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1 **Microstratigraphic reconstruction of formation processes and paleoenvironments at the Early**
2 **Pleistocene Cornelia-Uitzoek hominin site, Free State Province, South Africa**

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15 **Abstract**

16 The Cornelia-Uitzoek fossil site has produced a large collection of bones, Acheulean artifacts and a
17 *Homo* sp. tooth dated to ~1 million years ago. The faunal assemblage defines the Cornelian Land
18 Mammal Age and is characterized by a number of extinct species of large mammals that reflect an
19 open grassland environment. Bones were accumulated by hyenas, whereas artifacts appear to be
20 chance inclusions, although they suggest human presence in the immediate surroundings. Previous
21 studies established the absolute chronology of the site and a broad stratigraphic sequence. However,
22 the sedimentary units identified in the field were not linked to specific formation processes, thus
23 limiting the understanding of the depositional history of the site and its potential in reconstructing
24 Pleistocene environments. Using a microgeoarchaeological approach based on infrared
25 spectroscopy and micromorphology of sediments, we were able to determine the formation and
26 post-depositional processes of the entire stratigraphic sequence, and to show that the site is
27 characterized by alluvial sediments accumulated under different river flow regimes. Our results
28 provide context to the faunal and lithic assemblages and are in agreement with existing
29 paleoenvironmental data for the site.

30 **Keywords:** paleoenvironment; micromorphology; FTIR; Cornelian; Acheulean; formation
31 processes; South Africa

32 **1 Introduction**

33 Early Pleistocene open-air archaeological and fossil sites are rather rare occurrences in the central
34 interior of South Africa, as they are confined to preserved “pockets” of sediments bearing artifacts
35 and bones deposited in the shallow valleys of meandering rivers, such as the Vaal and its tributaries
36 (e.g. Mason, 1961; Helgren, 1978; Li et al., 2017; Kuman and Gibbon, 2018). Considered their
37 paucity, these sites are an exceptionally important source of information about hominin adaptation
38 to open landscapes and changing environments, especially in a region located outside the Malmani
39 dolomitic karst landscape that is home to the Cradle of Humankind, which produced a large number
40 of fossils including hominin remains (Eriksson and Altermann, 1998; Kuman, 2016). Therefore, the
41 characterization of paleoenvironments at these alluvial sites using sediments and bones as a proxy
42 holds considerable value for our understanding of the evolution of early hominins in southern
43 Africa.

44 One of these notable localities in the interior is Cornelia-Uitzoek, a Pleistocene fossil-
45 bearing site near the town of Cornelia, in the Highveld plateau of the northeastern Free State
46 Province of South Africa (henceforth Free State), at 1540 m a.s.l. (Figure 1). The site is the type
47 locality of the Cornelian Land Mammal Age (LMA), a period between ~1.1 and 0.6 Ma
48 characterized by a number of extinct species of large mammals that follows the Makapanian and
49 precedes the Florisian LMAs (Cooke, 1974; Hendeby, 1974; Lacruz et al., 2002; Brink, 2004; Brink
50 et al., 2012). In addition, Cornelia-Uitzoek has produced a substantial assemblage of Acheulean
51 artifacts and a *Homo* sp. tooth dated to ~1 Ma (Clark, 1974; Brink et al., 2012).

52 The most prominent faunal occurrence found at the site is a large bone bed located at the
53 bottom of the sequence, which was dated to ~1 Ma using paleomagnetism (Brink et al., 2012).
54 Bones make up the typical Cornelian assemblage dominated by open-grassland and water-
55 dependent species and were accumulated by hyenas in a burrow, as suggested by the presence of
56 coprolites and gnawing marks. The same locality yielded the largest concentration of Acheulean
57 artifacts at the site, including handaxes and cleavers. At present there is no explicit link between
58 bones and artifacts, which are interpreted as chance inclusions in the bone bed from an ancient land
59 surface, based on their random occurrence throughout the deposit and on the absence of cutmarks
60 on bones (Brink, 2004). It should be noted that the presence of all stages of the operational chain
61 except for cores may indicate local finishing and use of bifaces (Brink et al., 2012).

62 The study of Brink et al. (2012) established a general stratigraphic sequence of the site by
63 differentiating sediment types at the macroscopic scale. However, sedimentary features were not
64 linked to specific formation processes, and as a result the depositional history of the site is not well

65 understood, especially in relation to faunal assemblages. Therefore, the present study is aimed at
66 addressing outstanding questions regarding site formation processes, including how the latter can
67 provide insights into changing paleoenvironments during the Early Pleistocene. To achieve this
68 goal, we employed a microgeoarchaeological approach based on Fourier transform infrared
69 spectroscopy (FTIR) and micromorphology of sediments, which address different aspects of the
70 microscopic record (e.g. Goldberg and Berna, 2010; Weiner, 2010; Karkanas and Goldberg, 2019).
71 More specifically, FTIR was used to differentiate clay minerals and determine the preservation state
72 of bones, whereas micromorphology allowed the study of sediments at the microscopic scale and
73 within their original depositional context. By doing so, we were able to identify microscopic
74 sedimentary structures and components related to different regimes of alluvial deposition and post-
75 depositional alteration, which are in agreement with other paleoenvironmental proxies, such as
76 faunal assemblages and stable isotopes analysis of tooth enamel. In addition, our results support the
77 interpretation of the bone bed formation proposed by Brink (2004), according to which hyenas
78 burrowed an existing paleo-donga, and provide context to the local landscape in which early
79 hominins lived.

80 **2 Materials and methods**

81 *2.1 Site settings and sampling strategy*

82 The Cornelia-Uitzoek occurrence was discovered and excavated in the 1920s by E. C. N. van
83 Hoepen, who first described the stratigraphic sequence and faunal collection (van Hoepen, 1930,
84 1932b, a, 1947). Another excavation season led by A. C. Hoffman took place in 1953 (Clark, 1974),
85 whereas K. W. Butzer later described the sedimentary context (Butzer, 1974). Surface collection of
86 fossils was resumed in the early 1990s by J. S. Brink (Bender and Brink, 1992), who started a new
87 excavation program in 1998 (Brink and Rossouw, 2000).

88 The latest investigations uncovered a large amount of faunal and lithic evidence, and
89 determined its chronology and geomorphological context (Brink et al., 2012). The site is located
90 within a pocket of alluvial clay and gravel deposits carved into the local Permian shale bedrock of
91 the Ecca Group (Karoo Supergroup), a mudstone made of clay minerals and fine-grained quartz.
92 Shale has been intruded in places by Jurassic dolerite, a mafic subvolcanic rock similar to basalt
93 (see Toffolo et al., 2017 for a detailed mineralogical description). The alluvial sequence has been
94 incised by the Schoonspruit River, a left-bank tributary of the Vaal River that flows in a northerly
95 direction, about 50 m west of the site (Tooth et al., 2004). Geological and climatic constraints and
96 the limited bedload of the Schoonspruit in recent times favored bank erosion, which determined the
97 formation of deep erosional gullies, locally termed “dongas” (Figure 2 and Figures S1-S4). These

98 features exposed clusters of fossils and artifacts at different elevations within the stratigraphic
99 sequence.

100 In this study we followed the stratigraphic sequence and sedimentary units established by
101 Brink et al. (2012), which is summarized in Table 1. From bottom to top, the sequence features
102 Ecce shale, Banded Gravel Bed (BGB; Figure 3), Mottled Yellow Clay (MYC; Figure 4),
103 Laminated Orange Clay (LOC; Figure 5-6), Orange Coarse Gravel (OCG; Figure 7), Dark Grey
104 Clay (DGC) and Black Turf Soil (BTS; Figure 8). The bone bed appears as a linear and horizontal
105 intrusive feature (such as a burrow), about 2.5 m long, with limited vertical displacement of bones
106 (50 cm) and a poorly consolidated sedimentary matrix compared to the surrounding MYC (Figure
107 4) (Brink, 2004: Figure 4). These features led Brink (2004) to propose that hyenas reused and
108 burrowed an existing paleo-donga or similar erosional feature to make their lair.

109 In order to determine the formation processes that led to the accumulation of the deposits
110 and to reconstruct paleoenvironments based on the sequence of different sedimentary environments,
111 we opted for a microgeoarchaeological approach geared towards the identification of mineral
112 components and diagnostic sedimentary structures (Goldberg and Berna, 2010; Karkanas and
113 Goldberg, 2019). In particular, we used FTIR spectroscopy to characterize clay minerals and bones,
114 and micromorphology of sediments to observe microstratigraphy and all the features and
115 components that are not visible to the naked eye but contain valuable embedded information
116 regarding depositional processes.

