

Coastal eolian sands, paleosols, and Pleistocene geoarchaeology of the Southwestern Cape, South Africa

Karl W. Butzer

Department of Geography and the Environment, The University of Texas at Austin, Austin, TX 78712, USA

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Abstract

Narratives of Pleistocene prehistory for MIS 4 to 9 are primarily constructed on the basis of what appear to be subcontinuous archaeological records in cave sites, with subsidiary geo- and bioarchaeological research attempting to determine the nature of external environments and biotic resources from the inside, rather than the outside. The present study seeks to establish a detailed chronostratigraphy for faunal and archaeological sites linked with coastal sediments in the Southwestern Cape province. Accelerated shore deflation during glacio-eustatic oscillations of sea level deposited multiple eolianites, and textural changes of such calcified sands identify both transgressive and regressive sea level trends. These provide a proxy for local shore proximity, sometimes directly linked to 'high' sea level stands. Such sediments are subdivided into lithostratigraphic sequences by multiple paleosols, that range from ABC-soils to calcretes or plinthite/ferricrete horizons. Repeated intervals of solution or karstic activity created underground cavities that allowed fossil bone to collect in or below hyena lairs. Such fills further connect sedimentary units with pedogenic events, to integrate local stratigraphies into a regional lithostratigraphy that can be readily correlated with global chronostratigraphies (MIS stages and Dansgaard-Oeschger events), derived from polar ice and deep sea cores, as well as long stalagmite and pollen records. The faunal assemblages (see Table 9) of MIS 5 and early 4 were penecontemporaneous with pedogenic phases that record greater moisture during intervals when sea level oscillated a little below that of today. Dominated by larger grazers, such assemblages argue for a more open environment than the modern fynbos (sclerophyllous heath/brush) and specifically a land cover of higher productivity and nutritional status. Such conditions probably affected only a fraction of MIS 5 time. Middle Stone Age (MSA) assemblages are limited to late MIS 4 cave/overhang sites, also linked to such pedogenic phases, although an MSA-like site dates to MIS 5d. Older littoral sands, modified by plinthite development, include the Acheulian and faunal site of Duinefontein 2 that may represent MIS 9. Visible evidence for human occupation (including cave/overhang sites) during MIS 4 to 9 (see Table 9) was strikingly discontinuous in the Southwestern Cape begging questions about the number of prehistoric groups, demography, spatial patterning, and ecological context.

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1. Introduction

The majority of known Pleistocene archaeological sites are found in caves, which favor sedimentation and preservation. Most 'open-air' sites, which must always have been much more common, have been reduced to reduced surface palimpsests that have sometimes been buried under younger deposits, but retain no integrity as records of human activities. The exceptions are open-air sites found in environments with comparatively rapid

deposition, such as loess sheets, marshes and lakes, or in tectonic grabens like the East African rift system and its northward extension to Ethiopia and the Jordan Valley.

Less familiar are coastal, open-air sites, found within eolianites. Over the years these have been reported from the Mediterranean Basin, but they are particularly important in the Southwestern Cape region of South Africa (Fig. 1), another but restricted area of summer-dry and semi-arid Mediterranean climate (at about 32–34° 40' S). This sector is dominated throughout the year by the westerlies and the anticyclonic circulation of the South Atlantic (counterclockwise). During the

* Tel.: +1-512-328-3255; fax: +1-512-471-5049.

E-mail address: laguna@mail.utexas.edu.

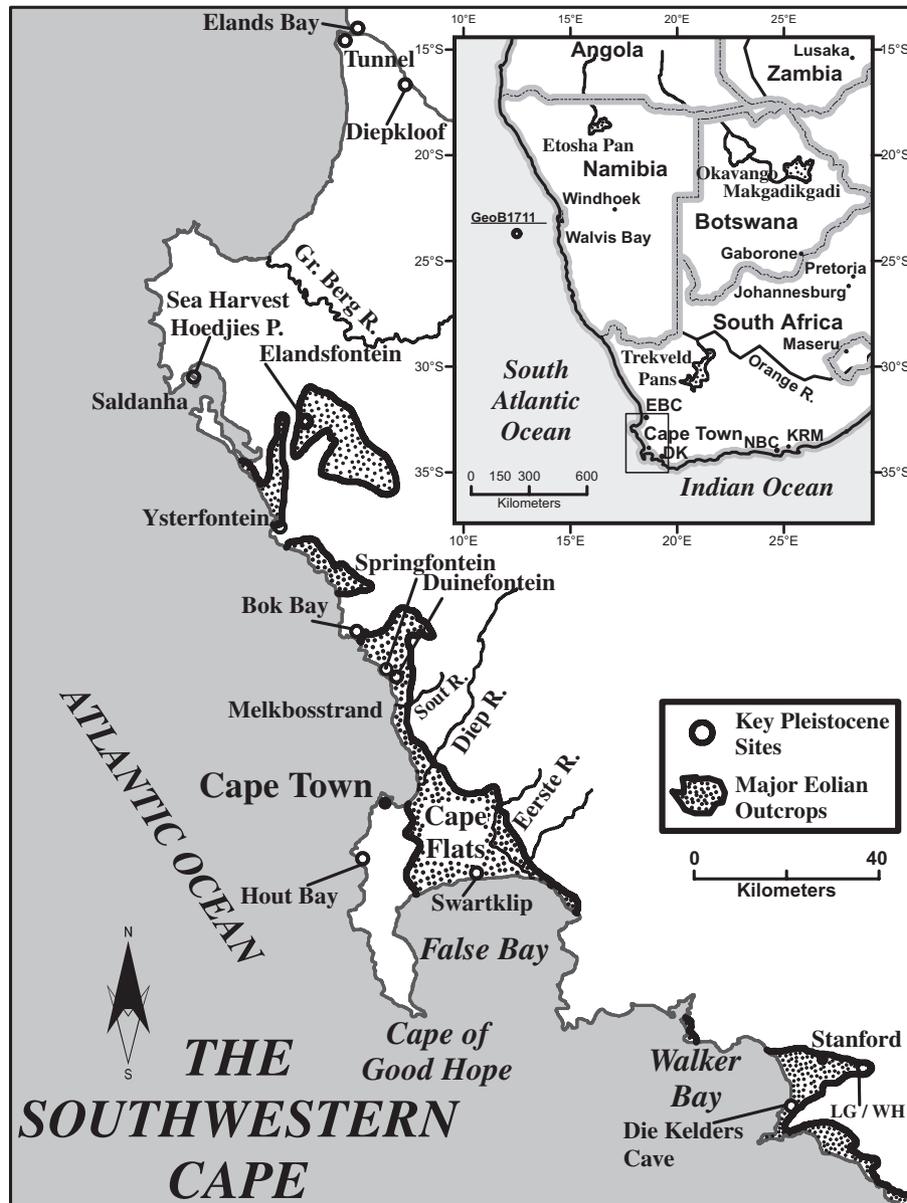


Fig. 1. Archaeological and fossil sites of the Southwestern Cape, showing major outcrops of eolian sands south of Saldanha Bay.

winter months the Southwestern Cape is buffeted by a long series of westerly storms, that direct strong northwesterly winds against the western coast; during the summer the South Atlantic high pressure frequently shifts southeastward, bringing stiff southeasterlies to bear on False Bay (Fig. 1). These two patterns explain the extensive distribution of eolian sands that cover much of the coastal lowlands, interspersed with tall outliers of Paleozoic clastic rocks, such as the Table Mountain quartzite which towers 1000 m above Cape Town [29]. Further inland the Cape Folded ranges form an almost unbroken front, so that streams tend to be short, recycling quartz sands.

Weathering and recycling of quartzite-derived sands created extensive bodies of sand-sized quartz (Fig. 1),

that were introduced to the edges of the continental shelf by stream transport, and moved along the coast by longshore currents and wave action. Periodically such 'beach' sands have been deflated, to accumulate inland as dune fields, against a superimposed rhythm of glacio-eustatic regressions and transgressions that created multiple generations of eolianites. Since caps of Mesozoic or Cenozoic limestone are of limited extent [23], the eolianites are primarily lithified as a result of solution and precipitation of bioclastic debris, such as marine shell. This cementation process provided long-term stability, despite or because of repeated episodes of pedogenic alteration (soils vs. crusts). Over time, such favored littoral contexts created a complex and productive record of local and global environmental

change, directly linked to archaeological or fossiliferous accumulations with which they are interstratified.

Pleistocene archaeology related to marine isotope stages (MIS) 3 to 6 is beyond the effective range of ^{14}C and AMS, but alternative chronometric methods continue for the most part to produce inconsistent or dubious results. It is therefore encouraging that the complexity of environmental changes during MIS 3, 4 and 5 is now being revealed by pollen stratigraphies in France and the Mediterranean Basin [1,19,59,60,77,78,82], that parallel the records of ice cores from Greenland and Antarctica [7,33,57,63]. These suggest several superimposed cyclical patterns, such as the Dansgaard-Oeschger ‘interstadials’, implying that these are global climatostratigraphies, more applicable to continental records than the customary, idealized stratigraphies of deep sea cores [51]. It has been suggested but not demonstrated that fine-grained, glacio-eustatic littoral records may also approximate the variability of these ‘new’ proxy records [53,76]. This paper proposes that a set of detailed coastal stratigraphies, based not on beach deposits or coral formations, but on eolianites and paleosols, can indeed be synthesized as another chronostratigraphic yardstick for the complexity of MIS 4 and 5.

The study focuses on a set of five major local stratigraphies in the Southwestern Cape: Swartklip, Linkerhandsgat-Windheuvel, Sea Harvest, Springfontein and Duinefontein. It also examines (or re-examines) information from Hout Bay, the Elands Bay area, and Die Kelders Cave. Sedimentological study of the stacks of eolianites shows that they can be both transgressive and regressive, representing fluctuations of relative sea level at or near the modern coast. In combination with the marker soil zones, these transgressive or regressive pulses are cross-correlated between sites on the basis of repetitive sequences. The resulting *regional* master stratigraphy has three major and seven minor transgressive fluctuations, plus 11 major and minor soil zones during the early Upper Pleistocene. These are all beyond the range of ^{14}C dating (>43 ka [kilo-anno]), and have four key mammalian faunal horizons of similar age, including several artifactual occurrences, one a Middle Stone Age site. The last phase was coeval with accelerated mechanical weathering, under cold climatic conditions. It will be argued that the major transgressions record MIS 5a, 5c and 5e, and that the minor ones suggest Dansgaard-Oeschger oscillations during MIS 5 and the beginning of MIS 4, since such features represent the interface between marine and continental processes. Only at Duinefontein is there a further, detailed stratigraphic sequence that includes an Acheulian site and two faunal horizons, the older of which is somewhat archaic and found in eolianite modified by plinthite development. This segment of the record is older than MIS 5, possibly pertaining to 7 and 9.

The Southwestern Cape offers a wealth of faunal studies, in fact an unrivalled record of such Pleistocene assemblages, some integral to archaeological sites, others not. These faunas are not consonant with that found historically in this biotic environment [21], and speak for a different ecology [42,43]. The record of sediments and soils provides the necessary geoarchaeological context to elucidate the faunal evidence. Finally there are more speculative questions about the Pleistocene human presence in the Southwestern Cape: (a) is the settlement record sporadic or reasonably continuous over time, and (b) was it limited to particular habitats and niches, linked to particular biota?

2. Establishing a lithostratigraphic framework: the Swartklip fossil site

2.1. Introduction

One of the more challenging study areas is that of the Cape Flats, where dune fields, eolianites, and marine sediments sweep across a narrow peninsula between the Indian and Atlantic oceans. On the Indian Ocean side a full array of such features is spectacularly exposed along the shores of False Bay, with 15–25 m cliffs composed entirely of Quaternary sediments. The major paleontological site of Swartklip or ZW is here (‘black rock’), situated at $34^{\circ} 05' 14''$ S and $18^{\circ} 39'$ E, some 29 km southeast of Cape Town (Fig. 2).

The first report on the Swartklip site was by Singer and Fuller [67], who described fauna from a dislodged block lying on the beach below the cliffs, appending a brief but perceptive description of the marine and eolian deposits. Hendey and Hendey [37] give a detailed account of the faunal assemblages, as well as a sketch of the fossil inclusion, but do not discuss the overall stratigraphy. Siesser [66] offers valuable insights on beach rock and calcrite development, while geological development of the local Quaternary is characterized in sweeping terms by Barwis and Tankard [4], who overlook the paleosols. The most recent analysis and interpretation of the Swartklip fauna is provided by Klein [40,43,46]. The fossils are embedded in the sands of a fissure fill, exposed by progressive wave-undermining of the cliff face; diagonally oriented, the exposed cross-section of bone-bearing deposits, before partial collapse in 1976, was about 1.5 by 6 m, and situated at 16–18 m above mean sea level (msl).

The rich Swartklip fauna is inconsonant with the modern environment. Marine forms are not represented, but it includes freshwater forms such as clawless otter, water mongoose and hippo, as well as southern reedbuck (*Redunca arundinum*) in high frequencies (MNI, minimum of 34 individuals recorded), suggesting adjacent streams or standing bodies of freshwater,

whereas the closest such water today is the Eerste River, 8 km away [40]. Equally impressive is the prominence of large grazers, including wildebeest (MNI 31), springbok (MNI 18), white rhino (MNI 5), and extinct giant forms of buffalo and horse, in what is now a low-carrying capacity environment with small to medium-height, sclerophyllous heath (*fynbos*) and very little grass [21]. Consistent with such large ungulates, the carnivores are well represented and include lion (MNI 3).

The aridity of the modern environment is not climatic but edaphic: the Cape Flats are almost exclusively underlain by quartz sand and the water table is low. The surface consists of fixed eolian bedforms, once sculpted by southeasterly summer storms, now being deflated or remodeled as active parabolic or blow-out dunes, due to modern vegetation disturbance by expanding squatter settlements. Only significant changes of climate and the land–sea interface would provide abundant surface water and more productive herbaceous pasturage.

The importance of Swartklip is enhanced by the fact that it probably offers the longest and most complex Quaternary sequence of the Southwestern Cape. Its repeated facies shifts and modest but informative paleosols are critical for litho- and climatostratigraphic evaluation.

2.2. Methodology

Four sections were described and measured along a 2 km stretch west of the Car Park, near the intersection of the coastal and Swartklip roads (Fig. 2). Bedding

properties and geometry were recorded and pedogenic features examined, followed by laboratory study of 139 sediment samples, including 15 modern analog scrapings from various littoral micro-environments. Most of the Quaternary samples were calcified, requiring pretreatment in acid prior to wet-sieving. Sediment parameters were calculated for the critical sand fraction by the formulas of Folk [27]. The mean (Mz), sorting (So, standard deviation), skewness (Sk), and kurtosis (K) provide useful indices to help identification of facies.

The subsequent empirical presentation attempts to strike a reasonable compromise in reporting field and laboratory data. The verbal categories are as follows: Mz under 0.5 ϕ , ‘very coarse’ sands; 0.5–1.5 ϕ , ‘coarse’ sands; 1.5–2.5 ϕ , ‘medium’ sands; above 2.5 ϕ , ‘fine’ sands. Sorting (σ) of 0.4–0.8 is noted as ‘good’, 0.8–1.2 as ‘moderate’, and greater than 1.2 as ‘poor’. Although measures of sorting or skewness are seldom cited, they were regularly applied to evaluating facies comparability. Means are regularly given in Tables 1–8, and cases of upward fining or coarsening are indicated by arrows between values.

Calcium carbonate equivalents (CCEs) are high, ranging from 12 to 44% for unconsolidated analog samples, in good part reflecting molluscan debris among the sands, while the majority of Quaternary counterparts run from 37 to 75%, as a result of secondary calcification. But there are decalcified zones within the profiles, associated with multiple soils, many of them eroded. At times there also was karstic corrosion, including solution of the fossil cavity. Leaching and

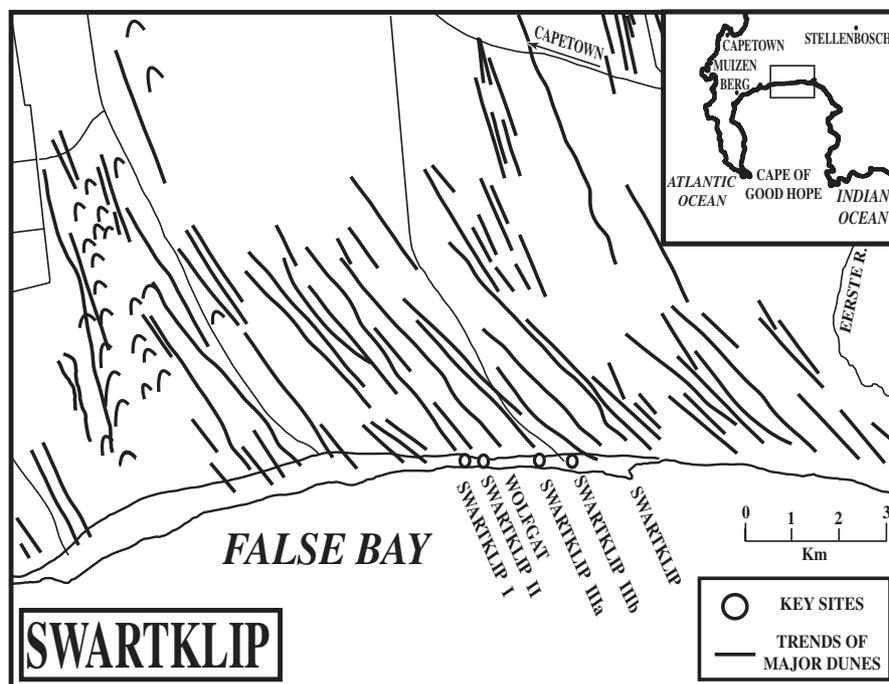


Fig. 2. The Swartklip profiles on False Bay, against the linear dunes of the Cape Flats, reflecting southeasterly summer gales. For location see Fig. 1.

pedogenesis led to accumulation of subsoil ca-horizons, and might be followed by formation of calcareous crusts (*croûtes zonaires*) and true calcretes or petrocalcic horizons [68]. The CCEs for major calcic horizons are given in Table 1. Decalcified sands are almost exclusively quartz, with only traces of feldspars, gray quartzite, metamorphic minerals and mica, shale fragments, foraminifera and occasional organic siliceous debris. Finally, colors (dry) conform to the nomenclature of the Munsell Soil Color Charts, without including distracting numbers for chroma and value; unless otherwise stated, the hue is a monotonous 10 YR.

With specific qualifications, these comments on methodology also apply to the other local sequences.

2.3. *The stratigraphic column*

One of the most complete sequences is exposed 2 km west of the Car Park, at the Swartklip I site of Hendey and Hendey [37]. It is here subdivided into eight major stratigraphic units, based on field and laboratory criteria, that can be traced along the intervening 2 km with assistance of the marker paleosols, as shown in the composite diagram of the four columns in Fig. 3 and outlined in Table 1. No one profile is complete, so that the missing segments are elaborated in the otherwise abbreviated presentation of the remaining profiles (Fig. 3). A more detailed analysis is given by Butzer [16].

The fossil bed comes from Unit 5a i (Table 1). It consists of compact, weakly stratified, white coarse sands with thin, discontinuous and wavy, non-parallel beds. Sorting is moderate and skewness positive, similar to Unit 4d, from which the residual sediment was derived after decalcification. The fossils, which are not calcified, occur in subhorizontal clusters, without preferential orientation but with association of anatomically adjacent parts [40]. Smaller bovids are better represented by cranial material, larger ones by post-cranial parts, suggesting accumulation by predators, probably hyenas [40].

2.4. *Interpretation of the Swartklip sands*

A stepped, linear model proposed by Barwis and Tankard [4] grossly oversimplifies the stratigraphic complexity of the sequence, which is multicyclic, and their facies classification does not do it justice. Interpretation of the sands at Swartklip must be based on both detailed field observation and laboratory discrimination. Yet sediment parameters are not diagnostic in isolation, as already remarked by Singer and Fuller [67], and must be combined with bedding properties, and whether texture fines or coarsens upwards.

2.4.1. *Regressive and transgressive eolianites*

Unit 1 represents a classical eolianite, inclined upslope at 8–15°, crossbedded with backsets up to 30°. Bioclastic debris is prominent, texture coarse and skewness positive. Very coarse laminae suggest creep or even intermittent wave transport during storm surges. Unit 1 dips below modern sea level, implying that msl was a little lower than today. It also is ‘embanked’, presupposing some sort of sea cliffs, only meters inshore.

That said, the terminal parts of Unit 1 fine sharply upwards, arguing for a switch from a rising to a falling sea level. More representative of such a cyclic process is Unit 4, which begins with foreset medium sands and terminates with coarse topset beds, recording a rising sea level, with hints of subsequent fining and incipient regression. The topset beds at the culmination of this unit can be explained by a leveling off of the eolianite at the elevation of the sea cliff in the background. In other words, the eolianite is mainly transgressive and breaks off not long after the next regression begins. West of Swartklip I this can be observed for Unit 7, represented by a great boss of foreset beds at 7–13 m above modern high tide.

2.4.2. *Beach sands*

Two incontestable shelly beach sands are identified in Unit 5 from profiles IIIa and IIIb, beginning with a progression of sands, culminating in the highest shelly beach at +6–8.5 m. At each site the initial medium sands match the sediment parameters of modern, high-tide swash zone analogs, while the later, coarse sands conform to those of low-tide swash. Interpretation of the sediment packages at each site as a transgressive beach sequence therefore seems reasonable, conforming with eolianites elsewhere on the Cape south coast (see Ref. [17]).

