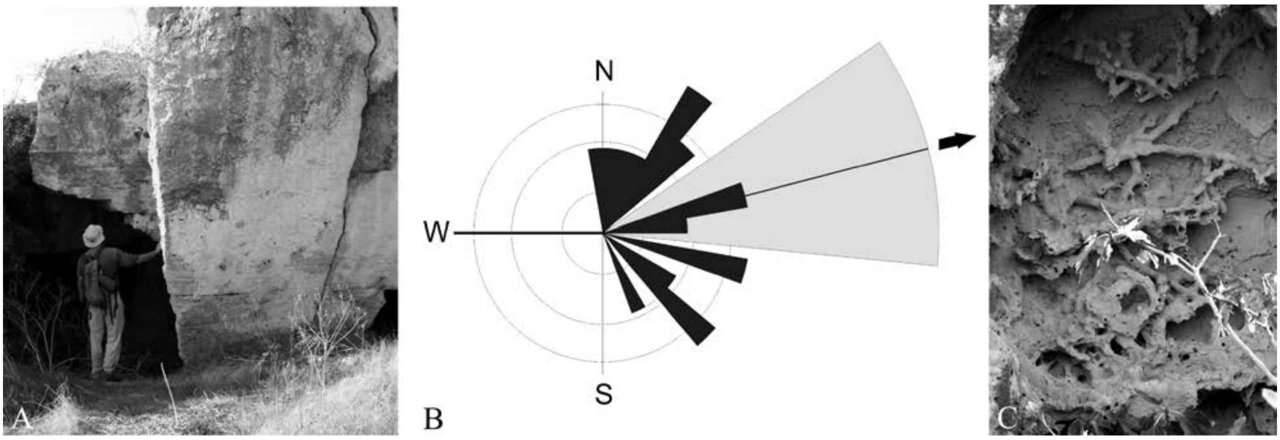

Fig. 2. Aeolian outcrop at the Agia Solomoni archaeological site in Paphos. **A.** Exposed section of the aeolianite, at the entrance to one of the subterranean burial chambers. **B.** Rose diagram of dune cross-bed dip directions showing that the dunes were formed by sand, transported onshore by south-westerly winds. **C.** Section of the aeolianite with abundant rhizoliths.

