



## Mid-Pleistocene Hominin occupation at Elandsfontein, Western Cape, South Africa



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### ABSTRACT

The current understanding of landscape scale variation in mid-Pleistocene hominin behavior is limited. Most of our understanding derives from a few localities in eastern Africa. Consequently, we know very little about hominin landscape use outside this region, despite the fact that mid-Pleistocene hominins occupied other climatic zones including temperate, and mid-latitude ecosystems. The winter rainfall zone in South Africa represents one of the world's most diverse ecosystems. Although mammal diversity is relatively low in these habitats this is compensated by the tremendous floral diversity. Buried Pleistocene land surfaces in the region provide an opportunity to understand how humans adapted to this unique, mid-latitude environment prior to the Last Interglacial. The dunefield locality of Elandsfontein in the Western Cape of South Africa is one of the richest known paleontological and archeological sites in southern Africa. It records details of landscape formation history, enabling detailed reconstruction of the ancient environments in this winter rainfall-dominated region. This dunefield archive allows us to posit the taphonomic history of newly excavated archaeological material and previously collected specimens. Here we provide initial results from the excavation and geological analysis of the Elandsfontein dunefield and provide new insights into the formation history of the archaeological and paleontological deposits. This includes indications of multiple pedogenic intervals and groundwater table fluctuations. The combination of geological, paleontological and archaeological data provides a framework for evaluating how hominins interacted with the unique ecosystems of the Cape Floral Region of South Africa during the mid-Pleistocene.

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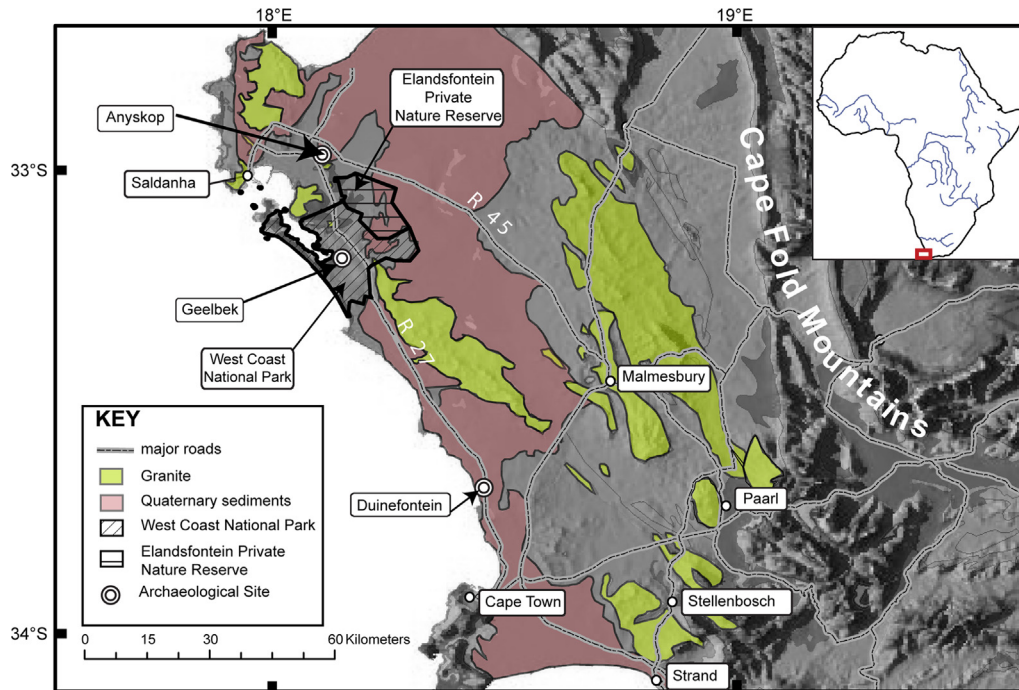
### 1. Introduction

The Pleistocene has been marked by frequent and rapid oscillations in climate (Trauth et al., 2005, 2010; deMenocal, 2011). This

variation is said to have provided the impetus for major, geographically widespread biotic changes (Vrba et al., 1995; Potts, 2012a,b). Its impact on African landscapes is particularly important (Cohen and Umer, 2009) and provides the context for the evolution of the human lineage (Behrensmeier et al., 1997; Potts, 1998, 2012b). Much of this information relating to human evolution and paleoenvironmental change for the African continent has been explored in the East African rift system where tightly constrained geochronology provides detailed information about

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**Fig. 1.** Location map of research area. Geography of other Quaternary localities with similar lithological contexts discussed in the text. Quaternary deposits and granitic outcrops are highlighted overlain on a digital elevation model (SRM). Geologic and topographic information provided by Western Cape Department of Maps and Survey. Geologic boundaries based on Besaans (1972).

changes in terrestrial landscapes through time (Bobe et al., 2002; Kingston, 2007; Plummer et al., 2009). In South Africa this record is limited to cave deposits in the northern interior of the continent (Reed, 1997; Herries et al., 2010); open-air sites in the central part of the sub-continent or the more recent records (<200 ka) in cave deposits along the Cape coast (Marean, 2010). Terrestrial archives, particularly those associated with hominin occupation and paleoecology, are particularly limited prior to the Last Interglacial (125 ka) (Stynder, 2009; Roussouw et al., 2009). This is despite the fact that widespread coastal eolianites along the South African coast provide a uniquely rich record of ancient environments, ecology and human behavior during a critical period in human history (Roberts, 1996; Butzer, 2004; Cowling et al., 2005). These eolianites, the product of multiple phases of eolian deposition and stability, preserve detailed information about the interaction between humans and their environments in the ecologically diverse winter rainfall system (WRZ) (Felix-Henningsen et al., 2003; Cowling et al., 2005). The distinct ecological features of this biome make this region particularly suited to understanding hominin adaptation to environmental variance (Potts, 1994; Kelly, 1995; Binford, 2001). However, very little is known about the ecology of this ecosystem prior to the Last Glacial Maximum (Stynder, 2009; Rossouw et al., 2009).

Currently there are very few mid-Pleistocene localities where sufficient contextual information can be collected to investigate behavioral variation. This problem is particularly acute for the period from ~1.7–0.25 Ma when the Acheulean Industry is commonly found. The Acheulean is often associated with a particular type of tools (Large Cutting Tools, usually greater than 10 cm) and temporally associated with hominins that precede our species (Millard, 2008). The Acheulean is also thought to accompany many important biological and behavioral changes in hominin evolution such as increased brain size and increased consumption of animal tissue (Shipman and Walker, 1989; Ruff and Walker, 1993; Aiello and Wheeler, 1995). Acheulean archaeological sites that

record artifacts in a detailed depositional, ecological, and climatic context are extremely rare. This problem is compounded in South Africa where Acheulean sites are known mostly from isolated localities with little geochronological control (Herries, 2011).

Elandsfontein (EFT), on the West Coast of South Africa, records evidence of multiple concentrations of artifacts and fossils in association with paleoenvironmental proxies and hominin fossil material (Drennan, 1953). This locality provides a rare opportunity to explore hominin behavior in an eolianite context where geochronological studies are feasible (Fig. 1). The Quaternary sediments at EFT represent the largest single repository of information (~11 km<sup>2</sup>) about environments prior to the last Interglacial in the uniquely diverse Cape Floral Kingdom. This biome is critical for understanding the environments in which modern humans evolved (d'Errico et al., 2005; Marean et al., 2007; Texier et al., 2010). Here we describe the recovery of *in situ* faunal and archaeological collections that documents hominin occupation of the Western Cape of South Africa in the mid-Pleistocene, between approximately 1.0 and 0.6 Ma. The technological strategies reflected in the archaeological record at EFT may indicate the interplay of lithic and food resources in the behavioral strategies of Acheulean hominins (Potts et al., 1999; Grove, 2011). They help to document the patterns of adaptive versatility prior to the appearance of modern humans.

### 1.1. Elandsfontein

The history of research at EFT spans the last six decades with the initial survey of fossil and archaeological material taking place in the 1950's (Drennan, 1953; Singer, 1956; Singer and Crawford, 1958; Singer and Heltne, 1966), followed by a series of excavations in the southern part of the dunefield in the mid-1960s (Singer and Wymer, 1968; Deacon, 1998). Initial surveys recovered a hominin calvarium, which is variably referred to as the "Saldanha" or "Hopefield" specimen. Subsequent excavations documented artifacts and fossils

beneath a “dark brown sand” (Singer and Wymer, 1968). The most notable was the site referred to as Cutting 10 where 47 Large Cutting Tools (a diagnostic tool of the Acheulean industry) were recovered in association with large mammalian fossils ( $n = 716$ ; Singer and Wymer, 1968). Singer and Wymer (1968) suggested that surface finds may represent a separate horizon of fossils from those recovered *in situ*. Except for the description of Cutting 10, there has been no further description of *in situ* material. Subsequent work in the 1980’s and 1990’s focused on surface collections (Avery, 1989). This work included documentation of the presence of possible hyena den accumulations, which may explain some of the high densities of fossils from surface occurrences. This also exemplifies some of the challenges of understanding the provenance of surface collections at EFT (Avery, 1989). The most recent work has focused on the analysis of unsystematic surface collections that were made by multiple collectors (including school children from the nearby town of Hopefield town) primarily in the 1950’s through to the 1970’s. This material is collectively referred to as “Elandsfontein Main” (EFTM) and may represent an amalgamation of multiple fossil horizons (Klein, 1988; Klein and Cruz-Urbe, 1991; Klein et al., 2007).

For the past 50 + years, research at EFT has been limited to a relatively small area ( $\sim 3 \text{ km}^2$ ) (Singer and Wymer, 1968; Butzer, 1973; Avery, 1989; Deacon, 1998). Previous mapping efforts and our own surveys suggest that fossiliferous and artifact-rich Pleistocene sediments may cover an extensive area of between 6 and 15  $\text{km}^2$  (Mabbutt, 1956; Besaans, 1972). The numerous paleoecological proxies recorded in these deposits may represent the one of the largest repositories of evolutionarily significant information on the ecology of the high diversity Cape Floral Kingdom.

The Western Cape of South Africa is host to a climatic and physiognomic biome that is often referred to as the Winter Rainfall Zone (WRZ) (Cowling and Lombard, 2002). This biome is characterized by extremely high levels of endemism and biodiversity (Proche et al., 2006). This ecosystem, and its associated coastal resources, may have provided the context for the appearance of major innovations in human behavioral evolution such as early evidence of engineered stone properties and the complex use of pigments for symbolic purposes (Brown et al., 2009; Marean, 2010; Henshilwood et al., 2011).

Currently, there is no comparative framework to understand how earlier populations survived in these winter rainfall environments. Acheulean hominins may have been able to adapt technological strategies to enhance extractive foraging in a marginal environment like EFT, where food resources may have been geographically and temporally variable and stone resources are virtually absent (Deacon, 1998; Braun et al., 2008a). This speaks to the ability of hominins to use cultural stores of information to modify ecological constraints in diverse environments, which is a hallmark of the modern human condition (Hill et al., 2009). The ability to make rapid adjustments to changing conditions would have provided the impetus behind strong selective pressures for culturally-mediated foraging strategies (Silk and Boyd, 2010).

## 1.2. Geology of Elandsfontein

EFT is located in the Strandveld region in the Southwestern Cape of South Africa. It lies in a predominantly eolian landscape dominated by fynbos vegetation and is located in a winter rainfall zone (Mabbutt, 1956; Cowling and Lombard, 2002; Cowling et al., 2005). The Strandveld, or coastal plain, is covered by sands predominantly of quartz and shell composition and interspersed with outcrops of both granite and shale (Besaans, 1972; Scheepers and Nortje, 2000; Chase and Thomas, 2007, Fig. 1). The coastal dune systems in the region are formed via the deflation of beach sediment, and therefore the lithological composition of the dunes mirrors both marine

(calcareous tests of marine organisms) and terrestrial influences (mainly quartz grains). Dunefields in the Strandveld primarily take the form of dune plumes, which comprise plume shaped masses of onshore transgressive dune sand that may penetrate more than 15 km inland from the coast (Roberts et al., 2009). They range in age from Miocene to Recent (Roberts, 2006a,b; Chase and Thomas, 2007; Roberts et al., 2009). EFT is one of several open air archaeological and paleontological localities preserved in these dunefields on the Southwestern Cape (Cruz-Urbe et al., 2003; Kandel et al., 2003; Butzer, 2004).

Previous geological studies of the fossil and artifact bearing strata at EFT include those by Mabbutt (1956), Needham (1962), Singer and Wymer (1968), Butzer (1973), Roberts (1996), and Deacon (1998). These studies recognized distinct features of the sediments at EFT that appear in outcrop and excavation such as indurated calcareous sands that form topographic highs (the ‘Calcrete Ridge’), gray sands with white nodules and ferruginized zones which vary from sinter traces of iron stained nodules to partially lithified ferricrete zones. These studies have led to various interpretations of site formation including combinations of eolian deposition and erosive events, fluvial deposition, and pedogenic processes (Mabbutt, 1956; Singer and Wymer, 1968; Butzer, 1973; Deacon, 1998). Currently there is no systematic survey of the sediments in relation to exposures of sediments from archaeological excavation or any other exposures of the underlying stratigraphic relationships. Previous interpretations of the stratigraphy of the fossil-bearing sediments are based largely on the minimal surficial exposures (Butzer, 1973; Klein et al., 2007) and have yet to be placed in full stratigraphic context.

## 1.3. Current research at Elandsfontein

Research at EFT between 2008 and 2012 has focused on providing a more detailed understanding of the context of human occupation in the Cape Floral Region during the mid-Pleistocene. Here we provide initial results from the excavation and geological analysis of extensive trenches that give new insights into the formation history of the archaeological and paleontological deposits. Current data acquisition and analysis are focused on providing a contextual link between behavioral and paleoenvironmental data as previous investigations suffered from insufficient contextual information. As a result it has been difficult to use this information to understand the interaction between hominins and these ancient environments. We document the presence of remarkably continuous surfaces that reflect similar ecological and geomorphological processes over an extensive ( $\sim 6 \text{ km}^2$ ) area (Fig. 2). We provide new information on the sedimentological context of the archaeological and paleontological deposits that allow for meaningful contextual association between behavioral data and spatially associated proxies of the paleoenvironments. Despite the dynamic nature of these landscapes our data indicate that several localities preserve archaeological material that has suffered minimal post-depositional disturbance.

