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# Palynology of Middle Stone Age spring deposits in grassland at the Florisbad hominin site, South Africa

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## ABSTRACT

New pollen evidence and a review of past palynological research at the Pleistocene Florisbad thermal spring mound, which produced faunal, hominin and archaeological remains, allow a reconstruction of past conditions in the central Free State grassland, South Africa. Pollen sequences at the spring consist of alternating pollen-rich organic peaty horizons interrupted by hiatuses or pollen-poor layers of sandy and clayey deposits. The paleoclimatic interpretation of pollen sequences in springs like Florisbad, which contain a mixture of local and regional pollen and are influenced by spring mound cycles and changes in swamp configuration, requires consideration of taphonomy and site geomorphology to separate local from regional influences. By correlating the pollen stratigraphy in different parts of the site we suggest that the lower layers containing the Florisbad hominin (dated to 259 ka) and its associated Middle Pleistocene fauna, experienced cool moist and grassy conditions. Dating of some of the overlying Middle Stone Age layers suggest that they encompass the Last Interglacial period (MIS 5e; ca. 124–119 ka). In these levels the pollen evidence of upland fynbos shrubs unexpectedly suggests that cool conditions prevailed. This raises questions about the taphonomy, precision of the age estimate of occupation or the way we interpret pollen spectra.

## 1. Introduction

The presence of fossil pollen in the Florisbad spring deposits in the central interior grassland of the Free State province in South Africa (Fig. 1a, b), was first reported in the Third-Pan-African Congress on Prehistory, Livingstone (Zambia) in 1955 as one of the first palynological studies in South Africa (van Zinderen Bakker, 1957). The spring site, located approximately 48 km north north-west of Bloemfontein and at an altitude of 1275 m above mean sea level, is of historical and paleoenvironmental importance because it produced archaeological remains and an ancient hominin fossil, with associated fauna (Dreyer, 1935; Brink, 1987, 1988, 2016). In view of these discoveries and the presence of organic deposits, E. M. van Zinderen Bakker recognized the site as a possible source for paleofloristic investigations (van Zinderen Bakker, 1951, 1957; Neumann and Scott, 2018). The sequence of deposits at Florisbad provided some of the first radiocarbon dates of African material (Libby, 1954; in van Zinderen Bakker, 1957). These results suggested an age of at least 40,000 yr BP indicating great antiquity but were shown to be even older (J. C. Vogel in Kuman and Clarke (1986)) and closer to 300,000 yr BP (Grün et al., 1996). The pollen record from Florisbad was the first in the central grassland region of southern Africa and suggested marked changes in paleoenvironmental and climatic conditions, particularly in the apparent balance between karroid and grassland vegetation types (van Zinderen Bakker, 1957).

Paleobotanical reconstructions of environments associated with fossil faunas and hominins, like Florisbad, often derive from not well-dated deposits. In a global Earth system where a sequence of regular long-term climate oscillations took place (Railsback et al., 2015), it is frequently not possible to place them accurately. We can potentially narrow down age estimates of a sequence based on past environmental evidence obtained from fossil pollen. Paleoenvironmental change in the central interior of southern Africa is not well documented, due to the limited number of sites such as lakes, so that attention has been given to spring sites, e.g. Florisbad, Aliwal North and Wonderkrater (Coetzee, 1967; van Zinderen Bakker, 1957; Scott, 1982a, Scott, 2016; van Aardt et al., 2015).

In the Free State grassland, Florisbad is probably the only site with a long pollen history reaching back to the Middle Pleistocene and which contains important evidence of faunal and human presence (Dreyer,

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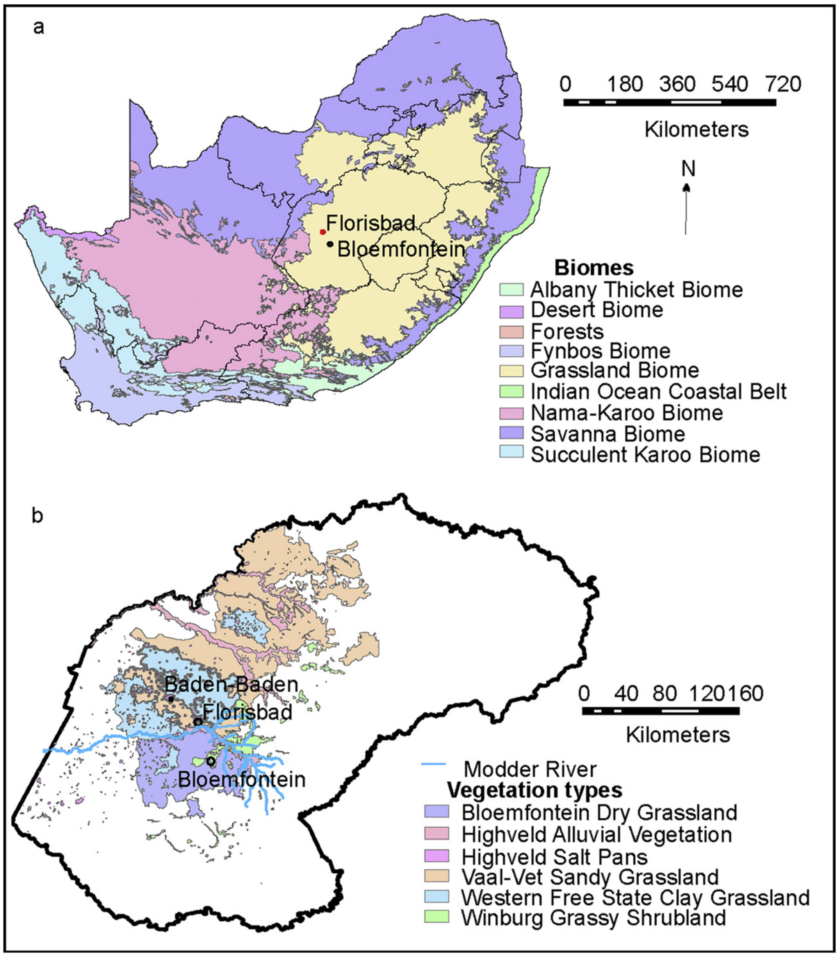

**Fig. 1.** Locality map of Florisbad in relation to biomes (a) and vegetation types (b).

1935; Kuman and Clarke, 1986; Brink, 1987). Up to now, its palynological interpretation has been far from clear due to several factors including poor pollen representation in different layers, and uncertainty about aspects of the early pollen studies (van Zinderen Bakker, 1957, 1989; Scott and Rossouw, 2005). For instance, some of the problems in assessing the work were the lack of sample provenance information, contradictory inferences between pollen and geological data (van Zinderen Bakker, 1957, 1989; Visser and Joubert, 1990, 1991), lack of climatically diagnostic pollen types in the low-diversity grassland vegetation and incomplete and problematic dating. Due to these limitations, it is not yet possible to correlate the Florisbad paleoenvironmental sequence (van Zinderen Bakker, 1957, 1989; Scott and Nyakale, 2002) to other sites in the central interior of South Africa. These include places like Kathu Pan, Wonderwerk Cave, Equus Cave, Deelpan, Alexandersfontein Pan and Baden-Baden (Beaumont et al., 1984; Butzer, 1984a,b, 1988; Scott, 1987; Scott et al., 2012, 2013; Scott and Thackeray, 2015; van Aardt et al., 2015). Questions that arise include the following: Why do the pollen sequences in previous studies at Florisbad appear to differ (van Zinderen Bakker, 1957, 1989; Scott and Nyakale, 2002)? What sequence of environmental changes played a role in the formation of the site (van Zinderen Bakker, 1957, 1989; Toffolo et al., 2015; Toffolo et al., 2017)? How do these conditions relate to the faunal and archaeological finds and extinctions, and what were environmental conditions that the Florisbad hominin and successive MSA groups experienced?

Due to extensive excavations around the site, previously studied sections (e.g., van Zinderen Bakker, 1957) have been removed and cannot be repeated. Although currently exposed walls are covered for protection, from a palynological point of view, they may be deteriorating due to desiccation or bioturbation over time. An opportunity to extend the Florisbad pollen record presented itself when Michael Toffolo sampled several sequences for a micromorphological study of the deposits and made his sub-samples available for pollen analysis, including those of Test Pit 2 (Toffolo et al., 2017). New paleonvironmental information of the Middle Pleistocene and later, may apart from its potential usefulness in anthropology, contribute to regional reconstructions and modeling of southern African paleoclimates, which are poorly understood. Since Florisbad is such a unique site with its fossil human, faunal and archaeological remains combined with paleobotanical potential, it is essential to obtain the optimal paleoenvironmental information to understand aspects such as human subsistence and faunal extinctions in the Free State grassland. Furthermore, it provides a rare opportunity to improve the paleoclimatic record, especially if palynological data can be placed in an improved chronological framework.

We attempt therefore to improve the available data and understanding of climatic changes in the region by reconsidering van Zinderen Bakker's (1957, 1989) pollen studies while also introducing new results. This may provide a provisional reconstruction that can serve as a platform for future palynological and paleoenvironmental research.

### *1.1. Florisbad setting*

The open-air spring site is located in the south of a large playa (pan) in a depression called Soutpan, (Fig. 2a, b), which is one of several pans that occur in the western Free State, and covers an area of >30 km$^2$. The climate is typical of the central interior Highveld. It experiences arid to semi-arid conditions, receiving between 450 and 530 mm of annual precipitation concentrated between November and March.