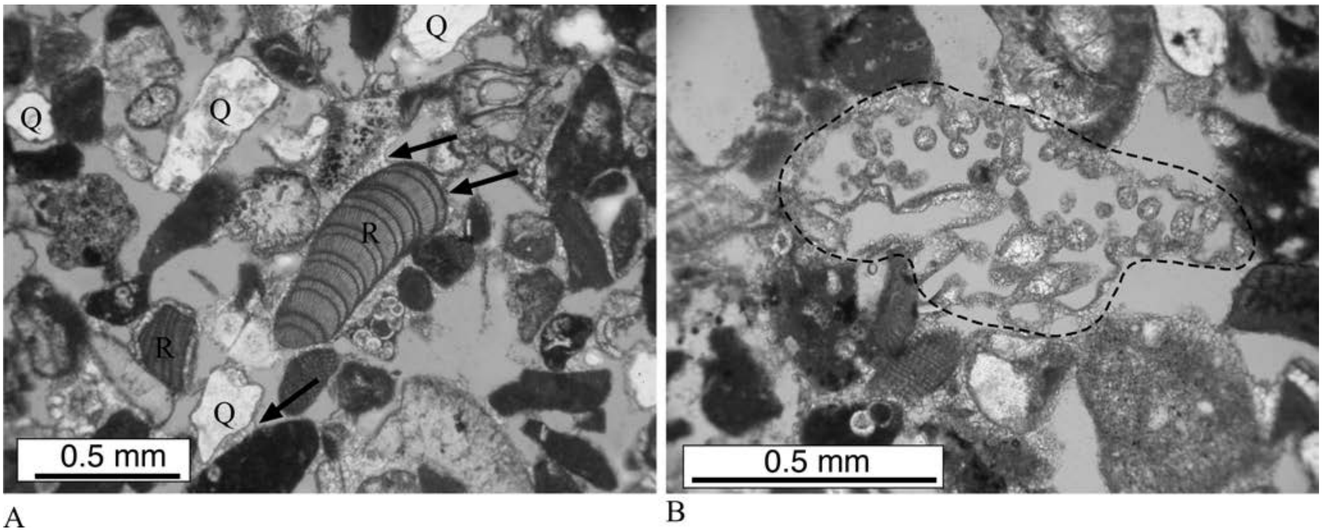

Fig. 3. Photomicrograph of aeolianite. **A.** Quartz grains (Q) and diverse bioclasts, including red algae (R), are visible. Meniscate calcite cement (arrows) is concentrated at points of grain contact, and was precipitated above the water table (within the vadose zone). Cementation post-dates track formation. **B.** Micrite envelope around a former aragonite grain (dashed line). The aragonite was dissolved after aeolian transport of the grain and its burial within the dune. Percolating meteoric water dissolved the aragonite, leaving only its outline and the tubes within it that had already been coated by small calcite crystals. Aragonite is more soluble than calcite and is commonly dissolved during early freshwater diagenesis.

can form a shallowing-upward, stacked sequence of "ghost tracks" *sensu* Fornós *et al.* (2002). If observed on horizontal surfaces, these ghost tracks may be misinterpreted as undertracks.

SEDIMENTOLOGY

The aeolianites of Paphos consist of 1–2-m-thick cross-bedded sets of both grainflow and wind-ripple strata, dipping towards the south-west (Fig. 2A, B), and sand sheets characterized by flat-bedded, wind-ripple strata. Rhizoliths larger than 1 cm in diameter are abundant (Fig. 2C), indicating that woody plants partially stabilized the dunes. The sediment consists of fine- to medium-grained calcareous sand, which was blown onshore from the beach, generating low coastal dunes and aeolian sand sheets.

Thin-sections of the aeolianite reveal meniscate calcite cements (Fig. 3A) as well as abundant micrite envelopes (Fig. 3B). The track-bearing aeolianite does not yet have an absolute date, but is considered to be of Late Pleistocene to Early Holocene age, as are many other coastal aeolianites in the Mediterranean area (e.g., Fornós *et al.*, 2009; Andreucci *et al.*, 2010b; Pascucci *et al.*, 2014). This age is supported by the fact that no Pliocene or Early Pleistocene mammals are known from Cyprus.

TRACK EXPOSURES

Agia Solomoni site

The main locality is within the city of Paphos, by the Agia Solomoni Church, and is a subterranean cemetery, carved into the aeolianites. All the observed tracks are found