## 2. Methods and materials

### 2.1. Field survey and mapping

Field research at EFT has been directed at understanding the spatial associations between artifacts and fossils, as well as the formational history of these deposits. As such, the research has been focused on the extensive exposure of stratigraphic features that are not visible from the surficial geology. Over 13 major excavations ( $>4 \text{ m}^2$ ) and 111 systematic trenches (“shovel test pits” or STPs) were excavated throughout the dunefield. These STPs were



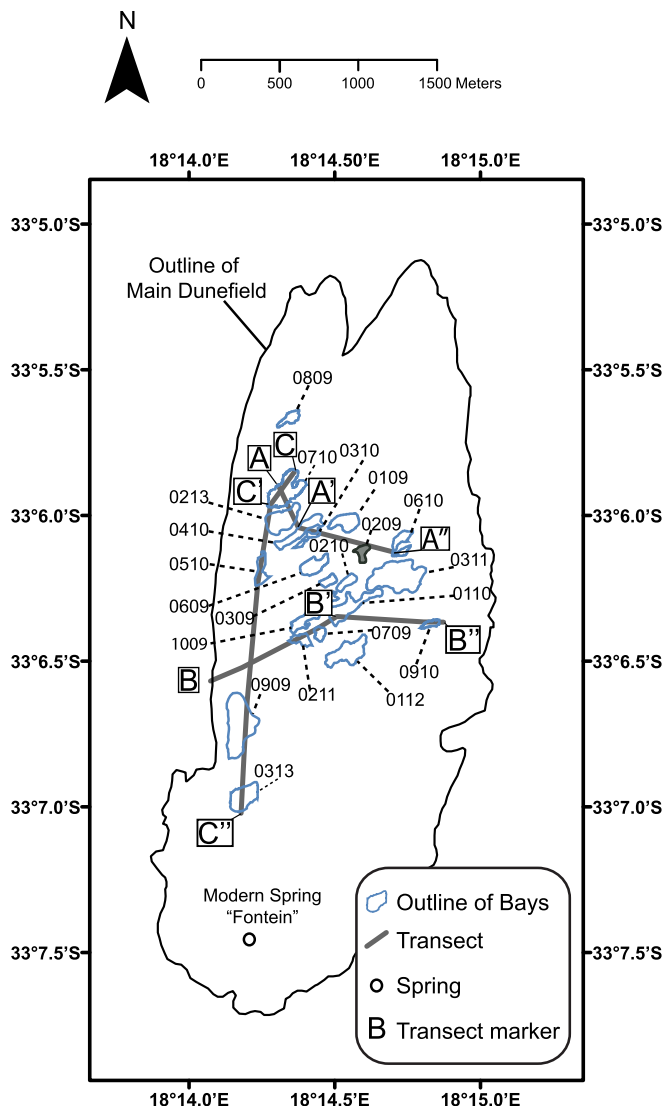


Fig. 2. Site map with location of bays and transect locations. Geological descriptions of these transects are described in Fig. 3.

necessary since present eolian activity has deposited 1–6 m of cover sand. These STPs were executed according to a standardized procedure whereby 2 m<sup>2</sup> pits are excavated in altimetric intervals of 20 cm in depth (or smaller intervals if they passed through stratigraphic contacts) and all sediment was sieved with a 3 mm mesh. The excavations extended deep enough to allow for the exposure of at least 1 m of stratigraphy. Trenches (STP) that were situated near particularly important stratigraphic contacts were extended using an auger for an additional 4 m (vertical). Each stratigraphic horizon was associated with a unique identifier (these are referred to as “lot numbers”) that links the sieve finds and sedimentary samples from each horizon to the specific stratigraphic unit. All information on these STPs was recorded using field GIS software (ESRI ArcPad) on a Trimble Nomad handheld computer. This was combined with a wide-ranging, field-based GIS survey of the surficial geology to provide the locations of major geomorphological features across large lateral scales. In addition, we employed total station surveys to document the spatial relationship of all excavations and associated STPs. Although not all STPs could be accessed with a total station, 83 of the 111 trenches have associated altimetric data from total stations allowing for an extremely accurate (<1 cm) control on the relative heights of the stratigraphic horizons.

Deflation hollows between large modern dunes are the major spatial units of analysis in the present study. These deflation areas were named based on the sequence of investigation as well as the year they were investigated (e.g. 0209 was the second deflation hollow investigated in the year 2009). These deflation hollows are often referred to as “bays” following earlier studies at EFT and nearby dunefields (Mabbutt, 1956; Singer and Wymer, 1968; Kandel et al., 2003; Fuchs et al., 2008). We have identified several of the bays investigated by earlier research teams. Although published reports of the research at EFT did not include locality maps (Singer and Wymer, 1968), Deacon (1998) developed a detailed map of the research area (H. Deacon pers. com.). Two bays, “Queenie Bay” (0710) and “Homo Bay” (0909), were clearly identified based on these documents. *Homo* Bay is named for the hominin specimen recovered from this region in 1953 (Drennan, 1953), but the explanation of the moniker for “Queenie Bay” remains unknown. The surface collection frequently described as the “Bone Circle” has not been definitively relocated (Inskip and Hendey, 1966). We believe that the 0510 bay lies in the vicinity of the “Bone Circle” site however no indications of the earlier surface collection are visible.

## 2.2. Sedimentology and stratigraphy

Sedimentary data were generated from field and laboratory observations taken from surface exposures, archaeological excavations and STPs. All stratigraphic sections were measured and drawn from excavated exposures because active dune sands cover the majority of the Pleistocene strata.

Thin sections were prepared for a representative set of lithologies observed at EFT, with unconsolidated and porous samples imbedded in resin and cut into billets. Samples were evaluated using a petrographic microscope (at 2×, 4×, and 10× magnification). A Retsch Camsizer device at the University of Pennsylvania Sediment Dynamics Laboratory was used for quantitative analysis of sediment size and shape following methods outlined by Jerolmack et al. (2011). Forty-four sand samples representing a full range of the observed lithologies were characterized with the Camsizer. Fifty logarithmically spaced size classes of grain size, ranging from 0.05 to 3 mm, were defined based on the measured grain diameter,  $d$ . Sphericity was defined as  $SPHT = 4\pi A/P^2$ , where  $A$  represents the area of a particle and  $P$  the length of its perimeter or circumference. Sorting was determined using a normalized dispersion parameter,  $\sigma$ , which is defined as:  $\sigma = (d_{90} - d_{10})/d_{50}$  where the subscripts are the percentage by volume of the sample below the diameter specified.

In preparation for SEM imaging, sands were first sieved to remove the fine fraction. Coarse grains were individually selected with tweezers and set aside. The selected grains were rinsed in a 15% HCl solution to remove coatings, rinsed with deionized water, bathed in H<sub>2</sub>O<sub>2</sub> to remove any residual organic matter, and then rinsed with deionized water a final time. Using a Polaron SC7640 Sputter Coater, the mounted specimens were coated with a 5 nm thick coating of platinum. Samples were viewed with a JEOL JSM 6700F Scanning Electron Microscope at Johns Hopkins University.

## 2.3. Paleomagnetism

We investigated the magnetic properties of 18 large block samples from a variety of lithologies throughout the dunefield. We conducted detailed paleomagnetic analysis, following protocols outlined in Herries et al. (2006), Herries and Shaw (2011) and Pickering et al. (2013), on 14 of the specimens that were suitable for analysis. Samples were oriented in the field using a Suunto magnetic compass and clinometer and final declinations were corrected to

true north using the International Geomagnetic Reference Field accessed through the British Geological Survey (available at <http://www.geomag.bgs.ac.uk/gifs/jgrf.html>). Samples consisted of a range of silica and calcium carbonate indurated sands and calcrete deposits that were collected as block samples and sub-sampled in the laboratory to create between 3 and 5 sub-sample cylinders per block. Many of the samples contained holes in them or were only lightly indurated making sampling difficult in many cases. Final mean directions for each block sample and paleopole positions were calculated using Fisher (1953) statistics. Samples were measured on an AGICO JR6 magnetometer at either the University of Liverpool Geomagnetism Laboratory (UK) or the Australian Archaeomagnetism Laboratory at La Trobe University (Australia). The primary characteristic remanences (ChRM) in the samples were isolated by both alternating field (AFd) and thermal demagnetization (THd) and using a Magnetic Measurements Thermal Demagnetiser and Molspin AF Demagnetiser. Final directions were calculated using principle component analysis (Kirschvink, 1980) and were considered reliable if they had a MAD (maximum angular deviation) value of <15 and final K value for block samples >30. The polarities of the final block sample were assigned to normal (N), reversed<sup>®</sup> or intermediate (I) polarity according to their palaeopole positions (intermediate samples having palaeolatitudes (P.Lat: Table 1) values of <45° and fully reversed or normal polarity samples having values >45°). This produced a sequence of polarity intervals and reversals that were then correlated to the Geomagnetic Polarity Time Scale (GPTS; Ogg, 2012) and other well established geomagnetic polarity events and excursions (see Kidane et al., 2007; Dirks et al., 2010; Herries and Shaw, 2011) to produce potential age ranges for the various deposits and site as a whole.

#### 2.4. Fabric analysis and documentation of site integrity

Deflation is a major concern when excavating archaeological localities in regions where eolian activity is the dominant sedimentary process. In particular, the creation of fossil and artifact lag deposits by winnowing and removal of the surrounding sand matrix, and the development of single palimpsests by the collapse of multiple horizons of archaeological material need to be considered (Schiffer, 1987; Waters, 1992; Dincauze, 2000). Deflation may create false assemblages with undermined integrity, such that the materials recovered are not behaviorally or ecologically associated (Binford, 1981); this has been documented for Paleolithic assemblages at several localities along the Western Cape (Kandel et al., 2003). The aeroturbation process is largely subtractive making it difficult to assess the extent to which it has affected on buried horizons

(Fitzsimmons et al., 2009). Objects can also move during aeroturbation. For example, the Geelbek Object Movement Experiment (GOME) documented lateral movement of over a meter in a single year of deflation for objects in, as well as on the surface of, dune sands (Kandel et al., 2003). Any attempt to understand the behavioral association between the artifacts and fossils at EFT requires data targeted at discerning the extent of eolian processes.

We investigated the influence eolian activity on the EFT archaeological assemblages using several methods. We applied a method initially employed to archaeological sites on the Channel Islands by Rick (2002), which are subjected to extreme aeroturbation, with winds reaching 100 km/h Rick (2002) documented that lighter elements are preferentially removed at localities where deflation has occurred such that a deflated archaeological horizon is dominated by large mammalian elements. Rick's study was based on a comparison of the frequency of fish bones (which tend to be smaller and lighter than mammalian bones) versus mammalian bones across multiple stratigraphic horizons. At localities that were unaffected by aeroturbation, the frequency of mammalian bones tracks the frequency of smaller fish bones throughout the stratigraphic sequence. At deflated localities the frequency of mammalian bones increase as fish bones decrease. Here we identify patterns within a single 1 × 1 m unit with the highest density of material within various excavations at EFT. We evaluate the significance of these patterns by conducting two sample Kolmogorov–Smirnov tests on cumulative distributions across the stratigraphic column within an excavation.

A similar investigation of deflation processes by Kandel et al. (2003) documented that bones that are longer than they are wide tended to align themselves with wind direction. This can be documented using the orientation of specimens as defined by bearing and plunge which is analogous to the geological measurements of strike and dip (McPherron, 2005). Sites that have undergone extensive, post-depositional aeroturbation can be recognized by an orientation of specimens that is aligned with the dominant wind direction. We investigate the differences in mean orientation from modern day wind direction, which is predominantly northwest-southeast (Roberts et al., 2009). However, in the event that wind directions differed in the past, the statistical tests we use determine whether the orientation data represents a deviation from a random pattern. Thus any preferential orientations that are aligned with paleo-wind directions can be identified.

We used a total station to capture three dimensional coordinates on the two extremities of the long axis of specimens that were greater than 2 cm using methodologies described by McPherron (2005), McPherron et al. (2005) and Bernatchez (2010). We also

**Table 1**  
Paleomagnetic results.

Sample ID	Declination	Inclination	K <sup>a</sup>	No. <sup>c</sup>	Paleo latitude	Polarity <sup>b</sup>	Lithology
9006	68.2	−65.0	969.0	3	37.7	I	Lithified sand, ferricrete horizon, Upper Pedogenic Sands
9007	210.5	21.2	91.8	3	−54.4	R	Banded micrite in calcareous quartz sand, pinnacle exposure
9008	203.5	47.1	84.0	3	−69.2	R	Calcareous quartz sand, on floor of <i>Homo</i> Bay
9011L	214.5	24.9	519.6	2	−52.8	R	Banded micrite in calcareous quartz sand in Deacon Cutting
9011U	117.9	−65.1	271.5	2	7.7	I	Banded micrite in calcareous quartz sand in Deacon Cutting
9013	72.4	−64.7	463.3	3	34.8	I	Micrite and fine sand, calcareous quartz sands
9015	244.8	−31.6	50.4	3	−10.4	I	Lithified sand, white nodular horizon, Upper Pedogenic Sands
9016	353.5	−18.9	405.1	3	65.9	N	Lithified sand, white nodular horizon, Upper Pedogenic Sands
9017	216.8	33.0	801.3	3	−53.7	R	Lithified sand, white nodular horizon, Upper Pedogenic Sands
9018	328.1	−31.1	6.4	3	57.4	N	Calcareous quartz sand with reworked carbonate grains and gastropods
9019	190.3	57.2	152.5	3	−80.3	R	Calcareous quartz sand, Calcrete Ridge
9021	88.6	−37.2	135.7	3	12.3	I	Ferricrete ridge
9022	23.4	−55.1	33.2	3	70.6	N	Lithified sand, white nodular horizon, Upper Pedogenic Sands
9023	23.4	−41.8	20.0	3	67.6	N	Calcareous quartz sand with reworked carbonate grains

<sup>a</sup> Estimated precision (dispersion) parameter from Fisher (1953) statistics.

<sup>b</sup> N = normal, R = reversed, I = intermediate.

<sup>c</sup> The number of samples that the paleopole data is based. This is the number of subsamples per block sample.

excavated localities where aeroturbation was currently affecting archaeological deposits. In particular, we excavated one locality near the 0609 bay where, over the course of 3 years, we witnessed materials being deflated onto a single surface. This locality was excavated as if it was an archaeological site and we applied the various site formation methodologies to this locality as well.

This locality, termed a “deflation experiment”, was used as a control state to identify the patterns that would be expected in a deflated horizon. This control collection was compared against *in situ* archaeological horizons to determine if the orientations were similar to that which had been identified in the deflated horizons. We evaluate the presence of oriented specimens that deviate from a random pattern using Rao’s test for a uniform distribution. This test was chosen because it is non-parametric and does not assume a von Mises distribution (Russell and Levitin, 1995). Bearing and plunge values were calculated using the Newplot software developed by McPherron and Dibble (2001). These tests follow methods outlined in McPherron (2005). We test the significance of differences in orientation between the “deflation experiment” data set and archaeological data sets using the Mardia-Watson-Wheeler test (Mardia, 1972).

