Pleistocene vertebrate trace fossils of Robberg Nature Reserve

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Received 17 February 2019. Accepted 21 October 2019

More than 140 Late Pleistocene trace fossil sites have been identified in aeolianites and lithified foreshore deposits along a 350 kilometre stretch of the Cape south coast in South Africa. Robberg Nature Reserve lies within this area and contains a zone of concentration of such tracksites, which complement the Pleistocene vertebrate body fossil record and assist in shedding light on the palaeoenvironment and palaeoecology of the Palaeo-Agulhas Plain. Ichnofossil sites unique to or of special significance within Robberg Nature Reserve include a substantial palaeosurface exposure that allows an estimate of track density, the best-preserved rhinoceros trackway identified to date, very well preserved artiodactyl tracks in the form of natural casts, small equid tracks, large elephant transmitted tracks, and well preserved sub-surface golden mole burrows with a burrow chamber. Aeolianite layers at Robberg have recently been dated to Marine Isotope Stage (MIS) 3. Samples that we have obtained for dating from the main palaeosurface underlie these dated layers and are anticipated to contribute to the understanding of the Pleistocene geology of the Robberg Peninsula. The protected status of the area lends itself to conservation, replication, interpretation and education initiatives.

Key words: Late Pleistocene, trackways, aeolianites, foreshore deposits, Robberg.

INTRODUCTION

Palaeoecological studies in areas with Pleistocene deposits and archaeological sites are strongly based on faunal assemblages found in caves and rock shelters (e.g. Marean *et al*. 2007, 2014). Through our ongoing work, we corroborate and complement these records with a relatively new proxy for the Cape south coast as we identify ichnofossils and vertebrate trackways preserved in cemented coastal rocks. We hereby contribute to studies of the broad continental shelf and the now-submerged Palaeo-Agulhas Plain during multiple Pleistocene sea-level oscillations (Cawthra *et al*. 2015, 2018).

Globally, aeolianites (cemented palaeodunes) (Fairbridge & Johnson 1978) occur typically between 20°–40°N and 20°–40°S (Brooke 2001). Pleistocene aeolianites on the Cape south coast form stacked dune deposits of calcarenite, along with palaeosols. These have been extensively studied, most recently by Bateman *et al*. (2004, 2011), Carr *et al*. (2007, 2010), Roberts *et al*. (2008, 2009) and Cawthra *et al*. (2018). These fossil dune systems are often indicators of palaeoenvironment and can provide clues regarding palaeoclimate (Roberts *et al*. 2013).

During the course of our 12-year study we have identified more than 140 tracksites in Late Pleistocene aeolianites and lithified foreshore exposures along a 350 km stretch of the Cape south coast (Helm *et al*. 2017, 2018a–c, 2019a,b). Findings have included significant range extensions for extant species, and tracks of extinct species. Furthermore, a hominin presence on these dunes was confirmed through the discovery of a tracksite containing forty hominin tracks on the ceiling of a cave 33 km west of Robberg (Helm *et al*. 2018c).

The age of these aeolianites and lithified foreshore deposits can be obtained with optically stimulated luminescence (OSL) and amino acid racemisation (AAR) chronology. Resulting dates obtained from within our study area range from ~400 ka to ~35 ka with punctuated periods of dominant preservation (Roberts *et al*. 2008, 2012; Bateman *et al*. 2011; Cawthra *et al*. 2018; Carr *et al*. 2019).

Roberts & Cole (2003) provided an explanation for the abundance of trace fossils in coastal aeolianites in southern Africa: cohesive moist sand provides an effective moulding agent, high sedimentation rates promote swift burial of tracks, and deposits are rapidly lithified through partial solution and re-precipitation of bioclasts. Shoreline erosion then re-exposes the trace fossil-bearing surfaces.

Aeolianite exposures on Robberg form the eastern limit

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Palaeontologia africana **54**: 36–47 — ISSN 2410-4418 [Palaeontol. afr.] Online only
Permanently archived on the 10th of December 2019 at the University of the Witwatersrand, Johannesburg, South Africa
The article is permanently archived at: http://wiredspace.wits.ac.za/handle/10539/28633

of our study area (the western limit is Arniston), and form a zone of concentration of Pleistocene ichnofossils. The purpose of this article is to document and interpret the vertebrate trace fossils that we have identified in the Robberg Nature Reserve (which is a Provincial Heritage Site and a World Heritage Site), in particular those that are regionally or globally unusual or unique.

GEOLOGICAL CONTEXT

The 185 ha Robberg Nature Reserve, established in 1980 and administered by CapeNature, lies 28 km east of the town of Knysna and 7 km southwest of the town of Plettenberg Bay on the Cape south coast of South Africa. The entire Robberg Peninsula, which extends into the Indian Ocean, is protected in the reserve. The peninsula forms the southern boundary of Plettenberg Bay, which is one of a number of eastward-opening bays with a similar log-spiral shape that occur on the Cape south coast. The Robberg Peninsula has a west–east orientation, with a length of 3.7 km, a maximum width of 0.75 km, and a maximum elevation of 148 metres above sea level. The main irregularity in the peninsula's otherwise fairly regular outline is formed by The Island (Die Eiland), a 450 m × 150 m aeolianite stack with west–east orientation, at the southern end of a 500 m long tombolo that projects south from the peninsula (Fig. 1).

The Robberg area comprises deposits from four distinct geological eras and time periods:

- Palaeozoic rocks of the Cape Supergroup,
- Mesozoic rocks of the Robberg Formation (quarzitic sandstones of the Early Cretaceous Robberg Formation and younger Cretaceous conglomerates) – these comprise the majority of outcrops on the peninsula (Toerien 1979; Reddering 2003),
- Late Pleistocene aeolianites,
- unconsolidated Holocene dunes and sand.

The Late Pleistocene track-bearing aeolianites along the Cape south coast are within the Waenhuiskrans Formation, which forms part of the Bredasdorp Group (Malan 1989). The aeolianite outcrops at Robberg occur at the easternmost end of the distribution of these deposits (Carr *et al*., 2019). Aeolianites found east of Plettenberg Bay form part of the Algoa Group. The aeolianites are composed of medium- to fine-grained sand with a high carbonate content derived from marine shell fragments. As Quaternary tectonic activity was minimal along what is now the Cape south coast (Fleming *et al*. 1998), *in situ* bedding planes lie close to their original angles of deposition.

Also within the Bredasdorp Group are marine deposits of the Klein Brak Formation (Malan 1991), which include shoreface and foreshore deposits (Roberts *et al*. 2012; Cawthra *et al*. 2018). Lithified foreshore deposits may also contain fossil tracksites. The distinction between aeolianite and lithified foreshore deposit is not always straightforward, as is evident from an examination of the current coastline where the transition from beach to dune is not always abrupt.

