# Site-formation processes at Elands Bay Cave, South Africa

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#### ABSTRACT

Elands Bay Cave is a small coastal rock shelter formed in quartzite that contained up to ca. 3 m of anthropogenic and geogenic deposits with archaeological materials dating to the Middle Stone Age through Later Stone Age. Today, only the lower portion of the sedimentary sequence, comprising ca. 1.2 m of sediment remains. A geoarchaeological study of the remaining deposits was undertaken in conjunction with renewed excavations of the site (2010-2012). A ground penetrating radar survey revealed that the excavation area targeted the deepest portion of the sedimentary infill within the rock shelter. Furthermore, micromorphological analyses of the remaining Middle and Later Stone Age deposits indicate that combustion features are present. Fourier transform infrared spectroscopy and x-ray diffraction measurements were used to identify secondary minerals, including taranakite, hydroxylapatite, gypsum, variscite, ardealite, opal, and whitlockite. The distributions of these secondary minerals-present mainly as microcrystalline nodules-track zones of moisture within the sediment, as well as areas where calcium carbonate (e.g. ashes, shell) and bones are not preserved. In addition to the chemical dissolution of several components of the archaeological assemblage, secondary processes impacting the Elands Bay Cave deposits include bioturbation and mechanical fragmentation of rocks and charcoal. Despite the effects of post-depositional alteration, our study indicates a good degree of localized preservation of the stratigraphic units.

KEY WORDS: micromorphology, site formation processes, diagenesis, FTIR, XRD, SEM-EDS, ground penetrating radar, organic petrology, rock shelter, cave, combustion features, environmental archaeology, Middle Stone Age.

Elands Bay Cave is a widely cited case study used to introduce students to the fundamental concepts of environmental archaeology. Highlighted in first-year texts such as Renfrew and Bahn (2008), the site provides a compelling story that links Later Stone Age human habitation of the cave and exploitation of local marine resources with paleoenvironmental proxy data. Less well-known, but still significant to the

southern African archaeological community are the Middle and earlier Later Stone Age deposits within the site, which in combination with the Later Stone Age midden, provided Parkington and colleagues a medium for the development of a unique method of stratigraphic nomenclature that facilitates lithostratigraphic analysis and today is employed throughout the Western Cape (e.g. Porraz et al. 2013). For geoarchaeologists, the site is additionally significant due to the presence of deposits that range from merely rich in anthropogenic sediment to the midden that is composed almost entirely of material of human origin. The site thus provides a laboratory for the study of anthropogenic deposits, as well as the post-depositional processes unique to siliceous bedrock settings that impact their preservation.

The geoarchaeological study described here expands upon previous stratigraphic and sedimentological studies conducted at the site (e.g. Butzer 1979), and aims to reconstruct the formation processes that operated at a site scale, including human and non-human depositional mechanisms. We employ a combination of high-resolution analytical methods including micromorphology, microspectroscopy, organic petrology and elemental compositional analyses of present-day moisture inputs to the site in order to: 1) make micro-scale observations of mm- to cm-scale stratigraphic units and features defined on the basis of sediment composition, fabric and structure; and 2) to document the mineralogical traces of post-depositional chemical diagenesis. The results of these analyses are integrated with site-scale observations of cm- to dmscale stratigraphic units and lateral variation therein with the aim of reconstructing a probable sequence of deposition and stasis—intimately related to human occupation of the site—and the post-depositional chemical and physical processes that contribute to the distribution of archaeological materials and features observed today.

## SITE LOCATION, GEOGRAPHY AND GEOLOGY

Elands Bay Cave (alt. Elandsbaai) is located at the northern extent of St Helena's Bay at Cape Deseada on the west coast of South Africa, approximately 180 km north of Cape Town (Fig. 1). The site, along with other important localities such as Diepkloof Rock shelter and Kraal (Parkington & Poggenpoel 1987; Porraz et al. 2013), Tortoise Cave (Robey 1987) and Dunefield Midden (Parkington et al. 1992), forms part of a Middle and Later Stone Age archaeological landscape centred around the Verlorenvlei (Parkington 1981)-a rich, wetland ecosystem that provides a wealth of resources in a mostly semi-arid coastal landscape (Baxter 1997). The Verlorenvlei consists of a river, a marsh and a large, semi-estuarine coastal lake or vlei that is 13.5 km long, 1.4 km wide at its widest point, and covers an area of 10 km<sup>2</sup> (Baxter 1997). The Verlorenvlei River catchment, covering ca. 1890 km<sup>2</sup> (Noble & Hemens 1978), begins 40 km to the west, fed by tributaries that drain the Piketberg, Olifants River, Swartberg and Mannberg mountain ranges. The river follows a northwest/southwest structural trend across the sandy coastal plain until the town of Redelinghuys, where the marshy, meandering landscape becomes constricted by a narrow valley that extends westward to Grootdrift. Here the river transitions into a marsh which opens up at Diepkloof, marking the beginning of the open-water vlei. The coastal lake continues until Verlorenvlei Farm, where the lake becomes marshy again. Here the Verlorenvlei narrows to a single channel, which trends south until crossing a narrow rock ridge and terminating at a sand bar at the beach of Elands Bay (Baxter 1997).



Fig. 1. Maps showing location of Elands Bay Cave and other localities mentioned in text. Adapted from Baxter (1997) and Sinclair et al. (1986).

South of Elands Bay the coast follows a steep sandstone cliff that rises locally to 160 m above modern sea level and trends south-southeast for ca. 6 km until merging with the coastal plain (Miller 1987). In front of this cliff line is a sandy beach with an extensive dune system reaching up to 16 m in height. North of Elands Bay, the coast is less rocky and consists of an undulating, hilly coastal plain that rises about 20–30 m above modern sea level and is dominated by an active dune field that locally exceeds elevations of 90 m.

The landscape surrounding the Verlorenvlei is commonly called the Sandveld and is part of the larger Cape Floristic Region. The juxtaposition of cold, upwelling Atlantic waters, the arid coast, and a source of fresh water provides a unique combination of vegetation types, including West Coast Strandveld, Lowland Sand Plain Fynbos, Karroid Shrubland, Dry Mountain Fynbos, and Marsh Vegetation (Sinclair et al. 1986; Baxter 1997). Despite the obvious source of fresh water, the area surrounding Elands Bay Cave is semi-arid and meets the criteria for classification as a Mediterraneantype climate (Baxter 1997). The Verlorenvlei area falls within the winter rainfall zone so that precipitation, which averages ca. 270 mm/year (Robertson 1980), is highly seasonal, with nearly 80 % of rain accumulating from April to September (Sinclair et al. 1986). Temperature data from Cape Columbine, the nearest weather station, record average July minimums at 10°C and the February maximum as 21.1°C, with an annual temperature amplitude of 4.3°C and daily temperature amplitude of 6.9°C (Butzer 1979). Maximum temperature inland from Elands Bay can reach over 40°C in the summer, and Baxter (1997) reports personal anecdotes of night-time frost in interior valleys during the winter; however, the temperature fluctuations at Elands Bay are modulated by the sea. Advective fog is common along the coast, particularly in the spring and autumn, providing a much needed source of moisture for coastal vegetation. Despite these coastal effects, the hot, dry summers lead to high evaporation, recorded

at Lambert's Bay to the north of Elands Bay as 1400 mm, or seven times the annual rainfall (Robertson 1980).

The late Precambrian Malmesbury Formation and the Siluro-Devonian Table Mountain Group make up the bedrock of the area, with the latter comprising ca. 30 % of the surficial geology in the area (Baxter 1997). The Table Mountain Group within the Verlorenvlei drainage is composed of weakly-metamorphosed, red-coloured, medium- to coarse-grained sandstones, cross-bedded, fine-grained, shaley sandstones, and conglomerates. The fluvial conglomerates comprise the Piekenierskloof Formation, which is overlain by the estuarine shaley sandstones, which comprise the Graafwater Formation (Visser & Toerien 1971; Theron 1983). The Table Mountain Group bedrock forms minor escarpments, kopjes (buttes), and ridges that follow the regional northwest-southeast structural trend and stand above the extensive surficial sands of the Sandveld. The southern bank of the Verlorenvlei River is marked by such a ridge, which follows a northwest-southeast trending strike-fault (Tankard 1976; Rogers 1987) beginning at Redelinghuys. This 120 m high ridge continues to the coast at Elands Bay, where it is known as either Elandsberg or Bobbejaansberg, and terminates at Baboon Point at the modern coastline, where Elands Bay Cave is located.

The bedrock around Verlorenvlei and across the area known as the Sandveld is draped in aeolian and fluvial sandy deposits, locally up to 67 m thick that likely formed as a result of fluctuating sea-levels during the Tertiary and Quaternary (Baxter 1997). Rogers (1982) places these sands into three distinct formations. The lowermost is the Elandsfontyn formation, which consists of peaty clay and sand. This is overlain by the Varswater formation, which is a conglomeratic phosphorite; and the uppermost, which Rogers (1982) places within the Bredasdorp formation and subdivides into three units, the youngest of which is unconsolidated sands. Butzer (1979) suggests that these unconsolidated sands were emplaced around 12 500 BP. The modern soils that form within the sandy deposits are well-drained arenosols that are mostly fine-grained, loose, and poor in nutrients and weatherable minerals (Talbot 1947; Schloms et al. 1983). Interior soils are generally acidic, whereas littoral soils are generally alkaline and show an enrichment in phosphorous and nitrogen relative to other soils along the west coast (Talbot 1947; Baxter 1997). Calcretes, ferricretes and other hard pans are common (Baxter 1997).

#### QUATERNARY LANDSCAPE CHANGE AND LOCAL PALEOENVIRONMENTAL RECORDS

Although the Verlorenvlei is an important component of the modern ecology of Elands Bay, the vlei and coastline were not always in their current configuration since the area has undergone significant change throughout the Quaternary as a result of fluctuating sea levels. Visser and Toerien (1971) report a series of marine terraces along the coast near Elands Bay ranging from 120 m to 3 m above modern sea level. The highest erosional marine terrace is found north of Elands Bay and is covered in fossiliferous phosphatic sands, likely dating to the late Tertiary; a later terrace at 60 m above modern sea level is also recorded nearby (Visser & Toerien 1971). Miller (1987) argues that Elands Bay Cave itself, and other nearby shelters located at around 40 m above modern sea level, may have been scoured during previous marine high stands. Tankard (1976) also reports a relict boulder beach near Elands Bay Cave at 13 m above

modern sea level—possibly correlating with early Pleistocene high-stand markers from Saldana Bay—and argues that the ca. 5 m above modern sea level wave-cut platform at Baboon Point found directly below Elands Bay Cave may have formed initially during the middle or early Pleistocene, but was probably re-scoured during the late Pleistocene marine transgression.

During phases of marine regression, sea levels at Elands Bay dropped more than 100 m below modern levels exposing 30-40 km of coastal plains and leading to significant down cutting by the Verlorenvlei River (Baxter 1997). Additionally, the bedrock ridge of Elandsberg Mountain and Baboon Point, which forms a rocky, submerged groyne at the entrance to Elands Bay today, would have been subaerially exposed. Faunal evidence from Elands Bay Cave (Klein & Cruz-Uribe 1987) suggests that during the last glacial, the exposed continental shelf likely supported a grassland ecosystem inhabited by large grazers; however, this does not necessarily imply that conditions were significantly drier during the terminal Pleistocene and Last Glacial Maximum. To the contrary, charcoal and pollen recovered during excavations at Elands Bay Cave contained species assemblages including Afromontane taxa, indicating higher available soil moisture than today (Baxter 1997; Cartwright & Parkington 1997; Cartwright 2013). Cowling et al. (1999) hypothesized that this higher moisture was caused by sustained precipitation resulting from westerly cyclonic fronts along the western portion of the Cape Fold Belt. In contrast, more arid conditions in the eastern part of the fynbos biome resulted from cooler and more restricted moisture driven by the Agulhas current. The argument for wetter conditions during the Last Glacial Maximum along the western coast, and particularly at Elands Bay, is supported, according to Parkington et al. (2000), by the presence of hedgehog (Erinaceus frontalis) remains from Pleistocene layers at the cave. Furthermore, measurements made by Klein (1991) on dune molerat (Bathyergus suillus) humeri from Elands Bay Cave imply more humid conditions in the region between 9500 and 13 600 BP (Parkington et al. 2000; Klein & Cruz-Uribe 2016 this issue).

During the marine transgression following the Last Glacial Maximum low stand, the shoreline migrated landwards, submerging the exposed coastal plain and, together with temperature amelioration and intensified aridity, led to significant alteration of the regional ecology. Sea levels, which rose at a rate of 50 cm per 100 years, also transgressed during the Holocene, particularly at 8000 BP, 5500 BP and 4000 BP, with the later event appearing to exceed modern sea-levels (Baxter 1997). Afromontaine elements became significantly reduced by the terminal Pleistocene and by 6500 BP, and floral communities generally resembling those found today in the Sandveld appear to have become established at this time. The trend towards aridification, particularly pronounced in the mid-Holocene, is implied, according to Parkington (1987) by the secondary formation of gypsum within Elands Bay Cave.

The changing landscape around Elands Bay Cave is also reflected in changing subsistence practices of its inhabitants. During the terminal Pleistocene, when the exposed coastal plain was only partially submerged, the occupants at the site exploited the large grazers found in the grasslands; however, by ca. 11 000 BP, when the shoreline was about 5 km from the cave, the inhabitants began exploiting marine resources, evidenced by the presence of shellfish remains at the site. By 9000 BP fully developed shell-midden deposits are found at Elands Bay Cave. At the same time, many of the

larger grazer species disappear from the archaeological record and are replaced by smaller browsers (Klein & Cruz-Uribe 1987).

Paleoenvironmental data for time periods prior to the terminal Pleistocene and Last Glacial maximum are more sparse. Butzer (1979) constructed a composite stratigraphic sequence for the region, relying largely on colluvial deposits and paleosols exposed about 1 km east of Elands Bay Cave near a train tunnel excavated through the Elandsberg. He argues that the base of the sequence, a wave cut platform at 13 m above modern sea level, likely corresponds to MIS 9 and is overlain by colluvial deposits and aeolian sands that he attributes to a cold-period and phase of marine transgression corresponding to MIS 8 and 7. A polyphased soil, consisting of a subsurface horizon with prismatic structure overprinted by calcrete, formed on top of these units and likely corresponds to several different climatic phases of MIS 7. This soil is overlain at the Elandsberg tunnel section by colluvial deposits, what Butzer called grèzes litées, and which he argued were representative of cold-climatic conditions during MIS 6b. Furthermore, he correlated the colluvial materials with the lowermost stratigraphic units at Elands Bay Cave, which contain large angular debris and coincide with the earliest evidence for Middle Stone Age occupation at the site. Butzer argued that the transition between MIS 6a and 5e is represented by an accumulation of aeolian transgressive sands at the Elandsberg tunnel section, and that 5e proper is represented by the 6 m above modern sea level beach deposit and associated lagoonal deposits at Verlorenvlei. The correlation of this beach deposit with MIS 5e contradicts Hendey and Volman (1986) who argue that the 3 m above modern sea level shorelines found across the Western Cape Province correspond to 5e, and those at higher elevation likely pre-date the last interglacial. At the Elandsberg tunnel section, Butzer described strongly prismatic soils which formed on the aeolian sand deposited during the transition between MIS 6a and 5e. He correlated this soil with deeply oxidized cambic soils found at Verlorenvlei and also other 'aeolian soils' found in the uplands, and argues that this paleo-catena represents the last major phase of pedogenesis in the Elands Bay area. He noted that this period of soil formation is followed by a phase of slope denudation, corresponding with MIS 5b, with the well-developed red soils being subjected to slope wash at both the Elandsberg tunnel section and also in the Verlorenvlei. These reddish-coloured slope deposits are cemented by a calcrete, which Butzer correlated to MIS stage 5a and which is overlain by a rockier, colluvial deposit which he suggested corresponds to colder conditions during MIS 4.