2.4.3. *Dunal sands*

The eolianites at Swartklip were ‘fixed’, i.e. embanked against or just over the cliff face, and can be distinguished from dunal sands that were mobile and that moved inland atop the cliffs. Only one such fossil dune complex (Unit 8a) is represented at Swartklip, with weak stratification, variable calcification, and medium sands.

The unconsolidated eolian surface sands (Unit 8b) are of medium to fine grade, although surficial sands on the Cape Flats have been impacted by human disturbance for at least four centuries. Of theoretical interest are the lithified spines of the linear dunes trending northward from the coast (Fig. 2). These may be inland counterparts to some of the eolianites at Swartklip.

2.5. *The pedogenic record*

Under the head of pedogenesis, Barwis and Tankard (Ref. [4], pp. 1287–1288) only discuss calcrete and allow for but a single pedogenic calcrete forming “a continuous

Table 1
Composite stratigraphy and soil zones of Swartklip

<i>Unit 8b</i>	Recent, eolian surface sands (1.2 m; Mz 2.47), reflecting current eolian processes, but modified by human disturbance (blow-out dunes).
Soil 18	Light brownish gray ochric (A-)horizon, with thin calcic horizon or crust (to 80% CCE), and basal solution pipes (60 cm).
<i>Unit 8a</i>	Medium eolian sands (2.8 m; Mz 2.18 [σ 0.38 for nine samples]); partly calcified; cover lithified linear dunes inland.
Soil 17	Thin, laminated crust with rhizoliths (5 cm). Followed by minor stream cutting.
<i>Unit 7d</i>	Medium sandstone, possibly colluvial (40 cm; Mz 1.87).
Soil 16	Laminated crust, in part petrocalcic (35–74% CCE) (15 cm).
<i>Unit 7a/c</i>	Regressive, foreset to topset, coarse to medium eolianite; low angle crossbeds; basal rhizoliths and calcification (3.1 m; Mz 1.21 → 2.27).
Soil 15	Colluvial, pale brown ochric soil with oxide stained quartz grains, reworked by erosion; underlying sediment deeply decalcified; basal rhizoliths or calcic horizon represent truncated base of original soil (60 cm).
<i>Unit 6a/b</i>	Regressive, topset, coarse to medium eolianite (2.5 m; Mz 1.31 → 1.69); planar crossbeds at base; partly fills stream-cut channel; colluvial at top.
Soil 14	Laminated crust (5 cm) over rubble horizon, in part embedded in light gray ochric horizon; laterally becomes thick and petrocalcic (70% CCE) (30 cm); solution pockets below. Followed by stream entrenchment (regression).
<i>Unit 5d</i>	Shelly coarse beach sandstone (40 cm; Mz 1.61), in part with articulated bivalves; some thin calcite laminae; covered by very coarse sandstone (60 cm; Mz -0.17). Sea level 8.5 m above high tide.
Soil 13	Laminated crust (68–73% CCE) (5–10 cm).
<i>Unit 5c</i>	Coarse and medium beach sandstone (Mz 1.39 → 2.40), in part with shell hash, grading upslope to a topset, coarse eolianite (3.0 m; Mz 1.57); transgressive. Calcification of bedding planes and rhizoliths at base.
Soil 12	Light gray ochric soil (50 cm).
<i>Unit 5b</i>	Medium to fine sandstone, partly colluvial (120 cm; Mz 2.03 → 3.37).
Soil 11	Light brown ochric soil, decalcified, with blocky structure (20 cm).
Soil 10	Laminated crust (40 cm) or petrocalcic horizon (92% CCE) (30 cm), incorporating calcrete debris and residual silty fine sand; over calcic horizon (50 cm).
<i>Unit 5a ii</i>	Medium sandstone (70 cm; Mz 2.27).
Soil 9	Colluvium (20 cm) over pink laminar crust (70–84% CCE) (5 cm), on truncated, light brown ochric soil (35 cm) with calcic horizon; elsewhere, enrichment of iron, reddish yellow (7.5 YR) staining of bedding planes, oxide coated quartz or Fe aggregates, above basal rhizoliths.
<i>Unit 5a i</i>	Transgressive, foreset to topset, coarse eolianite (0.9 m; Mz 1.21); locally interrupted by another calcic soil. Colluvium derived from this bed provides the matrix of the fossil deposit .
Soil 8	Truncated soil, preserved as calcic horizon of fine sand (35 cm) or discontinuous crusts; deep solution hollows and karstic fissures that enclose the Swartklip I fossil site .
<i>Unit 4d</i>	Transgressive, topset coarse eolianite (3.0 m; Mz 0.83); planar crossbeds.
<i>Unit 4c</i>	Transgressive, foreset medium eolianite (5.0 m; Mz 2.33); high angle crossbeds. Mole rat burrows.
<i>Unit 4b</i>	Medium sandstone, partly colluvial, with terrestrial snails; oxide films on quartz grains (75 cm; Mz 1.86).
<i>Unit 4a</i>	Medium sandstone, partly colluvial, with basal rhizoliths (150 cm; Mz 2.27).
Soil 7	Reddish yellow (7.5 YR) ochric horizon with blocky structure (25 cm).
Soil 6	Eroded, laminar crust.
<i>Unit 3c</i>	Transgressive, foreset coarse eolianite (2.0 m; Mz 1.26); with terrestrial snails at top.
<i>Unit 3b</i>	Mainly regressive, topset to foreset, medium eolianite (2.0 m; Mz 2.08); large scale crossbeds; terrestrial snails at top. Fossil bovid .
<i>Unit 3a</i>	Transgressive, coarse beach sandstone (2.5 m; Mz 1.46); low-angle crossbeds; basal rhizoliths and soil derivatives.
Soil 5	Light gray ochric horizon, embedding oxide-stained grains, elsewhere eroded and reworked as colluvium (50 cm).
<i>Unit 2c</i>	Medium regressive sandstone of eolian origin, possibly reworked (1.0 m; Mz 1.79).
Soil 4	Rhizoliths and calcic fillings of minor solution fissures.
<i>Unit 2b</i>	Transgressive, medium sandstone (75 cm; Mz 2.25), with terrestrial snails.
Soil 3	Thin laminated crust or rhizoliths.
<i>Unit 2a</i>	Transgressive, foreset to topset eolianite (2.0 m; Mz 2.02 → 1.20), with interbedded calcite or rhizoliths and terrestrial snails.
Soil 2	Eroded, laminated crust or thin petrocalcic horizon (60–66% CCE).
Soil 1	Grayish brown fine sand (50 cm), mainly eroded.
<i>Unit 1</i>	Transgressive, then regressive, foreset, very coarse eolianite, fining upward as terrestrial snails replace marine bivalves (over 4 m; Mz 0.35 → 2.90); with large scale, high angle and planar crossbeds.

Primary depositional units are identified in italics, and major soils and crusts as well as faunal archaeological horizons are highlighted in bold. Mean textures (Mz) of sands are averages, and trends may be noted by arrows. Modal thicknesses are given. Colors are white or very pale brown (buff) unless otherwise noted.

cementation to the formation of multiple fine laminae of cryptocrystalline calcite, that typically are sub- or discontinuous. Such features never crosscut bedding planes, because they are linked to sediment laminae of selective permeability: enrichment was primarily effected by lateral seepage or ‘throughflow’ waters. Once formed, a fine laminar crust is relatively impermeable and continues to thicken, perhaps indefinitely. At least ten examples can be identified in the profiles.

2.5.4. *Capping crusts*

The visible surface of most sedimentary units at Swartklip is calcified by a subcontinuous lamellar crust that may be 5–15 cm thick and is not fully cemented. The upper contact is smooth and hard, due to repeated solution and recrystallization, as well as prolonged sand blast, but the lower boundary is gradual, with increasingly wide-spaced and discontinuous calcite laminae. Such crusts will originally have begun to form in the subsurface, along bedding planes or at the base of weak soil profiles, to be later exposed by erosion. They are here attributed to throughflow. Nine cases are apparent in the various columns (Table 1), some intergrading with the next category.

2.5.5. *Petrocalcic crusts*

In some cases a capping crust may attain 20–30 cm thickness, to form an indurated and continuous petrocalcic, K-horizon [68] or ‘full’ calcrete, in which the laminar structure of the upper part may be largely obscured by recrystallization. The presence of this more extreme variant in some micro-settings, in place of less developed capping crusts, may be due to surface concavities that concentrate throughflow waters. Dips of 10–20° in the petrocalcic crust near the top of profile IIIb illustrate erosional irregularities that served to locally accelerate the processes of surficial cementation. Four major examples are recorded.

2.5.6. *Calcrete slabs*

The presence of broken up petrocalcic material in three cases (Units 4b and 5b of profile I, and 5b of IIIb) shows that surface crusts were sometimes undermined and eroded, prior to accumulation of a new sedimentary unit. That suggests long intervals between some of the units, as well as a greater prominence of initial colluvial processes than can be identified by other criteria.

These various features clarify that ‘calcretes’ do not crosscut primary sedimentation structures at Swartklip, and they did not form in the capillary zone above the groundwater table; instead, they follow the laminate structures of the sediments and were enriched with calcite by selective lateral movement of throughflow waters. Although not necessarily qualifying as soils, they frequently record the base of otherwise eroded soil profiles. More importantly, they are valid pedogenic

criteria for periodic fluctuations in the calcium bicarbonate saturation of soil waters. They argue for high seasonal contrasts of moisture availability, in a subhumid or semi-arid environment, accentuated by a permeable and arid, arenaceous substrate.

The calcium bicarbonate in solution in soil waters was provided by dissolution of bioclastic debris in local sediments. That requires a quota of precipitation and percolation, and would be accelerated by cool temperatures and organic acids derived from decomposition of organic debris. These qualifiers become critical to explain the evidence for significant solution, including karst formation, at the end of Unit 4d, and the local presence of solution pipes below soils over both Units 5d and 7a in profile IIIa.

The karstic solution that created the fossil cavity as well as a fissure network with a vertical relief of 2.5 m at Swartklip I demands a fairly radical explanation—substantially greater precipitation, a good mat of humic soil with adequate ground cover, and a higher-productivity vegetation than that provided by the modern sclerophyllous heath. Dissolution is optimal with temperatures not much above freezing, tentatively suggesting a cool wet season.

The package of minor soils encompassed by Unit 5 (see Table 1) may not carry as much weight in arguing for a more mesic climate, but it does document a qualitative difference with respect to present-day conditions. Light gray or light brown ochric horizons are quite modest as such, but two such examples are essentially leached, and one has moderate structure. Furthermore, oxide staining, oxide-coated quartz grains, and ferric aggregates found at the root of truncated Soil 9 indicate some mobilization of sesquioxides, either by throughflow enrichment or vertical translocation of aerosols.

Last but not least, over 30% silt and clay embedded in the crust of Soil 14 cautions against assuming that the preserved horizons are fully representative of the pedogenesis responsible for such modest soils. Nonetheless this ratio of silt and clay can hardly be attributed to comminution of quartz sand, and presupposes a major component of eolian dust. The source of such loess-grade dust poses a problem in that the False Bay shelf is flooded by sorted, fine to very coarse sands (see Ref. [6]), an unlikely source for regressional deflation of silt-sized particles; further, sediment influx from local streams such as the Eerste River is very coarse (Ref. [6], Fig. 2). Eolian dust would therefore have to come from much further afield (see Section 8.1).

Of the 18 ‘soils’ identified in Table 1, nine are laminar or petrocalcic crusts that presumably were initiated as ca-horizons at the base of soil profiles, but continued to form after erosion of the epipedon. Nine others retain an epipedon, often of a colluvial nature, commonly with additional characteristics: (a) ochric epipedons, light gray or grayish brown (two soil zones); (b) with

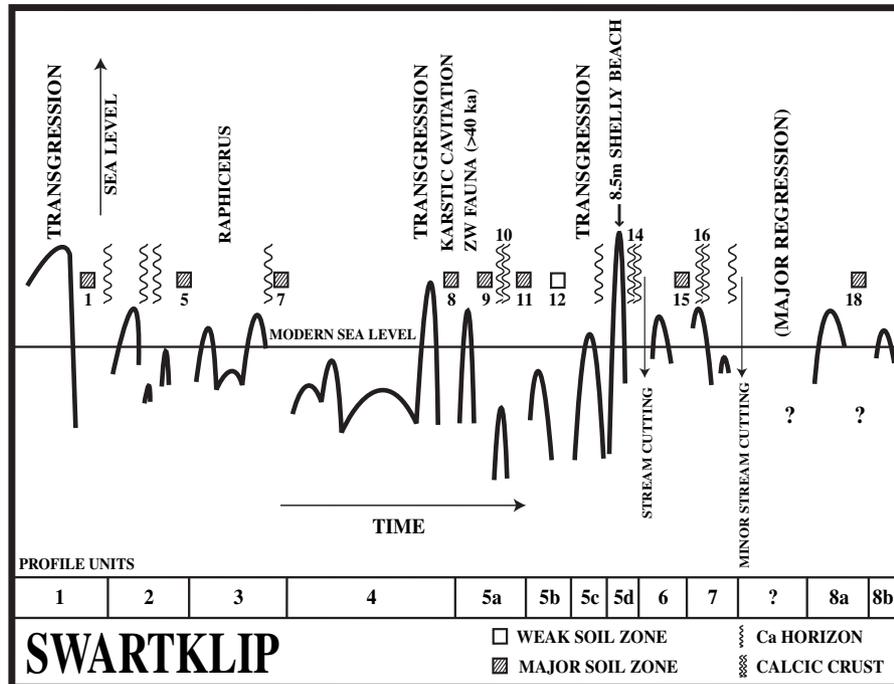


Fig. 4. A heuristic model for interpretation of the Swartklip sequence of sediments and soils in terms of relative time and sea level change (see text). Only major soils are identified by number. Climatostratigraphic interpretation is deferred to Fig. 13.

ca-horizon, light brown (one soil zone); (c) with ca-horizon and basal solution pipes, light brownish gray (two soil zones); (d) with blocky structure and deep decalcification, light brown or reddish yellow (soil zones 7 and 11); and (e) with oxidation staining of bedding planes or quartz grains, with deep decalcification and ca-horizon (soil zones 9 and 15).

Category (a) would represent a *Xeropsamment* in the US Soil Taxonomy [68] (formerly regosols), while (b) and (c) qualify as *Typic Calciorthids*. Categories (d) and (e) are intermediate between calciorthids and *Camborhids*, with incipient cambic horizons, given the erosion that has taken place. Some of the capping crusts and petrocalcic horizons suggest truncated, *Typic Paleorhids*. In short, despite the context of a quartz sand substrate, this is a varied group of some environmental significance, heightened by the probable presence of aerosolic or loessic components. The role of such paleosols as stratigraphic markers is critical.

2.6. Preliminary stratigraphic dating

Taking synthetic representation a step further, Fig. 4 offers a graphic model for the data developed in Table 1. To suggest a temporal dimension, the modal thickness of the sedimentary units, factored by sediment caliber, is used as a very imperfect proxy for time, with interruptions for soil zones or crusts. The result is explicitly *not* to scale. Similarly the vertical trace of sea level is inferred from transgressive or regressive facies, with

levels proportional to textural grade (Mz). A gap between Units 7 and 8a is assumed without compelling lithostratigraphic grounds, while that between 8a and 8b is based on notable differences in lithification. The high sea level of Unit 5d is at 11.5 m above mean sea level, but only about 8.5 m above storm surges at high tide.

The measured elevation of this high sea level marker carries no stratigraphic import in the Cape Province, for a number of reasons: prominent shoreline features that have been cut into bedrock can conflate two or more distinct stands at similar levels, and beaches within sedimentary packages may be at different elevations than abrasional shorelines, in part because of high tidal amplitudes (3 m or more), the efficacy of storm surges, wave energy, and sediment supply and autocompaction. There also appear to be gentle tectonic deformations, all of which make correlation by altimetry next to meaningless. Neither are there any diagnostic molluscan forms. Important is that the 'high' sea level recorded by Unit 5d cannot be assigned to the deep sea 'glacial' or 'cold' MIS 3 or 4.

The other 'high' sea levels of Fig. 4 are no more than heuristic devices to identify transgressive or regressive trends from proxy data. Thus, Unit 1 has a transgressive facies that extends from below msl to at least 4 m above; but initial texture is so coarse that actual sea level probably peaked well above modern msl. Unit 8b is recent and remains un lithified, so that 8a could be expected to represent the end-Pleistocene/early Holocene glacio-eustatic transgression; the 8a sediments lack

a transgressive facies, but being perched on top of the cliff, that may not be significant.

As a provisional working hypothesis, prior to the concluding synthesis (Section 8.2), it is suggested that Units 1–7 represent MIS 5, which is consonant with an early Upper Pleistocene placement of the fossil fauna [40]. It also agrees with an ostrich eggshell radiocarbon date of ‘greater than 40,000 years’ (I-6840) [40]—a material that has proven to be unusually reliable. Other ostrich eggshell has a very tentative racemization age between roughly 186 and 127 ka [46]. Given the early Upper Pleistocene fauna, and placement between the second and third transgression of the Swartklip sequence, the faunal deposit is tentatively assigned to a slightly cooler phase, during the second half of the Last Interglaciation. These issues are discussed further in Section 8.2.

Major channel downcutting after Unit 5 and a measure of stream incision after Unit 7 imply repeated and concentrated runoff. They also require solution and decalcification along the channelways, since stream incision followed upon calcification and the formation of laminated or petrocalcic crusts thus had to cut through lithified strata. This argues for intervals of heavy precipitation, essentially permanent subsoil moisture, as well as a lower sea level. Even more than the stack of paleosols, this presupposes a radically different vegetation on the Cape Flats and their littoral zone. Fortunately there is a palynological investigation to fall back on. The results do not provide direct correlations with the Swartklip succession, but offer an instructive image of a dissimilar ecology.

2.7. A model for vegetation ecology

The paleoenvironmental import of the fossil fauna and multiple paleosols of Swartklip is complemented by the pollen records studied by Schalke [62] northeast of Cape Town and in the center of the Cape Flats. This last core, located at 33° 57' S and 18° 33' E, is situated in the middle of the Cape fynbos or macchia, dominated by taxa with small and hard, leathery or oily leaves. A scrub of 2–3 m elevation is typical of dune ridges, with a low macchia of 1 m found on undulating topography, and communities of grasses and rushes in some marshy swales (*vleis*) [62].

The Cape Flats profile (Ref. [62], Appendix 5) has pollen from sandy clays at 4.1–6.2 m depth, and the 19 spectra have 12–44% *Podocarpus* or yellowwood, a southern hemisphere tree that dominates the ‘temperate rainforest’ of Knysna and Tsitsikamma, much further east along the Southern Cape coast. The presence of macro-remains such as stomata throughout the profile makes clear that *Podocarpus* was indeed present locally. Open water and semi-aquatic taxa, dominated by Restionaceae, Liliaceae and Potamogetonaceae, account for 1–12% of the pollen in various spectra, while marshy

and other wet environments are represented by 5–23% (Rubiaceae, Typhaceae, Cyperaceae). Dune pioneers (Euphorbiaceae, Aizoaceae, Rosaceae) range from 0 to 6% and related coastal taxa (Anacardiaceae, Portulacaceae, Geraniaceae) run 1–8%. *Macchia* is represented by taxa such as Proteaceae, Myrtaceae and Ericaceae at 10–27%. These difficult and relatively obscure families, as discussed by Schalke, document a variety of environmental mosaics (see also Ref. [21]) that, excluding ‘universal’ plants, comprised at different times: (a) macchia with ponds or marsh; (b) *Podocarpus* and *Ilex* woodland with ponds and macchia; (c) woodland and macchia with marsh; (d) macchia with active dunes and *Podocarpus*; and (e) *Podocarpus* woodland with macchia and active dunes.

This was not a rainforest at any time (contra Ref. [73], p. 328), but a complex mosaic of evergreen trees and woody shrubs, with ponds or marsh and sometimes active dunes. There was little grass (Graminaceae under 4%), but a great variety of other herbaceous annuals, together averaging over half of the total pollen. In other words, each of the mosaic types identified above was open in character—not the best ungulate grazing, but an order of magnitude better than in recent times.

Dating of these spectra is problematical, in that the ‘extended’ ¹⁴C dating by Groningen that Schalke once assumed to be valid has proved to be illusory. Thus, the dates of 41,500 ± 2100/-1800 b.p. (GrN 6525) on fossil roots at 4.5 m depth, and >43,000 b.p. (GrN 6524) on peaty clay at 7.0 m [62] are no more than minimum ages. It is more probable, but almost impossible to demonstrate, that these palynologically productive zones relate to Swartklip Units 4 and 5. The alternation of periods with ponds or marsh, and those with dune activation, would be compatible with Soils 8–12, repeatedly interrupted by sand accumulation at Swartklip. Whether or not contemporary, the ‘woodland/macchia with marsh’ mosaic (c), identified by the aquatic taxa in the Cape Flats profile, suggests a useful model for the vegetation mosaic available for the Swartklip fauna.

3. Two inland sites near Stanford: Linkerhandsgat and Windheuvél

Two minor fossil sites are located off Walker Bay, 15 km NE of the seashore in a triangular valley, surrounded by steep ranges with a relief of over 500 m. Talus and screes are well developed on the slopes of Table Mountain quartzite, with porphyritic granite exposed at the base [28]. At least two generations of alluvial fans with reddish, mollisolic soils (on sandy substrates, now under heath) debouch from breaks in the mountains. But the western valley floor is dominated by modern ‘drift sand’ and undulating, ancient eolian bedforms. In between, stream incision has created

a valley floor relief of 30–35 m, with the interfluves capped by eolianite.

