Hominin tracks in southern Africa: A review and an approach to identification

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Three Late Pleistocene hominin tracksites have been reported from coastal aelioanites in South Africa. Two have been dated to 124 ka and 117 ka , and the third is inferred to be 90 ka. There are no other globally reported sites for probable *Homo sapiens* tracks older than 46 ka. Given this documented record, a search for further hominin tracksites in southern Africa may well yield additional positive results. However, this is a field that demands scientific rigour, as false positive tracksites (pseudotracks) may occur. Criteria have been developed for the identification of fossil vertebrate tracks and hominin tracks, but these are specific neither to southern Africa nor to aeolianites. An important caveat is that the tracks of shod humans would not fulfil these criteria. Preservation of tracks varies with facies and is known to be suboptimal in aeolianites. An analysis of the tracks from the three documented South African sites, along with pseudotracks and tracks of questionable provenance, allows for the proposal and development of guidelines for fossil hominin track identification that are of specific relevance to southern Africa. Such guidelines have broader implications for understanding the constraints that track preservation and substrate have on identifying diagnostic morphological features.

Keywords: trackways, hominin, Pleistocene, aeolianites, pseudotracks.

INTRODUCTION

South Africa boasts the only Pleistocene hominin tracksites older than 46 ka that have been attributed to *Homo sapiens* (Lockley *et al*. 2008, 2016; Bennett & Morse 2014; Helm *et al*. 2018c). This claim acknowledges that the Vârtop Cave tracksite, Romania (constrained to 62–97 ka) is attributed to *Homo neanderthalensis* (Onac *et al*. 2005), and that species such as *Homo naledi* (Berger *et al*. 2015; Harcourt-Smith *et al*. 2015; Dirks *et al*. 2017; Helm *et al*. 2018c) or *Homo helmei* (e.g. Grün *et al*. 1996) cannot be fully excluded as trackmakers at the South African sites.

This is an important period in the evolution of modern humans, and these tracksites can therefore contribute significantly to southern African research on this subject. Reviews of global hominin tracksites are to be found in Lockley *et al*. (2008) detailing 63 sites, and Bennett & Morse (2014) detailing 44 sites.

We note the extensive Holocene hominin track exposures dated to 0.5–1.5 ka in the Kuiseb Delta near Walvis Bay, Namibia (Morse *et al*. 2013; Bennett & Morse 2014; Bennett *et al*. 2014). While we acknowledge the important role that these Holocene tracks have played in studies of hominin gait and track morphology on level surfaces, our focus here is on hominin tracks in southern Africa of Pleistocene age or older.

The three identified South African Pleistocene sites are, in order of discovery (Fig. 1):

1) The Nahoon tracksite, near East London in the Eastern Cape Province, was discovered in 1964 (Deacon 1966; Mountain 1966). Sandstone slabs containing the tracks collapsed, and were recovered and housed in the East London Museum six months after being reported. They have been dated through Optical Stimulation Luminescence (OSL) to ~124 ka (Jacobs & Roberts 2009). The tracks occur in the Nahoon Formation of the Algoa Group (Le Roux 1989).
2) The Langebaan tracksite, north of Cape Town on the Cape west coast in the Western Cape Province, was discovered in 1995 (Roberts & Berger 1997; Berger & Hilton-Barber 2000; Roberts 2008). The tracks were recovered and are housed in the Iziko South Africa Museum, Cape Town. They have been dated through OSL to ~117 ka (Roberts 2008). The tracks occur in the Langebaan Formation of the Sandveld Group (Roberts *et al*. 2006).
3) The Brenton-on-Sea tracksite, on the Cape south coast in the Western Cape Province, was discovered in 2016 (Helm *et al*. 2018c). The track-bearing layer is not manually recoverable, and photogrammetry was performed to provide a digital record. The tracks were inferred to ~90 ka , using carbonate diagenesis and

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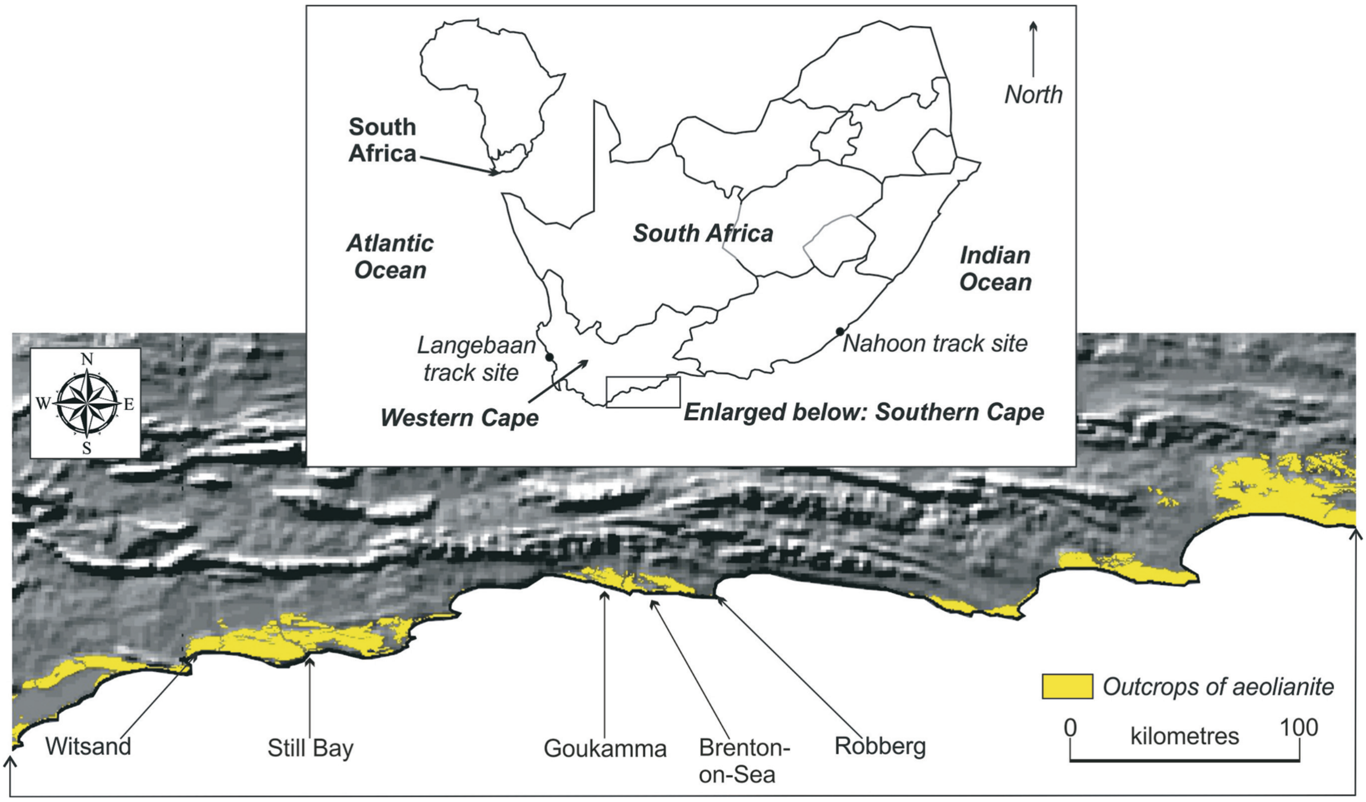

Figure 1. Map of southern Africa with an enlargement of the Cape south coast showing the distribution of Pleistocene aeolianites and sites mentioned in the text.

stratigraphic correlation to OSL-dated sites. The tracks occur in the Waenhuiskrans Formation of the Bredasdorp Group (Malan 1989).

All three hominin tracksites occur in coastal aeolianites, which are cemented palaeodunes and interdune areas of calcarenite (Fairbridge & Johnson 1978). These extend intermittently along much of South Africa's present-day coastline, and are best exposed in embayments on or near the shoreline (Roberts *et al*. 2013). Quaternary tectonic activity has been considered minimal along this coastline (Roberts *et al*. 2006). *In situ* material therefore lies close to its original angle of deposition, which is often consistent with the angle of repose of wind-blown sands (~10°–30°). The track-bearing surfaces at all three sites were on *in situ* slopes representing dune surfaces. The Nahoon and Brenton-on-Sea tracks took the form of natural casts, while the Langebaan tracks were impressions (natural moulds). The Nahoon and Langebaan sites each contained a trackway comprising three tracks. The Brenton-on-Sea site possesses up to 40 tracks, with some partial trackways.

Late Pleistocene vertebrate fossil tracksites in coastal aeolianites are not uncommon in South Africa, and have also been recorded elsewhere (Lea 1996; Clemmensen *et al*. 2001; Bromley 2001; Fornós *et al*. 2002). An ongoing multidisciplinary project looking at Pleistocene ichnofossils, along a 275 km stretch of the Cape south coast between Witsand in the west and Robberg in the east, has yielded more than 100 tracksites (Helm *et al*. 2017, 2018a–c). All three southern African hominin tracksites were closely associated with the tracks of other vertebrates. Some track-bearing areas may be intermittently exposed or covered by sand. In coastal areas characterised by cliffs, erosive forces often lead to cliff collapse and the exposure of new sites, while known tracksites on fallen slabs slump into the ocean. Roberts & Cole (2003) proposed that the ubiquity of vertebrate traces in coastal aeolianites may be attributed to the cohesiveness of moist sand (providing an effective moulding agent), high sedimentation rates (promoting the rapid burial of traces), rapid lithification via partial solution and re-precipitation of bioclasts, and shoreline erosion (effectively re-exposing the fossil-bearing palaeosurfaces).