In addition to the contribution in this issue (Cartwright 2016) the most detailed study to date of botanical remains from the Verlorenvlei area pre-dating the terminal Pleistocene comes from the Middle Stone Age site of Diepkloof Rock shelter, which is located about 17 km inland from Elands Bay along the Verlorenvlei River (Cartwright 2013; see also Fig. 1). Cartwright identifies several key changes in vegetation throughout the Diepkloof sequence, beginning in deposits containing pre-Still Bay artefacts and continuing through the post-Howiesons Poort deposits. She notes that the pre-Still Bay charcoal remains are dominated by Afromontane species and that with the beginning of the Still Bay, the assemblages shift towards favouring more thicket-like vegetation. At the same time, the Still Bay is when we see the earliest evidence for wetland vegetation associated with the Verlorenvlei. More taxa associated with these wetland environments are present in the Howiesons Poort, at the same time that plant communities appear

to become more diverse and representative of thicket and shrubland environments. Cartwright (2013) notes that the presence of Afromontane taxa in the Diepkloof sequence parallels a similar pattern in the Middle Stone Age charcoal record from Elands Bay Cave (Cartwright & Parkington 1997). The higher diversity of fynbos taxa within the Diepkloof sequence relative to that from Elands Bay Cave may reflect the influence of sea levels on the vegetation communities around the coastal site (Cartwright 2013). Cartwright (2013) urges caution, however, in using the data from these sites to directly infer environmental change. Rather, she points out that the charcoal assemblages at sites like Elands Bay Cave and Diepkloof reflect not only the available floral resources surrounding the site, but also human selection of these resources, potentially biasing a purely environmental interpretation.

## Previous geoarchaeological studies at Elands Bay Cave

Elands Bay Cave and the landscape surrounding the Verlorenvlei have been the focus of relatively intensive geoarchaeological research for the past several decades (Butzer 1979; Miller 1981, 1987; Baxter 1997; Miller et al. 2013). Butzer (1979) published the first geoarchaeological study of the sediments from Elands Bay Cave as part of a larger geomorphic and geoarchaeological study of the region around the Verlorenvlei. He noted the presence of three distinct lithostratigraphic units at the site: 1) a basal, 30 cm thick unit composed of 'frost-shattered rubble' that corresponds with phase L of the recent excavations (see Porraz, Schmid et al. 2016 this issue); another unit above, around 1.3 m thick, that was composed of "lenticular hearth and refuse deposits rich in charcoal powder", corresponding roughly to phases K through D of the current excavations; and 3) the LSA shell-midden deposits which were dug by Parkington (1976) in the original excavations of the 1960s and 70s (Butzer 1979: 162-3). For Butzer, the presence of 'frost-shattered', angular rubble at the base of the sequence, and the presence of similar deposits at Diepkloof and across the landscape of Elands Bay suggested to him that the western coast of South Africa experienced harsh climatic conditions during the Middle Pleistocene, particularly during MIS 6 (Butzer 1979, 2004). Butzer collected a total of 6 sediment samples from Elands Bay Cave for more detailed granulometric and compositional analysis. His results showed that the inorganic component of the sediment prior to 12 500 BP had mean grain sizes between 200 and 500 µm. Younger sediments at the site were better sorted and contained grains ranging between 100 and 200 µm. He interpreted this pattern as reflecting a shift in the source of sediment to the cave, such that the younger, finer sediments represented a greater influence of aeolian 'backshore sands', probably related to the terminal Pleistocene marine transgression. He also argued that the contribution of autochthonous sediment from the cave bedrock decreased by 50 % between 20 000 and 11 000 BP, and that the increase in aeolian sands at the terminal Pleistocene caused an increase in overall sedimentation rates.

Miller (1981, 1987) conducted a more detailed study of the sediments from Elands Bay Cave, collecting a total of 90 loose sediment samples on which he conducted granulometric analyses focusing on the 32  $\mu$ m to 2 mm size fraction. Miller agreed with Butzer's assertion that the deposit of coarse angular blocks found in the lowermost unit (phase L) formed as a result of freezing of the cave ceiling and walls. He termed this layer a 'basal lag' and argued that finer material was leached from the lower part of this layer, based on an increase in coarseness with depth. He thought that the removal of a portion of the fine fraction may have occurred during a period of prolonged exposure of the surface of this layer and that an increase in the fine fraction at the top of the layer may indicate the downward translocation of finer sediment from overlying deposits. Miller's analyses also reproduced the trend in grain size distributions found by Butzer; the older deposits (layers 24–12, or following the current stratigraphic designations phases K through D) were more poorly sorted and coarser, and younger deposits, dating between 12 500 to 8000 BP were finer and better sorted. However, Miller interpreted the trends differently. He argued that "more vigorous winds … during the last glacial and immediately post glacial" accounted for the presence of coarser grains and the poor sorting of the older sediments at the site (Miller 1987: 64). These winds may have also contributed to an increase in the addition of autochthonous material derived from the cave walls and ceiling, according to Miller (1987).

## Geochemical analyses and diagenesis of bone

Butzer (1979), as part of his geoarchaeological study of Elands Bay Cave, conducted several geochemical analyses of the sediment, in addition to presenting field descriptions and particle-size data. He reported a general trend of decreasing calcium carbonate and increasing phosphorous with depth within the second lithostratigraphic unit (phases I through D), a pattern that Butzer interpreted as changing patterns in the presence of 'fired shell' and 'bone phosphate' (Butzer 1979: 163).

Sillen and Parkington (1996) conducted a more detailed study of bone chemistry and chemical diagenesis at Elands Bay Cave. They measured the carbon and nitrogen content of bone, and also measured the crystallinity of the mineral fraction of the bone, using infrared spectroscopy to determine the splitting factor (Weiner & Bar-Yosef 1990; Bar-Yosef et al. 1993). The goals of this study were to assess the use of crystallinity measurements as a tool in determining relative chronology and to examine the link between organic and mineral processes in bone diagenesis. Sillen and Parkington (1996) reported a relatively strong correlation between age and crystallinity index measurements for bones younger than 20 000 BP at the site, but weak correlation between age and crystallinity index for older bones. They noted a strong correlation between nitrogen content and crystallinity index, which they interpreted as implying a link between diagenetic processes influencing the organic and mineral components of the bone. Sillen and Parkington (1996) also argued that since the nitrogen, carbon, and crystallinity measurements correlate better between themselves than with the dates of their corresponding stratigraphic layers, either 'microenvironmental' factors influenced the rate of diagenesis, or there was mixing between stratigraphic layers at the site. They favoured the latter explanation, ruling out spatial variation in the degree or type of diagenesis at the site, and instead argued that measurements similar to those made in their study can be used to assess the stratigraphic integrity of archaeological sites.

# RESEARCH GOALS OF THE CURRENT GEOARCHAEOLOGICAL STUDY

Elands Bay Cave has been the focus of intensive archaeological research for several decades and, as described above, numerous geoarchaeological studies have been carried out on the site's deposits. In the current study our aim is twofold: 1) to provide detailed stratigraphic and geoarchaeological observations that can help us

interpret the cultural, environmental and geochronological data collected during the recent excavations and 2) to provide a formation history of the site and specifically the Middle and earlier Later Stone Age deposits. The previous geoarchaeological studies conducted by Butzer (1979) and Miller (1987) were largely aimed at placing the site's sequence within a climato-stratigraphic framework that the researchers could then correlate with environmental change that occurred across the broader landscape. These research questions fit well with the goals of the previous Elands Bay Cave excavations, which pioneered an environmental approach to archaeological investigations. We share these goals; however, our approach is different. Rather than viewing the deposits as largely an archive of environmental change, we view the deposits as having accumulated as a result of geologic, biologic and anthropogenic agents. Additionally, we recognize that following accumulation, these deposits were variably influenced by sometimes intensive post-depositional alteration. Therefore, our goal is to identify the sources for sedimentary components at the site, to determine the agents of accumulation, and to identify the processes that caused the sediments to become altered following deposition. By unravelling these various processes that influenced the site over time, we can construct a site-formation model that allows us to contextualize the results of other researchers and also identify natural and cultural influences on the site's deposits.

### METHODS

For this study we employed a combination of field and laboratory techniques. Fieldbased methods included site and profile description combined with ground-penetrating radar (GPR) survey. We also collected environmental water samples for chemical analysis and sediment block samples for microcontextual analysis.

## GPR

We carried out a GPR survey of the cave's deposits with the goal of estimating the depth to bedrock across the site and to investigate any larger scale patterns in the geometry of the deposits. For this survey we employed a Geophysical Survey Systems, Inc. (GSSI) SIR-3000 control unit with a 400 MHz central-frequency antenna and an externally-mounted survey wheel with 2 cm triggering interval. We collected the GPR data within a single geophysical survey grid measuring 11 x 12 m, which covered the majority of the cave's floor and which was referenced to the established site datum. The data were collected unidirectionally along the Y and X axes at lines spaced at 20 cm intervals. In order to maximize data collection in irregular survey areas, particularly along the back wall of the cave, we extended the survey beyond the area of the grid. Despite in-field gain corrections raw GPR profiles exhibited weakly contrasting amplitudes below modern sand, and required experimentation with band pass filtering to enhance weak stratigraphic boundaries.

Post-processing routines for the GPR data were conducted in GSSI's RADAN software and included position correction (time zero), background removal (for removal of banding related to digital noise), hyperbolic-based migration (for depth calibration), high and low pass filtering (for suppression of unwanted noise), and time-varied gain enhancement (for enhancing signal degradation with increased depth). For all spatially coincident survey data, profile lines were combined into one

file using the Super3D function of RADAN and processed simultaneously. The data were interpreted in cross-section view (2D) and as time slices. Ground-truthing data for refining depths to significant strata, including bedrock basement, were provided by the recent archaeological excavations.

## Water chemistry

In order to determine the source for various elemental inputs to the deposits, we collected samples of rain water and water seeping through a joint in the bedrock at the front of the cave. The samples were collected during a late summer rain storm that began in the evening and continued into the following morning. We gathered water in plastic flasks at the start of the precipitation event and on the morning of the following day. At the end of the rain storm, we collected a sample of water that had begun to flow and drip from the joint. We sealed the water sample flasks with Parafilm® and electrical tape and kept the samples refrigerated prior to analysis.

We filtered the water samples and split them in order to preserve some of the water for later analysis. We also ran a blank for control of possible contamination from the filters. Determination of the elements Al, B, Ba, Ca, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, P, Sr, and Zn was performed using an inductively coupled plasma-optical emission spectrometer (ICP-OES) Perkin Elmer Optima 5300 DV with a Meinhard nebulizer and a baffled cyclonic spray chamber housed in the Laboratory of Soil Science and Geoecology at the University of Tübingen. The optimal instrumental conditions for axial view were: RF generator power 1.4 kW, plasma gas flow rate: 15 L min<sup>-1</sup>, nebulizer gas flow rate, auxiliary gas flow rate: 0.3 L min<sup>-1</sup>, pump rate: 1.0 mL min<sup>-1</sup>. The following analytical lines were used for determination of the analytes: Al 396.153 nm; B 249.677 nm; Ba 233.527 nm; Ca 317.933 nm; Cr 267.716 nm; Cu 327.393 nm; Fe 238.204 nm; K 766.490 nm; Li 670.784 nm; Mg 285.213 nm; Mn 285.213 nm; Na 589.592 nm; Ni 231.604 nm; P 213.617 nm; Sr 407.771 nm; Zn 206.200 nm.

## Microcontextual analysis

# Micromorphology

We collected a total of eight block samples of intact, oriented archaeological sediment for micromorphological and microcontextual analyses. We removed the blocks from profiles exposed during the recent excavations and stabilized them for transport using plaster-of-Paris bandages or toilet paper and packaging tape. In the laboratory we dried the samples at 40°C for at least 24 hours and then indurated them under vacuum with a mixture of polyester resin and styrene in a ratio of 7:3. We used methylethylketone peroxide as a catalyst with 3-5 ml per litre of resin and styrene. Once the mixture had gelled, we heated the indurated samples again at 60°C for at least 24 hours in order to completely harden the resin. We then sliced the blocks with a tile saw, producing chips measuring 6 x 9 cm. When this size of chip did not offer complete coverage of the block sample, we sub-sampled so that some block samples have two corresponding thin sections, with sub-sample A located stratigraphically higher than sub-sample B. Panagiotis Kritikakis (Geoarchaeology Laboratory, University of Tübingen) thin-sectioned the resulting chips to 30 µm thickness. We scanned the thin sections using a flat-bed scanner (Arpin et al. 2002) and analysed them under the naked eye and at magnification up to 200 x using plane-polarized light (PPL), cross-polarized light (XPL), oblique incident

light (OIL) and blue-light fluorescence. We described the thin sections using protocols and terminology developed by Stoops (2003) and Courty et al. (1989).

Fourier Transform infrared (FTIR) spectroscopy and Fourier Transform infrared microspectroscopy (µFTIR)

In addition to block samples, we also collected loose samples of sediment and samples of visible nodules from the exposed profiles for mineralogical analysis. We analysed the loose samples with a Cary 630 (Agilent Technologies) portable FTIR with a diamondcrystal attenuated total reflectance (ATR) attachment. Spectra were initially collected using the MicroLab PC software, and later exported to the Essential FTIR software package for further mineral identification and analysis. The spectra were generated from 32 co-added scans at 4 cm-1 resolution over a spectral range of 400–4000 cm-1. Initial mineral identifications were made using a spectral library search with databases composed of KBr and ATR spectra generated by S. Weiner (http://www.weizmann. ac. il/kimmel-arch/infrared-spectra-library), the RRUFF project (www. RRUFF. info; Lafuente et al. 2015), and using a personal mineral collection (S. Mentzer).

Analysis of loose samples of sediment and nodules can provide valuable information about mineral assemblages present within a site and their spatial and stratigraphic distribution (e.g. Weiner & Goldberg 1990; Weiner et al. 2002). However, this approach is not always useful for determining the sequence of formation of secondary minerals or their relationship to other sedimentary or diagenetic components or processes. Therefore, we decided to conduct FTIR analysis directly on the thin sections using a Cary 610 FTIR microscope connected to a Cary 660 FTIR bench (Agilent Technologies). We collected spectra on secondary minerals, bone fragments and other components in thin section using a germanium-ATR (Ge-ATR) objective with 32 co-added scans at 4 cm-1 resolution between 4000 and 570 cm-1. We collected the data as individual point measurements (sampling area  $\sim$ 50–70 µm diameter), as well as automated measurements on a grid using the Resolutions Pro software package. As with the loose samples, mineral identifications were conducted using spectra exported to the Essential FTIR software package and searched against reference spectral libraries, including a library generated from heated bone reference samples in thin section. All spectra generated from this study are available to view online (www. geoarchaeology. info/FTIR).

## μ-XRD

In order to confirm and clarify several of the mineral identifications made using FTIR, we conducted analyses directly on thin sections and loose mineral nodules using a  $\mu$ -XRD<sup>2</sup> diffractometer (BRUKER D8-Discover GADDS) located in the microanalytical laboratory of the CCA-BW in the Applied Mineralogy at the University of Tübingen. The microdiffractometer was equipped with a Co-sealed tube running at 30 kV/30 mA. Measurements were performed using either a 50  $\mu$ m polycapillary X-ray optic or a larger 500  $\mu$ m monocapillary X-ray optic with 300  $\mu$ m pinhole, and a 14 cm two-dimensional detector (BRUKER VANTEC-500) covering 40°20 in one diffraction image. Diffraction patterns were produced by integrating two diffraction images measured on different detector positions. Measurement times of each pattern were typically four minutes. In some cases, samples were rotated about a fixed vertical

axis in order to suppress single crystal intensities generated from oriented crystallites or single grains. Mineral identifications were conducted using the PDF-database of the International Centre for Diffraction Data (ICDD).

