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Late Pleistocene vertebrate trace fossils in the Goukamma Nature Reserve, Cape south coast, South Africa

Charles W. Helm[1,2*], Richard T. McCrea[1], Martin G. Lockley[3], Hayley C. Cawthra[2,4], Guy H.H. Thesen[2] & Joshua M. Mwankunda[5]

[1]*Peace Region Palaeontology Research Centre, Box 1540, Tumbler Ridge, British Columbia, V0C 2W0, Canada*

[2]*African Centre for Coastal Palaeoscience, P.O. Box 77000, Nelson Mandela University, Port Elizabeth, 6031 South Africa*

[3]*Dinosaur Trackers Research Group, Campus Box 172, University of Colorado Denver, P.O. Box 173364, Denver, 80217-3364, U.S.A.*

[4]*Marine Geoscience Unit, Council for Geoscience, P.O. Box 572, Bellville, 7535 South Africa*

[5]*Ngorongoro Conservation Area Authority, P.O. Box 1, Ngorongoro Crater, Arusha, Tanzania*

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More than 100 Late Pleistocene trace fossil sites have been identified in aeolianites along a 275 kilometre stretch of the Cape south coast. A zone of concentration of such sites exists within the Goukamma Nature Reserve, both along the coast and along the Goukamma River. These sites provide insight into the Pleistocene fauna along the Cape south coast. Features include lion trackways, multiple elephant tracksites, a long trackway most likely attributable to long-horned buffalo, medium-sized carnivore tracks, avian tracks, equid tracks attributable to the giant Cape horse, numerous artiodactyl tracks, and burrow traces. The ephemeral nature of the tracksites makes regular surveys of these areas desirable, along with site documentation and trackway replication and preservation initiatives. The protected status of the area offers opportunities for geoheritage appreciation.

Keywords: Late Pleistocene, trackways, aeolianites, Goukamma.

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INTRODUCTION

Aeolianites are exposed along many parts of the South African coastline. Pleistocene aeolianites, or cemented palaeodunes, of the coastal environment are geographically extensive, forming stacked dune deposits of calcarenite with interbedded palaeosols (Fairbridge & Johnson 1978; Murray-Wallace *et al*. 2010). The distribution of such deposits is relatively common in mid-latitude regions (typically between 20° and 40° N and S) and they have been recorded in both hemispheres (Brooke 2001). Globally, the formation of aeolianites has been recorded under varying glacio-eustatic climate regimes ranging from intervals of sea-level stability associated with interglacial highstands (Roberts *et al*. 2008), periods of relative sea-level change at the termination of glaciation (Vacher & Rowe 1997), and under both sets of conditions (Bateman *et al*. 2004). Along the Cape coast, extensive early studies of aeolianite have been conducted by Siesser (1972), Hendey & Volman (1986), Martin & Flemming (1987), and more recently by Bateman *et al*. (2004, 2011), Carr *et al*. (2007, 2010), Roberts *et al*. (2008, 2009) and Cawthra *et al*. (2018). Fossil dune systems along the South African coast are sensitive barometers of fluctuations in palaeo-environments and palaeoclimate, as archived in their orientation, geometry, palaeontology and archaeological content (Roberts *et al*. 2013).

The aeolianites are composed of medium- to fine-grained sand with a high carbonate content derived from marine shell fragments. These dune deposits lithify as a result of the downward percolation of rainwater in the meteoric diagenetic zone, which mobilizes the carbonate shell component in the dune, re-depositing the carbonates as interstitial cement within the sandstone matrix (Flügel 2004).

A preliminary ichnological ground survey of aeolianites along the Cape south coast between Witsand and Robberg, a distance of 275 km, was conducted by C.W.H. between 2007 and 2017, results of which will be published elsewhere. More than 100 tracksites were identified during the course of this survey. Such surveys can provide an independent source of palaeoecological data, and can complement information from the body fossil record. Although there may be a bias towards the preservation of the deeper tracks of larger, heavier animals, ichnofossils in aeolianites provide direct evidence of the locomotion and

*Author for correspondence. E-mail: helm.c.w@gmail.com

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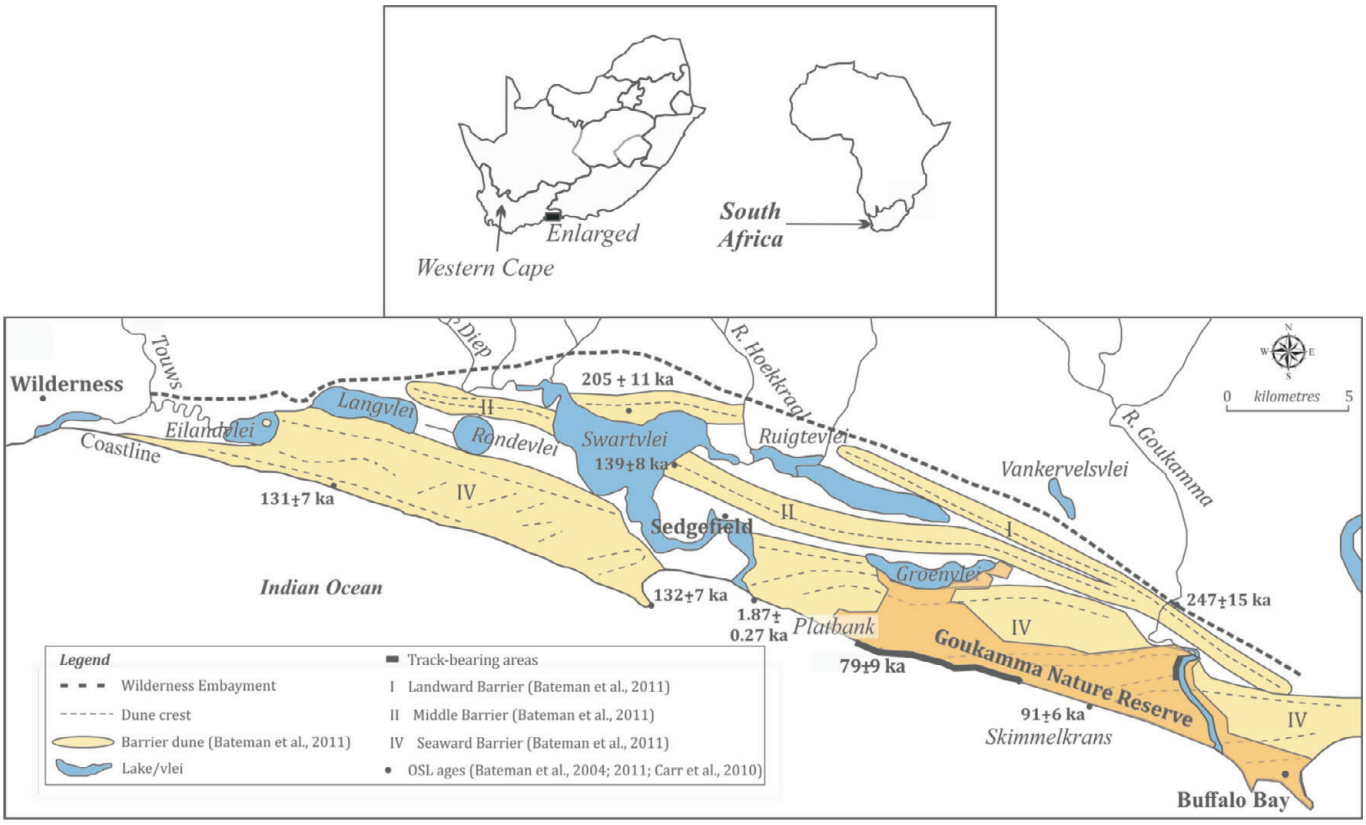


Figure 1. The stratigraphy and geomorphology of the coastline at Goukamma Nature Reserve and the Wilderness Embayment, modified from Bateman *et al*. (2011) and Cawthra *et al*. (2014). The seaward cordon is composed of basal Marine Isotope Stage (MIS) 5 deposits, draped by a veneer of Holocene wind-blown sands. Track-bearing areas within the Goukamma Nature Reserve are indicated.

frequency of animals moving over dunes and interdune areas. Tracks of extinct species or range extensions of extant species may be identified, which may have palaeoecological implications (Helm *et al*. 2018). The age of track-bearing aeolianites can be determined using optically stimulated luminescence (OSL) dating.

Along this stretch of coastline three main zones of concentration of fossil tracks were noted. One of these zones lies within the Goukamma Nature Reserve, which is managed by CapeNature (Fig. 1). It is the only such zone of concentration of tracks that is situated within a protected area. The purpose of this article is to formally document the vertebrate trace fossils that have been identified in the Goukamma Nature Reserve, to discuss some of the more unique and unusual tracksites, and to consider aspects of their preservation and interpretation.