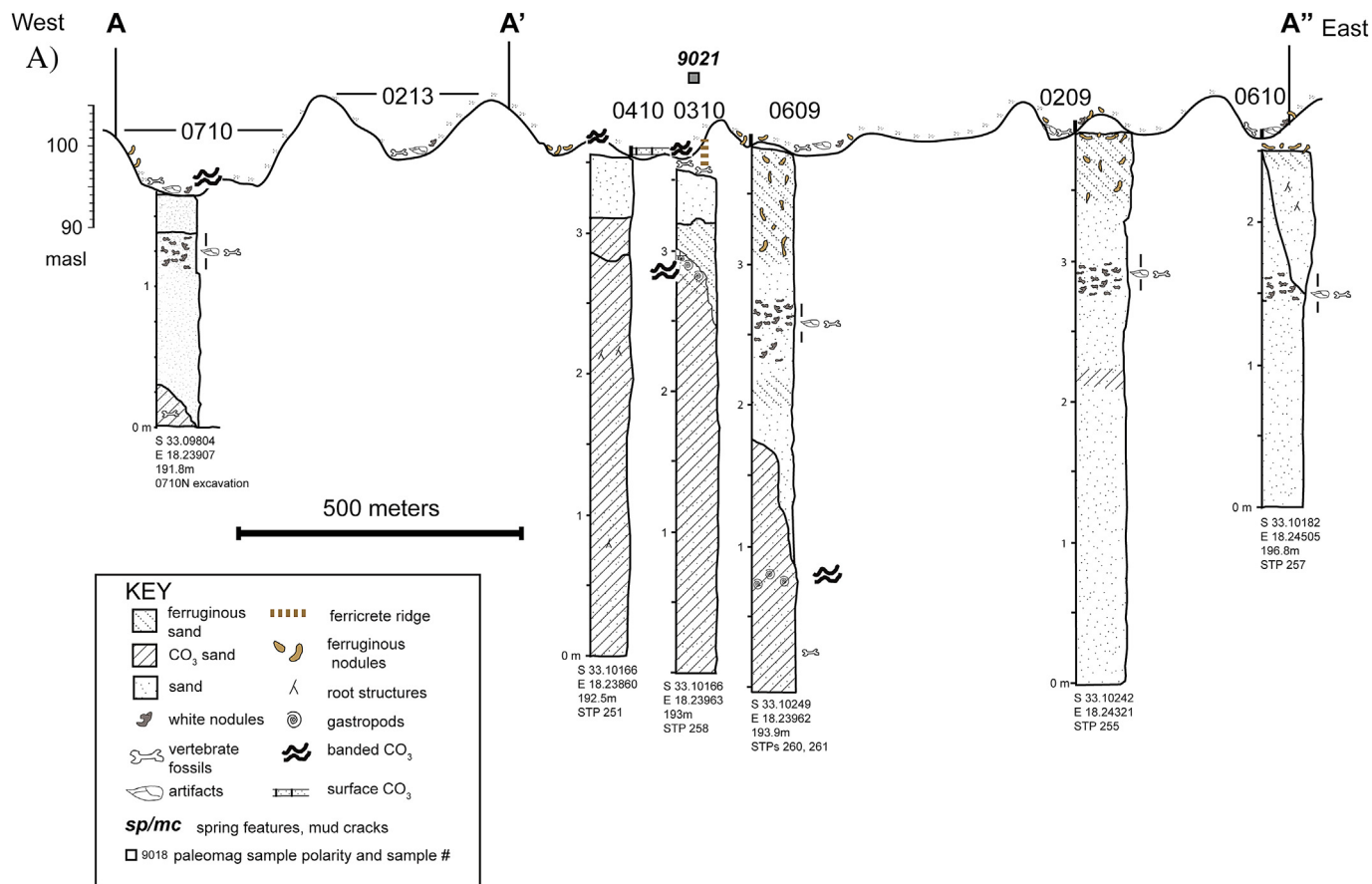
In addition to spatial integrity analyses, we investigate the distribution of artifact size classes to determine the degree of post-depositional modification to the archaeological collection. Schick (1986) has previously identified the distribution of artifact size

classes in experimental scenarios (where no post-depositional modifications occurred). She documented that experimental knapping localities have extremely high numbers of smaller shattered fragments. Localities with higher frequencies of smaller artifact fragments are likely to have undergone less post-depositional modification. We also include data for the Middle Paleolithic site of Fontechevade (Dibble et al., 2006). We include data from this locality because previous studies have indicated this site was heavily affected by water action. We provide this as an example of an archaeological signature that is indicative of post-depositional modification. We test the significance of the differences between assemblages using the Kolmogorov–Smirnov two-sample test. We use Schick’s (1986) size classes as the ordinal variable to construct the cumulative distributions for the comparison of assemblages.

### 3. Results

#### 3.1. Sedimentology and stratigraphy

Stratigraphic observations are summarized in Fig. 3 and schematically represented in Fig. 4 to represent the typical lithologies that are observed throughout the dunefield. The entire thickness of the observable stratigraphic sequence at EFT is approximately 4 m.



**Fig. 3.** Stratigraphic sections along 3 transects that are marked in Fig. 2 and run A) west to east in the north of the dune field, B) west to east in the southern part of the dunefield and C) north to south across the ‘Calcrete Ridge’. Surface features are indicated with symbols on topography but they do not represent *in situ* observations. Measured sections plotted along these transect indicate subsurface expression of the lithology, artifact and fossil distributions. Scales for stratigraphic sections and vertical topography are different, through all sections (and all topographic profiles) are drawn at the same scales, respectively. The scale of the stratigraphic sections is plotted in meters above sea level. The relative horizontal position of the sections corresponds to their longitude. These sections are chosen because they are representative of lithology found in the bay. The top of each section is marked by a thick black tick. GPS coordinates (WGS-84 coordinate system) and name for each section are listed at the base of each section. The names of bays are noted. In places where paleomagnetic samples were taken along these transects, sample numbers and polarity (fill squares = normal, open = reversed) are noted.

The stratigraphy is only visible through excavation pits or trenches that expose the Pleistocene deposits below the modern sand.

The Quaternary sediments of the EFT dunefield are expansive and likely underlie an area that is much larger than the current exposure in the modern active dune system. Presently sediments can be found in three major areas: the main dune field (the largest and northernmost of these exposures), West Site, and the Farm-house Site. Our mapping suggests that there are 55,000 square meters of exposure currently visible in the main dunefield. The area of exposure was likely larger in the past, as suggested by maps provided by Mabbutt (1956), prior to the invasion of alien vegetation (*Acacia mearnsii*) which has halted some of the dune activity. Further exposures of Quaternary deposits can be found approximately 2 km to the west at a locality that Mabbutt (1956) described as “West Site”. The third region of deposits is a system of smaller exposures, badly affected by trampling, that surrounds the original farmhouse and the modern day spring (“the fontein”). Although our preliminary investigations suggest that these deposits are likely contemporary, we limit this present discussion to deposits exposed in the northern dunefield (Fig. 2). There is a remarkable continuity in the stratigraphic horizons throughout the dunefield such that

specific horizons can be traced laterally at scales of  $10^2$ – $10^3$  m. Mabbutt (1956) documented exposures that reflect a repeated sequence of sedimentary and pedogenic features throughout the dunefield. He also noted that these beds tend to be found at lower elevations in the western portion of the dunefield. Quaternary deposits at the eastern extremity of the dunefield are found at approximately 103 m above sea level (masl) and the western extremity of the deposits sit at 93 masl. It is likely these exposures extend laterally to the east and west of the dunefield. Singer and Wymer (1968) documented the presence of stone artifacts and fossils at depths of between 2 and 3 m on either side of the dunefield.

We identify 4 main lithologic units that comprise the Quaternary sediments at EFT and that are observed throughout the dune field. We report descriptions of these units in the sections reported in Fig. 3 and summarize the surface exposures at EFT in Fig. 4.

3.1.1. Upper Pedogenic Sands

These sands are found throughout the dune field in Bays 0209, 0609, 0909, 0110, 0610, 0710, 0211, and 0112 (Fig 3) and range from 1 to 3 m in thickness. The tops of these sands are either exposed at the surface, covered by modern dune sand, or eroded away. This

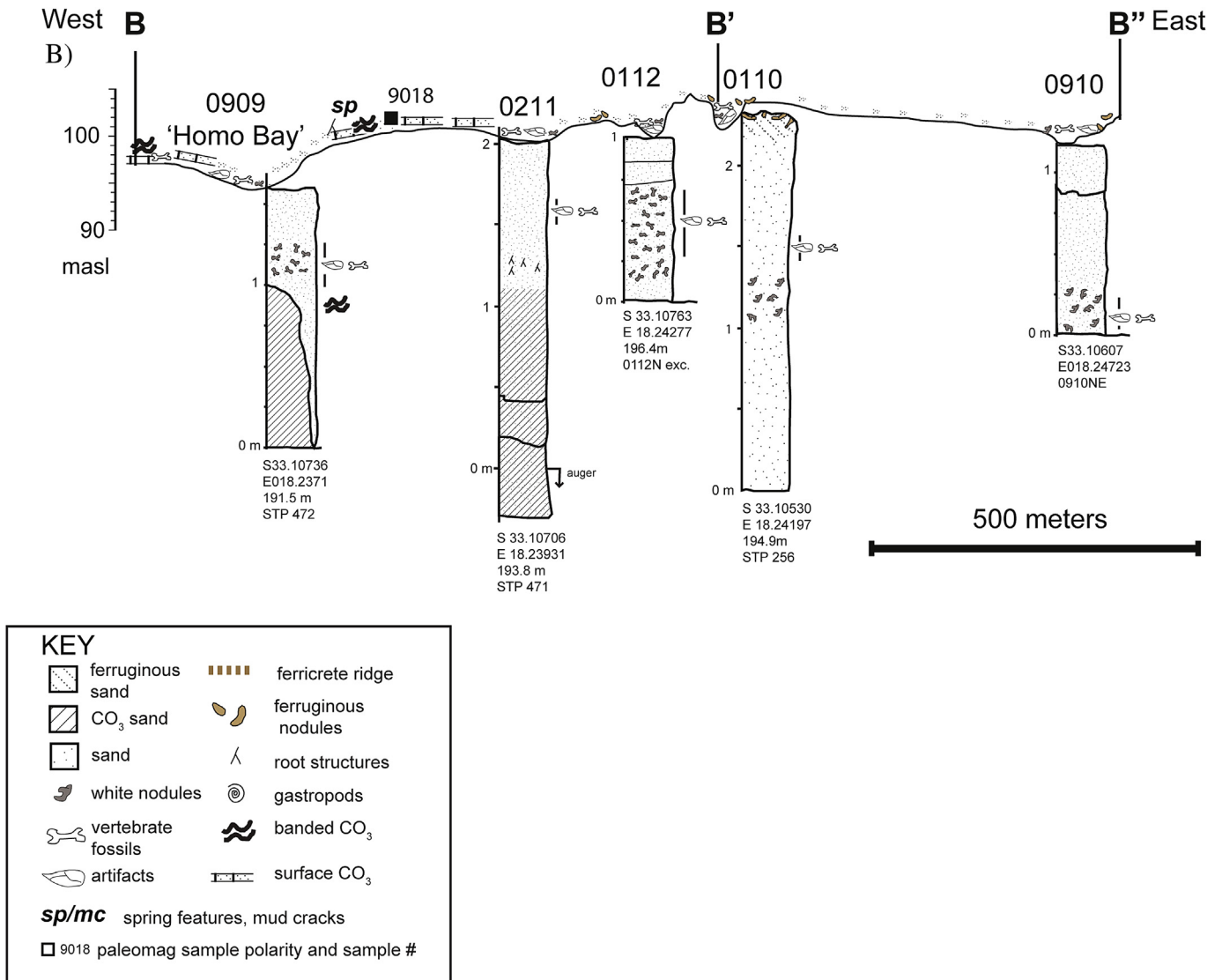


Fig. 3. (continued).



unit is characterized by unlithified, well sorted, fine grained, rounded to sub-angular quartz sand (Figs. S1–S2, Table S1). Medium and coarse grains are rounded where fine grained sands are generally sub-angular. Grain size, shape, sorting and lithology are relatively uniform through this sequence (Figs. S1–S2, Table S1). No bedding structures are preserved. Color changes and the presence of nodular zones differentiate these sands into horizons (see Table S1). A horizon of white cemented sand nodules (0.5–10 cm) is the diagnostic feature of this unit. We divide our description of the Upper Pedogenic Sands based on vertical position relative to this white nodular horizon.

The white nodular horizon ranges from 10 to 130 cm thick. The white nodules contain sand grains that are invariant in composition from the surrounding unlithified sand matrix (Fig. S1). The nodules are predominantly cemented by a siliceous cement and some having minimal carbonate content (Fig. S1). Typical sands surrounding these nodules are very pale brown (10YR 8/2) to light brown color (7.5YR 6/3), although they are brown (7.5YR 5/3) in Bay 0910 (Table S1). These sands are composed almost entirely of quartz. They are mostly sub-angular fine sand grains but also include rounded medium and coarse grains (Table S1, Figs. S1–S2). Grain surfaces are often etched in hand sample. Cracked grain surfaces can be observed in thin section (Fig. S3). Artifacts and *in situ* vertebrate fossils are routinely associated with this white nodular horizon and are limited a 15 cm vertical distribution at the top of the nodular horizon if it extends deeper. No invertebrate fossils are found in this unit or elsewhere in the Upper Pedogenic Sands. Vertical and sub-vertical variations in sediment color (0.5–1.0 cm diameter, 3 cm in length) are present in both the white nodular horizon and the ferricrete nodular horizon. These are likely indications of burrowing.

In some areas, the fossiliferous and artifact-bearing white nodular horizon is overlain by well sorted medium grain yellowish brown sands (10YR 5/4) that contain dark brown, iron-oxide cemented sand nodules that are elongate in shape (<20 cm in length) (Fig. S1) (in Bays 0209, 0110, 0609; see Fig. 3). These ferricrete nodules contain sand with the similar size, shape and lithology as the surrounding sand. In sections where the Upper Pedogenic Sands are not capped by ferricrete nodules at the surface, it is because they have been eroded away (e.g., Bay 0610) or because they may not have ever been present, which is likely the case in the southern portion of the dune field (e.g., Bay 0909). When present, the ferricrete nodules form a zone that can be up to 80 cm thick; they usually extend to the surface or they are buried by modern sands.

The white nodular horizon is underlain either by fine white (10YR 8/1), non-calcareous, well sorted quartz sand (e.g., Bays 0209, 0610, Figs. 3 and 4; Fig S1) or by carbonate cemented quartz sands (described in Section 3.1.2). The contact between the non-calcareous and calcareous sands is gradational in some places (e.g., Bay 0710) whereas it is sharp, non-uniform, and non-conformable in others (e.g. Bay 0609, STP 472, STP 473). In places where this contact is gradational, the carbonate cement is associated with yellow (10YR 8/6) to reddish yellow (7.5YR 8/6, 7/8) staining, whereas the surrounding sand is white (10YR 8/1) and low in carbonate content (e.g., base of 0710N excavation and STP492, base of 0909S excavation).