The Pleistocene aeolianite exposures which form the

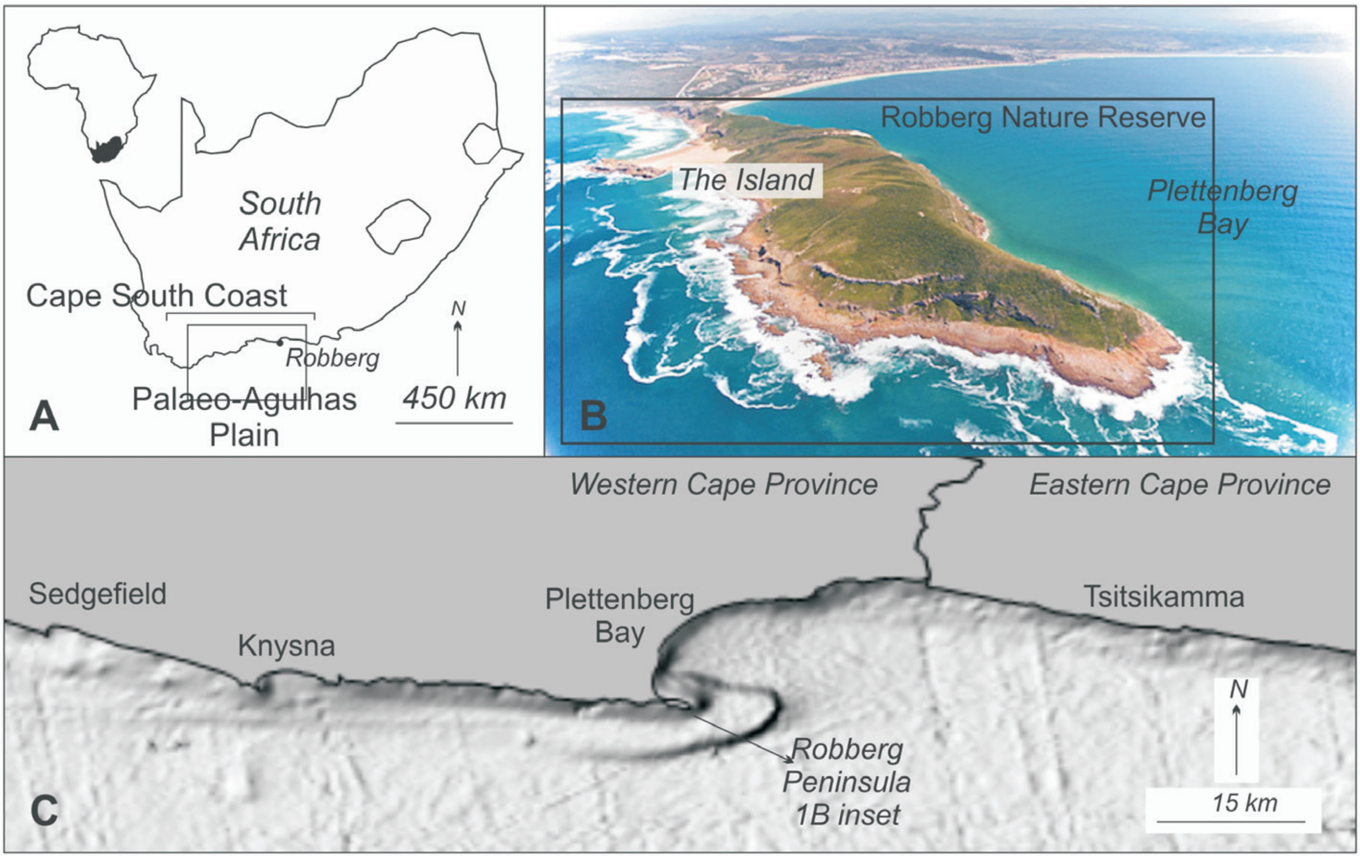

Figure 1. **A**, Location of Robberg in relation to the Cape south coast and Palaeo-Agulhas Plain. **B**, The Robberg Nature Reserve and the Island (https://www.nightjartravel.com/parks/robberg-nature-reserve Date accessed 9 February 2019). **C**, Bathymetry of the continental shelf in the vicinity of Robberg, illustrating the sediment spit adjacent to the Peninsula. Data from de Wet (2013).

subject of this article are found in two main areas at Robberg:

- The Island, which is composed of Pleistocene sediments and overlying Holocene unconsolidated sand,
- the southeast margin of the peninsula, where high-angled foreset beds are exposed over a distance of more than a kilometre.

Butzer & Helgren (1972) described the stratigraphy of The Island, including two palaeosols (P1 and P2) separated by ~8 m of aeolianite and an estimated thickness of over 30 m of aeolianite below the level of P1. This terminology was adopted by Carr *et al*. (2019) in their dating studies, and we follow the same terminology here.

The oldest aeolianite ages obtained from the study of Carr *et al*. (2019) are from the southeast margin of the peninsula: 55.5 ka ± 3.7 ka – 67.0 ka ± 4.2 ka. The sampled aeolianite between P1 and P2 on The Island yielded dates in the range of 34.7 ka ± 2.9 ka – 41.6 ka ± 2.8 ka. Aeolianites below P1 on The Island were not sampled in this study, due to rough seas and risk to personal safety.

These dates represent a significant difference from those obtained in aeolianites sampled elsewhere along the Cape south coast, and are the first to be recorded from Marine Isotope Stage (MIS) 3. Previous studies (Bateman *et al*. 2004, 2011; Carr *et al*. 2010; Cawthra *et al*. 2018; Roberts *et al*. 2008, 2012) had suggested dune accumulation associated with interglacial sea-level high-stands from MIS 11, MIS 7 and MIS 5e. However, dune deposits preserved on the now-submerged continental shelf were associated with both transgressive and regressive sea-level events of MIS 5d and MIS 4 (Cawthra *et al*. 2018). MIS 3 along the Cape south coast was associated with a marine regression (Bateman *et al*. 2011). The dated Robberg aeolianites thus form a number of 'firsts' for the Cape south coast: the first documented currently non-submerged examples of onshore accumulation, the first examples not associated with an interglacial sea-level high-stand, and the first examples from MIS 3.

The Robberg Peninsula is characterised by a number of caves, mainly on its southern aspect. Many of these are of archaeological significance (e.g. Butzer & Helgren 1972; Klein 1972). Rudner & Rudner (1973) summarized the archaeological work, beginning in 1880, which had been carried out in these caves, following which 48 human skeletons were reposited in the Iziko (South African) Museum. Goodwin (1946) described the 'Robberg Industry', suggesting that it represented the 'capital of certain phases of Later Stone Age culture', characterised by large numbers of tools made from bird bones and a number of painted gravestones. Rudner (1971) reported that eighteen of these painted stones were reposited at the Iziko (South African) Museum. Helm *et al*. (2019c) described a trilobite manuport found in a small cave on the northern aspect of the peninsula.