## Scanning electron microscopy (SEM)

Mineral identifications using FTIR and  $\mu$ -XRD<sup>2</sup> were aided in part by elemental data collected directly on minerals visible in thin section using a LEO 1450 VP SEM housed in the Department of Geosciences at the University of Tübingen. The thin sections were sputter coated in gold to minimize charging. Compositional analyses were conducted over points and areas using an EDS detector.

## Autoradiography

Because at least one of the identified secondary minerals contained K, and could therefore influence how we calculate dose-rate for the luminescence age estimates, we conducted autoradiography on chips corresponding to the analysed thin sections. The autoradiography was performed using an imaging plate (IP-Fuji 25 cm x 25 cm), which contains beta sensitive crystals (BaFBr:Eu+2). The chip was placed on the imaging plate, in a shielding lead box, for 43 days. We then scanned the imaging plate (Dürr Medical HD-CR 35 Bio). Under lighting, each pixel emits a light whose intensity is related to the beta dose received during the exposure of the imaging plate to the sample. The resulting image represents the spatial distribution of beta dose in the sample (Rufer & Preusser 2009).

### Organic petrology

Organic petrology is a field that studies the organic components of rocks and deposits using qualitative and quantitative microscopy. The approach is widely used in geology, particularly for the assessment and analysis of coal and other organic rich rocks of economic interest (Taylor et al. 1998); however, it has recently been applied successfully in archaeology, and specifically geoarchaeology as part of a microcontextual research strategy (e.g. Ligouis 2006; Goldberg et al. 2009; Stahlschmidt, Miller, Ligouis, Goldberg et al. 2015; Stahlschmidt, Miller, Ligouis, Hambach et al. 2015).

The organic petrologic analyses in this study were carried out at the Laboratory for Applied Organic Petrology at the University of Tübingen on well-polished indurated blocks that corresponded to thin sections analysed using micromorphology and other microanalytical techniques (EBC-12-01 and EBC-12-04). The samples were analysed using reflected white light and fluorescence and focused on describing the form and properties (e. g., anisotropy) of organic particles, referred to as 'macerals'. Further analysis, including measurement of the reflectance values of the macerals, was conducted on a Leitz DMRX-MPVSP microscope photometer in reflected white and blue-light, using oil immersion objectives between 20x and 50x. Analysis of the form, property and reflectance of the macerals can help identify the origin of the organic material, and assess its degree of humification and/or charring.

### RESULTS

## Field observations

Elands Bay Cave is situated at 42 m above modern sea level within a cliff of Table Mountain Group bedrock at Baboon Point (Fig. 2). The cave, which is ca. 18 m across



Fig. 2A. View of Baboon Point, composed of Table Mountain Group quartzites and conglomerates, in which Elands Bay Cave is located. 2B) View of Elands Bay Cave.

and 10 m deep, faces the ocean to the southwest. Because the site is wider than it is deep, and since daylight reaches most corners of the site, Elands Bay Cave is best described as a rock shelter; however, because of the long history of research referring to the site as a cave, we will continue this convention. The morphology of the site is generally rectilinear and follows the sub-horizontal bedding planes and vertical joints of the Table Mountain Group bedrock.

The present excavations focused on a small portion of the site initially exposed by Parkington as a test pit (squares F5, E5, and D5) during his original excavations. We established a new grid system for the site in order to facilitate the collection of spatial data using a total station (see Porraz, Schmid et al. 2016 this issue for details). Although all exposed profiles in the test pit were described and studied, excavations focused on the eastern profile of the pit, particularly sub-squares 1c, 2c, 2d, 11c, and 11d.

During excavation and field description we identified 8 major phases of deposition, which we assigned letter designations (see Porraz, Schmid et al. 2016 this issue for details) (Fig. 3). Each phase is composed of more than one layer or Stratigraphic Unit (SU), which was the smallest unit of excavation and archaeological analysis. Following standard practice on the western coast of South Africa, the SUs were generally given names that begin with the letter of the phase in which the SU is grouped. For example, SUs grouped into phase K have names including Kelly and Kent.

The lowermost phase, L, rests directly on the bedrock and has a maximum thickness of 10 cm. It appears mostly as black lenses within dark brown sandy sediment. Bones were absent from the basal SUs, which include Letty to Lovan. This phase is overlain by another phase up to 35 cm thick called 'Keva/Lara', referring to the two layers present within the main stratigraphic sequence. It is composed of large, angular blocks of quartzite roof spall and artefacts which exhibit a horizontal to sub-horizontal orientation. In some portions of this sedimentary phase, the deposits appear clast-supported. This phase corresponds with the basal deposits of the sequence described by Butzer (1979) and Miller (1987) as a 'frost-shattered' deposit. As in the deposits from phase L, Keva/Laura contained no faunal remains. The deposits are particularly rich in lithic artefacts and likely correspond to an early phase of the Middle Stone Age (Porraz, Schmid et al. 2016 this issue; Schmid et al. 2016 this issue). Tribolo et al. (2016 this issue) report an uncertain age of 83  $\pm$  14 ka on a burnt fragment of quartzite from Keva/Laura.

Phase K which includes SUs from Kali to Kent is easily distinguished from the underlying deposits by its general lack of large, angular roof spall. It is ca. 15 cm thick and appears dark brown in colour, and is composed of sandy silt. Clear bedding, laminations and lenses are present within this phase, and are particularly noticeable within the southern portion of the eastern profile. Phase J, which is ca. 20 cm thick and corresponds to SUs Jacob to Kelly in the main stratigraphic sequence, appears generally lighter in colour compared to phase K and displays similar bedding structures and laminations. These phases remain undated.

Phase I corresponds to SUs Igor to Ines and has a maximum thickness of 25 cm. The sediments of this phase appear generally dark brown in colour and exhibit light-coloured lenses and fine laminations, some of which appear reddish in colour. Igor appears yellowish in the field, and the base of the layer is marked by a laterally discontinuous concentration of angular roof spall, mostly 5–15 cm in size. Ines, at the base of phase I consists largely of degraded fragments of roof spall. Radiocarbon measurements



Fig. 3A. Excavation grid indicating the areas excavated by Parkington and Porraz during the current campaign. The main profile of study for this work is the eastern profile, a drawing of which is presented in 3B. Here, the location of micromorphological samples is indicated by the squares, with sample numbers included (e.g. M.1 is EBC-12-01).

obtained on charcoal from this phase returned ages between 36.8 and 38.9 ka cal BP and optically stimulated luminescence (OSL) ages were consistent with these dates (Tribolo et al. 2016 this issue). The lithic industry in phase I is consistent with a late phase of the Middle Stone Age (Porraz, Schmid et al. 2016 this issue). Phase I is overlain by phase H which is up to 20 cm thick and shows a slight inclination to the south. It includes SUs



Fig. 4A. Photograph of the interior of Elands Bay Cave with the excavation area exposed. Note the joint in the back wall along which water seeps during rain events (red arrow). The white streaks are secondary minerals that form as the water evaporates. Also note that within the excavation area, the deposits appear darker to the south and east, indicating a wetting front associated with the joint. 4B) A close-up view of the secondary minerals forming along the back wall.

Harry to Ibis. Phase H appears generally homogenous and is sandier than underlying deposits. Bones were not found in phases I, H, J or K during excavation.

Phases D and F include SUs Delport to Fuzy and they together comprise a total thickness of around 55 cm. This phase is composed of interstratified lenses and pits that are light in colour and resemble *en cuvette* hearths. Radiocarbon dating of charcoal from phase F places deposition between 22.1 and 24.2 ka cal BP, although luminescence ages on quartzite blocks from the base of the phase suggest a slightly earlier start to accumulation (Tribolo et al. 2016 this issue). Radiocarbon dates on charcoal obtained from phase D returned ages between 19.4 and 18.8 ka cal BP (Tribolo et al. 2016 this issue). Porraz, Igreja et al. (2016 this issue) identify the lithic industry from phase F as corresponding to the early LSA, and phase D as corresponding to the Robberg. Faunal remains were found during excavation in these phases, but were poorly preserved.

The stratigraphically highest unit excavated during the most recent excavations was phase C which consisted of a large pit that sloped towards the southern wall of the cave and that contained yellowish-brown sand and some marine shell. Artefacts in this unit were not abundant.

A vertical joint in the bedrock of the cave runs along the top and back of the cave ceiling and wall, oriented perpendicular to the entrance of the site (Fig. 4). When it rains, water seeps and runs along this joint and when the water evaporates, it deposits a rim of secondary minerals parallel to the orientation of the joint. The effects of this water seep appear to continue from the joint into the archaeological deposits as a wetting front: the southeastern corner of the excavations in squares F5, E5 and F4 exhibits an inverted cone-shaped zone where few, if any, large secondary mineral nodules appear. The rest of the profiles in the current excavation area, particularly to the north and west, are thoroughly permeated by large, white powdery nodules,



Fig. 5. Photograph of the eastern profile, showing the wetting front. To the north of the dotted white line, large secondary nodules, mostly of gypsum, form and physically disturb the deposits. To the south of the line, secondary nodules are smaller and do not significantly alter the physical structure of the deposits.

some larger than 10 cm in diameter (Figs 5, 6). Parkington identified the secondary mineral as gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O), and suggested that its formation was linked to increasing influence of marine aerosols during and following the late Pleistocene marine transgression (Parkington 1987). Our FTIR measurements on loose samples of these nodules confirmed their identification as gypsum (Table 1). Within the wetting front, nodules are present, but are much smaller-generally less than 1 cm in diameter-

Gypsum	CaSO <sub>4</sub> ·2H <sub>2</sub> O	
Hydroxylapatite	$Ca_{10}(PO_4)_6(OH)_2$	
Taranakite	$(K,Na)_{3}(Al,Fe^{3+})_{5}(PO_{4})_{2}(HPO_{4})6\cdot18H_{2}O$	
Ardealite	$Ca_2(HPO_4)(SO_4) \cdot 4H_2O$	
Whitlockite	$Ca_{18}Mg_2H_2(PO_4)_{14}$	
Variscite	$AlPO_4 \cdot 2H_2O$	
Opal	$SiO_2$ (amorphous, hydrated)	
Dawsonite	NaAlCO <sub>3</sub> (OH) <sub>2</sub>	

TABLE 1

A list of secondary minerals identified in this study, along with their chemical formulae.



Fig. 6A. Photograph of the western profile, showing extensive impregnation of the deposits by secondary nodules. 6B) A krotovina along which secondary gypsum has formed. 6C) A block of quartzite that has been partially destroyed by the formation of secondary gypsum.

and appear as small flecks or thin veins with a beige colour. FTIR measurements on loose samples of these nodules revealed that they are composed of taranakite ((K, Na)<sub>3</sub>(Al,Fe<sup>3+</sup>)<sub>5</sub>(PO<sub>4</sub>)<sub>2</sub>(HPO<sub>4</sub>)6·18H<sub>2</sub>O). SEM-EDS measurements indicate that the mineral is rich in potassium. Towards the outer edge of the wetting front, round, cm-sized, yellowish nodules appear. FTIR measurements on loose samples of these

nodules identified them as hydroxylapatite  $(Ca_{10}(PO_4)_6(OH)_2)$ . Additional minerals identified from loose samples include quartz (SiO<sub>2</sub>), which is present in the bedrock and sand grains, white masses of opal (amorphous hydrated SiO<sub>2</sub>), cream-colored nodules of ardealite  $(Ca_2(HPO_4)(SO_4) \cdot 4H_2O)$  mixed with gypsum, aragonite (CaCO<sub>3</sub>) in fragments of marine shell, and dawsonite (NaAlCO<sub>3</sub>(OH)<sub>2</sub>), which is present as small green crystals which formed on the aluminium casing of the dosimeters used for luminescence dating.

The extensive formation of large, secondary nodules of hydroxylapatite, taranakite, and in particular, gypsum, has had a significant impact on the physical preservation of the deposits. Some large blocks of *éboulis* have been physically broken down by the formation of the nodules. In addition, the growth of the nodules has led to disturbance of the stratigraphic layers. Within the wetting front, laminations and lenses are clearly distinguishable. Outside of this zone, the large gypsum nodules appear to have homogenized the deposits, making it difficult, if not impossible, to follow distinct layers across the entire excavation pit. Bioturbation has also played a role in disturbing the deposits, but to a much lesser degree. Several krotovinas are visible in the profiles, including one where secondary gypsum has grown along the edge of the burrow. The excavators also noted that bones were found through much of the deposits outside the wetting front, but were almost completely absent from within it. Shells were only present within burrows.

## GPR

Surface conditions at Elands Bay Cave comprised a layer of sand fill. Obstructions were minimal, though a barrier fence limiting access to the rock art was slightly restrictive. Initial field data showed relatively low dielectric contrasts due to aridity of the area, and there was attenuation from salt spray and long-term salt accumulation in the deposits. Field data therefore displayed weak signal amplitudes with few strong reflectors below the interface of modern sand and archaeological strata. Post-fieldwork digital processing served to enhance the data and increased interpretability, significantly enhancing GPR profiles and enabling time slicing of the dataset. Time slicing delineated a large excavation block from previous excavations (Fig. 7), and facilitated spatial correlation between this and more recent excavations to the south. Of note are the distinct reflections from sand bags in the more recent unit, and clear boundaries of previous excavation blocks.

Stratigraphic profiles at the site were briefly exposed when sand bags were removed from the recent excavation units. GPR profiles were consistent with excavation profiles and showed at least four discernible units overlying a pronounced and undulating bedrock reflector (Fig. 7). These units identified in the GPR survey likely correspond with phases L and Keva/Laura (unit I), phases J-I (unit II), phases D-F (unit III) and the modern sand fill (unit IV). Phase L (unit I) is apparent in the GPR data and appears to fill a bedrock depression. This unit pinches-out to the north, where bedrock or roof fall is exposed at the ground surface. In some locations unit I appears to thicken to the south and then thins toward the southern cave wall. Parallel to the rear wall the other units follow this general pattern, while perpendicularly, units thicken toward the entrance following the bedrock trend.



Fig. 7A. Post-processed and interpreted example of north-south trending GPR profile. This profile crossed the area of the current excavations. 7B) Post-processed and interpreted example of west-east trending GPR profile. This profile also crossed the area of the current excavations. 7C) Three-dimensional reconstruction of bedrock topography from GPR data. Note variable bedrock surface and relatively deep depression in south-central section of the site. This basin is infilled with the coarse deposits of phases L and K.

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### Water and sediment chemistry results

The results of the elemental analysis of drip water collected from along the joint is presented in Table 2. Most measured elements showed a general trend towards enrichment following percolation through the bedrock and overlying deposits. Of particular note, Ca, K, Mg, Na, and P were particularly enriched relative to the rainwater collected outside of the cave. Because the rainstorm occurred during the late summer, this water composition likely represents a seasonal end-member of dripwater composition that ranges from concentrated in contaminants to more dilute, as rains flush through bird guano, dassie middens, and other organic materials accumulated above the site during the dry season (spring, summer and fall). We expect late winter dripwater to have a different composition.