117 Sediment and bone samples were collected from freshly exposed sections of the bone bed
118 (MYC unit) and different locales within the dongas in order to study the full stratigraphic sequence,
119 which is not entirely represented in one single section (Figure 3-8). Depositional units were
120 sampled at different locales and multiple bulk sediment samples were collected at random intervals
121 to address lateral variability. However, at the macroscopic level sedimentary units appeared
122 homogeneous over tens of meters and thousands of square meters in surface area. The DGC was not
123 recognized as a separate sedimentary unit in the field and thus was not sampled. Bones were
124 randomly selected from the bone bed collection curated at the Florisbad Research Station of the
125 National Museum to study their degree of diagenesis. Samples were immediately analyzed at an on-
126 site laboratory that included an infrared spectrometer and a petrographic microscope (Weiner,
127 2010). Preliminary information on mineral components and particle size was obtained with smear
128 slides. A few milligrams of bulk sediment sample were mounted onto a glass slide using Entellan
129 New (Merck) and analyzed at the on-site laboratory using a Nikon Optiphot petrographic
130 microscope at different magnifications (20x, 50x, 100x, 200x, 400x).

131 2.2 *Fourier transform infrared spectroscopy (FTIR)*

132 Bulk sediment samples were collected using a stainless-steel spatula, placed in 40 ml plastic vials
133 marked with progressive sample numbers, and their composition was determined at the site using
134 FTIR spectroscopy. After return to the home laboratory at the Florisbad Research Station, bones
135 were analyzed as well to determine their degree of preservation. A few milligrams of each sediment
136 ($n=57$) and bone ($n=15$) sample were homogenized and powdered in an agate mortar and pestle.
137 About 0.1 mg were left in the mortar, mixed with approximately 0.5 mg of KBr (FTIR grade,
138 Sigma-Aldrich) and pressed into a 7-mm pellet using a hand press (PIKE Technologies). Infrared
139 spectra were obtained at 4 cm^{-1} resolution in 32 scans within the $4000\text{--}400\text{ cm}^{-1}$ spectral range using
140 a Thermo Fisher Scientific Nicolet™ iS5 spectrometer. Phase identification was performed using
141 OMNIC v. 9, standard literature (Farmer, 1974; van der Marel and Beutelspacher, 1976), and the
142 reference collection of FTIR spectra of standard materials provided by the Kimmel Center for
143 Archaeological Science, Weizmann Institute of Science (<http://www.weizmann.ac.il/kimmel-arch/infrared-spectra-library>).

145 2.3 *Micromorphology of sediments*

146 Micromorphology was used to study sediments within their original depositional context, in order
147 to determine their formation and post-depositional processes. Boundaries between sedimentary
148 units were selected to highlight changes in depositional environments. In addition, samples from the
149 middle portion of the MYC unit and bone bed were collected to differentiate their contents. Intact
150 blocks of sediment ($n=11$) were carved from sections, air-dried for several weeks and finally oven-
151 dried at 40°C for three days. Samples were then embedded in a mixture of polyester resin (NCS
152 General Purpose Polyester) and acetone (ratio 7:3), with the addition of 1.5 ml catalyst per liter of
153 mixture. Hardened blocks were sliced with a rock saw to obtain 55×75 mm chips, which were
154 shipped to Arizona Quality Thin Sections (Tucson, Arizona, USA) for thin section preparation.
155 Two additional samples were prepared at the thin section laboratory of the University of Bordeaux
156 (France). All the thin sections were polished to a thickness of $30\text{ }\mu\text{m}$. Micromorphological analyses
157 were carried out using Olympus BX41 and Leica DM2500 P petrographic microscopes at different
158 magnifications (20x, 25x, 40x, 50x, 100x, 200x, 400x). Descriptions and interpretations are based
159 on conventional criteria developed in the specialized literature (Courty et al., 1989; Delvigne, 1998;
160 Stoops, 2003; Flügel, 2004; Goldberg and Macphail, 2006; Stoops et al., 2010; Macphail and
161 Goldberg, 2017). We use here the concept of “microfacies” (MFT) as described by E. Flügel, i.e.
162 “*the total of all sedimentological and paleontological data which can be described and classified*
163 *from thin sections [...]*” (Flügel, 2004: 1). This term defines discrete assemblages of sediment types

164 based on the information retrieved from the analysis of thin sections. Considered that some
165 depositional units occur repeatedly throughout the stratigraphic sequence (e.g. MYC and LOC) and
166 that multiple thin sections were obtained from these units, the use of MFTs allows rapid reporting
167 of results. This approach to the study of thin sections includes the basic interpretive level of each
168 MFT (e.g. Goldberg and Aldeias, 2018).

169 **3 Results**

170 The chemical phases identified with FTIR spectroscopy are displayed in Figure 8. Sedimentary
171 components and structures observed in thin section are shown in Figure 9 and Figure 10; MFTs are
172 listed in Table 2. Below follows a description of the stratigraphic sequence from bottom to top,
173 based on the framework established by Brink et al. (2012). Micromorphological terminology by
174 Stoops (2003) is noted in *italics* between brackets next to the explanation of the relative feature at
175 its first appearance.

176 *3.1 Bedrock and Banded Gravel Bed*

177 The sedimentary sequence rests on top of Ecça shale. An unconformity separates bedrock from the
178 BGB (Figure 3), a layer of gravel characterized by normal graded bedding and dated to the
179 Matuyama reversal (>1.07 Ma). The coarse components (mainly cobbles to very fine pebbles with a
180 few boulders at the base) are mostly fragments of Ecça shale and Jurassic dolerite and they are
181 supported by a clayey matrix towards the top. Cross bedding is visible in places.

182 *3.2 Mottled Yellow Clay and Laminated Orange Clay*

183 The next unit in the sequence is the MYC (Figure 4), a layer of massive pale-yellow to pale-green
184 clay (depending on moisture), dated to the Jaramillo subchron (1.07-0.99 Ma). This deposit includes
185 the hyena bone bed that yielded a rich assemblage of Cornelian-age fossils, a human tooth, and
186 Acheulean artifacts (Brink, 2004). The sedimentary matrix of this layer comprises a mixture of clay
187 minerals of the smectite (dominant) and kaolinite (minor) groups, as indicated by the absorptions at
188 3690, 3620, 1090, 1032 and 525 cm⁻¹, and a minor amount of quartz (absorptions at 797, 779, 694
189 and 470 cm⁻¹) and feldspars (absorption at 646 cm⁻¹). Yellow mottles exhibit stronger absorptions of
190 kaolinite clays at 3697, 3620, 1009, 911, 791, 750, 670 and 536 cm⁻¹ (Figure 9). Black clay nodules
191 rich in manganese oxides occur in places (broad absorption at 3405 cm⁻¹). Bones are characterized
192 by the occurrence of fluoridated carbonate hydroxyapatite on the outer surface of cortical tissue
193 (absorption at 604 cm⁻¹ higher than the absorption at 567 cm⁻¹; Figure 9) (Geiger and Weiner,
194 1993).

195 Observed in thin section, the MYC shows the characteristic features of the “clay” MFT
196 (Table 2), which exhibits a dominant fraction of silt-sized grains of quartz and feldspar embedded
197 in a pale-green clay (*porphyric c/f related distribution*). Coarser sand-sized grains occur frequently,
198 thus making the coarse fraction poorly to moderately sorted. Porosity is represented by thin,
199 elongated voids that separate angular blocks of sediment (*angular blocky microstructure* with
200 *planes*), with a few cylindrical, elongated voids (*channels*). Below the level of the bone bed, the
201 fabric of the coarse fraction appears to be oriented horizontally in places due to bedding;
202 fragmented, horizontal silty-clay crusts showing normal graded bedding occur as well (Figure 10a-
203 b). No bedding was observed within the bone bed fill, and a substantial proportion of rounded, very
204 fine pebbles (2-4 mm) of shale make up the coarse fraction together with poorly sorted quartz
205 sand/silt (Figure 10c). The poor degree of compaction of shale pellets determines the occurrence of
206 voids resulting from loose packing (*simple packing voids*) and in general of greater porosity
207 compared to lower levels. Throughout the entire layer, the fine fraction is characterized by domains
208 of clay minerals oriented in small patches, along random straight lines, or around grains and pores,
209 as evidenced by their birefringence fabric (*stipple speckled, striated, granostriated and porostriated*
210 *b-fabric*, respectively; Figure 10d). Post-depositional processes (*pedofeatures*) are represented
211 mainly by the translocation of clays through groundwater movement. Two distinct events were
212 observed: dense accumulations of clay in pores (*intercalations*) and void coatings composed of
213 dark-green clay; laminated void coatings and dense void infillings of yellow clay, often juxtaposed
214 to the dark-green clay features (Figure 10e-f). In addition, different types of Fe-Mn oxide aggregate
215 nodules are superimposed on the fine fraction, shale fragments and clay coatings/infillings (Figure
216 10g). Reddish Fe-Mn oxide halos around pores (*hypocoatings* and *quasicoatings*) occur as well
217 (Figure 10h).