METHODS

Following a brief survey in 2016, two visits were conducted to the areas of aeolianites in the Robberg Nature Reserve in 2017, followed by a further two visits in 2018. Collaboration with CapeNature included the issuing of a research permit. Visits to the sites on The Island had to be timed with spring low tide on days with minimal swell, as significant risks to personal safety were identified during adverse conditions associated with high tides and rough seas.

Global Positioning System readings were obtained for tracksites using a handheld device, with accuracy of 5–10 metres. Measurements of track length, track width, and pace length and stride length were recorded (*sensu* Stuart & Stuart 2000; Van den Heever *et al*. 2017). Tracings were made of selected trackways.

Photographs were taken of tracks, and photogrammetry (Mallison & Wings 2014) was performed on selected sites. Point clouds and digital terrain models were compiled using Agisoft Photoscan Professional (v.1.0.4) and colour topographic profiles were created with CloudCompare (v.2.6.3.beta). Tracings were made using clear acetate film.

Outcrops were investigated in the field through comparison and correlation to the sites documented and dated by Carr *et al*. (2019). Standard field techniques were applied in understanding the context of the ichnofossils. Geological samples were obtained for thin sections and petrography. Samples for OSL dating were obtained.

Locality data were reposited with the African Centre for Coastal Palaeoscience and with CapeNature. Discussions were held with CapeNature regarding potential preservation and education initiatives, and tracksites were reported to Heritage Western Cape.

RESULTS

In places, where there were adequate palaeosurface exposures, aeolianites in the Robberg Nature Reserve were found to be rich in fossil tracks, preserved as natural impressions (epirelief) or natural casts (hyporelief). Further evidence of tracks was noted in cross-section at multiple horizons; however, such tracks were generally less easy to attribute to specific track-making taxa than those exposed on surfaces. In other areas there were massive or well-cemented deposits without many exposed bedding planes – minimal evidence of tracks was found in such areas.

The main palaeosurface on The Island

One surface on The Island contains particularly impressive tracks. We refer to it as the main palaeosurface (Fig. 2). The track-bearing layer, preserved mostly in hyporelief as a cave ceiling and on the underside of ledges, is formed by a truncation surface dipping at 10° to the southwest. This interface truncates multiple thin-bedded aeolian foresets aligned at ~30°, which dip to the west. The truncation surface lies below the erosional remnants of the overlying beds which form a promontory which measures a maximum of 28 m × 16 m, shown in Fig. 2. The truncation surface can be followed laterally, where tracks are evident in profile. Tracks appear as natural casts and are particularly well exposed in two locations, due to removal of the underlying layers by erosion.

The first of these exposures of the main palaeosurface occurs on the inaccessible ceiling of a sea cave (Fig. 3). The floor of this cave is submerged, and is ~2m deep at low

Figure 2. Arrows indicate the main palaeosurface. The dark area on the right is the entrance to the tunnel. The dark area on the left behind the standing figures is the 'door', one of the entrances to the sea cave.

tide. In addition to being open to the sea, the cave has two landward entrances, which we termed the 'window' to the east and the 'door' to the west. An adequate view of the tracks can only be obtained by entering the sea and looking upwards, while contending with wave action. The track-bearing surface on the ceiling is irregular in outline, with maximum dimensions of 6.5 m × 3.0 m, and an area of 12 m^2. More than 80 tracks are evident on this surface (most of them probably medium-sized bovid and equid). Hence there is a track density on this surface of almost seven tracks/m^2.

The second of these exposures of the main palaeosurface is on the ceiling of a tunnel, which is 16 m in length, orientated in a northeast–southwest direction, with a maximum height of 2 m and a maximum width of 2.5 m (Fig. 4). It is situated a few metres west of the sea cave described above. The floor contains a number of pools, as the tunnel is subjected to wave action at high tide. Part of the ceiling (1.0–1.2 m wide and extending the length of the tunnel) is formed by the above-mentioned truncation surface. Multiple natural cast tracks were evident on this surface, with the better preserved tracks found in the seaward (southwestern) 6 m of the tunnel.

These included a series of three exceptionally well-preserved large bovid track casts ~12–13 cm long, 8–9 cm wide, and 7 cm deep, with pace lengths of 25 cm and 31 cm (Fig. 5). Images were obtained for photogrammetry. The size and relative dimensions suggest that they may have been made by the Cape buffalo (*Syncerus caffer*).

Seaward of these bovid tracks we found a large tridactyl

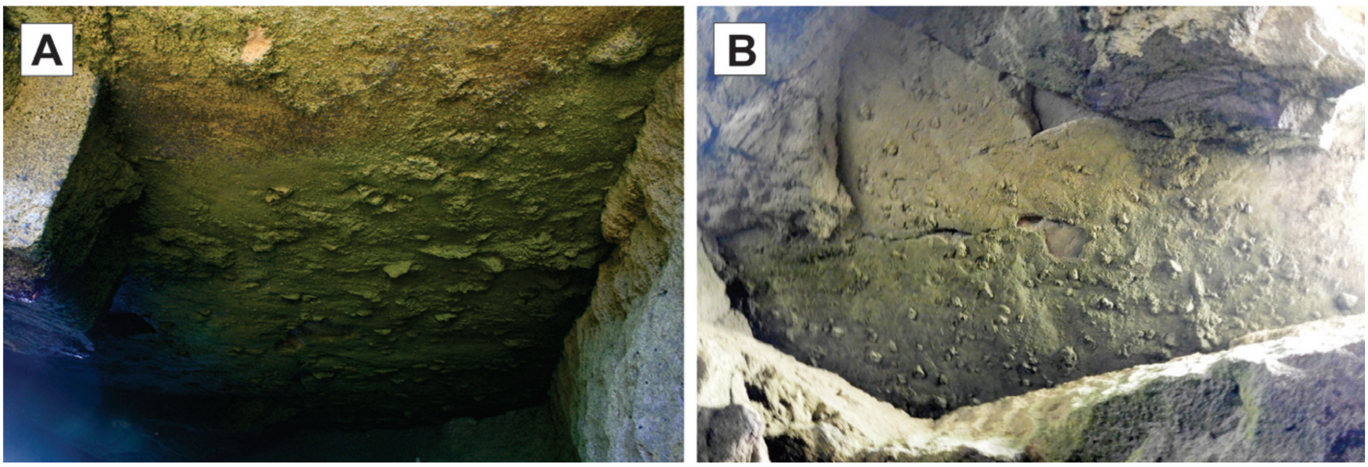

Figure 3. A, The main palaeosurface on the inaccessible ceiling of the sea cave, viewed from the 'window'. The width of the track-bearing surface is 3.0 metres (photograph reproduced with permission from Daniel Helm). **B**, The main palaeosurface, viewed from the submerged floor of the sea cave. Maximum dimensions of the track-bearing surface are 6.5 m × 3.0 m (photograph reproduced with permission from David Scott).

Figure 4. The main palaeosurface on the ceiling of the tunnel, illuminated to show multiple natural cast tracks.