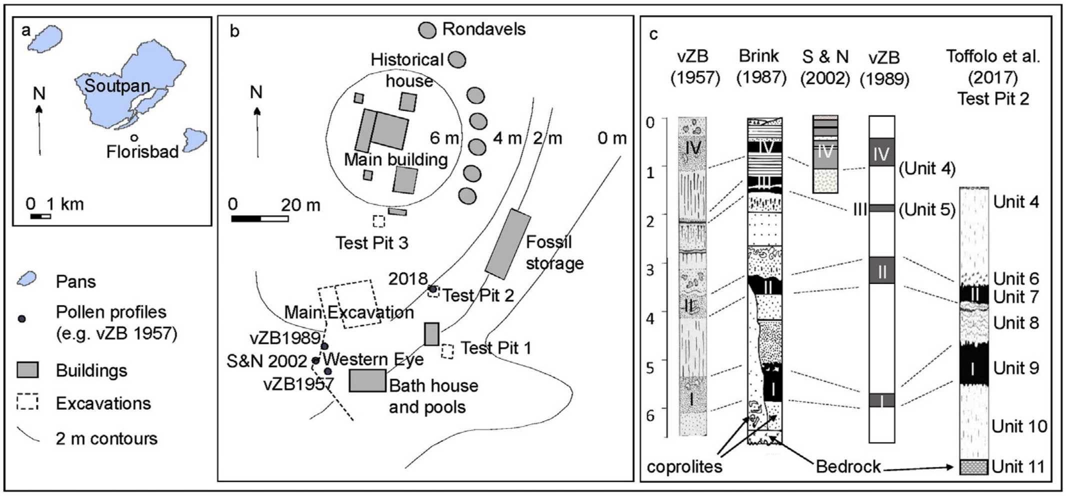

**Fig. 2.** Florisbad locality map (a), map of the c. 300 ka old spring mound with pollen profiles, the Western Eye (sources of the spring collection fauna) and the Main Excavation (MSA floor and fauna) (b), and stratigraphic profiles, i.e., Brink (1987) for fauna and van Zinderen Bakker (vZB) (1957, 1989), Scott and Nyakale (S&N) (2002) and Test Pit 2 (this study) for pollen (c). Roman numbers and unit numbers refer to peat and other deposits respectively (Toffolo et al. (2017).

Precipitation is usually associated with thunderstorms, which result in high run-off and low infiltration under high evaporative conditions. Summer temperatures are high ranging between 30 and 33 °C and winters are prone to temperatures below 0 °C at night with severe frost, especially in July (Mucina and Rutherford, 2006).

The vegetation types surrounding Florisbad belong to the Grassland Biome and include Western Free State Clay Grassland, Vaal-Vet Sandy Grassland and Highveld Salt Pan Vegetation types (Mucina and Rutherford, 2006). The Western Free State Clay Grassland is similar to previously reported veld types, the Dry Cymbopogon-Themeda Veld (Acocks, 1953) and Dry Sandy Highveld Grassland (Low and Rebelo, 1996). This vegetation type mostly occurs on the flat bottom-lands and contains high numbers of grass species and dwarf karoo shrubs belonging to the Asteraceae family (Mucina and Rutherford, 2006) and is similar to the Vaal-Vet Sandy Grassland (Mucina and Rutherford, 2006), which is found on the undulating plains and hills. This vegetation usually consists of low tussock-grasses with some relict low shrubs on the dolerite hills. It is in contrast with the azonal Highveld Salt Pan vegetation that occurs in Soutpan below the spring (Fig. 2a) which is mostly dominated by species of Amaranthaceae, Poaceae, Cyperaceae and Asteraceae (Mucina and Rutherford, 2006).

### 1.2. Dating and stratigraphy

The mound associated with the spring is about 7 m high occurring on the edge of Soutpan and which according to Marshall (1988), possibly formed part of a putative paleo-river system. The spring mound grew because of eolian sediment trapped in the moisture and vegetation of the spring that formed organic layers of peaty deposits. These were at times submerged by lakes that covered the entire area (Visser and Joubert, 1991; Toffolo et al., 2017). This accumulation includes a cluster of spring vents that resulted from fissures in the underlying dolerite intrusion in Permian shales of the bedrock and broke through to the surface (Rubidge and Brink, 1985; Kuman and Clarke, 1986; Grobler and Loock, 1988). The formation of alternating organic and eolian deposits resulted in a complex layered pattern that was dissected by migrating spring "eyes" (Rubidge and Brink, 1985). Several of these were active and appeared at different times disturbing the horizontal stratigraphy of layers (van Zinderen Bakker, 1957). In 1912, an explosive earthquake event of the spring brought older material to the surface (Hoffman, 1955). Movement of material in the spring vent can be problematic for dating of the sequence (van Zinderen Bakker, 1957) but published profiles (Kuman and Clarke, 1986; Kuman et al., 1999) show that spring material is capped by younger sands so that fossils are probably close to their original positions despite disturbance.

The site is much older than 50 ka, as previously thought (van Zinderen Bakker, 1957) and far beyond the limit of radiocarbon dating. Initial dating was problematical especially in the case of the radiocarbon method because of contamination from younger material (Kuman and Clarke, 1986). The fossils trapped in the spring mound are of Middle Pleistocene, Late Pleistocene and Holocene age (Kuman and Clarke, 1986; Brink, 1987, 1988, 2016; Grün et al., 1996).

Although uranium series and thermoluminescence dating methods were unsuccessful (Kuman and Clarke, 1986; Kuman et al., 1999), radiocarbon dating by J. C. Vogel (in Kuman and Clarke, 1986) was later complemented with other dating methods in the deeper deposits (Grün et al., 1996; Brink, 1997). They comprised electron spin resonance (ESR) and optically stimulated luminescence (OSL) (Grün et al., 1996;) from Test Pit 3 that showed that the spring is at least of Middle Pleistocene age. Despite the wide range of ages, varying between 100 and 350 ka for ESR and OSL dates, a reasonably reliable broad chronology was established for the spring deposits but finer layers are mostly not dated. A tooth associated with the cranium has been dated to 259 ± 35 ka by the ESR method (Grün et al., 1996; Brink, 1997, 2016). An overlying level associated with the MSA was dated to ca. 175 ka using OSL dating, and the MSA living floor to ca. 121 ka using ESR dating (Grün et al., 1996; Brink, 1997).

For the 6 m of Test Pit 2 (Fig. 2b), of which new pollen analyses are reported in this study, the total age range is between roughly 280 ka at the bottom, and an unknown time at the top. The latter must be younger than 121 ka but older than 12 ka according to correlation of units with the dates obtained by Grün et al. (1996) in Test Pit 3 (Toffolo et al., 2017).

In connection with radiocarbon dating, the presence of roots of alien *Pinus* and *Eucalyptus* plants that have spread at Florisbad during historical times was suggested to be the cause of contamination (J.C. Vogel pers. com.; Kuman and Clarke, 1986). The Last Glacial Maximum is not represented in the available sequences but overlying peaty layers (Peat IV) were dated to the Holocene using radiocarbon dating (Kuman and Clarke, 1986; Scott and Nyakale, 2002). In connection with Holocene peaty layers, Scott and Nyakale (2002) took care to remove minute roots in dating samples. The results (c. 7 ka or 6290 yr BP (uncalibrated) for the lower half of Peat IV or B2) seem to provide older ages than those in previous studies than J. C. Vogel's dates (Kuman and Clarke, 1986; van Zinderen Bakker, 1989) of between c. 3550 and 5530 yr BP (uncalibrated). A discrepancy appeared between the radiocarbon dates of Peat IV (<12 ka) in the western spring excavation and the ESR date (15 ka) of the same layer in Test Pit 3 where it changes to red sand higher up the mound (Coetzee and Brink, 2003; Grün et al., 1996; Scott and Nyakale, 2002; Toffolo et al., 2017). The disagreement is noticed with correlation of sedimentary units using micromorphology,the elevations of layers and the occurrence of Lockshoeck artifacts, a tool type found in deposits broadly dated to 12–8 ka (Mitchell, 2002: 143). Toffolo et al. (2017) raised the possibility that Peat IV might be slightly older than previously thought. However, in the absence of a tight absolute chronology for the terminal Pleistocene and Holocene, here we refer to the available radiocarbon dates obtained directly from Peat IV (Scott and Nyakale, 2002).

Much of the early research at Florisbad focused on faunal assemblages and the stone implements left by early inhabitants of the region (Broom, 1913; Dreyer, 1935, 1938; Hoffman, 1953, 1955; Meiring, 1956; Ewer, 1957; Hooijer, 1958). The archaeological, paleontological and geomorphological finds from the studied Florisbad deposits include early Middle Stone Age (MSA) artifacts and fauna (Dreyer, 1935; Kuman and Clarke, 1986; Butzer, 1988; Grobler and Loock, 1988; Brink, 1987; Joubert et al., 1991; Visser and Joubert, 1991; van Zinderen Bakker, 1995; Grün et al., 1996; Kuman et al., 1999; Toffolo et al., 2017). What makes the site especially unique is the recovery from the deepest part of the deposit of a hominin cranium that include facial bones, which was referred to as an archaic *Homo sapiens* (Clarke, 1985; Kuman and Clarke, 1986) but has also debatably been designated to an intermediate form between *H. heidelbergensis* and *H. sapiens* (Brink, 1987, 1988, 2016). It is associated with Florisian fauna and more specifically with the so-called spring collection from the spring vent that intrudes the layered deposits (Brink, 1987) (Fig. 2c). The occurrence of lechwe provides evidence of swampy local conditions (Brink, 1987, 1988, 2016; Codron et al., 2008). The upper deposits, from levels dated to MIS stages 6 and 5, also contain Middle Stone Age (MSA) tools and fossil Florisian fauna including aquatic species such as hippo, that were found together on a living floor (Grün et al., 1996; Brink, 1987, 1988, 2016; Kuman et al., 1999).

The units of spring deposit (Table 1) that were described in the early papers are four dark organic layers that alternated with lighter sandy layers (le Roux, 1978; Kuman and Clarke, 1986; Butzer, 1988; van Zinderen Bakker, 1989; Visser and Joubert, 1991; van Zinderen Bakker, 1995; Kuman et al., 1999). They were recently treated in detail in Toffolo et al. (2017), who described their chemical composition, micromorphology and formation processes (Table 1). In the discussion of the mound we refer either to the dark organic layers as Peats I–IV (Fig. 2c) and the sands as Sands 1–4 as reported in van Zinderen Bakker (1989), or otherwise to the detailed alphabetical system, A-P, of Kuman and Clarke (1986) or the numerical system, units 1–10, of Toffolo et al. (2017).