SEM images of grains from sands in the nodular horizon indicate smooth, rounded grains which match the profile for grains influenced by eolian transport (Fig. S3). Irregular grains that were present had bulbous protrusions. Features expressly typical of high-energy fluvial or marine transport, such as conchoidal and

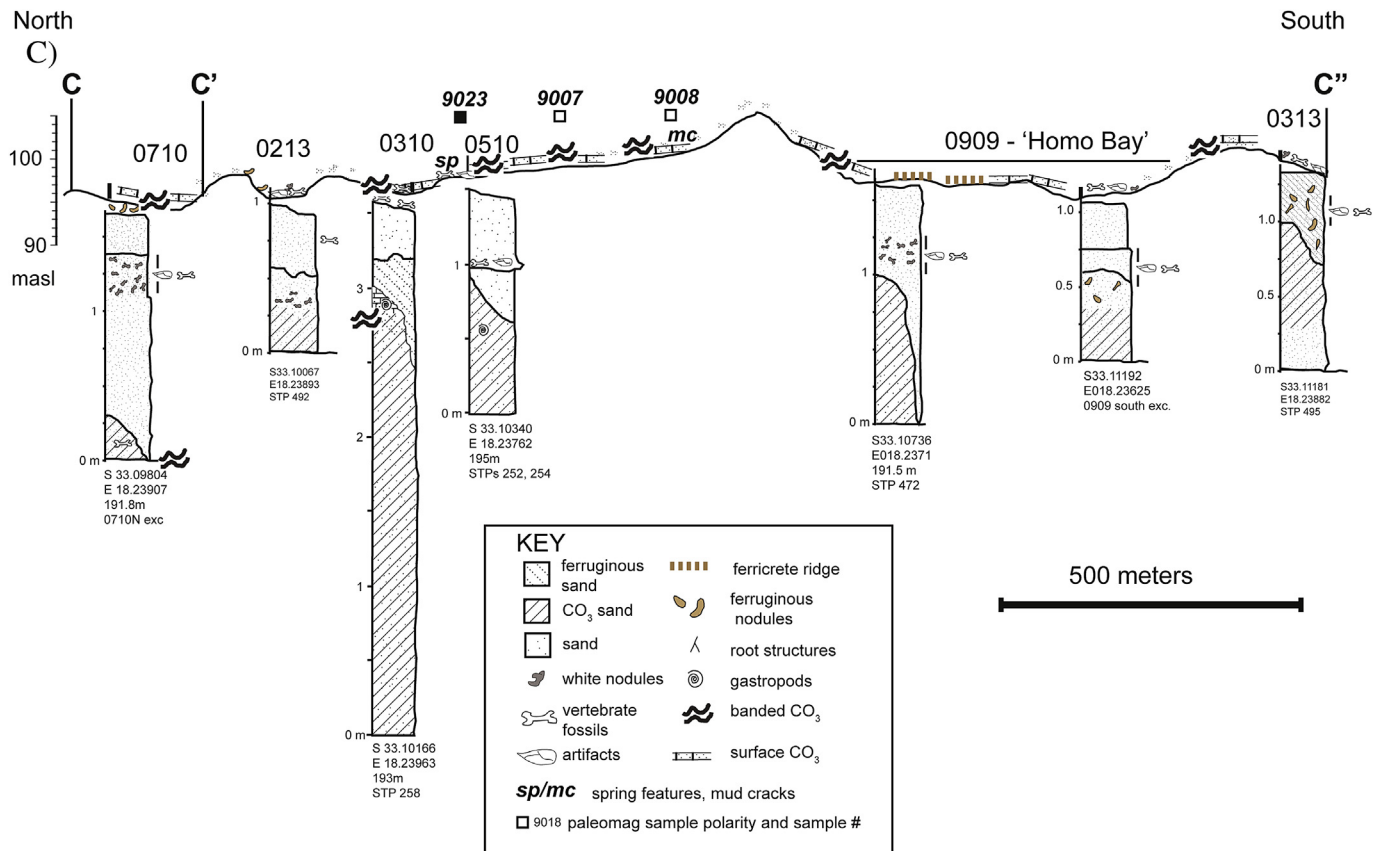
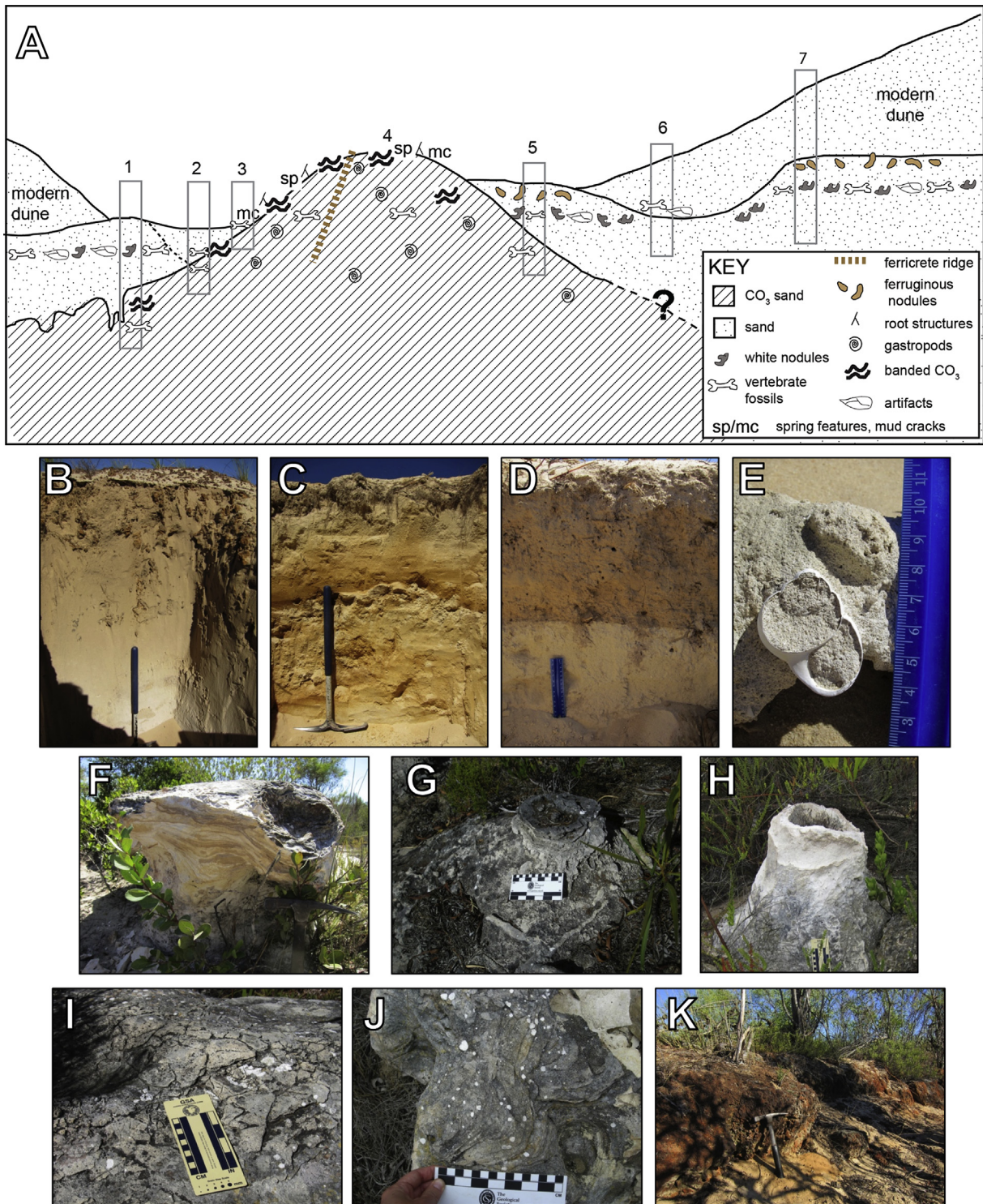


Fig. 3. (continued).





**Fig. 4.** A schematic illustration and photographs of lithologies observed at EFT, their stratigraphic relationships, and their relationship to archaeological and fossil occurrences. A) Schematic diagram that describes the different scenarios (1–7) in which artifacts and fossil are found in the dunefield. See Section 4 of text for references of these different scenarios and examples of these different locations within the dunefield. B) upper pedogenic sequence in STP 260 in Bay 0609 with ferricrete nodules at top of pit and the white nodular horizon at the base, C) ferruginous sandstone and buried banded carbonate in STP-258, Bay 0310, D) lag deposit buried by coarse sand in STP 254, Bay 0510, E) *Trigonephrus globulus* shell in the Calcareous Quart Sand, F) pedestal of banded micrite with flow features and *T. globulus* shell in Bay 0909, G) circular spring-eye feature, root casts and cocoon molds in calcareous sand on the 'Calcrete Ridge', H) ovate spring-eye feature with cocoon molds on surface, I) mudcracks in micrite, J) surface flow features atop banded micrite, and K) ferricrete ridge.

arcuate fractures (Cater, 1984; Mahaney, 2002), were absent. The rounded and bulbous grains were often marred by few signs of significant mechanical damage apart from general abrasion. Overall, very few sharp or angular features could be seen on the grains.

### 3.1.2. Calcareous quartz sands

These pale yellow (2.5Y 8/2) to white (10YR 8/2) sands are found exposed on the surface and underlying the Upper Pedogenic Sands. These sands are characterized by carbonate cement, and rounded;

well sorted fine quartz grains (Figs. S1 and S2). Bedding is absent from this unit. In some places these sands contain medium sized grains of rounded shell material (Fig. S1). Absence of these reworked grains is associated with more dispersed carbonate cement and carbonate coatings on the quartz grains. Ferruginous staining is often associated with this dispersed carbonate cement. This unit contains *Trigonephrus globulus* (see Roberts et al., 2009), and mammalian long bones, none of which are diagnostic to genera. No artifacts have been found in this unit. This unit is often capped by banded carbonate and biogenic features described below (see Figs. 3 and 4), although in some instances banded micrite can be found within this unit.

### 3.1.3. Surface carbonate

There are multiple surface expressions of indurated carbonate. The majority of surface carbonate is indurated expressions of the variants of the Calcareous Quartz Sands. In addition, there is banded micritic carbonate that ranges from 1 to 30 cm in thickness and usually caps the Calcareous Quartz Sands, though it is sometimes intercalated with these sands (Deacon Cuttings 1 and 2; Bay 0310; see Fig. 4F,G, and J and Scenarios 3 and 4 in Fig. 4A). In some places banded carbonate is accompanied by biogenic features, root structures, cocoon cast and molds, polygonal cracking, and concentric ovoid features that can be up to 30 cm in diameter (Fig. 4F–J). When visible in three dimensions these concentric features extend up to 70 cm in depth. Shells of *Trigonephrus globulus* and other gastropods are often associated with these surface carbonates. All of the carbonate-rich sediments at EFT are marked by distinct dissolution and reprecipitation features, particularly near lithologic boundaries. Carbonate rich sediment, including the surface carbonate, is more frequent on the western portion of the dunefield and forms a topographic high.

### 3.1.4. Ferricrete ridges

Southwest to North–East trending ridges of ferruginous cemented sandstone outcrop on the surfaces of the EFT dune field. These ridges extend from  $10^1$  to  $10^3$  m in length. The sands in these ridges are non-calcareous, dominated by sub-angular fine grained quartz (Fig. S1, Table S1); they are lithologically indistinct from the sands observed in the Upper Pedogenic Sand sequence. Ridges are up to 1 m wide and can extend more than 2 m deep into the sub-surface, as exhibited by our excavations and from photos of excavations of similar units in the 1960s by Singer (Pers. comm.). They are often more resistant to chemical and mechanical weathering and as a result often crop out 1–3 m above the surrounding sediments. The ridges are reddish-yellow and have a clinker-like appearance. These ridges cross-cut the Calcareous Quartz Sand but we have not observed them cross-cutting the Upper Pedogenic Sand sequence.

## 3.2. Geochronology

### 3.2.1. Paleomagnetic data

A range of different lithologies were sampled from the EFT locality including calcrete, micrite, ferricrete and sandstones indurated by both calcium carbonate and silica (silcrete). The remanences vary greatly and in some cases, such as the banded carbonate spring deposits, the remanence may have formed at or close to the time of deposition (Fig. 6, Table 1). In others the remanence is held by a chemical remanence, (e.g., sandstones) and could have formed at a time significantly after deposition.

Magnetic analyses of Calcareous Quartz Sands and micrite exposed along the western margin of the dunefield along a feature described as the ‘Calcrete Ridge’ recorded consistent stable and reversed polarities that suggest an age  $>780$  ka (Fig. 3c; samples

9007, 9008, 9011, and 9019), except for samples 9018, 9023 and 9011U. The upper part of sample 9011 had visibly undergone extensive alteration and this is likely the reason for intermediate polarities in the top of this block. Samples lower in the stratigraphy exhibited a reversed polarity. Sample 9018 had very inconsistent directions between subsamples with a K of only 6.4, although they also had some of the most stable remanence of any of the samples at the site (Fig. 6). Sample 9023 had quite scattered directions and a low unblocking temperature ( $<300$  °C), although generally the remanence was removed in the EFT samples at higher temperatures between 300 and 550 °C.

Sandstones and ferricretes (ferruginous silica cemented sand) within the dunefield recorded intermediate and normal polarity directions, except for sample 9017, which records a reversed polarity. The polarity in these samples is likely a chemical remanence that would have formed as the sand became indurated with silica and as such the remanence may represent the polarity of a period much later than the deposition of the sand and underlying fossils. The reversed polarity of sample 9017 may suggest that these deposits were formed at  $>780$  ka, although this single reversed polarity sample needs confirmation from further analyses. While normal polarity directions may indicate magnetization within the last 780 ka, this need not be the case and it may also represent the time period between 1.07 and 0.99 Ma (the Jaramillo SubChron). The occurrence of reversed polarity samples among similar samples also makes this possibility more likely. A palaeomagnetic analysis of South African silcrete (Brown et al., 2009) indicated that silcreted can hold a stable remanence. However, the majority of the Elandsfontein silica-cemented sandstones are not well developed and are often only lightly indurated. These samples contain numerous holes, which allow for more recent detrital contamination. Some of these samples have complex overlapping magnetic components giving rise to very erratic demagnetization behavior (Fig. 6; sample 9015), which may reflect this complex diagenetic history. These deposits perhaps may represent the early forms of eventual silcrete horizons. The high incidence of intermediate polarity may reflect this early formation process.