### Micromorphology and microcontextual analysis

We collected a total of eight block samples for micromorphological analysis (Table 3) and 33 loose samples for other mineralogical analyses. Sampling for micromorphology

Element	Water sample 1	Water sample 2	Water sample 3	Blank
Al	0.014	0.102	0.593	Below detection limit of 0.004
В	0.038	0.101	0.463	0.011
Ba	0.008	0.021	0.027	0.001
Ca	2.635	13.220	79.403	0.381
Cr	Below detection limit of 0.002	Below detection limit of 0.002	0.003	Below detection limit of 0.002
Cu	Below detection limit of 0.003	0.022	0.010	Below detection limit of 0.003
Fe	0.015	0.101	0.788	0.002
K	2.067	11.327	101.457	Below detection limit of 0.073
Li	Below detection limit of 0.005	Below detection limit of 0.005	0.017	Below detection limit of 0.005
Mg	1.330	9.522	97.464	0.168
Mn	Below detection limit of 0.002	0.003	0.003	Below detection limit of 0.002
Na	7.409	65.621	811.178	0.388
Ni	Below detection limit of 0.002	0.002	0.004	Below detection limit of 0.002
Р	0.501	1.357	2.169	Below detection limit of 0.007
Sr	0.008	0.109	0.778	0.001
Zn	0.003	0.036	0.018	0.005

#### TABLE 2

Elemental analysis of rain and seep water from Elands Bay Cave, along with measurements made on the blank. Values are reported as mg/L. Sample 1 was collected on 30 March 2012 from rain water, a day after it had started to storm. Sample 2 was collected on the 29 March 2012, from rain water when it had just begun to storm. Sample 3 was collected on the 30 March 2012, from seep water within the cave.

Sample	Profile location	Stratigraphic designa- tion	Chronocultural designation	
EBC-12-08	Southern profile	Contact of phases D/F	Early LSA (phase F), dates between 24.2 and 22.1 ka cal BP; Robberg (phase D), dates between 19.4 and 18.8 ka cal BP.	
EBC-12-07	Eastern profile	Farik, Fael, Dorothee	Early LSA (phase F), dates between 24.2 and 22.1 ka cal BP; Robberg (phase D), dates between 19.4 and 18.8 ka cal BP.	
EBC-12-06 (a and b)	Eastern profile	Fuzy, France	Early LSA, dates between 24.2 and 22.1 ka cal BP.	
EBC-12-03	Eastern profile	Henri	Late phase of MSA, not directly dated	
EBC-12-05	Southern profile	Phase I (above Imriz)	Late phase of MSA, dates between 36.8 and 38.9 ka cal BP.	
EBC-12-04	Eastern profile	Ibis	Late phase of MSA, dates between 36.8 and 38.9 ka cal BP.	
EBC-12-02	Eastern profile	Ines, Imriz, Imran	Late phase of MSA, dates between 36.8 and 38.9 ka cal BP.	
EBC-12-01	Eastern profile	Keva, Kelly/Kent	Contact between early phase of MSA and a later, undated phase of the MSA.	

#### TABLE 3

A list of block samples collected for microcontextual analysis, along with sample location, and stratigraphic, chronologic and cultural information.

focused on the eastern profile, known as the Main Section (squares 1c, 2d and 2c), since 1) this was the primary profile of investigation for the current excavations, 2) it provided us with complete diachronic coverage of the sequence excavated by the current excavations, and 3) this profile exhibited the least amount of physical disturbance by secondary nodule formation. However, we aimed to examine not only diachronic variations in the deposits, but lateral variations as well. Therefore, we also collected block samples from the southern profile. Below we provide the results of micromorphological and microcontextual analyses, beginning with the stratigraphically lowest sample.

## EBC-12-01

We collected this sample from the contact between SU Keva and SU Kelly/Kent, which is the top of the coarse, 'frost-shattered' deposits of the MSA I overlain by later Middle Stone Age occupations. The contact is clearly visible in the block so that it was possible to divide the thin section into two distinct depositional units (Fig. 8).

In both Keva and Kelly/Kent the groundmass exhibits a close to single-spaced enaulic c/f-related distribution, with the coarse fraction composed mostly of a poorly sorted mixture of fine-to-medium sand-sized, subangular grains of quartz and rare feldspar. The fine-fraction is mostly composed of microaggregated silt-sized fragments of finely-comminuted organic material, some of which appears humified and some carbonized. The characteristics of the groundmass identified here are similar throughout most of the Elands Bay sequence, and also resemble the groundmass identified at other Middle Stone Age quartzite rock shelters, such as Sibudu (Goldberg et al. 2009) and



Fig. 8. Flatbed scan of EBC-12-01. This sample was collected from the contact between Keva and Kelly/ Kent, which represents a significant unconformity in the Elands Bay sequence.

Diepkloof (Miller et al. 2013). Material coarser than medium sand is also present at about 20–30 % abundance. The coarser components include: 1) well-rounded, coarse sand-sized grains of single crystal and polycrystalline quartz, 2) centimetre-sized, angular, elongated fragments of weakly metamorphosed quartzite, likely derived from spalling of the cave ceiling and walls, and 3) sub-angular fragments of woody charcoal, generally less than 0.5 cm in size. Some of the fragments of quartzite roof spall appear



Fig. 9. Microphotographs from EBC-12-01. 9A) The contact between Keva and Kelly/Kent. Note the horizontally oriented clasts of quartzite, indicating the erosional surface on Keva. On top of this surface is a lenticular concentration of charcoal, possibly representing a combustion feature. PPL. 9B) A clay rich aggregate in which secondary nodules of variscite have formed, SU Keva. XPL. 9C) Another clay rich aggregate, SU Kelly/Kent, note the absence of variscite, which is only found in aggregates in SU Keva. PPL. 9D) Fragment of bone, partially dissolved. Bone was not found in these SUs during excavation, but a few sand-sized fragments, often altered, have been identified in thin section. PPL. 9E) Burrow, indicating bioturbation. Evidence for bioturbation at Elands Bay Cave is mostly limited to discrete passage features, as those seen here. PPL. 9F) Fragment of quartzite derived from the bedrock, undergoing in situ granular disaggregation as the result of secondary formation of taranakite. PPL.

to have disaggregated in situ, contributing to the sand-sized fraction of the ground mass (Fig. 9). Additionally, the elongated quartzite fragments in most of Keva show no preferred fabric; rather they display a random orientation. There are a few, rounded, medium-to-coarse sand-sized aggregates of silt and clay present in Keva. The clay fraction in these aggregates display a stipple-speckled to striated b-fabric. Some of these aggregates show evidence for chemical alteration in the form of radial, crystalline intergrowths that exhibit low-order grey and yellow interference colours. We analysed the composition of these intergrowths directly in thin section using µFTIR, SEM-EDS and  $\mu$ XRD. FTIR spectra obtained from these crystals had a broad peak around 1620,a shoulder at 1140, and peaks at 1025, 1005, 905, 585 wave numbers. The EDS measurements indicated that the mineral contained Al and P. µXRD measurements made directly on the thin section identified the mineral as variscite (AlPO, 2H<sub>2</sub>O). Other nodules of secondary minerals were visible in Keva in addition to the variscite found forming in the silty clay aggregates. These nodules are typically 1-2 mm in size and appear pale vellow in PPL, exhibit low-order greys in XPL, and strongly fluorescing under blue-light fluorescence. At higher magnifications (200x) individual crystals, up to 30 µm in size, are visible and display a platy habit in parallel aggregates. We collected uFTIR measurements of these nodules directly on the thin section and obtained spectra with diagnostic peaks at 1097, 1056, 1013, 949, 696, 642, and 601 wave numbers, confirming an identification of taranakite, (K,Na)<sub>3</sub>(Al, Fe<sup>3+</sup>)<sub>5</sub>(PO<sub>4</sub>)<sub>2</sub>(HPO<sub>4</sub>)<sub>6</sub>·18H<sub>2</sub>O, with SEM-EDS analyses suggesting that the phase is rich in K.

The contact between Keva and Kelly/Kent is locally sharp and clear. The upper portion of the lower depositional unit shows an increase in the coarser fraction (medium to coarse sand). Furthermore, elongated fragments of quartzite roof spall exhibit a horizontal, preferred orientation at the contact. The sharp, upper portion of the contact is directly overlain by a cm-thick lens containing angular, 0.5 cm fragments of charcoal. This lens also appears to have a lower proportion of coarse sand compared to sediment above or below, and is dominated by fine sand. The sharp contact and charcoal-rich lens do not appear to be laterally continuous across the thin section, but both appear to be locally disturbed by mesofauna biogalleries.

The upper depositional unit (Kelly/Kent) contains similar sedimentary components and exhibits generally similar micromorphological characteristics as those described for the lower unit (Keva). The c/f-related distribution is close- to single-spaced fine enaulic; however, the coarse fraction here appears slightly finer than that described for Keva. Additionally, there are fewer cm-sized fragments of quartzite roof spall (ca. 10 % abundance). These appear to exhibit a horizontal to sub-horizontal preferred orientation which parallels the weakly expressed, sub-cm thick sedimentary bedding visible in the thin section. Silt and clay aggregates exhibiting stipple-speckled and striated b-fabric are also present in Kelly/Kent, albeit finer grained (0. 5 mm) and in lower abundance (< 5 %) compared to those found in Keva. Additionally, the aggregates in Kelly/ Kent do not exhibit any secondary crystal intergrowths. Other secondary nodules are present and appear similar in appearance and abundance to those described in Keva.  $\mu$ FTIR measurements of these nodules made in thin section confirmed that they are also composed of taranakite.

Organic petrographic analyses confirm the observation that finely comminuted organic material constitutes a significant portion of the sediment in these samples



Fig. 10. Photomicrographs collected in reflected light used in the organic petrographic analysis 10A) a fragment of fat-derived char from Kelly/Kent in sample EBC-12-01. Fat-derived char is relatively common at Elands Bay Cave and suggests that the occupants were either burning bone or cooking at the site. 10B) Kelly/Kent, EBC-12-01.A fragment of permineralized charcoal showing evidence of fungal attack. The large voids are the cell walls, and the smaller voids were caused by fungal attack. Many of the plant tissues at Elands Bay Cave show evidence for humification and fungal attack prior to burning.

(Fig. 10). The fine fraction of organics is composed of both woody and herbaceous tissues, with one well-preserved leaf fragment visible. Many of the tissue fragments show evidence of having been humified: their cell walls are swollen or incompletely dissolved by cellulose hydrolysis, giving them a corroded appearance. Gelified humus colloid droplets as well as fillings occur in the cell lumens. Additionally, the cell walls of most of the tissues are perforated as the result of fungal degradation. The observation of fungal degradation is supported by the presence of sclerotia within this sample.

Interestingly, the humification of these tissues appear to have occurred prior to combustion. In Keva, reflectance values range from 0.82 % to 1.87 % Ro, although most occur between 0.82 and 1.49 % Ro, allowing us to classify those with the lower values as low-reflecting fusinite (charcoal) whereas those with the highest values correspond with typical fusinite. These values are different from those measured in Kelly/Kent, where the tissue fragments exhibit values ranging between 0.62 and 1.22 % Ro.

Bone is almost completely absent from both Keva and Kelly/Kent. Only a single, sand-sized fragment of bone was found at the base of Kelly/Kent, and it appeared etched and did not fluoresce under blue light.

## EBC-12-02

This sample was collected from SUs Ines, Imriz and Imran. In the field, these layers appeared laminated and contained thin, light-coloured lenses. In thin section, we were able to identify six discrete depositional units (Fig. 11). The mineral component in the lowermost unit, unit 1, is poorly sorted and composed of coarse silt/fine sand to coarse sand. The fine fraction is largely composed of finely comminuted organic material that exhibits a granular microstructure. Rare fragments of quartzite bedrock are present, all under 0.5 cm in size, and display no preferred orientation. Unit 1 is capped by a thin (0.75 cm) lens of subangular fragments of charcoal (unit 2), ranging from silt-sized fragments up to 0.5 cm in size. The upper and lower units of this lens are sharp and clear. Mineral grains are almost completely absent from unit 2, a characteristic observed



Fig. 11. flatbed scan of EBC-12-02 indicating the depositional units identified in thin section. Note the large block of quartzite around which a crust of taranakite has formed. Here one can see that units 2 and 5 are rich in charcoal, and unit 5 has a sharp lower contact.

from other charcoal lenses at similar Middle Stone Age sites, such as Diepkloof (Miller et al. 2013). The third depositional unit is dominated by cm-sized, elongated, angular fragments of bedrock that display a clear horizontal orientation. The interstitial material between the fragments of bedrock is composed of sand-sized mineral grains and microgranular organic material, resembling the groundmass described for unit 1 in this sample. The charcoal lens and overlying angular bedrock fragments likely marks the contact between layers Ines and Imriz. The contact between unit 3 (the bedrock fragment unit) and the overlying unit (unit 4) is gradational. Here, the fine organic component appears coarser than that described for unit 1; rounded fragments of charcoal, about 0.5 mm in diameter, are common. Additionally, the fine granular organic component appears partially aggregated, reducing the overall porosity of the unit. The upper contact of unit 4 is sharp and clear, apart from a small portion that is disturbed by passage features. Unit 5 is largely composed of sub-angular fragments of charcoal; the fine fraction is also composed of charcoal, but exhibits a granular microstructure. Mineral grains are absent from the base of unit 5 although a large, horizontally-oriented, cm-sized fragment of bedrock is present. Above this fragment, mineral grains ranging in size from coarse silt to sand are present but not at the frequency encountered in units 1 or 4. The upper contact of unit 5 is clear but diffuse and appears disturbed, likely as a result of bioturbation. Unit 6 appears much lighter in colour than the other depositional units encountered in this sample. It contains mineral grains that are poorly sorted and range in size from coarse silt to coarse sand. Fragments of charcoal or organic material are rare and when present, appear rounded. A few rounded aggregates of clay and silt are present. Bedrock fragments are also rare, apart from a large, 2 cm sized rounded fragment.

The fine fraction of unit 6 is composed almost exclusively of secondarily-formed materials, accounting for the light colour of the unit. Throughout the rest of this sample, secondary nodules are also common and appear generally similar to the material found in unit 6. In PPL the nodules range in colour from pale yellow to dark orange and present as either discrete nodules, often no larger than 1–2 mm in size to 1.5 mm sized crusts and weakly-developed veins. In XPL the nodules range from anisotropic to weakly isotropic, exhibiting low order grey to yellow interference colours. In units 1–5, the secondary components appear more nodular, whereas in unit 6 they are diffuse, comprising a dominant part of the fine fraction. We collected FTIR spectra on the nodules and crusts directly on the thin section confirming that many are composed of taranakite, as identified in sample EBC-12-01. Other nodules are composed of amorphous silica, or opal (Fig. 12). In addition, the large, rounded fragment of quartzite bedrock in unit 6 is coated in a 1.5 mm thick crust of taranakite.

We collected an autoradiograph image of the corresponding chip from this sample (Fig. 13). The taranakite crust forming on the quartzite block clearly showed higher radioactivity relative to the surrounding sediment, suggesting that the taranakite was rich in potassium. Within this crust we noted several distinct voids that appear bladey and have a radial distribution. The morphology of the voids, and their orientation, suggests that they are pseudomorphic after a crystal intergrowth of gypsum which has subsequently dissolved. Very few, sand-sized fragments of bone are present and appear sub-rounded, stained and altered. These fragments do not fluoresce under blue light and FTIR measurements collected directly from the thin section suggest that the bones are composed of the original hydroxylapatite.