Once such tracksites are exposed, erosive forces can cause the quality of preserved morphology to rapidly deteriorate. Subtle features such as claw marks may initially be discernible, but within as little as four years may no longer be evident. Consequently, for example, canid tracks may come to resemble felid tracks (Helm *et al*. 2018b). Compared with substrates such as volcanic ash, or cave floors which often remain undisturbed, aeolianites may provide suboptimal preservation of track morphology. While natural cast hominin tracksites are not common elsewhere (Lockley *et al*. 2008), tracks in the form of natural casts are frequently encountered in southern African coastal aeolianites. The three hominin tracksites have proved the potential for coastal aeolianites to preserve such features and to contribute to the sparse global record of hominin tracks. Placed in a global perspective, there are only six generally accepted older hominin tracksites in the world (Bennett & Morse 2014; Lockley *et al*. 2008; Lockley *et al*. 2016) and one putative but not universally accepted site (Gierliñski *et al*. 2017).

Helm *et al*. (2018c) concluded, with regard to the

Brenton-on-Sea site: 'We need not only to expose further tracks at the site described, but to monitor the exposure of further tracksites and document them rapidly with high quality methods.' The interest generated by the discovery of this site may result in further reports of purported hominin tracks, and some of these may be made by people without an ichnological background. It would be prudent, then, to develop a framework through which to assess the merits of future hominin tracksite claims in southern Africa. Such a framework will need to rely on diagnostic morphological characteristics of the individual prints and trackways, as well as the nature of the substrate and preservation and post-depositional characteristics that may have influenced the tracks.

Principles have been established for the identification of vertebrate tracks, e.g. the 'ten paleoichnological commandments' of Sarjeant (1989). The two salient points of relevance here are:

- 'Quite evidently a trackway – a series of successive footprints of both, or of all four, feet – is the best possible basis for the definition of a footprint ichnospecies. A set of prints – impressions of all four feet, or at least of a manus and a pes – is the next best basis.' (In the case of a bipedal hominin this implies a trackway of at least two tracks.)
- 'The lithology should always be described and information given on the paleontological context – the nature of any associated body or trace fossils – and on any associated sedimentary structures, since this information will facilitate environmental interpretation.'

More specifically, Tuttle (2008) developed criteria for the identification of hominin tracks:

- The hallux (digit I) is aligned with the four lateral toes (digits II–V), which are short and straight.
- The tip of the hallux is bulbous, not tapered.
- The tips of the hallux and adjacent second and third toes do not project markedly beyond one another.
- A prominent medial longitudinal arch is evident.

Similar principles were addressed in Lockley *et al*. (2007) and Kim *et al*. (2008). Bennett & Morse (2014), Belvedere *et al*. (2018) and Falkington *et al*. (2018) advocated advanced digital techniques for track identification. With respect to the last of Tuttle's criteria, we note that in modern humans a prominent medial longitudinal arch is not invariably present, and that there is considerable variability in the degree to which it is evident. We therefore suggest that it may best be considered as a useful criterion, rather than an absolute requirement.

There is a significant literature on tetrapod tracks in so-called aeolian or dune facies, which has generally focussed on dry desert sand dunes (erg facies) from the pre-Pleistocene, mostly the Mesozoic and Paleozoic. The relevance of this literature to our study is that it deals with aspects of track preservation in dune facies that have broad significance, specifically with what is generally called 'extra-morphological' preservation, which implies suboptimal foot morphology preservation (Haubold 1996; Lockley 2000).

The purpose of this review is 1) to apply established principles of hominin track identification to southern Africa, 2) to review the merits of established tracks and putative tracks and pseudotracks, and 3) to develop principles and guidelines for hominin track identification in southern Africa.

METHODS

Descriptions of the three established southern African sites were reviewed. Sites containing features resembling hominin tracks were photographed and documented through hand-held Global Positioning System readings. Regional, national and global literature was searched for reports of putative hominin tracks that had been considered erroneous or unconfirmable, and anecdotal reports of colleagues were reviewed. The merits of established and putative hominin tracks in southern Africa were considered, using the principles established by Sarjeant (1989) and Tuttle (2008).

REVIEW OF SITES

Established hominin tracksites

Comparative features of the three established southern African tracksites are presented in Table 1.

Nahoon

Roberts (2008) provided a comprehensive description of the Nahoon hominin tracks. The original trackway comprised three natural cast tracks, forming a left-right-left sequence (Fig. 2a). The sandstone slab curated at the East London Museum only has two tracks (the first left-right sequence). The first left track provided the best preservation and morphological detail. Displacement rims (push-up mounds) were evident (Fig. 2a). A track length of 19.2 cm was recorded, with maximum width of sole of 8.5 cm, and maximum width of heel of 6 cm. A well-developed medial longitudinal arch was noted. Casts of digits I–IV were well preserved, shortening progressively from a larger hallux. A cast of digit V was not evident. The heel impression was shallow compared with those of the forefoot and hallux. This was interpreted as evidence of progression up a dune slope, with the foot touchdown made with the ball of the foot rather than the heel, and a resulting relatively short pace length (defined as the distance between corresponding points on two successive tracks – left-right or right-left) of 33.0 cm. Stature inferences were made using a formula (footprint length × 6.67) derived from global mean data of Mietto *et al*. (2003), yielding a height estimate of 128 cm, and a conclusion that the trackmaker was probably a juvenile.

Langebaan

Roberts (2008) provided a comprehensive description of the Langebaan hominin tracks. The trackway comprised three natural mould tracks that formed a right-left-right sequence (Fig. 2b). The left track was the best preserved, followed by the first right track. Substantial displacement rims were noted. The trackway was interpreted as descending diagonally down a dune face, and involving a direction change. Track length of 22.8 cm was recorded. A

Table 1. Comparison of reported features for the Nahoon, Langebaan and Brenton-on-Sea hominin tracksites, and the tracksite east of Still Bay.

Tracksite	Nahoon	Langebaan	Brenton-on-Sea	East of Still Bay
Age of rock	Pleistocene	Pleistocene	Pleistocene	Pleistocene
Type of rock	Aeolianite	Aeolianite	Aeolianite	Aeolianite
Casts/moulds	Casts	Moulds	Casts	Infill in moulds
Number of tracks	3	3	Up to 40	4
Potential for more tracks	Yes	Yes	Yes	No
Number of tracks in longest trackway	3	3	5?	4
Number of track-bearing layers	1	1	2	1
Unimodal direction	N/A	N/A	Yes	N/A
Track length (cm)	19.2	22.8	23, 17, 12	18
Pace length (cm)	33.0	50.0	85, 72	31
Estimated stature (cm)	128	152	153, 116	120
Medial longitudinal arch	Present	Present	Present	Possible
Digits present	I–IV	? I, II, V ?	I–IV	No
Hallux aligned with other toes	Yes	?	Yes	N/A
Hallux tip bulbous	Yes	?	Yes	N/A
Tips of digits 1,2,3 do not project markedly beyond each other	Yes	?	Yes	N/A
Angle of slope	17°	15°	20°	Cannot be determined
Travel direction on slope	Up	Diagonally down	Down	Unsure
Heel depth (cm)	1.2	L1: 4.3; R1: 2.3	5.5	Not measurable
Forefoot depth (cm)	1.5	L1: 4.9; R1: 5.3	4	Not measurable

medial longitudinal arch was present in the left track. Roberts (2008) reported poorly preserved impressions of digits I, II and V in the first right track, with digits II and V being shorter than digit I. Digit impressions were not evident in the other tracks. The impressions were deep, with the ball of the foot penetrating further into the substrate than the heel. Roberts performed simulations on dune slopes and explained this by proposing that a human walking downhill in soft sand would make contact with the dune surface with the ball of the foot rather than the heel, with the arch strongly flexed. It was furthermore suggested that the push-up mound might partially collapse into the track, potentially obscuring evidence of digit impressions. Pace length of 50.0 cm was recorded. Stature inferences using the formula of Mietto *et al*. (2003) yielded a height estimate of 152 cm, and a conclusion that the trackmaker was probably an adult. Roberts reportedly excavated the adjacent area, and exposed additional tracks. However, these were in a soft substrate, and were described as 'ephemeral'. They were left *in situ* and covered (Graham Avery, pers. comm. September 2018).

Brenton-on-Sea

Helm *et al*. (2018c) provided a detailed account of the Brenton-on-Sea hominin tracks (Fig. 3 and Fig. 4). Two track-bearing bedding planes containing natural cast tracks were reported on the ceiling of a ten-metre-long cave, with up to 35 tracks on the upper bedding plane and up to five tracks on the lower bedding plane (31 cm below the upper bedding plane). On the upper bedding plane there were two exposed surfaces: a southern surface towards the mouth of the cave, and a northern surface

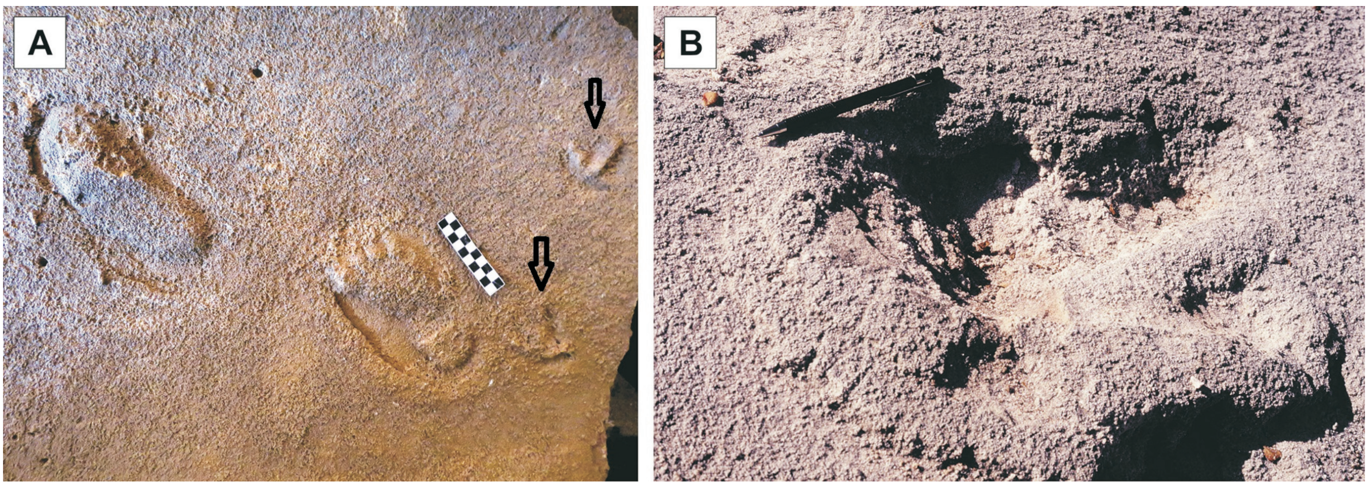

Figure 2. **A**, The two Nahoon hominin tracks, in association with avian tracks which are indicated by arrows; scale bar = 10 cm. **B**, The Langebaan left track, with large displacement rim (photograph by David Roberts, courtesy of Thalassa Matthews).