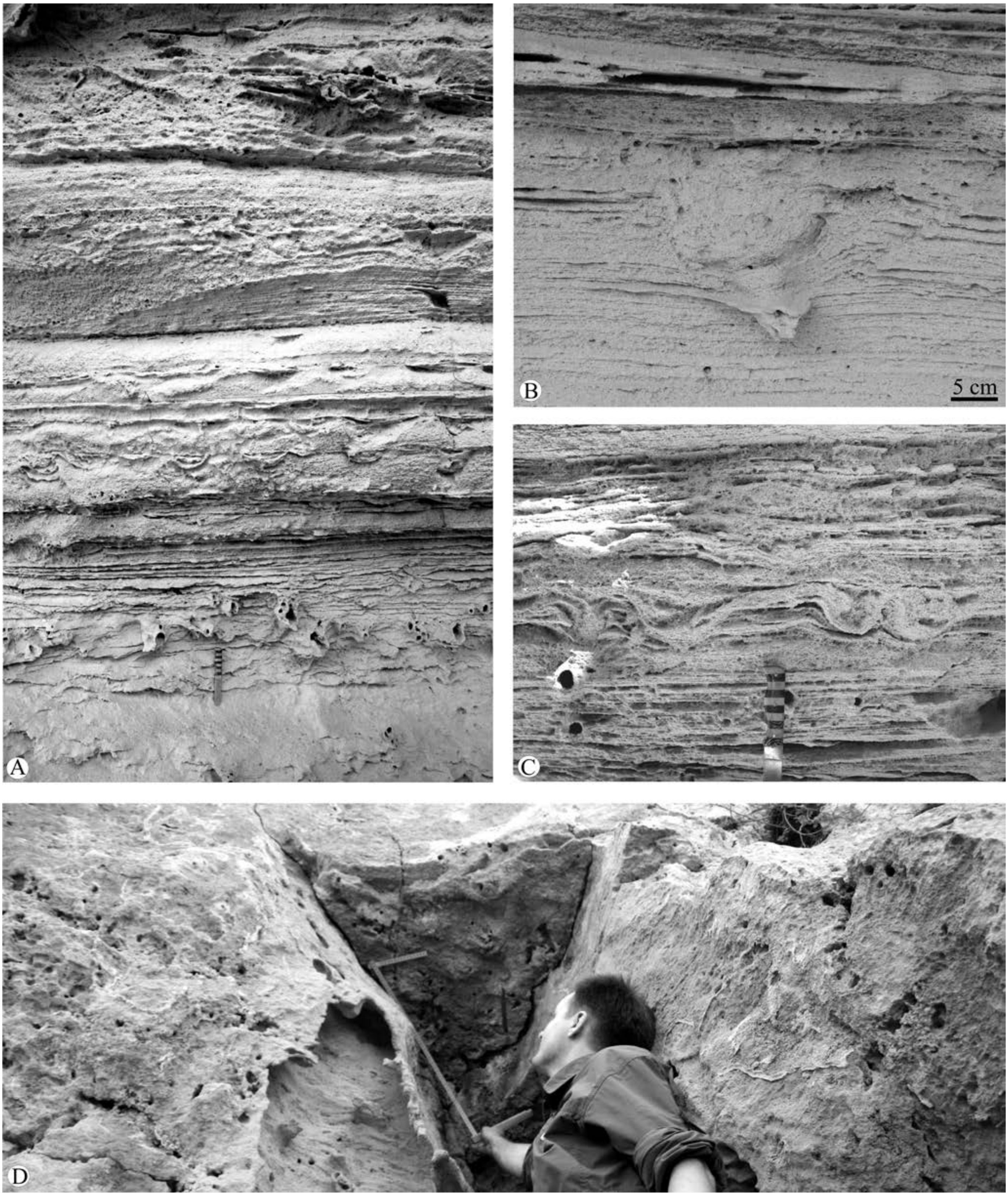

Fig. 4. Tracks at the main exposure at Agia Solomoni. **A.** Exposed section of the aeolianite showing abundant horizons with tracks and rhizoliths. **B.** Single tracks, showing homogenous infilling. **C.** Horizon with two pairs of partly overlapping tracks. **D.** Several tracks exposed at the base of overhanging bed.

exposed in vertical sections in the aeolian outcrops and appear as flat-bottomed, bowl-shaped depressions in the laminated sand sheets. Some exposures show as many as 10 tracks per m^2 of vertical section (Fig. 4A–C). At some horizons, the tracks appear at evenly spaced intervals (Fig. 4A), and along other horizons, tracks appear in pairs that partly overstep each other (Fig. 4B). Horizontal exposures of the tracking surfaces were not encountered at any locality.

However, an overhanging part, showing the natural cast of a partial tracking surface, revealed the contours of a number of tracks, preserved in positive epirelief below the overhang (Fig. 4D). The exposed track casts, however, are only preserved as bowl-shaped casts and do not reveal any anatomical details of the trackmakers' feet.