Paleomagnetic analysis of travertine and tufa deposits elsewhere in South Africa provide precedent for reporting reliable paleomagnetic data from these lithologies (Morinaga et al., 2010; Hopley et al., 2013; Pickering et al., 2013). Previous studies have reported the recovery of stable polarity from tufa deposits if they are not too porous. In this sense they are akin to speleothems, from which reliable detrital and chemical remanent magnetizations have been recovered (Herries and Shaw, 2011; Lascu and Feinberg, 2011; Pickering et al., 2013). X-ray fluorescence microscopy studies of iron distribution in speleothem show that the paleomagnetic signal was almost entirely dominated by detrital grains of magnetite that were calcified into the speleothem during flooding or deposition from dripwater (a detrital remanent magnetization; DRM). Reviews of speleothem magnetism studies concluded that the recorded remanence formed within a few years after deposition and that chemical remanences (CRM) form at the time of deposition, unlike some sediments that record a more significant post-depositional remanent magnetization (pDRM) (Latham and Ford, 1993; Lascu and Feinberg, 2011; Pickering et al., 2013). One caveat with this type of analysis is the potential for contamination of detrital material in porous tufa. We interpret the paleomagnetic data on carbonate materials at EFT in light of these studies that shows the potential for tufa and other open air calcium carbonate deposits to record stable polarities that represent the time of their deposition over significant timescales.

In contrast, the mineralogy and overprinting history of sandstones can be complex (Hounslow et al., 1995). The geomagnetic remanence in sandstones is often held by magnetic minerals that



have formed *in situ* after deposition due to chemical alteration and weathering, although remanence can also be held by detrital magnetite grains that represent a pDRM closer to the time of sedimentation (Hounslow et al., 1995; Hounslow and McIntosh, 2003). This is more likely to be the case at Elandsfontein in the primary calcium carbonate indurated sandstones than those indurated with silica, which maybe secondary. The remanence of the majority of samples in this study is carried by ferrimagnetic minerals that likely originate from small amounts of a fine-grained detrital sediment fraction. A study of estuarine sandstones from the nearby Langebaanweg fossil site by Roberts et al. (2011) identified that stable magnetic directions could be recovered from such deposits on a timescale of ~5.2 Ma and that the magnetism was often carried by antiferromagnetic minerals formed by early diagenesis and weathering. The EFT sandstones derive from terrestrial settings and are Quaternary in age. They have had much less time for a CRM to form and they seem to be dominated instead by a detrital fraction that could hold a primary remanence but may also have become remagnetised during lithification and associated diagenesis.

### 3.2.2. Biostratigraphy

The age estimations of the Quaternary deposits along the West Coast of South Africa have previously been based on the biostratigraphy of their associated fauna (Klein, 1972, 1983; Klein and Cruz-Urbe, 1991; Roberts and Brink, 2002; Klein et al., 2007). The absence of materials that are conducive to radiometric techniques has hindered more precise age estimates of these deposits. Recent geochronological investigations of Pleistocene deposits in the Western Cape have resulted in substantial changes in the age estimation of many of the well-known paleontological localities (Roberts et al., 2009). Based on biostratigraphy Klein et al. (2007) suggest that EFT must be younger than 1.0 Ma because of the presence of *Syncerus (Pelorovis) antiquus* which they suggest evolved from *P. oldowayensis* subsequent to the formation of Bed IV at Olduvai Gorge, which has been dated to >1.07 Ma (Tamrat and Thouveny, 1995). Klein et al. (2007) indicate that the site must be older than 0.6 Ma based on the presence of *Rabaticeras*, an acelaphine bovid that has a last appearance datum (LAD) in the Afar basin around 0.6 Ma. Although these species are highlighted as the most diagnostic taxa, other taxa have been recovered from EFT that do not conform to this age estimate (Table 2). The large felid

*Megantereon whitei* (dirk-toothed cat) as well as the short necked giraffe *Sivatherium* stand out as anomalies in this 1.0–0.6 Ma estimate. Neither of these taxa has been documented from deposits younger than 1.0 Ma elsewhere in Africa (Geraads, 1985). Nonetheless, these age estimates are somewhat tenuous, being based on occurrences in different environments, at localities far removed from EFT. A more detailed investigation, that takes into account the biostratigraphic details of the southern African sub-continent may be more pertinent and is now possible with the recent dating of many South African deposits (Herries et al., 2009, 2010, 2013; Herries and Adams, 2013). *Megantereon whitei* and *Sivatherium* both occur in South Africa between 1.6 and <1.4 Ma at Cooper's Cave D (de Ruiter et al., 2009). *Hippotragus gigas* occurs at sites older than 780 ka, such as Buffalo Cave (1.07–0.78 Ma; Herries et al., 2006), although *Hippotragus cf. gigas* has also been noted at Swartkrans Member 3 as late as sometime between 1.3 and 0.6 Ma (Herries and Adams, 2013).

Above we detailed stratigraphic evidence that suggests that surface fossils have been collected from both the Upper Pedogenic Sands as well as the Carbonate Quartz Sands units. Due to the difficulty in ascribing surface fossils to a specific stratigraphic unit, and the effects this might have in averaging the age of the deposits, our current age estimates are based only on those fauna that we have recovered *in situ* during our excavations or STPs. Here we will focus exclusively on fauna recovered from the 0209 excavation in the Upper Pedogenic Sands as this is the largest well documented excavation to date. The excavations and survey in bay 0209 were conducted between December 2009 to March 2011. The fauna recovered from the 0209 excavation document the co-occurrence of hominins, through their artifacts, along with several extinct taxa (see Fig. S4). A large suid, recovered from the excavation, is similar to specimens that have previously been described at *Kolpochoerus paiceae* (Klein et al., 2007). However, these specimens are dentally indistinguishable from *Kolpochoerus heseloni (limnetes)* (Bishop et al., 2006; Bishop, 2010). The size and shape of these specimens appear to be similar to those found in Bed III/IV of Olduvai Gorge, Tanzania (Bishop, 2010) at >1.07 Ma (Tamrat and Thouveny, 1995). Similar specimens have been recovered from the 1.07–0.99 Ma deposits from Cornelia-Uitzoek in the interior of South Africa (Brink et al., 2012). Excavations at the 0209 locality recovered a partial cranium of an extinct long horned buffalo, *Syncerus (Pelorovis) antiquus*. This species is ubiquitous throughout the African continent for much of the Pleistocene (Marean, 1992; Faith et al., 2012). It has also been recovered from deposits as old as 1.07–0.99 Ma, such as Cornelia-Uitzoek (Brink et al., 2012). Specimens attributed to the genus *Syncerus* (sp.) have also been described from 1.6 to <1.4 Ma old deposits at Cooper's Cave D and at Swartkrans Members 1–3 between 2 and 1 Ma in Gauteng (de Ruiter et al., 2009; Herries et al., 2009; Herries and Adams, 2013). Olduvai Bed IV may not represent a First Appearance Datum (FAD) for this taxon. We have also documented the presence of *Rabaticeras* in new excavations in association with stone artifacts (but not at the 0209 locality). *Rabaticeras* is last seen in South Africa at Gladysvale Cave between 0.780 and 0.578 Ma (Lacruz et al., 2002). Of particular note was the recovery of a single specimen of extinct short necked giraffe *Sivatherium* sp. from the 0209 locality. This documents the co-occurrence of this extinct species and trace fossils of hominins at EFT and suggests that the locality is either older than 1 Ma or that EFT represents the last regional appearance datum for this species.

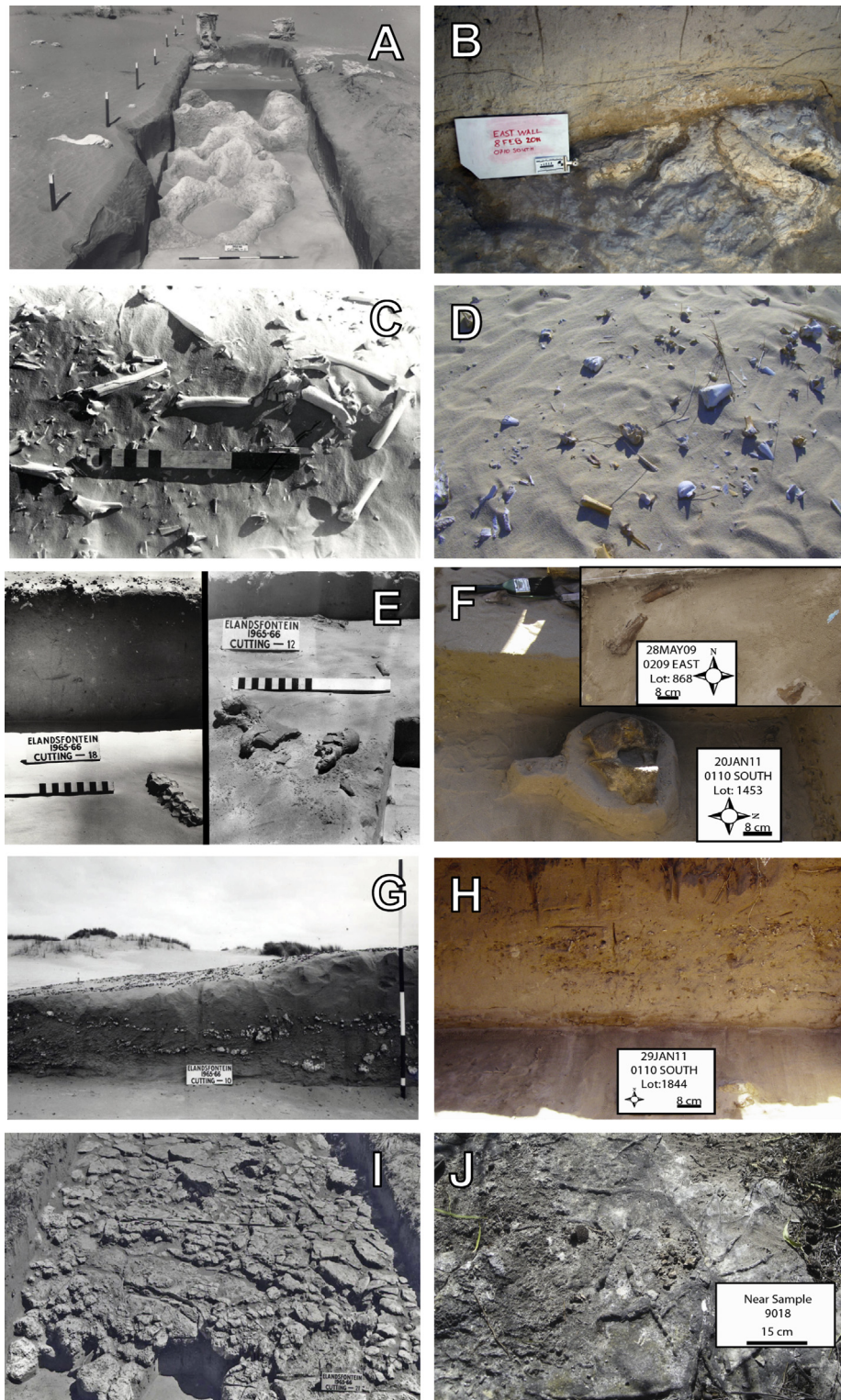
Age estimates from biostratigraphic markers provide the greatest amount of information for these Quaternary deposits yet they also suffer from complications associated with differential extinction of species throughout the African continent (Faith et al., 2012). It is necessary to support these age estimates with independent lines of evidence. Initial paleomagnetic results

**Table 2**  
Faunal remains recovered from 0209 Excavation.

Taxon	MNI <sup>b</sup>
Bovidae	
Alcelaphini	
<i>Alcelaphus</i> sp.	1
cf. <i>Connochaetes gnou</i>	1
Bovini	
<i>Syncerus antiquus</i>	3
Hippotragini	
<i>Hippotragus gigas</i>	1
Tragelaphini	
cf. <i>Tragelaphus</i> sp.	1
<i>Sivatherium</i> sp.	1
Giraffidae	
Suidae	
<i>Kolpochoerus heseloni</i>	3
Carnivora	
Viverridae	
	1
Equidae	
<i>Equus capensis</i>	3
Rhinocerotidae	
Elephantidae	
<i>Loxodonta atlantica</i>	1
Rodentia	
<i>Bathyergus</i> sp.	15
<i>Hystrix africaeustralis</i>	1
<i>Lepus</i> sp.	1
<i>Otomys</i> sp.	1
<i>Chersina angulata</i>	3
Chelonia	
<b>Total</b>	<b>48</b>
NISP <sup>a</sup>	661

<sup>a</sup> -NISP refers to Number of Identified Specimens.

<sup>b</sup> -MNI refers to Minimum Number of Individuals.



**Fig. 5.** Photos of characteristic geological features from the EFT dunefield. These photos pair features found during our more recent excavation with those recorded by [Singer and Wymer's excavations \(1968\)](#). A–B: Buried Calcareous Quartz Sand deposits exposed in excavations. We believe these excavations represent buried erosional surfaces as depicted in scenarios 1, 2, and 3 in [Fig. 4](#). C–D: These are deflated surface collections of artifacts and fossils found on the surface in the Elandsfontein dunefield. We believe these photos depict scenario 3 or 6 in [Fig. 4](#). E–F: These are photos of fossils recovered *in situ* from excavation in the Upper Pedogenic Sands horizon. We believe these photos depict scenarios 5 and 7 in [Fig. 4](#). Note that the inset photo of photo 5F is from the 0209 excavation. G–H: These photos represent the buried white nodular horizon that is found throughout the EFT dunefield. Note that despite the similarity of these two horizons they are found in areas of the dunefield that are approximately 900 m apart. We believe these photos depict scenarios 5 and 7 in [Fig. 4](#). I–J: Spring deposit surfaces found in excavation and at the modern surface. These deposits represent surficial carbonate formation that is likely the result of active springs in the past. We believe these photos depict scenario 4 from [Fig. 4](#).



**Table 3**  
Artifacts recovered from the 0209 Excavation.

Artifact type	Quartz	Silcrete	Quartzite	Hornfels	Quartz porphyry	Unknown	Totals
Whole Flakes	16	60	1	0	0	8	85
Retouched Flakes	0	5	2	0	0	0	7
Flake Fragments	402	470	3	1	3	7	886
Cores	12	25	1	0	1	1	40
Large Cutting Tools	0	2	0	0	0	0	2
Totals	430	562	7	1	4	16	1020

indicate that calcareous deposits along 'Calcrete Ridge' in the EFT dunefield recorded consistent stable reversed polarities that suggests deposition either between 0.99 and 0.78 Ma or prior to 1.07 Ma, the latter of which seems more likely given the fauna that has been recovered from the Upper Pedogenic sands are stratigraphically above the Calcareous Quartz Sands (Figs. 3 and 6). In contrast, sandstones within the dunefield record generally intermediate or normal polarity directions that could suggest that they were deposited in the Jaramillo SubChron between 1.07 and 0.99 Ma or a later chemical overprint within the Brunhes Chron. We interpret these results as documenting the presence of deposits that clearly predate the Brunhes–Matuyama boundary, suggesting the possibility that all archaeological materials from Elandsfontein may be older than 0.78 Ma.