GEOLOGICAL CONTEXT

Less than a quarter of the coastline surveyed between Witsand and Robberg comprises aeolianite exposures; the remainder comprises Palaeozoic quartzite exposures of the Cape Supergroup, Palaeozoic granite exposures of the Cape Granite Suite, and long expanses of beach and unconsolidated Holocene dunes.

Where Pleistocene aeolianites occur along this coast, exposed bedding planes are common. Some tracksites are exposed *in situ*, while others have dislodged and now lie at the base of coastal cliffs. Quaternary tectonic activity was minimal on the Southern Coastal Plain (Fleming *et al*. 1998), and the *in situ* bedding planes therefore lie at or close to their original angles of deposition, which are often at the angle of repose of wind-blown sands (~10–30°). Planar bedded, steeply dipping dune facies alternate with low-angled laminated facies that represent interdune areas. The aeolianites are interrupted in places by palaeosols containing a high abundance of rhizoliths. Factors that promoted track preservation may have included the favourable substrate constituted by moist dune sand, swift burial due to high sedimentation rates, and the high bioclastic carbonate content of coastal dunes, which promoted rapid calcification (Roberts 2008).

The track-bearing aeolianites along the Cape south coast are from the Late Pleistocene Waenhuiskrans Formation, which forms part of the Bredasdorp Group (Malan 1989). These aeolianites have been dated to between 400 and 60 ka through optically stimulated luminescence (OSL) and amino acid racemization (AAR) chronology (Roberts *et al*. 2008, 2012; Bateman *et al*. 2011; Cawthra *et al*. 2018).

In the area of the Goukamma Nature Reserve the stratigraphy described falls within the Wilderness Embayment (Illenberger 1996; Bateman *et al*. 2004, 2011). The large, roughly shore-parallel ridges of the Wilderness Embayment are also referred to as cordon dunes (Illenberger 1996). These aeolian deposits comprise unconsolidated sand to heavily lithified aeolianite and are separated by several back-barrier lakes. Notable phases of construction have been constrained to between 241–221 ka, 159–143 ka, 130–120 ka, 92–87 ka and post 6 ka (Bateman *et al*. 2011). These appear to be associated with regressive phases subsequent to sea-level high stands. Around 91 ka BP, sea levels were as much as 45 m lower than at present, and the coastline may have been as much as 60 km seaward of

today's coast. At 79 ka BP sea levels were ~25 m lower than at present, and the coastline was 1–2 km from today's coast in the study area (Fisher *et al*. 2010; Cawthra *et al.* 2014; Marean *et al*. 2014).

The Goukamma area is characterized by stratigraphy consisting of composite Marine Isotope Stage (MIS) 5 deposits at the base, draped by a Holocene unconsolidated unit of modern dunes (Bateman *et al*. 2011). Malan (1989) noted lateral variation in the aeolianites of the Waenhuiskrans Formation, with well-cemented exposures in the west, and less well-cemented exposures further east. The latter are more likely to cleave along bedding planes, yielding large surfaces that may be suitable for ichnofossil identification. The aeolianites in the Goukamma area occur towards the eastern end of the Waenhuiskrans Formation, and consequently contain numerous suitable bedding plane exposures.

METHODS

Annual visits were conducted to the aeolianites of the Goukamma Nature Reserve from 2012–2017. Global Positioning System readings were obtained for tracksites using a handheld device, with accuracy of 5–10 metres. Measurements of track length, track width, pace length and stride length were recorded (*sensu* Stuart & Stuart 2000). Results were recorded in centimetres, as track definition was not considered to be sufficiently sharp to render measurement in millimetres accurate. Tracings were made of selected trackways. Contact was made with CapeNature staff to discuss potential preservation and education initiatives.

Two distinct track-bearing areas are present in the Goukamma Nature Reserve: coastal tracks and riverine tracks. So as to allow for optimal low-angle illumination on the track-bearing surfaces, the coastal tracks were mainly studied in the early morning, while the riverine tracks were mainly studied in the early afternoon.

Photogrammetry (Mallison & Wings 2014) was performed on selected sites, using a Canon PowerShot ELPH 340 HS camera with 4608 × 3456 resolution and pixel size of 1.34 μm × 1.34 μm, using a 4.5 mm focal length. 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).

RESULTS

There are two main track-bearing areas within the Goukamma Nature Reserve: a 6 km coastal stretch of aeolianites east of Platbank, and a 500 m aeolianite exposure situated 2 km inland along the west bank of the Goukamma River, which forms the only known non-coastal Late Pleistocene fossil track area in the southern Cape. More than 30 vertebrate ichnofossil sites were identified.

Locality data are reposited with the African Centre for Coastal Palaeoscience at Nelson Mandela University, South Africa, and the Peace Region Palaeontology Research Centre in British Columbia, Canada. Photogrammetric data are reposited at the Peace Region Palaeontology Research Centre, and will be available through the Accessible Vertebrate Ichnology Database (AVID), the international database due to go online in 2018 (avid.prprc.com).

Previous OSL dating close to the coastal sites yielded ages of 91 ka ± 6 ka and 79 ka ± 9 ka (Bateman *et al*. 2011). Dating of the inland sites has not yet been conducted.

Changes were noted from year to year in the amount of sand cover on coastal beaches. Rock layers close to the shoreline are therefore sometimes exposed (typically after heavy storms) and at other times are covered by sand. Some tracksites are consequently only occasionally visible. Tracks are ephemeral, and new exposures were noted, while some previously identified tracks had been eroded or disappeared. The presence of graffiti was noted, as fallen aeolianite blocks with large, smooth surfaces have proven attractive to modern vandals. In some cases graffiti destroyed fossil tracks, whereas at one site it caused surface layers to fail, exposing tracks in an underlying layer.

A range of trace fossil types was noted: track impressions in original dune surfaces, undertracks, tracks in cross-section, natural casts of tracks on the under-surfaces of overhangs, and burrow traces, as well as rhizoliths. Some of the tracks were made in soft substrates, and lacked sufficient detail to identify the trackmaker to species, genus or family level with confidence.

Avian tracks: In 2014, two adjacent sites above the Goukamma River featured tridactyl tracks (Fig. 2). One slab contained three tracks (digit III = ~7 cm, digits II and IV = ~3 cm in length), two of which appear to form a trackway (Fig. 2A). Smaller tracks (digit III = ~2 cm in length) were noted on an adjacent slab (Fig. 2B) that also contained graffiti. By 2017 these surfaces had become severely eroded and the tracks were no longer identifiable.

Elephant tracks: The linear dimension values in association with empirical observations of morphology (e.g. distinctive, slightly oval pes tracks and relatively circular manus tracks) make elephant impressions readily identifiable (Liebenberg 2000; Stuart & Stuart 2000). These tracks occur at six widely separated localities within the Goukamma Nature Reserve, are often associated with large sediment displacement rims, and sometimes contain an infill layer. Dimensions of two measured tracks are 28 cm × 26 cm (Fig. 3A) and 23 cm × 20 cm (Fig. 3B). In cross-section the tracks may disturb the underlying substrate by up to 30 cm, creating soft sediment deformation structures (Fig. 3C). At one site such deformations were noted in seven discrete layers over a stratigraphic sectional height of 10 m. At another site a section of 26 m has multiple discrete layers containing such structures. Where these bedding plane surfaces are exposed at these sites, tracks with size and shape consistent with elephant trackmakers are evident. We did not identify any unambiguous large abiotic traces on aeolianite surfaces. Undertracks are present in the layers immediately below the track-bearing layers. At one coastal site natural casts of elephant tracks have been eroded into unusual shapes (Fig. 3D).