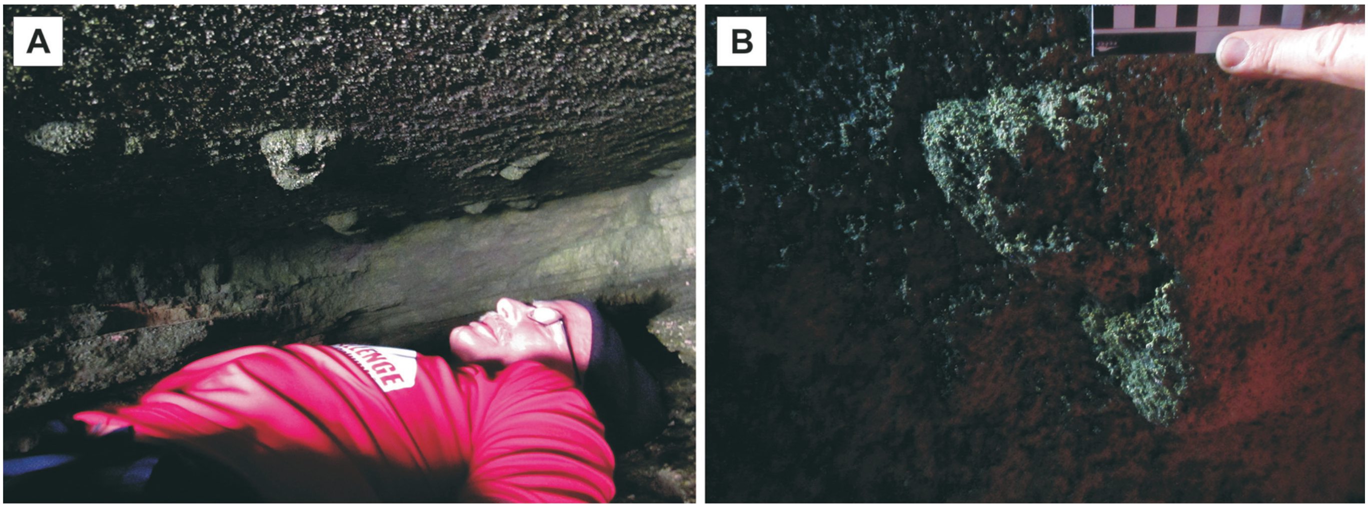

Figure 3. **A**, Natural cast tracks on ceiling of cave, Brenton-on-Sea (photograph courtesy of Guy Thesen). **B,** Natural cast hominin track in natural light, Brenton-on-Sea; scale bar = 10 cm.

deeper within the cave. More tracks were evident in cross-section in the lateral walls of the cave in this bedding plane. Track preservation and morphology were variable. Tracks on the northern surface (Fig. 3) had been made in a firmer substrate; nine of these exhibited digit casts. Tracks on the southern surface (Fig. 4) had been made in a softer substrate, lacked digit casts, and exhibited downslope displacement rims. The tracks were orientated in a downslope direction in a unimodal distribution. Many tracks exhibited deep heel casts. One trackway consisted of a right-left sequence of two large tracks, with maximum length of 23 cm, maximum width of 10.5 cm, and maximum depth of 5.5 cm. One of these exhibited the most detailed morphology, with casts of hallux and digits II–IV evident and a prominent medial longitudinal arch (Fig. 3b). Many of the smaller tracks were ~17 cm in length. The smallest track measured 12 cm in length. Pace length for the large trackmaker was 85 cm, and a short-long gait pattern was noted. Pace length for a probable trackway evident in one of the lateral walls measured 73 cm. Stature inferences using the formula of Mietto *et al*. (2003) yielded an estimated height of 153 cm for the large trackmaker.

Helm *et al*. (2018c) concluded that the nine tracks on the northern surface that contained digital casts were made by bipedal humans, while those on the southern surface approximated hominin footprint morphology, but lacked diagnostic hominin footprint characteristics to allow for unequivocal identification. However, their occurrence in the same bedding plane, and with similar downslope bearing as the tracks in the northern surface, strongly suggested a hominin origin. The site had been identified in 2015, at which point only the southern surface had been examined in detail (Fig. 4). Probable hominin track characteristics had been noted, but these were not conclusive enough at the time to justify identifying it as a hominin tracksite (Helm 2018).

It was proposed that confirmation of the hominin origin of the tracks seen in cross-section could be obtained by excavating the surrounding rock layers to reveal the full extent of these natural casts. Helm *et al*. (2018c) interpreted the short-long gait pattern of the large trackmaker and the deep heel casts as representing a rapid downslope gait that involved heel-planting to aid stability in a relatively soft substrate.

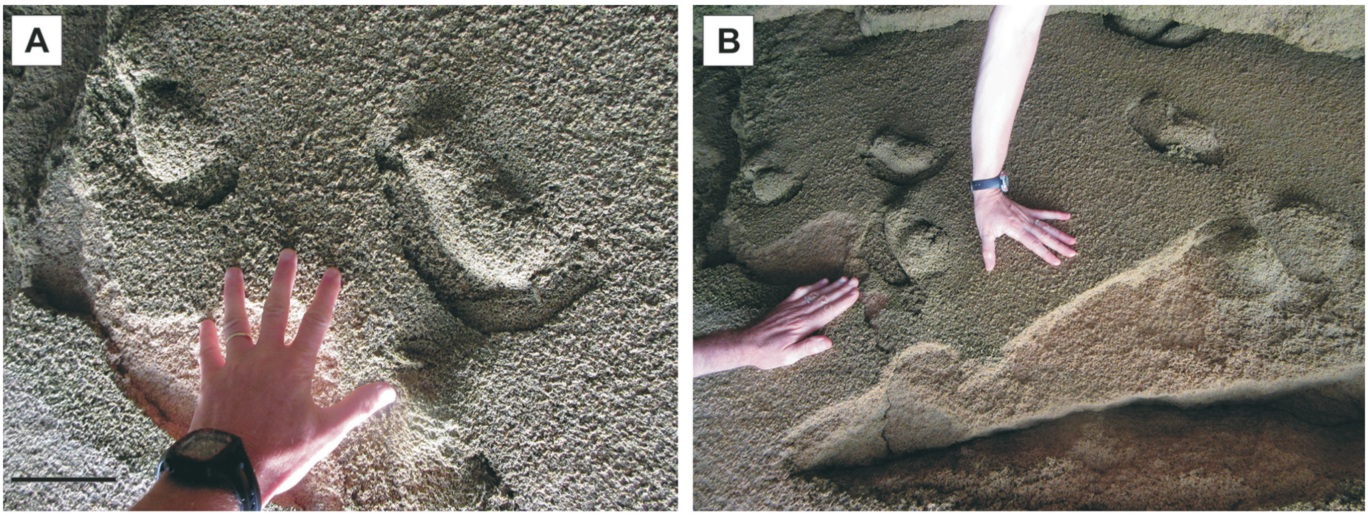

Figure 4. **A, B**, Tracks on southern surface of Brenton-on-Sea tracksite, photographed in 2015; scale bar = 10 cm.

Possible hominin tracksites

Trackway east of Still Bay

Roberts *et al*. (2008) reported on a site that was rich in Late Pleistocene vertebrate trackways, including elephant tracks, in coastal aeolianites east of Still Bay. OSL dating yielded rock ages from ~91–140 ka. Helm *et al*. (2012) reported on a trackway within 50 m of the site described by Roberts *et al*. (2008). This trackway suggested a possible shod hominin trackmaker (Fig. 5a). The sequence of four tracks (right-left-right-left) was identified on a loose aeolianite slab in 2009 following a rockfall. A gradual direction change to the right was evident. The slab (natural mould surface: concave epirelief) and counter-slab (natural cast surface: convex hyporelief) lay adjacent to each other. Track outline, size, pace length and stride length (defined as the distance between corresponding point of two successive right tracks or left tracks) were consistent with a juvenile human track-maker (Table 1). However, Helm *et al*. (2012) concluded that it was not possible to identify the tracks as human in origin, because:

1. Only the second and third prints were distinct. They concluded that a longer trackway was needed to allow for ichnotaxonomic assignment.
2. The exposed layer that outlined the first three tracks contained wind-borne infill, and the fourth track in the sequence was poorly defined. The true impressions made were therefore not identifiable. Removing the infill to expose the original track layer was not considered feasible.
3. There was no evidence of digit impressions.