('cloverleaf pattern') trackway of at least six tracks, with size and morphology consistent with that of black rhinoceros (*Diceros bicornis*); the best-preserved example was a natural cast of a right track, with features that distinguished it from tracks of white rhinoceros (*Ceratotherium simum*), e.g. outer toe relatively small, and situated relatively far from the middle toe (Liebenberg 2000; Stuart & Stuart 2000; Van den Heever *et al*. 2017). Mean length = 23.4 cm; mean width = 23.2 cm; $n = 5$. One track appeared to point in the opposite direction, suggesting a trail that was used in both directions. This trackway was difficult to interpret because there were smaller tracks beside it, as well as possible composite prints or overprinting. While in places the track morphology was well preserved, clear signs of erosion due to wave action were present. Images for photogrammetry were obtained and a tracing was made, although the confined space and small distance between floor and ceiling made this challenging (Fig. 6).

One track with morphology consistent with long-horned buffalo (*Syncerus antiquus*) track was present close to the rhinoceros trackway (11 cm long, 12.5 cm wide). Images for photogrammetry were obtained and a tracing was made (Fig. 7). Many unidentifiable tracks were present in the same area, along with large casts seen in profile

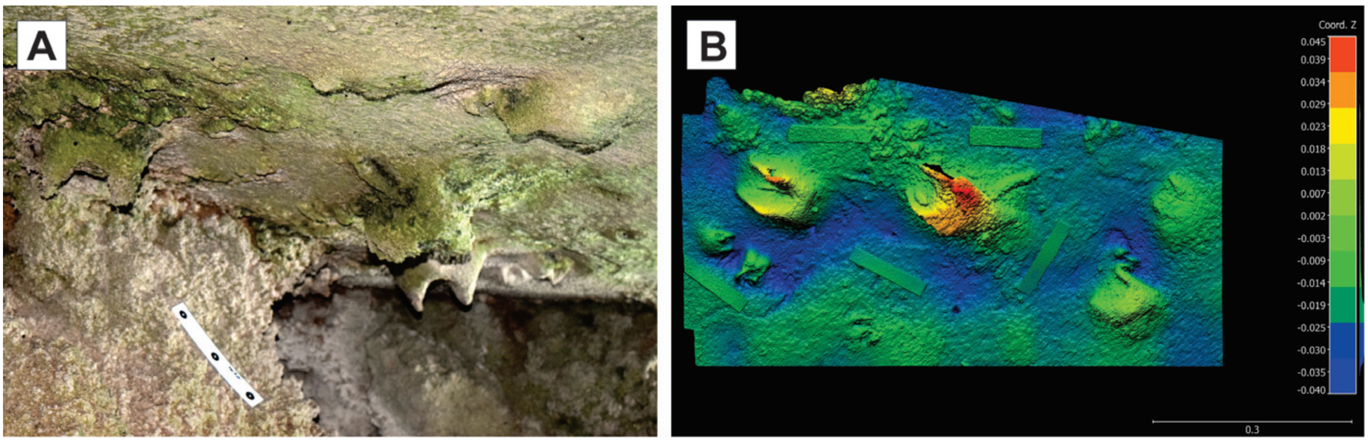

Figure 5. **A**, Natural casts of large bovid tracks on the ceiling of the tunnel. **B**, Photogrammetric model with colour vertical profile of large bovid tracks on the ceiling of the tunnel. Model constructed from 90 images from Canon EOS 700D with 5184 × 3456 resolution and pixel size of 4.384 × 4.384 μm using an 18 mm focal length. The average camera altitude was 0.240 m. The precision of the model is 0.143 pix. Vertical scale is in metres. Horizontal white scale bar = 30 cm.

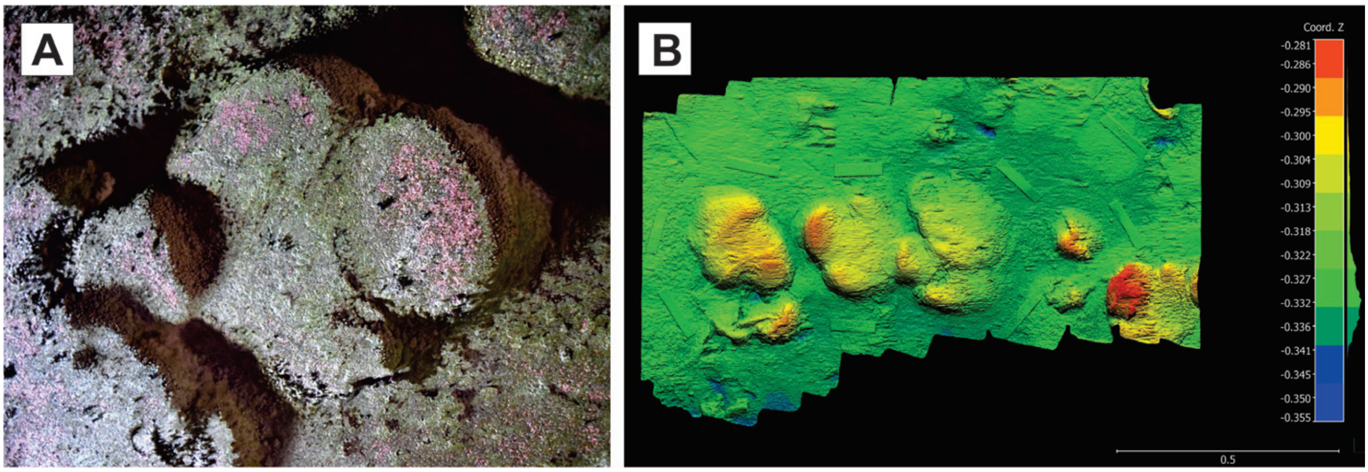

Figure 6. **A**, Natural cast track of black rhinoceros (*Diceros bicornis*) on the ceiling of the tunnel. The track measures 24 cm in length and 23 cm in width. **B**, Photogrammetric model with colour vertical profile of a portion of the *Diceros bicornis* trackway. Model constructed from 94 images from Canon EOS 700D with 5184 × 3456 resolution and pixel size of 4.384 × 4.384 μm using an 18 mm focal length. The average camera altitude was 0.302 m. The precision of the model is 0.153 pix. Vertical scale is in metres. Horizontal white scale bar = 50 cm.