### EBC-12-04

This sample was collected from layer Ibis, and is stratigraphically lower than EBC-12-03, but higher in terms of depth below datum. In the field, and in thin section, the sample appeared laminated, and in thin section we were able to identify seven distinct



Fig. 12. Microphotographs of EBC-12-02. 12A) The taranakite crust growing on the large quartzite fragment, with pseudomorphic voids after gypsum. PPL. 12B) Same view as 12A, but at higher magnification and under blue light fluorescence. 12C) Nodules of taranakite growing within a fragment of charcoal, and physically destroying it. 12D) The quartzite bock with the taranakite crust, XPL.

depositional units (Fig. 14). The lowermost unit, unit 1, appears lighter coloured than most other units described in this sample. The mineral grains range in size from coarse silt to coarse sand and are poorly sorted. They also appear slightly more rounded than mineral grains described in samples collected stratigraphically below EBC-12-04. The fine fraction is composed largely of finely-comminuted, organic material and individual phytoliths are also present. Organic petrographic analysis and associated reflectance measurements on the tissues indicate that they are derived from herbaceous and woody plants and have been burnt. Apart from a large, cm-sized block of quartzite at the top of the unit, there are only a few, sub-rounded granule-sized fragments of quartzite bedrock. Aggregates of clay and silt are present and are more abundant than in either EBC-12-01 or EBC-12-02. These aggregates appear throughout sample EBC-12-04. In addition, many of the aggregates composed of clay and silt appear to be chemically altered and even partially dissolved. We collected one FTIR spectrum on a soil aggregate that confirmed that it was composed of quartz and clay. However, another spectrum collected from a different aggregate showed that it was composed of amorphous silica. Sand-sized and even larger fragments of bone are present in unit 1 at ca. 5-10%abundance and appear more frequent towards the top of unit 1. The bones appear partially dissolved and stained and altered. They do not fluoresce in blue light.



Fig. 13. Autoradiography image of a portion of sample EBC-12-02. The white ring (indicated by the arrow) is the taranakite crust forming on the quartzite block. The slight variation in morphology compared to the thin section is because the image was produced from the chip. These results indicated that the taranakite is the potassium-rich end member, an observation confirmed by the SEM-EDS results.



Fig. 14. Flatbed scan of EBC-12-04 indicating the depositional units identified in thin section.

The contact between units 1 and 2 is clear yet diffuse. The fine and coarse fraction of unit 2 is largely composed of charcoal, including 0.5 cm sized sub-angular fragments of woody charcoal, and smaller fragments of herbaceous charcoal. Mineral grains are present, and appear similar to those in unit 1, albeit in lower proportions. The contact between unit 2 and the overlying unit 3 is sharp but irregular. Unit 3 appears to be a lens that is relatively light-coloured in PPL and generally resembles unit 1; however, the fine fraction appears to be more granular here and contains more mineral



Fig. 15. Microphotographs of sample EBC-12-04. 15A) A sand-sized fragment of spongey bone that appears altered. 15B) A weathered, fissured rock fragment, likely derived from the local conglomeritic bedrock. It is surrounded by fragments of charcoal. PPL. 15C) A thin lens of charcoal. PPL. 15D) Laminated, articulated phytoliths. PPL.

constituents, including clay minerals. Fine-sand-sized, rounded fragments of charcoal are present, as are fine-sand-sized, rounded aggregates of clay and silt. A single, sub-angular fragment of partially dissolved spongy bone, 1.5 mm long, is present in the centre of the lens.

The contact between unit 3 and 4 is clear and locally diffuse. The layer is lighter coloured, and in this respect resembles both units 1 and 3; however, it can be distinguished from the underlying unit 3 by a very thin and discontinuous lens of herbaceous charcoal. Unlike units 1 and 3, the abundance of sub-rounded fragments of granule-sized charcoal is about 20 %. In addition, unit 4 contains three fragments of rock that are distinct from the more typical quartzite (Fig. 15). These include a centimetre-sized fragment of what appears to be an extensively weathered metamorphic rock, a fragment of iron-rich siltstone, and a smaller fragment of a weathered, possibly sedimentary rock. These may derive from the local conglomeritic bedrock, the Piekenierskloof Formation. The contact between unit 4 and 5 is sharp, clear and continuous across the thin section. The fine fraction at the top of unit 4 appears compacted, such that the c/f-related distribution appears porphyric. Additionally, the top of this unit contains numerous granule-sized, subangular fragments of spongey bone that appear stained and also partially altered and dissolved. They do not fluoresce under blue light.

Unit 5 is composed almost exclusively of charcoal that is mostly sub-angular and medium-sand sized. Much of it appears herbaceous. A few fragments of clearly noncarbonized (i.e. humified) plant material is also present. Organic petrographic analysis identified several elongated, permineralized organic clasts that are rich in silt-sized grains of quartz and that exhibit a network-porous texture reminiscent of peat. These fragments do not appear to have been heated, but appear humified. Mineral components are almost completely absent from this unit. The contact with the overlying unit 6 is clear, and sharp to diffuse. This unit is locally discontinuous across the thin section and is light coloured in PPL, and isotropic in XPL. The sediment generally lacks mineral components at its base, but contains quartz, ranging in size from coarse silt to coarse sand at its top. The lower part of the unit is composed almost exclusively of articulated phytoliths. The contact with the overlying unit, where present, is sharp and clear, and is marked by a thin lens of charcoal and elongated, mm-sized fragments of quartzite bedrock located at the base of unit 7. This unit displays the typical single-spaced to close fine enaulic c/f-related distribution found elsewhere at the site; however, the structure fine fraction appears more compact than that described for units 1 and 3 in this sample. Additionally, there are several thin lenses and horizontal concentrations of charcoal that give the unit a weakly laminated to bedded appearance. Of particular note is a 2-3 mm thick, laterally discontinuous lens of horizontally oriented herbaceous charcoal and laminated, articulated phytoliths. Charcoal is finely comminuted and generally dispersed evenly through the unit. Larger, subangular fragments, ranging in size between 3 mm to 8 mm are present as well, at 5–10 % abundance.

There are very few secondary mineral nodules present in this sample, especially when compared to sample EBC-12-02. Several mm-sized nodules of what appears to be taranakite are present at both the base and top of this sample. Direct  $\mu$ FTIR measurements made on these nodules in thin section, shows however, that they are composed of amorphous silica.

## EBC-12-05

This sample was collected from the south profile, directly above layer Imriz within depositional phase I, making it roughly stratigraphically equivalent to samples EBC-12-02 and EBC-12-04. As noted in the field, and described from other thin sections from phase I, the deposits in this sample appear bedded and laminated, and 6 distinct depositional units could be identified in thin section (Fig. 16). Only a very small area of the lowermost unit, unit 1, is present in the thin section. The unit appears light brown in PPL it is more compact than other deposits, such that at lower magnification it appears partially porphyric. There is a single, sand-sized, sub-angular fragment of bone present. The upper portion of this unit appears partially reddened and it has a sharp, irregular contact with the overlying unit 2. Portions of this contact have been disturbed by bioturbation. Unit 2 is locally up to 1cm thick and is composed of sand-sized, subrounded fragments of woody and fibrous charcoal, with more elongate fragments displaying a preferred, horizontal orientation. Sand and silt-sized grains of quartz are less abundant here than in unit 1, at about 10 %.

Unit 2 has a gradual to locally sharp contact with the overlying unit 3, which appears lighter in colour and is generally similar to unit 1 in composition and microstructure; however, this unit contains more and larger sub-angular sand-sized fragments of



Fig. 16. Flatbed scan of EBC-12-05 indicating the depositional units identified in thin section. Note the sharp contact between the charcoal-rich unit 2 and the underlying reddened unit. Additionally, note the yellowish crust at the top of unit 5.

fibrous and woody charcoal, at about 20 % abundance (Fig. 17). Stringers of articulated phytoliths are present, as are angular fragments of what appears to be fat-derived char (Goldberg et al. 2009). A large passage feature in this unit indicates some degree of disturbance by bioturbation.

The contact with unit 4 is gradual and marked by a lighter colour in PPL and a significant decrease in the amount of charcoal present. This unit has a similar frequency and occurrence of quartz grains as described for unit 3 and 1; however, the fine fraction is composed largely of phytoliths, many articulated but showing no preferred orientation



Fig. 17. Microphotographs of sample EBC-12-05. 17A) A stringer of articulated phytoliths. PPL. 17B) Fragments of fat-derived char. PPL. 17C) The outer rim of a biogallery. PPL. 17D) a crust that formed at the contact between units 5 and 6. MicroFTIR analysis of this crust shows that it is composed of opal and taranakite. PPL.

and appearing chemically altered. Finely comminuted organic material is also present as are silt-sized, ovular crystal aggregates with weak, low-order interference colours.  $\mu$ FTIR measurements made on these aggregates in thin section identified them as opal. Some bone fragments are present in this unit; all are sand-sized and sub-rounded. Direct measurements on these bone fragments in thin section with the FTIR suggests that they have been burnt, based on comparison with experimental reference samples in thin section and molecular changes to bone apatite with heating reported by Thompson et al. (2013). One in particular appears greyish in colour in PPL and has been heated to high temperature, as indicated by the presence of a peak at 625 cm-1. As with other units in this sample, unit 4 appears partially disturbed by bioturbation.

The contact with overlying unit 5 is relatively sharp and irregular. This unit generally resembles unit 3 in appearance. It contains several sub-angular, sand-sized fragments of bone that appear partially dissolved, as well as sand-sized aggregates of clay and silt. Unit 5 is relatively thick, ca. 2 cm, and exhibits no clear structural features or fabric. The top of this unit is capped by a mm-thick crust that appears yellow to brown in PPL. In XPL the lighter-yellow coloured areas appear strongly birefringent and exhibit first-order grey and white interference colours. The darker brown areas are isotropic.  $\mu$ FTIR measurements made on this crust in thin section show that it is variably composed of opal and taranakite. In places it appears partially disturbed and fragmented, likely as a

result of bioturbation. Where the crust is still in place, the contact with overlying unit 6 is sharp but where disturbed by bioturbation, the contact is more diffuse. Unit 6 has a similar composition to units 1, 3, 4, and 5 as described in this sample. The base of the unit contains sand-sized fragments of sub-angular charcoal; however, the proportion of charcoal in the unit dramatically decreases, so that the upper portion of the unit generally resembles unit 4. It contains articulated phytoliths, but at a lower frequency than unit 4, as well as opal, and finely comminuted, humified organic material.

In addition to the diagenetic crust, secondary nodules, ranging in size from ca. 100  $\mu$ m to 2 mm, are also present throughout this sample. They are generally pale yellow to dark brown or orange in PPL. The nodules that appear darker in PPL also generally appear more isotropic in XPL, whereas the pale yellow nodules exhibit weak interference colours under XPL, with lower order greys to yellows. The optical characteristics of these nodules are generally similar to those described from sample EBC-12-02. *In situ* measurements made with the  $\mu$ FTIR confirm that they are composed of amorphous silica and taranakite.

### EBC-12-03

This sample was collected from layer Henri and appeared relatively homogenous both in the field and in thin section. Coarse-sand-sized and larger, sub-angular to sub-rounded fragments of woody and herbaceous charcoal are present at 10–20 % abundance and are evenly distributed throughout the sample. Additionally, sand-sized, sub-angular fragments of what appears to be cortical bone are more numerous in this sample than in any of the stratigraphically lower samples. The fragments of bone appear stained, and altered or partially dissolved. Elongated, angular fragments of quartzite bedrock, most under 1cm in size, are present throughout the sample and do not exhibit any preferred orientation. Rounded aggregates of clay and silt, most mm-sized, are present as well.

Secondary nodules, most between 0.5 and 2 mm in size, are present throughout the sample (Fig. 18). Some of the nodules appear dense, light yellow in PPL, isotropic, and fluoresce under blue light. Others are less dense and appear greyish yellow in PPL. These nodules display low-order grey to yellow interference colours under XPL and fluoresce more strongly than the other nodules. In many instances, both types of material are found in the same nodule. In general, these nodules resemble those found in samples EBC-12-01 and EBC-12-02 and FTIR measurements made on them directly in thin section confirm that they are composed of either taranakite, opal, or a combination of both. In some places, the secondary nodules have grown within fragments of charcoal, thereby causing physical breakup of the charcoal.

Passage features are common in this sample, suggesting that bioturbation accounts for the general homogenous appearance of the deposit and the lack of orientation of elongated fragments of bedrock. There are two cm-sized, sub-rounded fragments of laminated organic material that may hint at a former fabric of the deposit that has since been destroyed.

## EBC-12-06

We collected this sample at the contact between layers Fuzy, France, and the stratigraphically undifferentiated portion of the eastern profile that has been significantly affected by nodule growth. Because of the size of this sample we subsampled for thin



Fig. 18. Microphotographs of sample EBC-12-03. 18A) A general view of the deposits, showing secondary nodules of taranakite and opal, as well as a few fragments of bone. Bone was not found during excavation, but sand-sized fragments were visible in thin section. PPL. 18B) A biogallery, indicating the effects of bioturbation on the deposits. 18C) A secondary nodule composed of taranakite and opal, based on microFTIR analysis conducted directly on the thin section. PPL. 18D) Same view, but under blue light fluorescence.

sectioning, so that thin section EBC-12-06B is stratigraphically below EBC-12-06A (Fig. 19). Distinct units are visible in thin section that likely correspond to the units described in the field. The lower 2 cm of EBC-12-06B likely corresponds to Fuzy and contains a poorly sorted mixture of mineral grains ranging in size from coarse silt to coarse sand which is embedded within a fine matrix of finely comminuted organic material. There is little to no pore space between the silt-sized grains of organic material, such that this portion of the sample exhibits a porphyric c/f-related distribution. The upper portion of this sample has a similar composition to the lower portion; however, it is more porous, so that it displays a close to single-space fine enaulic c/f-related distribution. Passage features are present in this sample, suggesting some influence of bioturbation on fabric and composition of the deposit.

Unlike the other samples collected from Elands Bay Cave, EBC-12-06 contains a significant amount of fragmented bone, present at about 10 % abundance. The fragments of bone range from angular to sub-rounded, range in size from fine-sand to gravel, and appear stained, altered and partially dissolved; however, the proportion of bone that appears altered is lower than that described from stratigraphically lower samples. Measurements made directly on the bones in thin section using the µFTIR



Fig. 19. Flatbed scan of sample EBC-12-06 (top and bottom). Note the presence of fragments of bone and secondary nodules.

show that some are burnt. Elongated fragments of bone display no preferred orientation and they appear to be more frequent in the lower portion of the sample (layer Fuzy) compared to the rest of the sample, which likely corresponds to layer France.

Gravel-sized fragments of quartzite bedrock are also present in this sample, and are distributed evenly throughout, at an abundance of ca. 20 %. Unlike bedrock fragments found in other samples, here the fragments do not appear elongated but rather are more equant. One rounded fragment of sandstone, ca. 2 cm in size, exhibits a textural coating of silt and sand. Since textural pedofeatures are otherwise almost completely absent from the deposits at Elands Bay Cave, it is likely that this coating was inherited from the original source of the grain, possibly a soil from outside of the cave. As in other samples collected from Elands Bay Cave, this sample contains aggregates of clay and silt. Larger, gravel-sized, sub-angular to sub-rounded fragments of woody charcoal are also present at a slightly lower abundance compared to the fragments of bedrock, and are evenly distributed throughout the thin section.

The upper thin section from this sample, EBC-12-06A, covers the stratigraphically undifferentiated deposit. The micromorphological characteristics of this sample are very similar to those described for EBC-12-06B, apart from some weakly expressed lamination towards the bottom of the thin section. Additionally, a cm-sized angular fragment of iron oxide is present in this sample. This fragment also displays well-developed, laminated limpid clay coatings, suggesting that it, like the rounded grain of sandstone found in EBC-12-06B, likely originated from a soil outside of the cave. However, it is possible that it was collected and transported to the site by humans.