Helm *et al*. (2012) noted that the third track in the sequence was in the shape of a sandal (Fig. 5b) and noted that one explanation for the absence of digit impressions was that the trackmaker was shod. They postulated that humans in the region when the tracks were made may have possessed the ability to fashion footwear. Considering alternative explanations for the trackmaker, they noted that equids sometimes register their front tracks just ahead of their hind tracks, and that such a phenomenon, associated with lack of track detail due to the presence of infill, could have created the shape of a sandal.

The track-bearing slab has subsequently slumped further down a sandy slope. By 2017 it had almost entered the ocean, and the counter-slab was no longer identifiable.

Goukamma trackway

A trackway containing four tracks on the coastline within the Goukamma Nature Reserve was identified in 2010 (Fig. 6a). It sheds further light on the potential for other vertebrates to create track shapes that approximate hominin footprint shapes in coastal aeolianites. The tracks occur as natural moulds on a loose slab. Alternating short and long pace lengths are apparent. Displacement rims and digit impressions are not evident. Three of the tracks are reasonably well defined. One of these, if considered in isolation, has an outline that resembles the track of a shod human. However, when seen in the context of the trackway, this analogy breaks down as the putative medial longitudinal arch appears on the lateral aspect of the track.

Brenton-on-Sea east cave trackway

At the eastern end of the Brenton-on-Sea aeolianite exposures lies a small cave, situated ~5 vertical metres above mean high tide level. It contains a wealth of tracks, both natural casts on the ceiling and natural moulds on the upper surfaces of slabs that have fallen from the ceiling. The ceiling represents the infill layer on a dune slope. Most of the tracks appear to have been made by artiodactyls, and a single avian trackway is present. In addition a natural cast trackway comprising four tracks with a possible hominin outline is evident on the ceiling (Fig. 6b). Maximum track length = 15 cm; maximum width = 7.5 cm; mean pace length = 37 cm. Displacement rims are present, and are most pronounced at the downslope end of the tracks. Digit casts are not evident. A feature plausibly resembling a medial longitudinal arch is present in the first and second tracks. Track preservation is suboptimal.

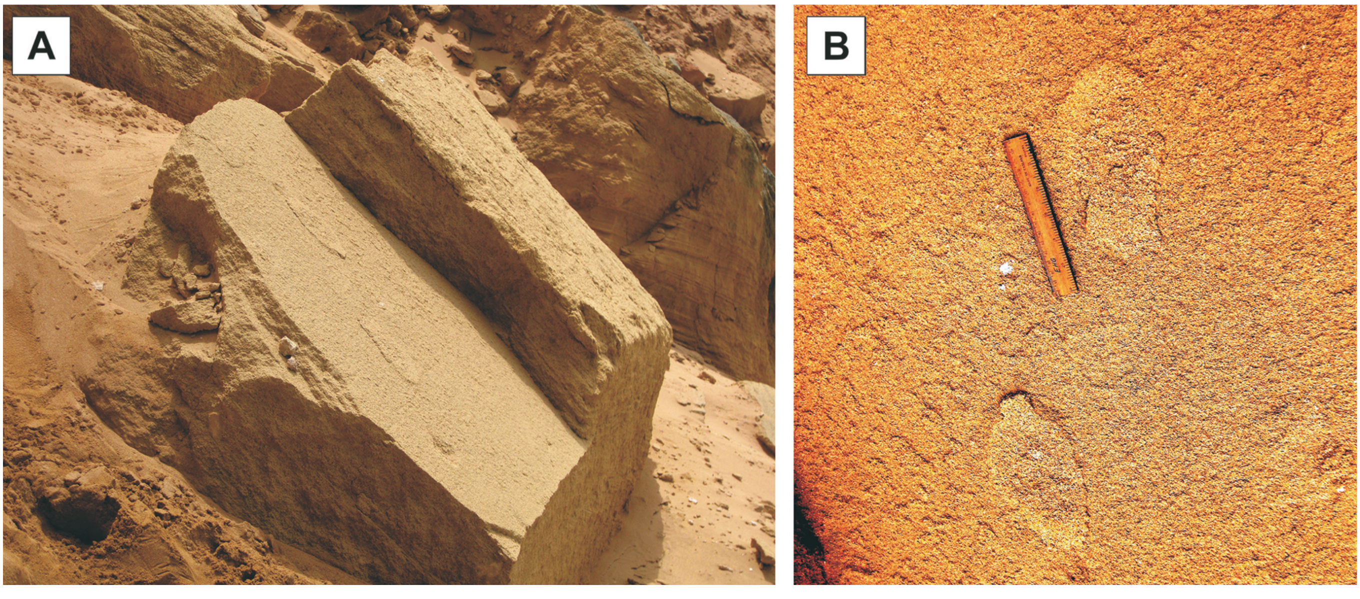

Figure 5. **A**, Possible hominin trackway east of Still Bay. **B**, Second and third tracks in trackway east of Still Bay; scale bar = 15 cm.

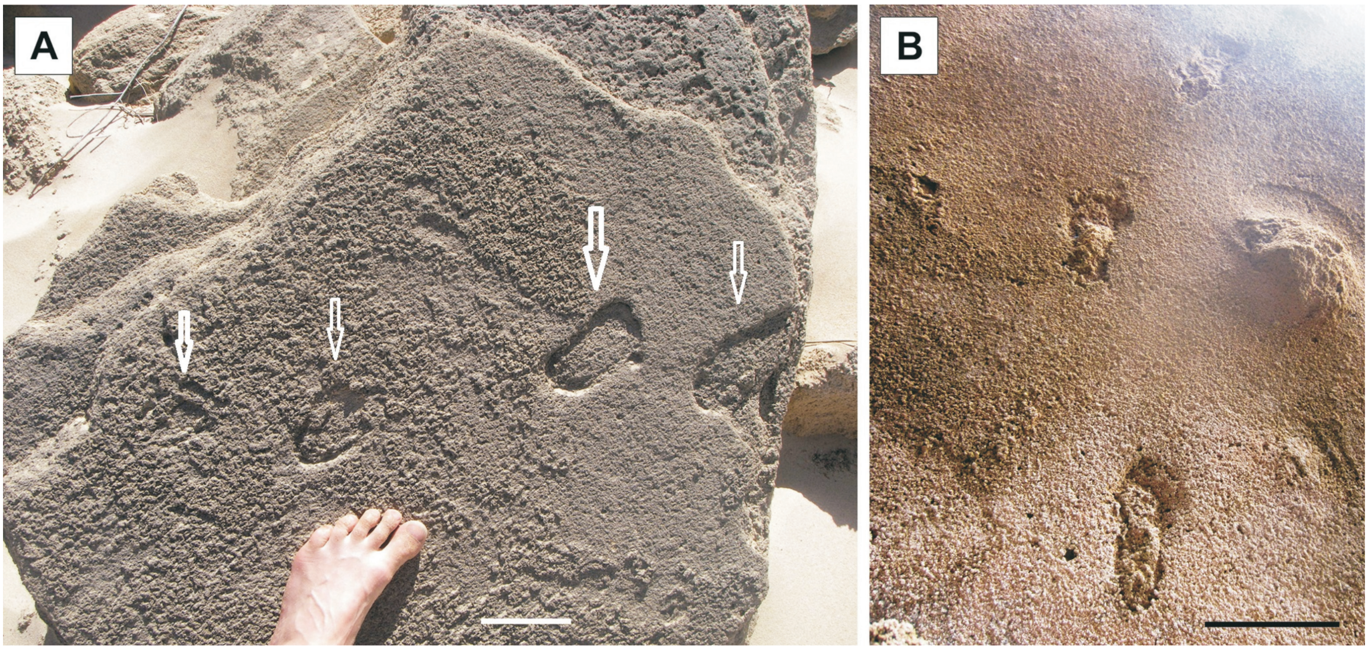

Figure 6. **A**, The Goukamma trackway; scale bar = 10 cm. Arrows indicate tracks; the thicker arrow indicates the possible shod hominin track outline. **B**, The Brenton-on-Sea east cave trackway; scale bar = 10 cm.

Single features resembling hominin tracks

Three single impressions in coastal aeolianites along the coastline within the Goukamma Nature Reserve were identified in 2016. We name them Goukamma I, Goukamma II and Goukamma III. Each bears a resemblance to the outline of a hominin track. No features to suggest trackways are apparent. Two resemble right tracks; one resembles a left track. Possible digit outlines can be identified in one of these. A plausible medial longitudinal arch is evident in all three.

Goukamma I resembles an impression of a right human footprint (Fig. 7a). Maximum length = 21 cm; maximum width = 11 cm. The putative ball impression appears separate from the heel impression. The outline of a possible medial longitudinal arch is present. There is a suggestion of the outline of a hallux and of digits II–IV.

Goukamma II resembles an impression of a gracile right human footprint (Fig. 7b). Maximum length = 21 cm; maximum width = 8.5 cm. The outline of a possible medial longitudinal arch is present. There is no evidence of digit outlines.

Goukamma III resembles an impression of a left human footprint, with a narrow heel and wide ball (Fig. 7c). Maximum length = 21 cm; maximum width = 11.5 cm. There is a suggestion of a pronounced medial longitudinal arch. The lateral margin is straight. Antero-medial detail may be lost. There is possible weak evidence of an outline of digit V.