218 A sharp erosive boundary separates the MYC from the LOC (Figure 5-6), a layer composed
219 of alternated beds of clay and fine gravel and dated to the Matuyama reversal (0.99-0.78 Ma). Clay
220 beds exhibit the same FTIR spectra as the MYC, with black patches of Fe-Mn oxides and yellow
221 mottles richer in kaolinite minerals, whereas gravel is composed of rounded fine pebbles of local
222 Ecca shale. Bones exhibit absorptions of fluoridated carbonate hydroxyapatite.

223 Clay beds show the microscopic characteristics of the “clay” MFT (Table 2). In addition to
224 the features observed in the MYC, the LOC clay beds exhibit cm-deep bands of diffuse Fe oxide
225 halos (*impregnations*) (Figure 11a), close to the boundary with the overlying layer. These bands are
226 superimposed on the fine fabric (*groundmass*) and represent ancient surface zones of enhanced Fe
227 oxidation, favored by a concentration of plant material and microorganisms in a fluctuating water
228 table, possibly in relation to river floods (Courty et al., 1989; Lindbo et al., 2010). A similar process

229 occurred in the case of dense void infillings composed of silt embedded in red clay (Figure 11b).
230 These pedofeatures are related to the presence of root casts of woody and/or herbaceous plants, a
231 common occurrence at the site (Figure 12). These vertical channels are pseudomorphs of roots
232 derived from ancient surfaces and were observed throughout the entire sedimentary sequence,
233 except for topsoil. The decay of plant material due to microorganism activity favors the
234 mobilization of Fe and its subsequent precipitation due to exposure to air in the channel left by the
235 root (Lindbo et al., 2010). This is later infilled by coarse sediment from the overlying layer.
236 Furthermore, clay beds are characterized by a greater proportion of Fe-Mn oxide aggregate nodules.

237 Gravel beds show the characteristic features of the “fine gravel” MFT (Table 2). Coarse
238 fraction is composed of shale pebbles (very fine to medium) linked by clay bridges that often coat
239 grains (*chitonic to concave gefuric cff related distribution*), whereas fine fraction is rarely present
240 (Figure 11c). Pores derive from the spatial arrangement between pebbles and from their degree of
241 compaction (*weakly separated granular microstructure to vughy microstructure with compound*
242 *packing voids, regular vughs and star-shaped vughs*). Similar to previous sedimentary units, the
243 LOC exhibits juxtaposed dark-green and yellow clay coatings with superimposed Fe-Mn aggregate
244 nodules (Figure 11d).

245 3.3 Orange Coarse Gravel and Black Turf Soil

246 Another sharp, wavy and erosive boundary, which corresponds to the beginning of the Brunhes
247 chron (<0.78 Ma), marks the transition between the LOC and the OCG (Figure 7). Clasts are
248 medium to very coarse pebbles and show different fabric depending on the location within the
249 layer. Cross-bedding and imbrication are visible in places, especially in the lower portion of the
250 unit.

251 The chemical composition of the fine fraction is comparable with the MYC and LOC,
252 showing a mixture of kaolinite (dominant) and smectite clay minerals (Figure 9). Bones were not
253 found in this sedimentary unit. A number of cm-size nodules coated with a black film exhibit
254 absorption bands of kaolinite and Fe-Mn oxides. These components are concentrated at the
255 transition with the overlying topsoil and can be observed today at the top of the donga as a lag
256 product of the erosion of finer topsoil material (Figure 13).

257 The microscopic features of the OCG can be grouped under the “coarse gravel” MFT (Table
258 2), which presents similarities with the “clay” MFT. More specifically, the poorly sorted coarse
259 fraction is embedded in yellow clay (*porphyric cff related distribution*) and is characterized by
260 planes (*angular blocky microstructure*); the fine fraction exhibits prominent striated, porostriated

261 and granostriated b-fabrics. However, there are also notable differences, namely the greater
262 proportion of coarse particles, the occurrence of considerable amounts of dolerite pebbles (Figure
263 11e) and Fe-Mn oxide typic nodules, and the absence of intrusive pedofeatures, such as clay
264 coatings. Oxide nodules are mainly round and exhibit sharp boundaries, implying that they formed
265 elsewhere within the OCG before reaching their final location (*disorthic nodules*). Other nodules
266 instead clearly formed in situ (*orthic nodules*), as suggested by their irregular boundary or
267 concentric appearance (Figure 11f-g).

268 The OCG grades into the BTS (Figure 8), a soil profile characterized by an orthic A horizon
269 (Soil Classification Working Group, 1991). As stated, the transition boundary exhibits a large
270 number of 0.5-1 cm round pellets composed of Fe-Mn oxides. In places, especially at the top of
271 dongas and close to the erosion line, the BTS plant cover has disappeared, thus exposing soil
272 horizon to rain, erosion, and oxidation of organic compounds. The latter favored a change in color
273 from brown to dark grey, hence the thin Dark Grey Clay (DGC) layer reported by Brink et al.
274 (2012) as patches in between the OCG and BTS (Figure 14). In addition, the DGC layer is
275 characterized by large accumulations of Fe-Mn oxide pellets left behind as lag deposit after the
276 erosion of fine material. Therefore, the DGC appears to be a weathering product of the BTS and
277 thus its description coincides with the latter.

278 Looking at FTIR spectra, the BTS sediments are composed of a mixture of kaolinite
279 (dominant) and smectite clay minerals, quartz and feldspars. Compared to the MYC and LOC, they
280 contain a larger proportion of kaolinite minerals. The microscopic features of this sedimentary unit
281 are ascribed to the “topsoil” MFT (Table 2) and comprise a poorly sorted coarse fraction (quartz silt
282 and sand) embedded in a dark-brown clay with undifferentiated b-fabric and large amounts of
283 amorphous organic matter. Plant fibers occur as well and are part of the current vegetal cover.
284 Porosity is almost absent and confined to a few channels created by plant roots in an otherwise
285 massive microstructure. The latter is disrupted by extensive areas of intense bioturbation, as
286 indicated by the presence of *Oribatida* mites excrements (Figure 11h) (Kooistra and Pulleman,
287 2010). Besides faunal activity, pedofeatures include typic orthic and disorthic nodules of Fe-Mn
288 oxides, especially close to the boundary with OCG.

289 **4 Discussion**

290 The results of FTIR and micromorphological analyses presented herein allow the interpretation of
291 the stratigraphic sequence in relation to archaeological, faunal, geologic and environmental
292 evidence previously published for the site and the region.

293 *4.1 Formation and post-depositional processes*

294 Starting from the bottom, it appears that the unconformity between bedrock and BGB may account
295 for multiple cycles of sedimentation and erosion that took place between the Permian and Early
296 Pleistocene, a common feature in southern African sedimentary contexts, including the Free State
297 (e.g. Looock and Grobler, 1988; Toffolo et al., 2017). Based on the large clast size (up to boulders),
298 the BGB is a point bar or channel deposit accumulated under high-energy water conditions
299 consistent with a braided river system, perhaps the paleo-Schoonspruit, whose catchment basin
300 drained an area characterized by local Karoo-aged lithology.

301 Further up in the sequence, the localized horizontal fabric of the coarse fraction and the
302 presence of clay crusts lend support to the interpretation of the MYC as an overbank deposit in a
303 meandering paleo-Schoonspruit, characterized by low-energy water; in particular, clay crusts
304 represent remnants of ancient depositional surfaces (Courty et al., 1989; Vingiani et al., 2018).
305 Instead, the bone bed fill shows no layering and a greater proportion of pores (low compaction) and
306 coarse components, including rounded, very fine pebbles of shale and poorly sorted quartz. These
307 features are consistent with a chaotic accumulation of sediment as infill of a “pocket” within the
308 MYC, which might be the result of hyena burrowing and bone concentration, and colluvium
309 deposition as observed in present-day donga channels (Figure 15). Micromorphological
310 observations thus seem to support the interpretation advanced by Brink (2004) and Brink et al.
311 (2012) regarding the location of the hyena den within a paleo-donga or channel created by localized
312 erosion in the vicinity of the river.