**Table 1**
Relevant lithological units of spring deposits in previous publications. Contents: Artifacts (Lockshoek (l), MSA (m)); Fauna (bone (b), coprolite (c), hominin (h)). Age references: Kuman and Clarke (1986); Grün et al. (1996); Kuman et al. (1999); Scott and Nyakale (2002). Ages of 12 ka and younger from the western spring-eye area and older dates from Test Pit 3.

| van Zinderen Bakker (1957, 89), Butzer (1988) | Kuman and Clarke (1986) | Toffolo et al., (2017) | Artifacts, fauna | Age (ka) |
|---|---|---|---|---|
| Peat IV | B1 | 4 | | <7 ka |
| | B2 | 4 | l, b | <9.3 ka |
| Sand 4/Peat IV | C | 4 | | 9.3–12 ka |
| Sand 4 | D | 4 | m | |
| Peat III | E | 5 | | |
| Sand 3 | F | 6 | m,b | 121 ± 6 |
| | G | 7 | | |
| | H | 7 | m,b | |
| | I | 7 | m,b | |
| | J | 7 | | |
| Peat II | K | 7 | | |
| Sand 2 | L | 8 | m,b | |
| | M | 8 | m,b | 157 ± 21 |
| | N | 8 | | |
| Peat I | O | 9 | m,b?,h?,c | 259 ± 35 |
| Peat I/Sand 1 | P3 | 10 | m,b,c | |
| Bedrock | Q | 11 | | |

### 1.3. Previous pollen analyses

Pollen is not preserved or is scarce in several sandy eolian layers. It only occurs in some dark organic sands and peats e.g., Peats I–IV as reported in the first studies (van Zinderen Bakker, 1957, 1989; Scott and Brink, 1992). The layers of eolian sand or alkaline and oxidized pan or lake deposits, which formed under evaporative conditions, are mostly barren of pollen or contained a low concentration due to both grain size sorting or oxidative conditions under strong evaporation. Furthermore, occurrences of productive organic rich layers are limited and restricted to the central area of the spring mound near the spring vents (Rubidge and Brink, 1985). A potential problem for pollen analysis is that flowing water may also cause a certain degree of mixing because material in the spring can apparently be reworked in horizontal layers to create an anomalous stratigraphy (van Zinderen Bakker, 1989; Brink, 1997). Another constraint is that old surfaces exposed for a long time before being covered, may have lost pollen through droughts and oxidation or the pollen underwent corrosion, shrunk or were wrinkled (van Zinderen Bakker, 1957, 1989).

After van Zinderen Bakker's (1957) publication on the great western spring eye in the northern extension of excavations (Fig. 2b), he followed up this work using new samples collected from nearby exposures of the Main Excavation made by Kuman and Clark in 1986 (van Zinderen Bakker, 1989). van Zinderen Bakker's (1989) pollen samples were collected away from the disturbed spring area in the Main Excavation where the deposits were in chronological sequence (Fig. 2b). He increased the number of pollen samples from 27 (in his 1957 paper) to 46. In order to shed more light on developments within the spring and in the wider surroundings, he attempted a different strategy. In the first paper, he focused on the Poaceae/Asteraceae ratio to estimate the moisture availability, which can be interpreted as reflecting changes between wetter grassland and drier karroid conditions. Here he included Chenopodiaceae (Amaranthaceae) and Cyperaceae pollen types in order to present a more holistic interpretation with diverse assemblages (van Zinderen Bakker, 1989). He also found small numbers of cool upland fynbos types in the lower levels that seemed to be evidence of lower temperatures than at present. Scott and Rossouw (2005) noted that van Zinderen Bakker (1989) did not specify if his Asteraceae pollen included *Stoebe* type pollen or not. This type is prominent in most Late Pleistocene pollen assemblages associated with cooler conditions in southern Africa including a wide region from Namibia to the mountains of the eastern Free State (Scott, 1982a, 1987, 1989; Scott et al., 2004; Scott et al., 2013, 2018; van Aardt et al., 2015). Its absence at Florisbad seemed unusual especially in the older layers, which could be associated with cool conditions. In the present study, we assess the available evidence for the occurrence of *Stoebe* type pollen.

Contradictory reconstructions were noted between the geological interpretations of Visser and Joubert (1991) and pollen results provided by van Zinderen Bakker (1989, 1995) (Scott and Brink, 1992). The latter indicated an arid dry lake (pan) environment and the former suggested lake conditions for Sand 2 (van Zinderen Bakker, 1989) (Units L and M sands in Kuman and Clarke, 1986; Unit 8, Toffolo et al., 2017). Where Visser and Joubert (1991) attributed this unit to higher lake deposits from the basin that flooded the spring area, the high proportions of Amaranthaceae (Cheno/Am) pollen (van Zinderen Bakker, 1989) signified halophytic vegetation and dryness. Scott and Brink (1992) attempted to explain the discrepancy as possibly due to infiltration of this pollen through mud cracks into the lake deposit, assuming the original pollen was lost through desiccation and oxidation. This matter will be reconsidered in this paper (see Discussion).

## 2. Material and methods

### 2.1. Test Pit 2

Test Pit 2 (Figs. 2, 3 and 4) was studied using the samples provided by Michael Toffolo (Toffolo et al., 2017) of which 50 were received in sealed plastic bags. They did not cover the bottom 2 m (Unit 10). The organic peat and silt samples that were solid, were cleaned to avoid modern pollen contamination but this was not possible for the loose sandy ones. Samples were digested in 10% HCl and 5% KOH before performing heavy liquid mineral separation with $ZnCl_2$ (density of 2) to separate organic fractions including pollen (Scott, 1982a; Scott and Nyakale, 2002; Scott et al., 2005). Samples containing clay or silt components were also washed with 40% HF to remove the remaining minerals. Spikes of exotic *Lycopodium* spore tablets (Lund batch no. 3862) were used to determine the pollen concentration per gram (Stockmarr, 1971). The material was then stained with safranin and mounted in microscope slides using glycerin jelly. The slides were scanned and palynomorphs identified using 40× and 100× (oil-immersion) objectives. We attempted to count >250 pollen grains per sample, but this was not always possible. Microscopic charred particles (charcoal) were also recorded for <50 and >50 μm fractions.

### 2.2. The Main Excavation area

A number of different pollen records from previous studies (van Zinderen Bakker, 1989; Scott and Brink, 1992; Scott and Nyakale, 2002) are combined here in a single diagram representing 63 spectra from c. 6 m of deposits covering roughly 280 ka. Some uncertainty exists as to the precise provenance of van Zinderen Bakker's (1989) samples, which form most of the pre-Holocene part of the sequence. His notes, which were stored at the UFS, consisted of graph-paper sheets with depths and pollen percentages, and several notebooks. Judging from the notes and charts we conclude that the pollen sequence was mainly derived from sections in the vicinity of the “great western spring eye” along the western section of the Main Excavation by Kuman and Clarke (1986) (Fig. 2b). However, the percentages of the nine levels of Sand 2 (van Zinderen Bakker, 1989), or levels from Layer M (Kuman and Clarke, 1986; Kuman et al., 1999), were missing from his notes. In the paper, however, they contained high proportions of Amaranthaceae pollen (van Zinderen Bakker, 1989). According to van Zinderen Bakker (1957) in his first study, levels corresponding with this section were found to be unproductive with no pollen. We assume that they were not rich in pollen but that he updated them later in a more rigorous attempt to obtain counts (van Zinderen Bakker, 1989). In order to estimate the missing percentage values, we measured the published pollen curves by van Zinderen Bakker (van Zinderen Bakker, 1989: his Fig. 3) and reconstructed the frequencies.

**Fig. 3.** Photograph of Makisang Nyakale at the spring “Western Eye” (Kuman and Clarke, 1986) where it is capped by Peat IV along the western wall of the Main Excavation. Scott and Nyakale's (2002) section was taken on her left about 1 m away. Van Zinderen Bakker's (1989) sequence is assumed to have been derived from further to the north in the vicinity of the suitcase, which is standing on the sand of F (Unit 6) with dark layers of E and B1 (Peats III and IV from Units 5 and 4 of Toffolo et al., 2017) above it.

**Fig. 4.** Unit 8 sand (Toffolo et al., 2017) with a light-colored sandy load structure in the black Unit 9 organic layer, Test Pit 2. Scale = 20 cm.

Two pollen counts of hyena coprolites from the lowermost levels (P3, Kuman and Clarke, 1986) are probably those that are listed in van Zinderen Bakker (1989). We present them here together with four others that came from the spring vent structure (supposedly from levels associated with Peat I) (Scott and Brink, 1992; Scott et al., 2003; Scott and Rossouw, 2005). For the Holocene levels, we replaced the upper six of van Zinderen Bakker's spectra (van Zinderen Bakker, 1989) with 19 samples of Scott and Nyakale (2002) that provide a more detailed and better dated sequence. This is justified because there is also uncertainty regarding the exact depths of van Zinderen Bakker's (1989) Holocene samples, which differ between the notes and the published pollen diagram (van Zinderen Bakker, 1989: his Fig. 3). The latter diagram suggests that Peat IV is c. 40 cm thick and Kuman and Clarke (1986) report that the dated section of Peat IV (B1) is c. 60 cm (25–85 cm) thick, while Scott and Nyakale's (2002) peat section is c. 100 cm thick. Following Dreyer's indication (in Kuman and Clarke, 1986) that it becomes thicker towards the south, we assume that van Zinderen Bakker's pollen sequence represents an area adjacent, and to the north, of Scott and Nyakale's (2002) profile. A photograph of this section (Fig. 3) and the area to the north show the thinning of the dark peaty layer towards the north. The lower half of Peat IV (Unit 4) persists to the north towards overlying red sand in Test Pit 3 (Toffolo et al., 2017).

### 2.3. Comparing the pollen data from the Main Excavation and Test Pit 2

With the aim of bringing the results of Test Pit 2 in context with previous palynological research, the available results from the excavations at the Main Excavation (Kuman and Clarke, 1986; van Zinderen Bakker, 1989; Scott and Brink, 1992; Scott and Nyakale, 2002), are presented in the same format to allow comparison. However, because the two sets of data are from different times and produced by different analysts using different taxonomic groupings, we present simplified diagrams combining some taxa into bigger units.