Secondary nodules, generally ranging in size from 200 µm to ca. 1 cm are present in both thin sections (Fig. 20). FTIR measurements on loose samples of these nodules collected in the field identified the minerals as gypsum and apatite, which was confirmed by measurements made with the µFTIR directly on the thin sections. Further measurements made with the uFTIR confirmed that some of the nodules are also composed of whitlockite  $(Ca_{18}Mg_2H_2(PO_4)_{14})$ , based on the presence of a multicomponent peak centred at 984 cm-1, a sharp peak at 601 cm-1 and a doublet at 555 and 542 cm-1. A single nodule containing ardealite was also identified in EBC-12-06. Additionally,  $\mu$ FTIR measurements confirmed the presence of taranakite nodules within the sample. The nodules of gypsum and whitlockite are difficult to distinguish from one another in thin section when relying solely on optical characteristics. Both exhibit bladey crystals, ca. 20 µm in size, with low-order white and grey interference colours, with random crystal orientation. They do not fluoresce under blue light. Some nodules of gypsum appear slightly yellowish in PPL at low magnification, whereas others are transparent and exhibit no obvious colour. Hydroxyapatite nodules are yellowish in PPL and appear cryptocrystalline to amorphous. Others appear to be composed of parallel bundles of individual crystals that have a booklet-like appearance. The hydroxylapatite nodules are either isotropic in XPL or exhibit weak, low-order white and grey interference colours. They fluoresce under blue light. The nodules of taranakite are generally sand-sized and appear grey in PPL. They fluoresce strongly under blue light and are either isotropic or exhibit milky, low order interference colours under XPL. Taranakite, gypsum and hydroxylapatite nodules occur throughout all of EBC-12-06; however, their spatial distribution is variable. Taranakite is more common towards the



Fig. 20. Microphotographs of EBC-12-06. 20A) Larger, better preserved fragments of bone are more common in this portion of the site. Here, secondary nodules of hydroxylapatite and gypsum are visible. PPL. 20B) Some of the fragments of bone have been physically broken apart by the growth of secondary minerals, here, gypsum. PPL. 20C) Although bones are better preserved here than elsewhere in the site, some still exhibit evidence of partial dissolution, as exhibited by their irregular form. PPL. 20D) a fragment of iron oxide. PPL.

base of EBC-12-06b whereas gypsum and hydroxylapatite are more common towards the top of EBC-12-06a.

## EBC-12-07

We collected this sample from the eastern profile from layers Farik, Fael and Dorothee, although no obvious stratigraphic units were identifiable in the thin section. The mineral grains in this sample seem to be present at a higher abundance than in other samples, up to 50 %. Sand-sized, sub-rounded to sub-angular fragments of charcoal are present in relatively low abundance (5–10 %). Bone is relatively abundant, at about 10 %, and appears most frequently as sand-sized, subangular fragments that display a range of colours, from yellow to orangish-brown in PPL. Some appear greyish-white and appear milky in XPL, suggesting that they are calcined. Other fragments of bone appear partially dissolved. Elongated components, such as fragments of bedrock, bone and charcoal, do not display any preferred orientation. This, and the presence of passage features, suggests that these deposits were influenced by bioturbation.

Nodules are present in this sample, although they are generally smaller than elsewhere, such as in sample EBC-12-06. Here they are generally mm or smaller in size and range

in colour from grey to pale yellow in PPL. Under XPL they appear isotropic to weakly birefringent with lower order interference colours. Measurements made on these nodules in thin section using the  $\mu$ FTIR confirmed that they are variably composed of hydroxylapatite and opal.

## EBC-12-08

We collected this sample from the south profile near the contact between stratigraphic phases F and D, making it stratigraphically equivalent to sample EBC-12-7. There is only one depositional unit within this sample. This sample is distinct from most other samples from Elands Bay Cave in that it contains a relatively higher proportion (ca. 15 %) of angular, equant fragments of quartzite, likely derived from the cave ceiling and walls. Additionally, this sample has a relatively higher proportion of gravel-sized, sub-rounded fragments of charcoal, present at about 30 % abundance. Sand-sized, subangular fragments of bone are also present, at ca. 10 % abundance, and display a range of colours and states of preservation, similar to those described in sample EBC-12-07. Elongated components do not appear to display any preferred orientation.

Nodules are present in this sample and are similar in size and frequency to those described in sample EBC-12-07. They appear grey in colour in PPL and exhibit milky white interference colours in XPL, and sometimes occur as coatings on grains of quartz. *In situ* measurements made on these nodules in thin section using the  $\mu$ FTIR showed that these are variably composed of hydroxylapatite and opal. A single round nodule displayed similar characteristics to the other nodules found in this sample, but contained several spherulitic crystals within it and appeared yellow in PPL and displayed lower order grey and yellow interference colours in XPL (Fig. 21). Measurements on this nodule made with the  $\mu$ FTIR suggest that this nodule is heat-altered phosphate, based on the presence of the 625 cm-1 peak (Thompson et al. 2013).

## DISCUSSION

The results from our study show that the deposits of Elands Bay Cave formed through various depositional and post-depositional processes influenced by geologic, biologic and anthropogenic agents. Here we discuss the roles that these various agents played in the accumulation of sediments at the site and integrate these results to present a synthetic formation model.

#### Geologic processes and sources

Both Butzer (1979) and Miller (1987) argued that Elands Bay Cave itself is a former sea cave scoured out during a previous marine high stand. We see no evidence supporting or rejecting this claim. However, we believe that a more significant feature governing the formation of the cave is a vertical joint in the bedrock that runs the entire length of the ceiling and along the back wall. GPR data collected during this study suggests that this joint continues under the sediments and is the cause for the basin-like structure in the buried bedrock of the cave. Erosional processes-whether initially induced by wave action or not-likely exploited the joint as a zone of weakness, so that enhanced erosion along the joint eventually led to the formation of the cavity. The main processes of bedrock erosion within the cave today seem to be spalling, granular disaggregation, and possible aeolian abrasion, which is implied by the smooth surfaces on the walls of the



Fig. 21. Microphotographs of EBC-12-08. 21A) Bone fragments are relatively common here, but still exhibit evidence of dissolution. PPL. 21B) A nodule of hydroxylapatite that has been heated, based on measurements collected with the microFTIR directly on the thin section. PPL. 21C) Same view, but XPL. 21D) Same view, but under blue light fluorescence.

cave. The presence of ancient rock art on the cave walls suggests that modern erosion of the cave walls occurs at a very slow rate. These erosive processes, particularly spalling and granular disaggregation, contributed to the accumulation of geogenic deposits within the cave. Both Butzer (1979) and Miller (1987) suggested that the formation and accumulation of roof spall within the site, particularly in phase L, was induced by frost action. Given that modern-day temperatures in the area around Verlorenvlei do not regularly fall below freezing, this claim would imply that the climate on the west coast during the Pleistocene was at times significantly cooler than today. Butzer (1979) correlated the spall-rich deposit at Elands Bay Cave with other colluvial deposits found outside the cave. He used these observations to argue for a wide spread period of cold conditions during MIS 6 (Butzer 1979).

We find the arguments for frost-induced spalling at Elands Bay Cave equivocal. The link between coarse-grained, spall-rich layers in caves and cold climatic conditions was argued by researchers such as Laville (1973) working in the Paleolithic caves of southwestern France. These formation models generally interpreted red-coloured layers within the caves as representing *in situ* pedogenesis initiated during warm, wet interglacial periods. Layers rich in spall, or *éboulis*, formed as a result of frost-induced spalling and could therefore be correlated with cold, glacial periods. Subsequent geoarchaeological

studies showed that the red-coloured layers were not in situ soils, but were composed of colluvially reworked soil material (Goldberg 1979). Additionally, studies on the effects of frost action on rock suggests that formation of *éboulis* is a more stochastic process than was previously assumed, making it difficult to directly correlate a spallrich layer with a specific climatic period (Lautridou & Ozouf 1982; Bertran 1994; Goldberg & Macphail 2008). Furthermore, the occurrence of a layer rich in coarse material does not necessarily imply a higher rate of accumulation of coarse material. A similar pattern can appear when the rate of *éboulis* accumulation remains constant, but the accumulation of finer sediment is variable. Therefore, we see no reason to apply outdated formation models developed for karstic caves in temperate Europe to sandstone shelters in semi-arid Africa. Rather, the more parsimonious explanation for the formation and accumulation of spall at Elands Bay Cave is salt-crystal growth. Salt-induced spalling is an active process occurring in Elands Bay today. The salts that form in the cave likely have their ultimate source from the ocean; however, the occurrence of salt-induced spalling is not necessarily a proxy for shoreline proximity: salt-induced spalling has been observed as a modern-day process at more interior sites as well, such as Diepkloof and Sibudu (Goldberg et al. 2009; Miller et al. 2013; Miller & Mentzer pers. observation).

Individual silt- and sand-sized grains of quartz and occasionally feldspar are a significant geogenic component of the sediments at Elands Bay Cave. Based on our qualitative observations of the thin sections, we estimate that they occur at between 10 % and 50 % abundance. Both Butzer (1979) and Miller (1987) addressed the issue of source and deposition for the sandy component of sediments at Elands Bay Cave. They both noted that the sand-sized fraction from phases L through D was poorly sorted, but Miller concluded that this was a result of high energy winds, whereas Butzer thought that this was a result of a strong influence of sand grains derived from the cave ceiling and walls. In thin section we also observed that the mineral fraction is poorly sorted, and displays a wide range of degree of rounding, with some grains appearing sub-angular and others appearing well-rounded. Given the heterogeneity of the mineral grains, we would tend to agree with Butzer's interpretation. It is likely that most of these grains derived from granular disaggregation of the cave ceiling and walls. However, as Butzer (1979) pointed out, some of the grains also likely derived from the *in situ* break down of blocks of bedrock contained within the deposits. We observed this process in the field, as large nodules of gypsum appeared to have broken apart sandstone blocks that were soft and saprolitic. Additionally, in thin section, we observed smaller blocks of bedrock that appeared partially disaggregated as a result of secondary mineral formation. These observations show that post-depositional processes can contribute sand-sized grains of quartz to deposits, suggesting that we should be cautious when attempting to interpret granulometric data from sandstone rock shelters or caves as purely a function of depositional energy. Furthermore, the process of in situ disaggregation of sandy bedrock could contribute a portion of quartz grains to the sediment that have not been completely bleached, complicating luminescence age estimates (Tribolo 2016 this issue).

Another significant geogenic component of the deposits at Elands Bay Cave are sand-sized aggregates of sand, silt and clay. Based on the stipple-speckled and striated b-fabric exhibited by the clay fraction of these aggregates, and the lack of any obvious autochthonous source of clay within Elands Bay Cave, we believe that these aggregates derived from soils located outside of the cave. Similar aggregates have been reported from a variety of cave and rock shelter sites around the world, often associated with ashy deposits (Goldberg 2001, 2003; Pinhasi et al. 2014; Villagran et al. 2016). Although the abundance of the aggregates varies from layer to layer at Elands Bay Cave, they are ubiquitous throughout the studied sequence. Modern-day soils in the vicinity of Elands Bay Cave are almost exclusively weakly-developed arenesols that lack well-developed argillic horizons. However, Butzer (1979) reported the presence of more strongly developed paleosols in the region. He did not provide detailed descriptions of the horizons within the paleosols but did note that some of them display deep cambic horizons and some display blocky structures. Unfortunately, we do not have any reference samples from these paleosols to compare to the soil aggregates found in the cave. However, given the sandy nature of modern soils in the region, we believe that these aggregates derived from soils that formed under much different environmental conditions than those prevailing today.

In other South African rock shelters, the presence of soil aggregates may be due to human activity. For example, Miller et al. (2013) and Goldberg et al. (2009) reported the presence of soil aggregates at the Middle Stone Age sites of Diepkloof and Sibudu. In Sibudu Goldberg et al. (2009) documented gleyed soil aggregates containing diatoms, which they argued were most likely transported to the shelter on the roots of sedges collected by humans from the nearby Tongati River for the construction of bedding.

The soil aggregates at Elands Bay Cave do not appear more frequently in layers that we interpret as anthropogenic features, making it unlikely that the aggregates indicate a human mode of accumulation. Butzer (1979), in his description of a section exposed near the Elandsberg tunnel, noted the presence of reddish-coloured colluvial deposits that he interpreted as pedosediments formed during a phase of landscape denudation in MIS 5b. The ubiquity of soil aggregates throughout the sequence at Elands Bay Cave suggests that they cannot be linked directly to any specific climatic event; however, it is possible that processes contributing to landscape denudation posited by Butzer were also responsible for the deposition of soil aggregates within Elands Bay Cave.

## Anthropogenic deposits and processes

Sedimentary components that are likely anthropogenic in origin are ubiquitous throughout the sequence at Elands Bay Cave. These components include fragments of charcoal, chipped stone, bones (both burnt and unburnt) and phytoliths. Many of these components are found as individual, isolated occurrences within the ground mass; however, these components also occur as distinct lenses and laminations that likely represent discrete anthropogenic depositional events. We encountered most of the anthropogenic lenses within depositional phase T which appeared laminated in the field. The most common type of anthropogenic deposit found in the Elands Bay Cave samples were charcoal lenses. The charcoal in these lenses appeared both woody and herbaceous; however, some of the charcoal in these lenses was present as silt-sized aggregates, implying some degree of post-depositional alteration, possibly as a result of soil microfauna preferentially ingesting the charcoal, a process observed at other sites (Mentzer et al. 2014; Baykara et al. 2015). Silt- and sand-sized grains of quartz are generally absent from these lenses, or present in relatively low abundance (ca. 5 %),

particularly when compared to other microstratigraphic units where grains of quartz are generally present at much higher abundances (up to 50 %). Goldberg et al. (2009) and Miller et al. (2013) also noted that in other Middle Stone Age sandstone shelters in South Africa, grains of quartz are often absent or present in low abundances from charcoal-rich lenses. They argued that this implies a rapid accumulation of the charcoal, suggesting that these lenses represent anthropogenic combustion features. At Sibudu and Diepkloof, charcoal lenses are sometimes overlain by lenses of calcareous ashes or phosphatic or siliceous material which may have been derived from the diagenetic alteration of ashes. In the deposits examined in this study at Elands Bay Cave, calcareous materials, including ashes, are completely absent, which is likely a result of dissolution induced by acidic conditions within the sediments (see below). Unlike Sibudu and Diepkloof, however, we see little evidence for phosphatised or otherwise altered lenses of ashes above the charcoal lenses. An exception to this is found within Phase I where some of the charcoal lenses appear capped by lenses of laminated, articulated phytoliths. The charcoal in these lenses is generally herbaceous and also appears laminated. Goldberg et al. (2009), Wadley et al. (2010) and Miller et al. (2013) interpreted the association of laminated herbaceous charcoal with a capping lens of laminated phytoliths as representing burnt plant bedding. Given reports of laminated phytolith layers from several Middle Stone Age sites, including Sibudu (Goldberg et al. 2009; Wadley et al. 2011; Miller 2015) and Diepkloof (Miller et al. 2013; Miller 2015), it is possible that the phytolith layers at Elands Bay Cave also represent burnt bedding. However, unlike Sibudu, where numerous examples of phytolith layers have allowed researchers to carefully study their occurrence, we only have a few examples of this type of deposit at Elands Bay. Therefore, we make the identification of burnt bedding at Elands Bay Cave cautiously.