At the main exposure along Apostolou Pavlou Avenue, a total of 87 tracks were measured, and their dimensions plotted against their frequency (Fig. 5). The majority of the tracks were between 4 and 16 cm in diameter, with single tracks up to 23 cm in diameter.

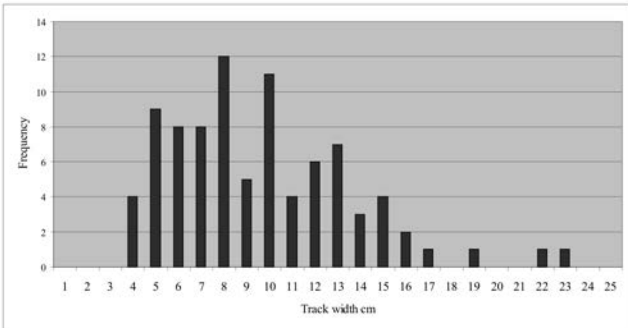

Fig. 5 Graph showing the frequency of the tracks and their measured diameters.

The Tombs of the Kings

A second locality with tracks was found 2 km northwest of Paphos harbour at the UNESCO World Heritage Site, the Tombs of the Kings (Fig. 1). The Tombs of the Kings are an extensive subterranean cemetery dating back to 300 BC, where all the graves have been carved out of the relatively soft aeolianite. This has created a large number of clean, well-exposed vertical surfaces in the aeolianite. The tracks are less abundant here than at the main locality in Paphos, and only single tracks were encountered, except at one surface in the atrium of tomb number 6 (Hadjisavvas, 2011), where two consecutive tracks were observed in the same horizon (Fig. 6).

DISCUSSION

All the observed tracks appear in the sand-sheet deposits and the infilling of the tracks is most commonly homogenous and structureless, which shows that the infilling of the tracks occurred rapidly after the tracks were emplaced. On the basis of the analysis of the sediment and the presence of numerous rhizoliths, the authors interpret the tracks to have been made on a low-relief landscape composed of partly vegetated, small dunes and aeolian sand sheets. Although dissolution of aragonitic skeletal material led to rapid lithification by vadose calcite, the tracks must have been emplaced in uncemented sand quite soon after its deposition.

The sizes of the tracks range from 4 cm to 23 cm in diameter, with the majority between 5 and 15 cm in diameter. However, when measuring diameter in vertical sections of tracks, the measurement obtained must be regarded as a minimum diameter, as it often is impossible to see if the section is through the middle of a track (the true diameter), or a tangential section (a smaller diameter).

Possible trackmakers

The endemic Late Pleistocene–Holocene fauna of Cyprus, based on skeletal remains, is limited to very few species and a close correlation between tracks and trackmakers should be possible. Dwarf elephants and dwarf hippos have been documented on Cyprus from Late Pleistocene layers at Aetocremnos during the excavations carried out by A. Sim-