Pseudotracks

John Almond (pers. comm. March 2018) reports being directed to a number of alleged human tracksites in rocks

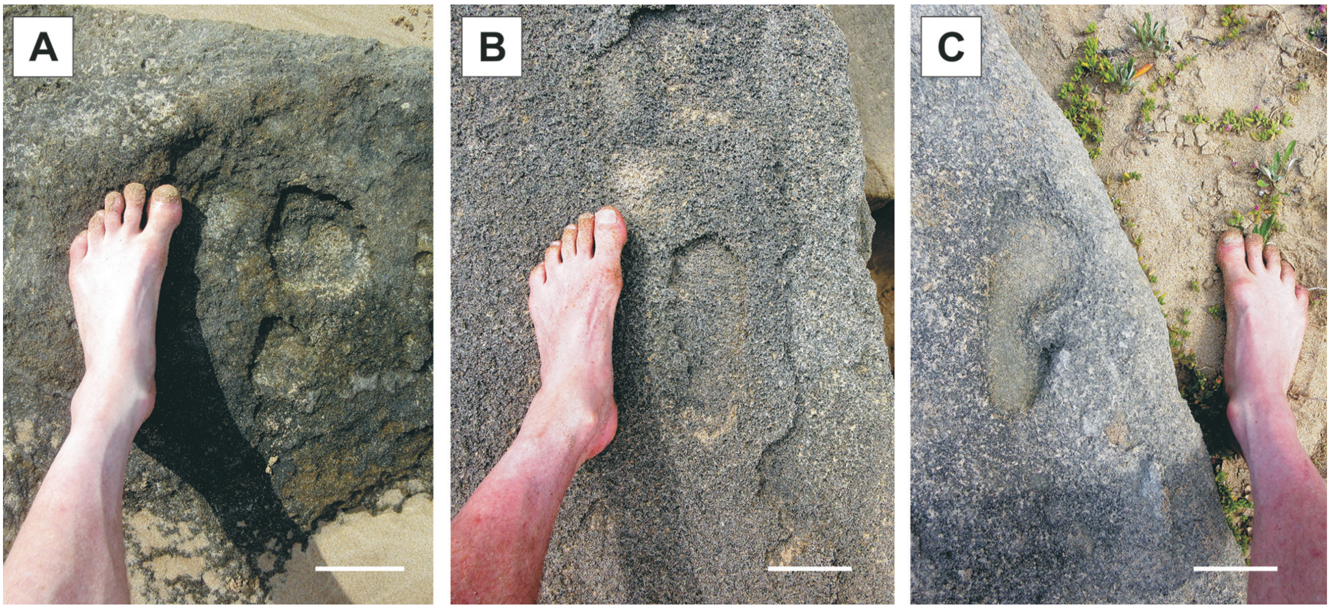

Figure 7. Individual possible hominin tracks from the Goukamma coastline. **A**, Goukamma I; scale bar = 10 cm. **B**, Goukamma II; scale bar = 10 cm. **C,** Goukamma III; scale bar = 10 cm.

in southern Africa of Precambrian or Palaeozoic age. These have represented fortuitous weathering phenomena, usually of a single impression of approximately the size and shape of a human footprint in rocks of an implausible type (e.g. igneous) or age (e.g. Palaeozoic). An example of such weathering from near Chrissiesmeer, in Mpumalanga Province, is instructive, because it has become well known through the Internet (Tellinger 2012) and because it illustrates identification pitfalls. Images of this alleged single human footprint, without an accompanying scale bar and without geological context, may at first glance appear fairly convincing (Fig. 8a), and could possibly be interpreted as meeting Tuttle's criteria (although there are incongruous features in alleged digits II–IV). There is even the suggestion of a displacement rim in front of the alleged hallux. Once a scale bar is added, it becomes apparent that the alleged footprint is ~1.2 m in length. The formula of Mietto *et al*. (2003) yields a completely implausible stature estimate of ~8 m. Furthermore, the rocks in which this impression occurs are composed of granite, aged at 3100 ma. Such irrefutable considerations have not prevented the spread of legends of prehistoric giants. An eloquent, geologically-correct rebuttal has been posted (Mitchell 2013).

DISCUSSION

The following discussion points are germane to the approach to hominin track identification in southern Africa, and the purpose of this review.

International considerations

Since their discovery in 1976 the Pliocene hominid trackways at Laetoli, Tanzania (~3.66 Ma), attributed to *Australopithecus afarensis*, have been the oldest known examples of their kind. A recent publication by Gierliński *et al*. (2017) potentially changed that, with the report of a possible Late Miocene (~5.7 Ma) hominin tracksite on the Mediterranean island of Crete. The merits of this claim remain a subject of scientific debate. In the southern African context, one implication of both the Tanzanian and Crete sites is that a search for hominid tracks should not be confined to Pleistocene aeolianites, but could be extended into potentially suitable Pliocene and late Miocene sediments, especially as the record of bipedal hominids extends back at least to the mid-Pliocene (e.g. Granger *et al*. 2015).

We note the approach of creationists with alternative beliefs about the age of the earth, in particular in the United States of America. The Creation Museum in Kentucky, operated by 'Answers in Genesis', espouses a Young Earth Creationist worldview, and portrays an earth of ~6 ka and the temporal co-existence of humans and dinosaurs. The Creation Evidence Museum in Texas is a similar facility. Alleged hominin tracks in bedding planes that contain authentic, but poorly preserved dinosaur tracks have helped to foster such beliefs. The Paluxy River tracks in Texas (Farlow *et al*. 2010) form the best-known example, where Cretaceous dinosaur tracks and alleged human tracks in the same layer were touted as evidence against the geological time scale. The alleged human footprints have subsequently been shown to represent either dinosaur tracks with metatarsal impressions, non-biogenic erosional features, or deliberate hoaxes that were carved by locals, sometimes for monetary gain (Weber 1981;

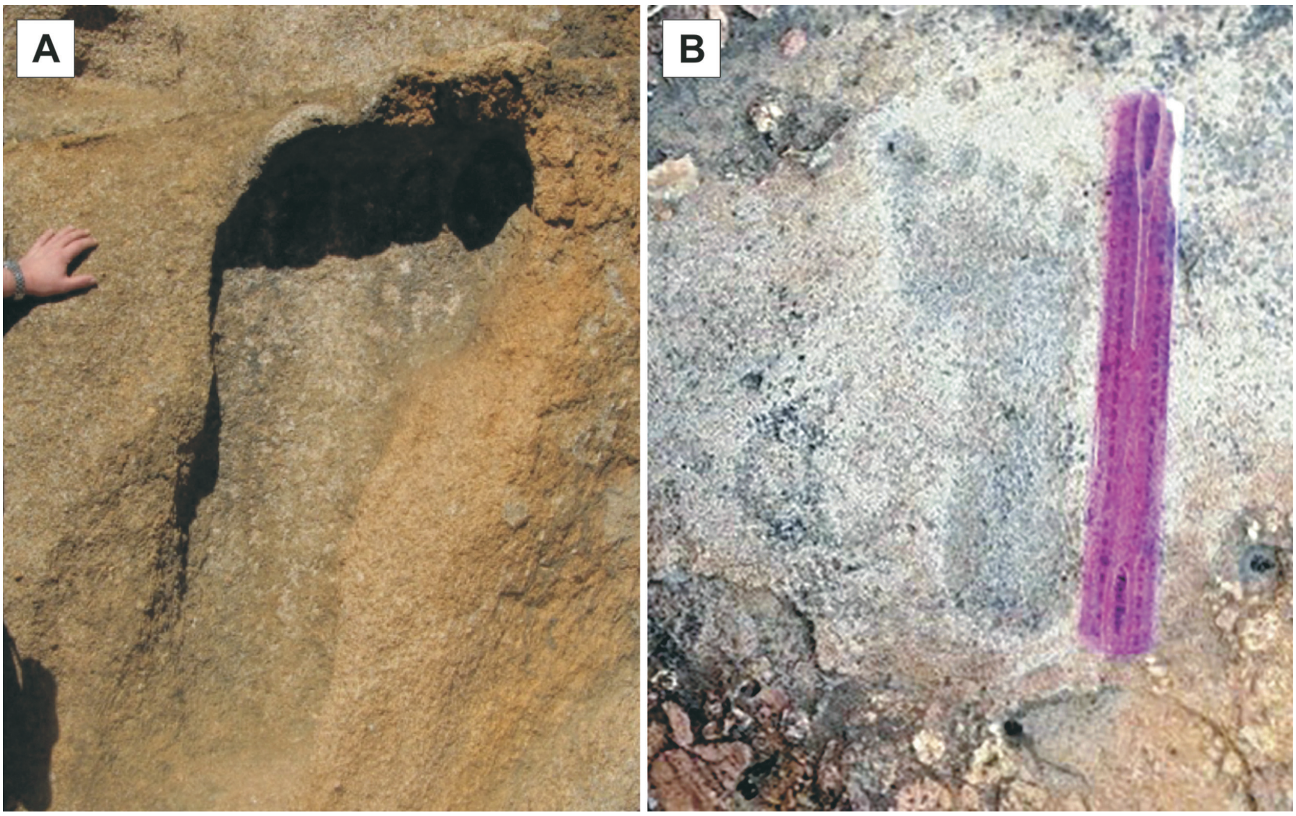

Figure 8. **A,** Pseudotrack, created by weathering granite, resembling a giant human footprint from Mpumalanga Province (photograph courtesy of Francois Duminy). **B**, 'Queen Nzinga's footprints', Pungo Andongo, Angola; scale bar = 30 cm (photograph courtesy of Laura Franklin).

Godfrey 1985; Kuban 2012). Likewise, Cretaceous pterosaur tracks from Korea have been misinterpreted by creationists as human footprints (Kim *et al*. 2012).

Also falling in the category of 'possible hominin tracks' are purported 40 000 year old hominin tracks from Mexico (González *et al*. 2006; Huddart *et al*. 2008). These, and their dating, have proved controversial. They are probably not hominin tracks (Renne *et al*. 2005), and would not meet the authenticity criteria we use.