313 Bones appear to be well preserved, and this is confirmed by the occurrence of fluoridated
314 carbonate hydroxyapatite. This mineral is known to form in extremely old fossils (e.g. Piga et al.,
315 2011) and in more recent bones exposed to fluoride-rich groundwater (e.g. Toffolo et al., 2015) due
316 to the replacement of OH^- ions with F^- ions in more symmetrical locations within the crystal lattice
317 of carbonate hydroxyapatite. As a result, bone mineral becomes more resistant to chemical
318 weathering (Newesely, 1989; LeGeros, 1991). Based on their good state of preservation from both
319 the morphological and chemical point of view, bones must have been exposed on the surface only
320 briefly, and the bone bed buried rather quickly by overlying sediments.

321 In addition, several post-depositional processes considerably affected the MYC. First, the
322 striated b-fabric and angular blocky microstructure are typical of shrink/swell processes in smectites
323 (Courty et al., 1989), which were identified with FTIR, and are consistent with a pronounced vertic
324 behavior of sediments (Toffolo and Berna, 2008; Kovda and Mermut, 2010). These processes likely
325 contributed to the slight slumping and fragmentation of some bone specimens observed by Brink

326 (2004). Second, pores are often coated/filled with dark-green clay and yellow clay. The former is
327 the result of fine illuviation from a vegetated topsoil, now lost, that developed on the MYC layer,
328 whereas the latter may be ascribed to several episodes of fine illuviation (based on the laminated
329 appearance of the coatings) from overlying layers (Courty et al., 1989), e.g. the OCG; according to
330 FTIR, yellow clay mottles include a larger proportion of kaolinite minerals compared to the general
331 sedimentary matrix, and that is the main component of clay minerals in the OCG. Third, the
332 presence of Fe-Mn redoximorphic features in the form of coatings and nodules juxtaposed or
333 superimposed on coarse and fine components points to periodic waterlogging of sediments (Courty
334 et al., 1989). Fe and Mn ions are mobilized under waterlogged conditions and subsequently oxidize
335 upon drying, creating aggregate nodules and hypo- and quasi-coatings of pores (Lindbo et al.,
336 2010). The antiquity of these pedofeatures is demonstrated by the occurrence of yellow clay
337 coatings in voids characterized by Fe-Mn oxide hypo-coatings (Figure 10h). In addition, the fact
338 that bones exhibit Mn staining and patches of fluoridated carbonate hydroxyapatite indicates they
339 were exposed for prolonged periods to groundwater rich in both elements.

340 The MYC and LOC appear to be the product of similar formation and post-depositional
341 processes. The thick layer of MYC was deposited as overbank during floods and provided the
342 surface where hyenas dug their lair and accumulated carcasses. The same land surface was likely
343 characterized by human presence and possibly sporadic occupation; the occurrence of Acheulean
344 handaxes and cleavers together with flakes and blanks suggests that artifacts were produced close to
345 the site (Brink et al., 2012). Their inclusion in the bone bed fill could be due to deliberate discard,
346 or it might be the result of the burrowing activity of hyenas and later colluvium in the paleo-donga
347 channel. In the absence of clear occupation surfaces, the latter hypothesis seems the most likely
348 based on micromorphological data. However, this does not rule out the possibility that humans
349 roamed the site (as indicated by the tooth). The erosive contact with the overlying LOC, which
350 corresponds to a stripped land surface from which the dark-green clay translocated downwards into
351 voids, marks a change in the depositional pattern, with clay beds similar to the MYC that alternate
352 with fine gravel beds accumulated under conditions of slightly higher-energy water. As observed in
353 the field, where multiple bone scatters were recorded at different levels within the LOC, each of the
354 clay and fine gravel beds provided temporary land surfaces that functioned as accumulation sites for
355 bones and artifacts, although not in the same proportions as in the hyena bone bed. Given the small
356 size of these bone assemblages and the cyclic sedimentary pattern, it appears that hyenas were not
357 the primary depositional agent of bones in the LOC. The presence of Fe oxide bands and root casts
358 seems to support the occurrence of stable vegetated surfaces at different stages in the formation of
359 the sedimentary unit, which would have encouraged human settlement of the area.

360 The large amount of pebble-sized clasts and the presence of cross-bedding and imbrication
361 indicate that the OCG was deposited by high-energy water in a point bar or straight channel of a
362 meandering river system (Courty et al., 1989). After deposition, this sedimentary unit underwent
363 shrink/swell processes, represented by the prominent striated b-fabric. In addition, a large portion of
364 the yellow clay that makes up the fine fraction translocated into the LOC and MYC through
365 eluviation processes, thus creating the yellow clay coatings and infillings observed in lower units.
366 In fact, the OCG is today the least visible sedimentary unit at the donga, due to its lower resistance
367 to weathering. Its dissolution promoted the accumulation of a thin layer of shale clasts and Fe-Mn
368 oxide nodules, which were left behind as lag deposit.

369 One last episode of alluvial deposition in conditions of low-energy water promoted the
370 formation of the BTS. In addition, the presence of medium and coarse sand rounded grains of
371 quartz points to an eolian component of the coarse fraction. This is a common characteristic at
372 terminal Pleistocene-Holocene sites in the Free State (e.g. Lyons et al., 2014; Toffolo et al., 2017).
373 This sedimentary unit lacks secure chronological pegs but considering the occurrence of sporadic
374 Middle Stone Age artifacts and the almost completely reworked nature of the sediments, it seems
375 that the age of this layer may well exceed 50 ka.

376 4.2 *Paleoenvironments*

377 Given the scarcity of paleo-climatic data for the Free State before 500 ka (e.g. deMenocal, 2004;
378 Scott and Neumann, 2018), it is difficult to draw interpretations in that sense based solely on the
379 sedimentary context. In addition, river flow in this region has been shown to be primarily affected
380 by the erosion and retreat of dolerite knickpoints, which determine the slope and degree of sinuosity
381 of riverbeds, rather than climate. The retreat of knickpoints ultimately depends on base level fall
382 rates of the Vaal, which in the Plio-Pleistocene were governed by a complex mix of tectonic uplift
383 and climate change at the regional level (Tooth et al., 2004 and references therein). However, recent
384 paleoenvironmental data for the Limpopo River catchment basin, located to the immediate northeast
385 of the Free State, show an increase in aridity after 1 Ma (Caley et al., 2018). Therefore, assuming
386 wetter conditions before this threshold, which may have implied an increased flow regime of the
387 Vaal and other rivers in the region and thus faster riverbed incision, it would seem that the BGB and
388 the erosional hiatus with the overlying MYC were formed as a result of knickpoint retreat and
389 larger water supply at the source. More detailed sedimentary and climatic data for this period in the
390 northeastern Free State is nevertheless required in order to support this suggestion.

391 The occurrence in the bone bed of ungulates and water-dependent species, such as
392 *Hippopotamus gorgops* (giant hippo) and *Syncerus antiquus* (giant long-horned buffalo) (Brink,

393 2004; Brink et al., 2012), together with the low-energy water environment characteristic of
394 meandering rivers, suggest that the MYC represents a grassland landscape characterized by surface
395 waters (i.e. oxbows, backwaters and swamps), similar to what is observed today in the upper reach
396 of the Klip River in the Memel Seekoeivlei Nature Reserve, located about 70 km east of Cornelia.
397 There, in areas characterized by soft sandstone bedrock away from dolerite outcrops and
398 knickpoints, the river meanders within a large valley, creating oxbows and backswamps during
399 summer rains (Tooth et al., 2002). This kind of environment probably developed also in the broad
400 shale valley of the paleo-Schoonspruit around Cornelia-Uitzoek, thus attracting herbivores and with
401 them carnivores and humans. Therefore, sedimentary and faunal evidence show that during the
402 Early Pleistocene the central interior of South Africa offered a lush habitat favorable to human
403 settlement, besides the well-known Malmani dolomitic karst. A later parallel in terms of grassland
404 paleoenvironment with plenty of water is represented by Florisbad, in the mid-western Free State
405 (e.g. Brink, 1987, 1988; Kuman et al., 1999; Brink and Henderson, 2001; Toffolo et al., 2017).