Two faunal sites are located 7.5 km ESE of Stanford, with 600 mm precipitation, one of the wettest locations discussed here. That may explain the prominence of karstic solution features of Linkerhandsgat (LG), situated N of the Modder River at 120 m elevation, and Windheuvel (WH), to the S at 175 m (South African 1:50,000 topographic sheet 3419 BC, 1969). LG has an exposure of only 4 m, but complements the 12 m sequence of Windheuvel (WH). The vegetation is sclerophyllous, and the complexity of its structure is greatest where agricultural land use has been abandoned longest. A mix of low trees, bush and grass is found on the interfluves and along the riparian fringe, with low bush in between.

Notice was first drawn to the sites by Cooke [20], who described a chalky limestone and calcified sands with fossils, including hyena, jackal and a hartebeest at Linkerhandsgat, and reedbeek and impala (? springbok) at the adjacent farm Nooitgedacht; he also refers to a larger private collection, which remains unpublished.

The sites were visited in the company of Richard Klein, who made further collections at LG-East, which now has the following MNI counts: wildebeest (5), southern reedbeek (3), blue antelope, bontebok and springbok (2 each), and greater kudu (1). The composite count further includes jackal, hyena, rock hyrax, dune molarat, rhino, grysbok, and roan antelope (Klein, pers. commun.). This is an assemblage dominated by grazers, quite similar to the Swartklip fauna. That makes LG/WH of some comparative interest.

Nineteen sediment samples, including two analogs, were processed in the laboratory. Given the elevation and distance from the modern coast, the eolianites are expectably of finer grade than at Swartklip. Yet five of the samples have abundant marine molluscan debris, some coarser than 1 mm. All but one are negatively skewed, indicating coarse tails. Sorting is good to moderate. Textural classes can be adjusted to highlight contrasts: medium-coarse sands (Mz 1.7–2.4), medium sands (Mz 2.5–2.6), and fine sands (Mz 2.65–3.1). Kurtosis values increase as grain size decreases.

The composite profile, rich in colluvia and pedogenic features, is described by Table 2 and Fig. 5. Although the LG/WH sequence has three prominent eolianites, the hallmark is its suite of ten buried soils. Of these, four represent calcium bicarbonate mobilization on a large scale, including massive but unstructured cementation (Soil 9), laminated crusts (Soils 4 and 6), and petrocalcic recrystallization of initial laminated crusts (Soil 2). These suggest sustained throughflow within eolian veneers and colluvia under piedmont surfaces. The calcium will have been largely supplied by local solution of bioclastic material or eolian dust. Subsurface calcite enrichment at LG/WH will originally have taken place under ochric topsoils, now generally lost. The original soil types were *Calciorthis* or, in the case of Soil 2, a *Paleorthis*, without accepting the US Soil Survey [68] implication that time is the key variable in differentiation.

Colloidal silica was mobilized as a secondary cement in relation to Soils 2 and 6; such silica presumes weathering of feldspars or carbonate rocks in a soil

Table 2
Sediment stratigraphy and soil zones at Linkerhandsgat and Windheuvel

Soil 11	Holocene/Modern, grayish brown umbric horizon, some organ-pipe solution at base.
Soil 10	Karstic cavitation deep inside Unit 6.
Soil 9	Cementation of soil (8) and Unit 6 (54% CCE).
Soil 8	Strong soil with sandy loam texture (19% clay), sesquioxide enrichment, and some basal solution.
Unit 6	Regressive, medium to fine eolianite (2.5 m; fining upward Mz 2.52→2.93).
Soil 7	Partial decalcification, humification, sesquioxide enrichment, and implied subsoil solution. Weathered sediment from this soil probably filled a now degraded cavity at <i>LG-East</i> with concentration of fossils and rare artifacts (Mz 2.23; 39% CCE).
Unit 5	Transgressive, coarse eolianite (1.5 m; Mz 2.05→2.37; CCE decreases upwards from 56 to 35%); light gray; with large marine shell debris.
Soil 6	Laminated crusts (67% CCE), light brownish gray, with silica mobilization, impregnating Unit 4b and sealing fossil fill at WH (88% CCE; 49% silica in non-calcic residual).
Unit 4	Mainly colluvium (0.5–0.8 m; Mz 2.95→3.02), incorporating eroded peds of Soil 5, and filling solution cavities with fossil accumulations and rare artifacts at WH (Mz 2.57; 43% CCE).
Soil 5	Light brownish gray soil with oxide enrichment, blocky structure; basal karstic solution and cavities >1 m.
Soil 4	Laminated crust with cementation of Unit 3 (58–80% CCE).
Unit 3	Colluvial mix of derived soil (12% clay and silt), crustal rubble, and fresh eolian sand (0.3 m; Mz 2.60→2.80).
Soil 3	Truncated soil, probably a humic, brownish loamy sand, with solution of underlying crust.
Soil 2	Petrocalcic horizon, with silica mobilization and complete recrystallization of initial laminar crusts (95% CCE; silica 41%).
Unit 2	Possibly a colluvial mix of fine, regressive eolian sand and weathering residues (1.0–1.3 m; Mz 3.10).
Soil 1	Solution of some deep pipes or fissures (>1 m).
Unit 1	Transgressive, coarse eolianite (>6.0 m; Mz 1.58→2.25), well stratified with small scale planar crossbedding (dips 4–5° NNW); much molluscan debris.

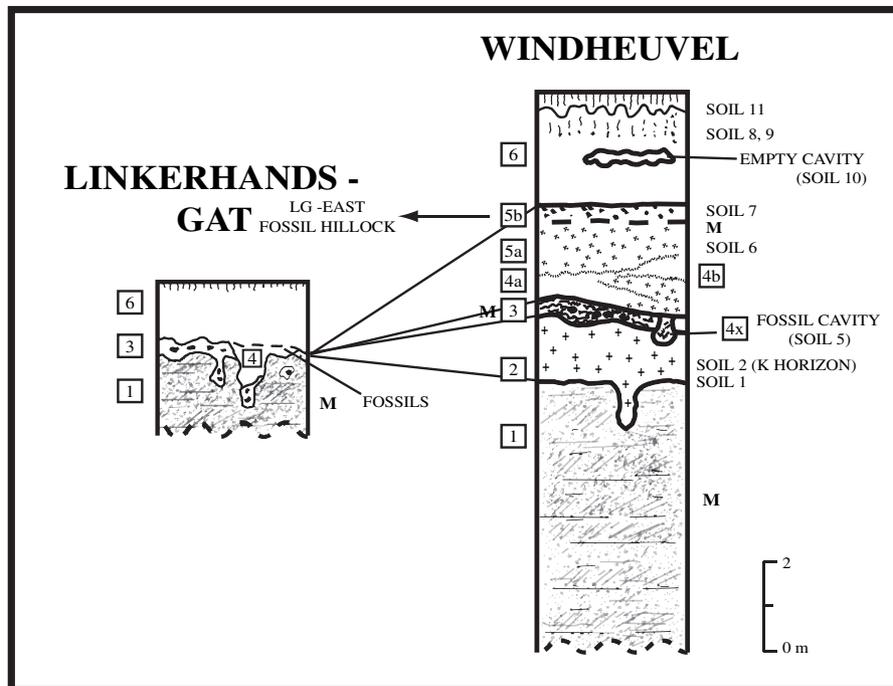


Fig. 5. Profiles for the faunal sites Linkerhandsgat and Windheuvvel, Stanford district.

environment with pH approaching 10, compared with a current pH range of 7.60–8.15. Mountain streams are now red with mobilized sesquioxides, but shaley Table Mountain interbeds may be rich in feldspars, and reappear in screens. More probable as a source of silica are older eolianites exposed in the Modder catchment. In any event, silica mobilization implies long-distance surface runoff.

The remaining six soils are associated with calcite solution and removal, rather than accumulation, and suggest substantial percolation of precipitation, through a less alkaline soil environment, with little seasonal interruption of lateral water movement. In two cases, the surviving pedogenic record is limited to deep karstic cavitation (Soils 1 and 10). The other five involved basal solution, but without the calcic horizons common at Swartklip. The surface soil (11) has a 30–50 cm umbric horizon above soil pipes, and much the same is reconstructed for Soil 3; these can be considered as *Typic Xerochrepts*. Soils 5, 7, and 8 were humified to some degree, had soil structure and free sesquioxides, or a loamy texture, and soil pipes at the base; they suggest *Typic Camborthids*.

Categories rather than labels are important here, because they illustrate the degree to which the local soils are more ‘evolved’ than any of those at Swartklip—admittedly on finer sands, but a quartz substrate nonetheless. Further, nine of the interbedded paleosols were marked by active solution of underlying crusts or calcified eolianites. That not only infers episodes of abundant surface and subsoil water but, given the

multiple paralthic units in the substrate, it also requires free lateral drainage of the dissolved load. Such elutriation would only be possible if the Modder River simultaneously cut a channel down through earlier sediments and crusts. Periods of karstic solution, creating rock cavities (Soils 1, 5 and 10), must therefore have been accompanied by channel entrenchment—at times of substantial and perennial discharge. The karstic cavities eventually filled with sediment, during the waning phase of solution, in some cases incorporating animal bone. Thus, the fossiliferous beds are directly or indirectly linked to periods of abundant water. Such conditions were more mesic than those provided by the fynbos of the modern landscape.

The fossiliferous beds accumulated in existing karstic cavities, and there are no visible hyena burrows. Presumably sediment and bones washed in from higher levels. But despite the presence in some of the pockets of (unretouched) quartzite flakes, these occurrences do not imply former archaeological sites, as opposed to colluvial washing of surface and subsurface debris to include occasional artifacts. The three probable colluvia suggest vigorous sheet or rillwash, implying an incomplete groundcover and more xeric conditions. This hints at a cyclic shift from eolian processes → karstic solution and stream downcutting → infilling of cavities → colluvial reworking → calcification (see also Ref. [18], Fig. 9).

Stratigraphic placement of the LG/WH eolianites, soils, and associated features is attempted in Fig. 6, according to the same procedure outlined for Fig. 4. Again this graphic representation is used as an heuristic

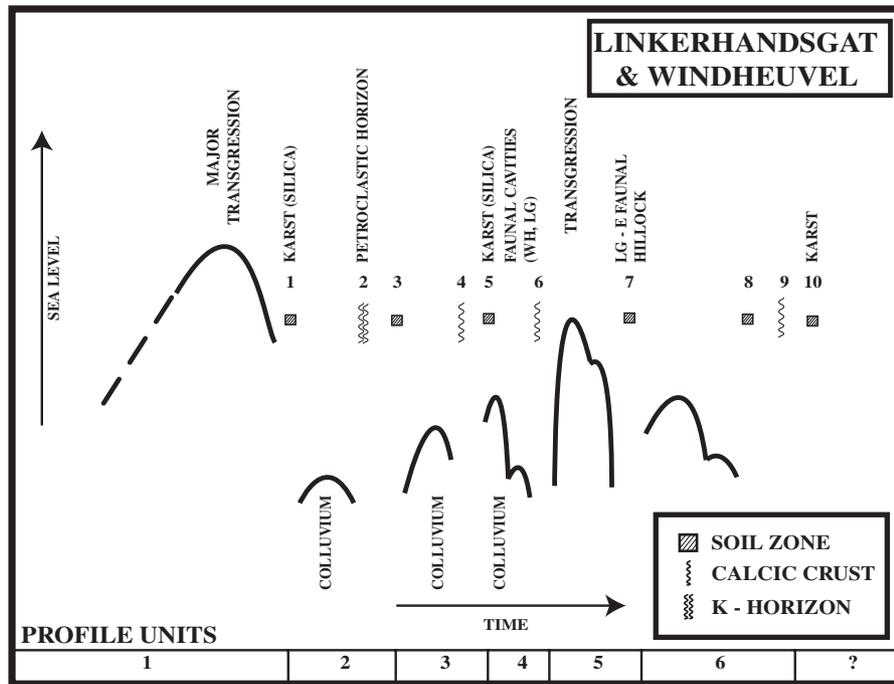


Fig. 6. Interpretation of the Linkerhandsgat/Windheuvvel sequence.

device to highlight a complicated sequence, and the same caveats apply. The framing eolianites (Units 1 and 5–6) and the succession of multiple soils and interruptions (Soils 1–6) in Fig. 6 closely parallel both the arrangement and ecological interpretation of Soils 8–13, between Units 4 and 5b–7 at Swartklip (Fig. 4). The faunal lists are similar in terms of taxa and the environment they imply.

If there once were earlier eolianites at WH, equivalent to Swartklip Units 1 and 3, they are obscured by cover sediments, if not decalcified and degraded. The absence of Unit 8 at WH is readily explained by distance from the coast, and equivalent eolian sands should be sought in the younger eolian terrain closer to Walker Bay. Remarkable is the broad sweep of Pleistocene eolianites in the Modder catchment to more than 18 km inland of the former shoreline, on to the edge of the piedmont alluvial fans. In fact, accumulation was a result of SE winds, across the low intervening mountains, since the sands thin out northwards, towards Stanford, their elevation falling from over 250 to 50 m. This attests to winds more sustained and potent than anything experienced today.

4. Saldanha Bay: sea levels and sites at Sea Harvest and Hoedjies Punt

A Middle Stone Age (MSA) midden was reported from Saldanha Bay by Volman [80], complemented by

important faunal collections and some human remains [32,43]. The site, no longer accessible, was located next to the Sea Harvest cannery, 1 km south of Saldanha near the harbor jetty and railroad spur that forms the SE end of Smitswinkel Bay (33° 1' 23" S, 17° 57' 0" E). There is a fairly complete stratigraphic sequence here, and the presence of a good number of karstic cavities with artifacts allows reconstruction of pedogenic phases. The Sea Harvest deposits continue on to the narrow peninsula of Hoedjies Punt, where Cooke [20] identified sea lion (? fur seal) from a fossil occurrence, probably near recently reported sites 1.2 km SE of the Sea Harvest cannery.

A total of 38 sediment samples were analyzed from these sites and modern analogs, to complement the field descriptions. Various scatterplots of the textural parameters indicate a fairly homogeneous group, with only seven samples emerging as a distinctive subset, on the sole criterion of mean size (Mz). But the other parameters are useful to identify sediments reworked in fissure fills.

The base of the sedimentary sequence at the Sea Harvest site is given by a dark gray (5Y) quartz-porphry of the Saldanha-Langebaan pluton, of early Paleozoic age. Strongly jointed and tending to spheroidal weathering, the top 50–150 cm are saprolitic and of light gray (10 YR) color. The surface of these rocks represents a wave-cut platform, visibly culminating at 6–7 m above modern high tide. That provides a datum for the stratigraphy, outlined in Table 3 and discussed further below.

Table 3
Cumulative sediment stratigraphy and soil zones at Sea Harvest

Soil 12 <i>Unit 12/Fill D</i>	Capping laminated crust (79% CCE), also honeycomb in Fill D. Surface colluvium with coarse, corroded pebbles (0.4–2.0 m; Mz 2.74) and angular slope rubble in ravine (3.0 m), with fine sandy matrix; preceded or accompanied by vigorous surface erosion; mechanical weathering prominent. Entrenchment of ravine (6–7 m), possibly breaching of cavern B/C
Soil 11 Soil 10 Fills B/C and G1	Corrosion of near-surface concretions in soil zone (now eroded), with oxide staining. Calcification, with formation of large concretions in Units 9 and 11, or laminated crusts in cavities G and B/C. Colluvial infillings of cavities and cavern, roof spall (mechanical weathering) in C, including MSA site (Fill B) and main Sea Harvest fauna (Fills B and C).
Soil 9 <i>Unit 11</i>	Karst activity, opening cavities G and B/C in the substrate. Crossbedded eolianite (dunes) (1.5–3.5 m), light gray (2.5 Y), large-scale, low to high angle trough crossbeds, with smaller scale planar crossbeds (NW and NE dips); initially transgressive and medium-coarse (Mz 1.73→1.63), final phase medium sands (Mz 2.37); much ground up marine shell, traces of phosphate pellets. Erosion
Soil 8 <i>Unit 10</i> <i>Unit 9</i>	Truncated, partly decalcified soil with ca-horizon. Regressive, fine eolianite (0.6–1.1 m; Mz 2.95), some low angle crossbedding (dip 3–5°E); (proliferations of <i>Trigonephrus</i>). Regressive, fine eolianite (1.2–2.0 m; Mz 2.51→2.58); horizontal bedding. Erosion (accumulation of Fills A, E?)
Soil 7 <i>Unit 8b</i> <i>Unit 8a</i>	Truncated soil, with deep calcification (80–90% CCE) and major mobilization of silica (20%); sesquioxides present; basal rhizoliths. Medium eolianite (0.4–2.4 m; Mz 2.35), possibly main source of fossiliferous Fill A. Fine eolianite (0.5–1.1 m; Mz 2.65), source of Fill E.
Soil 6 Soil 5	Karstic dissolution of cavities in substrate and corrosion of surface crusts. Capping laminated crust (90% CCE) with subsoil concretions, silica enrichment (16.5%), and laminar calcite in substrate cavities.
Soil 4 <i>Unit 7</i> <i>Unit 6</i>	Truncated soil, with oxide mobilization and ferric micro-concretions in subsoil and dissolution of cavities along joints and bedding planes in substrate. Regressive, fine eolianite (0.5–0.7 m; Mz 2.90→2.99); low-angle crossbedding. Abundant <i>Trigonephrus</i> . Transgressive eolianite, coarsening upwards (1.5–2.5 m; Mz 2.90→1.62), weak bedding (4–6° NE), reappearance of phosphate sands midway; broken land snails throughout, ground up marine shell near top.
Soil 3 Soil 2 <i>Unit 5</i> <i>Unit 4</i>	Capping laminated crust (85% CCE). Truncated pink soil (7.5 YR) with oxide enrichment. Transgressive, medium-coarse eolianite (0.75–1.4 m; Mz 1.85), dipping 2–6° NE. Regressive, fine to medium eolianite (0.5–3.5 m; Mz 2.45→2.57), some low-angle crossbedding and ground up marine shell; rhizoliths below two sedimentary breaks. Lowest subunit partly silicified (14%; CCE 82%). Abundant land snails.
Soil 1 <i>Unit 3</i> <i>Unit 2</i> <i>Unit 1</i>	Capping laminated crust (81% CCE); silicification in Unit 2 probably earlier. Regressive (?), medium eolianite (1.0–1.8 m; Mz 2.08), some cobbles, horizontal laminated bedding (2–5° NW). Regressive, medium eolianite (0.4–1.1 m; Mz 2.15), with rhizoliths midway, terrestrial snails (mainly <i>Trigonephrus</i> sp.), and 16% colloidal silica in non-carbonate residual. Cobble beach with medium-coarse sand matrix (0.3–1.5 m; Mz 1.72), on +6 m wave-cut platform; with abundant marine mollusca.

4.1. Fossiliferous and archaeological deposits at Sea Harvest

There are more than a dozen ‘pockets’ of fossil bone in the Sea Harvest exposure (Fig. 7), most found in shallow but elongated solution cavities at the base of Units 7 and 9. They illustrate the complexity of ‘fossil beds’ and document repeated micro-climatic change.

Prototypical is Filling E, which forms a wedge 2.5 m long and 30–40 cm thick, directly under Unit 7. Crudely stratified, it incorporates concretions and corroded slabs of a laminated crust, embedded in a very pale brown, fine sand, packed with broken bone, that later was secondarily cemented (84% CCE). These

relationships imply that karstic solution attacked the capping crust on top of Unit 7 at about the same time as it created the cavity. The colluvial infilling therefore is younger and incorporated bone that first collected at a higher level.

Filling A (Fig. 7) is even more complex. First a joint-fissure, 1 m deep and 30 cm wide, was opened by solution under Unit 7; but before any sediment could accumulate, its walls were covered by thick, laminated crusts, implying significant calcite accumulation higher up, i.e. the capping crust on top of Unit 7. Later the cavity reopened, thanks to a new phase of solution, and was then partially filled with steeply dipping, medium-grade ‘bone beds’. It was then sealed by a thin, laminated

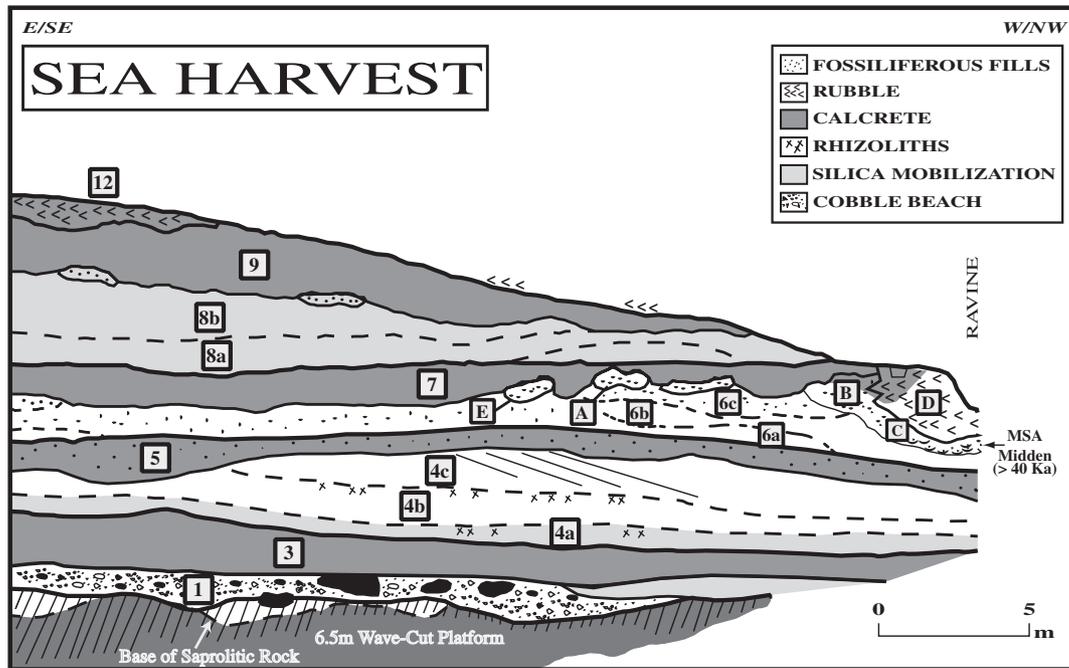


Fig. 7. Easternmost part of the Sea Harvest profile, fossil cavities, and Middle Stone Age midden. Drawn to scale.

crust, indicating a return to calcification dominant. Access to the surface was terminated again, and a soft chalky sand built up in the small remaining void. The sequence of micro-environmental change thus runs from fissure solution → calcification → re-solution → partial filling with colluvium → calcification. The bone bed (Fill A) has a textural distribution closest to that of Unit 8b, while Fill E matches that of Unit 8a.

