SCANNING ELECTRON MICROSCOPE IDENTIFICATION OF PLANT MATERIAL USED IN ANCIENT EGYPTIAN FOOTWEAR

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1. *Introduction*

Fifty-four samples (each comprising one or more type of plant) from twelve sandals in the Ägyptisches Museum und Papyrussammlung, Berlin were submitted for scanning electron microscope (SEM; Figure 1) examination, imaging, and the identification of plant materials (Figure 2, Table 1). In addition to these samples, seventeen others were taken from footwear (six pieces; Figure 3, Table 2) in the collections of the British Museum, London, and twenty-eight (from eight objects; Figure 4, Table 3) in the collection in the Petrie Museum of Egyptian Archaeology, University College London. These form part of a larger programme of investigation focusing on sandals and other footwear: the Ancient Egyptian Footwear Project (AEFP). The AEFP is a multidisciplinary and ongoing research venture, concentrating on the study of archaeological artefacts and their (museological) context, iconography, philology, experimental archaeology, and, where appropriate, ethno-archaeology, in order to better understand footwear's meaning and position within ancient Egyptian society.[1]

2. *Materials and methods*

2.1. Sampled Objects

Pieces were chosen because no plant identification had been made yet, the identification was only partial (e.g. only the material of the soles was identified), or the identification was somehow unclear. There were several types[2] of sandals selected, all of which have been described in detail elsewhere[3]:

[1] See Veldmeijer (2011a). For more information and a list of publications, see www.leatherandshoes.nl.

[2] Here, the footwear is only referred to by type; no further distinction will be made. See the relevant AEFP publications for the more detailed typology.

[3] Only those publications are mentioned that include a detailed description as well as detailed information on the typology, dating and distribution; the reader is referred to the final archaeological analysis of the AEFP for additional publications.

Figure 1. The variable pressure scanning electron microscope (VP-SEM) at the British Museum which was used for the identification of plant materials from the selected ancient Egyptian sandals. Image: C.R. Cartwright. © The Trustees of the British Museum.

– Sewn Sandals ÄM 6994/2 (Gourlay 1981a: 62; 1981b: 56, pl. XXb; Montembault 2000: 38-39; Veldmeijer, 2009a; 2011);
– Sewn-Edge Plaited Sandals ÄM 3324, ÄM 26547, ÄM 1397, ÄM 620 (all, Figure 2) UC769 (Figure 3), EA4445, EA55411, EA36210 (all, Figure 4) (Gourlay, 1981a: 58-64; 1981b: 45-59, pl. Vd-f; XXa, c[4]; Montembault, 2000: 33-35; Veldmeijer, 2010a);
– Coiled Sandals ÄM 18473 (Figure 2); UC28033, UC28302, UC28303, 28314i (all, Figure 3); EA4418, EA4432 (both, Figure 4) (Veldmeijer, 2007; 2009b; 2011b[5]);
– Composite Sandals ÄM 3325, ÄM 17081, ÄM 20471 (all, Figure 2); UC28015, UC28362i (both, Figure 3) (Montembault, 2000: 39-43; Veldmeijer, 2013);
– Open Shoes ÄM 18448, ÄM 6992/1, ÄM 6992 (Z-346) (all, Figure 2); EA4464 (Figure 4) (Veldmeijer, 2009c; 2010b).

[4] But see Veldmeijer (2010a) for reclassification.
[5] But see Veldmeijer & Ikram (2014: 21-22) for reclassification.

2.2. Taking Samples

Sampling selection for SEM examination, imaging, and the identification of the plant materials of the twelve sandals in the Ägyptisches Museum und Papyrussammlung, Berlin was carried out by André J. Veldmeijer (AJV). Fifty-four samples were taken in total. In addition, six sandals from the collection of the British Museum, London were selected by AJV, and twenty samples were taken from these by Caroline R. Cartwright (CRC). Finally, seven sandals from the collection of the Petrie Museum of Egyptian Archaeology, University College London, were selected by AJV, and seventeen samples were taken from these by CRC.

It is standard practice to keep sample sizes to a minimum and to try to avoid sampling any areas with macroscopically visible adhesives or conservation consolidants that might affect identification (see below) or areas that may have been restored or repaired in modern times. After years of handling, objects often have some modern material (including fibres) that have adhered to their surfaces (Figure 5), although these may not have been apparent macroscopically at the time of sampling.