406 The formation of pedofeatures caused by shrink-swell episodes during the Pleistocene (i.e.
407 dark-green clay coatings juxtaposed to subsequent yellow clay coatings originated from younger
408 units), lends support to the hypothesis of the existence of a summer rainfall regime already at that
409 time. Prolonged periods of drought during winter months and rainfall concentrated in summer may
410 account for the presence of shrink/swell features. The possible existence of a paleo-donga, as
411 suggested by thin sections, would also be a product of seasonal rains. This scenario seems in
412 agreement with faunal data. Several individuals from the bone bed exhibit enamel $\delta^{13}\text{C}$ values
413 $>0\%$, which are characteristic of a diet based on C_4 grasses, and diagnostic phytoliths from these
414 plants were recovered from the same context (Codron et al., 2008). Plants that produce energy
415 through C_4 processes typically grow in environments where groundwater is scarcely available due
416 to high evapotranspiration, and this is a common trait of the Highveld grasslands especially during
417 winter, the dry season (Mucina and Rutherford, 2006). The Limpopo paleoenvironmental dataset
418 shows an increase in aridity after 1 Ma that may support the evidence from sediments, fauna and
419 phytoliths (Caley et al., 2018).

420 This C_4 grassland environment persisted in the LOC, as evidenced by the low-energy water
421 deposition of clay and fine gravel beds with multiple bone scatters of Cornelian age, and by root
422 casts indicative of ancient land surfaces. However, the sharp boundary with the MYC might
423 represent a relatively brief period of high-energy water erosion that removed the original land
424 surface. A similar process likely stripped the latest land surface of the LOC and subsequently
425 deposited the OCG. As mentioned for the meandering river, the deposition of coarse gravel might
426 be a result of knickpoint exposure further upstream, which caused an increase in slope, a decrease

427 in sinuosity, and thus a more rapid flow able to transport coarser clasts (Tooth et al., 2004). The
428 presence of dolerite pebbles in the OCG and not in sedimentary units above and below seems to
429 support this interpretation, as these components would derive from the erosion of exposed dolerite.
430 In addition, the regional trend towards increased aridity after 1 Ma (Caley et al., 2018) seems to
431 exclude higher flow regime from the source as a possible cause for increased water energy and
432 coarser sediment supply. The absence of faunal material in the OCG and the lack of data from other
433 proxies (e.g. phytoliths, pollen) hinder a proper reconstruction of the paleoenvironment at this stage.
434 Nevertheless, the occurrence of younger Acheulean artifacts towards the top of the OCG (Brink et
435 al., 2012), perhaps transported by water, indicates that humans were present in the area.
436 Additionally, the persistence of C₄ grasslands in the Highveld from the Cornelian through to the
437 Florisian LMA as shown by faunal evidence (e.g. Brink, 1987, 1988; Lacruz et al., 2002; Brink,
438 2004; Codron et al., 2008; Brink et al., 2012; Brink et al., 2015; Brink, 2016), suggests that this
439 kind of environment existed also at the time of deposition of the OCG. This is further confirmed by
440 the fine alluvium altered by pedogenesis that makes up the BTS, the last layer deposited by the
441 paleo-Schoonspruit during a meandering stage similar to previous ones, before the beginning of its
442 current incising phase in the study area.

443 **5 Conclusions**

444 Cornelia-Uitzoek is the type locality of the Cornelian LMA (~1.1-0.6 Ma) and has produced a large
445 faunal assemblage dated to ~1.0 Ma that is the result of bone accumulation by hyenas. In addition,
446 the occurrence of a human tooth and several Acheulean artifacts indicates that hominins occupied
447 the area around the site. This important paleoecological occurrence offered the opportunity to study
448 in depth the environments in which humans lived, in a region that features an extremely limited
449 number of human fossils. Using a microgeoarchaeological approach based on FTIR spectroscopy
450 and micromorphology of sediments, we were able to identify mineral phases and microscopic
451 sedimentary structures typical of deposition by low- and high-energy water, and thus we could
452 determine the formation and post-depositional processes of the entire stratigraphic sequence,
453 including the bone bed that yielded the faunal and lithic assemblages. What emerged is an alluvial
454 environment dominated by local geology, which determined the amount and type of sediment
455 supply. Phases of low-energy water deposition in a meandering river system were conducive to the
456 formation of oxbows and backswamps that supported populations of large- to small-sized ungulates,
457 as well as carnivores and humans. Instead, high-energy water led to erosional hiatuses in the
458 stratigraphy and to the deposition of coarse material, bearing little or no faunal/lithic evidence.
459 Increasing aridity as seen at a regional level in southeastern Africa and locally based on the
460 presence of post-depositional shrink/swell and redoximorphic features, faunal assemblages and

461 stable isotopes datasets, points to C₄ grasslands as the dominant biome, which later expanded in the
462 Florisian LMA. Faunal and sedimentary evidence highlight the role of the central interior of South
463 Africa as favorable habitat for the evolution of early hominins, and the importance of addressing
464 site-formation and post-depositional processes by looking also at the microscopic record.

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480

References

481

- 482 Bender, P.A., Brink, J.S., 1992. A preliminary report on new large mammal fossil finds from the
483 Cornelia-Uitzoek site, *South African Journal of Science* 88, 512-515.
- 484 Brink, J.S., 1987. The archaeozoology of Florisbad, Orange Free State, *Memoirs van die Nasionale*
485 *Museum, Bloemfontein* 24, 1-151.
- 486 Brink, J.S., 1988. The taphonomy and palaeoecology of the Florisbad spring fauna, *Palaeoecology*
487 *of Africa and the Surrounding Islands* 19, 169-179.
- 488 Brink, J.S., Rossouw, L., 2000. New trial excavations at the Cornelia-Uitzoek type locality,
489 *Navorsing van die Nasionale Museum Bloemfontein* 16, 141-156.
- 490 Brink, J.S., Henderson, Z.L., 2001. A high-resolution Last Interglacial MSA horizon at Florisbad in
491 the context of other open-air occurrences in the central interior of southern Africa: an
492 interim statement, in: Conard, N.J. (Ed.), *Settlement dynamics of the Middle Paleolithic and*
493 *Middle Stone Age*, Kerns Verlag, Tübingen, pp. 1-20.
- 494 Brink, J.S., 2004. The taphonomy of an Early/Middle Pleistocene hyaena burrow at Cornelia-
495 *Uitzoek, South Africa, Revue de Paléobiologie* 23, 731-740.
- 496 Brink, J.S., Herries, A.I.R., Moggi-Cecchi, J., Gowlett, J.A.J., Bousman, C.B., Hancox, J.P., Grün,
497 R., Eisenmann, V., Adams, J.W., Rossouw, L., 2012. First hominine remains from a ~1.0
498 million year old bone bed at Cornelia-Uitzoek, Free State Province, South Africa, *Journal of*
499 *Human Evolution* 63, 527-535.