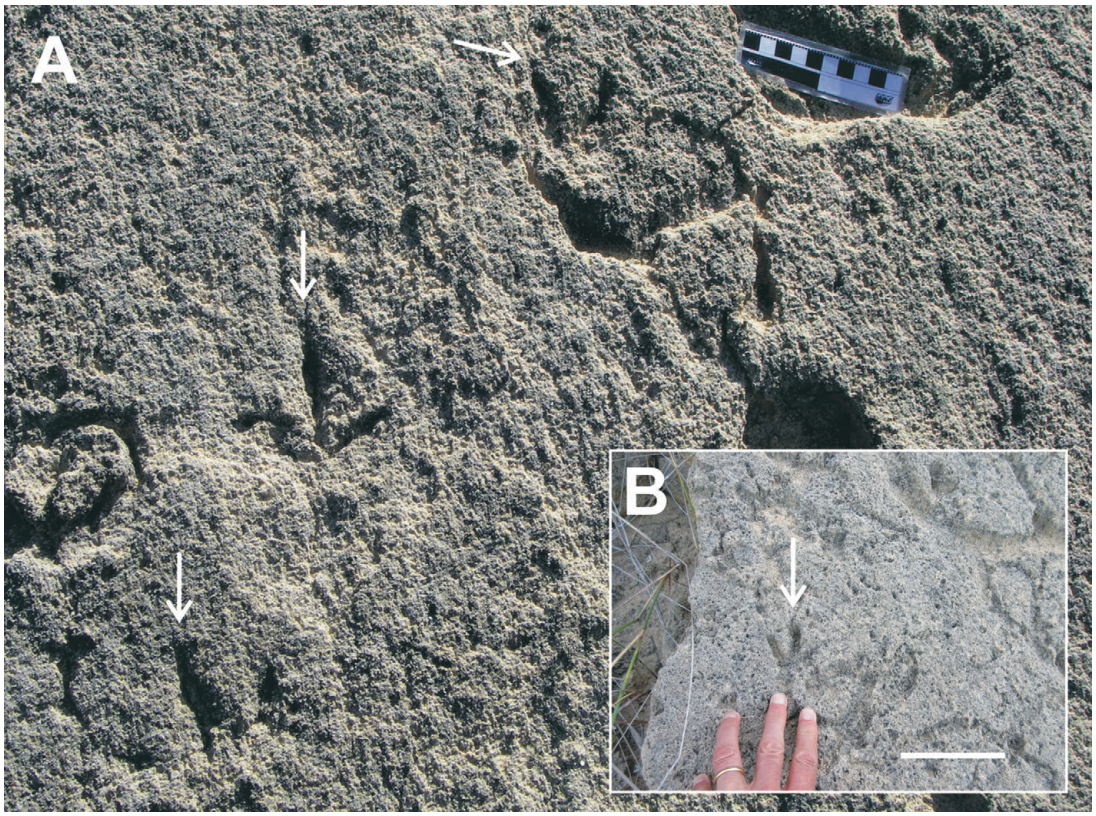


Figure 2. **A**, Avian tracks on aeolianite slab beside Goukamma River; scale bar =10 cm. For each track, the arrow points to Digit III. **B**, Small avian track on aeolianite slab adjacent to that shown in A; scale bar = 4 cm. Graffiti is evident.

Large artiodactyl tracks: A fallen block below a prominent cliff on the Goukamma coast contains a large artiodactyl (>10 cm) trackway which is more than 5 m in length, and which contains 17 consecutive tracks on a steeply inclined surface (Fig. 4). The tracks overlap the midline of the trackway (Fig. 4C). The tracks have a typical artiodactyl morphology, with two digit impressions separated by an interdigital sulcus, which is open anteriorly

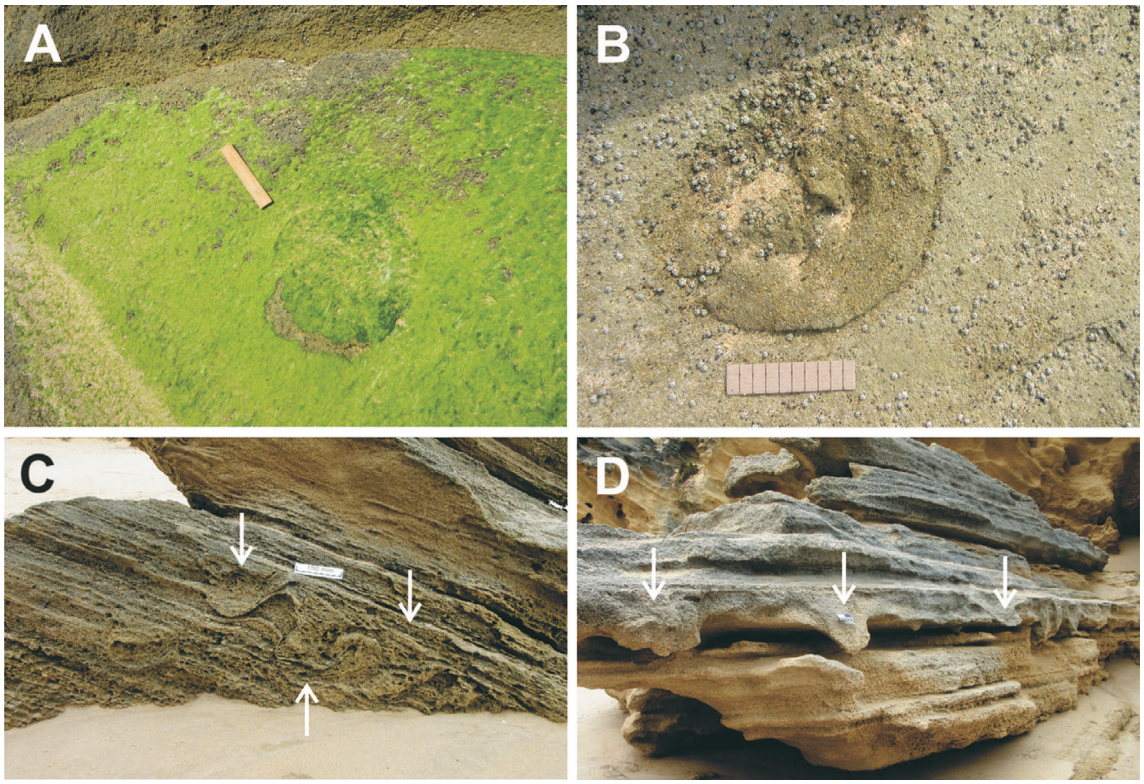


Figure 3. **A**, Elephant track measuring 28 × 26 cm on algae-covered rock, with sediment displacement rim; scale bar = 15 cm. **B**, Juvenile elephant track with infill, 23 cm × 20 cm; scale bar = 10 cm. **C**, Elephant tracks in cross-section, Goukamma Nature Reserve coastline; scale bar = 15 cm. **D**, Arrows indicate elephant track natural casts eroded into unusual shapes, Goukamma coastline; scale bar = 10 cm.