There are numerous cavity fills at the basal contact of Unit 9. One has two distinct fills: the first (G1) is a medium sand, fossiliferous and cemented (78% CCE, with opaline silica), while the second (G2) is a fine sand, less calcified (66% CCE, with little silica), with some fossils and soil aggregates derived from partial solution of G1. In this case the sequence again marks two cycles of available moisture, going from karstic cavitation → infilling → calcification → partial solution and further infilling → calcification. Fill G1 matches the textural parameters of the top part of Unit 11, while G2 has no obvious counterpart in the upper half of the Sea Harvest profile.

Of particular interest are the interfingered Fills B, C, and D (Fig. 7). While B and C represent the filling of an almost 3 m deep cavern dissolved in Units 6 and 7, D is at the bottom of the adjacent ravine and extends up to the slope above it. Intervening entrenchment by the ravine apparently breached the side wall of the cavern, changing it to an overhang, and eroded part of its sediment, so that Fill D protrudes into B and C. Fill C now is 50 cm thick, and consists of coarse sand, with dispersed coarse angular rubble, derived from the cave

roof (Unit 7), and calcified (78% CCE); it encloses what can fairly be described as a shell midden, consisting mainly of limpets (*Patella* spp.), with numerous artifacts identified as MSA III [80,81], as well as abundant animal bone (discussed below). Fill C is overlain by B, originally some 2 m thick, slightly coarser and better sorted than C, with similar calcification (77% CCE) but more roof spall, fewer animal bones, and no archaeology. A terminal crust in B is older than the calcification of Fill D. The roof spall of B is not necessarily due to frost-weathering, but it is angular and uncorroded, and therefore produced by mechanical weathering, rather than solution. Climate was evidently changing in a cyclical fashion during accumulation of Fills B and C, both of which match the textural parameters of the final sands of Unit 11. Together with Fill G1, they fit between Units 11 and 12.

The ravine Fill D rests on a shelly palimpsest of C, and encroaches laterally on B and C; it also extends upward into bedded slope rubble that dips 8° down into the former ravine. This coarse gravel to cobble-grade rubble is 3 m or more thick and consists of angular slabs and splices reworked from Units 7 and 9, together with corroded concretions, sometimes split, typical of Unit 12. The textural parameters for the fine sand matrix of Fill D also are a tight match for Unit 12. The matrix is incomplete, however, i.e. voids remain between the rubble aggregates. The upper part of the ravine fill shows increasing reddish yellow (7.5 YR) mottling, by limonitic iron, that preceded development of steep laminasets of calcite (15–30°), that in turn crosscut

the original stratification and emerge from bedding planes in Fill C, as a result of throughflow. The resulting crust and honeycomb are correlated with the capping crust on Unit 12.

In sum, the fossil and archaeological fills of Sea Harvest add important detail to the macro-stratigraphy and soil horizons, and bring into focus the terminal switch from solution to mechanical weathering.

The fossiliferous pockets at Sea Harvest were first examined by Q.B. Hendey, with occasional, opportunistic collecting until 1977, when R.G. Klein and G. Avery sieved part of what remained of Fill B or C. Two ¹⁴C dates on ostrich eggshell are >40 ka [32]. The Middle Stone Age artifacts are described by Volman [80], who links them with the shell midden, as one of the oldest known sites recording human exploitation of coastal resources.

However, the bulk of the animal bone is not associated with artifacts or cut marks due to butchery using stone tools. Instead it shows evidence of hyena chewing, or etching in a hyena’s digestive tract; together with the presence of 60 hyena coprolites and the patterned selection of bones, this favors attribution of the fossils to the activities of the brown hyena, *Hyaena brunnea* [32]. The ecological import of the fauna requires emphasis. First, the marine shell (limpets attach themselves to rocks in the intertidal zone), rare fish, fur seal, and dolphin indicate coastal proximity. Second, the sandy substrate and presumed cliffs provided ideal

habitats for dune molerat, rock hyrax, and hare. Third, the large mammals are dominated by grazers, including in numerical importance (MNIs): springbok (*Antidorcas cf. australis*) (10), wildebeest or hartebeest (9), giant Cape zebra (*Equus capensis*) (4), blue antelope (*Hippotragus leucophaeus*) (4), southern reedbuck (*Redunca arundinum*) (4), and bontebok (*Damaliscus dorcas*) (4). These taxa require good herbaceous ground cover and, like the faunas from Swartklip and Linkerhandsgat, indicate open vegetation, with an abundance of grass, although the presence of browsing kudu (*Tragelaphus strepsiceros*) implies the presence of some tall bush with palatable leaves. The main carnivores are hyena, jackal and leopard.

The size of black-backed jackals and dune molerats is climatically sensitive [44]. The jackals are larger than their modern successors in the Southwestern Cape [32], but the molerats fall within the range of modern variability [34,45]. This suggests relatively cool and moist, rather than cold conditions [32].

4.2. Discussion and local synthesis

Taken together with the fossil crevices and MSA site, the Sea Harvest profile offers a complex record, summarized in Table 3 and Figs. 7 and 8. The lower part may be simplified, given that older cavity fills are not preserved, and some features will be conflated to

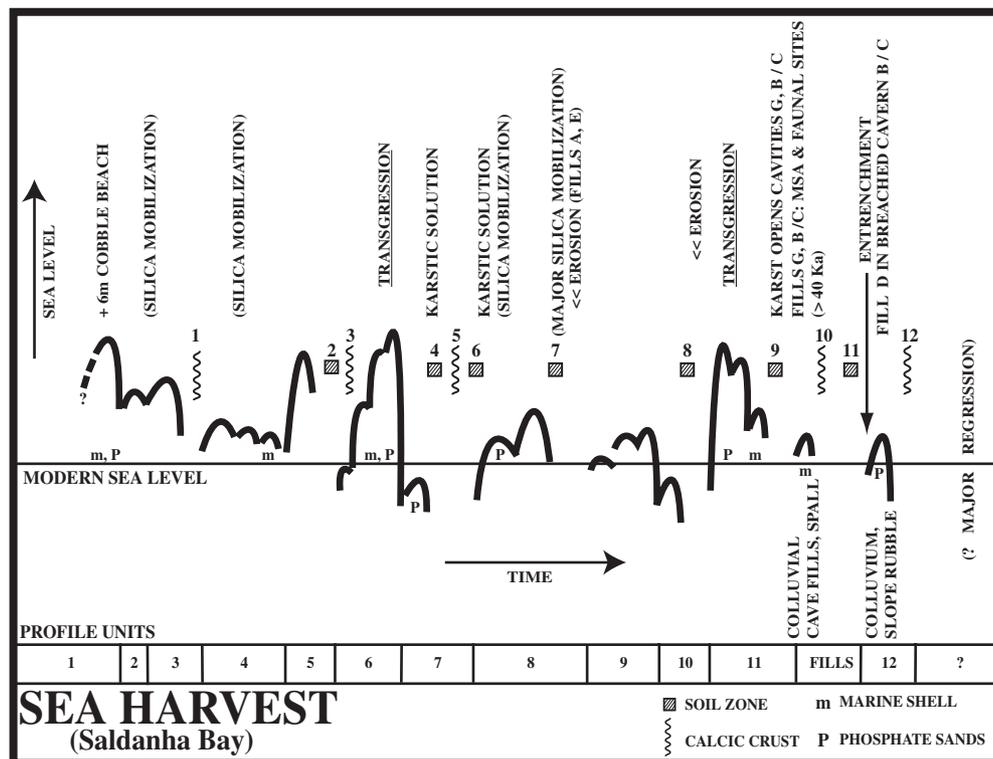


Fig. 8. Interpretation of the Sea Harvest sequence.

abbreviate the number of soil and calcic horizons. The results are transformed to the graphic representation of Fig. 8, which attempts to give an heuristic impression of relative changes of sea level, with levels proportional to textural grade (Mz). A crude estimate of relative time is included, again based on modal thickness of the depositional units, factored by sediment caliber.

Conspicuous is the cobble beach of Unit 1; the relative elevation shown is suggested by the matrix texture, but its real level was probably higher than that of the other major transgressions (Units 6 and 11). Midway during the sustained transgression of Unit 6, wave action again came close enough to the rocky promontory at Saldanha to remobilize older phosphate sands, which then continued to be recycled until Unit 8a. This was repeated during the transgression of Unit 11, when the shore was sufficiently close for small fragments of marine shells to blow in, although there are no traces of interbedded beach sands, and none could be expected, given the modern elevation of the deposits.

Despite the importance of the transgressive facies, Units 2–10 are topset eolianites, mainly dominated by land snails. Crossbedding is only conspicuous in Units 4 and 7, but stratification of each bed, and the disposition of the whole set, indicates accumulation in the form of sand sheets, driven primarily by southeasterly winds. Crossbedding in Unit 11 is blatant, and argues for a progression of dunal forms, stronger winds, and protracted periods with additional southwesterly storm vectors.

Most of the Sea Harvest strata are heavily calcified, and the characteristic alternation of hard, ‘ribbed’ strata (Units 3, 5, 7, 9 and 11) and ‘softer’ beds are only distinguished by laminar calcite enrichment in the former, rather than differences of texture. The most common pedogenic features are capping laminated crusts (Soils 1, 3, 5 and 12), that have lost their epipedons through erosion, and represent *Typic Paleorthids*. Two additional truncated soils, with more diffuse calcic horizons (Soils 8 and 10), qualify as *Typic Calciorthids*.

Opaline silica is present in many of the recrystallized, calcite laminae and crusts, although all the crusts dissolve in cold acid and are technically therefore not ‘silicified’. Such silica, which breaks down into a colloidal scum in acid, is prominent in Units 2, 4a and 7, but without requiring special taxonomic status. However, in the case of Soil 7 the prominence of silica through 3 m of deposit warrants description as a *Durixerollic Calciorthid*. Colloidal silica at Sea Harvest is probably derived from hydrolytic weathering of porphyry plagioclase, and subsequently mobilized in highly alkaline throughflow waters, with a lag, in the wake of lateral bicarbonate movement.

Soils 2 and 4, although truncated, involved sesquioxide mobilization and enrichment, with small ferric

concretions present in Soil 4, which also effected karstic cavitation in the substrate. The first possibly, the second almost certainly once represented a *Typic Camborthid*. Evidence for corrosion and oxide staining of subsoil concretions in the strongly eroded Soil 11 also hints at something intermediate between a calciorthid and a camborthid.

Karstic cavitation deep within the substrate (Soil 9), combined with partial dissolution and breakdown of laminated crusts (Soil 6), speaks for abundant and mainly perennial subsoil water. The karstic phenomena associated with Soil 4 open the possibility that other intervals of karstic activity (Fig. 7) were also once linked to ABC soil profiles. The entrenchment after Soil 11 involved at least some karstic solution and required concentrated runoff.

Chemical weathering and solution, mobilization, or calcification dominated Sea Harvest at most times when sand was inactive. But mechanical weathering becomes evident in Fill B/C, with production of roof spall, and with the slope rubble of Unit 12. Colluvium, produced by topsoil removal, is inconspicuous in the earlier record, but becomes a hallmark with Fill B/C and Unit 12, preceded by vigorous surface erosion (denudation). In short, mechanical weathering first appeared and soon became paramount at the end of the Sea Harvest sequence; at the same time, mechanical erosion assumed a visible role that it did not have before. Whether the spall or the openwork rubble (incomplete matrix) was produced by frost weathering is uncertain, given the basically friable nature of the products. But 70 km north at Elands Bay (see Section 7.2 below), frost is indicated by quartzite spalling in a similar stratigraphic position [13]. Certainly, the seasonality of precipitation and concentration of runoff had increased dramatically, and it is probable that climate was also becoming colder.

The first 11 units shown graphically in Fig. 8 highlight three transgressions, separated by longer intervals of lower sea level, fluctuating around msl with an unknown amplitude. The whole sequence is older than 40 ka, and suggests an essentially complete record of MIS 5. The MSA site and most of the fauna appear to pertain to a period of climatic transition, probably the slippery slope between MIS 5 and 4. Later phases of the Pleistocene at Sea Harvest have left no tangible record, presumably because of the major regression during MIS 2 and 3. End-Pleistocene transgressional dunes are also absent.

4.3. Middle Pleistocene fissure fills at Hoedjies Punt?

Parts of the Sea Harvest eolianite complex continue 1.6 km SE along a narrow peninsula to Hoedjies Punt. There are up to 32 m of eolianite and unconsolidated sands resting on an extension of the marine platform of Sea Harvest, now at an average elevation of 3 m. Sea

Harvest Units 1 to 4 pinch out along the way, but dunal structures recalling Unit 11 are prominent in the upper part of the Hoedjies Punt sequence. The lower 8 m represent a medium eolianite (Mz 2.15), cemented by a wavy, laminated crust, that may include Units 8 and 9 of Sea Harvest.

About 400 m back from the headland, several fissure and cavity fills, of different dimensions, appear on the SW side. One of these was about 1.5 m deep, a white, semi-cemented medium sand (Mz 2.23), laminated, with fine subangular rubble from the enveloping eolianite. An adjacent, fossiliferous pocket has abundant silica (12%).

On the NE face, a buff medium sandstone (83% CCE, but only 4% silica) dips 3–8° and fills subhorizontal fissures, interbedded with splices of older eolianite. Some of these fills have abundant, intact limpet shells and MSA artifacts (see Ref. [80]).

The large mammals of the fossiliferous fills are dominated by wildebeest, springbok, and grysbok (Ref. [43], Fig. 6), but the fauna is smaller and has fewer taxa than Sea Harvest. Again the archaeological association is separate from the fossil fills, underscoring a different agency of accumulation, with respect to dissimilar openings to the exterior.

Recently claims have been put forth for Middle Pleistocene hominid teeth from Hoedjies Punt [70], claims that require closer scrutiny. The discoveries in question reflect the fact that Klein's fossil sites were partially bulldozed in 1975, at which time road grading opened new exposures, designated as HDP 1 and reported to be a scant 10 m from Klein's original site. My first caveat is that the stratigraphic context specified by Stynder et al. (Ref. [70], Fig. 2) has a midden and a fossiliferous cavity in 'fine shelly sands', capped by a 2 m thick 'calcrete carapace', found below the new road. But no such shelly sands or massive crust were present in the original section. Instead, the new exposures appear to tap into small residuals of older deposits described from very near here by Tankard (Ref. [72], Fig. 4) as eolianite resting on 'Early Pleistocene shelly marine limestone', and below that a Miocene beach deposit (with phosphorite and granite boulders), undercut and filled by a late Pleistocene boulder beach, with interstitial 'coarse shelly quartzose sands'. The fissure fills described [70] are not developed in the Hoedjies Punt eolianite sequence, and appear to be at a level lower than Klein's fossil fills.

As illustrated and described by Stynder et al. (Ref. [70], pp. 602–603), a cemented midden with MSA tools, limpet shells and burnt animal bone is 'disturbed by grading' and apparently intrudes under a massive petrocalcic crust with a uranium-series age of about 300 ka (Ref. [5], p. 602). A second fill with densely packed mammalian bone is found 2 m lower down; it lacks both marine shell and artifacts, yet is claimed to be the source of four hominid teeth, belonging to a single

individual, even though spread through a vertical range of 20 cm; the metrical features of these teeth are large, and are believed to pertain to a Middle Pleistocene hominid. The upper fill is dated c. 117 ka by infra-red stimulated luminescence (IRSL) and thermoluminescence (TL). Similar dating for the lower fill suggests 'a maximum age of c. 550 ka', while the foraminiferal assemblage purportedly indicates an age between 180 and 480 ka. Lastly, it is claimed that the faunal assemblage can be correlated externally, to chalk up a maximum age of 250 ka. Thus, it is argued that the fossil fill with the hominid teeth was "most probably deposited between 200 ka and 300 ka ago" (Ref. [70], p. 372).

This is not very convincing. (1) The section [70] has at least the hominid teeth coming from an unroofed and exposed section of the fill, opening the possibility for disturbance (further grading activities during the 1980s [Klein, pers. commun.]) and incorporation of younger remains from the slope above. (2) It is questionable whether IRSL and TL will properly identify the age of reworked mineral grains, derived from their original source material. (3) Foraminifera, if they indeed can be dated with any precision, will probably be derived from the original source material, i.e. the 'shelly sands'. (4) The fauna is quite similar to that of Klein [43] (and pers. commun.), and closely comparable to that from Swartklip, Sea Harvest and Duinefontein (DFT) 1, instead of (a) the early Middle Pleistocene (700–400 ka) fauna from Elandsfontein Main (EFTM), which has a host of extinct genera or species such as *Metridiochoerus andrewsi* and *Antidorcas recki* [47], or (b) the late Middle Pleistocene (300–150 ka) fauna of DFT 2 which has an extinct antelope and forms of buffalo, wildebeest and kudu that are intermediate between those from EFTM and ZW or SH [22,46]. The Hoedjies Punt fauna is *not* Middle Pleistocene, but the petrocalcic crust and 'shelly sands' probably are older than anything at Sea Harvest.

4.4. Another MSA site at Ysterfontein

Of comparative interest to Sea Harvest are more recent excavations at Ysterfontein (YFT 1), some 45 km southward along the coast (Fig. 1). Although there has been no geoarchaeological study, the published profile [34] is informative. The upper 2 m of what appears to be a deeply stratified sequence has a matrix of variably calcified sand; this grades up into a jumble of eolianite and calcrete blocks, then a horizon (10–20 cm) of unspecified rubble, and finally a more homogeneous bed of sterile sand (15–30 cm), covered by a 'massive calcrete' that may represent the collapsed roof of an overhang (Ref. [34], p. 956). The substantial inventory of MSA artifacts 'closely resembles' the assemblage from the SH midden site and 'recalls' those from the MSA layers at

Die Kelders (Ref. [34], p. 950). The fauna is dominated by black mussels, limpets and penguins, with fur seal and two species of cormorant, identifying a site directly at the coast. The as yet small assemblage of mammalian bone is similar to that of the other Cape sites discussed here.

Clearly this is a promising site that merits further study. The published materials suggest a site and stratigraphic context remarkably similar to that of Fills B, C and D in the MSA overhang at Sea Harvest.

5. ‘Melkbos’: Duinefontein and Springfontein

One of the most important ‘open air’ sites of the Southwestern Cape is Duinefontein, formerly known as Melkbos, and located on the Atlantic coast 30 km N of Cape Town (33° 41’ S, 18° 26’ E). The substrate is formed by Pliocene beds (limestone sands with pelletal phosphate, basal gravels) resting on granite at 11 m below msl (Ref. [23], Fig. 177, pp. 276–279). A late Pleistocene faunal assemblage was collected at a location now known as Duinefontein 1 by Hendeby [36] and Klein [41], who also noted the presence of MSA artifacts in sands, calcrete and ferricrete, that according to Hendeby rest on a +6 m wave-cut platform. The platform in question is actually at +12–17 m, but it is notched at its base (see Section 6.2 below). Inskeep [39] considers the artifacts nondescript. There also is a lower surface of +4 m, more recently obscured by sand; traces of shelly ‘beach rock’ with pebbles are found here, with late MSA (? ‘First Intermediate’) surface artifacts, and a ¹⁴C shell date of >43.2 ka [39,79].

Acquisition of the area for the projected Koeberg nuclear power station in about 1970 led to exploratory trenching, with discovery of further fossil concentrations, some within massive calcified deposits, others below older ferricrete horizons. In the latter case a faunal assemblage was directly linked to an archaeological site (DFT 2), initially thought to be MSA but since confirmed as Acheulian [22,41,46]. Partly excavated in 1973 and 1975, construction of the power plant precluded further research until 1997–2001, when the excavation was greatly expanded, but continued to be impeded by a high water table.

There is no thick eolianite cover within the present Koeberg Nature Preserve, so that more recent eolian features at the site take on stratigraphic and environmental interest, particularly as they extend northward to cover eolianites and paleosols directly behind the beach, at Springfontein.