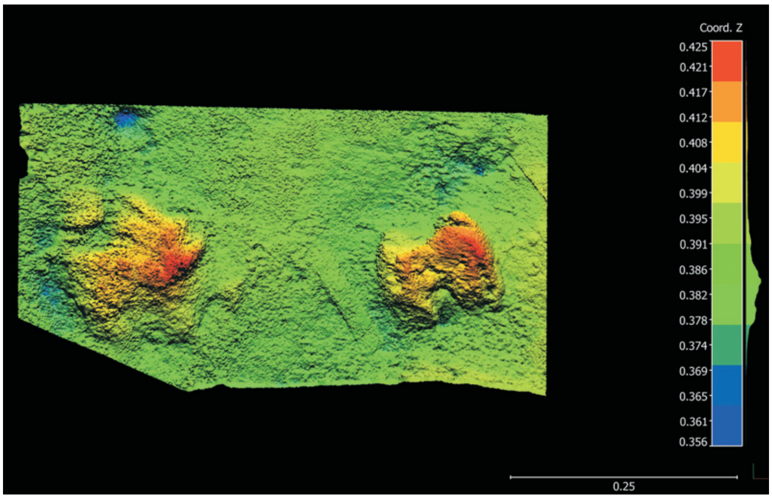

Figure 7. Photogrammetric model with colour vertical profile of long-horned buffalo (*Syncerus antiquus*) track on the ceiling of the tunnel. Model constructed from 12 images from Canon EOS 700D with 5184 × 3456 resolution and pixel size of 4.384 × 4.384 μm using an 18 mm focal length. The average camera altitude was 0.396 m. The precision of the model is 0.158 pix. Vertical scale is in metres. Horizontal white scale bar = 25 cm.

at the junction of southeastern wall and the ceiling, which might represent a continuation of the rhinoceros trackway.

Above the level of the main palaeosurface, 11 track-bearing layers were evident in cross-section in a section of 150 cm. Where some of these layers exhibited small surface exposures, small bovid tracks (3.5–4 cm in maximum length and width) were evident in epirelief.

Three samples for OSL dating were obtained, from above, at and below the main palaeosurface. The sample taken at the level of the palaeosurface is lithologically composed of a thickly-bedded planar unit. The grain size is medium- to very-coarse grained sand, and constituent clasts are made up of quartz, feldspar, heavy minerals and abundant shell fragments. These features and primary structures are consistent with foreshore deposits.

Other caves at The Island

Four sea caves line a small bay on The Island. These are accessible only at spring low tide in calm conditions. Three of these caves contain tracks, as impressions on fallen blocks on the floors, or as natural casts on the ceilings (Fig. 8a). Nearby large ceiling surfaces have a high potential for exhibiting tracks, but remain inaccessible for safety reasons.

Most of the tracks are not of good quality, but the exception is a series of four tracks with equid features (presence of hoof wall, absence of interdigital sulcus, suggestion of a ‘frog’) (Liebenberg 2000; Stuart & Stuart 2000; Van den Heever *et al*. 2017) on the upper surface of a loose block on the floor of one of these caves. Maximum track length = 8 cm; maximum width = 8 cm (Fig. 8b).

Loose blocks at The Island

Numerous enormous fallen blocks characterise parts of The Island. In one area there is a zone of concentration of tracks evident as impressions (pirelief), as natural casts (hyporelief), or in profile. Most of these are elephant tracks, with oval pes tracks and circular manus tracks readily identifiable (Liebenberg 2000; Stuart & Stuart 2000; Van den Heever *et al*. 2017). Some of these are at the upper size limit of extant adult bull elephant tracks, e.g. a 55 cm × 45 cm natural cast, and a manus-pes pair with one track measuring 57 cm in length.

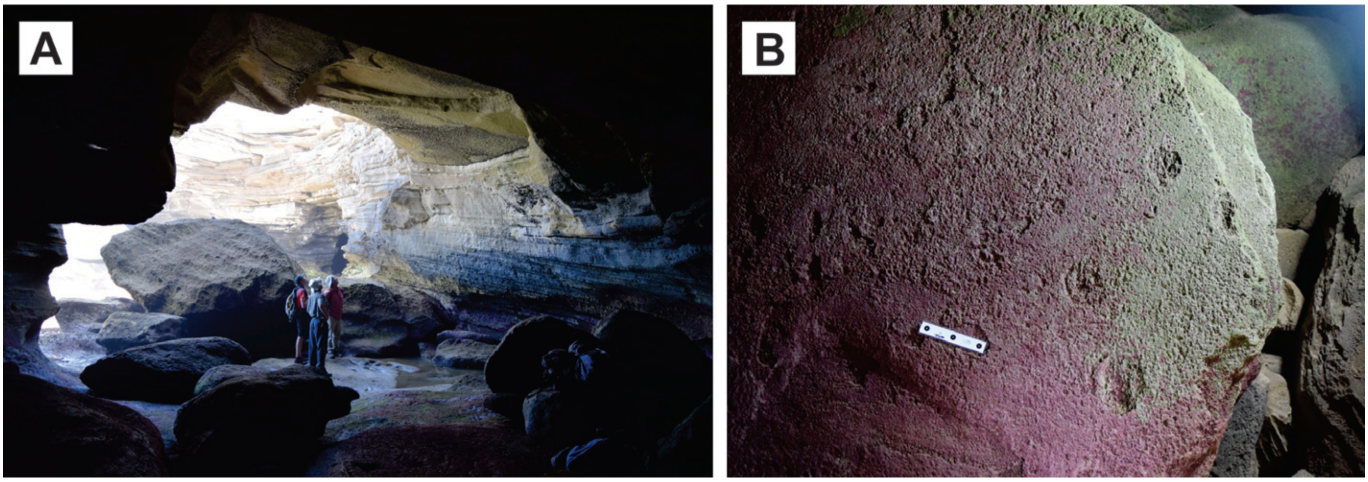

Figure 8. **A**, One of the track-containing caves on The Island. **B**, Equid tracks on a loose block in one of the caves on The Island; scale bar = 10 cm between outer black circles.

On a large fallen block, 7.5 m in length, more than 6 m in width, and up to 2 m in thickness, elephant tracks occur as natural casts on the southern surface, which lies at an angle of 130º to the horizontal. The opposite surface, which is therefore the side on which tracks could have been registered, thus needs to be viewed from below, as it is tilted 50º past vertical. On it three very large depressions are evident, two of which are oval and one of which is rounder (Fig. 9a). Respectively these measure 62 cm long, 51 cm wide, 5 cm deep; 70 cm long, more than 52 cm wide (truncated), 7 cm deep; 65 cm long, 62 cm wide, 7 cm deep. They are 112–117 cm apart.

While these depressions exhibited the shape of elephant tracks, they appeared too large to have been made by any extant elephant. The likeliest explanation for these features was that they were elephant transmitted tracks, which would typically be larger, less well-defined and with a greater width-to-depth ratio than the actual tracks. We returned to the site and were able to confirm this by examining a further portion of the surface, accessed through a narrow gap in between smaller slabs and talus. Here further depressions were evident, and one of these contained the infill of an elephant hindfoot track, with the surrounding layers and transmitted track layers clearly visible (Fig. 9b). The track infill measured 40 cm × 30 cm, and the maximum length of the transmitted track measured 80 cm.

A number of fallen blocks reveal a high frequency of track-bearing layers seen in cross-section. Return visits to this area have led to the continued discovery of new tracks.