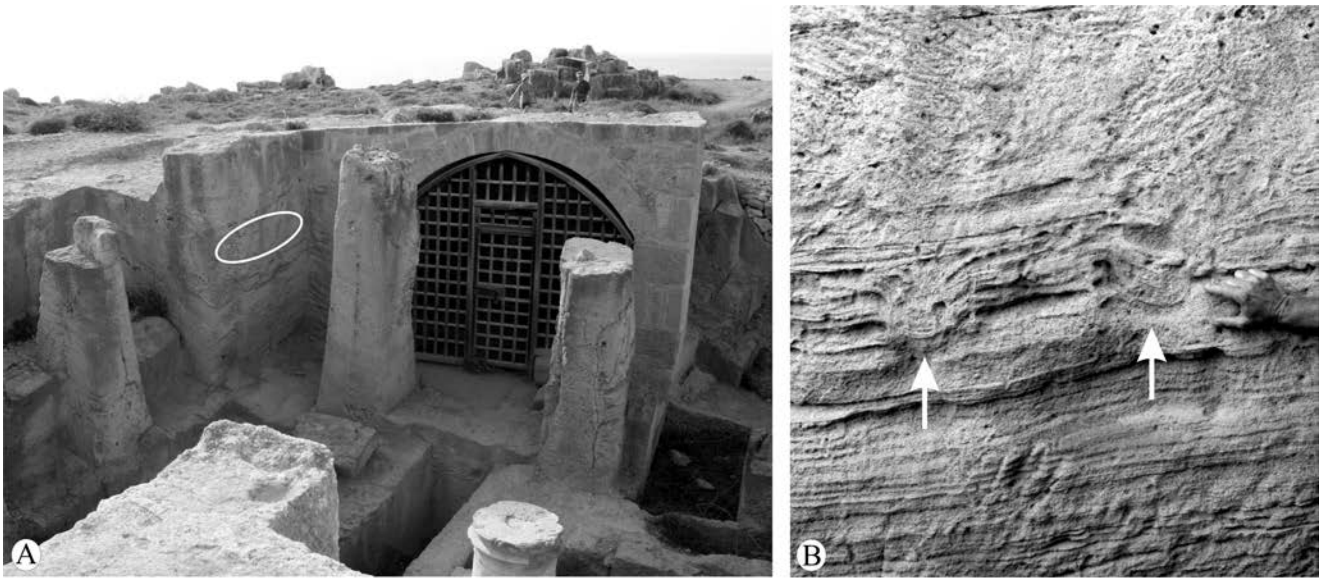

Fig. 6. Tracks from the UNESCO World Heritage Site, the Tombs of the Kings. **A.** Tracks found in the walls at the atrium of tomb number six, indicated by white circle. **B.** Close-up of the two tracks, circled in A.

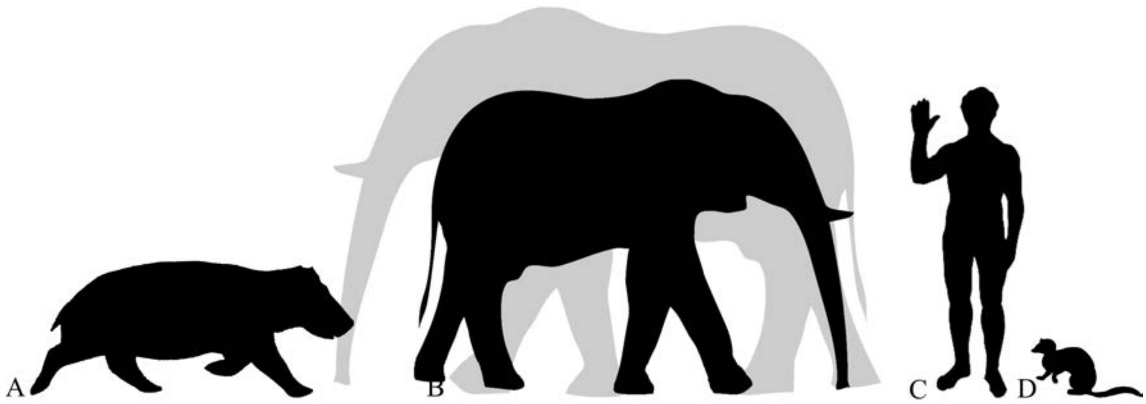

Fig. 7. Silhouettes of the possible trackmakers from the limited endemic fauna of Cyprus. All drawn to the same scale. **A.** Dwarf hippopotamus, *Phanourios minor*. **B.** Dwarf elephant, *Elephas cypriotes*, with the possible larger species indicated in lighter grey. **C.** Human, *Homo sapiens*. **D**. Genet, *Genetta plesictoides*

mons in the 1990s and at Agia Napa since 2001 by ongoing excavations by G. Theodorou. Both sites have brought to light an endemic fauna composed of abundant hippos, *Phanourios minor* Desmarest, 1822, and scarce elephant bones (Theodorou *et al.,* 2007a).