5.1. Holocene dunes as models for Pleistocene eolian features

The dune fields that account for the old farm name of Duinefontein (‘dune spring’) are part of a plume of sand

stretching 25 km northward up the coast from the mouth of the Diep River near Cape Town. Running through a terrain of Paleozoic quartz schists, this stream injects sand into the sea, to be moved N by longshore currents and waves; eventually it is deflated from storm deposits in the intertidal zone (3.5 m amplitude), and reworked by wind in a nearshore ridge or cordon of sand at 6–9 m above msl and with 3–5 m relief (Fig. 9). The cordon sand still has almost as much bioclastic component as the swash zone, with CCE in the range of 30%. Southeasterly gales, that can persist for days during the summer months, gradually remove sand from the lee side of the coastal cordon into a series of dunes that feather out across Duinefontein with a due north $\pm 10^\circ$ trajectory. Most prominent is a complex linear dune, with three subparallel ridges in the south (20 m elevation and 8 m relief), converging as two ridges (12 m relief), and eventually a single, high spine (15 m relief). Discontinuous, widely spaced, and more irregular lines of dunes to the east are partly degraded and mainly fixed by vegetation. To the west there are similar, discontinuous but active dunes, separated by broad surfaces devoid of vegetation and veneered by ‘drift sand’. North of DFT 1 sand is being removed from the coastal cordon by serpentine and subcontinuous lines of eolian sand being transported inland by winter, westerly storms. Eventually these merge with outliers of the main linear dune, forming a dense cluster of bizarre ‘w’-dunes (Fig. 9). There are no barchan dunes (as per Ref. [36], p. 91), but some of the w-dunes grade into parabolic ones.

This seemingly complicated description is readily followed in Fig. 9, and there are important implications:

1. Whether or not elaborate transgressive dunes develop depends on the supply of sand and effective aerodynamic patterns, but most transgressive eolianites are similar in form and origin to the coastal cordon, which has enough biogenic carbonate to favor calcification and preservation, as sea level rises and sand continues to build up and outward, into the backshore.
2. The narrow swales directly behind the coastal cordon or between the ridges of the complex linear dune are a result of deflation, as surface winds are funneled between higher spines. More extensive but irregular level tracts between the coastal cordon and the linear dune complex are also subject to deflation and sand blast, so that drift sand is never very thick. Such swales and depressions stabilize when they intersect the rainy season groundwater table, at which point they support vegetation, may become marshy flats (*vleis*), and display subsurface mottling through seasonal oxide mobilization or carbonate accumulation. The surface texture of such swales may be coarser than that of active dunes, as finer sands are winnowed out by deflation, to leave a lag of coarser sand.

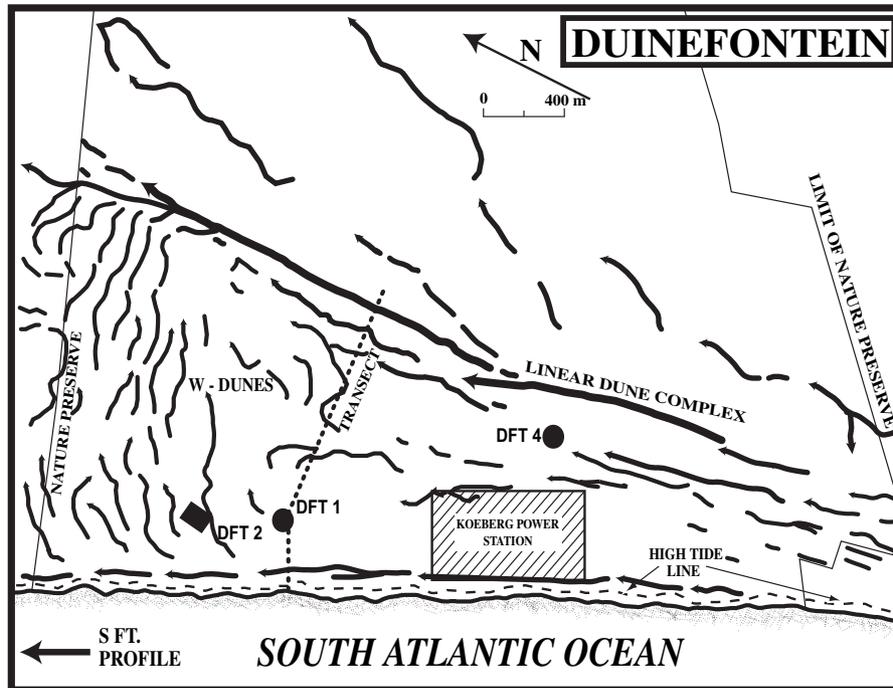


Fig. 9. Linear and w-dunes in the Holocene sand plume at Duinefontein. Springfontein is directly adjacent to the north (left).

3. The elevation of the land surface at Duinefontein, under the eolian bedforms, increases from south to north (average slope 0.2°), as a result of selective preservation of calcified Pleistocene deposits in the north. The w-dunes mainly accumulated on ground rising from 10 to 40 m elevation, between the coastal cordon and the linear dune complex.
4. At Duinefontein the sands of eolian cordons or ridges become progressively finer inland: the mean grain size (Mz) for the coastal cordon is about 1.8, for an intermediate ridge 700 m from the coast 2.7, and for the partly vegetated, main linear dune at 1.1 km inland, Mz is 3.2. Grain size is unrelated to dune prominence but determined by distance from the sand source.
5. CCE decreases inland, from 30% to 7% and finally 0%, as sand color changes from white to pale brown in leached sands. Precipitation is approximately 400 mm and barely changes across a distance of 1 km. The differences are due to time, and the sands of the linear dune complex must be substantially older and, barring climatic change, may have begun accumulating early in the Holocene.

5.2. The Springfontein profile

Just north of the Koeberg Nature Preserve a small Car Park opens on a once public beach, formerly identified by a posted sign as 'Van Riebeeck Strand'. But since the town of that name lies south of Koeberg, the

name Springfontein (after the former farm 'Klein Springfontein') is more appropriate, and facilitates identification on topographic maps. A section 1.5 km in length was measured along the beach exposures here, terminating opposite the rocky islet known as Robbesteen ('Seal Rock') at $33^\circ 39' S$, $18^\circ 25' E$.

The composite profile (Fig. 10 and Table 4) includes 11 units or subunits with a cumulative thickness of 35 m, as well as ten soil horizons. Twenty-six samples were analyzed in the laboratory, in addition to eight analog samples from adjacent Duinefontein. Calcification in this profile is lower and more variable than in other sequences studied, namely a mean CCE of 35.4% ($\sigma 20.0$), compared with 77.7% ($\sigma 6.8$) at Sea Harvest, and 53.1% ($\sigma 13.2$) at Swartklip. There is only a negligible amount of opaline silica, so that the colloidal and floating organic matter released in acid was titrated and trapped in a filter, to give a rough estimate of the organic component. 'Weakly' organic refers to 0.4–0.9%, 'moderate' 1.0–1.9%, and 'high' 2.0% or more organic matter.

Compared with the Sea Harvest profile, that of Springfontein has significantly finer sands: Mz 2.34 ($\sigma 0.44$) at SH, Mz 2.92 ($\sigma 0.48$) at SFT. But the Springfontein suite is far better sorted and less variable: So 0.44 ($\sigma 0.11$) at SFT, So 0.70 ($\sigma 0.23$) at SH. The most economical explanation is that the Springfontein sands are multicyclic, first derived from quartz sands in the Diep River drainage, then transported northward along the coast, before being deflated from the beach and reworked by wind inland. Further, at SFT and DFT,

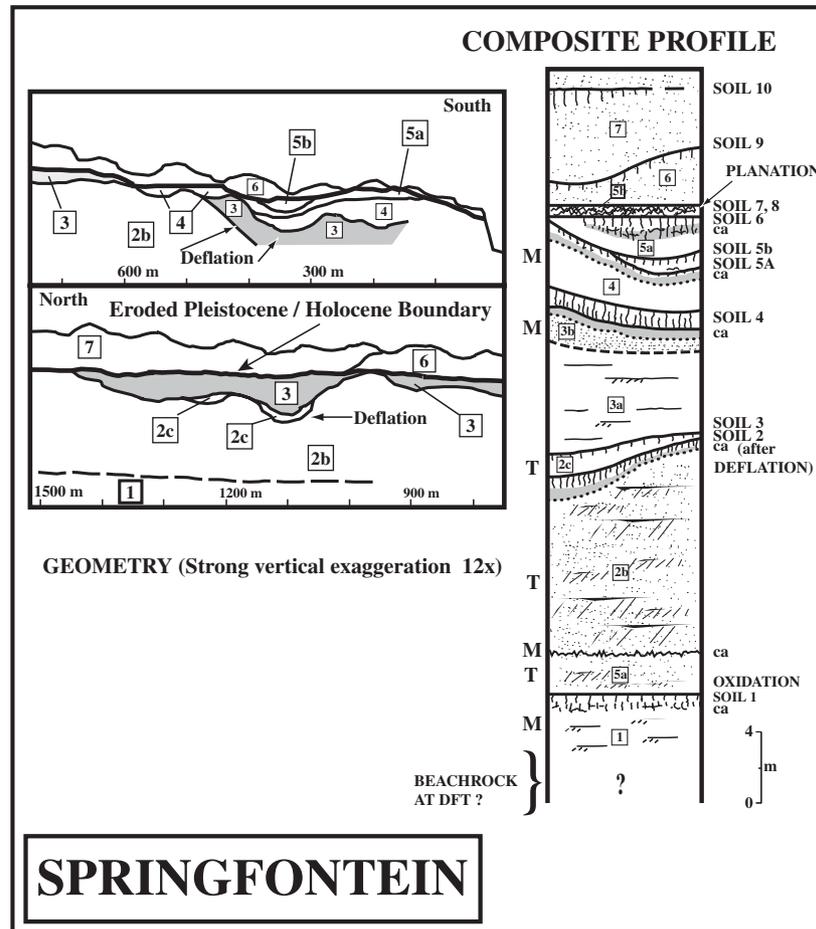


Fig. 10. The Springfontein section and composite profile.

older eolian sands dip to well below modern sea level and will have been partly eroded on the adjacent platform. At Sea Harvest, there was no supply of fluvial sands, and waves attack rocky headlands. Thus, all the SFT sands lie between Mz 2.0 and 3.4, while those at SH range from Mz 1.6 to 3.0. The thresholds for identifying transgressive vs. regressive sands are different at the two sites. Sand origin also helps explain the much reduced CCE at SFT, where both the multicyclic sand and a finer grained texture should reduce the bioclastic component that weathers to calcite.

The most impressive, transgressive eolianite at Springfontein is Unit 2b, a medium-grade sand, with intermediate to large scale, eolian crossbedded units of beta-type, in part high angle, with μ -type cosets or small-scale, high angle, planar crossbeds. Sea level must have been high and the shore nearby, but no beach sands are exposed in the profile. The only other probable transgressive unit is 3b, but it lacks visible bedding.

The textural parameters of Units 3a, 4 and 5a form a special, tightly clustered group of fine sands, very well sorted (So 0.28–0.44), negatively skewed, and mildly

leptokurtic. They are identical to sands of the complex linear dune at DFT, and may relate to well-defined, low-energy conditions well inshore. But they fill swales or larger concavities and have horizontal stratification. They point to a somewhat lower sea level for much of the time span represented by the profile.

Unlike at Sea Harvest there is no well-defined transgressive unit late in the consolidated part of the Springfontein sequence, nor is there a basal transgressive beach, although this may be recorded by the +4 m 'beach rock' near DFT 1 (see Ref. [79]). The oldest exposed sediments at SFT belong to Unit 1, namely extra fine, very well sorted, strongly negatively skewed, and also strongly leptokurtic sands. These three samples are unique in our collection of 280 analyses from the SW Cape, but are patently regressive.

The unconsolidated cover sands of presumed Holocene or very recent age are medium-grained and mildly negatively skewed. Of interest is the presence of two generations, the sand grains of the older being slightly weathered, and light gray rather than white in color. LSA materials, including some 'sites', are found in or on both generations. Soil remnants are now limited to

Table 4
Composite profile of sedimentary units and soil zones at Springfontein

Soil 10 <i>Unit 7</i>	Grayish brown ochric soil (120 cm, A-horizon), weakly organic, but only in swales. White, medium sand (6 m; Mz 2.28–2.38), mainly active w-dunes. LSA artifacts .
Soil 9 <i>Unit 6</i>	Light gray or brownish gray, ochric soil (50 cm), weakly organic. Transgressive, light gray medium sand (3.5 m; Mz 2.42); old dunes partly reactivated recently by livestock disturbance. LSA artifacts .
	Planation
Soil 8 Soil 7/Unit 5b Soil 6	Light gray, laminated crust, enveloping Soil 7 and Unit 5b. Former cambic horizon (50 cm, B-horizon), with highly organic, sandy clay loam (39% silt and clay; Mz 3.33). Light brownish gray, ochric horizon (45 cm), of moderately organic sand; over light gray, calcic Bca-horizon (85 cm), a highly organic sandy clay loam (55% silt and clay; 86% CCE), with angular blocky to prismatic structure. Limited to swale, partly colluvial.
<i>Unit 5a</i>	White, fine loamy sand (2 m; Mz 2.88–3.28; with 23% silt and clay), mainly colluvial.
Soil 5b	Light brownish gray, ochric A-horizon (30 cm) of leached, sandy loam (9% CCE), with mineralized bone ; over light gray Aca-horizon (15 cm; 57% CCE) of moderately organic sand.
Soil 5a <i>Unit 4</i>	Light gray, ochric A-horizon (10 cm) of sand; over white ca-horizon (60 cm; 47% CCE) of weakly organic sand. Regressive, white fine eolianite (4 m; Mz 3.15→3.25).
Soil 4	Light gray ochric A-horizon (30 cm) of weakly organic sand, with subangular blocky structure; over light gray Aca-horizon (80 cm; 34% CCE) of highly organic sand with weak structure; over white ca-horizon (50 cm; 52% CCE) of moderately organic sand. Grades laterally into capping crusts (10–30 cm) on slopes.
	Deflation
<i>Unit 3b</i> <i>Unit 3a</i>	Transgressive, fine but coarser eolianite (1 m; Mz 2.72). Regressive, fine eolianite (5 m; Mz 3.38), weak planar crossbedding; trace basal laminated calcite.
Soil 3 <i>Unit 2c</i>	Light gray ochric soil (30 cm) of weakly organic sand. White, fine sand (0.9 m; Mz 2.77), in swale only and possibly colluvial.
Soil 2	Light brownish gray, truncated AB-horizon (80 cm) of highly organic, sandy loam (37% silt and clay); over Bca-horizon (60 cm; 27% CCE). Developed in swale, and grades upslope into laminated crusts.
	Deflation
<i>Unit 2b</i> <i>Unit 2a</i>	Transgressive, white medium eolianite (12 m; Mz 2.12→2.20), with large-scale crossbedding. Regressive, white fine eolianite (1.5 m; Mz 2.88); high angle crossbedding.
Soil 1	Pale brown ochric A-horizon (50 cm), with slightly organic, leached sand and weak, blocky structure; over buff AC-horizon (35 cm), with moderately organic sand; and a buff ca-horizon (15 cm; 60% CCE) with calcite laminae.
<i>Unit 1</i>	Regressive, white, very fine eolianite (> 4 m; Mz 3.57→3.67), with planar crossbedding.

swales, and are humified, without a difference in fine components.

5.3. Springfontein soils and their archaeological implications

The paleosols of the Springfontein profile (Fig. 10) are unusually well preserved. They also are richer in silts and clays, and more organic than usual for these littoral sediment suites. Striking examples of such enhancement are all found in former surface concavities, and give way to more rudimentary profiles or laminated crusts on higher slopes. While the organic matter is authigenic, the silts and clays could not be derived from the pure quartz sands of the substrate: they clearly point to eolian silts or long distance aerosols.

In terms of the USDA Soil Taxonomy [68], the Holocene dune fields under favorable circumstances are/were stabilized by *Xeropsamments* (Soils 9 and 10). The most complex soils (represented by 2 and 6) are *Xerollic Camborthids*, that may grade into *Typic Calciorthids* or *Paleorthids* on convex slopes. Several other soils

(1, 4, 8, 5b) suggest intergrades between *Typic Calciorthids* and *Camborthids*. Soil 7, now embedded in a laminated crust, was a *Xerollic Camborthid* later transformed into a *Xerollic Paleorthid* (Soil 8). Once again, such classifications serve to caution that the more vestigial and often truncated soils of Swartklip or Sea Harvest may not be representative of their contemporary soil landscapes.

Identification of organic and loamy to clayey paleosols in the swales of Springfontein also has explanatory value. The incipient vleis found in contemporary swales at DFT illustrate potential contexts, but offer poor analogs. The swale soil fabrics at SFT lack evidence of sesquioxide mobilization, mottling or a perched water table. They do record accretion of organic colloids and the presence of expandable clays, arguing for perennial ‘wetland’ vegetation, but not permanent water, and for a seasonally wet subsoil, but not saturated with water.

The field evidence (Fig. 10) indicates discontinuous swales with a depth of 2.5–5 m, a width of 100 or 200 m, and lateral slopes of 1–5° around an almost level floor

of 20–60 m diameter. These suggest models for the discrete clusters of faunal remains, and sometimes associated artifacts, found at the DFT sites. In one instance (Soil 5b) mineralized bone was recovered from a leached, organic A-horizon at SFT. *Syncerus caffer*, *Raphicerus*, tortoise and ostrich eggshell were identified by R.G. Klein. A ¹⁴C date was attempted on Cape buffalo long bone, but no collagen was preserved; the assay on (open-system) CaCO₃ yielded a dubious value of 20,750 ± 315 bp, nonetheless old enough to preclude a Holocene age for the sediments in this swale. These same levels have also yielded scattered artifacts [41].

These topographic, sediment, and soil inferences and strictures offer a contextual model for the type of circumscribed bone and artifact cluster at DFT 2 [41,46], despite post-depositional alteration of the sedimentary matrix, namely intermittent surface water and sticky, muddy soil during the rainy season, probably with a more permanent ground cover of grasses, sedges and shrubs. In short, they are ideal sites to attract game, entrap animals on occasion, and provide favorable taphonomic conditions for burial and preservation. A minor faunal occurrence in SFT Soil 5b underscores the potential of such a model.

Comparison of Figs. 8 and 11 suggests both similarities and differences with the Sea Harvest sequence. The density and rhythm of paleosols at Springfontein is much the same, as is the presence of at least some fauna. There is no record of a terminal transgression at SFT (Fig. 11), but there are prominent Holocene dunes, absent

at Sea Harvest. Each profile is unique. The dynamics of accretion are controlled by potential sediment supply, orientation of the beach and direction of effective winds at a particular time, and the slope of the now submerged coastal platform. It is all too easy to ignore such mesoscale factors in forging big-picture syntheses.

6. Archaeological and faunal sites at Duinefontein

6.1. Duinefontein 1 and 4

The cover sediments of Springfontein are stripped away at DFT, to expose older sediments with novel pedogenic features. During pre-construction backhoe testing, a massive calcrete horizon was intersected at DFT 1, 2, and 4. DFT 4 is immediately behind the Koeberg station, with top at 18 m msl (Fig. 9), and is summarized in Table 5.

The DFT 4 sequence closes with a former petrocalcic horizon that has been substantially degraded by solution. But the sediments were more affected by reduction as a consequence of groundwater saturation, prior to calcification. This ‘upper gley sequence’ embeds two units (3a, 3b) of regressive, fine-grained eolianite, discolored by reduction of iron compounds, with large prismatic peds cutting across the bedding planes, and nodules near the base. The ‘lower gley sequence’ is topped by a thin regressive eolianite, altered to a strong paleosol, and later intruded by calcic sands (Unit

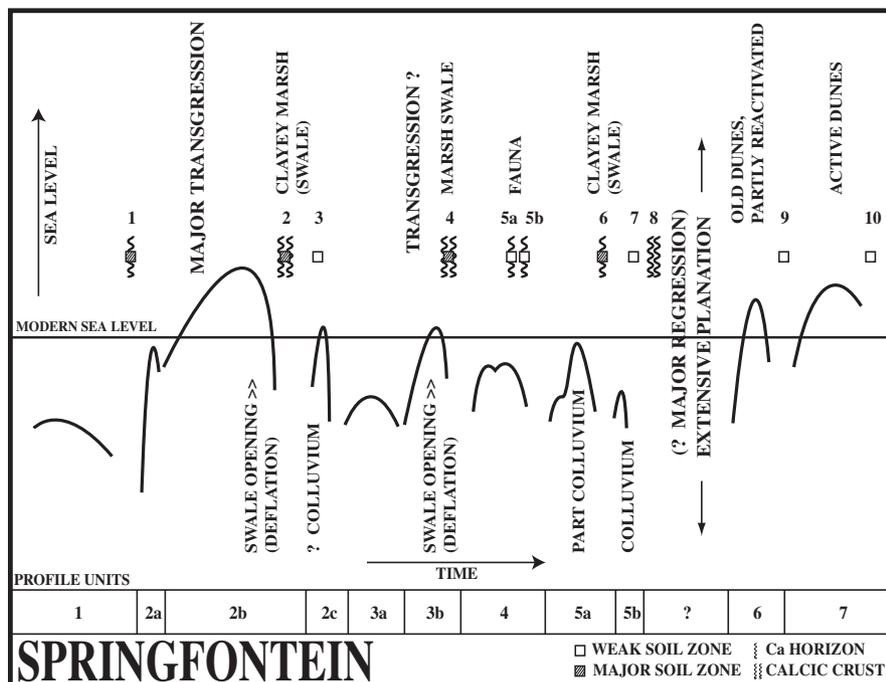


Fig. 11. Interpretation of the Springfontein sequence.