## 3. Results

Micrographs of deposits and the pollen results are presented in Figs. 5, 6 and 7. The former shows the pollen spectra of the section in Test Pit 2 next to the illustration of Toffolo et al. (2017) and the latter represents the combined results from the Main Excavation (van Zinderen Bakker, 1989; Scott and Brink, 1992; Scott and Nyakale, 2002).

### 3.1. Test Pit 2

The stratigraphic unit designations of the pollen samples (Toffolo et al., 2017) correspond fairly well to lithological changes with the exception of the transition between Units 8 and 9 (Fig. 6a). This is due to uneven separation between them with load structures of Unit 8 in the upper part of Unit 9 of which an example is shown in Fig. 4. Only samples from the part of the Test Pit 2 sequence between the main organic horizons of Toffolo et al. (2017) were productive.

The more solid dark organic, gray to black deposits, of which outsides of samples were removed to clean them, showed no contamination. The soft light colored sandy samples were often contaminated by modern exotic pollen. Contaminants are exotic alien pollen of plants introduced from other continents, mostly the tall alien invasive trees (neophytes) *Eucalyptus* and *Pinus*, of which many are currently growing around Florisbad. Pollen grains of dense alien invasive *Prosopis* shrubs from neighboring farms were absent probably because local growths were cleared from the spring area several years before the current excavations. We assume that modern pollen grains could infiltrate loose sandy exposures of the excavations through penetration of rain water and also through root cavities and bioturbation (Fig. 5a–d, see Discussion).

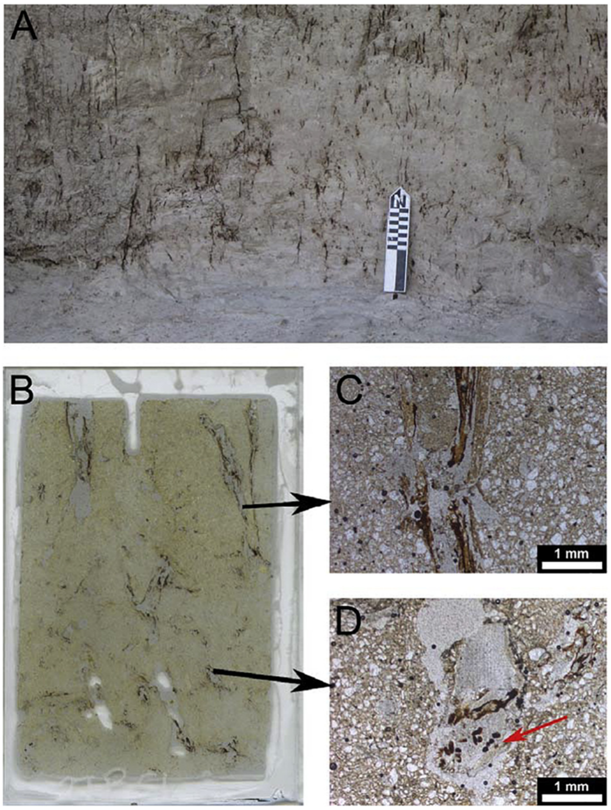

**Fig. 5.** Microscopic evidence of bioturbation Unit 4 in Pit 2. Ubiquitous presence of modern roots (scale: 20 cm) (a), scan of a thin section from Unit 4 (short side of frame: 5 cm) (b), photomicrograph of a close-up showing a root channel infilled with finer material from overlying sediments (c) and photomicrograph of a root channel filled with ellipsoid excrements possibly produced by oribatid mites (see Coetzee and Brink, 2003) (red arrow) (d).

The loose sandy samples with modern exotic pollen types were excluded from the diagram (Fig. 6) together with samples that were very poor in pollen. Counts of more than a hundred pollen grains could be achieved in only 31 samples. Of these 11 pollen bearing levels contained exotics (up to 50% of the pollen) of which 8 were discarded. Three samples with negligible contamination (<0.34% aliens) were kept in the data set (at 46.5, 120.1 and 214 cm). Finally, of the 50 samples prepared only 25 samples were retained for inclusion in the pollen diagram (Fig. 6).

The pollen concentration in different layers varies strongly from none, or very low numbers of pollen in the sandy units, to >400,000/g in the dark organic layers (Fig. 6). The microscopic charcoal follows the pollen concentration curve closely and therefore, like the pollen, seems to have perished in the same levels due to changing conditions of preservation. Caution is therefore necessary with inferring burning events from the peaks as they may reflect preservation in an incomplete record.

The pollen zonation shows strong variation between the major pollen types but does not always repeat the same pattern between the sandy and peaty layers. The Poaceae and Asteraceae pollen ratio can possibly provide an indication of karroid conditions and is presented on the right of Figs. 6 and 7. Although there is a tendency for this ratio to be high in the peaty layers, there is strong variation and no consistent pattern of succession of pollen throughout the sequence (Fig. 3e) (see Discussion).

Our general interpretation of the pollen sequence is that Unit 9 (Toffolo et al., 2017) shows declining swampy and grassy vegetation with Cyperaceae in favor of more Asteraceae and eventually Amaranthaceae, the latter probably indicating local evaporative conditions at Test Pit 2. Unit 8 shows a gradual return to grassy vegetation and contrary to expectation, despite low organic matter contents, this sandy layer has the strongest Cyperaceae percentage at the cost of Asteraceae (see discussion). Above c. 140 cm depth in Unit 8, low numbers of *Passerina* (Thymelaeaceae) occur as well as in the overlying Units 6 and 7. Unit 7 starts with high proportions of grass and Cyperaceae pollen. Amaranthaceae and Asteraceae that indicate renewed evaporative conditions gradually replace this. These conditions continue in the lower part of Unit 6 but then it changes to a grassier and swampy environment only to return to an Asteraceae assemblage at its top.

### 3.2. The Main Excavation area

The new combined pollen diagram that tentatively covers the entire spring sequence (Fig. 7), provides a record of roughly the last 280 ka. The pollen diagram gives a close representation of van Zinderen Bakker's (1989) illustration but does not look exactly like it. Minor differences are attributed to depths that differed between his original notes and the 1989 paper and in other cases where he must have reconsidered or changed the identifications of types like *Zygophyllum*, Apiaceae and Crassulaceae. Where there is uncertainty about these types, we have grouped them together under “Unidentified and other” (Fig. 7) (see discussion). Another notable difference is that Thymelaeaceae pollen in the notes is not mentioned in van Zinderen Bakker's (1989) publication. In the paper, he did not include a curve for unidentified and other pollen types and we assume some of the apparent minor discrepancies can be attributed to this.

We added the pollen data from the six hyena coprolites that fit between the bottom sample (brown sand) and Peat I in the diagram. Because the exact depths were unknown we used artificial levels (depths = 610–630 cm) that are presumably close to where they originally came from (van Zinderen Bakker, 1989; Scott and Brink, 1992). Their consistently high grass pollen assemblages are similar to Peat I (see Discussion).

The relationship of pollen and lithology of the different layers are discussed in the original publications (van Zinderen Bakker, 1989; Scott and Brink, 1992; Scott and Nyakale, 2002). Like in Test Pit 2,

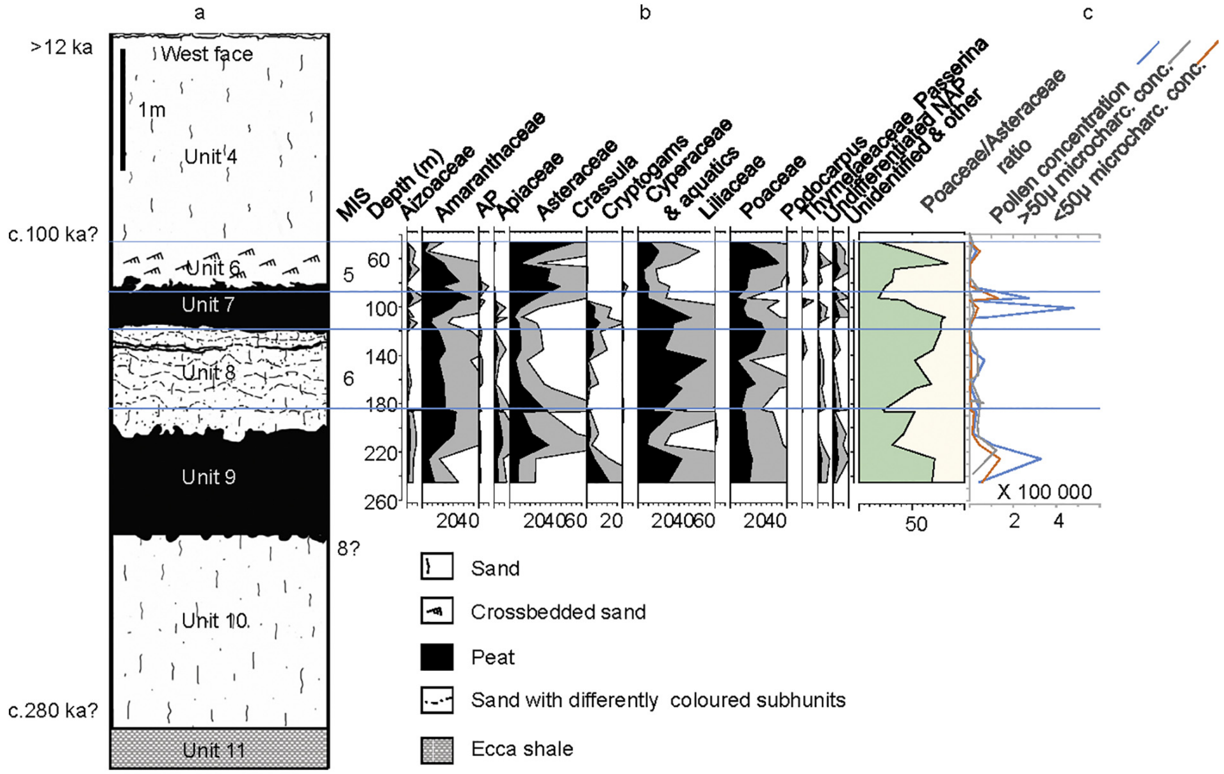

**Fig. 6.** Lithological column of Test Pit 2 with estimated ages from Toffolo et al. (2017) (a), pollen percentage diagram of organic horizons in Units 6–9 (b) and pollen concentration, micro-charcoal and Poaceae/Asteraceae ratio (c). Unit 4 had no pollen. Levels below 245 cm (lower part of Unit 9, and Units 10 and 11) were not sampled for palynology.

the pollen types do not follow the lithological pattern of alternating organic and sandy horizons in the same way, e.g., Cyperaceae pollen is prominent in some peaty levels but also in the less organic sandy layers. Marked spikes of Amaranthaceae do not consistently follow the deposit type. Overall, however, the Poaceae/Asteraceae pollen ratio is high in the peaty layers, except in Peat III where the assemblage includes prominent Asteraceae and Amaranthaceae pollen (Fig. 7).