### 3.3. The 0209 locality

This following section will focus on the results from the extensive survey and excavation that was completed at the 0209 locality. We focus our work on this particular locality because it is illustrative of the contextual details of the main artifact bearing horizon in the Upper Pedogenic Sands. We also make reference to excavations at the 0510 locality, but these are mostly for comparative purposes. Excavations at the 0209 site were initiated by the discovery of multiple artifacts and fossils on the surface and in STPs. Excavations began in an area where the upper part of the Upper Pedogenic Sands were well exposed as a resistant horizon that was 30–90 cm above a concentration of artifacts and fossils. This resistant horizon had been exposed by modern erosion in some areas (Fig. 4). Excavations were also initiated in this area because of the discovery of several vertebrae that were preserved in anatomical position, suggesting minimal post-depositional disturbance. This is a phenomenon that had been documented previously at EFT, and also at Duinefontein (Cruz-Urbe et al., 2003; Fig. 5).

Excavations continued in 1 × 1 m squares at 10 cm increments within stratigraphically defined levels. The final extent of the excavation was 79 m<sup>2</sup> with an average depth of 40 cm and greatest depth of 1.2 m. The excavation recovered a total of 1020 stone artifacts and 3117 fossil specimens (including microfaunal elements) (Tables 2 and 3). Although many of the fossil specimens recovered were not identifiable, 20% of the collection could be identified to family and/or element. The most abundant taxa, as characterized by minimum numbers of individuals (MNI), is the small mammal Cape dune mole rat (*Bathyergus*). The presence of at least 48 individuals of a variety of taxa (Table 2) suggests that this was a location where animals were frequently killed by predators (e.g., ambush point), or were brought there by an accumulating agent (e.g., hominins, hyenas). This is further supported by the high diversity of species identified in the 0209 excavation. While this list represents only a fraction of the diversity of species identified from the Elandsfontein Main (Klein et al., 2007) or Duinefontein 2 (Cruz-Urbe et al., 2003) collection, the relatively high number of specimens recovered in a restricted stratigraphic and geographic locality is notable; for comparison, the excavation of the Duinefontein 2 horizon is almost 6 times the size of the 0209 excavation. The fossils and artifacts

from 0209 were restricted to a relatively distinct horizon where out of the 166 fossil bearing units (1 m<sup>2</sup> within a stratigraphically defined level ≤ 10 cm thick), 68% were associated with the white nodular horizon. Artifact densities (average 12.9 artifacts/m<sup>2</sup>) are relatively low compared with many Paleolithic sites (e.g., Koobi Fora 2.5–288.5 artifacts/m<sup>2</sup>; Schick, 1986), yet the 0209 locality has one of the highest densities of artifacts/m<sup>2</sup> relative to other Middle Pleistocene sites known from the Cape Floral Region (e.g. Elandsfontein Cutting 10: 1.1 artifacts/m<sup>2</sup>; Duinefontein 2: 5.2 artifacts/m<sup>2</sup>; Cruz-Urbe et al., 2003; Singer and Wymer, 1968).

Stone artifacts recovered from the excavation include several different raw materials (Table 3). All aspects of the reduction sequence are represented in the assemblage. Based on preliminary geochemical data and the morphology of the cortex on the artifacts we believe these materials derive from outcrops of silcretes near the Berg River and cobbles of igneous rocks from the Vredenberg Peninsula (Braun et al., 2008a). The lozenge shape of some of the igneous cobbles suggests that these materials were collected from beach deposits near Saldanha Bay. Cobbles of similar lithology and morphology can be found in raised beaches near the present day town of Jakobsbaai on the western shore of the Vredenberg Peninsula. These sources are upwards of 40 km away from the excavations at EFT. The archaeological assemblage at the 0209 locality includes artifacts that are indicative of the Acheulean industry (i.e. Large Cutting Tools, biface retouch flakes) although the majority of the artifacts recovered are simple cores and flakes. Of particular interest was the high frequency of small shatter that was recovered from the sieve during the excavation (see 3.5.3 below; Fig. 3a).

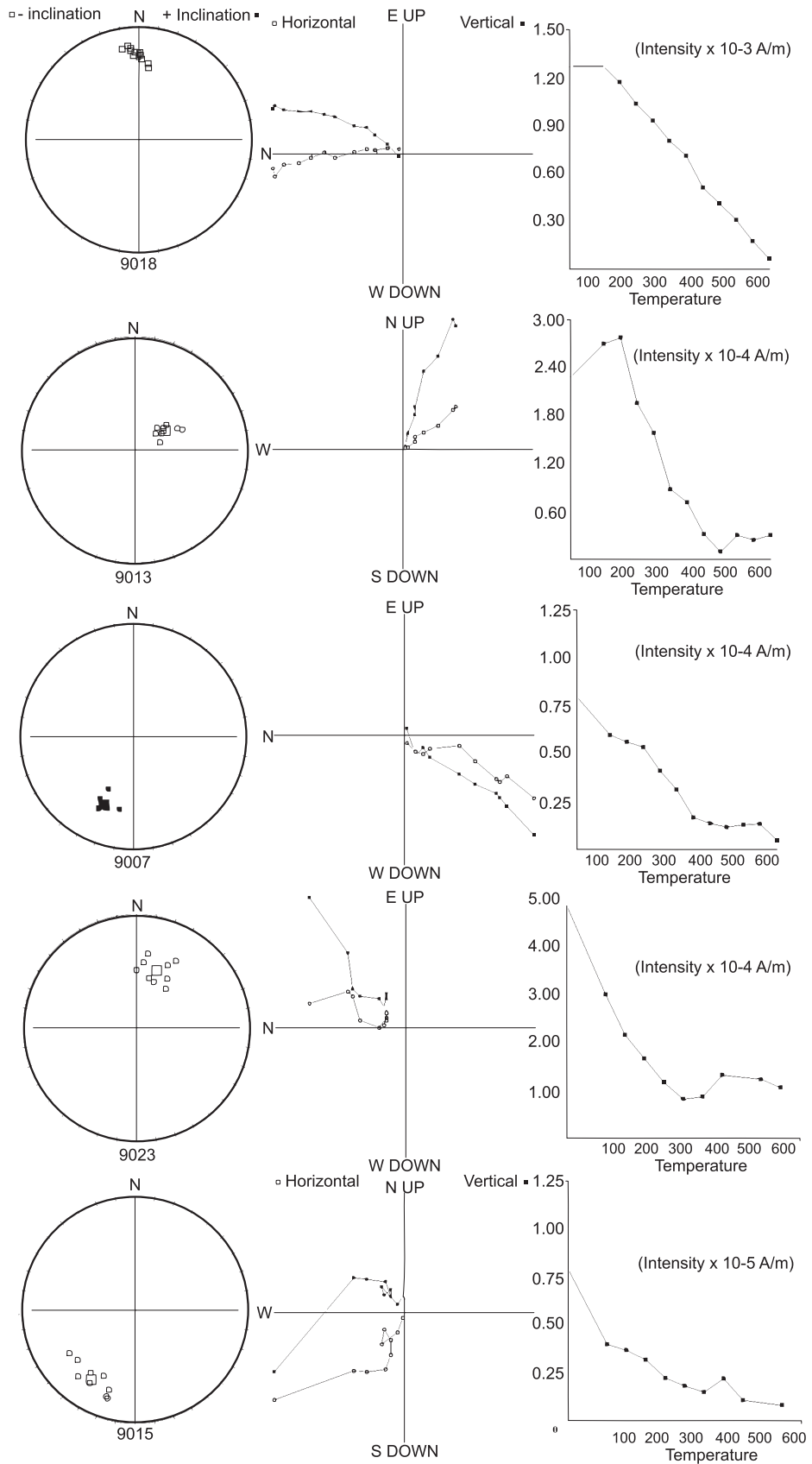
Faunal remains from the 0209 excavation contain many small bone fragments of long bones shafts (long bone shaft fragments = 22.8% NISP [number of identifiable specimens]) indicating minimal post-depositional disturbance. Some of these specimens record evidence of hominin butchery as well as damage caused by carnivore ravaging. A full taphonomic analysis of these specimens is currently underway but initial investigations already reveal higher frequencies of hominin induced damage than has been reported for surface collected material (Milo, 1994). The species identified from the excavation are usually associated with a variety of habitats with both grazers (*Alcelaphus*, *Syncerus*, *Equus*) and browsers (cf. *Tragelaphus*, *Diceros*) represented. Further in-depth investigations of the paleoecology of the Cape Floral Region, based on these excavated assemblages, are forthcoming.

### 3.4. Site integrity at 0209

Site integrity of the 0209 locality was investigated using three main proxies for post-depositional modification: 1) The orientation of elongated specimens; 2) The altimetric distribution of macromammal vs. micromammal specimens; 3) The size distribution of artifacts recovered from the excavation.

#### 3.4.1. Orientation and plunge

Orientation data could not be compared across all localities as at least 15–20 orientations are necessary to confidently identify a pattern in the bearing or plunge data. Although excavations



**Fig. 6.** Thermal demagnetization spectra (Equal-area projection, Orthogonal vector plot, Intensity) for samples of normal, intermediate and reversed polarity and illustrating a range of demagnetization behaviors and stability of remanence.

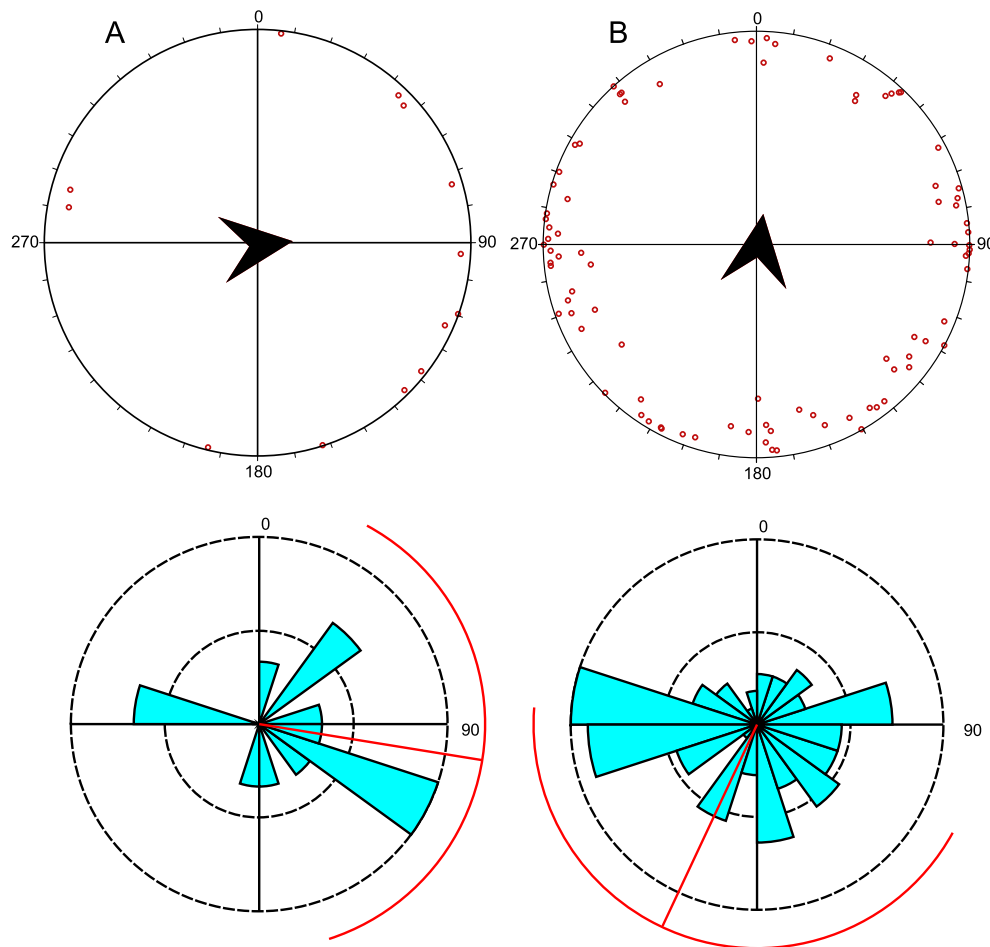
recovered several *in situ* specimens, the un lithified sand substrate made it difficult to recover specimens whose bearing or plunge had not been modified during the excavation process (McPherron, 2005). Excavations at 0209 and the “deflation experiment” recovered 18 and 95 orientations respectively (Fig. 7). Orientations from the 0209 excavation indicate that the distribution of orientations is not significantly different from a random distribution (Rao's  $U = 132.8$   $p = 0.398$ ) with a mean angle of orientation is  $99.21^\circ$ . The deflation exercise, however is significantly different from a random distribution (Rao's  $U = 159.9$ ;  $p = 0.003$ ) and has a mean angle of  $205.3^\circ$ . The appearance of the rose diagram suggests that this pattern is actually affected by a bimodal distribution that is oriented with an axis that is more aligned with an east-west orientation. Comparisons between the 0209 and “deflation experiment” data sets indicate that there are significant differences between the two data sets (Mardia-Watson-Wheeler  $W = 4.6$ ;  $p = 0.016$ ).

The previous tests were based on the assumption of an oriented assemblage whereby the orientation is investigated as if any of the  $360^\circ$  were possible orientations. However, when long bones are aligned with a wind direction, by deflation processes, it is possible for them to be oriented with a wind pattern such that a  $0^\circ$  orientation would be just as likely as a  $180^\circ$  orientation (when wind directions are due north-south). Davis (1986) has suggested that when geological processes have the impact of aligning specimens along a particular axis it is best to investigate circular statistics on a hemisphere (by doubling values on either side of a meridian). When we investigate the “deflation experiment” using this method

it is clear that this assemblage is significantly different from random (Rao's  $U = 163.3$ ;  $p = 0.001$ ) and the mean orientation is  $91.26/271.26^\circ$ . The data from 0209 is still not significantly different from a random distribution (Rao's  $U = 135.5$ ;  $p = 0.356$ ) with a mean orientation of  $104.65/284.65^\circ$ .