Golden mole traces at The Island

Branching epifaunal *in situ* burrow traces measuring 130 cm and 300 cm were noted beside a boardwalk on The Island (Fig. 10a). The shorter burrow contained two branches, measuring 60 cm and 50 cm in length. Burrow diameter was measured at ~7 cm. These burrow traces are consistent with those of extant golden mole (Insectivora, Chrysochloridae, e.g. *Amblysomus* sp.) (Stuart & Stuart 2000). This site lies within the section of aeolianite between palaeosols P1 and P2, and can therefore be inferred to be in the younger MIS 3 aeolianites in the ~35–42 ka range (Carr *et al*. 2019).

Robberg Peninsula

Branching epifaunal burrow traces were identified on the surface of a fallen block towards the southeastern end of the Robberg Peninsula (Fig. 10b). Burrow diameter of

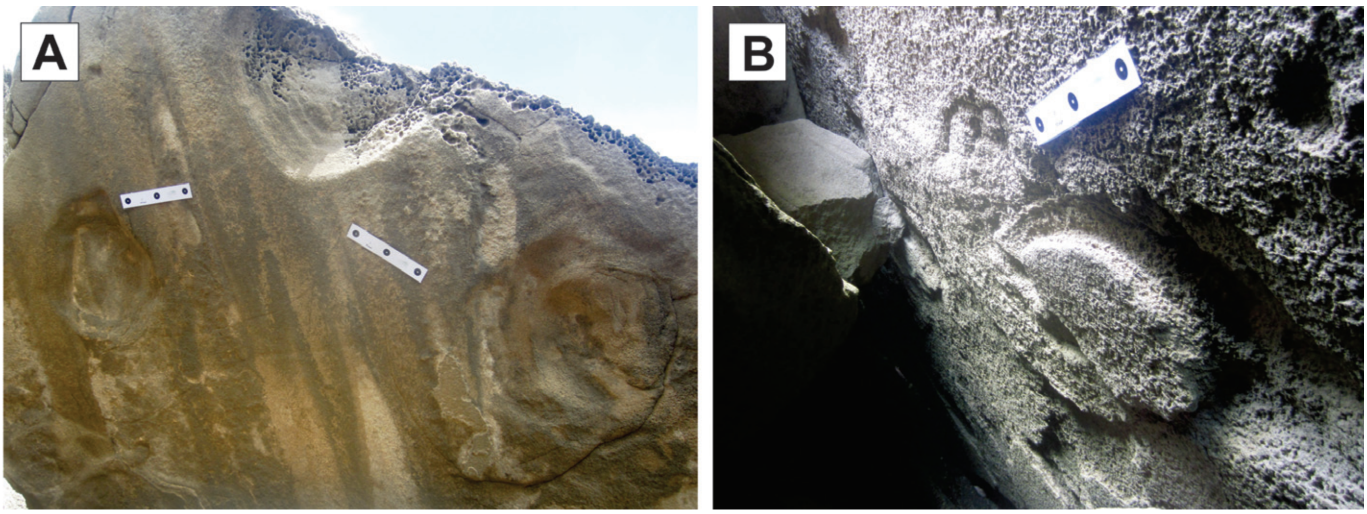

Figure 9. **A**, Three large elephant undertracks; scale bars = 25 cm between outer black circles. **B**, Infill of an elephant hindfoot track, situated within an undertrack; scale bar = 25 cm between outer black circles.

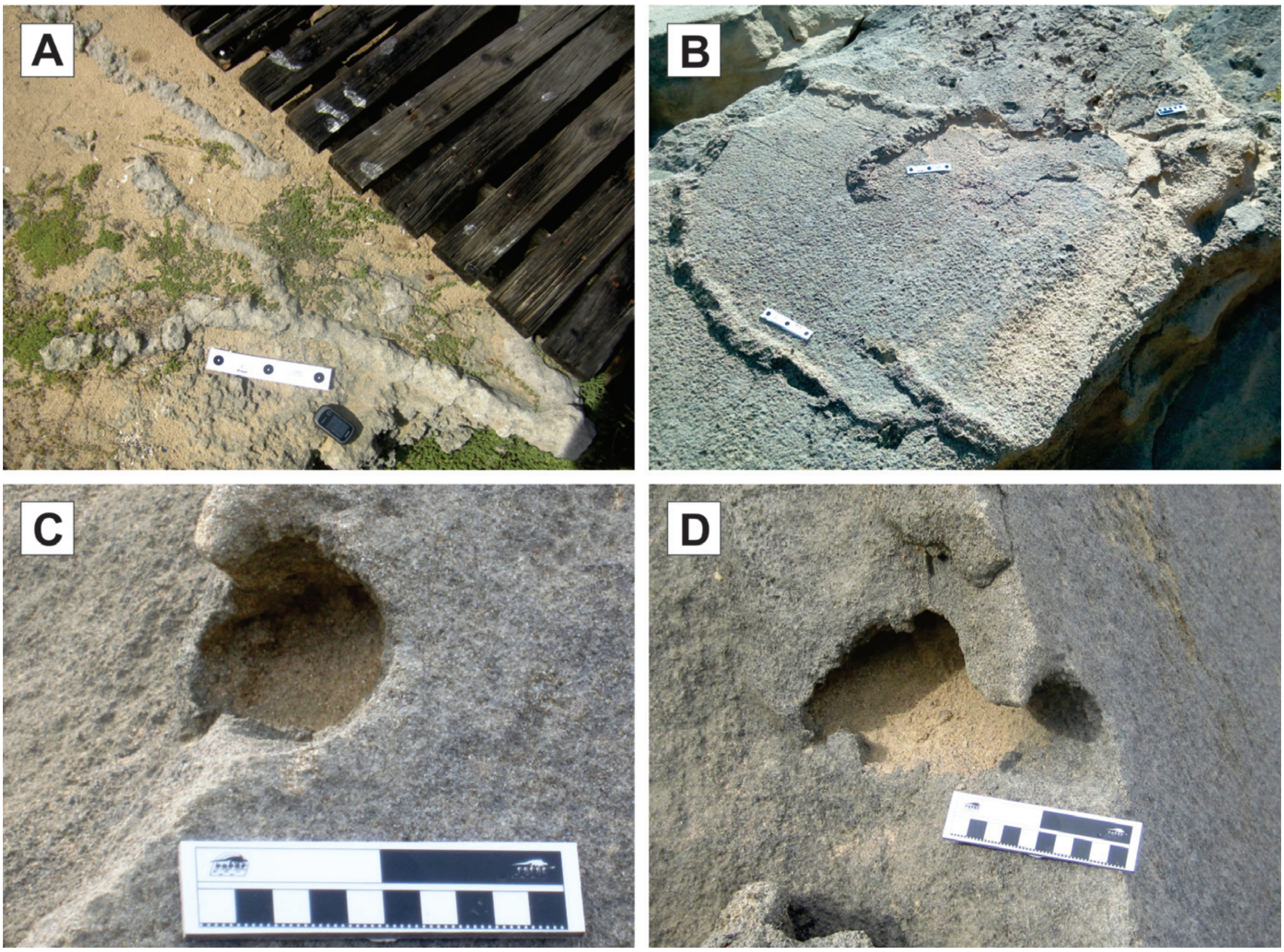

Figure 10. **A**, Golden mole burrow traces beside a boardwalk on The Island; scale bar = 25 cm between outer black circles. **B**, Golden mole burrow traces on Robberg Peninsula; scale bars = 10 cm between outer black circles, except for the far scale bar, wich = 10 cm. **C,** Cross sectional view of burrow trace from Robberg Peninsula; scale bar = 10 cm. **D,** Infaunal burrow trace from Robberg Peninsula; scale bar = 10 cm.