The occurrence and structure of combustion features within the Middle and earlier Later Stone Age deposits at Elands Bay Cave appear diachronically variable, at least within the studied section. Anthropogenic deposits from phase I appear thin and laminated, whereas combustion features within stratigraphically later phases, such as phase D and F exhibit a basin-like morphology, resembling en cuvette hearths, and appear superimposed. Samples collected from phases D and F, particularly samples EBC-12-07 and EBC-12-08, were rich in burnt anthropogenic components, such as charcoal and burnt bone; however, the components in these samples were not organized into any clear microstructure but rather appeared dispersed throughout the ground mass. This pattern is in contrast to the thin, sometimes laminated anthropogenic lenses identified in samples from phase I, particularly in EBC-12-02 and EBC-12-04. As in many Middle Stone Age sites in South Africa, the deposits at Elands Bay Cave preserve evidence for discrete depositional episodes where humans were the main agents of accumulation. In phase I, the anthropogenic lenses are not directly stacked on top of one another, but are often separated by thin layers that appear more geogenic in nature. These separating layers do not exhibit any clear bedding structures, but consist of homogenous mixtures of quartz sand, finely comminuted organic material, and anthropogenic components, such as charcoal and occasionally bone. In other instances, such as in sample EBC-12-02, combustion features are capped by, or rest directly on, thin layers composed largely of angular blocks of roof spall. Other micromorphological studies of anthropogenic deposits from Middle Stone Age sites in South Africa report

a similar pattern of anthropogenic materials or deposits separated from one another by deposits with a more natural origin. For example, at Die Kelders, Goldberg et al. (2000) reported thin layers and lenses of burnt organic material and bone that appeared to rest on distinct microsurfaces and which were separated from other similar layers by deposits composed largely of aeolian sand. Karkanas et al. (2015), working at Pinnacle Point 5–6, reported similar anthropogenic layers, rich in carbonized plant material, ashes and burnt bone, that were separated by layers of geogenic sands. They noted that the density of the anthropogenic layers relative to the geogenic layers increased during MIS4, a pattern they interpreted as indicating an intensification of use of the site. At Diepkloof, Miller et al. (2013) reported that the deposits associated with the Intermediate Howiesons Poort and earlier occupations consisted of discrete lenses of charcoal and ash that were separated by reddish-coloured layers composed of sandand silt-sized grains of quartz, humified organic material, and sand-sized fragments of bone and charcoal. Although these reddish layers contained components that have a clear anthropogenic source, they also contained a high proportion of geogenic and biogenic components. However, unlike at Die Kelders or Pinnacle Point, Miller et al. (2013) suggested that these deposits were significantly influenced by anthropogenic trampling, an interpretation also offered by Goldberg et al. (2009) to explain similar deposits associated with Howiesons Poort and earlier occupations at Sibudu. The deposits from phase I at Elands Bay Cave are most similar to those described at Die Kelders and the Intermediate HP at Diepkloof. These deposits are in contrast to those described from post-Howiesons Poort occupations at Sibudu (Goldberg et al. 2009) and those associated with Intermediate to post-Howiesons Poort occupations at Diepkloof (Miller et al. 2013): here, anthropogenic lenses and layers of charcoal, ash and phytoliths rest directly on top of each other and are not separated by layers with a more geogenic nature.

Given the limited spatial extent of the current excavations and the micromorphological sampling at Elands Bay Cave, it is difficult to interpret the frequency and occurrence of anthropogenic deposits throughout the sequence in terms of intensity of site use or organization of domestic space, as was attempted at Diepkloof (Miller et al. 2013) and Sibudu (Goldberg et al. 2009; Wadley et al. 2011). However, the occurrence of combustion features separated by geogenic layers seems to imply that at least during the accumulation of phase I, repeated periods of occupation were followed by longer periods of limited or no occupation.

## Biogenic processes of accumulation and alteration

Biological sources of sediment and processes of deposition can be difficult to identify and distinguish from anthropogenic sources and processes. Sand-sized fragments of bone which, despite adverse preservation conditions, are found throughout the deposits at Elands Bay Cave, could have been deposited by humans or animals. While burnt bones are usually assumed to be indicative of human activity, it is not always clear if the burning of the bone was intentional or accidental. Even more ambiguous in terms of anthropogenic versus biologic source is the finely comminuted organic material that makes up a significant portion of the fine fraction of deposits from Elands Bay Cave. Much of this material is silt-sized and displays a reddish- or chestnut-brown colour in PPL, implying that it is humified and not carbonized. However, many of

the silt-sized fragments of organic material appear black and opaque, suggesting that at least some proportion may have been carbonized. Distinguishing between humified and carbonized organic material can be difficult in thin sections (Stahlschmidt, Miller, Ligouis, Hambach et al. 2015); however, organic petrographic analysis of two of the Elands Bay Cave samples has clarified the nature of the fine organic fraction. Most exhibit reflectance values classifying them as fusinite, implying that they have been altered to some degree by heating and are therefore charcoal. However, our analysis also shows that prior to burning, the organic material underwent varying degrees of humification. This observation has two possible interpretations. One, the occupants of Elands Bay Cave collected plant material for their fires that was old and partially humified, a behaviour proposed for the site of Lapa do Santo in Brazil, based on similar observations (Villagran et al. 2016). Or two, the occupants of Elands Bay Cave built their fires directly on humic-rich surfaces, leading to unintentional combustion of organic material already contained within the sediment (Mallol et al. 2013). Scenario one would imply a largely anthropogenic source for the organic material at the site, whereas scenario two could imply either a biological or anthropogenic source. Based on the current samples and observations at Elands Bay, it is not possible for us to state which scenario is more likely.

Biologic influences on the deposits at Elands Bay Cave are more readily apparent as post-depositional processes. Evidence for bioturbation is prevalent at the site. In thin section, passage features, usually 1 cm or smaller in diameter, are relatively common and in the field, krotovinas, often ca. 5 cm in diameter, are easily identified. One krotovina from the northern profile of the current excavations is particularly noteworthy. It exhibits a white crust of secondary minerals, most likely gypsum, which formed along its outer boundary resulting in a ring-like appearance in profile. This krotovina was first encountered during Parkington's initial test excavations into the Middle Stone Age deposits (per. comm.) and served as a key reference point for correlation between his and the current excavations. Although evidence for bioturbation is common at Elands Bay Cave, the burrowing animals did not completely homogenize the deposits. Even in areas of the excavation where we find passage features and krotovinas, preservation of distinct layers and laminations imply relatively minimal stratigraphic disturbance, at least within the wetting front.

## Chemical diagenesis at Elands Bay Cave

Significant observations that may be linked to biologic processes at Elands Bay Cave are the effects of post-depositional chemical diagenesis. All of the deposits analysed in this study have undergone some degree of chemical and physical alteration as the result of dissolution or secondary precipitation of diagenetic minerals.

Chemical diagenesis of archaeological cave deposits has only been intensively studied from limited contexts: most studies have targeted limestone caves with ashy sediments from the eastern Mediterranean (Goldberg & Nathan 1975; Weiner & Goldberg 1990; Weiner et al. 1993; Karkanas et al. 1999; Karkanas et al. 2000; Weiner et al. 2002). There, the main agent of diagenetic alteration is phosphoric acid, along with other types of acids, which in these caves is often assumed to derive from the decomposition of bird and bat guano (Shahack-Gross et al. 2004). Researchers working at sites such as Kebara, Hayonim, Tabun and Theopetra showed that phosphate-rich

solutions reacted with the calcite from limestone blocks and ashes to form secondary minerals composed of apatite. Under conditions of low pH, apatite itself is not stable and other phosphate minerals—some containing K, Al, and/or Fe—preferentially form, such as montgomervite, crandallite, or taranakite. For example at Kebara, Weiner et al. (1993) identified a block of dolomite that fell to the floor of the cave and was subsequently buried. The carbonate-rich rock reacted with the phosphate-solution in the deposits, forming a reaction rim of secondary minerals on the rock's surface. The first mineral to form was apatite (or dahllite, as they reported it), which was replaced by a non-stoichiometric calcium-phosphate phase which was in turn coated by crandallite, montgomervite and leucophosphite. The succession of mineral formation found on this block suggested to the authors that these minerals represented a reaction cascade, with minerals replacing one another over time. Karkanas et al. (1999), working at Theopetra Cave, reported a similar reaction cascade, but one found across several meters within the sediments of a single geological layer, that progressed from calcite to apatite to montgomervite or crandallite, and finally taranakite. Both the reaction rim on the dolomitic block from Kebara and the alteration zone in the sediments from Theopetra show a pattern of initially high Ca proportions in the original material progressing towards secondary minerals with higher proportions of Al, Fe, and K. Karakanas et al. (2000) point out that these elements can be found in ashes derived from the burning of wood, but that they can also be found in clays, which would begin to breakdown under low pH conditions (Shahack-Gross et al. 2004). These studies suggested that the presence of more 'advanced' phosphate minerals, such as taranakite or leucophosphite, implies the occurrence of a reaction cascade through the preceding minerals. However, Karakanas (2010) points out, based on the calculation of mineral phase diagrams, that although apatite is the stable phosphate mineral under alkaline pH conditions, the phosphate mineral phase that forms under acidic conditions is not solely dependent on pH but also on the available ions in solution. For instance, in situations where Ca ions are not available, such as in an already decalcified deposit, low pH phosphate minerals containing Ca, such as crandallite, will not form, but rather taranakite and other minerals lacking Ca will preferentially form. Similarly, the availability of Al in solution can govern whether the formation of crandallite or montgomervite is preferred.

The formation of secondary phosphate minerals is governed by the specific chemistry of the solutions present in the deposits, which can vary spatially within a site, can change over time and can be different from site to site. Therefore, the identification of secondary minerals can be informative about variation in past sedimentary conditions, such as pH, moisture availability, and oxidation conditions. Furthermore, by understanding how these types of conditions have changed over time, we can better assess the preservation of certain classes of artefacts and deposits at archaeological sites (Karkanas 2010). For example, under high concentrations of phosphorous in solution, materials commonly found at archaeological sites that are composed of carbonates-such as limestone blocks, shells and ashes-will alter to form secondary calcium phosphate minerals, such as hydroxylapatite. Under low pH conditions, other secondary phosphate minerals, such as crandallite or montgomeryite, can preferentially form since apatite is not stable under these conditions. Under low pH conditions, other common archaeological materials composed of apatite, such as

bone, will also not be stable. Berna et al. (2004) experimentally demonstrated that bone contained within sediment with a pH above 8.1 is stable and that bone in sediment with a pH of 7.4 to 8.1 will recrystallize and be replaced by more stable forms of apatite. When pH of the sediment drops below 7, bone readily dissolves releasing P ions into solution which can then form secondary phosphate minerals. Therefore, the presence of secondary, low-pH phosphate minerals in an archaeological deposit can tell us about past conditions that may have been adverse for the preservation of shell, ashes and even bones. At Kebara, Weiner and others (Weiner et al. 1993, 2007) used the spatial distribution of taranakite and other minerals that can form under low pH conditions in the cave's deposits to explain the presence or absence of bone. They noted that taranakite, crandallite and montgomeryite were present in deposits where bone was absent. Apatite and calcite were present where bones were found. Therefore, they argued that the spatial variation in occurrence of bone was not linked to human behaviour, but rather to chemical diagenetic processes influencing the deposits after burial.

The study of chemical diagenesis in archaeological cave and rock shelter sites in South Africa has been limited when compared to those of the Levant. At Die Kelders, Goldberg et al. (2000) reported that calcareous sands and ashes underwent phosphatisation thereby leading to slumping and physical deformation of the deposits. They did not conduct mineralogical analyses such as FTIR on the deposits, but identified the main secondary phosphate mineral forming at Die Kelders as apatite, based on micromorphological thin section analysis. Schiegl and Conard (2006) also reported secondary minerals found forming in the deposits from Sibudu. Using FTIR analysis of loose samples, they identified apatite and gypsum as the main diagenetic minerals found at the site; however, using SEM-EDS analysis of polished and carbon-coated blocks of indurated sediment, they identified traces of leucophosphite, taranakite and crandallite. Karkanas and Goldberg (2010) similarly noted the presence of secondary apatite and sulfate minerals at Pinnacle Point 13-B. Here they identified lozengeshaped crystals of gypsum that had been replaced by anhydrite. Miller et al. (2013), working at Diepkloof Rock Shelter, also reported the presence of several diagenetic minerals found at the site. They noted the presence of secondary apatite and gypsum, but also noted that niter (KNO<sub>2</sub>) forms extensive surficial crusts at the site, and sveite  $(KAl_7(NO_3)_4(OH)16Cl_2 \cdot 8H_20)$  forms along cracks in the wall of the shelter.

The secondary minerals found at Elands Bay Cave generally fit with those identified at the Levantine and South African cave sites and include gypsum, hydroxylapatite, taranakite and variscite. We also identified three more uncommon minerals: ardealite, whitlockite and dawsonite. Ardealite has been identified in non-archaeological contexts within Eastern Mediterranean caves (Shahack-Gross et al. 2004), as well as in numerous studies of guano deposits (Marincea et al. 2004; Onac et al. 2006; Frost et al. 2011). Whitlockite has been identified in limited archaeological contexts, including within bones and dental calculus (Preus et al. 2011; Monge et al. 2014), as well as in secondary crusts attributed to decomposition of bird guano (Watchman et al. 2001). Both whitlockite and ardealite have been identified in South Africa at Sibudu (Mentzer et al. 2014), but their formation histories at this site are presently unknown. To the best of our knowledge, dawsonite has never been identified in an archaeological context, although it was documented as a weathering product in soils located in Olduvai Gorge (Hay 1963; Hay & Reeder 1978).



Fig. 22. Photograph of the eastern profile, showing the general distribution of secondary minerals.

Like at Kebara (Weiner et al. 1993), Hayonim (Weiner et al. 2002) and Theopetra (Karkanas et al. 1999), the distribution of secondary diagenetic minerals exhibits spatial variability at Elands Bay Cave (Fig. 22). Variscite was only identified in sample EBC-12-01 within layer Keva, which was the stratigraphically lowest sample collected for this study. Here, variscite is exclusively found as alteration nodules formed within soil aggregates. Variscite is known to form as a result of reaction between phosphateenriched groundwater and aluminium-rich rocks (Larsen 1942; Frost et al. 2004) or clays (Odriozola et al. 2010) and crystallizes under generally acidic conditions (Kittrick & Jackson 1955; Hsu 1982). Karkanas et al. (1999) report the presence of variscite as a cementing mineral within the lowermost unit of Theopetra cave and Weiner et al. (2002) noted its presence in sediments from Hayonim in association with leucophosphite and montgomervite. Karkanas et al. (2000) also note that at Kebara, bone found at the transition between sediments containing apatite and those containing montgomervite had transformed to variscite. Interestingly, the soil aggregates which have partially altered to variscite only appear in layer Keva. Based on the lithic assemblages found within Keva and underlying layers, the top of Keva likely represents a significant unconformity within the stratigraphic sequence. Soil aggregates found directly above this contact-within the same thin section-do not display evidence for variscite alteration. Therefore, the stratigraphic association of variscite with the oldest deposits at the site may imply an early phase of chemical diagenesis that predates the deposition of layers Kelly/Kent.

Taranakite has been widely reported as a secondary diagenetic mineral found in archaeological cave and rock shelter sites (e. g. Karkanas et al. 2000; Weiner et al. 2002; Schiegl & Conard 2006; Mentzer et al. 2014) and generally forms under low pH conditions. At Elands Bay Cave, taranakite has been found in almost every sample, but is particularly abundant in samples collected from within the wetting front, towards the southern end of the main section. In the field, we observed the taranakite as small, mm-sized flecks and similarly small rootlet-like veins. In thin section, the taranakite appears as small mm-sized nodules, often associated with secondary opal, and as crusts. Towards the edge of the wetting front taranakite is still present, but significantly less abundant than to the south; additionally, other minerals are present at this transition.