Table 5
Sediment stratigraphy and soil zones at Duinefontein 4

Unit 5/Soil 4	Brown (7.5 YR) umbric soil (70 cm), developed in cover sands.
UPPER GLEY SEQUENCE	
Soil 3	Capping crust, now partly decalcified.
Soil 2	High water table and formation of a weak gley-horizon.
Unit 3b	Regressive, light gray (2.5 Y), fine eolianite (1.5 m; Mz 2.77), horizontally stratified but with very coarse prismatic structure, and redox Fe but no mottling; subsequently a white (2.5 Y), calcic medium sand (Mz 2.14) intruded into some vertical fissures or within bedding planes of lower 3b, 3a and 2.
Unit 3a	Regressive, yellow (2.5 Y) fine eolianite (0.8 m; Mz 2.62), heavily mottled; with abundant calcareous nodules, probably formed in phreatic zone.
LOWER GLEY SEQUENCE	
Unit 2/Soil 1	Grayish brown (2.5 Y) umbric soil developed in stratified, fine regressional eolianite (35 cm; Mz 2.88); loamy sand texture (15% silt and clay).
Unit 1c	Transgressive, olive gray (5 Y) medium eolianite (50 cm; Mz 1.62); heavily gleyed (white and olive redox or g-horizon) after rise of long-term water table, perhaps with soil.
Unit 1b	Transgressive, white (5 Y) medium eolianite (150 cm; Mz 2.03), well stratified; pinkish (5 YR) mottling. With fauna .
Unit 1a	Transgressive, light gray (10 YR) medium eolianite (> 125 cm; Mz 2.17), with redox phenomena; base of section at water table.

2 and Soil 1, Table 5). Below it are >3.2 m of transgressive eolianite, forming a prominent gley horizon. Some animal bone was recovered from Unit 1b, but no artifacts. The most common ungulates present are bontebok (*Damaliscus dorcas*), wildebeest and greater kudu (R.G. Klein, pers. commun.).

DFT 1 exposes a different, yet analogous sequence, but is obscured by drift sand refilling the backhoe trench. Lateral relationships are imperfectly exposed, and thicknesses of the lower units are unclear. The sequence has two basic components, a 2.5 m boss of cemented sands (60–90% CCE) that forms a platform and rises at 1.5° from 12 to 17 m above msl, and a basal complex of iron-rich, yellow to red sands under

a ferricrete horizon (Table 6). Its seaward base may have been notched by a higher sea level [39].

The ‘calcic sequence’ begins with two regressive eolianites (Units 5a and 5b), altered as a first petrocalcic horizon, veneered by shelly beach rock and then partly dissolved and eroded, prior to the final, transgressive eolianite (Unit 7), and formation of a second petrocalcic crust. Units 5a and 5b at DFT 1 recall Units 3a and 3b at DFT 4, and may be equivalent, in which case the final transgressive sand (7) is missing at DFT 4.

The groundwater plinthite at DFT 1 (Soil 1, Table 6) appears to be a lateral, downslope equivalent to the ‘lower gley’ at DFT 4 (Soil 1, Table 5), but DFT 4 is

Table 6
Sediments and soil zones at the Duinefontein 1 hyena site

CALCIC SEQUENCE	
Soil 4	Second petrocalcic crust, now partly decalcified; probably polycyclic, affecting ~2 m of sediment; forms old, sand-blasted land surface, in part with litter of corroded calcrete boulders.
Unit 7b	Transgressive, white, fine eolianite (0.5 m; Mz 2.48–2.63), moderately sorted; partly recrystallized; with some buff mottling and recent, reddish soil pockets.
Unit 7a/Soil 3	Thin breccia lenticles under Unit 7, with irregularly shaped pebbles, reworked from a partially dissolved, older crust and then embedded in white cryptocrystalline calcite laminae (15 cm; Mz 2.80) by Soil 3; with buff mottling due to later oxidation in fluctuating water table. Hyena burrows with fauna probably dug below this level.
Unit 6	Lense of white, shelly beach rock, very coarse (Mz 0.18) but indifferently sorted due to winnowing; a beach at 11 m above msl.
Soil 2	First petrocalcic crust.
Unit 5b	Regressive, white eolianite (1.0 m; Mz 2.70), structurally modified by calcite laminae and large rhizoliths, discolored by strong, yellow mottling.
Unit 5a	Regressive, white eolianite (0.3 m; Mz 2.55), preserving original stratification despite calcite laminae.
FERRUGINIZED SEQUENCE	
Unit 4/Soil 1	Groundwater plinthite (weak ferricrete horizon), with yellowish red (5 YR) medium sand (30 cm; Mz 2.40) and vesicular (honeycomb) structure. Secondary carbonates present.
Unit 3	Former transgressive eolianite (?), pedogenically altered to yellow (10 YR) medium sand (Mz 2.03) with strong and extensive goethite staining and banding (strong brown, 7.5 YR). Non-calcic.
Unit 2	Former regressive eolianite (?), now forming a buff, medium sand (Mz 2.42), heavily mottled by yellow (10 YR) goethite, but incompletely decalcified.
Unit 1	Former transgressive eolianite (?), now a medium sand (Mz 2.13), heavily oxidized (light yellowish brown, yellow or buff, 10 YR). Non-calcic. Base of section not visible.

>1 km SE of DFT 1 so that this cannot be demonstrated without first exposing deep intermediate sections. Ferricretes, and their associated red and yellow soils, form in the subsoil as hydromorphic phenomena, in relation to a high but fluctuating water table. That implies considerably more water and a different geochemistry, i.e. mildly acidic soil waters (pH 5.0–5.5 instead of the modern pH range of 7–8). Plinthites and calcretes are antithetical, even though one may succeed the other over time. Soil 1 therefore marks a major ecological disjuncture.

A substantial fauna has been recovered from DFT 1 over the years, and a few artifacts (unretouched flakes) are present [36,41]. The bone apparently comes from hyena burrows at several levels within the ‘calcic sequence’, but their stratigraphic position could not be determined, given the poor quality of the exposures. Such burrows may have been dug after partial corrosion of the first calcrete. The ungulates comprise eland, Cape buffalo, southern reedbuck, blue antelope, wildebeest, grysbok and springbok, as well as the extinct, giant Cape zebra (Ref. [47], Table 1). Although these are mainly open country grazers, grysbok and reedbuck are predominant [41], complicating ecological interpretation. The assemblage is stratigraphically older than the faunas of Swartklip and Sea Harvest (see Ref. [43]), pertaining to an earlier MIS cycle (see Fig. 12). The large size of the carnivores suggests a relatively cool climate, like those of Swartklip [44,46].

6.2. Duinefontein 2

DFT 2 is one of the most important faunal and archaeological sites of the Southwestern Cape, representing a fossiliferous, multilayer set of Acheulian activity areas excavated over a surface of 500 m², mainly during 1997–2001 [22,46]. It is situated 380 m from the coast and 450 m NNW of DFT 1. Here there is a prominent ridge of calcified sediment forming a kind of platform that rises under cover sands from 12 to 16 m, and is identical to the ‘calcic sequence’ at DFT 1.

The site complex is within reddish sediments, analogous to the ‘ferruginized sequence’ at DFT 1, that project 25–30 m seaward from below the calcretes with a level surface at 10–11 m msl. Near the edge of the sharp topographic inflection at 11–12 m, a white 10–25 cm thick laminated crust covers the ferruginized beds, before it is reduced to scattered blocks of corroded (‘elephant rind’ weathering), laminar calcrete. The inflection probably represents a marine notch, locally marked by detached calcrete blocks, and presumably relates to Unit 6 of Table 6.

Below the incomplete calcrete cap at DFT 2 (Unit 5/ Soil 5, Table 7) are >1.2 m of reddish yellow (5–7.5 YR) to yellow (10 YR) sands, with irregular color zonation arranged in broad sweeps or large pockets. Clusters of pebble-sized ironstone concretions may be found in particularly red zones or attached to fossil bone. Further, along a central axis (formed by lines H-L

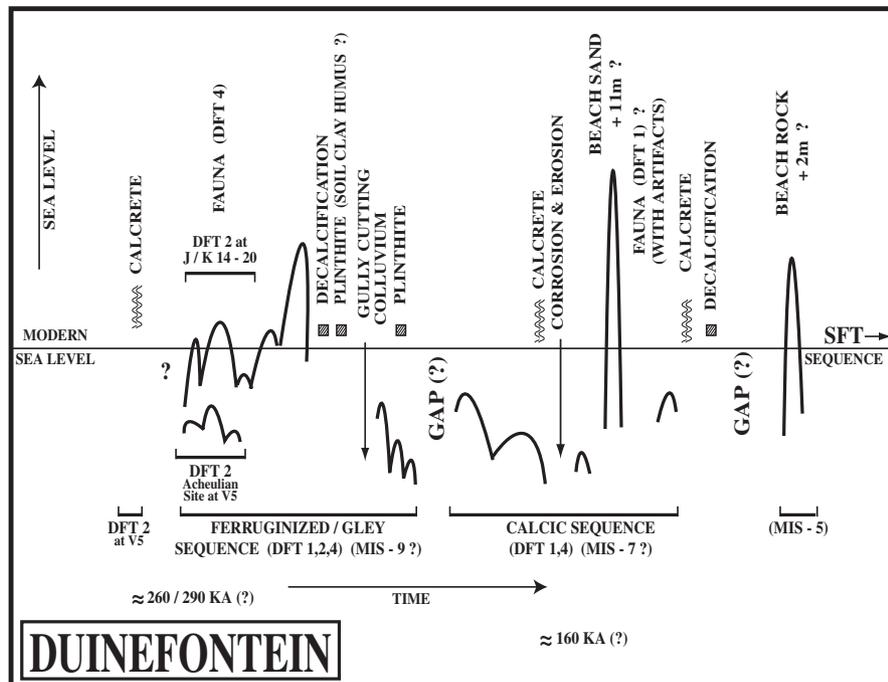


Fig. 12. A tentative model to interpret the composite stratigraphy and soil zones of Duinefontein (see Tables 5–7). The SFT sequence is linked to the right. Tentative dating assays are discussed in the text.

Table 7
Sediments and soil zones at the Duinefontein (2) Acheulian site

CALCIC SEQUENCE (abbreviated) (~160 ka?)	
Soil 7	Protracted solution and cavitation of calcrete, partly isolating the upper level, as pedestal blocks with elephant-rind weathering.
Soil 6	Formation of a laminated crust on upper level of the calcic sequence.
<i>Unit 6</i>	Upper level of calcic sequence, not studied at DFT 2, but probably equivalent to Unit 7 at DFT 1 (transgressive eolianite). Beach deposition to at least 11 m msl at DFT 1, cutting marine notch at the DFT 2.
Soil 5	Formation of a laminated crust on lower level of calcic sequence. U-series dates ~160 ka.
<i>Unit 5</i>	Lower level of calcic sequence, probably equivalent to Unit 6 at DFT 1 (regressive eolianite).
FERRUGINIZED SEQUENCE (A): Sector J/K 14–20	
Soil 4/Unit 4c	Resumption or continuation of plinthite formation, with local accretion of dense vesicular ('secondary') ferricrete (10–30 cm), strong brown (7.5 YR) to reddish brown (5 YR).
<i>Unit 4b</i>	Open vesicular ferricrete (20–25 cm), with soft fill of strong brown (7.5 YR), fine sand (Mz 2.73) and hard yellowish red (5 YR) ironstone.
<i>Unit 4a</i>	Colluvium (0–60 cm) of reddish yellow (7.5 YR) fine sand (Mz 2.57), with coarse prismatic structure and basal pisolitic granules.
Cutting of small NE-SW oriented gully across the site, undermining older ferricrete (Soil 3).	
Soil 3/Unit 3	Plinthite formation, with mobilization of iron compounds in hydromorphic subsoil, resulting in open, vesicular ('primary') ferricrete (30–50 cm), yellowish red (5 YR) and alteration of substrate by oxidation of Fe compounds. Weak humification and clay formation may have taken place at this time.
Soil 2	Decalcification of the underlying eolianites to a depth of >1.5 m.
<i>Unit 2c</i>	Medium eolianite (0–15 cm; Mz 2.47), now reddish yellow (5 YR).
<i>Unit 2b</i>	Medium eolianite (8–25 cm; Mz 2.00), reddish yellow (5 YR).
<i>Unit 2a</i>	Medium eolianite (>75 cm; Mz 2.23), reddish yellow (7.5 YR); includes a line of bone and artifacts (Horizon 3) at 70 cm below the ferricrete.
FERRUGINIZED SEQUENCE (B): NE sector of site (V5, R1)	
HORIZON 1	(?Lag of bone and artifacts)
<i>Unit 2c</i>	Fine eolianite (15–45 cm; Mz 2.59–2.72; So 0.49–0.52), reddish yellow (7.5 YR). OSL date of ~125 ka rejected.
HORIZON 2	(Semi-primary fossil and occupation surface, diffuse boundaries)
<i>Unit 2b</i>	Fine eolianite (20–25 cm; Mz 2.50–2.68; So 0.51–0.69), yellow (10 YR). OSL dates of ~265 and ~272 ka (?).
HORIZON 3	(Semi-primary fossil and occupation surface, diffuse boundaries, dipping W to below water table).
<i>Unit 2a</i>	Fine eolianite (>30 cm; Mz 2.67–2.68; So 0.45–0.52), yellow (10 YR). OSL date of ~292 ka (?).
Soil 1	Discontinuous calcrete (>60 cm), in part within lower Unit 2.
<i>Unit 1</i>	Fine eolianite, yellow to light gray, below water table.

and trenched by a backhoe along line J/K 14–20), the red/yellow sands are a little coarser and armored by two vesicular ferricretes (Units 3, 4b, 4c, Table 7). The surface of the first ferricrete dips 4° W but, in squares J 16–17, dips abruptly 25° E, to disappear beneath the water table. The resulting depression was filled by colluvium and then a secondary ferricrete (Units 4a–4c, Table 7), including reworked plinthite rubble; this terminates at the edge of the older ferricrete, which reappears in horizontal form in J/K 12. This curious feature resembles a former gully (3–4 m wide, 2–3 m deep, and running NE-SW) that undercut still-soft plinthite, which then slumped into the channel on its western side. But Fe compounds were still being mobilized at the time and impregnated the colluvial channel fill (Unit 4a).

In effect, (a) the red/yellow beds across DFT 2 are the so-called mottled zone of a 'laterite', (b) the sequence recorded in Table 7 as Ferruginized Sequence (A) is a lateral variant, the geometry of which indicates a former gully, and (c) the plinthite formed long before cutting of the marine notch.

Near the base of the exposed red/yellow sands is a highly discontinuous horizon of multicyclic calcrete, ranging in size from small, corroded blocks to a great slab centered in square R1 that is some 60 cm thick and several meters long. These are unreduced remnants of a very old calcrete (see Unit 2, Table 6), but their present disposition is puzzling in that blocks may be clustered vertically with steep dips, and their depth below Unit 5 (Table 7) is variable.

6.3. Fauna and archaeology of DFT 2

The reddish and yellow fine sands that were the focus of the excavations rise slightly in elevation to the east. Two semi-primary archaeological horizons serve to identify three units (Table 7, Ferruginized Sequence (B)) that exhibit vertical differences of color, sorting, clay content, and organic matter (approximated by loss on ignition). At 5 cm intervals, 15 samples in V5 showed that organic matter decreased from an average of 0.54% in Unit 2c to 0.39% in 2b and 0.31% in 2a. Clay similarly decreased from an average of 4.7% to 4.6%

and 2.6%. This suggests the presence of clay-humus colloids that decreased downwards through a profile of 80 cm, a weak soil that formed prior to calcrete formation, perhaps while the whole sedimentary unit was being decalcified and transformed by iron enrichment and plinthite formation in a mildly acidic hydro-morphic soil environment.

There is no evidence that the archaeological integrity of the bone and artifactual assemblages was compromised other than by some bioturbation and autocompaction. The archaeological horizons, as defined by dense scatters of tortoise remains, slope gently westward at 0.2–3.0°, probably following the original angle of eolianite stratification, now lost as a result of complete leaching of molluscan sands and pedogenesis. Bone of particular animals is often found in near-anatomical order, and with little fragmentation [22]. Carnivore tooth marks are far more numerous than stone artifact cuts or percussion marks (a 45 to 1.2% ratio in Horizon 2 [22]). Hyenas are believed to have been primarily responsible for carcass disarticulation and limb bone removal.

There are artifacts scattered all around the site, although these become more common upslope, including almost all the retouched pieces, handaxe-shaping flakes and a handaxe. In fact some 20% of the retouched pieces and cores are clustered together with a concentration of burnt bone fragments in an area 2.5 m in diameter. Across most of the site the association of artifacts and bone appears to be fortuitous: prehistoric people intermittently used parts of a site area where carnivore kills were more common.

That directs a central question to the environment where a varied fauna was regularly killed or scavenged by carnivores such as hyena and lion. A part of the answer lies in the nature of the impressive faunal assemblage [22]. This is dominated, in order of MNIs, by the extinct buffalo (*Pelorovis antiquus*) (21), wildebeest (20), kudu (12), grysbok (8), reedbuck (6), black and white rhinos (8), blue antelope (3), and Cape zebra (3)—an ecologically mixed or mosaic group, but heavily weighted towards large grazers. Springbok is notably absent. Reedbuck and hippo point to proximal water, as do bones of swamp rat and Saunder's vlei rat, and thousands of amphibian bones, representing at least eight taxa, including aquatic forms. That makes a strong case for a large interdunal marsh or pond, but not too far from the sea, given the presence of penguin and cormorant [22].

But there is no direct evidence in the analyzed sediments for such marshy conditions, with clay-humus decreasing downward irrespective of Horizons 2 and 3. The answer to this apparent contradiction lies partly in the bone and artifact distributions: artifacts are increasingly less common in the lower parts, and while buffalo is concentrated downslope (W), the remains of kudu, wildebeest and a solitary oryx are found upslope

(E). This suggests a subtle toposequence, from higher, partly bushy ground to lower elevations that were closer to water [22]. An eastward extension of the excavations would have to contend with an increasingly massive calcrete cover.

The notion of such a toposequence finds qualified support at Bok Bay (12.5 km N of DFT), where ferricretes give way (seawards) to black peaty sands with a ferruginous weathering horizon [49]. A marshy swale with seasonal water, as predicted by the SFT model, should be present a little west of DFT 2.

6.4. Stratigraphic interpretation of DFT

The potential inferences that can be assembled from DFT 1, 2 and 4 (Tables 5–7) are assembled in Fig. 12, following the same conventions used in reconstructing the previous time-lines of relative sea level change and pedogenic interruptions. But this 'curve' is more speculative, because none of the isolated exposures are adequate for a robust interpretation. They also represent an older time range, with a greater risk of oversimplification. For example, gaps of unknown duration are suggested prior to each of the high beaches. Finally, Fig. 12 suggests that the bone-and-artifact horizon in the DFT 2 backhoe trench records the same sequence as the profile from V5, except that in a lower-energy sector the grain size is finer. At Bok Bay [49] and Elandsfontein [11], ferricretes are commonly developed as ridges. These mark sinuous channel fills that were subsequently 'raised', after less indurated surrounding materials were eroded, to create an inverted stream topography [9]. The ferricretes of DFT 1 and 2 do not form 'ridges', but their linear and localized occurrence suggests some sort of drainage line.

For didactic purposes, Fig. 12 offers a provisional scenario of what may have happened prior to the Upper Pleistocene. That stratigraphic time limit is supported by a partly extinct later Middle Pleistocene fauna in the DFT 2 excavations, as discussed above [46] and supported by uranium-series dates of J.L. Bischoff (see Refs. [22,46]) for the capping calcrete (Soil 5) in square Q13: 152 ± 9 ka and 168 ± 20 ka. Feathers [25] has obtained 'subtraction' OSL ages of 292 ± 55 ka from sands in Unit 2a (Horizon 3), bracketing ages of 272 ± 83 ka and 265 ± 48 ka for Unit 2b, and 125 ± 25 ka for Unit 2c, as collected by R.G. Klein [pers. commun.]. The fact that Unit 2c must be much older than both plinthite and the capping calcrete (Table 7), and the improbability of a 140 ka hiatus in this conformable sequence, makes the youngest OSL date unacceptable, and casts doubts on the earlier dates, even though they seem at least to be in the right ballpark.

The sea level trace in Fig. 12 is limited to sea levels near those of the present, whether relatively higher or lower. The 'low' levels suggested by the Calcic Sequence

of Table 6 generated deposits of comparable Mz to the main dune ridge 1.1 km inland, while the sands between Horizons 1 and 3 (Table 7) approximate the Mz of the modern, minor dune ridge 700 m inland. At such times, the coast probably was about 1–2 km away from DFT 2, perhaps in the order of 5–15 m lower than at present. The major regressions are simply not recorded. Assuming that the two ‘gaps’ shown represent such regressions, and that the beach rock on the 4 m platform identifies the base of the SFT lithostratigraphy, the Calcic Sequence would pertain to the non-glacial MIS 7 and the Ferruginized Sequence to non-glacial MIS 9 (or alternatively, 9 and 11). That is very roughly compatible with the fauna.

6.5. Implications of the ferricretes and ferruginization

Assembling the preceding comments on the ferricretes with their striking reddish and yellow substrates, we encounter a soil type not present in the other study areas. The hallmarks are plinthite, that hardens to a red-brown ferricrete enriched in iron compounds (hematite and especially goethite), with little or no calcium carbonate or aluminum. The underlying ‘mottled’ and ‘pallid’ horizons are also enriched in iron but do not qualify as argillic. In the US Soil Taxonomy [68] these are *Plinthoxeralfs*, formerly part of the group known as Ground-water Lateritic soils.