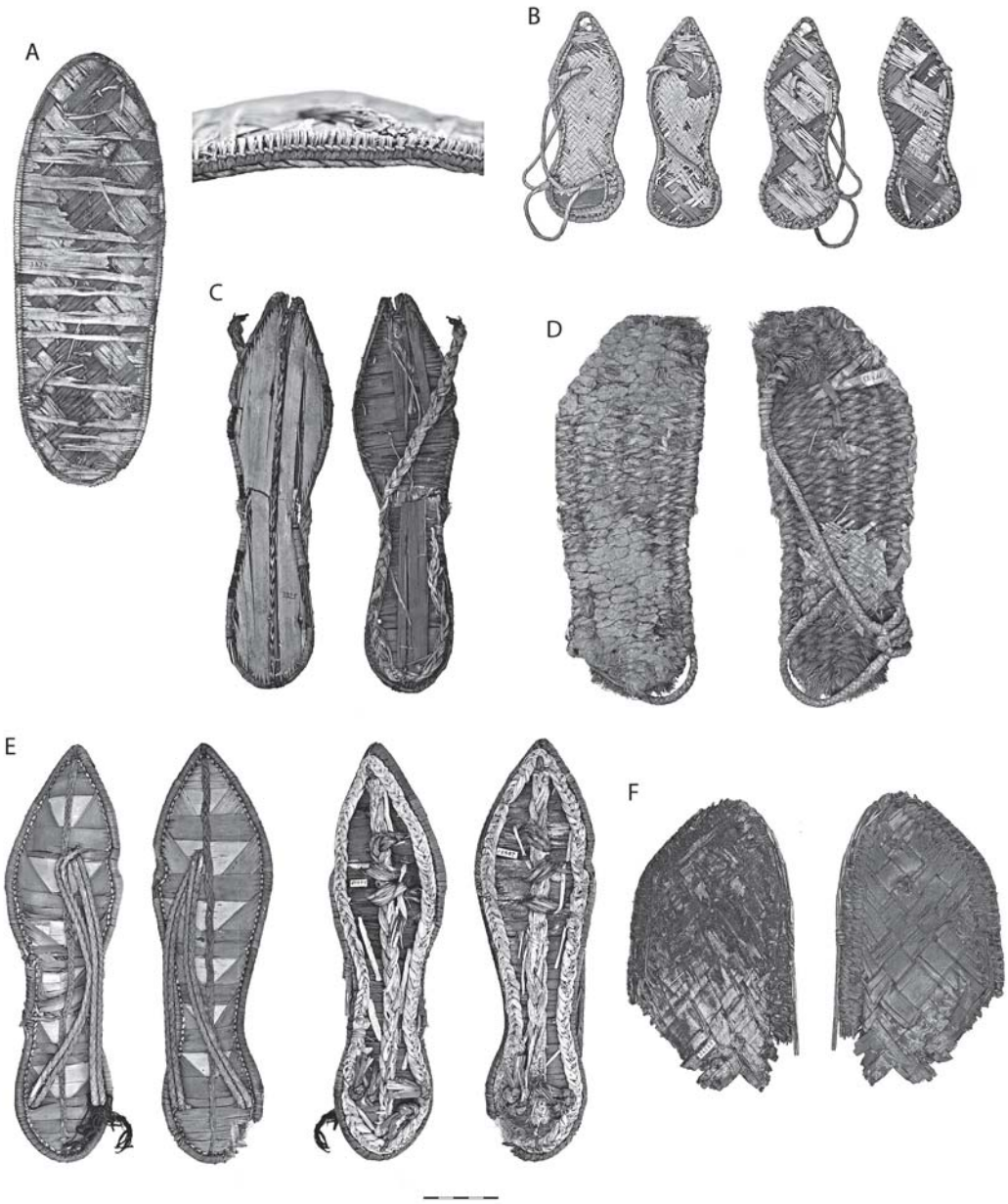
Some samples (e.g. 6992/1 'core of the edge of the sole') showed fungal hyphae and evidence of frass (fine powdery refuse produced by the activity of boring insects) when examined microscopically (Figure 6), which would have been very difficult to detect with a hand-lens (much less with only the naked eye).

Due to the generous permission of the three museums mentioned above to sample material in their collections, a large sample size could be obtained. Samples were not only taken from a wide variety of types of footwear, but also from various parts of each sandal or shoe, such as the edges, the sole, and the straps (Table 1).

2.3. Identification Procedure

Examination of the samples and comparative reference specimens was undertaken using a variable pressure (VP) SEM (Hitachi S-3700N), with the backscatter electron (BSE) detector mostly at 15 kV but sometimes also at 12 kV, depending on the sample. Magnifications ranged from x20 to x750. The preferred working distance was *c.*12 mm, but extended from 7 mm to 19 mm (as required). As the plant samples were in variable states of preservation, the SEM chamber was only partially evacuated (mostly 40 Pa, sometimes 30 Pa). With the BSE detector, 3D mode (rather than Compositional) was preferentially selected to maximize the opportunity to reveal diagnostic features for identification as well as traces of wear and abrasion due to preparation and/or use of the materials and to show dirt, encrustations, frass, and fungal hyphae.