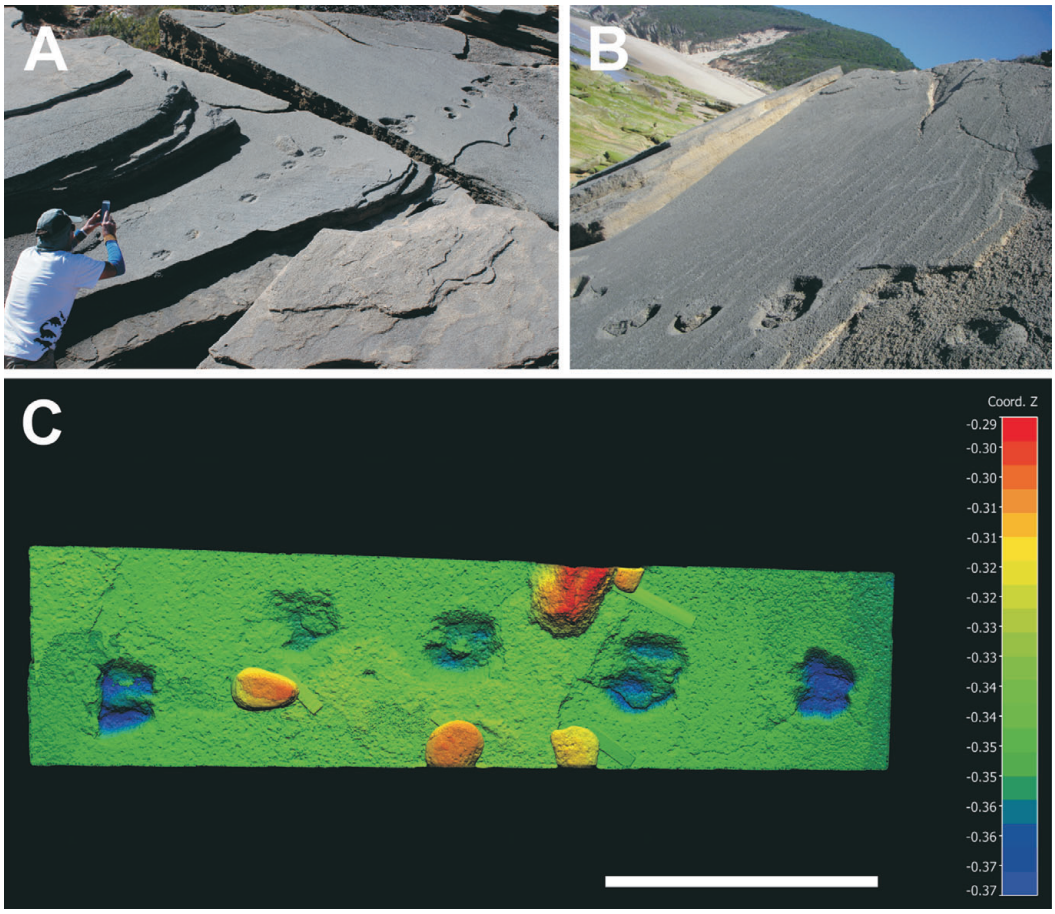


Figure 4. **A**, Co-author M.L. photographing large artiodactyl trackway on Goukamma Nature Reserve coastline; tracks 1–16 are visible (photograph reproduced with permission from Sinèad Hattingh). **B**, Large artiodactyl trackway viewed from above, showing tracks 9–15. **C**, False cloud depth model produced from the photogrammetric model of tracks 4–8 from large artiodactyl trackway. Sixty-four images from Canon PowerShot ELPH 340 HS (4.5 mm) with 4608 × 3456 resolution and pixel size of 1.34 μm × 1.34 μm using a 4.5 mm focal length. The average camera altitude was 0.327 m. The precision of the model is 0.126 pix. Vertical scale is in metres. Horizontal white scale bar = 0.5 m.

and posteriorly. Width equals or exceeds length in the better-preserved tracks (Table 1). Average pace length for the trackway is 31 cm, with an average stride length of 60 cm. Photogrammetric models and false-colour depth maps were made of tracks 1–2 and 4–8.

The tracks within this slightly sinuous trackway are highly variable along its length. The first three tracks are partially covered by a thin layer of infill. The final three tracks are poorly preserved undertracks. Tracks 4 to 8 were made on a firm substrate, are relatively shallow, and provide the best-preserved morphology. Tracks 9 to 14 were made on a soft substrate, and are large and deep (maximum length 23 cm; maximum width 33 cm, both in Track 9).

The trackway is intersected by a post-depositional structural crack halfway along its length. There are no significant sediment displacement rims associated with the tracks, and bedding planes in the cliffs behind the trackway, from which it originated, are close to horizontal. Wind-generated ripple marks are evident on the surrounding surface. Wind direction was from behind and slightly to the left of the trackmaker.

Table 1. Length and width data for large artiodactyl trackway from the Goukamma Nature Reserve coastline, South Africa.

Track number	Length (cm)	Width (cm)
01	12	13
04	11	14
05	12	12
06	12	12
07	14	14
08	10	12
Mean	11.8	12.8

Other artiodactyl tracks: These form a commonly encountered ichnofossil morphotype, which we divide into medium-sized (5–10 cm) and small-sized (<5 cm) tracks. Most of these cannot be identified to species level. A photogrammetric model and false colour depth image was made of one small, well-preserved track (length 3.2 cm, width 3 cm) (Fig. 5).

Equid tracks: Three tracks were identified in 2014 on a slab above the Goukamma River (length 14 cm, average width 13 cm) (Fig. 6A). There is no evidence of a cloven hoof, and a hoof wall is possibly present. In one of the tracks, the 'frog' is possibly evident. By 2017 this surface had been severely eroded and the tracks were barely identifiable.

Three very shallow tracks (Fig. 6B) were transiently exposed in 2017 on a fallen block on the coast. Hoof wall and 'frog' are evident (length 16 cm, width 13 cm). One of the tracks appears 'registered', with the hind foot impression superimposed on the forefoot impression, creating a slightly larger track appearance.

Large carnivore tracks: Two large carnivore prints, with

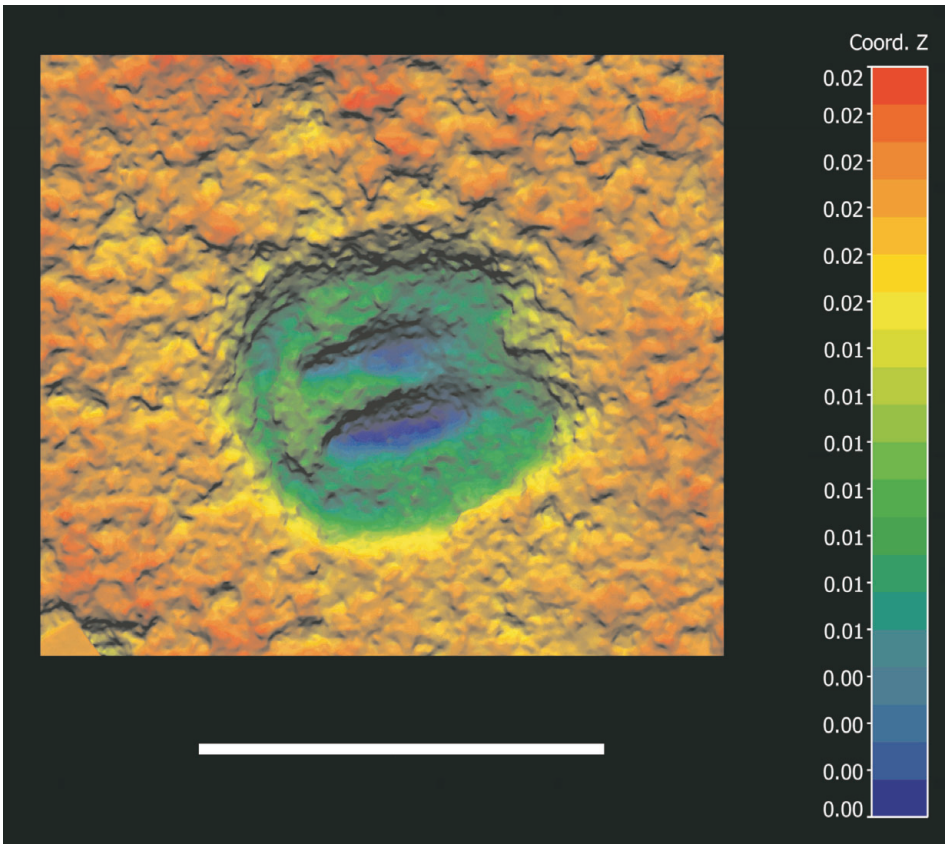


Figure 5. False colour depth map from a photogrammetric model of a small artiodactyl track from the Goukamma Nature Reserve coastline. Twenty-seven images from Canon PowerShot ELPH 340 HS (4.5mm) with 4608 × 3456 resolution and pixel size of 1.34 μm × 1.34 μm using a 4.5 mm focal length. The average camera altitude was 0.334 m. The precision of the model is 0.157 pix. Vertical scale is in metres. Horizontal white scale bar = 10 cm.

well-defined main pad and four digital pads, form a short trackway on a fallen block on the coast (Fig. 7). Claw marks are not evident. The hind edge of the main pad does not appear to be bifid. The main pad is somewhat triangular, with the anterior apex oriented along the line of the trackway. The leading edges of the front two toes do not appear to be side-by-side.

The first track (length 15 cm, width 13 cm, depth 3.0 cm)