Summary of variables on dune substrates

Attempts to develop guidelines for hominin track identification in southern Africa, or elsewhere, must take into account a number of variables. For now, we confine this discussion to aeolianites, recognizing that coastal dunes are only one type of paleoenvironment among many that have been classified as dune settings, and that hominin tracks may be discovered in other types of rock on the subcontinent. We also address a further variable, whether trackmakers were shod or unshod.

McKee (1944) noted that dune sand needs to be moist in order to preserve identifiable footprints, and that the steepness of the slope plays a major role in footprint morphology. Lewis & Titheridge (1978) noted that clear footprints are formed only in moist sand, as a result of surface tension lending cohesion to the sand grains. Bennett & Morse (2014) provided a detailed analysis on the role of substrate differences in hominin track morphology. As noted in these studies, if moisture content is too high or too low, track preservation suffers. Other mechanisms may come into play, such as when strong winds remove grains of sand from around the compressed area of a track, ultimately leading to pedestalling, in which the track then appears as a raised feature rather than a depression (Lockley 1991). Sand consistency is related to moisture content, but is also an independent variable, along with grain size. Firm surfaces make for shallow impressions, often with the preservation of exquisite detail, while less cohesive surfaces permit deeper impressions, often with accompanying lack of detail. Thus, there is an ideal substrate for track preservation between the extremes of too firm and too soft, and too wet and too dry.

Whether the angle of the surface is level or represents a dune slope is another important variable. Whether the trackmaker is moving upslope, downslope or is traversing the slope plays a further role. Displacement rims may provide valuable clues as to direction of movement in such situations.

Interpretation of tracks from established hominin tracksites

Table 1 includes comparison of reported features for the three established hominin tracksites. The Nahoon and Brenton-on-Sea sites meet the criteria of Tuttle (2008). This does not prove that the Langebaan tracks are not of hominin origin. Indeed, Roberts (2008) made a sophisticated argument for such an origin. However, it does demonstrate, as we advocate, that Tuttle's (2008) criteria are best used as useful tools rather than absolute verification rules. We have already noted how Tuttle's criteria may yield false positives if the geological and sedimentological context of the track in question is not understood.

Both the Nahoon (Fig. 2a) and Langebaan (Fig. 2b) tracks were justifiably celebrated. A visitor centre shaped like a human footprint was built at Nahoon. The Langebaan tracks received extensive coverage, became known as 'Eve's footprints', and were featured in a book (Berger & Hilton-Barber 2000).

Other authors have reviewed the data for the Nahoon and Langebaan tracks. Lockley *et al*. (2008) commented: 'Tracks at both sites are rather poorly preserved… The Nahoon Point tracks include small human footprints, about 19 cm long, with one showing moderately well-preserved toe impressions… The Langebaan lagoon tracks are larger… but less well-defined.'

Bennett & Morse (2014) noted the unequivocal nature of the Nahoon tracks, and proceeded to comment on the Langebaan tracks: 'The same cannot however be said for the tracks at Langebaan… The challenge is that the tracks have relatively poor anatomical form and consequently not all authorities are convinced that they are in fact human tracks. However on the basis of the limited trail and the distinct dome-shaped rim structures around the margins of the tracks a human origin remains the most likely interpretation. It is interesting within the literature both as an exercise in the correct interpretation of human tracks but also because of the importance of the rim structure in making an interpretation.'

Of note is the response of the discoverers of the Brenton-on-Sea site in 2015 (Helm 2018), when the tracks with digit casts had not yet been identified, and only the tracks made in a less cohesive substrate (and hence with a hominin track outline but no digit casts) were scrutinized (Fig. 4). At that point the site had similarities with the Happisburgh site that was identified in the United Kingdom in 2013, where approximately 50 tracks were dated to ~800 ka (Ashton *et al*. 2014). Although many tracks exhibited such an outline, evidence of digit impressions was only reported in two tracks. Soon after their discovery these tracks were destroyed by tidal forces. Following photogrammetric assessment, they were attributed to *Homo antecessor* (Ashton *et al*. 2014). Happisburgh has entered the hallowed pantheon of hominin tracksites. The discoverers of the Brenton-on-Sea site in 2015 chose a more cautious approach, believing that they could not at that point credibly defend the tracks as unequivocally hominin in origin.

A similar observation pertains to the Late Pleistocene Jeju Island tracksite in South Korea (Kim *et al*. 2009), where doubt could have arisen because none of the hominin tracks originally illustrated by these authors show diagnostic digit traces. However, at least two casts later found, examined and catalogued by these authors, and replicated (University of Colorado Museum specimens 230.249 –250 and tracing T 1347), show diagnostic heel, arch, ball and hallux morphology. Together with characteristic trackway patterns, this unequivocally confirms the published hominin track interpretation.

The discovery of the Nahoon and Langebaan tracksites predated the identification of *H. naledi*, a new Middle Pleistocene hominin species in southern Africa, and the tracks were attributed not just to *H. sapiens*, but to our own subspecies, *H. sapiens sapiens* (Roberts 2008). By the time the Brenton-on-Sea tracksite was discovered and described (Helm 2018c), the discovery of fossil remains of *H. naledi* from the Rising Star Cave in Gauteng Province had been announced (Berger *et al*. 2015). This site is more than 750 km from the Nahoon tracksite, and even further from the Brenton-on-Sea and Langebaan tracksites.

Helm *et al*. (2018c) noted: 'Until reliable criteria are developed to distinguish *Homo naledi* tracks from *Homo sapiens* tracks, we contend that both should be considered as plausible or at least possible trackmakers at hominin tracksites in southern Africa. However, the current estimated minimum age for *Homo naledi* is 236 ka (Dirks *et al*. 2017). It seems reasonable to consider *Homo sapiens* as an increasingly more probable trackmaker with progressively younger tracksites… '

The feet of *H. naledi* have been described as being predominantly modern human-like in morphology and function, and as having only minimal anatomical differences when compared to those of *H. sapiens* (Harcourt-Smith *et al*. 2015). Tracks of *H. naledi* and *H. sapiens* may therefore well be indistinguishable from each other. The species initially named *H. helmei* (from Florisbad, Free State Province), and dated to ~259 ka ± 35 ka (Grün *et al*. 1996), can likewise not be fully excluded as a trackmaker at the South African sites.

We regard the trackmaker at the three established tracksites as probably *H. sapiens*, while acknowledging the remote possibility of *H. naledi* or *H. helmei*.

Interpretation of tracks from possible hominin tracksites

The trackway east of Still Bay (Fig. 5) may be that of a shod hominin. It may also represent the tracks of an equid or artiodactyl. Medium sized perissodactyls and artiodactyls most commonly employ a 'direct register' gait, in which the hindfeet are placed directly on or in the tracks made by the forefeet. However, when these animals slow down, the hindfeet are placed behind the forefeet ('understep'); when they speed up, pace length increases, and hindfeet are placed ahead of forefeet ('overstep') (Van den Heever *et al*. 2017). In both cases, preservation in aeolianites, sometimes with an infill layer, may yield traces with a hominin track outline. This phenomenon may explain the track shapes seen in the trackway east of Still Bay, which therefore cannot be classified as hominin in origin. Helm *et al*. (2012) reached a similar conclusion, and published their article in part to draw attention to the potential for finding more hominin tracks in aeolianites. That article led directly to the discovery of the Brenton-on-Sea tracksite (Helm 2018).

The Goukamma trackway (Fig. 6a) probably represents a further example of this phenomenon, and is not compatible with a hominin trackmaker. The Brenton-on-Sea east cave trackway (Fig. 6b), while displaying dimensions, pace length and shape compatible with a juvenile hominin trackmaker, does not exhibit a level of track preservation that allows for a meaningful assessment, does not contain diagnostic digit casts, and only inconsistently displays a possible medial longitudinal arch. It is also situated on a surface that is rich in artiodactyl tracks. Although a hominin origin cannot be excluded, a baboon origin (e.g. *Papio ursinus*) is also possible, as is an artiodactyl origin with understepping or overstepping accounting for the features noted.

The three examples of single tracks at Goukamma (Fig. 7) have certain hominin characteristics, and are in rocks of the correct age and context. However, they may simply be erosional features that happen to exhibit hominin track features. Furthermore, being single impressions, they do not meet one of Sarjeant's (1989) salient paleoichnological commandments. At best these can therefore be listed as 'possible hominin tracks'.

Pseudotracks

The 'giant footprint' in Mpumalanga (Fig. 8a) falls into the pseudotrack category. Impressions in rocks are abundant, some inevitably resemble a hominin footprint, and very occasionally the likeness will be uncanny. Dismissing the notion of an 8 m tall Palaeozoic giant, however, does not exclude the possibility that accounts of tracks of *Gigantopithecus* (the large hominin known as the sasquatch in North America and the yeti in Asia) are without substance – such claims simply need to be scrupulously analysed (Lockley 1999; Meldrum 2007).

While the alleged tracks in Palaeozoic deposits are likewise classified as pseudotracks, some of these, if found in sedimentary rock surfaces, could conceivably be *bona fide* tracks of other trackmakers (e.g. *Chirotherium*). Such alleged tracks speak to the fascination lay people have for fossil human footprints. They can form useful cases for applying the approach we develop here.

Graffiti and petroglyphs

One final southern African phenomenon needs to be considered. Aeolianite surfaces are relatively easy to incise, and therefore may form attractive canvases for graffiti artists. Graffiti adorns rocks in some coastal areas, and has caused the loss of tracksites (Helm 2018b). The Langebaan hominin track-bearing surface contained graffiti which came perilously close to the tracks. The lesson is ominous: someone etched graffiti onto this surface before these important tracks were recognized by an ichnologist. Furthermore, local residents in Texas created deliberate human-footprint hoaxes. It is conceivable that a graffiti artist with an alternative agenda may carve hominin-like trackways into aeolianites or older rocks. Chisel marks or other signs of etching should therefore be excluded at potential tracksites. These concerns also raise the question of how to preserve important track evidence for posterity, using photogrammetry, moulding and replication, recovery, or a combination of these options.