- 500 Brink, J.S., Bousman, C.B., Grün, R., 2015. A reconstruction of the skull of *Megalotragus priscus*
501 (Broom, 1909), based on a find from Erfkroon, Modder River, South Africa, with notes on
502 the chronology and biogeography of the species, *Palaeoecology of Africa* 33, 71-94.
- 503 Brink, J.S., 2016. Faunal evidence for a mid- and late Quaternary environmental change in southern
504 Africa, in: Knight, J., Grab, S.W. (Eds.), *Quaternary environmental change in southern*
505 *Africa: physical and human dimensions*, Cambridge University Press, Cambridge.
- 506 Butzer, K.W., 1974. Geology of the Cornelia Beds, *Memoirs van die Nasionale Museum*,
507 Bloemfontein 9, 7-32.
- 508 Caley, T., Extier, T., Collins, J.A., Schefuß, E., Dupont, L., Malaizé, B., Rossignol, L., Souron, A.,
509 McClymont, E.L., Jimenez-Espejo, F.J., García-Comas, C., Eynaud, F., Martinez, P., Roche,
510 D.M., Jorry, S.J., Charlier, K., Wary, M., Gourves, P.-Y., Billy, I., Giraudeau, J., 2018. A
511 two-million-year-long hydroclimatic context for hominin evolution in southeastern Africa,
512 *Nature* 560, 76-79.
- 513 Clark, J.D., 1974. The stone artefacts from Cornelia, O.F.S., South Africa, *Memoirs van die*
514 *Nasionale Museum*, Bloemfontein 9, 33-62.
- 515 Codron, D., Brink, J.S., Rossouw, L., Clauss, M., 2008. The evolution of ecological specialization
516 in southern African ungulates: competition- or physical environmental turnover?, *Oikos*
517 117, 344-353.
- 518 Cooke, H.B.S., 1974. The fossil mammals of Cornelia, O.F.S., South Africa, *Memoirs van die*
519 *Nasionale Museum*, Bloemfontein 9, 63-84.
- 520 Courty, M.A., Goldberg, P., Macphail, R.I., 1989. *Soils and Micromorphology in Archaeology*,
521 Cambridge University Press, Cambridge.
- 522 Delvigne, J.E., 1998. *Atlas of micromorphology of mineral alteration and weathering*,
523 Mineralogical Association of Canada, Ottawa.
- 524 deMenocal, P.B., 2004. African climate change and faunal evolution during the Pliocene-
525 Pleistocene, *Earth and Planetary Science Letters* 220, 3-24.
- 526 Eriksson, P.G., Altermann, W., 1998. An overview of the geology of the Transvaal Supergroup
527 dolomites (South Africa), *Environmental Geology* 36, 179-188.
- 528 Farmer, V.C., 1974. *The Infrared Spectra of Minerals*, Mineralogical Society, London.
- 529 Flügel, E., 2004. *Microfacies of carbonate rocks: Analysis, interpretation and application*, Springer,
530 Berlin.
- 531 Geiger, S.B., Weiner, S., 1993. Fluoridated carbonatoapatite in the intermediate layer between glass
532 ionomer and dentin, *Dental Materials* 9, 33-36.
- 533 Goldberg, P., Macphail, R.I., 2006. *Practical and Theoretical Geoarchaeology*, Blackwell
534 Publishing, Malden, MA.
- 535 Goldberg, P., Berna, F., 2010. Micromorphology and context, *Quaternary International* 214, 56-62.
- 536 Goldberg, P., Aldeias, V., 2018. Why does (archaeological) micromorphology have such little
537 traction in (geo)archaeology?, *Archaeological and Anthropological Sciences* 10, 269-278.
- 538 Helgren, D.M., 1978. Acheulian settlement along the lower Vaal River, South Africa, *Journal of*
539 *Archaeological Science* 5, 39-60.
- 540 Hendey, Q.B., 1974. The Late Cenozoic Carnivora of the South-Western Cape Province, *Annals of*
541 *the South African Museum* 63, 1-369.
- 542 Karkanas, P., Goldberg, P., 2019. *Reconstructing Archaeological Sites: Understanding the*
543 *Geoarchaeological Matrix*, Wiley Blackwell.
- 544 Kooistra, M.J., Pulleman, M.M., 2010. Features Related to Faunal Activity, in: Stoops, G.,
545 Marcelino, V., Mees, F. (Eds.), *Interpretation of micromorphological features of soils and*
546 *regoliths*, Elsevier, Amsterdam, pp. 397-418.
- 547 Kovda, I., Mermut, A.R., 2010. Vertic Features, in: Stoops, G., Marcelino, V., Mees, F. (Eds.),
548 *Interpretation of micromorphological features of soil and regoliths*, Elsevier, Amsterdam,
549 pp. 109-127.

- 550 Kuman, K., Inbar, M., Clarke, R.J., 1999. Palaeoenvironments and Cultural Sequence of the
551 Florisbad Middle Stone Age Hominid Site, South Africa, *Journal of Archaeological Science*
552 26, 1409-1425.
- 553 Kuman, K., 2016. Development of the archaeological record in southern Africa during the Earlier
554 Stone Age, in: Knight, J., Grab, S. (Eds.), *Quaternary Environmental Change in Southern*
555 *Africa: Physical and Human Dimensions*, Cambridge University Press, Cambridge, pp. 349-
556 370.
- 557 Kuman, K., Gibbon, R.J., 2018. The Rietputs 15 site and Early Acheulean in South Africa,
558 *Quaternary International* 480, 4-15.
- 559 Lacruz, R., Brink, J.S., Hancox, P.J., Skinner, A.R., Herries, A.I.R., Schmid, P., Berger, L.R., 2002.
560 Palaeontology and geological context of a Middle Pleistocene faunal assemblage from the
561 Gladysvale Cave, South Africa, *Palaeontologia Africana* 38, 99-114.
- 562 LeGeros, R.Z., 1991. *Calcium Phosphates in Oral Biology and Medicine*, Karger, Basel,
563 Switzerland.
- 564 Li, H., Kuman, K., Lotter, M.G., Leader, G.M., Gibbon, R.J., 2017. The Victoria West: earliest
565 prepared core technology in the Acheulean at Canteen Kopje and implications for the
566 cognitive evolution of early hominids, *Royal Society Open Science* 4, 170288.
- 567 Lindbo, D.L., Stolt, M.H., Vepraskas, M.J., 2010. Redoximorphic Features, in: Stoops, G.,
568 Marcelino, V., Mees, F. (Eds.), *Interpretation of micromorphological features of soils and*
569 *regoliths*, Elsevier, Amsterdam, pp. 129-147.
- 570 Loock, J.C., Grobler, N.J., 1988. The regional geology of Florisbad, *Navorsing van die Nasionale*
571 *Museum Bloemfontein* 5, 489-497.
- 572 Lyons, R., Tooth, S., Duller, G.A.T., 2014. Late Quaternary climatic changes revealed by
573 luminescence dating, mineral magnetism and diffuse reflectance spectroscopy of river
574 terrace palaeosols: a new form of geoproxy data for the southern African interior,
575 *Quaternary Science Reviews* 95, 43-59.
- 576 Macphail, R.I., Goldberg, P., 2017. *Applied Soils and Micromorphology in Archaeology*,
577 Cambridge University Press, Cambridge.
- 578 Mason, R.J., 1961. The Acheulean Culture in South Africa, *South African Archaeological Bulletin*
579 16, 107-110.
- 580 Mucina, L., Rutherford, M.C., 2006. *The Vegetation of South Africa, Lesotho and Swaziland*,
581 South African National Biodiversity Institute, Pretoria.
- 582 Newsely, H., 1989. Fossil bone apatite, *Applied Geochemistry* 4, 233-245.
- 583 Piga, G., Santos-Cubedo, A., Brunetti, A., Piccinini, M., Malgosa, A., Napolitano, E., Enzo, S.,
584 2011. A Multi-technique approach by XRD, XRF, FT-IR to characterize the diagenesis of
585 dinosaur bones from Spain, *Palaeogeography, Palaeoclimatology, Palaeoecology* 310, 92-
586 107.
- 587 Scott, L., Neumann, F.H., 2018. Pollen-interpreted palaeoenvironments associated with the Middle
588 and Late Pleistocene peopling of Southern Africa, *Quaternary International* 495, 169-184.
- 589 Soil Classification Working Group, 1991. *Soil Classification - a Taxonomic System for South*
590 *Africa*, Department of Agricultural Development, Pretoria.
- 591 Stoops, G., 2003. *Guidelines for Analysis and Description of Soil and Regolith Thin Sections*, Soil
592 Science Society of America, Madison, WI.
- 593 Stoops, G., Marcelino, V., Mees, F., 2010. *Interpretation of Micromorphological Features of Soils*
594 *and Regoliths*, Elsevier, Amsterdam.
- 595 Toffolo, M., Berna, F., 2008. Analisi micromorfologica, FTIR e XRD, in: Gelichi, S., Piuzei, F.,
596 Cianciosi, A. (Eds.), "Sachuidic presso Forni Superiore". *Ricerche archeologiche in un*
597 *castello della Carnia*, Edizioni all'Insegna del Giglio, Florence, pp. 50-55.
- 598 Toffolo, M.B., Brink, J.S., Berna, F., 2015. Bone diagenesis at the Florisbad spring site, Free State
599 Province (South Africa): Implications for the taphonomy of the Middle and Late Pleistocene
600 faunal assemblages, *Journal of Archaeological Science: Reports* 4, 152-163.

601 Toffolo, M.B., Brink, J.S., van Huyssteen, C., Berna, F., 2017. A microstratigraphic reevaluation of
602 the Florisbad spring site, Free State Province, South Africa: Formation processes and
603 paleoenvironment, *Geoarchaeology* 32, 456-478.

604 Tooth, S., McCarthy, T.S., Brandt, D., Hancox, P.J., Morris, R., 2002. Geological controls on the
605 formation of alluvial meanders and floodplain wetlands: the example of the Klip River,
606 eastern Free State, South Africa, *Earth Surface Processes and Landforms* 27, 797-815.