The pollen sequence starts with the grassy assemblage in the Peat I and coprolite section in Units O and P of Kuman and Clarke (1986). It is followed by alternating peaks of Amaranthaceae and other pollen types and then by increasing Asteraceae and pulses of Cyperaceae pollen. An Amaranthaceae-dominated assemblage then returned with some Aizoaceae-type and Asteraceae pollen signifying the onset of dry conditions in Sand 2 (van Zinderen Bakker (1989) or Units L and M in Kuman and Clarke (1986) and Kuman et al. (1999)). Rare fynbos

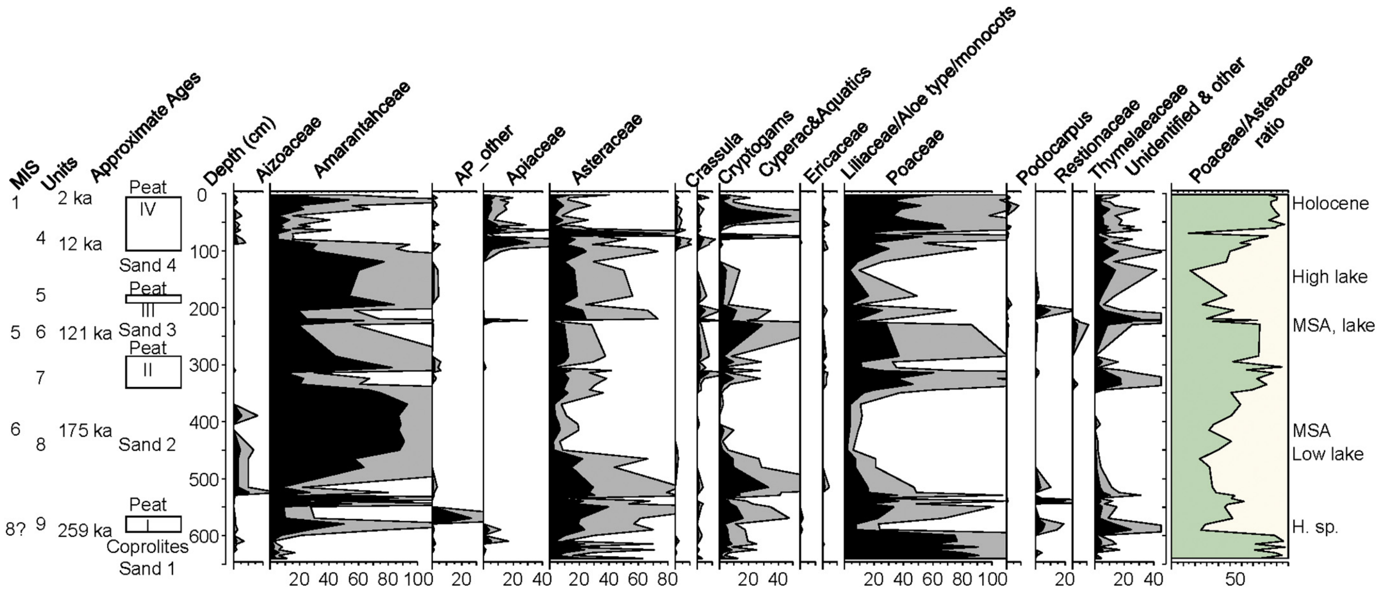

**Fig. 7.** Pollen percentage diagram for the Main Excavation (Kuman and Clarke, 1986), combining hyena coprolite pollen (van Zinderen Bakker, 1989; Scott and Brink, 1992) and the greater part of van Zinderen Bakker's (1989) sequence. His Holocene levels are replaced by those of Scott and Nyakale (2002). Units (Toffolo et al., 2017) and estimated ages (Grün et al., 1996) are given on the left and environmental features and archaeology on the right.

(Ericaceae and some Restionaceae) pollen typesare also present in Peat I. They were not found in the hyena coprolites but contained low numbers of other fynbos types (*Stoebe* type and a tentative *Cliffortia* specimen). Together the fynbos types in Peat I might suggest cooler conditions. The base of Peat II shows an increase in grasses followed by more Cyperaceae and Asteraceae and near its top an increase in Amaranthaceae. The sands between Peats II and III have a grassy assemblage with Cyperaceae indicating local moisture availability and swampy conditions (see discussion about lithological interpretation). As mentioned above, Peat III had prominent numbers of Amaranthaceae and Asteraceae and the latter possibly signifies a more karroid environment. Unit C (Kuman and Clarke, 1986) at 145.5 cm, which is c. 9 ka old according to the age model derived by Bacon (Blaauw and Christen, 2011) (Fig. 9), did not contain pollen although it is dark in color. This might be attributed to post depositional desiccation and oxidation of the organic contents that were originally derived from local moisture (Scott and Nyakale, 2002). The Amaranthaceae and Asteraceae composition persists in the sandy layers above Unit C and the lower part of Peat IV (B2, Kuman and Clarke, 1986). At the base of the lower part of Peat IV (c. 7.7 ka or 1.02 m, B2, Kuman and Clarke, 1986; Kuman et al., 1999), Amaranthaceae pollen is still prominent. From c. 0.85 m (c. 7 ka) it declines in the overlying levels and is replaced by Asteraceae and Apiaceae pollen types and is eventually dominated by Poaceae at c. 4.5 ka in the mid to late Holocene (Scott and Nyakale, 2002). This presents a markedly different picture than that of van Zinderen Bakker (1989) for the Holocene Peat IV, which contained higher proportions of Amaranthaceae ('Chenopodiaceae'). It could be due to a different sample provenance, the exact location of which we are not sure of, or to poor correlation of levels due to dating anomalies.

## 4. Discussion

### 4.1. General palynological concerns

Several palynological questions complicate reconstructions of long continuous vegetation records of the past at archaeological mounds like Florisbad, especially the occurrence of layers with no pollen or with poor pollen concentrations (Fig. 5). In reconstructing these paleoenvironments, complex factors have to be considered to address possible counter intuitive indications between pollen and geomorphological evidence that are complicated by the difficulty of distinguishing regional climatic effects from local changes.

Post depositional aspects should be considered, such as those that apply when a lake is empty or when pedogenesis occurs during dry cycles. For instance, absence of pollen in the upper sandy layers of the sequence in Test Pit 2 may be because rain-water penetrated the deposits, or evapotranspiration and root activity took place. More specifically, clay and silt translocation through root channels, identified in thin section, could well have been a vector for pollen movement from ancient (and modern) land surfaces down the profile (Fig. 5a–d). In addition, earthworms, ants and mites further locally reworked sediments. The latter is indicated by the presence of excrements (Fig. 5d). Nevertheless, the palynological results from Test Pit 2 coupled with previous studies in the western spring eye