Bate (1903, 1905) documented the occurrence of a very small elephant, *Elephas cypriotes* Bate 1902, the fossils of which have been collected at numerous sites all over Cyprus (Reese, 1995). However, the possibility of the occurrence of a larger elephant was discussed as early as 1929 by Vaufrey (1929). Later authors also mentioned the possibility of the existence of a larger elephant at Achna (Boekschoten and Sondaar, 1972). The existence was first confirmed in 2005, when a unique elephant skull was excavated by the National Kapoditstrian University of Athens in collaboration with the Geological Survey of Cyprus on the Xylofagou coast (Theodorou *et al.*, 2005). The material from Xylofagou and Aetocremnos is comparable with the dimensions of *E. tiliensis* Theodorou *et al.*, 2007b, confirming the existence of at least two Pleistocene elephant populations on Cyprus (Theodorou *et al.*, 2007a). The Agia Napa elephant remains from the *Phanourios minor* site are too fragmentary to prove the existence of the larger elephant species.

The relative ages of the two populations are currently unknown. It is clear, however, that the Aetocremnos findings prove the existence of the larger elephant species at least 10,700 years ago. The Xylofagou skull (Theodorou *et al.*, 2005) was excavated at a coastal locality from a fossiliferous layer overlain by layers of brackish-water sediments deposited at least to a height of 8 metres above the mean sea level. This indicates deposition within the climatic maximum of 60 – 70,000 years ago (Iliopoulos *et al.*, 2011). The scarce elephant remains, excavated at the hippo site at Agia Napa, have been dated at 13,500–11,000 years BP (Athanassiou *et al.*, 2014). The available skeletal material of the dwarf hippo, *Phanourios minor* Desmarest, 1822, suggests only one population on Cyprus, as the size variation falls within the normal distribution for the genus.

A third suspect for having a role in the occurrence of trace fossils in Cyprus is *Homo sapiens*. Up to now, there is no direct evidence for a human presence on Cyprus during the Late Pleistocene. During the excavations that took place at Agia Napa, on the eastern side of Cyprus, a well-preserved partial skull and some extremities of an endemic genet, *Genetta plesictoides* (Bate, 1903) were excavated from the undisturbed *Phanourios minor* layers, dated at 13,500–11,000 years (Theodorou *et al.,* 2007b). Genets could not have migrated by swimming to Cyprus as elephants or hippos did. So, it is necessary to discuss the possibility that 1) genets followed humans on their early trips well before the deposition of the fossiliferous layers of Agia Napa, or 2) that they migrated to the island on natural rafts. The possibility that humans arrived at Cyprus during the last main episode of low sea level cannot be excluded, and *Genetta plesictoides* possibly accompanied them. The fact that the Agia Napa partial skull is slightly modified suggests that *Genetta plesictoides* was on the island for some considerable time before the specimen was fossilized with the *Phanourios minor* remains, that is, well before 13,500 y BP.

No data on the estimated foot sizes of either *Phanourios minor* or *Elephas cypriotes* are available, but on the basis of skeletal reconstructions with an estimated amount of soft parts added, the authors estimate the feet of *Phanourios minor* to have been 8–12 cm in diameter, and the feet of *Elephas Cypriotes* to be 20–25 cm in diameter. Feet of elephants and hippopotami are sub-circular in outline with very short, blunt digits, and as such, are likely to leave circular impressions in the aeolian sands. Human feet on the contrary are elongated, roughly three times longer than wide. Therefore the diameter of a human track observed in cross-section can vary with a factor of three according to the orientation of the section observed, contrary to the rounded feet of hippopotami and elephants. When it is taken into consideration that the observed sections do not necessarily represent the maximum diameter of the tracks, but also can represent tangential sections, the observed sizes of tracks (Fig. 5), can convincingly be explained by the available trackmakers (Fig. 7).