607 Tooth, S., Brandt, D., Hancox, P.J., McCarthy, T.S., 2004. Geological controls on alluvial river
608 behaviour: a comparative study of three rivers on the South African Highveld, *Journal of*
609 *African Earth Sciences* 38, 79-97.

610 van der Marel, H.W., Beutelspacher, H., 1976. *Atlas of Infrared Spectroscopy of Clay Minerals and*
611 *their Admixtures*, Elsevier Scientific Publishing Company, Amsterdam.

612 van Hoepen, E.C.N., 1930. Fossiele perde van Cornelia, O.V.S., *Paleontologiese Navorsing van die*
613 *Nasionale Museum Bloemfontein* 2, 1-24.

614 van Hoepen, E.C.N., 1932a. Voorlopige beskrywing van Vrystaatse soogdiere, *Paleontologiese*
615 *Navorsing van die Nasionale Museum Bloemfontein* 2, 63-65.

616 van Hoepen, E.C.N., 1932b. Die stamlyn van die sebras, *Paleontologiese Navorsing van die*
617 *Nasionale Museum Bloemfontein* 2, 25-37.

618 van Hoepen, E.C.N., 1947. A preliminary description of new Pleistocene mammals of South Africa,
619 *Paleontologiese Navorsing van die Nasionale Museum Bloemfontein* 7, 103-106.

620 Vingiani, S., Minieri, L., Livadie, C.A., Di Vito, M.A., Terribile, F., 2018. Pedological
621 investigation of an early Bronze Age site in southern Italy, *Geoarchaeology* 33, 193-217.

622 Weiner, S., 2010. *Microarchaeology. Beyond the Visible Archaeological Record*, Cambridge
623 University Press, New York.

624

625 Captions

626 **Figure 1.** Map of southern Africa showing the location of Cornelia-Uitzoek.

627 **Figure 2.** General view of Cornelia-Uitzoek, looking north.

628 **Figure 3.** View of the shale bedrock and basal Banded Gravel Bed, looking north. Note the deep
629 incision cut into bedrock by the river and the erosional boundary between sedimentary units.

630 **Figure 4.** View of the Banded Gravel Bed and overlying Mottled Yellow Clay, looking south
631 (scale: 20 cm). The trench cross-cuts the bone bed. Solid line marks the boundary between
632 sedimentary units; dashed line marks the limit of the bone bed; white blocks and square are
633 micromorphology samples discussed in the text. Note faunal material in the section (arrows).

634 **Figure 5.** View of the Mottled Yellow Clay and Laminated Orange Clay, looking north. The
635 boundary between sedimentary units roughly coincides with the foot of the donga. Note horizontal
636 laminations in the erosional profiles.

637 **Figure 6.** View of the Laminated Orange Clay, looking east. Squares mark micromorphology
638 blocks (trowel: 15 cm).

639 **Figure 7.** View of the Laminated Orange Clay and Orange Coarse Gravel, looking south (scale: 20
640 cm). Note the erosional boundary between sedimentary units and vertical root casts. Square marks a
641 micromorphology block.

642 **Figure 8.** View of the Laminated Orange Clay, Orange Coarse Gravel, Dark Grey Clay and Black
643 Turf Soil, looking south (trowel: 15 cm). Note the diffuse boundary between topsoil and Orange
644 Coarse Gravel. Squares mark micromorphology blocks.

645 **Figure 9.** Representative FTIR spectra of sediments from Cornelia-Uitzoek.

646 **Figure 10.** Photomicrographs of representative thin sections from Cornelia-Uitzoek; all images in
647 plane polarized light, except for D in crossed polarized light. A and B: MYC, fragmented clay
648 crusts embedded within the MYC; C: MYC, rounded shale pellet from bone bed deposit; D: MYC,
649 striated b-fabric (lighter orange stringers) indicative of shrink/swell processes; E and F: MYC,
650 juxtaposed coatings of dark-green and yellow clay, bone bed deposit; G: MYC, Fe-Mn oxides
651 aggregate nodules (arrows) superimposed on clay coatings (pale yellow sediment in void); H:
652 MYC, Fe-Mn oxides coating and hypocoating (red-brown halos) around channel.

653 **Figure 11.** Photomicrographs of representative thin sections from Cornelia-Uitzoek; all images in
654 plane polarized light, except for E in crossed polarized light. A: LOC, Fe-Mn oxides impregnative
655 feature on groundmass (darker hue), note the marked boundary; B: LOC, coarse, dense infilling of
656 red clay and silt from overlying layers, caused by a root channel; C: LOC, shale pellets bound by
657 bridges of dark-green and yellow clay coatings; D: LOC, juxtaposed coatings of dark-green and
658 yellow clay; E: OCG, dolerite fragment; F: OCG, orthic (left) and disorthic (right) typic nodules of
659 Fe-Mn oxides; G: OCG, orthic concentric nodule of Fe-Mn oxides (arrow); H: BTS, ellipsoid
660 excrements deposited by mites (brown rounded dots).

661 **Figure 12.** General view of the donga, looking north. Note the numerous vertical root casts that run
662 through the Orange Coarse Gravel and Laminated Orange Clay. In the latter, cross-sections of the
663 casts are visible from the surface (profile in the background).

664 **Figure 13.** Pebbles of shale and dolerite coated with Fe-Mn oxides that formed at the boundary
665 between BTS and OCG. These components are a lag deposit produced by the erosion of BTS and
666 OCG during donga advancement (scale: 20 cm).

667 **Figure 14.** View of the topsoil, looking east. Areas that lost plant cover due to donga advancement
668 (arrows) appear dark grey in color due to the oxidation of organic matter in BTS. This deposit
669 occurs in patches at the edge of the donga and was named Dark Grey Clay by Brink et al. (2012).

670 **Figure 15.** General view of the donga, looking east. Note channeling caused by water erosion
671 (arrows).