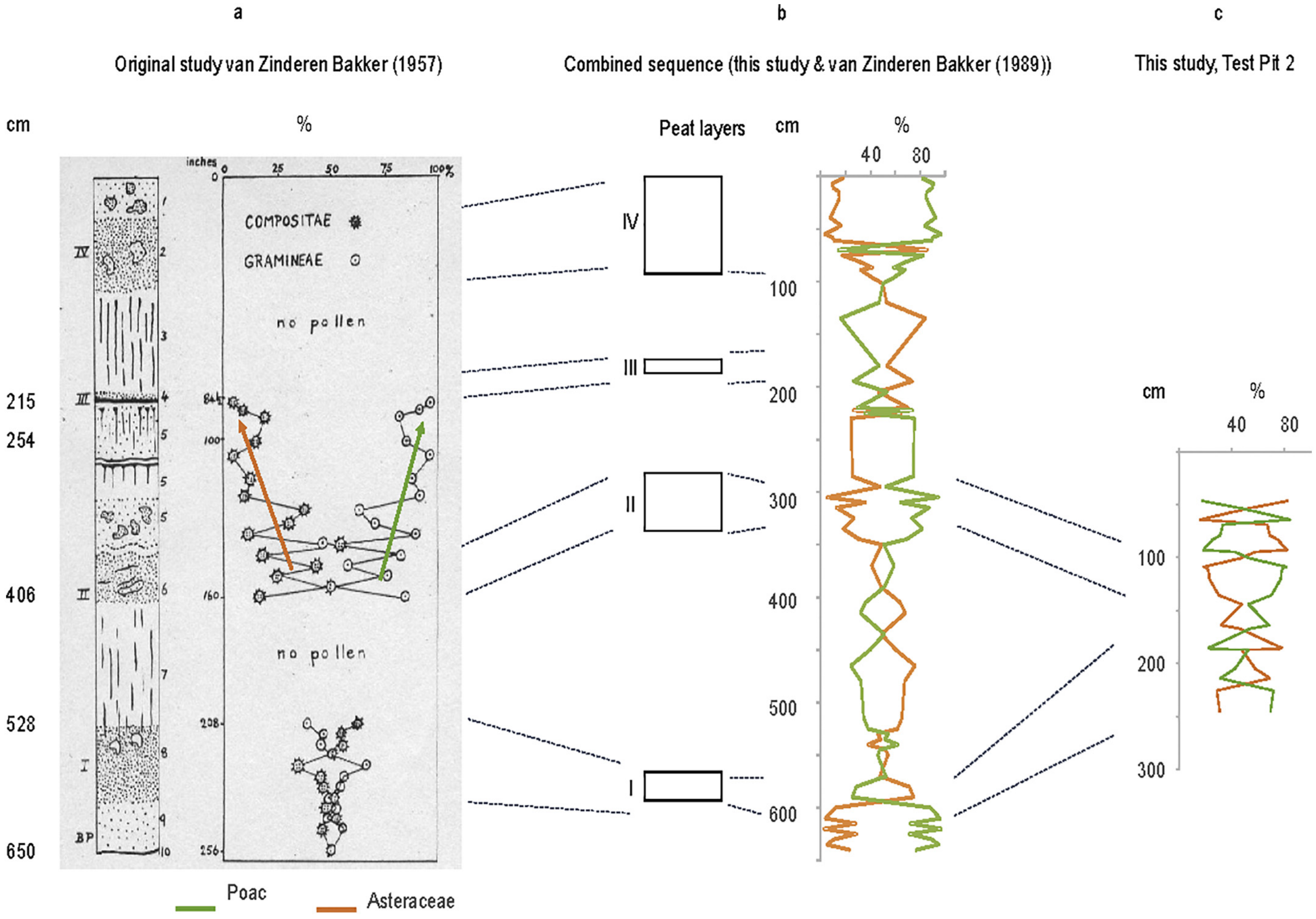

**Fig. 8.** Relative Poaceae and Asteraceae percentages based on their sum, modified after a) van Zinderen Bakker (1957), compared with those in b) the Main Excavation area according to van Zinderen Bakker (1989), Scott and Brink (1992), and Scott and Nyakale (2002) (center) and c) Test Pit 2 (this study).

area provide local insights on the paleoenvironments at the site if different taphonomic possibilities are weighed up. It is, however, more difficult to relate them to climatic conditions of the wide region, despite a possible strong causal link between local and regional events.

As the mound gradually grew bigger, pollen-trapping in the changing local setting was probably influenced by the changing topography of the spring site. During wet phases, as indicated by geological evidence, a full lake would cover the mound (Visser and Joubert, 1991; Toffolo et al., 2017) and would have had a marked effect on the pollen composition. When the mound became high, the upper deposits were less likely to be submerged and represent more eolian material (Test Pit 3) while those at lower elevation along the spring eye, either consist of peaty deposits, or during wetter phases, of lake deposits (Toffolo et al., 2017). The spring site that changed progressively largely determined the local plant distribution, of which it is assumed will be better represented in the pollen spectra than the vegetation from the distant surrounding region. Therefore, the growth of the mound in itself can be expected to have had an influence on the composition of pollen that was trapped. A lake would deposit a more regional atmospheric pollen mixture and less of the spring vegetation, and that might have been lost through oxidation when the lake dried out. During drier periods with no lake water, the spring would support local wetland vegetation, the pollen of which would dominate in peaty or nearby pan deposits. Different intermediate stages between these extremes are possible and could explain the spikey nature of the pollen sequences in the mound as it changed, e.g. spreading of pioneering vegetation on a dry lake floor. The gradual growth of the continuously changing mound could help explain why pollen cycles are not consistently repeated between wet and dry phases. Since the marked changes in the local pollen sequences might simply be the result of different local topographical or lacustrine settings that are unlikely to return to previous states, the ubiquitous pollen of members of dominant families, in which genera or species level are not identified, reflect mainly local events. The recorded changes in pollen composition in these groups are therefore not necessarily the direct result of climate change even if it is a primary driver. The most reliable way to observe a climatic signal will be to look for pollen of diagnostic plant types that do not occur in the region at present. These could be trees of the warmer savanna woodlands or fynbos shrubs from cool upland areas. The pollen fluctuations are sharp but it is clear that for the periods recorded in the study, the vegetation at Florisbad remained within either the Grassland or Nama Karoo Biomes (Mucina and Rutherford, 2006). No shift towards a Savanna Biome is recorded and the arboreal pollen present in some layers are typical of trees or shrubs of the cool Highveld environment like *Searsia* and *Ehretia*.

An aspect that received attention recently (Fitchett and Bamford, 2017) and that needs reconsideration, is the Poaceae (grass) to Asteraceae (composites) pollen ratio (Coetzee and Zinderen Bakker, 1952; van Zinderen Bakker, 1957; Coetzee, 1967). Van Zinderen Bakker (1989) used the Poaceae/Asteraceae ratio to search for possible trends in the surrounding vegetation. Comparison between of the Test Pit 2 (Fig. 6 and Fig. 7) and the spring eye sequence (Fig. 6 and Fig. 7) could be useful for correlation if it is assumed that the ratio is representative of the surrounding vegetation in the region rather than local swamps. This aspect has been important in earlier studies, e.g. at the Florisbad and Aliwal North thermal springs because of its potential to identify the contrasting climatic conditions between grassland and

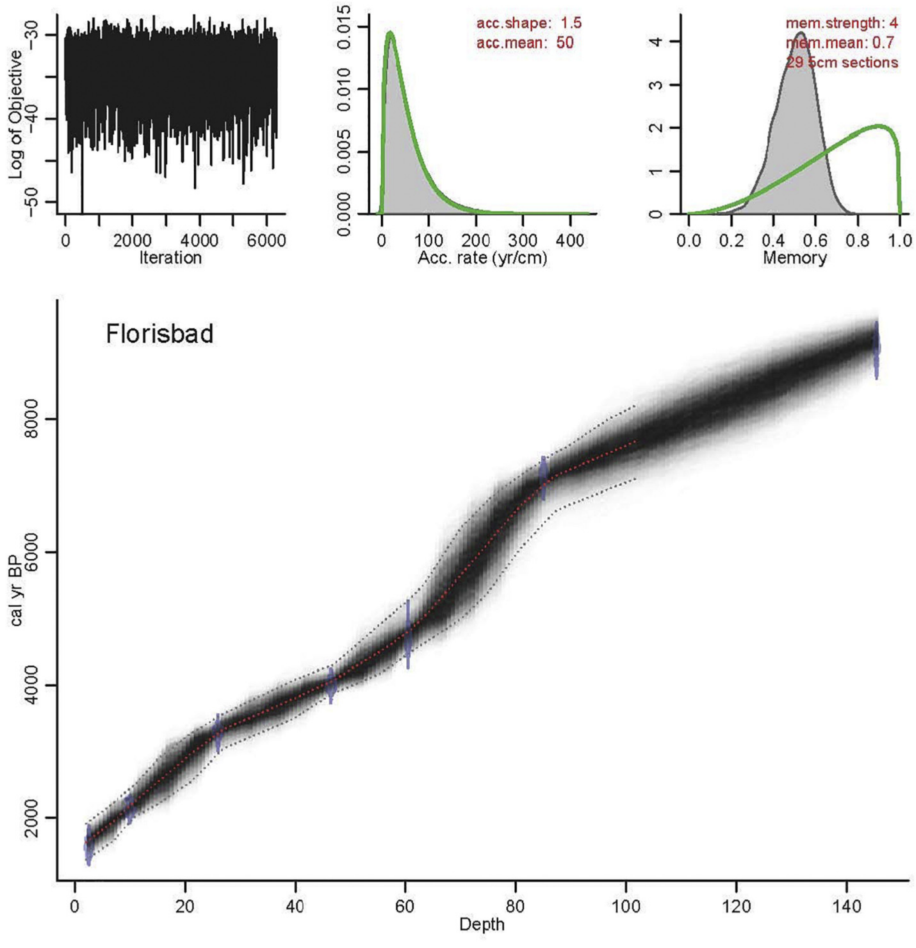

**Fig. 9.** "Bacon" age model (from Blaauw and Christen, 2011) for the Peat IV (Units B and C of Kuman and Clarke (1986) based on radiocarbon dates obtained from Scott and Nyakale, 2002).

shrubby karroid vegetation. If the ratio indicates regional karroid influences in the wide surrounding vegetation, one would expect that different sequences in the Florisbad spring mound would show a regional pattern irrespective of what happens in the spring mound that traps mostly local wetland pollen. The Poaceae to Asteraceae ratio can therefore be expected to be sensitive to regional climate change and not to the changing spring configuration. A problem, with this assumption is that in swampy sites the ratio could be biased by incorporation of local swamp grass species including *Phragmites*. It would increase the apparent grassiness of the vegetation. By excluding small Poaceae pollen (<20 μm), which presumably represents local *Phragmites* (Bonnefille and Riollet, 1980), from the rest of the grains, the bias can be minimized. However, we found low numbers of these small grass pollen grains and they were only in one level in Test Pit 2, at 144 cm (2% of total pollen). This finding suggests that *Phragmites* did not have a major influence and the small grass pollen grains were therefore not excluded from the data set. However, this does not mean that there is no bias in the sample as other swamp-loving grass species probably also grew in the spring.

Observing the Poaceae/Asteraceae pollen ratios in van Zinderen Bakker's two studies (van Zinderen Bakker, 1957, 1989) (Figs. 6, 7 and 8), we note that they differ but this aspect was not discussed in his second study. No clear trend in the Poaceae/Asteraceae ratios between the different peat layers (Peat I and II) is observed in Test Pit 2 and van Zinderen Bakker's (1989) profile (Figs. 6, 7 and 8a, b). Both peat layers, Peat I and Peat II (Fig. 8c), seem to start with more grass pollen but the patterns of this ratio in the two sequences are highly variable and differ. In the curves of van Zinderen Bakker (1957), the grass proportions increased markedly towards Peat III (green arrow in Fig. 8a). However, there seems to be an opposite trend in the western eye area and Test Pit 2 (Fig. 8b,c). There may be several explanations for this, e.g. local variation in vegetation over relatively short distances between the sites; non-continuous but highly variable deposition patterns recording different events; local vegetation shifts along past shorelines or spring margins or a plotting error. Therefore, even though the Poaceae/Asteraceae ratio has been shown to be a reliable measure in modern pollen studies in the veld away from spring sites (Coetzee, 1967) and although it is probably a useful measure in the Florisbad sequence, caution is needed in its interpretation in sites where spring or swamp vegetation differs from that in the surroundings.