~6–7 cm was recorded. One burrow was 140 cm in length, with a 40 cm branch. The second burrow was 110 cm long, with a 20 cm branch. At the northeastern end of this block the main surface layer is absent and a slightly lower surface takes its place; as a result the interior of the burrow is evident in this area. The burrows are consistent with those of the extant golden mole family (Insectivora, Chrysochloridae, e.g. *Amblysomus* sp.) (Stuart & Stuart 2000).

At the southwestern edge of the surface of this block an infaunal burrow of similar diameter was noted in cross-section (Fig. 10c). Fortuitously this could also be examined in longitudinal section, ending in a chamber 10 cm in diameter (Fig. 10d). OSL dates obtained by Carr *et al.* (2019) indicate an age range of ~56–67 ka for this area of aeolianites.

Nearby an eroded *in situ* natural cast trackway was noted under an overhang. West of these sites the upper surface of a large fallen block was noted to contain more than twelve large, poorly preserved natural casts (hyporelief) of large bovid trackmakers, probably a buffalo species.

DISCUSSION

Robberg Nature Reserve is of unique importance as a protected area that preserves the only true peninsula on the Cape south coast. Its geology, topography, biology, archaeology and spelaeology are justly celebrated, including through its designation as a World Heritage Site. The vertebrate ichnology reported here can now be added to this list, as a regionally significant and globally significant phenomenon.

Our observation that the rock sample obtained from the level of the main palaeosurface showed features consistent with a foreshore deposit was unexpected. Foreshore deposits are not geochronologically consistent with the MIS 3 dates obtained by Carr *et al*. (2019), nor the offshore bathymetry, which indicates that during MIS 3 the shoreline at Robberg would have been over 7 km seaward of the current shoreline, even during the MIS 3 sea high-stands that correlate with the two sets of OSL dates obtained by Carr *et al*. (2019). A possible scenario is that these layers were deposited during a more substantial sea high-stand, on top of older dune foresets. We suspect that the main palaeosurface and layers below it and immediately above it may represent rocks older than MIS 3, and anticipate that future chronological determinationss will allow for follow-up interpretations.

The main palaeosurface is an outstanding ichnofossil site, and we are not aware of other sites in the global track record that eclipse the sea cave and tunnel (with tracks on their ceilings) for physical splendour. These hyporelief cast surfaces at Robberg rank high on the four-point (0-1-2-3) preservation scale of Belvedere & Farlow (2016): i.e., in the range of 2–3. If we were to rank this surface among all the tracksites thus far identified from the Cape south coast in terms of objective criteria such as number and diversity of tracks, quality of preservation, confidence in attribution to trackmakers and *in situ* context (as a well-defined truncation surface) it would undoubtedly be one of the most significant.

Unfortunately, aeolianites in southern Africa do not readily cleave in such a way as to produce very large palaeosurfaces, although track-bearing layers can sometimes be followed for some distance in profile (e.g. Roberts *et al*. 2008). In our experience the ceilings of caves and overhangs have the potential to exhibit moderately large surfaces with large numbers of tracks as natural casts. The quality of preservation of hyporelief track casts on sub-horizontal and low-angle paleosurfaces on cave ceilings and under ledges, exemplified by the hominin tracksite 33 km to the west (Helm *et al*. 2018c), generally appears superior to that on upward-facing paleosurfaces and the inclined surfaces on fallen blocks. This may be due to these latter categories of surfaces being more susceptible to the direct downward or lateral forces of wave action and inundation. The main palaeosurface, where it is exposed on the ceiling above the sea cave on The Island, is an example of this phenomenon, with an impressive density of almost 7 tracks / m^2. While the physical challenges associated with this site have thus far prevented detailed analysis of these tracks; this challenge could be addressed with a dedicated effort and a high level of technical climbing skills.

Within the tunnel, the deep natural casts of large bovine tracks on the ceiling, resembling stalactite pairs, are striking aesthetic examples of their kind. The rhinoceros trackway in this tunnel is the most important of its kind thus far identified on the Cape south coast. A probable rhinoceros track was reported from east of Still Bay (Helm *et al*. 2019b), a poorly defined trackway was identified under an overhang at Brenton-on-Sea, and two parallel trackways were identified east of Wilderness. None of these showed the detail of the Robberg trackway, which is the only one of these examples that allowed identification to species level: the black rhinoceros (*Diceros bicornis*) was historically more common than the white rhinoceros (*Ceratotherium simum*) in the southwestern Cape, and has been recorded more often in the body fossil record (e.g. Klein 2007). Attempts to distinguish between the tracks of the two extant rhinoceros species have paleoecological implications due to their different feeding niches.

The long-horned buffalo (*Syncerus antiquus*) track in the tunnel near the rhinoceros trackway provides a substantial addition to the track record of this extinct species. Track width convincingly exceeds track length, allowing the species identification to be made with confidence (Helm *et al*. 2018b). The only long-horned buffalo trackway identified so far is within the Goukamma Nature Reserve (Helm *et al*., 2018b). Tracks of rhinoceros and long-horned buffalo were also found in close proximity to each other east of Still Bay (Helm *et al*. 2019b). The main palaeosurface at Robberg represents the first documentation of tracks with size and dimensions consistent with both long-horned buffalo (*S. antiquus*) and Cape buffalo (*S. caffer*) at the same site.

The four tracks on the surface of a fallen block floor of a cave at The Island add to the record of Cape south coast small equid tracks. Similar tracks have been noted at Brenton-on-Sea and east of Wilderness. Tracks of this size are easily distinguished from much larger equid tracks which have been recorded from east of Still Bay (Helm *et al*. 2019b), Goukamma (Helm *et al*. 2018b), east of Wilderness, and Brenton-on-Sea. These larger tracks have been ascribed to the giant Cape horse (*Equus capensis*) (Helm *et al*. 2018b), a species that is well documented in the body fossil record (e.g. Klein *et al*. 2007). Smaller tracks exemplified by those evident at Robberg are consistent with tracks of plains zebra (*E. quagga*), and equal to or slightly larger than tracks of Cape mountain zebra (*E. zebra*). *E. zebra* would be an improbable trackmaker on dune surfaces. The quagga (the southern race of the plains zebra that became extinct in the 19th century) appears to be the likely trackmaker, although juvenile *E. capensis* cannot be excluded.