In addition, the possibility should be considered that what appear to be human footprints could be ancient petroglyphs. Petroglyphs resembling human footprints have been described from Namibia, the Northern Cape

Province of South Africa and Botswana (e.g. Wilman 1933; Walker 1997; Gwasira 2012). Often they are found etched into Palaeozoic rocks or form part of substantial rock art galleries; in such cases their anthropogenic origin would be obvious. However, this distinction may not always be straightforward, as evidenced by the Pungo Andongo site in Angola, also known as 'Queen Nzinga's footprints' (Fig. 8b). Livingstone (1857) visited the site in 1854, and reported: 'We were shown a footprint carved on one of these rocks'. Willcox (1984) noted a subsequent interpretation (Rudner 1976) that Livingstone had thought it was a fossil footprint. It may be that the presence of plant fossils in the vicinity contributed to this perception. Rudner & Rudner (1970) described these footprints as petroglyphs, while Lategan & Van Wyk (2016) stressed their enigmatic, undated nature, and reached no firm conclusion as to their origin.

Tracks of shod hominins?

A barefoot hominin trackmaker may produce digit impressions. A shod hominin may not produce such impressions, irrespective of substrate conditions (Milàn & Bromley 2009). Two examples of erroneous claims for shod human footprints are illustrative.

Stokes (1986) drew attention to one such alleged footprint in Cambrian strata, which simply represented non-biogenic sedimentary structures, and thus formed a pseodotrack. Marsh (1883) reported a trackway of a purported biped comprising six large prints with a hominin outline from Nevada, associated with other vertebrate trackways. Mark Twain became embroiled in the ensuing discussion in which a human trackmaker wearing sandals was postulated (Lockley 1999). However, detailed trackway analysis revealed faint forefoot impressions, and the tracks were probably made by a large sloth. This interpretation has been confirmed by a study of trackways that indicate sloth–human interactions preserved in Pleistocene sediments in New Mexico (Bustos *et al*. 2018).

Given the remarkable achievements of inhabitants of the Cape south coast in the Late Pleistocene, which include early production of art and jewelry (Henshilwood *et al*. 2002, 2011), systematic incorporation of seafood into their diet (Marean *et al*. 2007), microlithic technology (Brown *et al*. 2012), and the use of fire as an engineering tool (Brown *et al*. 2009), it would not come as a surprise if such creative peoples also developed the skills and means to produce footwear. Foraging on Cape coastal rocks for seafood is hard on bare feet, and a significant laceration may have had profound consequences in the Late Pleistocene. Footwear would have reduced this risk, and the preservation of foot integrity must have been a priority for ancient foragers. Marean (2010) has suggested that these were the first foragers for seafood and that these habits may have saved the human species. It is conceivable that this new source of protein encouraged the development of footwear to provide protection from sharp rocks. Conversely, we acknowledge that footwear may impede travel on dune surfaces.

An argument for the early use of footwear, based on anatomical changes in foot bones, has been made by Trinkaus (2005). The earliest known evidence for such speculative changes is from a cave in China dated to ~40 ka.

The possibility of shod hominins making tracks that would not exhibit digit impressions must be considered in an analysis of hominin tracks in southern Africa. Tuttle's criteria apply to barefoot hominins, not shod hominins.

Pace lengths on dune surfaces

The Nahoon tracksite represents upslope travel, while the Langebaan and Brenton-on-Sea tracksites represent downslope travel. The short pace length (33 cm) recorded in the Nahoon trackway is plausibly interpreted by Roberts (2008) as representing upslope movement, combined with the shorter stride of a juvenile trackmaker.

The situation with the Langebaan and Brenton-on-Sea sites is less straightforward. Roberts (2008), referring to the relatively short pace length recorded in the Langebaan trackway, commented that 'This shortness of step/stride probably relates to the difficulty of negotiating sloping and unstable substrates.'

Helm *et al*. (2018c) interpreted the short-long gait pattern at the Brenton-on-Sea site, along with the deep heel casts observed in many tracks, as representing a rapid downslope gait that involved heel-planting to aid stability. A short-long gait pattern may also be an expression of left- or right handedness/dominance in a trackmaker (McCrea *et al*. 2015). Comparing the Brenton-on-Sea tracks with the Nahoon and Langebaan examples, Helm *et al*. (2018c) noted: 'The pace lengths we describe of 75 cm, 85 cm, and possibly greater than 105 cm, on a dune slope of equivalent or slightly greater angle, imply a more rapid trackmaker velocity, and may be consistent with a running gait.'

It is evident, then, that downslope travel has been used to justify a rationale for both short and long pace lengths. Furthermore, in the case of the Langebaan tracks the ball impressions are significantly deeper than the heel impressions, while the converse was noted for the Brenton-on-Sea tracks. While different modes of travel down dune surfaces are doubtless possible, these apparent incongruities draw attention to the absence of studies of habitually unshod humans walking or running on dune surfaces of different gradients.

Lieberman *et al*. (2010) showed that habitually barefoot human runners tend to land on the forefoot, while habitually shod runners tended to land on the heel. They demonstrated smaller collision forces in the barefoot runners who employed a forefoot strike. They noted that for most of human history runners were either barefoot or used minimal footwear. One might infer that in downslope bipedal travel more weight is likely to be borne on the heel and midfoot, and in upslope bipedal travel more weight is likely to be borne on the forefoot; it would therefore be less likely that downslope travel on a dune face would involve landing on the forefoot and creating a deep forefoot impression, but in any event the landing would be soft on such a yielding surface.

Analysis of hominin track morphology and gait has been performed on Holocene tracks on level surfaces in the Namib Desert (Morse *et al*. 2013) and on habitually barefoot subjects on a level surface in Kenya (Hatala *et al*. 2016a). We contend that such studies have limited applicability to the gaits of individuals who made tracks on the slopes of dune surfaces of up to 20°. Neoichnological study on upslope and downslope dune travel by habitually unshod humans is required, to complement the work of McKee (1944) on tetrapod locomotion on dry desert dune facies from the Paleozoic and Mesozoic.

Ichnofacies considerations

Proposed work on tracks in sand dunes has broader implications that are pertinent to, but beyond the scope of this paper, with reference to the aeolian 'archetypal' or at least globally distributed *Chelichnus* ichnofacies (Lockley *et al*. 1994, Hunt & Lucas 2007; Lockley 2007; Krapovickas *et al*. 2016). In short, desert dune facies, as distinct from interdune facies, particularly in the Palaeozoic and Mesozoic, have been labelled the *Chelichnus* and/or *Brasilichnium* ichnofacies, characterized by tracks of arthropods (mostly arachnids), small mammals and reptiles. The occurrence of large tetrapod tracks in coastal dunes, as described from southern Africa (Roberts 2008; Helm *et al*. 2018a–c) and elsewhere (Fornós *et al*. 2002) raises questions as to whether coastal dunes represent facies-fauna relationships (ichnofacies) that are distinctly different from those of desert erg systems.

The literature on dune facies tracks also touches on the quality of preservation in such a paleoenvironment, which as indicated above is an important concern in this study. As vertebrate ichnology has matured there has been an increasing awareness of the pitfalls of naming and classifying poorly preserved tracks which reflect 'extra-morphological' factors pertaining to substrate conditions rather than registering faithful renditions (tracks) of trackmaker foot morphology. Inappropriate names applied to extra-morphological tracks have even been named phantom ichnotaxa (Haubold 1996; Lockley 2000). These may be branded with the designation of *nomina dubia*, most often because they are undiagnostic of an identifiable trackmaker group. While hominin track ichnotaxonomy is not currently a complex field, names have already been applied to hominin tracks attributable to *H. sapiens* and pre-*sapiens* species (Kim *et al*. 2008) including fossil footprints from Africa (Meldrum *et al*. 2011). Again we advocate caution in identifying and classifying fossil footprints that lack a suitable suite of diagnostic characters.

Benefits of a 3D morphometric approach

Conclusions have been drawn from hominin tracksites on human foot morphology (Bennett *et al*. 2009; Bennett & Morse 2014) and human behaviour (Hatala *et al*. 2016b). Increasingly, three-dimensional models form a standard for methodology and documentation in vertebrate ichnology (e.g. Citton *et al*. 2017; Belvedere *et al*. 2018; Falkington *et al*. 2018). Photogrammetric analysis was employed to argue that the Happisburgh tracks were made by hominins (Ashton *et al*. 2014). Such approaches may be useful for the southern African sites in future, and may help to determine the number of trackmakers at the Brenton-on-Sea site once further tracks are exposed. However, the absence of neoichnological studies of humans on dune slopes needs to be addressed before a detailed 3D digital analysis of southern African tracks can be reliably achieved.

Hominin tracks in cross-section

No guidelines have been established to identify hominin tracks that are only evident in cross-section. An irregularity seen in cross-section in a bedding plane is a 'soft sediment deformation structure' (Molina *et al*. 2002). For all such structures both biogenic and non-biogenic origins should be considered. The occurrence of hominin tracks evident in cross-section in a lateral wall of the cave at the Brenton-on-Sea site raises the question of how such tracks can be identified with confidence when encountered elsewhere (Fig. 9). A hominin track seen in sagittal section should contain evidence of the profile of the heel, the ball, and possibly a digit. Other animal tracks in which the forefoot is not registered directly on the hindfoot could create a similar profile, but would not exhibit evidence of a digit anteriorly. We suggest that on dune slopes, downslope travel would cause the profile of the heel to be more deeply impressed than that of the ball, and that the opposite would be expected with upslope travel. If such patterns occur repeatedly in sediments of appropriate type and age, with appropriate track length, and appropriate pace length (increasing for downslope travel, decreasing for upslope travel), then we contend that identification of hominin tracks can be made with reasonable confidence. In time, as erosion of surrounding deposits occurs, the validity of such interpretations may be verified. Furthermore, identification of a bedding plane potentially containing hominin tracks seen in cross-section can prompt a dedicated search for tracks on surface exposures of this bedding plane.