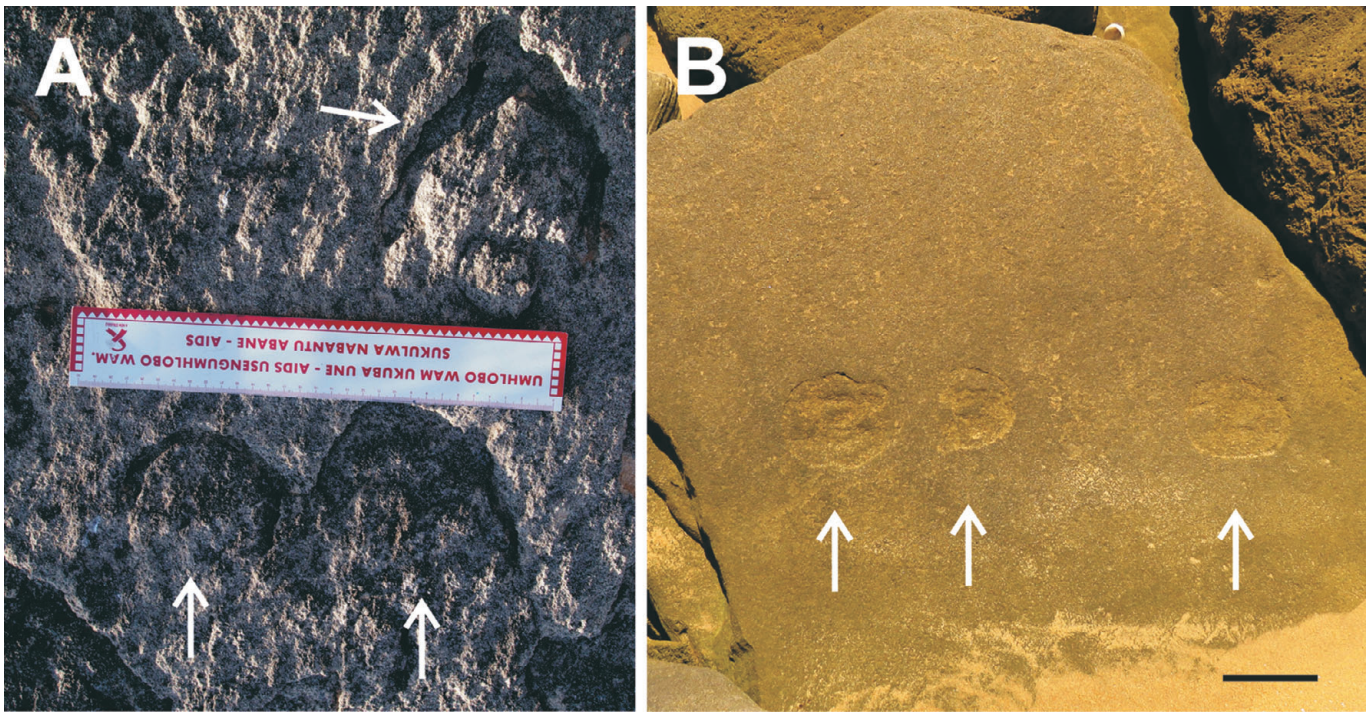


Figure 6. **A**, Three possible equid tracks (length 14 cm, average width 13 cm) above the Goukamma River; scale bar = 30 cm. **B**, Three equid tracks (length 16 cm, width 13 cm) on the Goukamma Nature Reserve coastline; scale bar = 15 cm (photograph reproduced with permission from Johan Huisamen).

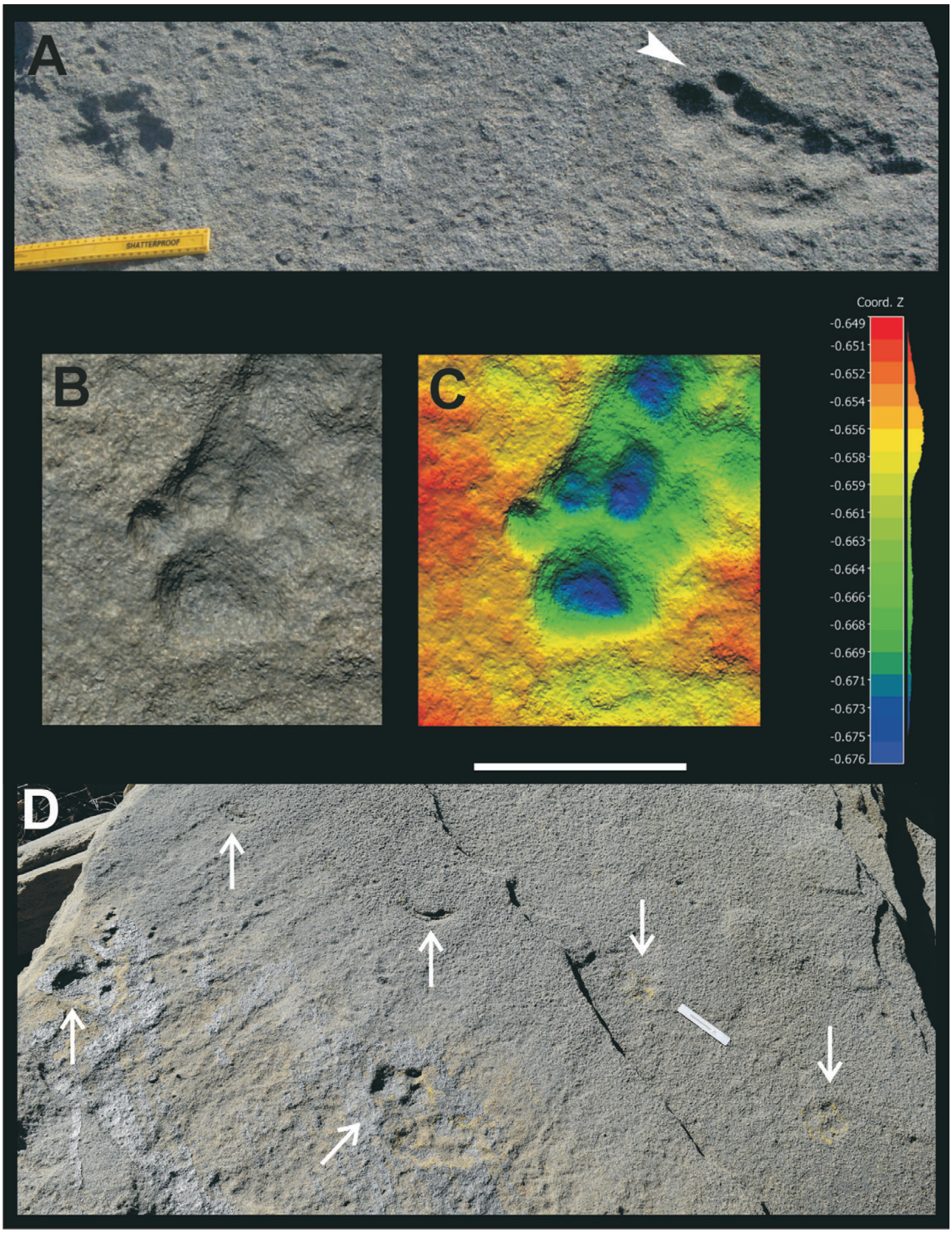


Figure 7. A, Large felid trackway from the Goukamma Nature Reserve coastline; the arrow indicates the track featured in B & C. Indentations anterior to this track likely represent impressions from the poorly preserved front track, with overprinting. Scale bar = 30 cm. **B**, Image capture of a 3D photogrammetry model of large felid track. **C**, Photogrammetric model with colour vertical profile of the large felid track. Model constructed from ten images from Canon PowerShot ELPH 340 HS (4.5 mm) with 4608 × 3456 resolution and pixel size of 1.34 μm × 1.34 μm using a 4.5 mm focal length. The average camera altitude was 0.299 m. The precision of the model is 0.152 pix. Vertical scale is in metres. Horizontal white scale bar = 15 cm. **D**, Arrows indicate six tracks: the two arrows at bottom left point to the trackway shown in A; the two arrows at top left point to crescentic in-filled tracks; the two arrows at right point to undertracks. Scale bar = 30 cm.

is not as well preserved as the second (length 17 cm, width 14 cm, depth 4.0 cm) but has a similar shape. Pace length is 76 cm. Indentations anterior to each track are indistinct but are likely related to overstepping. A photogrammetric model of the second track was created, along with false colour depth map (Fig. 7B,C).

On the same surface, ~65 cm to the left of this trackway and lying approximately parallel to it, there is another trackway of two tracks, each comprising a crescentic, in-filled depression. Distal to these two in-filled depressions the track-bearing surface is lost, but in the same line of progression are two carnivore undertracks on a layer ~1.5 cm below (Fig. 7D). These two undertracks (length ~12 cm, width ~12 cm), like the aforementioned trackway, have diagnostic felid morphology which becomes apparent under low-angle illumination. Pace lengths

between the four tracks in this trackway are consistent: 60 cm, 61 cm, 61 cm.

Sediment displacement rims are not evident around the tracks. A horizontal bedding plane between layers of steeply dipping beds is evident in the cliffs just above the track-bearing block. In late 2017 two large carnivore tracks were found 30 m from these trackways, on a loose block that had been exposed by the scouring action of high tides.

Medium-sized carnivore tracks: A medium-sized carnivore trackway on a slab on the banks of the Goukamma River comprises 14 tetradactyl tracks (length 4–5 cm) with a probable consistent pace length of ~30 cm (Fig. 8A,B). Well-defined main pads are evident and well-preserved digital pads appear to taper distally into probable claw impressions. The rock slab is submerged when the river mouth is closed. Between 2014 and 2017 the definition of the tracks in the distal portion of this trackway diminished. This portion of the slab is often exposed to wind and tidal action. In 2017, the tracks in the proximal portion of the trackway, which lay below the sand level and which we exposed, appeared well defined. The trackway occurs on a flat surface without a consistent pattern of sediment displacement rims. However, one track has an almost perfectly circular sediment displacement rim all around it.