A southern hemisphere overview of the genesis of ferruginous soils, with emphasis of the much wetter, subtropical climate zone of Natal, is given by Fitzpatrick [26], while a toposequence of ferruginized soils in the Cape Province is given by Ref. [35]. More proximal is the site of Elandsfontein where planar ferricretes are older than ferricrete ridges, but younger than a ferruginized calcite crust or the much older calcrete formed on eolian bed-forms [11]. A re-examination of Elandsfontein by Roberts [61] is simplistic, and confuses dendritic, inverted ferricrete channels with lithified dune spines. Roberts also explains iron precipitation by acidic, iron-rich waters from marshy swales coming in contact with biogenic carbonates in eolian sands, leading to an increase of pH and resulting precipitation. Such a process is quite inadequate to explain the persistence of plinthite formation long after total decalcification, thus the resumption of ferricrete formation after gully cutting at DFT 2 (Table 7). It also fails to explain the gley profiles of DFT 4, with their reduced iron but no plinthite, or why no plinthite formed in the swales of SFT. Last but not least, the oldest eolian sands at DFT 2 lack any discernible bedforms (contra Ref. [22]).

The formation of plinthite in some limited coastal sectors such as DFT and Bok Bay [49] begs the question of an iron source. There is no iron-rich bedrock at either Elandsfontein or DFT, but a minimum of 10 m of quartz sand, over quartzites at depth. That iron can only

be aerosolic, and mobilization assumes an acidic subsoil environment, in contrast to pH values of 7.1–8.0 measured in non-calcic quartz sands today. This requires a high-productivity vegetation cover and considerably more precipitation, as at Swartklip.

Another issue is the localized occurrence of plinthite or ferricrete. Concentrated surface and throughflow drainage in a more integrated drainage system would collect iron compounds and concentrate them in linear patterns. One such basin is defined by the modern subdunal topography, within a 1 km area around DFT 1 and 2 that excludes SFT or DFT 4. A high sea level would help plinthite formation, since the standing water table now dips down to below the seashore. But the DFT 4 profile verifies periods with a much higher water table that did not lead to plinthite accumulation. The water table responds more to secular changes of precipitation and groundwater volume than it does to standing head with respect to base level.

In sum, plinthoxeralfs are hydromorphic soils that form in anoxic and mildly acidic subsoils, with seasonal changes in the water table that promote small changes in pH, near the geochemical limits of iron solubility. Although sea levels were a little lower than today, the water table in mid-Pleistocene times was at least 2 m higher. Further, the increased acidity presumes a richer, decomposable mulch than that provided by sparse, sclerophyllous leaf litter. This matches the more productive, diversified, and complete groundcover implied by the stable of grazers found among the DFT faunas. In other words, there was a great deal more water available most of the year, and a different vegetation, to mobilize compounds of aerosolic origin and concentrate these along drainage lines, surface or subsurface. The environment and, by extension, climate was radically different during MIS 9.

7. Cold climate phenomena at the cave sites of Hout Bay, Elands Bay and Die Kelders

The major, littoral sedimentary sequences described here from Swartklip, Sea Harvest and Springfontein are mainly attributed to the long and complex MIS 5, with Duinefontein older still. Although there are some unconsolidated cover sands, and mobile or lithified dunes of end-Pleistocene or Holocene age, there is discontinuity in terms of distribution or lithification. The planation surface at SFT (Fig. 10) points to large-scale deflation or removal of most eolian bedforms by sheet flooding. An absence of other, littoral sediments reflects location, since coastal phenomena of MIS 4–2 should be best represented at –100 to 120 m, i.e. well below msl. But that is not a sufficient explanation, because it fails to consider the dramatically different

environmental context of the Southwestern Cape during the last glacial hemicycle: distinct processes were dominant in other segments of the regional environment, posing dissimilar equilibrium thresholds. Disequilibrium in response to severe glacial-age climate can be expected in the mountains (see Ref. [10]), and most of the surrounding ranges display several generations of well-developed talus and scree, suggesting frost-weathering and frost-assisted transport. The only sedimentary continuities are found in a number of cave sites, and even these are marked by breaks or shifts in depositional type or rates.

A continuous proxy record with qualified relevance to the Southwestern Cape is deep sea core GeoB1711-4, from 220 km WSW of Walvis Bay, Namibia, and spanning 135 ka [65]. It indicates a bimodal pattern of sea surface temperatures for the Benguela Current (MIS 5 and 1, vs. MIS 4–2), but more importantly it records the intensity of the southeasterly circulation that sweeps along the Western Cape coast. In response to Antarctic temperature changes, glacial paleo-winds resembled an intensified modern winter pattern, with stronger winds, greater upwelling, and a shift of some plant taxa to north of the Orange River [65].

In order to understand just how different the glacial environment was, three coastal sites were examined in the field: Hout Bay, on the windward side of the Cape of Good Hope (15 km SSW of Cape Town); Elands Bay (190 km N of Cape Town); and Die Kelders Cave (19 km SW of LG/WH).

In each case, there are frost-weathered rubbles either inside or outside a cave or overhang, while littoral deposits partially link the internal sediments and archaeology to the other lithostratigraphies.

7.1. Hout Bay

Along the northern perimeter of Hout Bay, fossil and recent eolian units rest on a cobble beach, and form part of a beach cordon cut by the road. A rock overhang, developed in a quartzite promontory, has a sequence of fills that begin with a segment of the same fossil beach at 6.5 m above msl. Both kinds of exposure have archaeological horizons collected or excavated by R.R. Inskeep [39], but unpublished. On the eastern margin of Hout Bay, Table Mountain quartzites rise steeply to 926 m, with lobes of scree or rock glaciers, suggesting frost-shattering, debris slides, and more incremental mass movements.

The stratigraphic sequence of the external beach sequence is summarized in Table 8. The basal beach has abundant MSA-type lithics, many fresh, with few formal tools, suggesting a quarry site on a storm beach. It is partly covered by a cumulative thickness of 17 m of alternating regressive and transgressive eolianites, that include a possible occupation surface, with similar artifacts, 3 m above the base, and within the first, regressive eolianite. The main body of the massive transgressive unit does not appear to be differentiated, but since soils are minimally preserved, it is likely that the sequence is much more complex.

The four fill units of the overhang, as also described in Table 8, complement the picture, with the two youngest undated, but the accessibility of large and small beach pebbles suggesting a similar msl as today and a Holocene age. Of primary interest is Fill B with convincing evidence of frost weathering of the overhang roof, followed by a major paleosol. Such post-depositional weathering and ferruginization are replicated

Table 8
Sediments stratigraphy at Hout Bay

HOUT BAY BEACH

Soil 1	Humic, brown medium-coarse sand (50–100 cm) (Mz 1.78; 6% CCE), decalcified and truncated. Partly under recent eolian sands, with LSA artifacts on surface.
<i>Unit 4</i>	Regressive eolianite (300 cm), decalcified, positively skewed, weakly crossbedded, interstratified with organic laminae (Mz 2.04)
<i>Unit 3</i>	Transgressive eolianite (10 m), calcified, positively skewed, with steep (25°) thin beds and high angle crossbeds (eolian β -crossbedding); abundant fine marine shell debris (Mz 1.73; 31% CCE). Upper contact slightly humified.
<i>Unit 2</i>	Regressive eolianite (4 m), negatively skewed, with some rhizoliths; shell date of >47 ka a meter from top. MSA (?) artifacts from apparent occupation surface.
<i>Unit 1</i>	Transgressive beach (7 m above msl, 5 m above high tide), with well-rounded, quartzite cobble gravel and matrix of medium-coarse sand (120 cm) (Mz 1.58). Numerous lithics of MSA affinity between and on top of the cobbles.

HOUT BAY ROCK OVERHANG

<i>Fill D</i>	Loose marine shell midden (30 cm), with matrix of gray (loamy) fine sand (Mz 2.90; 9% CCE), and occasional small beach pebbles. LSA occupation.
<i>Fill C</i>	Complex of well-stratified dark gray hearths, gray brown shell middens, and light brown gray organic-mineral lenses (fine sands, Mz 2.82; 8% CCE), partly decalcified (100 cm). LSA occupation level.
<i>Fill B</i>	Reddish yellow (7.5 YR), medium sand (Mz 2.37), subhorizontal with some interbedded shell lenticles, dispersed angular flakes and splices of quartzitic roof spall; decalcified (130 cm). Quartz grains extensively stained by iron oxides, and followed by erosional break.
<i>Fill A</i>	Quartzite cobbles in a matrix of brown fine sand (120 cm) (Mz 2.90).

in the post-MSA sands (level 3) at Die Kelders [12,50,74] and ‘oxidation Horizon 1’ atop cryoclastic MSA in NBC (Nelson Bay Cave) [9,17] further east, in the Southern Cape. Unfortunately, no paleosols are preserved in Units 1–3 of the Hout Bay ‘beach sequence’, and given the much wetter meso-environment (665 mm precipitation), exposed to the full force of winter rainstorms, there are no calcite crusts. This limits correlation of the Fill B paleosol with specific soils at Swartklip or Sea Harvest, although frost-weathering and slope mobilization above Hout Bay recall the processes responsible for accumulating Fills B and D at Sea Harvest. That impression finds support in the record in and around Elands Bay Cave.

Given the prominence of transgressive eolianites in Unit 3, the 6.5 cobble beach (Unit 1) in Hout Bay most probably records MIS 5e, and the superposed regressive eolianite Unit 2 would pertain to MIS 5d. That suggests a comparatively early stratigraphic age for the MSA-type artifactual horizons.

7.2. Elands Bay

The case for frost-weathering is strong around Elands Bay (39° 19' S, 18° 21' E), both in cave micro-environments and on external slopes. In the cave of that name, there is a basal, frost-shattered quartzite rubble, up to 30 cm thick [13]. With a ¹⁴C date of >40 ka, this unit has an early MSA (I) industry that may date back to MIS 6 [81]. Overlying this are 1.3 m of mineral-cultural deposit with next to no roof rubble with dates of 20,500–11,070 b.p. The sediments indicate that the cave contribution to mineral deposition declined about 50% between these dates, with coarser eolian sands becoming prominent after c. 12.5 ka as the shoreline moved closer and the sedimentation rate accelerated. Pollen study reveals an open vegetation with grasses and Asteraceae before 21 ka, a complex, open scrub woodland c. 21–17.5 ka, followed by an open vegetation with some bush to c. 12.5 ka [52]. In short, the frost spall is ‘early’ and the major ecological event during MIS 3 and 2 was brief and singular, namely a cool and wet period of woodland expansion at 21–17.5 ka.

In Diepkloof Cave, 14 km SE of Elands Bay, J.E. Parkington excavated an MSA level of over 1.1 m, with a midway date of >45.3 ka, and a thin LSA cover. The MSA industry has characteristic geometrics made in silcrete, identifying the Howieson’s Poort component, which apparently fits between MSA II and III, perhaps during MIS 5b [81]. Fine angular roof spall increases with depth [13].

Most impressive is a 15–20 m thick rubble sequence exposed at the Elandsberg (railroad) Tunnel, 1.2 km SSE of Elands Bay Cave, at about 50 m elevation and resting against a 25° slope rising 120 m up the quartzitic Bobbejaansberg (192 m). The sequence [13] begins with

up to 12 m of block-sized clasts, chaotically bedded with little matrix, eventually attaining an equilibrium slope of 10–15°. This is overlain by a sum total of 6–7 m of stony colluvia with ‘stranded’ blocks, a bedded talus (15°), and three petrocalcic horizons, two of which engulf soils with prismatic structure. On top of this is an unconsolidated 1–2 m sheet of brown (7.5 YR) stony colluvium, the surface of which is littered with large blocks or veneered by eolian sand.

The differentiation of five facies within the sequence [13] is in itself instructive. (i) There is only a single but massive body of chaotic blocks, disposed as coalescent lobes along the footslope. Moving in part as block streams, mobilized by incremental impact momentum, and probably aided by interstitial ice expansion, they imply a protracted period of accumulation and intensive frost-wedging of outcrops further upslope. (ii) The bedded talus, a meter thick, is differently graded (clasts under 15 cm diameter) and rests on an abrupt, smooth surface, suggesting lubrication and sliding, perhaps across a frozen substrate. (iii) The three cemented colluvia, typically over a meter thick, have matrix-supported clasts or blocks and are more correctly called debris or gelifluction flows. The fine sediment component requires laboratory study to determine the proportion of reworked eolian sand. (iv) The coarse prismatic structure, traced by wavy calcite laminae and sharp vertical fissure calcites, suggests loessic or aerosolic components. (v) The three massive petrocalcic crusts incorporate sufficient calcite that, given the local quartzite bedrock, argues for decalcification of substantial covers of eolian sand, rich in bioclastic carbonates.

Facies (i) and (ii) are typically montane, and distinctive of cold climates radically different from the almost frost-free lower elevations of the modern Southwestern Cape. They also imply considerable moisture, at least during winter, when there was little eolian sediment available on the uplands to provide a suspended matrix. Facies (iii) argues for periodic heavy rainstorms and a poor ground cover, to allow a wide range of mass movements such as slumping and debris slides, in addition to debris flows, at a time when large quantities of fine sediment had accumulated on the slopes. There also was ongoing frost-wedging, although at a slower rate than for facies (i) or (ii). Facies (iv) tentatively suggests a silt and clay fraction of more distant origin. Finally, facies (v) presumes dissolution of bioclastic carbonates as well as seasonally-concentrated moisture.

This sequence is too complex and its cumulative mass too great to convincingly attribute to a single MIS. Facies (i) and (ii) have no remotely analogous counterparts in the Sea Harvest sequence, but would be compatible with the coarse basal roof-spall of Elands Bay Cave, with its MSA I. If they and the directly superposed debris flows and calcite crusts were assigned to the Middle Pleistocene, it would leave one cemented debris

flow and one laminated crust to correlate with the end of the Sea Harvest sequence (MIS 5a/4 transition). The unconsolidated debris flow would presumably belong in MIS 2 or early 1, possibly marking another rupture of equilibrium c. 21 ka, when open woodland began to recolonize the area.

These climatostratigraphic correlations are to some degree speculative, but they raise the interesting possibility that the environment of the Southwestern Cape was, at times, much more harsh during the Middle Pleistocene than it has been since. It would also suggest that the bulk of the debris visible on the slopes of the coastal mountains, e.g. north of Stanford or at Hout Bay, is older than the Upper Pleistocene. The debris slides also imply that inland eolian sedimentation was a great deal more significant than is currently appreciated. But above all the Elandsberg Tunnel sequence, regardless of its age assignment, suggests that cold stress at certain times will have been a major environmental variable for the Pleistocene people(s) of the Southwestern Cape.

7.3. *Die Kelders*

Arguably one of the most significant Pleistocene archaeological sites of the Southwestern Cape is Die Kelders. This is a sea cave formed along the contact of the Table Mountain quartzite and Neogene limestone/conglomerate on Walker Bay, 3 km north of Gansbaai and 19 km SW of Linkerhandsgat (34° 32' S, 19° 22' E). In view of the proximity of the Stanford sites and the broader context of the other sites examined here, a brief look into Die Kelders Cave (DK) from the outside opens up alternative perspectives.

Perhaps the most interesting feature from this position is that at least two major eolianites are perched on the rocks directly above the site, representing units of lithified medium sand with a cumulative thickness of 20 m, separated by a colluvial soil [12]. Even if this external sequence would prove not to have direct links to the +2 m boulder beach within the cave, or elsewhere down the coast, our preceding case studies illustrate how textural shifts and pedogenic phases from open-air contexts convey information that might make the 5 m of sandy MSA deposits within the cave more intelligible in environmental terms. However, the MSA excavations at Die Kelders in 1972–73 [74] and 1993–95 [3,30,50] focused exclusively on the cave interior, ignoring the possibilities presented by a complex sediment and soil sequence directly outside.

Potential global links were suggested in the earlier excavations by sterile deposits above the boulder beach, by angular quartzite spall in the lower layers 13 and 14, or by blocks of collapsed roof rock in upper layers 5 and 6 that were attributed to a possible earthquake [74]. Tankard published textural parameters from 39

samples, covering the whole column through the LSA, although he did not exclude the silt and clay fractions from these statistics, which skews the results and limits the potential of external comparison by including a cultural component. Marean et al. [50] modify this picture, noting that roof rock already increases sharply in layer 8 and was heavily weathered at first, but fresher later; this precludes a single catastrophic event. These authors recognize the angular spall in 13 and 14 but note that it consists of quartzite from the cave walls, rather than limestone from the ceiling (although quartzite cobbles may still have been cemented into the base of the limestone unit). On the one hand, the attention focused on micro-components and transformations inside the cave [30] is commendable, but on the other hand the new excavations have provided no referents that could be compared with processes on the outside. Instead, they serve to downplay the rapid cyclic alternation of sands and archaeological deposits convincingly demonstrated by Tankard.

An opportunity has therefore been missed to establish an external stratigraphic and pedogenic context. Attempts to directly date the Die Kelders sequence have met only limited success. Both early and late 'uptake' models of electron spin resonance (ESR) yielded a random scatter of 'ages' (64–105 and 84–160 ka, respectively); with an assumed moisture content of 10%, these dates range between 64 and 75 ka, and are then converted to a suggested 'average' age of 70 ± 4 ka [64]. Five TL and OSL are equally unsatisfactory. The TL dates run from 50.7 to 79.7 ka, but are stratigraphically inconsistent, as are the OSL and IRSL dates, offered on the basis of different assumptions in regard to moisture content, so that the authors also resort to 'averaging', this time to a 60–70 ka range [24]. The temptation to assign an age on the basis of the Howieson's Poort variant/phase of the MSA [3,31] (see also Ref. [2]) is rejected by Anne Thackeray's [75] demonstration that there is no Howieson's Poort MSA in Die Kelders.

We are consequently left with a thick column of MSA deposits at Die Kelders that is roughly dated to somewhere between the end of MIS 5 and the beginning of MIS 4. The only analog is provided by the MSA sequence in the cryoclastic Black Loams of Nelson Bay Cave [9], above a cobble beach and under a ferruginized, finer deposit with strong soil structure, locally covered by non-cryoclastic rubble. But Die Kelders is far more open to eolian elements, and the archaeological hiatus of level 3 has been attributed to sealing of the cave by eolian sand [74], but that would presume eolian accumulation at a time of major sea level regression, which is highly unlikely. Die Kelders highlights both the utility of traditional lithostratigraphic investigation in open-air contexts, and the problems of what still are experimental dating techniques beyond the 40 ka limits of ^{14}C .

The Die Kelders fauna (Refs. [31], Table 3 and [48]) is dominated by local taxa, such as dune molerat, hare and rock hyrax, but also has marine forms (fur seal, dolphins and penguins), that indicate coastal proximity and, like the dating assays, exclude a late MIS 4 or younger age. There are a good number of bovids, represented by at least several specimens at most levels, including eland in ten of the MSA horizons, *Raphicerus* in six, and southern reedbeek (a wetland form) in four. There also was Cape buffalo (in three) and the extinct giant buffalo (in four) and, most remarkably, hippo (in seven) and black rhino (in four). This is a fauna that signals a beneficent environment, with productive and high nutrient-status grazing or browse. The unusual size of some taxa indicates a cool, moist climate, rather than stressful conditions. Although a hunting radius of at most an hour's walk can be assumed, the peninsula on which Die Kelders is situated is mantled by eolianites except for the rough, mountainous spine. It is implausible that such a fauna could have thrived in such an environment while sand was being actively blown across the now 7 km wide peninsula by southeasterly gales. A solution to this apparent conundrum would be to assume that the major fossil horizons coincided with multiple pedogenic intervals of the sort identified in this paper, probably towards the end of the early Upper Pleistocene record identified at Sea Harvest.

Paleosols have gradually become a standard part of Quaternary studies. The persistent climatostratigraphic problems at Die Kelders re-emphasize why paleosols should be more closely integrated with geoarchaeological research.

8. Concluding discussion

The results and implications of this study can now be reviewed, beginning with the analytical aspects and continuing with more general observations or larger issues.

8.1. Methods and criteria

The combination of detailed field recording and laboratory follow-up was indispensable. Some 280 textural analyses were carried out, and mean grain size proved particularly useful for quantitative diagnoses and to identify fining/coarsening trends within sedimentary units. Sorting and skewness, although not regularly reported, were valuable in recognizing facies shifts in a profile, or linking derivative fills to parent materials.

Soil zones of various kinds were invaluable as stratigraphic markers, apart from their paleoecological value. The delineation of detailed profiles appears to be becoming a lost art, in the rush to apply novel, if incompletely tested techniques, that are no substitute

for understanding the whole as the sum of its parts, and then following up on particular issues. Quaternary studies are comparative, in the first place, and interpretation benefits substantially from recognizing subtle or abrupt changes.

Sedimentology is predicated on a trinity of sediment source/supply, transport processes and modes, as well as forms of deposition. That is the key to the presence or absence of sediments, as well as their manifestation in a particular place and time.