We suggest the following checklist to aid in the identification of hominin tracks in cross-section:

1) Is a digit profile evident?
2) Is a ball profile evident?
3) Is a heel profile evident?
4) Is the morphology of the heel/ball/digit trace consistent with upslope/downslope travel?
5) Is the track length consistent with a hominin trackmaker?
6) Is a trackway pattern present?
7) Is pace length consistent with a hominin trackmaker?
8) Is the deposit of plausible geological type?
9) Is the deposit of plausible age?

The search for further hominin tracks in southern Africa

The stretch of coastline between Witsand and Robberg has received the most thorough track-prospecting coverage. Within this expanse there are four major zones of concentration of tracksites: east of Still Bay, Goukamma, Brenton-on-Sea and Robberg. The high rate of turnover, whereby new sites are exposed and known sites are

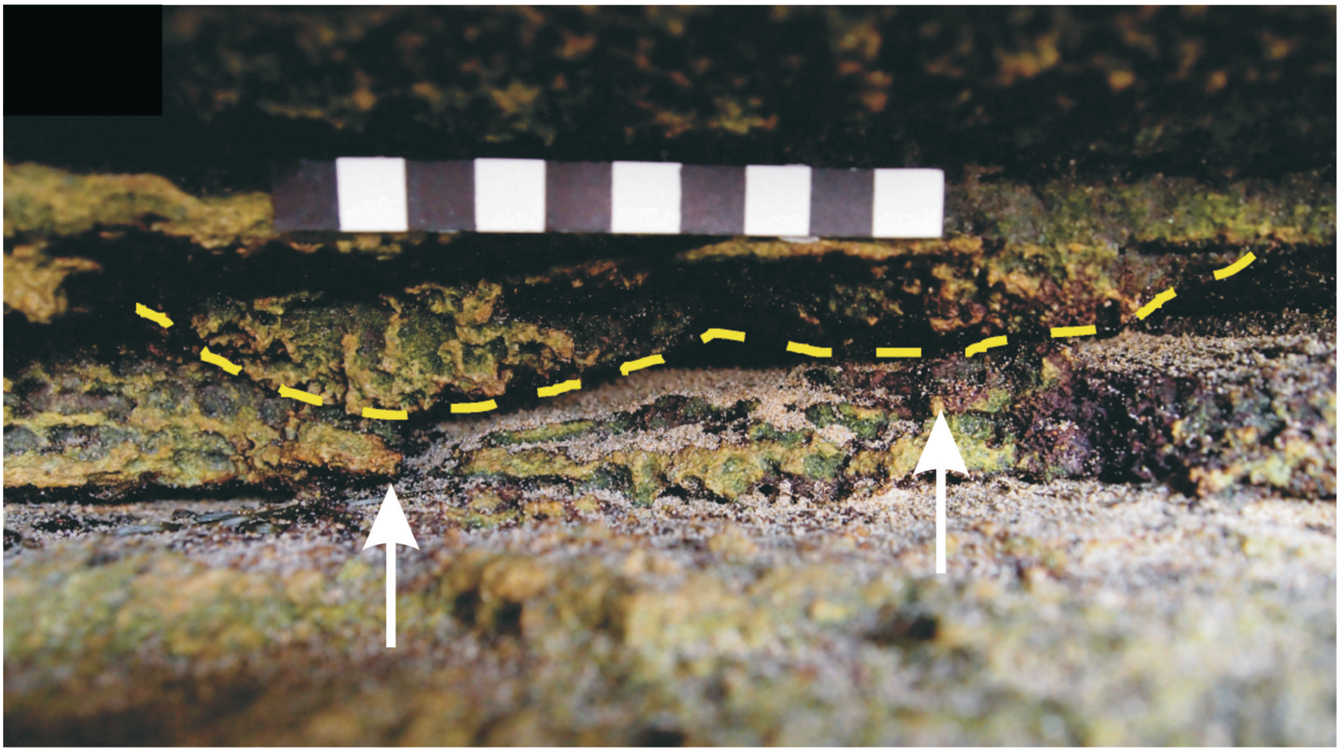

Figure 9. Hominin track in sagittal section, outlined in yellow, Brenton-on-Sea; left arrow indicates heel cast, right arrow indicates ball cast; scale bar = 10 cm.

eroded or slump into the ocean, implies that repeated visits to these areas should prove fruitful, especially after high spring tides and storm surges. Such notions are supported by the reported increase in storm surge events and resulting increase in coastal erosion rates along the entire South African coast (Smith *et al*. 2010; Mather & Stretch 2012).

Many southern African coastal aeolianites have not been examined for their tracksite potential. One way to approach this methodically would be to employ trained trackers to regularly comb suitable exposures for tracksites.

One reason why tracksites may have not been identified in the past is that the concepts of natural casts on ceilings and overhangs, or of tracks seen in cross-section, are not widely appreciated. Those who are familiar with the coastline and who readily identify natural mould trackways may be unlikely to find such tracksites, unless they are made aware of these possibilities. A further challenge is presented by most of the suitable aeolianite deposits being submerged on the continental shelf; an attempt at comprehensive documentation would need to include sub-marine studies. Finally, the Gierliñski *et al.* (2017) report on a possible hominin tracksite of Late Miocene age provides a reminder that a search for hominin tracks should not be confined to Pleistocene sediments.

Tuttle's criteria and Sarjeant's commandments revisited

We have advocated use of the complementary commandments of Sarjeant (1989) and criteria of Tuttle (2008): one espouses essential principles of vertebrate track identification and ichnotaxonomy; the other focuses on identification of hominin tracks. Commandments and criteria can be circumvented, and the examples we have provided indicate how this has previously occurred. They are not infallible, and we have shown also how rigidly following them without understanding the context of tracks can lead to erroneous conclusions. The digit morphology enshrined in Tuttle's criteria represents a 'gold standard' under ideal preservation conditions. They are not a *sine qua non*; insistence on their presence carries with it the virtual certainty of failing to identify tracks of shod hominins, or even hominin trackways with diagnostic pace and stride patterns, but no digit traces. We prefer to see them as guidelines and tools. However, we suggest following the maxim: 'to break the rules, you first have to understand the rules'. If commandments are broken and criteria are not met, compelling reasons need to be advanced to justify such approaches.

One further international example of a site attributed to a hominin trackmaker is illustrative. At Terra Amata in France a single track was identified in 1966, and was attributed to *Homo erectus*, with an age estimate of ~300 ka (Lockley *et al*. 2008, 2016; De Lumley *et al*. 2011). Using a single track to identify a trackmaker species (thus not following one of Sarjeant's commandments) should require exceptional evidence. However, Bennett & Morse (2014) describe it as a 'poorly defined track… the contextual information, date and quality of the track limit its value'. We therefore question whether Terra Amata should remain within the list of accepted hominin tracksites.

CONCLUSIONS

Fossil hominin tracks are a globally sparse phenomenon. The fact that South Africa has yielded the only three tracksites from the time of emergence of modern humans is significant, and Nahoon, Langebaan and Brenton-on-Sea have rightly become important names in the hominin track record. The contrasts between casting and physical recovery (Nahoon and Langebaan) and photogrammetry (Brenton-on-Sea) are striking, but these methods reflect historical circumstances and differing ways in which important scientific and heritage data are preserved and can be replicated, exhibited, and used for education purposes. While this is true for all tracks, hominin tracks have a special evocative and visual influence on the human psyche.

Coastal aeolianites in southern Africa have an impressive record of preserving hominin and other tracks, and a diligent search may deliver further hominin tracksites. The desire to identify such sites must be balanced with the need for rigour and repeatibility. Having reviewed the merits of established tracks and putative tracks and pseudotracks, we therefore suggest the following principles and guidelines:

– Use caution: do not identify tracks as hominin without solid evidence.
– Consider and discuss plausible alternative explanations for putative hominin tracks.
– Avoid trackmaker identifications based on single tracks, unless diagnostic evidence is compelling.
– Use Tuttle's criteria judiciously. They should not apply to shod humans. Rock age and type must be plausible for hominin trackmakers.
– Tuttle's criteria apply best to ideal substrates, but often do not apply in aeolianites. Therefore, evaluate evidence for substrate variables such as moisture, consistency and dune slope at the time of track registration.
– Systematically prospect for and compile regional and national inventories of exposed track-bearing surfaces.
– A schedule of repeat visits to known trackway-producing coastal aeolianites after storm surge events will help to identify fresh exposures.
– Assess new putative tracksite finds with caution, invite multidisciplinary collaboration, and use descriptors like 'possible', 'probable', and 'suggestive of' as necessary to avoid erroneous inferences and to promote further study.
– Incorporate photogrammetric studies and a 3D morphometric approach where feasible.

Aeolianites, despite their track preservation limitations, are track-rich and are currently the only known rock type in southern Africa to contain hominin tracks. While they may create track identification challenges, they can be celebrated as a geological phenomenon that provides an illuminating window into the lives of our ancestors. Further studies should enable ichnology to contribute fruitfully to African palaeoscience, aided by an organized strategy by trackers dedicated to scouring the coast. Hominin group size and group make-up may be determined, and hominin relationships to other Pleistocene tetrapods might be inferred. Aeolianites may facilitate fruitful locomotion studies and could perhaps reveal early evidence of human running, or even hunting strategies of the type indicated by recent Pleistocene tracksite studies in North America (Bustos *et al*. 2018).

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