250 KM



Bone bed



Valley fill and donga

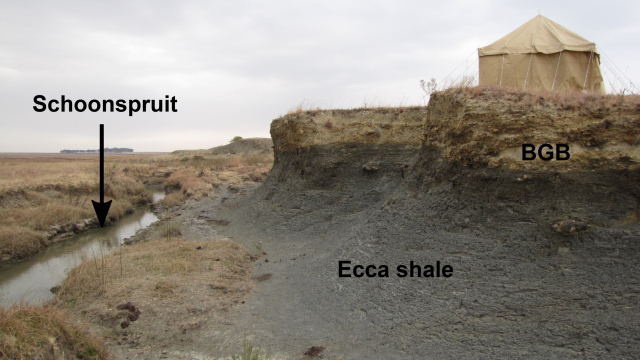


Schoonspruit



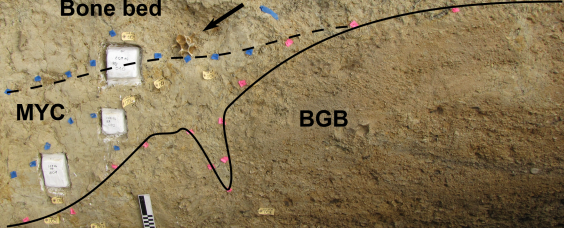
BGB

Ecca shale





Bone bed



MYC

BGB





LOC

MYC

LOC



OCG



LOC

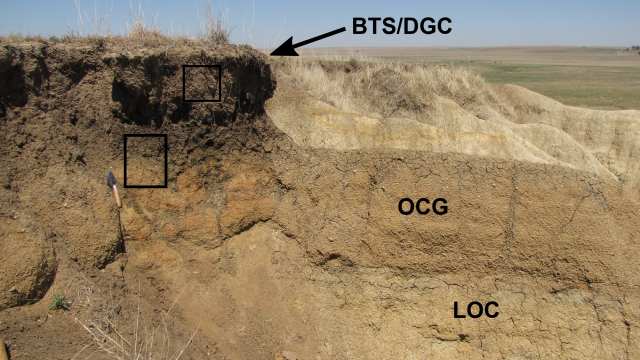


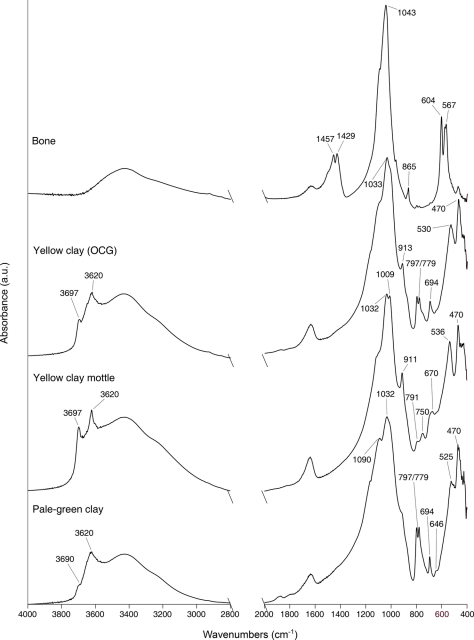
BTS/DGC

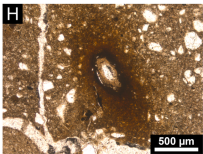
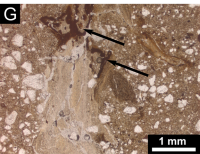
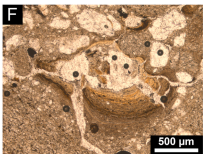
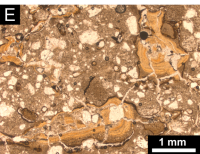
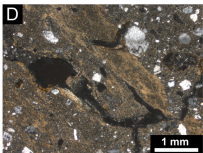
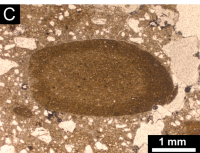
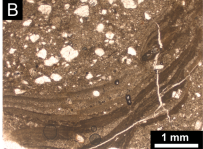
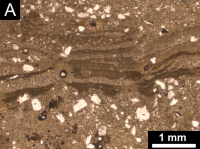


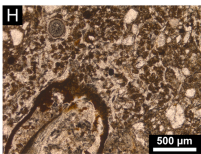
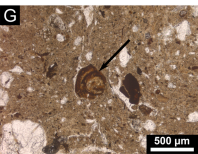
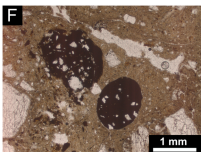
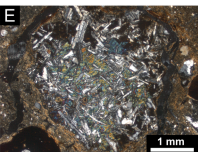
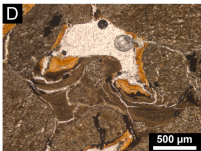
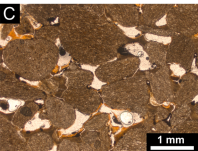
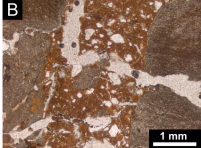
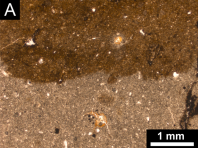
OCG

LOC

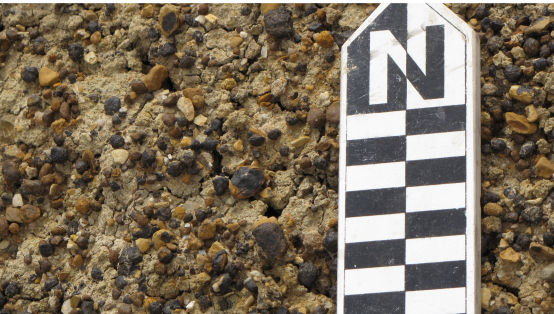














DGC



Table 1. Sedimentary units identified at Cornelia-Uitzoek from top to bottom, including data from Brink et al. (2012). Ages are based on paleomagnetism.

Unit	Description	Age (Ma)
Black Turf Soil (BTS)	Topsoil composed of dark brown clay, about 50 cm thick; it contains Middle Stone Age artifacts in places	<0.78
Dark Grey Clay (DGC)	Layer composed of dark grey clay, about 50 cm thick, contiguous to BTS; it contains younger Acheulean artifacts	<0.78
Orange Coarse Gravel (OCG)	Layer composed of gravel, up to 2 m thick at some locations	<0.78
Laminated Orange Clay (LOC)	Layer composed of alternating beds of clay and fine gravel, 2 m thick; it contains small clusters of bones	0.99-0.78
Mottled Yellow Clay (MYC)	Layer of massive pale-yellow to pale-green clay, 3 m thick; it contains a bone bed accumulated by hyenas and Acheulean artifacts	1.07-0.99
Banded Gravel Bed (BGB)	Layer of gravel characterized by normal graded bedding, 1 m thick	>1.07

Table 2. Microfacies types (MFT) identified at Cornelia-Uitzoek. The terminology follows Stoops (2003). MFTs as defined by Flügel (2004).

MFT name	Description	Formation process	Layer
Clay	<p>c/f related distribution: close porphyric to open porphyric.</p> <p>Structure and voids: weakly to moderately separated angular blocky microstructure with planes and few channels.</p> <p>Coarse fraction: sub-angular, silt-sized quartz and feldspar grains (dominant); sub-rounded to sub-angular, medium sand- to very fine sand-sized quartz and feldspar grains (common); rounded, coarse sand- to very fine pebble-sized shale pellets (few).</p> <p>Fine fraction: pale-green clay with stipple speckled b-fabric, and in places monostriated, cross-striated, porostriated and granostriated b-fabric.</p> <p>Pedofeatures: dusty dark-green clay coatings on voids with striated b-fabric; dusty dark-green clay intercalations with striated b-fabric; limpid yellow clay laminated coatings on voids with striated b-fabric; limpid yellow clay dense infillings with striated b-fabric; moderately to strongly impregnated Fe-Mn oxide orthic aggregate nodules in groundmass, shale pellets and clay coatings/infillings; Fe-Mn oxide hypocoatings and quasicoatings on voids; dark-green clay crusts with striated b-fabric; red silty clay dense infillings with stipple speckled b-fabric; limpid red clay laminated coatings on voids with striated b-fabric.</p>	Overbank deposit (meandering river), shrink/swell, fine and coarse illuviation	MYC, LOC
Fine gravel	<p>c/f related distribution: chitonic to concave gefuric.</p> <p>Structure and voids: weakly separated granular microstructure to vughy microstructure, with compound packing voids, regular vughs and star-shaped vughs.</p> <p>Coarse fraction: rounded, coarse sand- to medium pebble-sized shale pellets (very dominant); sub-rounded, medium sand-sized quartz grains (very few).</p> <p>Fine fraction: pale-green clay with stipple speckled b-fabric, and in places granostriated b-fabric.</p> <p>Pedofeatures: dusty dark-green clay coatings on voids with striated b-fabric; limpid yellow clay laminated coatings on voids and shale pellets with striated b-fabric; limpid yellow clay dense infillings with striated b-fabric; moderately to strongly impregnated Fe-Mn oxide orthic aggregate nodules in groundmass, shale pellets and clay coatings/infillings; Fe-Mn oxide hypocoatings of voids.</p>	Overbank deposit (meandering river), shrink/swell, fine illuviation	LOC
Coarse gravel	<p>c/f related distribution: close porphyric to open porphyric.</p> <p>Structure and voids: weakly to moderately separated angular blocky microstructure with planes and few channels.</p> <p>Coarse fraction: sub-angular, silt-sized quartz and feldspar grains (frequent); sub-angular to sub-rounded, medium sand- to very fine sand-sized quartz and feldspar grains (frequent); rounded, coarse sand- to very coarse pebble-sized dolerite fragments (few); rounded, coarse sand- to pebble-sized shale pellets (few); elongated fragments of plant tissue (very few).</p> <p>Fine fraction: pale-brown clay with random striated, granostriated and porostriated b-fabric.</p> <p>Pedofeatures: strongly impregnated Fe-Mn oxide orthic and disorthic typic nodules; weakly impregnated Fe-Mn oxide orthic aggregate nodules on groundmass.</p>	Channel/point bar deposit (meandering river), shrink/swell, eluviation	OCG
Topsoil	<p>c/f related distribution: close porphyric.</p> <p>Structure and voids: massive microstructure with rare channels.</p> <p>Coarse fraction: sub-angular, silt-sized quartz and feldspar grains (dominant); sub-angular to sub-rounded, medium sand- to very fine sand-sized quartz and feldspar grains (common); elongated plant fibers (very few).</p> <p>Fine fraction: dark-brown clay with undifferentiated b-fabric; amorphous organic matter.</p> <p>Pedofeatures: strongly impregnated Fe-Mn oxide orthic and disorthic typic nodules; spherical and ellipsoid excrements.</p>	Overbank deposit (meandering river), pedogenesis	BTS, DGC