### 3.4.2. Altimetric distribution of Micro and macromammalian remains

Fig. 8 shows the distribution of macromammal and micro-mammal specimens through the altimetric section of 5 localities. We include data from Rick's (2002) “East Unit 2” and “CA-SMI-481 Unit 1” for comparison as Rick noted that the former represented the signature of a deflated assemblage while the latter records a locality with minimal impact of aeroturbation. The increase in larger specimens (macromammal bones) over smaller specimens (fish bones), at surfaces that have been deflated, is indicated at the very top of the section for “East Unit 2”. Similarly the apparent dominance of macromammalian bones relative to micromammals can be seen at the surface of our “deflation experiment” data. The same pattern is expressed in the data from the 0510 excavation. This locality represents a pattern where fossils have been deflated as a lag and then subsequently buried (Scenario 2 in Fig. 4). At 10 cm below surface macromammals increase dramatically while micromammals decrease dramatically. This apparent decoupling of the frequency of finds is not evident in the 0209 data. The frequency of macromammals parallels the frequency of micromammals throughout the altimetric section, with a peak at 30 cm below



**Fig. 7.** Schmidt hemisphere and rose diagrams for the 0209 site (A) and the “deflation experiments” (B) depicting the bearing and plunge data for elongated specimens from each locality. See text for statistical comparison of this data. Rose diagrams are based on the bearing for each local grid (i.e. site north) as opposed to magnetic north. Wind direction is depicted by the black arrow in the center of the Schmidt diagram.

surface, at the 0209 locality. This pattern is similar to that seen at the “CA-SMI-481, Unit 1” locality described by Rick (2002) and is indicative of an assemblage that has not been heavily affected by deflation or aeroturbation.

### 3.4.3. Artifact size distribution

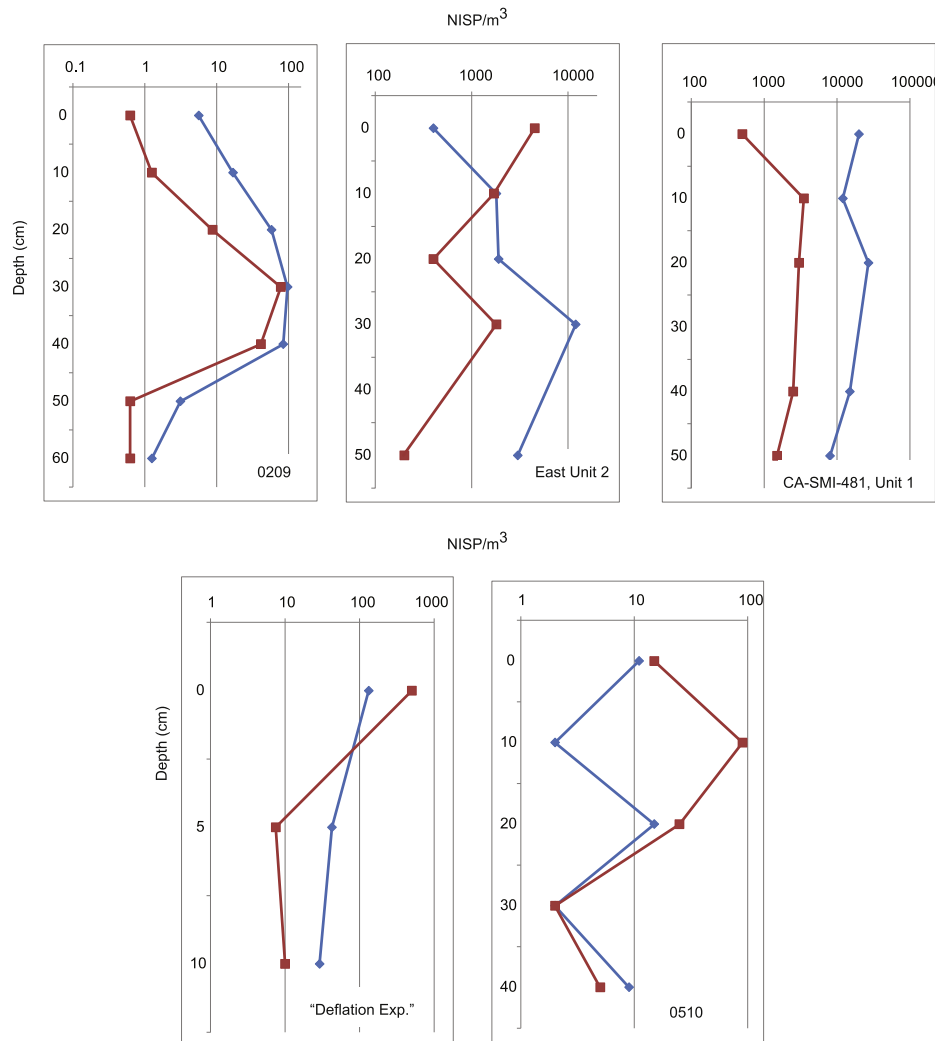
The vast majority of Paleolithic archaeological sites are recovered from depositional contexts where movement of water (in fluvial or lacustrine sedimentary regimes) results in the reorganization of archaeological materials (Schick, 1986; Nash and Petraglia, 1987; Schiffer, 1987). Frequently, this process results in the entrainment of the smaller fraction of stone artifacts. This leads to assemblages that are dominated by either larger (large flakes and cores) or smaller specimens (small chips and shatter). Schick (1986) noted that experimental assemblages that had undergone no post-depositional processes had a very high frequency of small chips and shatter. We compared the distribution of artifacts from the archaeological assemblage at 0209 with that from Schick’s 1A experiment (Schick, 1986). Results suggest that the distribution of artifacts within Schick’s artifact size classes for the 0209 assemblage is significantly different from experimental assemblages that have

been affected by winnowing (K–S Test of two samples;  $D = 0.607$ ;  $p < 0.001$ ; Fig. 9). Similarly, the 0209 assemblage is significantly different from the assemblage collected from the site of Fontechevade (Dibble et al., 2006) which is thought to have been affected by various post-depositional processes (K–S Test of two samples;  $D = 0.709$ ;  $p < 0.001$ ; this test only compares frequencies of specimens larger than 2 cm as Dibble et al. (2006) did not tabulate these smaller specimens. Interestingly, the frequency distribution of specimens for the 0209 excavation is significantly different from that described by Schick prior to any post-depositional winnowing (K–S Test of two samples;  $D = 0.420$ ;  $p < 0.001$ ). Fig. 9 indicates that this is the result of extremely high frequencies of the smallest size fraction (<1 cm) in the 0209 assemblage.

## 4. Discussion

### 4.1. Summary of the geology of Elandsfontein

Given the stratigraphic, sedimentological, archaeological, faunal, and paleomagnetic data presented in Section 3, we place the fossil and artifact occurrences at EFT into three groupings that we



**Fig. 8.** Altimetric distribution of larger and smaller finds through the excavated section at several different localities. Solid squares represent large mammal remains and diamonds represent fish bones at the sites of East Unit 2 and CA-SMI-481, Unit 1 from excavations by Rick (2002) on the Channel Islands of the coast of California. Solid squares represent macromammal remains and diamonds represent micromammal remains at the sites of 0209, 0510 and the “deflation experiment”. Note that the scale of the number of finds is based on NISP per cubic meter and represents a logarithmic scale. In deflated horizons large specimens (macromammals) increase while smaller specimens decrease (fish or micromammals). This pattern is not exhibited in the 0209 locality or the CA-SMI-481, Unit 1 locality.



describe below and characterize graphically in Fig. 4. Fig. 4 provides a schematic representation of the different settings in which fossils and artifacts are found at EFT. These descriptions compliment the broad scale geological description of the EFT region which is described in Roberts et al. (2011).

#### 4.1.1. Artifact and fossil horizon in the Upper Pedogenic Sands

We document a horizon that contains behaviorally associated, *in situ* artifacts and fossils within the white nodular horizon of the Upper Pedogenic Sands that is distributed over a 12 km<sup>2</sup> area. In some places this unit is overlain by ferruginous nodules and sand that does not contain any fossils or artifacts (e.g., Bays 0609, 0209, 0110; Fig. 4 Scenarios 5–7), whereas in other areas this ferruginous nodular horizon is absent (e.g., Bays 0909, 0112, 0211; Fig. 4, Scenario 1). The artifacts and fossils in this unconsolidated unit lie stratigraphically above the calcareous quartz sands as we have documented in several sections in Bays 0609 and 0710 (e.g., Scenarios 1 and 5 in Fig. 4). However, in some cases, only non-calcareous, white to gray, very fine quartz sands are observable >2 m below the fossil and artifact horizon (e.g., 0209 in Fig. 3a; Fig. 4 Scenario 7). Biochronological analyses place the fossil and artifact assemblages between 1.6 Ma and 0.578 Ma based on correlations with other South African sites. Overlying silica rich deposits, which cap the Upper Pedogenic Sands, record intermediate and normal polarity directions. However, this does not prove conclusively that the fossil and artifact rich sediments were deposited in the Brunhes Chron (after 0.78 Ma) as remanence may have formed much later than fossil deposition. The occurrence of a single reversed polarity sample is intriguing as it may suggest that the Upper Pedogenic Sands unit may be older than 0.78 Ma.

#### 4.1.2. Calcareous sands and carbonates

The calcareous quartz sands at EFT contain vertebrate and invertebrate fossils that are stratigraphically below and distinct from the artifact and fossil horizon in the Upper Pedogenic Sands (Fig. 4 Scenario A and E). The preliminary palaeomagnetic data indicate that this unit has reversed polarities and is thus older than 0.78 Ma, but based on the biostratigraphy of overlying horizons perhaps more likely >1.07 Ma. The occurrence of potential normal polarity deposits in the calcareous sands may indicate multiple formation events. Based on biochronological assessment of the age of the Upper Pedogenic Sands (~1.4–0.6 Ma), such normal polarity directions in the calcareous sands which underly the Upper Pedogenic Sands may relate to the beginning of the Brunhes Chron at <0.78 Ma. This perhaps indicates that some of the calcrete layers

formed at the same time as the normal polarity Upper Pedogenic Sands. Alternatively these normal polarities may be older and represent the Jaramillo Sub-Chron between 1.07 and 0.99 Ma. A magnetostratigraphic interpretation and complete age profile for the EFT deposit based on this data is still preliminary, however, these data illustrate the potential for recovering chronologically relevant data from mid-late Quaternary calcretes, silcretes and ferricretes. The fossils recovered from the calcareous sands do not provide any biostratigraphic information that helps us to further constrain the age. Our observations indicate that the vertebrate fossils in this unit usually occur as single specimens and thus are distinct from the concentrations, as well as specimens found in anatomical position, found in the Upper Pedogenic Sands. The fossils found in the calcareous sands are not associated with distinctive lithologic or stratigraphic features within the calcareous quartz sand. We have not observed any artifacts from this horizon.

#### 4.1.3. Lag and surface deposits

There are multiple variants of artifact and fossil occurrences that can be found in secondary depositional contexts at EFT. Some of these occur as the fossils, artifacts and nodules from the unconsolidated Upper Pedogenic Sands are deflated and collect on the surface of the more resistant, underlying Calcareous Quartz Sands (Fig. 4 Scenarios 2 and 6). Other varieties can include the conflation of fossils from both the Upper Pedogenic Sands and lower Calcareous Quartz Sands onto a single surface (Fig. 4, Scenario 3 and 4). Any of these scenarios may occur at the surface or as buried lag deposits (Fig. 5C–D).

#### 4.2. Synthesis of new data at Elandsfontein with previous studies

Our observations of the main lithologic units at EFT generally agree with those reported in previous studies (Mabbutt, 1956; Needham, 1962; Singer and Wymer, 1968; Butzer, 1973; Deacon, 1998; Klein et al., 2007). The new data that we present here provides additional descriptions of these units and clarification on their stratigraphic relationships, spatial distributions, and age. We use these data to clarify the context of the fossils and artifacts found at EFT that have been the focus of both previous and current studies. Mabbutt (1956) provided the first, comprehensive description of the sediments at EFT and most of his observations are reiterated by subsequent studies, with some modification (Singer and Wymer, 1968; Butzer, 1973; Deacon, 1998; Klein et al., 2007). Here we briefly review each lithologic unit in the context of previous observations. We do this so it is possible to put the previous observations from EFT into the context of what we report here.

#### 4.2.1. Upper Pedogenic Sands

Previous studies characterized this unit by documenting changes in color and the frequency of different types of nodules. These features were highlighted because there is vertical uniformity in grain composition and a lack of bedding features. The 'silver grey sands' that Mabbutt (1956) observed below the nodular horizon are equivalent to the white sands that we observe at depths >1 m below the nodule and fossil rich horizon (see Fig. 3, Bays 0209, 0610, 0110; Table S1). The calcareous nodules, sands and concretions observed by Mabbutt (1956), Singer and Wymer (1968), Butzer (1973); and Deacon (1998) and subsequently described by Klein et al. (2007) are equivalent to the white nodular horizon that we have described here. Lastly, the ferruginous sands and nodules that previous workers have observed stratigraphically above the white nodular horizon, are corroborated by our observations.

One main difference in our descriptions, relative to the existing literature, is that previous publications invariably refer to the white nodular horizon as calcareous: calcareous crust, nodules,

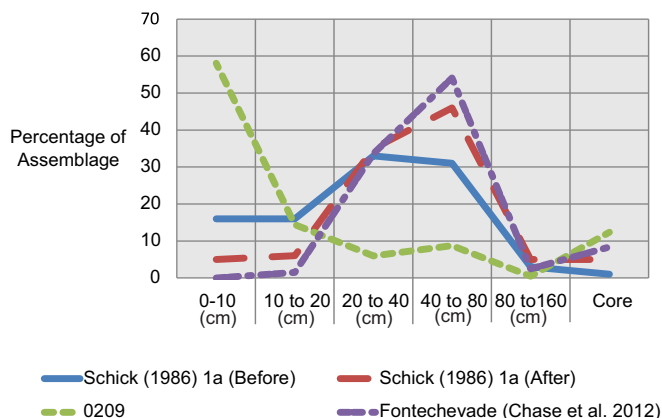


Fig. 9. Distribution of artifacts in different size classes (based on maximum length measurements) using categories defined by Schick (1986). Data is derived from Schick (1986); the excavations at the 0209 locality; as well as the database provided by Chase et al. (2009).

concretions or sands (Mabbutt, 1956; Singer and Wymer, 1968; Deacon, 1998; Klein et al., 2007). Although both Mabbutt (1956) and Butzer (1973) recognize that there is less carbonate in these nodules than in the calcareous sands and surface carbonate that comprise the 'Calcrete Ridge', we avoid using the term 'calcareous' in describing this unit because the nodules contain minimal carbonate. Our observations (field acid tests, petrography) of both surface and sub-surface expressions of these nodules and concretions indicate that they are predominantly silica cemented sand, with minor to no carbonate content. Without an acid test, the morphology and color of these nodules would suggest that they are indeed carbonate as they look very much like soil or groundwater carbonates; it is possible that they were initially deposited as carbonate but have subsequently been leached. A detailed study of the nature of this cemented sand and how it varies across the dune field is needed to fully understand the implications for site formation.