Fossil elephant tracks are a common phenomenon in aeolianites on the Cape south coast (Helm *et al*. 2018b, 2019b), despite only being relatively recently reported for the first time (Roberts *et al*. 2008). Their subsequent description from multiple sites indicates a widespread Late Pleistocene presence. OSL dating and stratigraphic comparison with dated sites has demonstrated that these tracks occur from MIS 5e, MIS 5c and MIS 5b. While it may be possible that the many elephant tracks noted at Robberg are from MIS 3, we cannot be certain of this as they all occur either *ex situ* on fallen blocks or in layers very close to the ocean that were not sampled by Carr *et al*. (2019).

The unique feature of the Robberg elephant tracksites is the huge depressions on one surface, which we interpret as elephant transmitted tracks. Such tracks have not previously been reported. The ability to confirm this phenomenon by finding the infill layer of an original track within the depression created by such a transmitted track, accessed via a gap into a small recess in a talus slope, was fortuitous.

The African Elephant (*Loxodonta africana*) is the only plausible trackmaker, as there is no evidence for elephant species such as *L. atlantica* surviving beyond 400 ka (Klein *et al*. 2007; Carruthers *et al*. 2008). The sites on the Cape south coast form the main corpus of known Pleistocene elephant tracksites in southern Africa, other than a single occurrence near Durban, over 800 km to the northeast (Cawthra *et al*. 2012).

The subsurface burrow trace sites reported from Robberg represent the best-preserved Pleistocene examples of their kind on the Cape south coast. Golden moles appear to be the most likely fossorial family to have made these burrows. Golden moles may move over sand dunes to the high-water mark to feed on isopods and amphipods. The burrow diameter of 6–7 cm suggests a larger trackmaker genus such as *Amblysomus* (pers. comm. Gary Bronner 2017). The infaunal burrow ending in a chamber is the only known example of its kind. Dating studies from the Robberg aeolianites (Carr *et al*. 2019) indicate that one of these burrow sites is from the ~35–42 ka range, and the other is from the ~56–67 ka range. Elsewhere in southern Africa, golden mole burrow traces have been reported from the Palaeogene Tsondab Sandstone Formation in the Namib Desert (Ward 1988). We have identified less well-preserved burrow traces of similar size at De Hoop, east of Still Bay, Goukamma and Brenton-on-Sea (Helm *et al*. 2019b).

CONSERVATION AND INTERPRETATION

The occurrence of a rich suite of Late Pleistocene tracksites within a protected area creates opportunities for conservation and the appreciation and interpretation of geoheritage through education. Fossil tracksites on the Cape south coast are ephemeral, being subject to erosion by wind and water, to cliff collapse, and to gravitational forces acting on slumped blocks and slabs. By geological standards aeolianites are soft, showing little resistance to erosion. Accelerated rates of erosion can be anticipated due to the increase in storm surge events reported from the entire South African coast (Smith *et al*. 2010; Mather & Stretch 2012). It is likely that the suite of tracksites we have described will be enlarged by a further dedicated search of all suitable bedding plane exposures, and as new sites become exposed. Ongoing exploration is therefore required.

The photogrammetric analysis and trackings of selected sites on the main palaeosurface may form the best means of replication available, given the access challenges to the ceiling above the sea cave and the moist environment in the tunnel associated with a very short period of access at low tide – these factors preclude traditional manual casting efforts. 3D models can be generated from the digital data, and this may provide an interesting means of presenting these ichnological phenomena to the public, for example in the small interpretive centre at the main parking area in Robberg Nature Reserve. Given the unique nature of the elephant transmitted tracks and the interest which these may elicit, photogrammetry, tracing and manual casting could be applied to the three more accessible tracks, although the fact that they occur on an angled overhanging surface will add to the challenges inherent in such efforts.

Tidal action has exposed the main palaeosurface, and has provided a window in which we can appreciate the magnificent tracks which are now visible. The same tidal forces will lead to their erosion and destruction, but will hopefully expose further portions of this palaeosurface and reveal further tracks. It is probably not feasible to mitigate any of the erosive forces acting on these tracksites.

Although the sites we have described are ichnologically exceptional, and potentially of interest to education and interpretation initiatives, we believe that such efforts should be concentrated in the information centre and through brochures and other media initiatives, rather than through site visits and guided tours, which in any event would only be practical for more able-bodied persons. Most of the sites we have described are either accessible only during extremely favourable tidal and weather conditions, or are situated in potentially unstable areas of loose blocks that are prone to moving and slumping, or in caves which will sooner or later collapse. In our research activities we control objective risks and minimize absolute risks, but we acknowledge that we cannot reduce these risks to zero. Expecting a similarly responsible approach by all visitors is unrealistic, and there is an ever-present risk of destruction of palaeosurfaces though vandalism. Rogue waves can occur even during what appear to be ideal conditions – we were starkly reminded of this through a frightening episode while performing photogrammetry on the main palaeosurface in the tunnel, and lost a camera to water damage as a result.

Furthermore, aeolianite surfaces are relatively fragile, and may suffer if exposed to repeated foot traffic. The boardwalks that have been installed by CapeNature fulfil an admirable role in keeping hikers off the aeolianites and on a shared route. One concern is the golden mole burrow site which is situated right beside one of these boardwalks and which could be unwittingly destroyed through trampling. Rerouting of the boardwalk a few metres away from this site is desirable.

Despite the caveats and challenges, we believe that justice can be done to these remarkable sites through replication, interpretation and education initiatives in collaboration with CapeNature.

CONCLUSIONS

For a relatively small area, containing a relatively small number of Pleistocene rock exposures, Robberg Nature Reserve contains an impressive suite of vertebrate ichnofossil sites. Together these complement and independently corroborate the traditional body fossil record from the region, and thus enhance understanding of the Pleistocene vertebrate fauna. Some of the sites and features we have described are globally unique, others are of national or regional significance. Together they form a phenomenon that we contend establishes Robberg as a site of special palaeontological significance in southern Africa.

We anticipate that our samples for OSL dating will add to the remarkable dating results on Robberg aeolianites that were recently published, and which revealed that Robberg harbours the only known aeolianites from MIS 3 along the Cape south coast. The protected status of the area creates opportunities for conserving and interpreting this impressive example of Cape south coast geoheritage. Ongoing exploration and documentation are required to record the evolution of known sites and to search for new sites.

We acknowledge the support of Natalie Baker and staff of CapeNature, Gary Bronner, Elbie Burger, Jacob Carrigan, Mark Dixon, Daniel Helm, Linda Helm, Martin Lockley, Tammy Pigeon, and David Scott. We thank Greg Botha and Martin Lockley for their thorough and helpful reviews, and Jonah Choiniere for his work as editor.

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