Four parallel, relatively straight trackways, all with the same bearing, exist on a fragile, vulnerable fallen slab on the sandy slopes above the Goukamma River (Fig. 8C). Preservation of track detail is poor, but main pads and digital pads can be discerned. Substantial sediment displacement rims are present (Fig. 8D). The longest, most obvious trackway initially comprised 11 tracks, but one track has subsequently been lost. Track lengths vary from 5.0 cm to 6.5 cm; pace lengths vary from 34.5 to 37.0 cm.

Burrow traces: Sinuous, anastomosing and branching epifaunal traces up to 10 cm in diameter are evident on a large fallen block at a coastal site (Fig. 9A,B).

Invertebrate traces: Numerous invertebrate traces, including burrows, are evident in both coastal and riverside aeolianites.

Rhizoliths: Large agglomerations of rhizoliths are a prominent feature in the coastal cliffs at Skimmelkrans.

DISCUSSION

Goukamma Nature Reserve is of unique importance as a 2,500 hectare protected area which preserves a 13 km stretch of coastline and 3 km of frontage along the Goukamma River. These environments boast numerous Late Pleistocene vertebrate fossil trackways. Further dating studies (especially of the aeolianites along the Goukamma River) are desirable, to complement the work of Bateman *et al*. (2011).

Avian tracks (Fig. 2): Prior to the study of fossil tracks in Cape south coast aeolianites, there was only one published record of an avian fossil trackway from South Africa, from Nahoon, over 500 km to the east (Roberts 2008). It contained a three-track trackway and a possibly a second faint avian trackway, in addition to the first hominin tracks reported from southern Africa. Fourteen avian tracksites have subsequently been identified along the Cape south coast (Helm *et al*. 2017), and will be fully described elsewhere. The Goukamma tracks thus form a part of this archive of Late Pleistocene birdlife. Trackmaker identification to family level is not possible in the case of the two Goukamma track surfaces, although the tracks bear some resemblance in size and morphology to those of gulls (Laridae) and shorebirds (e.g. Charadriidae). Their disappearance just three years after their discovery, a process that was possibly accelerated by stress to the track-bearing surface induced by the etching of graffiti, provides an example of the ephemeral nature of aeolianite ichnofossil sites.

Elephant tracks (Fig. 3): There is no body fossil evidence to suggest that earlier elephant species such as *Loxodonta atlantica* survived later than 400 ka (Klein *et al*. 2007; Carruthers *et al.* 2008), which leaves the extant African Elephant (*Loxodonta africana)* as the probable trackmaker. Despite their large size and being readily identifiable, fossil elephant tracks from South Africa were not reported until 2008 (Roberts *et al*. 2008) at a site east of Still Bay. Similar tracks have subsequently been identified along the Cape south coast in the Goukamma Nature Reserve and at Dana Bay and Brenton-on-Sea.

In the Goukamma Nature Reserve many elephant tracks are evident in cross-section as soft sediment deformation structures. These extend through multiple bedding planes, which measure up to 26 m in section. Abiotic forces can also create soft sediment deformation structures (Molina *et al.* 2002). However, we are confident in identifying these deformations as elephant tracks in profile, given the clear presence of elephant tracks on adjacent surface exposures of these track-bearing layers. This contention is buttressed by the absence of unambiguous abiotic traces on aeolianite surfaces in the Goukamma Nature Reserve. We conclude that elephants used certain areas repeatedly over time, moving over successive interdune surfaces and dune faces.

The Cape south coast sites are the only reported Pleistocene elephant tracksites in southern Africa, other than a single documented occurrence near Durban (over 800 km to the northeast) (Cawthra *et al*. 2012). Elsewhere in Africa, Musiba *et al*. (2008) reported Pliocene elephant tracks from Laetoli in Tanzania, Roach *et al*. (2016) reported Pleistocene elephant tracks from Ileret in Kenya, and Bennett *et al.* (2010) reported Holocene elephant tracks from the Kuiseb delta in Namibia.

Large artiodactyl tracks (Fig. 4): If the large artiodactyl trackway comprising 17 tracks had been made on a dune slope, sediment displacement rims would be an expected feature at the downslope end of the tracks. The absence of sediment displacement rims, and the fact that the bedding plane from which the track-bearing slab appears to have broken off is close to horizontal, suggest that the tracks were made in a relatively horizontal interdune area.

Amongst the tracks of extant large artiodactyl species, buffalo tracks most closely resemble these fossil tracks. However, the fossil track morphology noted differs subtly from that of the extant Cape Buffalo (*Syncerus caffer*). In these tracks, width consistently equals or exceeds length

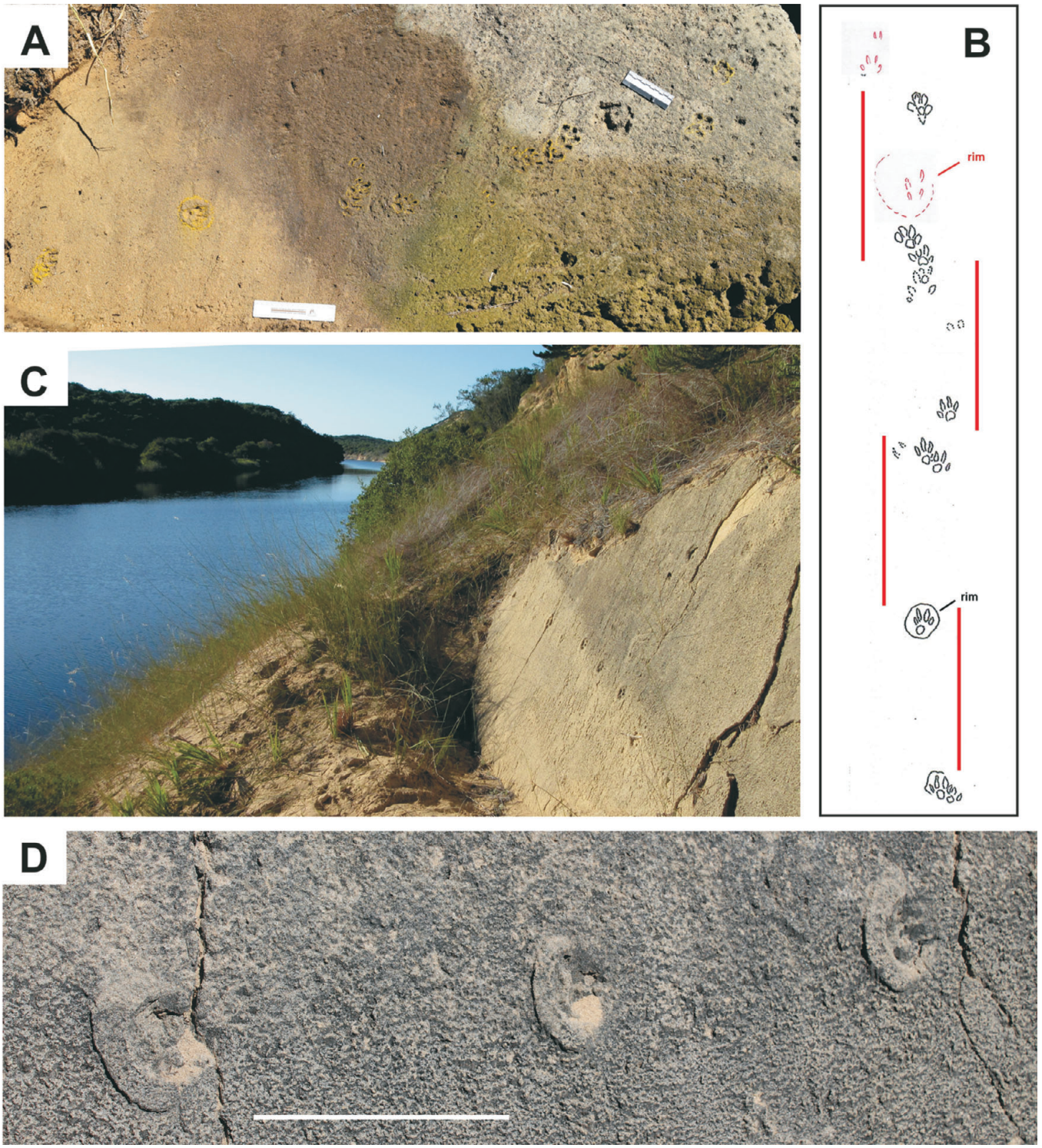


Figure 8. **A**, Medium-sized carnivore trackway comprising 14 tracks, outlined in chalk, beside the Goukamma River. Scale bars = 15 cm (left) and 10 cm (right). **B**, Tracing of trackway shown in A; red vertical lines suggest a constant pace length of ~30 cm. **C**, Medium-sized carnivore trackway comprising 11 tracks above the Goukamma River; four parallel trackways are present on this surface, but only one of these is distinct on this photograph. **D**, Detail of three tracks from trackway shown in C; prominent sediment displacement rims are present at the downslope end of the tracks (photograph reproduced with permission from Sinèad Hattingh); scale bar = 20 cm.