Singer and Wymer (1968) have provided the most thorough investigation of the context of fossils at EFT. They observed artifacts and fossils in the same settings that we have found: *in situ* and associated with the white nodular horizon that underlies a ferricrete nodular horizon. Singer and Wymer (1968) show that the fossils and artifacts were restricted to the white nodular horizon and that the sands above and below this horizon were sterile, which is consistent with our observations. This is evident in photos taken by Singer (Fig. 5E, G) and it is exemplified in "Cutting 10" described by Singer and Wymer (1968). The combination of previous observations, and those that we present here, document that this fossil and artifact horizon is a common feature throughout the dunefield. Klein et al. (2007) base their observations on surface collections, and they associate the EFTM fossil assemblages with the white nodular horizon. This is the unit from which both Singer and Wymer (1968) and this study have recovered *in situ* fossils and artifacts. We place the Upper Pedogenic Sands from EFT at top of the Sandveld Group (Roberts, 2006b).

The ferricrete ridges have been interpreted as inverted topographic expressions of ancient river beds (Butzer, 1973) and as oxidized remnants of dune trailing arms (Mabbutt, 1956). The uniformity of grain size, sorting, shape and lithology of these sands relative to the surrounding sands and the lack of bedding in these units, make a fluvial origin of these sands unlikely. It is also difficult to see how they represent remnant dunes as they cross-cut the 'Calcrete Ridge' which is itself likely part of a lithified paleodune system. Our working hypothesis is that these linear zones of ferricrete formed in a response to fluid flow along fractures in lithified eolianite. Possible sources of iron are the iron sulphides, which occur in the underlying Miocene peaty material of the Elandsfontein Formation (Cole and Roberts, 1996). Others have noted the similarity of the ridges at EFT to those at Bok Bai (Mabbutt, 1956; Butzer, 2004). A comparative study of the ridges at EFT to similar ones observed elsewhere would be an important component to any thorough study into the origin of the ferricrete ridges.

#### 4.2.2. Langebaan Formation

The Calcareous Quartz Sands described in Section 3.1.2 fits the description of what Mabbutt (1956) called Calcareous Sands and referenced as the Dorcasia Limestone, which was initially identified by du Toit (1917). This is also the unit that Tankard (1976) identified as the Langebaan Roberts (2006a) identified as the Langebaan Formation characterized by 'calcified bioclastic-siliclastics arenites of eolian origin, with interbedded calcretes'. The presence of the *Trigonephrus globulus* is noted in most descriptions of this unit (Mabbutt, 1956; Singer and Wymer, 1968; Butzer, 1973; Tankard, 1976; Roberts, 2006a,b). The absence of bedding in most exposures is consistent with pedogenesis, which follows patterns described at other Pleistocene dune deposits in the region (Roberts

et al., 2009). Mammalian fossils have been recognized in this unit by others, including Singer and Wymer (1968), but there was no indication of a highly fossiliferous horizon at this level. No artifacts have been recovered from this unit (Singer and Wymer, 1968).

Surface carbonate, banded micrite, and biogenic features associated with the Langebaan Formation likely postdate the initial deposition of the calcareous sands. Mabbutt (1956) suggest that the 'Ragged Calcretes' adjacent to and on the 'Calcrete Ridge' grade into the artifact horizon and that carbonate sands on the 'Calcrete Ridge' are lateral equivalents of the fossil- and artifact-rich nodule horizon but this is not supported by our observations. These features have not been discussed at length in other studies of EFT, but Mabbutt (1956) and Butzer (1973) recognized the complicated nature of the carbonate deposits on the 'Calcrete Ridge', which include the calcareous sands, banded micrite, solution features, pedestals, and buried detached surface blocks. Butzer (1973) argues that the linear nature of the ridge might be an erosional feature that has experienced dissolution, recalcification, and pedogenesis since initial deposition. He indicated that these events modified its surface expression and orientation. This is in contrast to other interpretations that the north-south orientation of the 'Calcrete Ridge' represents the orientation of an ancient dune (Mabbutt, 1956; Roberts et al., 2009). Our current study does not speak to the origin of the orientation of the ridge but our observations do provide additional indications that this was a zone of active dissolution and reprecipitation of carbonate. If it does represent a remnant of a paleo-dunefield then its inland position, relative to other nearby dunefields, may be an indication that sea level may have been higher at the time of its emplacement. A higher water table associated with rising sea level might explain the apparent abundance of water at Elandsfontein as indicated by spring carbonates and the presence of fauna that indicate standing bodies of water.

Regardless of the specific origin of the 'Calcrete Ridge', it was a topographic high during the deposition of the Upper Pedogenic Sands. It is also possible that the processes responsible for the formation of the surface carbonate features (Fig. 4F–J) on the 'Calcrete Ridge' were active before, during and after the deposition of the Upper Pedogenic Sands.

#### 4.2.3. Context of finds: *in situ* vs. deflated horizons

Our examination of these sediments indicates that it is possible to distinguish unaltered, *in situ* deposition of artifacts and fossils from conflated lag deposits. However, the identification of at least 2 fossiliferous horizons makes it difficult to place previous (or any) surface fossil collections into a firm stratigraphic context. We are confident that the Cutting 10 finds reported by Singer and Wymer (1968) come from the same white nodular unit as we have described here and that we associate with the major fossils and artifact bearing unit. However, given the surface nature of other finds from EFT, such as the EFTM or the Bone Circle assemblages (Inskeep and Hendey, 1966; Klein and Cruz-Urbe, 1991; Klein et al., 2007), we cannot place these fossils into the stratigraphic scheme that we present in Figs. 3 and 4 and we cannot eliminate the possibility that these assemblages are mixtures of materials from multiple stratigraphic horizons (see Scenarios 1 and 5 in Fig. 4). These collections may reflect collector biases and the density mediated destructive forces of eolian environments (Conard et al., 2008). Our preliminary data show that there are at least two stratigraphically distinct fossiliferous horizons (Figs. 3 and 4).

Our studies of the artifacts and fossils recovered from the Upper Pedogenic Sands indicate that they do not represent buried deflation horizons. The lack of artifact orientation (Fig. 7) as well as the parallel concentrations of macromammal and micromammal fossil specimens (Fig. 8) indicates that the concentrations of artifacts and

fossils have not undergone deflationary processes. Deflation does occur in the dunefield, as we have documented at localities, like in Bay 0510, which represent buried lag deposits. In addition to the data described here, we note the presence of numerous faunal elements that have been recovered in anatomical position. According to the results of the Kandel et al. (2003) GOME experiments, these elements could not have been affected by any significant deflationary processes and still have maintained these spatial relationships. The average distance that elements traveled after 1 year of deflationary processes in the GOME study was 1 m. Thus any elements that are still in anatomical position are unlikely to have been subject to these types of processes. Similar instances of faunal elements recovered in sealed deposits in anatomical position were documented by Singer and Wymer (1968) throughout the EFT dunefield (Fig. 5E).

The sum of this site formation data suggests that artifact and faunal assemblages throughout the EFT dunefield can be found in sealed deposits. These deposits represent instances of hominin behavior that do not reflect very long periods of exposure considering the excellent preservation of the fossils. The high density of artifacts as well as the presence of very high frequencies of small artifacts (even greater than those documented from experimental assemblages; Fig. 9) suggest that hominins were actively using and reshaping tools at these localities.

#### 4.3. Elandsfontein in the context of regional environmental change

Our large scale excavation, stratigraphic, and mapping efforts enable us to place the sediments at EFT into a regional context including eolian deposition, pedogenesis, and groundwater activity. We divide the sequence of events at EFT into those related to deposition of the Calcareous Quartz Sands, modification of these sands, and the eolian activity and pedogenic intervals associated with the artifact and fossil horizon in the Upper Pedogenic Sands. Based on the data we present here, we view the Pleistocene strata forming in the following way.

Deposition of the Langebaan Fm. calcareous sands with carbonate bioclast sand quartz grains, *Trigonephrus globulus*, and the occasional fossil mammal bone, likely represents eolian deposition of reworked beach sands that are distributed extensively along the western coast of South Africa (Roberts et al., 2009). The extensive dissolution, reprecipitation, and biogenic features on the surface of this unit, and occasionally within it, suggest intervals of an elevated water table and in some cases spring activity, during cessations in eolian deposition. Although we can not yet constrain the surface carbonate features to a specific time sequence, it is likely that surface carbonate precipitates represent multiple events of spring activity associated with an elevated water table throughout the Pleistocene. Springs are common in the region today and it is not unreasonable to consider greater near-surface groundwater and spring activity during sea-level high stands during the Pleistocene. Such a sea level high stand has been documented along the southern Cape coast at 19–20 m above present sea level just prior to 1.11 Ma. (Pickering et al., 2013), a time consistent with biostratigraphic dates for EFT. Similar, but undated 18–20 m sea level high stands also occur along the West Coast of South Africa and as far north as Port Nolloth (Roberts et al., 2009; Roberts et al. 2012; Herries pers. obs.)

The concentrations of artifacts and fossils recovered in the Upper Pedogenic Sands at EFT, stratigraphically above the Langebaan Fm., are tied to the genesis and maturation of soils within the Strandveld region of the west coast of South Africa. This phase of eolian activity, artifact deposition, and pedogenesis at EFT postdated deposition of the Langebaan Fm. calcareous sands. However, we do not yet know the timing of the surface carbonate precipitates

relative to the timing of the fossil and artifact deposition. Some of the surface carbonate could have been contemporaneous to or younger than the artifacts if elevated groundwaters and spring activity were repeated throughout the Pleistocene.

Leached, iron-rich soils have been recognized at other archaeological sites, such as Geelbeck (Felix-Henningsen et al., 2003) and are likely represented in some form at Duinefontein (Cruz-Uribe et al., 2003). These can be deeply stratified soils with variable levels of carbonate, iron oxides or silica (e.g., Netterberg, 1969; Felix-Henningsen et al., 2003). This pedogenesis represents periodic cessation of dune activity and the subsequent demobilization of dune sands due to stabilization by vegetation.

These processes were likely active in the EFT region during and soon after deposition of the fossil and artifacts in the nodular horizon. Carbonate and iron oxides may have been precipitated soon after deposition and then remobilized during later phases of pedogenesis or groundwater flow. The polygenetic nature of these soils suggests that it is not possible to associate any single pedogenic event with the fossil and artifact horizon. It is likely these pedogenic horizons reflect multiple overprinted events of soil formation and subsequent burial by eolian processes. This may also have affected the palaeomagnetic signature of such deposits. However, the excellent preservation of the fossils and artifacts in the white nodular horizon indicates that they were buried quickly and pedogenesis began shortly after deposition. Notably, if the white nodular horizon were initially deposited as carbonate (which would have been an excellent initial mechanism for bone fossilization), there would have been subsequent leaching events of this carbonate and precipitation of silica. This would account for the low carbonate content of the nodules and the silica cement of nodules in this horizon. This carbonate leaching is consistent with the low carbonate concentrations in teeth documented by Luyt et al. (2000). The nodular horizon that is consistently associated with the artifact and fossil bearing horizon may represent an interval of pedogenesis with initial carbonate deposition that was responsible for initial fossilization and subsequent leaching (Butzer, 1973; Felix-Henningsen et al., 2003; Fuchs et al., 2008). Similar patterns of intercalated levels of sands associated with variable carbonate and iron oxide rich pedogenic horizons have also been recognized at Duinefontein (Roberts, 1996; Cruz-Uribe et al., 2003).

#### 5. Implications for future research at Elandsfontein and surrounds

Recent research on human origins suggests that the ability to use cultural constructs to create internal stores of information is an ability that is unique to the human lineage. It is likely this ability that allowed for rapid adaptation to a variety of habitats (Boyd and Richerson, 1993; Hill et al., 2009; Potts, 2012a). Testing this model will require in-depth understanding of hominin behavior in numerous diverse habitats. Here we have reviewed our recent excavation and field geological research at the Pleistocene locality of EFT. Our data suggest that the Pleistocene strata at EFT have the potential to provide a record of human habitation, on a landscape scale, in an otherwise poorly understood ecological setting. The high microhabitat diversity of this biome is unprecedented elsewhere in Africa (Cowling and Lombard, 2002; Proches et al., 2006). The ability to understand the history of hominin adaptation in the Cape Floral Kingdom will be an integral part of understanding the evolution of hominin behavioral variability (Marean, 2010). The antiquity of this biome and its faunal associations are currently poorly understood (Kaiser and Franz-Odenaal, 2004; Klein et al., 2007; Stynder, 2009). EFT provides one of the few localities where the regional and local scale variation in this environment can be studied. Hominins clearly made and used stone artifacts at different



places on this landscape. The lack of sources of stone suggests that stone was transported to EFT and then flaked on site. It will be critical to understand how the frequency of these behaviors occurred in these highly variable environments, particularly because records of hominin behavior in southern Africa prior to the Last Interglacial are virtually absent.

Our archaeological and geological data suggest that it is possible to investigate the relationship between hominin behavior and several proxies of ancient environments (e.g., ecomorphology of faunal specimens; isotopic analysis of dental enamel and surface carbonates; mesowear of ungulate remains) over various spatial scales ( $10^2$ – $10^3$  m<sup>2</sup>). The data from EFT have the potential to provide inferences of the spatial diversity in hominin behaviors that are unknown outside East Africa (e.g., Rogers et al., 1994; Potts et al., 1999; Braun et al., 2008b; Stout et al., 2010; Blumenschine et al., 2012). These data also have the potential to elucidate the paleoecological impact of glacial/interglacial cycles on the winter rainfall system of southern Africa (WRZ). The frequently made assertion that the climate in Africa becomes drier during glacial periods is not corroborated by Quaternary sequences on the West Coast of South Africa (Carr et al., 2006; Chase and Meadows, 2007; Blome et al., 2012). The relative size of mammals at EFT compared to other Pleistocene localities has been interpreted by some as representing an interglacial period (Klein et al., 2007). However, the current arid conditions surrounding EFT could not have supported the diversity of grazers found in the EFT collection (Stynder, 2009). Current models of the change in rainfall regimes within southern Africa in the past may only extend into the Late Pleistocene. Changes in the dynamics of climate, topography and ecosystem dynamics of the Middle Pleistocene may have resulted in an environment that is unique and not easily compared with modern systems.

We have documented here that the spatial extent of the Quaternary deposits at EFT, as well as the relatively well protected nature of some sedimentary archives of past environments, are currently unparalleled in southern Africa. Although absolute contemporaneity across the entire research area is unlikely, the consistency with which certain pedogenic and stratigraphic markers exist suggests relatively similar ecological conditions during the formation of these horizons. Although smaller scale temporal variation almost certainly existed, we believe that general patterns of hominin behavior relative to environmental variance are decipherable from the records at EFT. In particular, major ecogeographic features, such as raw material locations (Gamble, 1986; Blumenschine and Peters, 1998), are likely to have remained constant. The time averaged nature of the deposits allows for the accumulation of paleoecological and hominin behavioral signals that are large enough to test associations between these variables (Blumenschine et al., 2008). The large spatial scale of our excavations and the ability to tie meso-scale geographic features to ancient habitats will provide a robust reconstruction of the environments of human adaptation at a critical period prior to the appearance of modern humans.

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### Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.quascirev.2013.09.027>.

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