8.1.1. *The eolianites*

The Pleistocene littoral eolian deposits include eolianites, accumulating as nearshore dune cordons, and cemented by solution of their bioclastic component, as well as free-ranging dunal sands, forming farther inland, and less calcified. In general, such littoral sands are transgressive when they coarsen upwards, as the deflation source moves closer, or regressive, when they fine upwards in response to a more distant source. Such properties are most likely to reflect modest fluctuations of eustatic sea level, when the shore was located only a few kilometers away from a site. Large scale marine regressions probably do not leave a sedimentary record inland of the present coastline. In that sense all such littoral eolian sands are 'transgressional', accumulating at times when the sea level was either a little lower or higher, i.e. rising or falling in response to oscillations around a non-glacial norm. Therefore, the eolian sequences studied here all pertain to 'warm' isotopic stages, which gives them chronostratigraphic value with reference to the isotopic stages of deep sea cores.

High sea levels that leave beach deposits above modern msl represent no more than brief episodes within much longer periods of relatively high, non-glacial sea level (see Ref. [38]). The records established here indicate three such episodes within the time range of MIS 5. Dating of the standard deep-sea isotope curves (see Ref. [51]) is not free of deductive reasoning (e.g. orbital theory), so that the inferred date of 125 ka for the main transgression of MIS 5e is 10 ka younger than its high-precision uranium series dating, which suggests that the stage 6/5e transgression began as early as 150 ka. Consequently, the 'age' of MIS 5 is no more than an approximation: it began between 140 and 130 ka, and terminated between 75 and 70 ka. The earlier 'warm' MIS (7) would date very roughly to 250 to 200 ka. However imperfect, the isotopic stages offer an overall time frame that inspires more confidence than current OSL and ESR dating assays.

8.1.2. *Pedogenesis*

Three basic types of pedogenesis can be identified in the Southwestern Cape record.

First there was the formation of 'standard' soil profiles with a variably organic epipedon, possibly a cambic

subsoil, and a ca-horizon of diffuse or concretionary carbonates. That involved humification, partial leaching, and possibly some enrichment of sesquioxides, probably derived from aerosols. In some cases leaching created deep soil pipes, in others karstic solution dissolved cavities in underlying, cemented sediments. Different degrees of available soil moisture or free water are implied, as well as groundcover and a measure of geomorphic stability. Most such soils are now truncated, because their topsoils were unconsolidated and easy to erode.

Equally common was the formation of laminated crusts, that sometimes coalesced or recrystallized into an indurated petrocalcic horizon, hardpan, or calcrete. Here, vertical leaching of carbonates was outmatched by calcite accretion from calcium bicarbonate-saturated throughflow waters. Soil water would be abundant but strongly seasonal in its availability, favoring repeated solution and precipitation. Originally formed in the subsoil, such calcite horizons were commonly exposed by later erosion, to form capping crusts or calcretes. Significant calcite mobilization and accretion in a quartz/quartzite environment depends on the availability of bioclastic, soluble carbonates; it is most likely in a seasonally-wet but semi-arid climate, and by no means implies a drier climate than at present. It takes place with pH values above 8.0. When alkalinity is above pH 9 or 10, silica may be dissolved in colloidal form, eventually to precipitate in its opaline state, commonly in association with calcite. Such silica components are prominent at Linkerhandsgat and Sea Harvest, reflecting availability of suitable feldspar sources.

Plinthite accretion presupposes mildly acidic soil waters and in sufficient quantity to transfer mobilized iron compounds, primarily by throughflow and in relation to a high but fluctuating water table. The lower pH argues for an acidic mulch at the surface and a radically different vegetation than found near the Cape today. When the water table drops and plinthite is exposed by erosion, it is converted to an irreversible, reddish brown ferricrete, on top of a reddish and yellow subsoil. These reddish ‘ferricrete soils’ speak for a substantially wetter climate and appear to be limited to a mid-Pleistocene time range. But the associated fauna was not substantially different than that characteristic during MIS 5, with large grazers dominant.

The soils of the first two types encompass several variants of aridisols, reflecting the edaphic limitations set by a quartz sand substrate. Only the ferricretes break out of this mold, as an example of the order alfisols, representing a greater intensity of weathering.

8.1.3. Aerosolic components

The clay-sized colloids and fine silt dust particles, that comprise the fine fraction of the various cambic horizons, present an important follow-up issue. Most

of this material will be a result of long distance transport, as has been globally demonstrated by a growing body of research [58]. Specialized study of the Cape’s paleosol silt-clays should determine if they derive from the Karoo and Kalahari, or much further afield in Patagonia. At higher latitudes, eolian dust or loess is primarily deflated from the ‘glacial flour’ of outwash streams, or from recycling of older loess by rivers of low hydraulic radius. In lower latitude arid zones, such dust is primarily derived, not from dune fields, but from seasonally dry or ancient exposed lake beds. In southern Africa the Etosha Pan (Namibia) and Makgadikgadi depression (Botswana) create measurable plumes of eolian dust, although these move in west-northwesterly directions today [8]. But glacial-interglacial and other Pleistocene climate shifts of the three winter circulation systems (the South Atlantic and South African anti cyclones, and the circumpolar westerlies) are implied by three distinct dune trends in the Kalahari [55,69]. In part, these linear dunes have different spacings, and the oldest are OSL dated 106 ± 10 ka.

Whereas dunes require sustained wind vectors to develop, atmospheric dust loading is initiated by episodic strong pressure fields, for example, when a cut-off upper low centered at 5° E and 30° S is impeded by a deep, blocking high over South Africa. Such tropospheric jet configurations are uncommon today, but core GeoB1711-4 (Ref. [65], Fig. 2) indicates a maximum of pollen influx from the Zambezi dry forest during MIS 5c, 5a and early 4. Pleistocene circulation anomalies could therefore have carried dust from the Makgadikgadi or the Trekveld pans (Western Cape, Fig. 1) to the study area.

8.2. Chronostratigraphic resolution

The major profiles established here (Tables 1–4 and 8) can now be integrated into a composite for the early Upper Pleistocene by detailed categorization and cross-correlation of soil zones as well as regressive or transgressive sedimentary units. Swartklip is the most complete, with Sea Harvest a close second. The LG/WH record only begins with Major Transgression II, and Springfontein lacks four soil zones near its base. Anchored on three ‘high’ sea levels, with numerous cyclic oscillations at or just below msl, and 11 simple or complex soil zones, Fig. 13 provides a fairly complete record of early Upper Pleistocene time in the South-western Cape. It is an *ordinal*, rather than quantitative trace, that represents MIS 5, but the frost weathering at the end suggests the transition from MIS 5 to 4. The subsequent abrupt break of sediment and soil records must have been a response to a major glacio-eustatic regression and coastal displacement.

Examining the placement of soil zones with respect to transgressive or regressive trends in each column, or in the Fig. 13 composite, reveals that the Cape soil zones

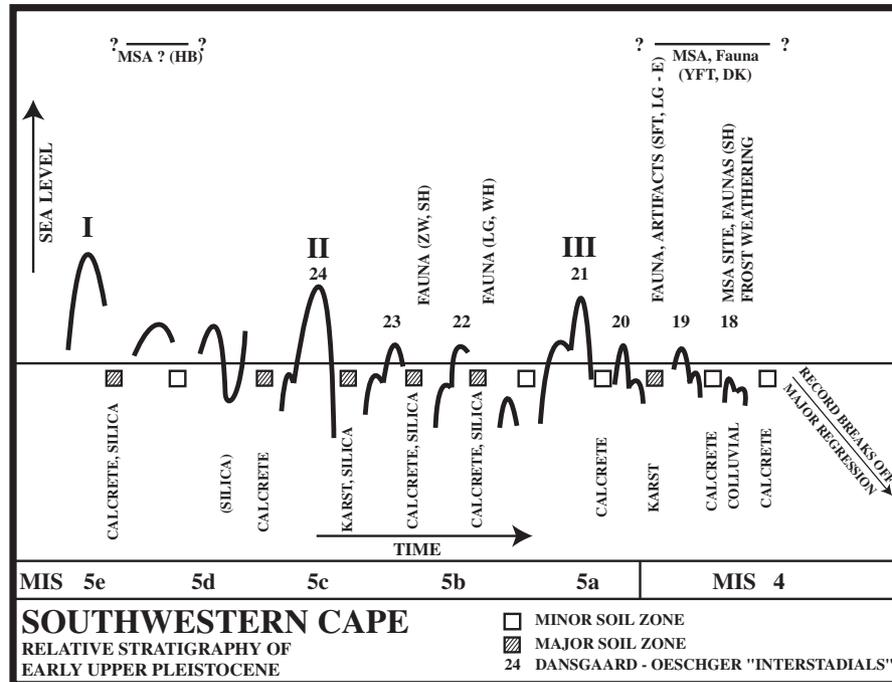


Fig. 13. Relative stratigraphy of sea level trends and soil zones for eolian faunal and archaeological sites of the Southwestern Cape. This segment, representing early Upper Pleistocene time (MIS 5 and early 4), was derived by cross-correlation of Tables 1–4 and 8, with corresponding figures. For the late Middle Pleistocene record, see Fig. 12.

tended to coincide with episodes of sea level a little lower than today. On a global scale, therefore, these soil zones coincided with minor glacial advances at higher latitudes. Local climate should have been a little cooler, and probably marked by more variable weather in the southern hemisphere westerlies, and perhaps affected by a slight northward shift of the Antarctic Polar Front (now near 50° S). The soil zones themselves argue for either a seasonal or perennial abundance of moisture, with wetter winters at some times, less arid summers at others. Applied to the six faunal horizons of Figs. 12 and 13, the linkage with soil zones implies that these faunas thrived during periods of slightly cooler temperatures and modestly greater precipitation, but without clarifying the specific kind of water balance.

This relative stratigraphy can now be converted to a global chronostratigraphy with reference to recent thinking on polar ice core, continental, and deep sea isotopic records that span much or all of the early Upper Pleistocene. That involves two steps, namely macrostratigraphy and micro-stratigraphy, the first a matter of MIS stages or substages, the second focusing on the superimposed global oscillations known as Dansgaard-Oeschger (DO) events or interstadials.

Different classes of proxy data suggest two possible models for MIS 5, which is commonly equated with the last interglaciation. Long pollen records in France [19,59,60,82], Italy [1], and Greece [77,78] indicate that arboreal taxa remained dominant during a stable MIS 5,

except for brief interruptions with open vegetation, during MIS 5d and 5b. But in detail, the key French profile of Grand Pile shows that forest composition was subject to dramatic successional change throughout MIS 5 [19], even though carbon isotopes from cave stalagmites in southwestern France and Israel imply that biogenic CO₂ recorded in the Vostok (Antarctic) and GIPS 2 (Greenland) ice cores shows an abrupt decline at the end of MIS 5e, that was only reversed during the MIS 2/1 transition [7,57]. The weak methane peaks for MIS 5c and 5a imply an early reduction of organic decomposition in global wetland ecosystems, as a result of drier climate and cooler temperatures [7]. On the other hand, sea surface temperatures off Namibia (core GeoB1711-4 [63]) suggest that MIS 5c and 5a at these latitudes were more prominent than they are in the temperature proxy records (deuterium and oxygen isotopes) of the Vostok core [57,63], defining an abrupt systemic change during MIS 4, rather than after MIS 5e. That probably is significant for evaluating the record of the Southwestern Cape in a broader frame.

It remains to explain the multiple eolianites (transgressive and regressive) and paleosols (of several distinct kinds) in the Cape record here assigned to MIS 5 and the 5/4 transition. Appreciation of the DO events has grown since the early 1990s as a global signal for complex interactions between the oceans and the atmosphere. Some 24 of these oscillations have been identified in the δ¹⁸O and methane records of Greenland ice cores

GRIP and GISP2 [7,33], as well as in laminated bands due to strong, monsoon-induced biological productivity in core 88/93 KL of the Arabian Sea [63]. They are incompletely replicated in most deep sea cores, despite notable exceptions [28], because of the insensitivity of such $\delta^{18}\text{O}$ records to shorter climatic fluctuations [33]. Here then is a mechanism that can explicate ongoing sea level oscillations, as well as changes in temperature, moisture, and organic productivity.

The DO events (IS 1-24) also suggest a chronostratigraphic framework, with reference to the Greenland ice cores, as calibrated by the presence of the Toba ash in core 88/93 KL, between IS 19 and 20, i.e. near the accepted boundary of MIS 5 and 4 [63]. Argon and potassium isotopes as well as fission track dating suggest an age of 74 ± 2 ka [63]. That would approximately date IS 20 to 24 (within MIS 5) at 75, 86, 92, 104 and 108 ka (see Refs. [7,63]). It would also fix MIS 5a (IS 20 and 21) at roughly 86 to 74 ka and MIS 5c (IS 23 and 24) at 109 to 98 ka. For MIS 4 a time span of 74 to 58 ka would include IS 18 at 64 ka and IS 19 at 70 ka.

In Fig. 13, the three intervals of high sea level are assigned to MIS 5e, 5c and 5a, with DO events 18 to 24 readily matching seven positive oscillations of sea level beginning with MIS 5c. This would relate the Southwest Cape regional stratigraphy to a global chronostratigraphy, within the range of accuracy currently possible on the basis of deep-sea and ice core research. That now allows a productive discussion of the archaeology and faunas, as synthesized in Table 9.

8.3. Fauna, flora, archaeology

To the non-specialist, the Pleistocene mammalian faunas of the Southwestern Cape may appear to show little variation. Such assemblages are dominated by large grazing ungulates, in contrast with the taxa or dominants of the fynbos fauna found in the area historically and during earlier Holocene time ranges [42]. The four most common large taxa were wildebeest, an open country grazer; southern reedbuck, a grazer found near water; blue antelope, a now-extinct endemic form of the more productive Southern Cape biome; and greater kudu, primarily a browser favoring tall bush.

That argues for a mosaic environment. Although less common, large to very large grazers such as buffalo and its giant, extinct relative, a very large horse and one or other zebra, or the black and white rhinos place similar emphasis on a productive, grassy groundcover, suitable to support a high mammalian biomass. That is underscored by relatively common springbok and even a single specimen of oryx (from DFT 2), a Kalahari form. This pattern is consistent over time and space. *Pelorovis antiquus* is found at DFT 2 (MNI 21) (MIS 9?), at ZW (MIS 5b), and at SH, HP, and DK (in four MSA levels) (all early MIS 4). Hippo (see Table 9), historically found north of the Great Berg River (Fig. 1), and implying open waters, is present at DFT 2, ZW, SH and DK (in seven levels). The ponding common in interdunal swales attracts game to water and hunters to game.

But it is improbable that such faunas were present continuously, at least over longer stretches of time. All are linked fairly directly to periods of soil formation, that record more mesic turns of the environment, much like the pollen core of the Cape Flats points to repeated shifts of vegetation mosaics with different carrying capacities. Yet the faunas appear to have been tolerant of dissimilar water balances, within some unknown range of more abundant moisture: they were associated with periods of karstic solution, silica mobilization, or calcification. Nor was there an evident faunal response to increasing winter cold early in MIS 4. In each case where there are sufficient jackal bones present, and to a lesser degree dune mole rat, the sizes suggest cooler and wetter conditions than today. This is consonant with the association of both pedogenesis and faunal horizons with sea levels a little lower than at present, implying slightly cooler temperatures.

Direct evidence on vegetation is unfortunately limited. Pollen evidence is at a premium in the Southwestern Cape, but the cores studied by Schalke [62] from the Cape Flats as well as north of Cape Town also suggest that improved grazing ecology was linked to complex mosaic environments including persistence of some fynbos, but in association with stands of yellowwood, i.e. elements of Knysna forest. The composition of

Table 9
Suggested chronostratigraphy for faunas and archaeology, Southwestern Cape

MIS (DO) stages		Fauna	Archaeological sites/occurrences	Industry
Early MIS 4	(IS 18 to 19)	DK	DK, YFT, ?EBC (Diepkloof)	MSA
	(IS 19/20)	SFT, SH, ?HP	SH	MSA
		LG	LG	?
MIS 5b	(IS 21/22)	LG, WH		
	(IS 22/23)	ZW, SH		
MIS 5d			HB	?MSA
MIS 7(?)		DFT 1	DFT 1	?
MIS 9(?)		DFT 2	DFT 2	Acheulian

Key to site names: DK (Die Kelders), YFT (Ysterfontein), EBC (Elands Bay Cave), SFT (Springfontein), SH (Sea Harvest), HP (Hoedjies Punt), LG (Linkerhandsgat), WH (Windhevel), ZW (Swartklip), HB (Hout Bay), DFT (Duinefontein).

groundcover in the open tracts is less clear. By contrast, at Elands Bay, most of MIS 2 and 3 appear to have coincided with an impoverished open vegetation, perhaps of low productivity, in keeping with the subarid climate of today [52]. There is little evidence for elements of the fynbos, perhaps because of cold temperatures (a mean reduction of 4 °C, see Ref. [71]).

The generally poor preservation of pollen contrasts with the good preservation of animal bone, which is variably mineralized but uncorroded. The same permeable subsoil environment, that allows mineralizing solutions to move readily in throughflow waters, exposes pollen grains to rapid oxidation, apart from the fact that pollen accumulation is low in mobile sands. The dearth of palynological data, except for exceptional micro-environments, such as caves, is therefore likely to continue.

The expanding number of MSA eolian sites, such as Ysterfontein [34], suggests that with greater attention to lithic surface scatters or by fortuitous construction activities many more will be discovered. The Acheulian site of DFT 2 could be expanded, and several other equivalent surfaces exist in the area. Sooner or later an even more productive site will be found in a thick vlei sequence. The comparatively late turn to excavating Pleistocene sites in littoral eolian contexts reflects the predilection of most archaeologists for traditional cave sites. Admittedly, open-air sites require different research strategies and carry different archaeological expectations, but given the proven faunal preservation there is a payoff, in terms of the potential information as to how mosaic environments were used by prehistoric people. As illustrated here, deep, eolian lithostratigraphies also provide better time frames than do cave sites. Above all a more systematic search for, and excavation of such littoral eolian sites might stimulate a fresh interest in Paleolithic spatial archaeology.

Largely ignored here has been the fact that Holocene dune fields show frequent LSA-type artifact scatters, for example at Springfontein. There also are LSA ‘sites’ in the process of eroding out of former soils. But it seems as if the only sites deemed worthy of study are midden sites in coastal caves. A notable exception has been the systematic search for external LSA sites around Elands Bay, which show interesting shifts of activity foci during the course of the Holocene [56]. By extension or analogy, there is much to be learned here for Pleistocene archaeology, including the importance of surface surveys.

In regard to spatial and temporal discontinuities of prehistoric settlement in South Africa in general, or the Southwestern Cape in particular, a few generalities can be offered without summoning a growing literature or engaging in related arguments. It once was the impression that MSA sites and surface occurrences were common during MIS 5, both in coastal zones and in the

interior. A basic contribution of this study is to show that MSA sites in the Southwestern Cape are few and far between (Table 9), with most dating to early MIS 4, perhaps a result of increasing cave utilization as climate became more severe. Even allowing for the possibility of many more sealed MSA sites—by two orders of magnitude—the number of MSA groups present in the area during MIS 5 times will have been so small as to seem no more than discontinuous settlement, in both temporal and spatial terms. That poses challenging ecological, if not demographic questions as to why.

For southern Africa as a whole this question is even more trenchant. We lack even a temporal approximation for the first emergence of the MSA. Further, MSA occupation during MIS 3 was reduced to a very few cave sites; in fact, the long settlement hiatus between MSA and LSA cave strata leaves the issue of ‘replacement’ obscure, with the earliest LSA poorly dated, somewhere between 40 and 30 ka. Even so, LSA sites remain very few in number until after 12 ka, only becoming common during mid-Holocene times. This is more than a matter of discovery and preservation, and calls for greater attention to the productivity and predictability of resources, in the context of changing subsistence strategies and particular landscape mosaics [15]. Unfortunately, too little prestige has been attached to spatially-oriented projects.

That brings us back to ecological interpretation of the faunal assemblages from the Southwestern Cape. They are comparatively large and numerous, with respect to other world regions. There now is an informative geoarchaeological context within which to place and interpret them. Given that only modest palynological advances are possible, the challenge is to use the available data and especially the paleosols to model the biotic environments with which the faunas were associated. The fynbos, with 68% endemics, did not disappear, but it must have been structurally modified to favor a significant expansion of grasses and forbs, presumably through a reduction of seasonal drought stress and increasing summer rainfall (see Ref. [17]). Since C4 grasses would benefit most from more summer rain, carbon isotopes from animal bone may be sensitive to such a shift. We also need to devise practicable matrices of weighted information categories for all taxa, including micro-mammals, ‘topographic’ specialists, carnivores, as well as large herbivores. These may allow ordination of community relationships by principal components analysis to achieve a better understanding of changing bioecologies in time and space.

Further deep sea cores with palynological data also are essential, in closer proximity to the Cape, and their many potential data sets must be studied in a directed fashion, to identify a greater number of relevant variables than were considered by CLIMAP and its successor programs. Devised some four decades ago,

that strategy, focusing on synchronic time-slices such as 18,000 BP, has outlived its utility. But the tendency to neglect or oversimplify the processes of diachronic change lingers on, and current models for Pleistocene and paleoecology in South Africa tend to be static and insufficiently systemic, at a time when we should be thinking outside of the traditional box.

We can offer a closing tribute to the indefatigable hyenas who created most of the fossil caches reported on here. By digging their lairs a meter or more into soft soil pipes or by tapping into karstic cavities, they destined their waste to accumulate underground, together with a sampling of contemporary soils, seasoned by stray lithic artifacts from the surface. They benefited from pedogenic processes, but in turn, their activities helped to illuminate the complex linkages between sedimentary units and soil formation, while also providing exceptional vistas of the animal populations from whom they lived, or the other predators and minor creatures with which they competed for food or space.

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