In the field, the edge of the wetting front is marked by the occurrence of large, white nodules of gypsum which are found extensively across the site. Millimetre to cm-sized nodules of gypsum are present in sample EBC-12-06, which was collected at the edge of the wetting front. Parkington et al. (1987) noted the presence of gypsum nodules and suggested that these likely formed as a result of marine aerosols entering the cave, which had an increasing significance as sea-levels transgressed the coast during the terminal Pleistocene and early Holocene. Given the proximity of the site to the modern shoreline, and the presence of dissolved ions within the drip water collected from the site, it is likely that at least some of the sulfate responsible for the formation of gypsum has a marine origin. However, gypsum has been noted in archaeological sites in South Africa that are not close to the modern shoreline, such as Diepkloof (Miller et al. 2013), Sibudu (Schiegl & Conard 2006; Goldberg et al. 2009), Bushman Rock Shelter (Badenhorst & Plug 2012), and Wonderwerk Cave (Goldberg et al. 2015). Furthermore, gypsum can form as a secondary mineral during the decay of organic material, in particular guano (Shahack-Gross et al. 2004). Karkanas and Goldberg (2010) suggest that the decay of guano is the likely source for gypsum found in deposits at Pinnacle Point 13B, another coastal, Middle Stone Age site in South Africa. In general, the source and formation of gypsum at Elands Bay Cave and other cave and rock shelter sites in South Africa seems to be complex and not linked to a single cause. Further adding to the complexity of gypsum formation at archaeological sites is the mineral's high solubility, which allows it to readily and quickly dissolve and reprecipitate. At Elands Bay Cave the gypsum found in profile appeared to have become more extensive during the decades separating the original excavations of Parkington and those of the current team (Parkington & Porraz, personal observation). In addition, there is evidence in the thin sections that the spatial extent of gypsum at the site was variable in the past. In sample EBC-12-02located towards the south of the main section within the wetting front-we identified voids formed within a crust of taranakite that appear pseudomorphic after gypsum. Today, gypsum is absent from this part of the site. The pseudomorphic voids suggest that gypsum was initially present here and that it predated the formation of taranakite within the deposits. The subsequent dissolution of the gypsum implies that this area of the site became wetter at some point in the past.

Most secondary nodules of hydroxylapatite are found in sample EBC-12-06; however, they also occur in samples EBC-12-07 and EBC-12-08. Of particular interest is the occurrence of secondary nodules of hydroxylapatite in sample EBC-12-08 (from depositional phase D and F) that appear to have been heated. The heating of these nodules was likely incidentally caused by fires built by the occupants of the site. This

would imply that some chemical alteration of the deposits had taken place prior to human occupation of the site during phase D and F, which Tribolo et al. (2016 this issue) date to ca. 19 000 BP.

We identified other secondary phosphate minerals in sample EBC-12-06, including whitlockite and ardealite. In total, these minerals were only identified in three nodules (two in thin section and one loose sample), and therefore it is difficult to propose specific formation pathways. However, both of these minerals have also been identified at Sibudu (Mentzer et al. 2014). As at Elands Bay Cave, ardealite at Sibudu occurs at a transition between a zone that contains sulfate minerals and a zone that lacks sulfate minerals. Whitlockite, on the other hand, needs magnesium to be present in order to form; currently we are not able to identify a possible source for the Mg at Elands Bay, but note that Mg is present within the dripwater at 97.464 mg/L. Further study of the occurrence of whitlockite and ardealite at South African rock shelter sites will hopefully clarify their formation in these types of contexts.

Although some taranakite is found at the edge of the wetting front, secondary nodules of hydroxylapatite are also present and are more numerous than any other type of secondary phosphate minerals in sample EBC-12-06. The nodules of hydroxylapatite appear in the field as yellowish, mm- to cm-sized round nodules, which are also clearly identifiable in thin section. The presence of secondary hydroxylapatite at the transition zone suggests that moisture contained within the sediments was more alkaline towards the north, compared to the zone where taranakite formed. The co-occurrence of gypsum-which is highly soluble-and hydroxylapatite-which is stable under alkaline conditions-suggests that the zone of alteration represents a spatial trend in moisture availability and pH conditions across the site: with wetter, more acidic conditions dominating to the south of the main sector. The most likely source for this moisture is the bedrock joint along which today moisture collects during periods of rainfall. This moisture likely seeps from the joint into the adjacent deposits, creating a wetting front with spatially variable moisture and chemical properties.

The effects of this wetting front are not only visible in the secondary minerals which formed, but also in the preservation of the archaeological remains and deposits themselves. No calcareous materials, such as plant-derived ashes, were found in the deposits despite frequent evidence for burning in the form of charcoal. Furthermore, within the area of the site where taranakite is dominant, no bones were recovered during excavation. In thin section we observed small, sand-sized fragments of bones within this zone, but many of them appeared partially dissolved or altered. Outside of this zone, where hydroxylapatite and gypsum are more dominant, bone was found during excavation and also more frequently in thin section. The absence of calcareous ashes and shell, and the spatial variation in distribution of bones at the site is likely a result of the acidic water which seeped through the joint in the bedrock and permeated the archaeological deposits. However, it is unlikely that the phosphorous found in the secondary phosphate minerals such as variscite and taranakite comes solely from the dissolution of bone. While the chemical break down of bone certainly released phosphorous into the deposits, it is interesting to note that the elemental composition of the drip water collected along the bedrock joint is enriched in elements necessary for the formation of the secondary minerals

found at the site. Phosphorous, which is required to form secondary hydroxylapatite, taranakite, variscite, ardealite and whitlockite, is found in relatively high abundance within the drip water along the bedrock joint as is calcium, which is necessary for the formation of hydroxylapatite, ardealite and whitlockite. Additionally, potassium and magnesium, which are enriched within the drip water, are necessary for forming taranakite and whitlockite, respectively. Other elements, such as aluminium, required to form secondary minerals such as variscite and taranakite likely derive from the dissolution and alteration of components contained within the deposits. We see evidence for this in the form of partially dissolved and altered clay-rich soil aggregates. In general, although the suite of minerals found at Elands Bay Cave is roughly similar to those reported from the Levantine and eastern Mediterranean Middle Paleolithic cave sites (Goldberg & Nathan, 1975; Weiner & Goldberg 1990; Weiner et al. 1993; Karkanas et al. 1999; Karkanas et al. 2000; Weiner et al. 2002), we do not see a need to invoke a reaction cascade (e. g. Weiner et al. 1993) to explain the occurrence of taranakite or other more extreme phosphate minerals.

The effects of the percolating water and secondary mineral formation on the site were not only chemical but also physical. The secondary formation of taranakite has led to the physical destruction of pieces of charcoal and fragments of bedrock. In addition, the growth of large nodules of gypsum has caused significant disturbance to the stratigraphic units and has led to the physical breakdown of large blocks of *éboulis*. The spatial variation in the formation of these minerals means that areas within the zone of taranakite formation preserve the original, finely laminated and bedded aspect of the deposits, but lack bone preservation; areas within the hydroxylapatite and gypsum zone have bones preserved, but have been physically reworked by extensive growth of secondary nodules.

#### Site formation model

Initial occupation of the site began during deposition of phase L. At this time saltinduced spalling produced a high proportion of quartzite flakes from the ceiling and roof of the shelter that filled in the basin-like bedrock base of the site. These quartzite roof spall flakes were likely exploited by the inhabitants for stone tool production; however, it is also likely that the inhabitants transported some higher-quality quartzite from further away (Schmid et al. 2016 this issue). In addition to the accumulation of roof spall, humans built fires, contributing charcoal and burnt bones, and either humans or other biologic agents transported plant material to the site that resulted in the accumulation of humified organic silt. Granular disaggregation of the bedrock and colluvial movement of soil aggregates also contributed to the accumulation of sediment within the site. At some point, accumulation ceased and the deposits were partially eroded leaving an unconformity on top of layer Keva. In thin section, the unconformity is indicated by a thin lag deposit composed of coarse grains of sand and horizontally oriented fragments of roof spall. It is difficult to estimate how much time is missing in the sequence between Keva and Kelly/Kent, especially since it was not possible to obtain reliable ages for these lower deposits (Tribolo et al. 2016 this issue). Furthermore, it is impossible for us to identify what process is responsible for the erosion. However, techno-typological analysis of the lithics suggests that the hiatus may represent a significant period of time, given that there are few similarities

between the assemblages from phase Land Keva/Lara and those from the nearby Middle Stone Age site of Diepkloof (Schmid et al. 2016 this issue; Porraz, Schmid et al. 2016 this issue). The hiatus found in the Elands Bay Cave sequence may represent a period of time covering almost the entirety of the Diepkloof sequence; however, more reliable geochronological data will be necessary to confirm this hypothesis. Prior to, or synchronous with the phase of erosion, acidic water seeping into the deposits through the bedrock joint likely caused decalcification of the deposits and led to the secondary formation of variscite within soil aggregates.

Prior to ca. 40 000 BP, sedimentation recommenced within Elands Bay Cave. Natural modes of accumulation-including roof spalling, granular disaggregation, and soil aggregate deposition-which were active in the earlier deposits, continued to be active in the later phases as well. Humans were also present at Elands Bay Cave with the initiation of sedimentation following the period of erosion. We can see clear evidence for this in the form of a thin charcoal lens, possibly representing a hearth, which was built directly on the erosional surface at the top of layer Keva. Overlying sediments associated with this phase contain multiple thin laminations and lenses of charcoal and laminated phytoliths. Interestingly, these anthropogenic deposits are often separated from one another by thin layers containing higher proportions of geogenic material, suggesting that occupation at Elands Bay during the latter part of the Middle Stone Age was sporadic and likely separated by periods of lowintensity site use or non-occupation. At some point during or after the accumulation of phases K-D, the deposits suffered chemical alteration. Initially, small nodules of gypsum were present as secondary minerals in the deposits, implying some degree of aridity. However, at some point the acidic water from the bedrock joint, which caused decalcification and variscite formation in phase K, also caused the gypsum closest to the joint to dissolve. Additionally, the acidic water seeping through the deposits led to decalcification, alteration of clays within the soil aggregates, and dissolution of bone. The dissolved bone released phosphorous into the deposits and this, combined with additional phosphorous and other ions from the seep water, led to the formation of secondary minerals such as taranakite. Further away from the joint the deposits were drier and pH conditions more alkaline, thereby enhancing the preservation of bone but also promoting the formation of secondary gypsum and hydroxylapatite which caused significant physical disturbance to the previously finely laminated deposits. It is difficult to determine when this phase of chemical alteration occurred at Elands Bay Cave. Parkington et al. (1987) suggested that the gypsum largely formed during the mid-Holocene as a result of climatic aridification. We find no evidence to support or refute this hypothesis. However, we would note that we have identified the presence of heat-altered nodules of hydroxylapatite within phases D-F, implying that at least some chemical alteration of phases K-D had occurred prior to ca. 19 000 BP.

Our study focused solely on the Middle and earlier Later Stone Age deposits at Elands Bay Cave. Most of the later period deposits were largely removed during previous excavations. Therefore, we can only offer a detailed site formation model for these time periods. However, the studies conducted by Butzer (1979) and Miller (1987) allow us to extend our model into the Later Stone Age. With the end of the Pleistocene and beginning of the Holocene, rising sea levels brought the coast line ever closer to Elands Bay Cave. With the transgressing sea, aeolian sands began to contribute significantly to the geogenic accumulation of sediment within the site, outcompeting the effects of granular disaggregation and roof spalling of the bedrock. Human occupation continued, but the dramatically changing landscape forced the inhabitants to change their subsistence strategies to exploit the ever closer coastline. The change in subsistence strategies also had a significant effect on the nature of anthropogenic deposition within the site. Beginning at 11 000 BP, marine shell is found within the deposits. Given the extensive decalcification of the lower deposits, any marine shell brought to the site by Middle Stone Age humans would have likely been dissolved. However, it seems likely given the spatial limits of the wetting front and zones of chemical alteration that the Later Stone Age deposits were largely outside of the effects of the acidic water seep. By 9 000 BP humans became the most significant depositional agent at Elands Bay Cave, forming a large shell midden which extensively filled up the site.

## CONCLUSIONS

The aims of our study were to provide a detailed geoarchaeological and stratigraphic data set that could be used to interpret the results from the recent excavation and also to develop a site formation model. Additionally, our study also allowed us to clarify some aspects of previous geoarchaeological studies (Butzer 1979; Miller 1987).

Field observations and the GPR survey provided valuable information regarding the formation and morphology of the shelter. In particular the GPR survey showed that the bedrock joint running along the wall and ceiling of the cave also continues into the floor, forming a basin that was filled in with the coarse angular debris of phase L. Furthermore, these results show that the test pit excavated by Parkington reached the bedrock of the site, and that there are no stratigraphically lower deposits present.

We also agree with Butzer's (1979) argument that the sandy component of the earlier deposits likely derives from the cave's bedrock, in contrast to Miller's (1987) argument that these grains are aeolian in origin. We agree with both Butzer (1979) and Miller (1987) that aeolian sands likely became a much more significant component of the site's sediments during the late Pleistocene and Holocene, when the transgressing shoreline contributed a more significant amount of dune sand. However, we disagree with Butzer's (1979, 2004) and Miller's (1987) assertion that the coarse angular debris found at the base of the sequence (phase L) formed as a result of frost action. We believe that salt-induced spalling is a more likely process at Elands Bay Cave, given the ubiquity of this process at other sandstone shelters across southern Africa.

Micromorphological analysis of the contact between SU Keva and the overlying deposits confirmed the presence of a significant unconformity, an observation made by previous excavators and geoarchaeologists (e. g. Miller 1987) and suggested also by the current excavations (Schmid et al. 2016 this issue; Porraz, Schmid et al. 2016 this issue). We were able to identify the presence of a thin lag deposit which had formed on the surface of SU Keva, implying a phase of erosion within the site. Our results showed that phase L at the base of the sequence is not a 'basal lag' (Butzer 1979; Miller 1987) but rather a deposit on which a thin lag eventually developed. Our results also showed that initial occupation following the phase of erosion occurred directly on this surface, as seen by the presence of a thin charcoal lens found directly on the surface of the lag deposit.

Elands Bay Cave is known for its late Pleistocene and Holocene material, in particular the Later Stone Age shell midden: a large, anthropogenic deposit. Our study focused on the underlying Middle and earlier Later Stone Age deposits and showed that during this time, humans also contributed significantly to the accumulation of sediment at the site. The Middle Stone Age deposits at Elands Bay Cave, particularly those from phase I are laminated like many other similarly aged sites in southern Africa and contain evidence for anthropogenic deposition in the form of charcoal and phytolith lenses. Our study showed that anthropogenic depositional events were often separated by periods of more natural accumulation, possibly implying a more sporadic use of the site.

Although portions of the sequence at Elands Bay Cave contain well-preserved laminations, much of the sequence has been disturbed by post-depositional chemical alteration. This study presents one of the first, detailed analyses of chemical diagenesis occurring within a non-calcareous cave or rock shelter. Although many of the secondary minerals identified are similar to those found in similar studies of karstic sites in the eastern Mediterranean and Levant, our study also identified other minerals, such as whitlockite. Furthermore, our study suggested that the reaction chain, argued for at sites like Kebara and Hayonim (Weiner et al. 1993, 2002) may not be necessary to explain the formation of taranakite or the dissolution of bone. Furthermore, our study of chemical diagenesis at Elands Bay Cave provided an explanation for the spatial variation in occurrence of bone and the preservation of stratigraphic units across the site.

Despite the strong effects of post-depositional alteration occurring within the deposits at Elands Bay Cave which limited to some extent our ability to date (Tribolo et al. 2016 this issue) and excavate the site, our results show that a geoarchaeological study that integrates field and microcontextual analyses can help unravel the often complex processes influencing a site's formation.

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