Prehistoric, seasonal visits between Cyprus and the eastern Mediterranean mainland, assisted by climatic oscillations and sea-level changes, could explain the deposits at Akrotiri-Aetokremnos (~11000–10000 BC). The oldest, until now, permanent settlement on the island seems to have been at Parreklishia Shillourokambos, around 8000 BC –

the so-called PPNB (Pre-Pottery Neolithic B) period. The round houses and the deep pits that possibly served as wells are the main characteristics of that period. They are also found at Kastros and a little bit later in the 6th millennium BC, and also in the Aceramic phase, at Khirokitia. The interaction and exchange between Cyprus and the nearby mainland created a mixed-farming subsistence economy, based on the introduction of wild animals such as pigs, sheep, goat and cattle. Later on, this was followed by the introduction of domesticated plants and animals and, in the mid-third millennium BC, of metallurgy. Clearly the Late Pleistocene–Early Holocene age of the aeolinites permits discussion of the possible role of humans in the formation of some of the Paphos tracks (Bar-Yosef, 2001; Guilaiane and Briois, 2001; Hetherinton and Reid, 2010; Ferentinos *et al.,* 2012; Knapp, 2013).

To sum up, the possible trackmakers of the Paphos tracks are: 1) two populations (one small- and one large-bodied) of elephants; 2) dwarf hippopotami; and 3) possibly humans. No tracks small enough to have been emplaced by genets have been discovered so far. Absolute dates for the Cypriot endemic mammals and humans are still highly inadequate. This is mainly true for the time of arrival of these species. Better known is the time of extinction of the larger elephants from Aetocremnos and the extinction of dwarf hippos, elephants and *Genetta plesictoides* from Aetocremnos and Agia Napa. The sizes of the Agia Napa elephants must be discussed in the future if new material should come to light. In addition, absolute dates for the aeolianites of Paphos are still missing.

Sites of future interest

Since their initial finds of tracks in the Paphos aeolianites (Milàn *et al.*, 2009) and the Kattavia aeolianite of Rhodes (Milàn *et al.*, 2007), the authors started a detailed search for further localities with possible track-bearing aeolinites in the numerous Greek islands of the eastern Mediterranean.

So far, possible tracks have been discovered in aeolianites on the Greek island, Elaphonisi Peloponnese, and a great number of tracks are found in the Zakynthos (Zante) Island aeolianites. At both sites, the sizes of the tracks suggest that the tracks were made by Quaternary elephants that inhabited the islands, until they became extinct during the Late Pleistocene. So far, no elephant skeletal remains have been documented from the Zante and Elaphonisi islands. Other extremely scarce, small tracks have been located in the Phalasarna area of southern Crete in very young aeolianites.

Some of the numerous tracks found at the Island of Zante (Zakynthos) are large, but to date no elephant skeletal remains have been found. However, Upper Palaeolithic stone tools have been found in the aeolinites or at the overlying palaeosol, indicating that humans could have been the producers of those tracks (Kourtessi-Philippakis and Sorel, 1996). Very scarce remains of normal-sized elephants, including a molar, have recently been collected from the sea bed at Kefallonia, in shallow water. This site is currently under study by Theodorou, but up to now there were no more additional discoveries on the sea bed.

CONCLUSION

The coastal aeolianites, exposed in subterranean grave complexes within and around Paphos, south-western Cyprus, were formed by south-westerly winds, blowing fine- to medium-grained calcareous sands onshore. The aeolianites are presumed to be of Late Pleistocene–early Holocene age, and contain abundant vertebrate tracks, exposed in vertical section.

The limited endemic fauna of Cyprus, consists only of dwarf hippopotami, dwarf elephants and genets. No tracks small enough to have been emplaced by genets were observed, indicating that all of the tracks belong to hippos and elephants, with the possibility that some might have been made by early human settlers.

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