Given the relatively long time span represented of c. 280 ka over only 7 m of alternating deposit types, it is conceivable that considerable hiatuses may exist and there is evidence for this (Butzer, 1988). The apparent faster sedimentation rate for the Holocene (c. 0.16 cm/year) than for the average of the whole sequence (0.03 cm/year) (Grün et al., 1996; Scott and Nyakale, 2002) could possibly be the result of hiatuses in the pre-Holocene parts. It is therefore possible that different sections do not necessarily match as parts may have been lost and may complicate pollen sequence correlations.

In connection with Scott and Rossouw's (2005) question whether van Zinderen Bakker (1989) included or excluded *Stoebe* type, which is potentially an important indicator for cooler conditions in southern Africa (Scott et al. 2012), we find that its absence is probably not due to lumping them with Asteraceae but to their scarcity in the studied Florisbad deposits. This pollen type only occurred in some of the hyena coprolites (Scott and Brink, 1992) and rarely in Test Pit 2. The reason could be that deposits of some relevant levels were lost to erosion in the hiatuses, e.g. immediately below the Holocene levels (see discussion below). We therefore believe van Zinderen Bakker did not lump the pollen in Asteraceae and this is supported by his surface pollen study where he did list *Stoebe* pollen separately in the table of modern spectra (van Zinderen Bakker, 1989).

A related uncertainty with van Zinderen Bakker's (1989) pollen diagram is whether he distinguished *Passerina* pollen in Thymelaeaceae. *Passerina* is another useful indicator of cool conditions in the interior of South Africa (Scott, 1982a, 1982b; Brook et al., 2010; Scott and Thackeray, 2015; van Aardt et al., 2015) and it was distinguished in Test Pit 2 as “Thymelaeaceae *Passerina*” (Fig. 3). If the genus was included in van Zinderen Bakker (1989) under Thymelaeaceae, the actual proportions are unknown.

The possible discrepancy about identifications of *Zygophyllum*, a small type of Apiaceae and Crassulaceae that appear in van Zinderen Bakker's (1957, 1989) papers from the Main Excavation area could be due to their small size and similar appearance. It is conceivable that there was some difficulty in distinguishing them and re-allocation may probably be the reason for the differences concerning these taxa between van Zinderen Bakker's notes and his 1989 paper. The prominence of *Zygophyllum* in van Zinderen Bakker's two papers of 1957 and 1989 is remarkable considering that we did not record its presence in any significant numbers in Scott and Nyakale (2002) nor in Test Pit 2. However, we do find high numbers of small Apiaceae pollen, similar to *Heteromorpha* type and *Hydrocotyle* type (Scott, 1982b), in the new samples from Test Pit 2 and these were also reported by Scott and Nyakale (2002). It is unlikely that they derive from *Heteromorpha* trees, which usually occur in montane woodland (Scott, 1989; Scott and Vogel, 1992, Carrión et al., 1999). The plants would not have survived easily at the exposed and frost-prone spring site of Florisbad. Our assumption is therefore that what van Zinderen Bakker assigned to *Zygophyllum* may be some of these small Apiaceae pollen grains. In fact, they might all belong to *Hydrocotyle*, which can be difficult to distinguish from the *Heteromorpha* type and therefore may represent swamp plants (Scott, 1982b). In that case, it would not be an indicator of arid conditions as is suggested in van Zinderen Bakker (1957, 1989).

### 4.2. Paleoenvironments

The reconstruction of the regional paleoenvironmental conditions is hampered by the lack of climatically diagnostic pollen. Dating by Grün et al. (1996) of key levels is very important but a detailed and reliable age model for the pollen layers older than Holocene is not available. Since there is no evidence of warmer temperatures (e.g. no increase in savanna woodland elements like Combretaceae), any attempt to link the sequence to the marine isotope stage chronology (MIS) (Railsback et al., 2015) is limited to where fynbos elements appear that may give indications of cooler upland vegetation.

An aspect of pollen distribution that needs further attention is that of pollen dispersal because of its implications for paleoenvironmental interpretations. We assume that in the productive peaty layers most pollen represents local swampy vegetation associated with the spring, while the pan or lake deposits that formed either under dry, barren lake-floor or deep water conditions contain pollen that were transported from distant sources, for instance by wind from pan shores to the lake, or from halophytes on a dry, cracked lake floor. This interpretation may explain the low pollen concentrations in these deposits that were exacerbated when lakes dried up and pan floors were exposed to oxidation. Seasonally oscillating lakes may help to address the apparently conflicting pollen and geological evidence (van Zinderen Bakker, 1989; Visser and Joubert, 1991). During cool Pleistocene events these lake levels could have been promoted by reduced evapotranspiration or even seasonal shifts in rain distribution from summer to winter rain. modeling Prominent Asteraceae pollen at the cost of Poaceae during phases of sand development may be due to less summer moisture (Figs 5, 6, 7 and 9).

The fynbos (Ericaceae and Restionaceae) elements in the lowermost silts (Unit P or Unit 10) and peat (Peat I, Unit O or Unit 9, Table 1) indicate cool conditions and could possibly represent MIS 8. *Stoebe* type in two of the associated coprolites may also be due to cool conditions. In both these layers and in the coprolites coming from Unit P (Kuman and Clarke, 1986) and from the adjacent spring vent structure (Scott and Brink, 1992), suggest a grassy environment. The coprolite contents are likely to efficiently reflect the regional grassy environment because it represents the wide roaming range of the hyenas where they consumed a regional spectrum, and not the local spring environment (Scott, 1987). Peat I supports the existence of a grassy environment although it may have contained more of the local grass pollen than the coprolites. The peat deposit, however, seems to be part of a drying cycle as there is an increase in Amaranthaceae pollen; which is in agreement with sedimentary evidence (Toffolo et al., 2017). Restionaceae are recorded in these levels associated with the Amaranthaceae, and replace Ericaceae in adjacent levels, which is also indicative of drying. The Restionaceae may have been a local element that thrived during seasonal drying cycles under a sub-humid climate but they suggest that conditions remained cool.

The overlying sand layer in van Zinderen Bakker (1989) (Sand 2, Units L and M or Unit 8) showed a marked increase in Amaranthaceae pollen but in its presumed equivalent, the Unit 8 succession in Test Pit 2 (Fig. 6), it comprises lower but still prominent proportions. This indicates dry pan-like conditions and contrasts to lithological findings of Visser and Joubert (1991) and Toffolo et al. (2017) who indicate lacustrine or channel deposit. Scott and Brink (1992) proposed that the high Amaranthaceae pollen might be due to post depositional infiltration in the deposits through cracks after the lake dried out and original pollen perished through evaporation and oxidation during seasonal contrasts. While this is possible, another explanation may be that lake levels were not very high and the lake dried out occasionally, or seasonally, favoring local halophytic vegetation along its shores while the spring eye might have been in a different position that did not promote swamp growth at the studied localities (Rubidge and Brink, 1985). In support of this, there is evidence for wave action in Unit 8 (M) that indicates a shallow lake fed by the spring (Toffolo et al., 2017). In this scenario, where a pollen difference is found over a relatively short distance, the lower numbers of Amaranthaceae that occurred in Unit 8 of Test Pit 2 than in the spring area, may be the result of water being retained longer at lower elevations. *Passerina* pollen is recorded here and suggests that relatively cool conditions occurred at times during this phase.

Peat II in the great western eye (van Zinderen Bakker, 1989) or Unit 7 (Toffolo et al., 2017), developed under grassy conditions but shows increasing Amaranthaceae and Asteraceae in its upper layers similar to the pattern observed in Test Pit 2, supporting the suggestion that these layers are probably coeval. The sands above Peat II (Sand 3, Units G-J or upper parts of Unit 7) show increasing grassy vegetation with Cyperaceae in both the Test Pit 2 sequence and the western spring eye sequence supporting the geological evidence for increased moisture availability (Visser and Joubert, 1991; Toffolo et al., 2017). Some *Passerina a*nd Thymelaeceae (undifferentiated) pollen grains occur in the equivalent sands (Unit 7 & Sand 3) suggesting relatively moist, and at times, cool conditions. In Kuman and Clarke (1986) the relevant sections at the spring area, which we assume is near to van Zinderen Bakker's sequence, the sands are much thicker than in Test Pit 2 and consist of different subdivisions (Units G–I). Here Unit 6 is of importance for its Middle Stone Age finds and its association with the 121 ka date (MIS 5e) but precise association of the pollen assemblages, the MSA activity and apparent raised lake level is currently not possible (Visser and Joubert, 1991; Toffolo et al., 2017). The unit is also recognized in Test Pit 2 based on sedimentary structures observed in thin section (Kuman and Clarke, 1986; Kuman et al., 1999; Grün et al., 1996; Toffolo et al., 2017).

In our reconstruction from van Zinderen Bakker's notes we find there must be a missing level which we could not identify by sample number. This creates uncertainty in the pollen data for Sand 3 between c. 220 and 285 cm from which MSA artifacts are thought to derive. The pollen diagram shows marked oscillations around these depths while there is poor resolution. In van Zinderen Bakker (1989), he did not specify the MSA position in Sand 3. However, it probably occurred around the 225 cm depth (Fig. 7) (sample 8458) where in his notes he mentioned MSA tools with sharp edges in close proximity to a hippopotamus skull. According to the notes, the hippo was in a pocket of white sand inside a black wavy peat layer from where the sample came. This level and an associated sample 9041 (222.5 cm) form part of a narrow spike of Amaranthaceae pollen (Fig. 7) that changes upwards to an assemblage with more grass, Asteraceae and Cyperaceae pollen at 220 cm, indicating an evaporative environment that became swampy. Around these levels, our Fig. 7 and van Zinderen Bakker's Fig. 3 differ somewhat.