(Table 1), a characteristic not apparent in the front feet or hind feet of *Syncerus caffer* or any other extant ungulate in the region (Liebenberg 2000; Stuart & Stuart 2000; Van den Heever *et al.* 2017). Noting that 'hooves follow horns' and that wider horns are associated with wider tracks (Lockley 1999), and that the extinct long-horned buffalo *Syncerus antiquus* had extremely long horns extending laterally, we consider it to be the most plausible trackmaker. In contrast, fossil buffalo trackways at Brenton-on-Sea, less than 20 km to the east, display dimensions consistent with tracks of *Syncerus caffer* (mean length 16 cm; mean width 15 cm, n = 5). In a discussion of artiodactyl tracks of this size in extant species, eland (*Taurotragus oryx*) needs to be considered as a possible trackmaker, but this species typically produces tracks that are slightly smaller and relatively narrower than buffalo

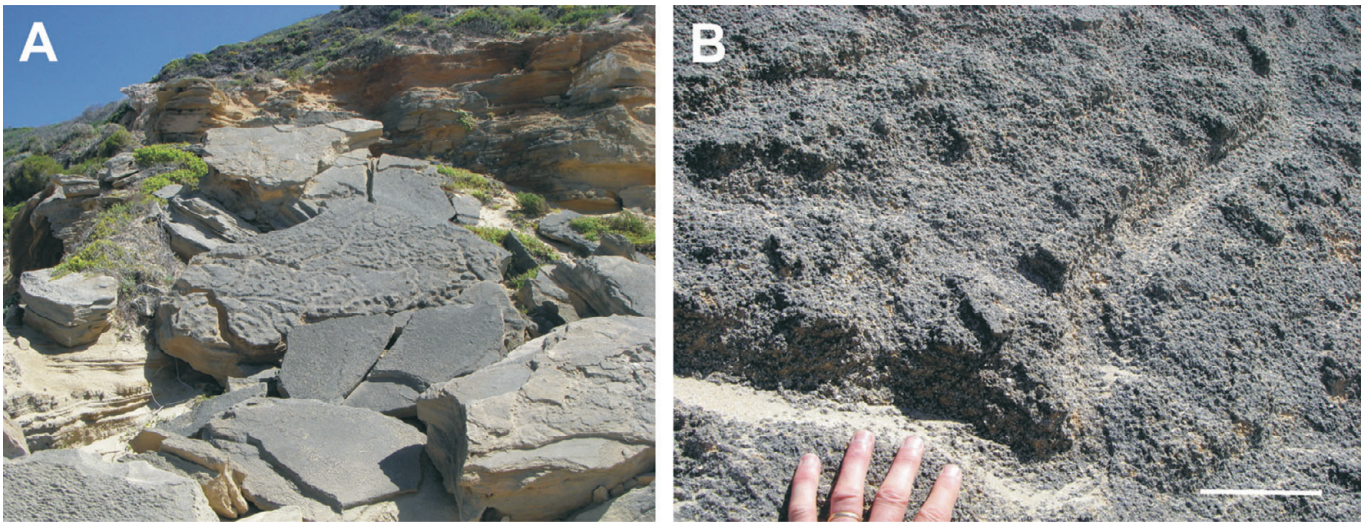


Figure 9. **A**, Branching epifaunal traces on fallen aeolianite slab, Goukamma Nature Reserve coastline. **B**, Detail of epifaunal traces shown in A; scale bar = 20 cm.

tracks (Liebenberg 2010; Stuart & Stuart 2010; Van den Heever *et al.* 2017).

A modern equivalent exists with short-horned and long-horned cattle populations in Africa. Our photographs comparing the tracks of short-horned cattle (a variety of *Bos taurus taurus*) from the southern Cape with long-horned Ankole cattle (a variety of *Bos taurus indicus*) in Tanzania indicate that Ankole cattle tracks are wider than they are long, and that short-horned cattle tracks have a length that is equal to or greater than their width (Fig. 10). Similarly, cattle farmers in South Africa recognize that the tracks of short-horned cattle can be distinguished from those of Nguni cattle with horns of medium length, the latter being proportionately wider. Age, sex, and the substrate on which cattle spend most of their time walking may conceivably affect track dimensions, but the experience of farmers is that such factors are less relevant than the differences between these two strains (N. Smit, pers. comm., 18 October 2016).

The only other known postulated tracksites of *Syncerus antiquus* comprise single tracks. They occur east of Still Bay (13.5 cm in length, 16 cm in width) and at Robberg (11 cm in length, 12.5 cm in width) and will be reported elsewhere. There has been debate as to whether *Syncerus*

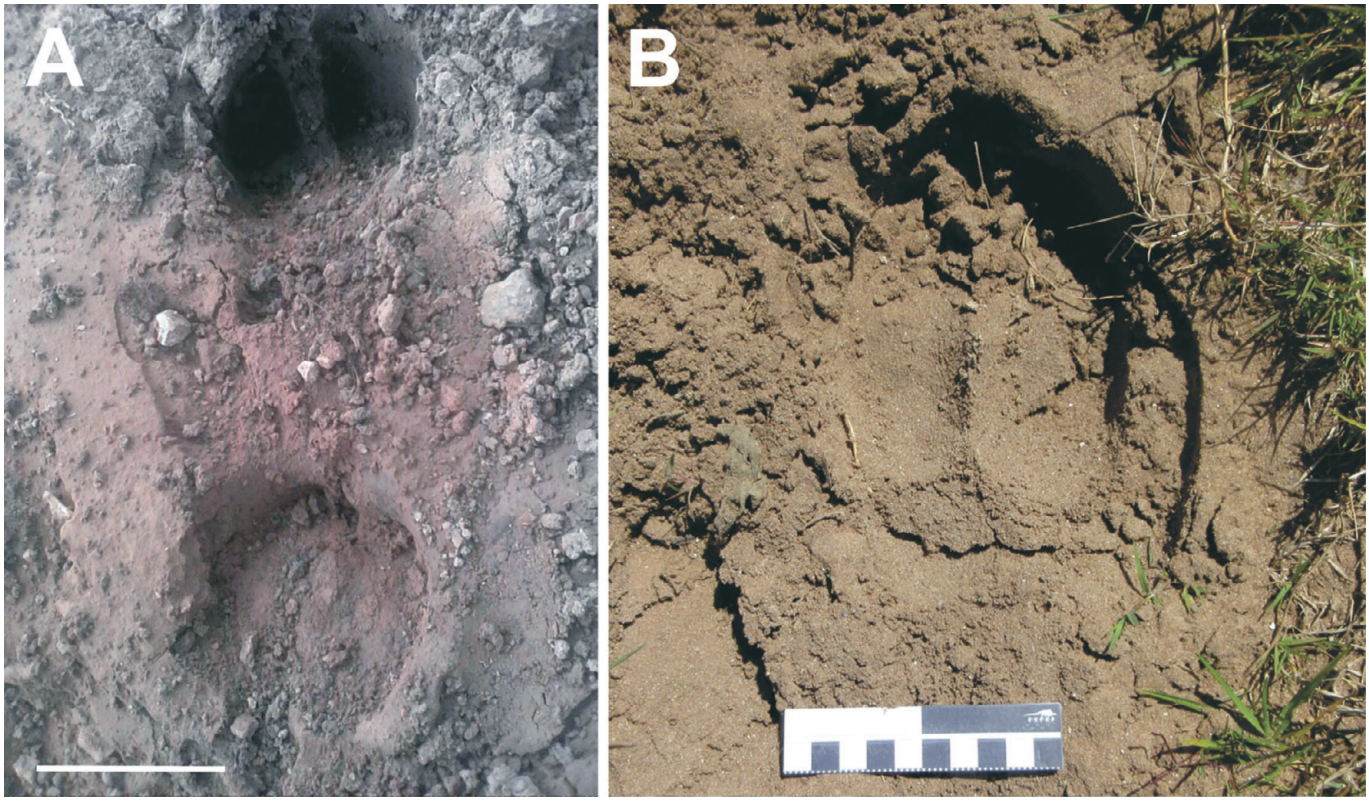


Figure 10. **A**, Two tracks of an extant species of long-horned Ankole cattle (a variety of *Bos taurus indicus)* from Tanzania, showing a track that is at least as wide as it is long; scale bar = 10 cm. **B**, A track of an extant species of short-horned cattle (a variety of *Bos taurus taurus*) from the Cape south coast, showing a track that is longer than it is wide; scale bar = 10 cm.

antiquus justifies its own genus, *Pelorovis.* In contrast, a suggestion that it might just represent a race of *Syncerus caffer* was rebutted (Klein 1994).

Other artiodactyl tracks (Fig. 5): The best preserved small artiodactyl track provides an example of the challenges associated with the identification of such tracks. It does not obviously resemble the typical track of any extant trackmaker. The two digit impressions are relatively parallel, unlike those of most small ungulates, which converge distally. Parallel impressions of this kind suggest the possibility of a klipspringer (*Oreotragus oreotragus*) having made the track, but they are larger than the klipspringer 'slots', and the klipspringer is a habitat specialist, unlikely perhaps to have been found on dune or interdune surfaces. Small ungulates such as common duiker (*Sylvicapra grimmia*) and Cape grysbok (*Raphicerus melanotis*) may splay their digits when treading in a soft substrate or when moving fast (Van den Heever *et al.* 2017); such factors may account for the appearance of this track. Juvenile bushpig (*Potamochoerus larvatus*) or warthog (*Phacochoerus africanus*) may also be considered as plausible trackmakers.

Equid tracks (Fig. 6): In the tracks above the Goukamma River, the lack of evidence of cloven hoof, associated with the possible presence of a hoof wall and 'frog', suggest an equid origin of these tracks. Slight variability in track width may be explained by equid hind tracks being proportionately longer and narrower than front tracks. The close proximity of the tracks to each other suggests the presence of more than one trackmaker. In contrast to these probable equid tracks, the three coastal tracks that were transiently exposed in 2017 exhibit equid features with greater certainty.

Equid tracks potentially occur in four known localities on the Cape south coast: east of Still Bay, Brenton-on-Sea, and the two sites in the Goukamma Nature Reserve. While the size of some tracks at Brenton-on-Sea (length ~10 cm) is similar to those of the extant Plains Zebra (*Equus quagga*) or slightly larger than the Cape Mountain Zebra (*Equus zebra*) (Liebenberg, 2000), the greater track dimensions at the site east of Still Bay (length 27 cm, width 20 cm), other Brenton-on-Sea tracks (length 14 cm) and Goukamma Nature Reserve (length 16 cm and 14 cm) suggest that these were made by the extinct giant Cape horse (*Equus capensis*). These would form the only known tracksites for this species. The large tracks east of Still Bay, at Brenton-on-Sea and the coastal Goukamma Natrure Reserve tracks appear conclusively to be of equid origin, whereas the tracks above the Goukamma River are suggestive of this interpretation but not conclusive. The rapid erosion of these tracks within just three years of their discovery provides another indication of the friability and vulnerability of these aeolianite ichnofossils.

Large carnivore tracks (Fig. 7): The absence of sediment displacement rims around the tracks, along with the presence of a horizontal bedding plane from which the track-bearing block probably originated, suggest that the tracks were made in a relatively horizontal interdune area. The morphological features noted indicate two large felid trackmakers, one larger than the other, moving in the same direction. The latest record of the lineage of the dirk-toothed cat of 600 ka (Klein 2007) greatly predates the OSL dates of the Goukamma aeolianites (Bateman *et al.* 2011). Other than lion (*Panthera leo*) with a track length of 12–15 cm (Liebenberg 2000; Stuart & Stuart 2000; Van den Heever *et al.* 2017), there is no known extant or Late Pleistocene carnivore capable of making tracks of the dimensions noted.

The size of the tracks, with length up to 17 cm that is larger than the extant African lion, suggests that they may have been made by the extinct Cape race of the African lion (*Panthera leo melanochaitus*) (Christiansen 2008; Mazák 1975). This suggestion is tentative, as carnivore body size may correlate with climate regimes, with glacial phases having larger sizes (Klein 1986). The discovery of two more large carnivore tracks in the vicinity of these trackways indicates that further such tracks should be sought as new surfaces become exposed.

Fossil lion trackways are not globally common. Within Africa, Pliocene lion tracks were discovered in 2013 at Laetoli, Tanzania (Musiba *et al.* 2008). Ten-thousand-year-old tracks of the extinct North American lion *Panthera atrox* were reported from Missouri in 'Cat Track Cave' (Graham *et al.* 1996), and tracks were reported from Tennessee in 'Jaguar Cave' (Lockley 1999). A site at Bottrop in northern Germany contained a 35–42 ka trackway of the extinct European cave lion, *Panthera leo spelaea* (Antón & Salasa 2012).

Medium-sized carnivore tracks (Fig. 8): The riverside trackway comprising 14 tracks (Fig. 8A,B) was probably made by a large herpestid species or a medium-sized canid species (Stuart & Stuart 2000; Van den Heever *et al.* 2017). There is no evidence of progression up a slope.

Although the four parallel carnivore trackways above the Goukamma River cannot be identified to family level, they are impressive examples of their kind (Fig. 8C). However, the fragility of the rock surface on which they occur is reason for concern. The consistent appearance of sediment displacement rims (Fig. 8D) behind the main pads suggests uphill gait up a dune slope. Direct register is likely evident, with hind tracks appearing directly on front tracks, indicative of a walking gait, which would be unlikely to create sediment displacement rims on a more level surface. Sediment displacement rims can also be caused by changes in gait direction, but these four trackways show no evidence of such changes, hence our conclusion of progression up a dune slope.

Burrow traces (Fig. 9): While other interpretations are possible, the branching traces with maximum width of 10 cm may be consistent with Repichnia. Fossil burrow traces discovered in 2017 at Robberg, 40 km to the east, were consistent with those of a golden mole (Chrysochloridae) and will be reported elsewhere, while the origin of the Goukamma Nature Reserve traces is less clear.

Invertebrate traces: The ubiquitous nature and the variety of invertebrate traces is worthy of further study.

Rhizoliths: The 'root forests' in palaeosols at Skimmelkrans are extensive and impressive, and are worthy of further study. Such unconformities within the deposits

represent gaps in coastal sedimentation, and imply prolonged surface exposure to enable sufficient time for vegetation to develop (Brooke 2001).

GEOHERITAGE AND CONSERVATION

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. Priorities for the trace fossil sites in the Goukamma Nature Reserve include:

1. Stabilization of track surfaces: Paraloid has already been applied to the lion trackway, thereby preserving it and rendering it less threatened by vandalism.
2. Replication: Photogrammetry represents the least invasive form of replication, and has been applied to selected sites, yielding the potential for the generation of 3D models. At present digital 3D data are not routinely converted into 3D-printed hard copy replicas. However, such processes are quite possible with available technology, especially in the case of smaller tracks. The creation of replicas using traditional methods such as silicone could be contemplated, but with acknowledgement of the slight risk of damaging fragile track surfaces.
3. Recovery: The lion trackways would be the most suitable, depending on resources available. Helicopter recovery could be considered.
4. Interpretation and education: the presence of a Visitor Centre in the Goukamma Nature Reserve creates an opportunity for poster displays, exhibits of replicas with optimally angled lighting, and field tours, along with web-based and social media educational initiatives. The advantages of field tours should be balanced against concerns about tracksite vulnerability; hence such tours may be easier to justify at sites where stabilization and replication have been applied.

CONCLUSIONS

For a relatively small area, the Goukamma Nature Reserve contains a substantial number of vertebrate ichnofossils that provide data on and insight into the Late Pleistocene fauna of South Africa. It merits consideration as at least a nationally significant phenomenon.

The tracks that we contend were probably made by *Panthera leo melanochaitus* and *Syncerus antiquus* represent the first documented trackway records for these extinct races or species, and serve to complement the specimen record and body fossil record (Christiansen 2008; Klein 1994; Mazák 1975). The tracks made by *Equus capensis* also fall into this category. The relative abundance of elephant tracks, including our observation of their occurrence in many metres of successive bedding planes, indicates repeated use of an area over time.

Repeated visits to these track-bearing areas are desirable, given their ephemeral nature and the rate at which new sites are exposed. Dating studies of the inland sites and the more significant coastal sites are required. The protected status of the area provides an opportunity for trackway conservation, geoheritage appreciation, and education.

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Tragically David Roberts, one of South Africa's outstanding ichnologists and Quaternary geologists, passed away in 2015. His many research papers bear testimony to his expertise. His anticipated further contributions to the research on southern African Pleistocene trackways and their taphonomy, preservation and interpretation are sorely missed. One of his final acts on the Cape south coast was to apply Paraloid to the Goukamma Nature Reserve lion trackway. His mentorship is gratefully acknowledged.

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