In Test Pit 2, Toffolo et al. (2017) associated the relevant MSA finds to Unit 6. In this level the pollen assemblage shows a change of increasing Amaranthaceae that were replaced by a markedly grassier phase - with Asteraceae and Cyperaceae - that suggests dry conditions. This changed later to a grass-dominated spectrum suggesting it became wetter so that the MSA people experienced changing environments. The Thymelaeaceae including *Passerina* in both sequences is of interest because of its potential implication for cooler conditions. If Unit 6 belongs to MIS 5e, we would expect warm conditions, not cool conditions, as indicated by this family. In Sand 3 (van Zinderen Bakker, 1989), Thymelaeaceae pollen (possibly including *Passerina*) is followed by a small peak of Restionaceae, which may support the contention of continued cool but drier conditions. These findings therefore, do not support the indication from the available dating (121 ± 6 ka) (Grün et al., 1996) that the MSA occupation occurred during MIS 5e. However, pollen of the family is absent in the lowermost levels of Unit 6 or Sand III, and this may therefore leave open the possibility of a warm phase represented in a thin section of deposits that correspond with MIS 5e. In view of oscillating climatic conditions and the error margin of available dating, these findings suggest the MSA occupation level might be outside the MIS 5e range and fall in MIS 5d, or else that it was not a prominent layer and was missed in pollen sampling.

In Test Pit 2 (Toffolo et al., 2017), the thin Unit 5 (Peat III, or Unit E) is missing and Unit 4 was unproductive for pollen. The pollen composition in van Zinderen Bakker's Peat III (van Zinderen Bakker, 1989) seems to differ from Peats I and II by not starting with increased Poaceae or Cyperaceae and aquatic pollen but with high Amaranthaceae and Asteraceae values suggesting cool dry, probably karroid conditions.

The sample resolution of Sand 4 (Units D and C) in the western spring eye sequence is very low. Prominent proportions of Amaranthaceae pollen occurred in the sand that represents transgression of lake water over the spring (Toffolo et al., 2017; Visser and Joubert, 1991). As mentioned earlier, the high proportions of pollen from these halophytic plants could be explained in different ways, e.g. as lakeshore elements that dominated the pollen production, or as post depositional pollen intrusion when the lake dried.

Within Sand 4, below Unit C (Kuman and Clarke, 1986), a hiatus probably accounts for the absence of last glacial maximum (LGM) pollen, which if it were present would likely have contained *Stoebe* and *Passerina* types. These pollen types are typical of LGM layers from MIS 2 deposits at the nearby Baden–Baden thermal spring site, which resembles Florisbad in having a spring mound and peat layers (van Aardt et al., 2015). Layers of similar age in the Florisbad sequence seem to be missing or exceedingly thin as deposits of this age must have formed on a spring mound that was gradually growing higher and as such may have been accumulating at a slower rate or were prone to erosion. At Baden–Baden, the *Stoebe* type pollen dating to c. 26 ka came from deep levels adjacent to the spring mound and had a better chance of being covered and preserved (van Aardt et al., 2015).

Finally, the uppermost layers B1 and B2 (Peat IV) represent the Holocene as described in Scott and Nyakale (2002) (c. 9308 cal yr BP or 8170 ± 90 yr BP uncalibrated at 145 cm), did not contain pollen below c. 100 cm (c. 7700 cal yr BP). Interestingly, the pollen progression in this peat layer differs from the earlier peaty horizons. It starts at c. 7000 cal yr BP (one sample in B2, Kuman and Clarke, 1986) with high proportions of dry land pollen (Amaranthaceae and Asteraceae). According to a new age model (Fig. 9) calculated by the “Bacon” method (Blaauw and Christen, 2011) based on the dates in Scott and Nyakale (2002), a brief dry karroid spell with Asteraceae vegetation occurred at c. 97 cm (5700 cal yr BP). This

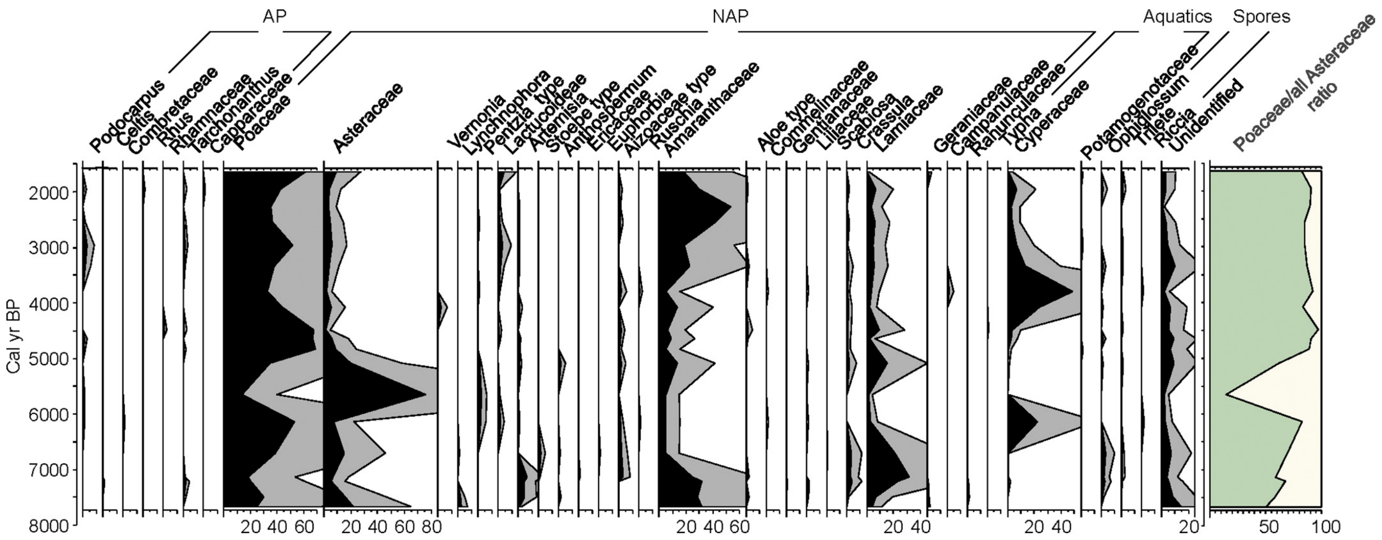

**Fig. 10.** Florisbad Holocene pollen percentages (Scott and Nyakale, 2002) for the Peat IV [Units B and C of Kuman and Clarke (1986)], plotted according to the updated age model ("Bacon" age model of Blaauw and Christen, 2011).

gradually started to change to a grass rich assemblage peaking at c. 60 cm (4800 cal yr BP) suggesting relatively humid conditions similar to the present situation (Figs. 7, 9 and 10).

## 5. Conclusions

The strong fluctuation in halophytic Amaranthaceae pollen in the spring sequences is the most striking aspect of the palynology at Florisbad. Related to this, the contradictory interpretation of geological evidence that the levels with prominent halophyte Amaranthaceae pollen represent lacustrine phases (Visser and Joubert, 1991; Toffolo et al., 2017) allowed us to reconsider the pollen taphonomy in the particular situation where different spring pan and surrounding vegetation types meet. The sharp increase of Amaranthaceae pollen is explained either by the possibility that it entered through post-depositional cracks (Scott and Brink, 1992), or was produced during evaporation in regular dry events when seasonal lakes dried and allowed these pioneers to spread along the shores or over the basin floor under evaporative and possibly warm conditions. This appears to have happened during Unit 8 (M) when a shallow lake occurred around the spring on the leeward side of the mound. Later during deposition of Sand 4 (Unit 4 or D) a larger lake covered the entire area (i.e. a paleo-lake Soutpan).

In Peats I and II the pollen spectra began with a grassy assemblage and ended with Amaranthaceae and Asteraceae, which may seem to be part of a drying out phase, but which in fact could actually be the opposite, viz., spring vegetation that is transgressed by lake deposits, which dried out occasionally to allow pioneering halophytes to spread. They either shed their pollen as pollen rain or enter the deposits through bioturbation or cracks and then underwent oxic conditions. The opposite pattern of succession is noted in the upper Peats (III and IV) where the cycles start with Amaranthaceae pollen. Here the parent plants may have covered the growing mound under relatively dry conditions. They were replaced by grassy vegetation as more moisture and a stronger spring developed while eolian sand was trapped by vegetation on the highest part of the mound.

It is clear that the hominins occupied the Florisbad mound and surroundings under cold continental climatic conditions. Local conditions fluctuated from wet when the pans were filled with water to drier conditions when the local spring was an important resource for hominins and fauna. The temperate grassland conditions imply frost, and during coldest phases it must have been more extreme than at present.

The palynological record can be improved by studying more sequences at Florisbad and Baden–Baden. Of prime importance will be the pollen analysis of Test Pit 3 at Florisbad and available auger samples in storage (Rubidge and Brink, 1985). Higher pollen counts are needed to obtain increased diversity for better paleoenvironmental inferences. The results should also be coupled with an ongoing phytolith study (L. Rossouw at the National Museum Bloemfontein, pers. com) (Scott and Rossouw, 2005; Rossouw, 2009). Constraints will, however, always be the poor pollen concentration in some layers and the accompanying problem of modern pollen and root contamination (Field et al., 2018). It is essential to couple such research with micromorphological studies of cracks by testing horizontal sections to determine how far the surface should be cut back in renewed sampling of pollen from existing exposures.

From this study the following main conclusions can be drawn:

- A long pollen record can be reconstructed from previous studies and it is aided by new pollen analysis from an excavation pit (Test Pit 2).
- The apparent contradictory palynological, faunal and geological evidence can be reconciled with consideration of pollen taphonomy and site conditions at Florisbad under decreased Pleistocene temperatures and changing seasonality. In this way the presence of the contrasting evidence of dry halophytic plants in levels that showed evidence of higher lake levels and contain aquatic fauna like lechwe or hippopotamus can be explained.
- The presence of humans appeared to have coincided with cool and moist but changing conditions.
- More work on palynology aided by phytolith analysis is necessary to obtain higher pollen diversity and environmental information.
- A new OSL dating program is required in order to correlate different trenches at the site and to place the faunal and archeological record firmly in the marine isotope stage chronology (Railsback et al., 2015).

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