Most of the (uncleaned) plant material examined was placed uncoated on adhesive carbon discs mounted onto aluminium SEM stubs; no other sample preparation was undertaken. The Oxford Instruments energy-dispersive X-ray spectroscopy (EDX) analyser attached to the SEM was used to provide elemental identification and semi-quantitative compositional information where necessary (e.g. to determine whether original crystals and inclusions were calcium or silica, and also the elemental composition of recent adhesions on sample surfaces). In one instance (see below) the Hitachi S4800 field emission scanning electron microscope (FE-SEM) was used with the secondary electron (SE) detector at 5 kV to identify a very fragile sample.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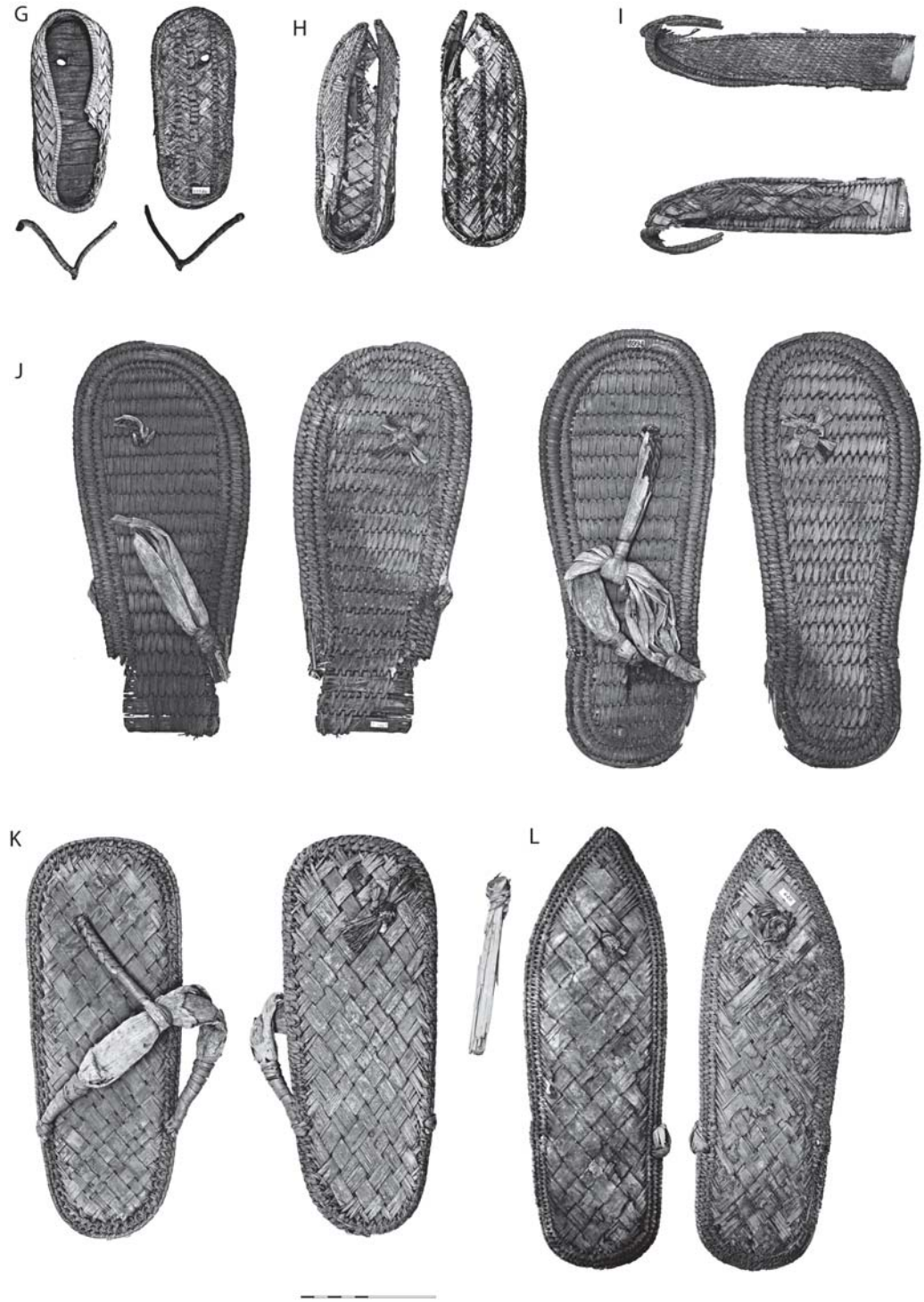

Figure 2. The footwear in the Ägyptisches Museum und Papyrussammlung, Berlin from which samples were taken. Photography by A.J. Veldmeijer. A) ÄM 3324, dorsal view, with a detail of the sewing of the edge; B) ÄM 17081, dorsal and ventral view; C) ÄM 3324, dorsal and ventral view; D) ÄM 18473, dorsal and ventral view; E) ÄM 20471, dorsal and ventral view; F) ÄM 26547, dorsal and ventral view; G) ÄM 18448, dorsal view; H) ÄM 6992/1, dorsal and ventral view; I) 6992 (Z-346); J) ÄM 6994, dorsal and ventral view; K) ÄM 1397, dorsal and ventral view; L) ÄM 620, dorsal and ventral view. Scale bar in cm.

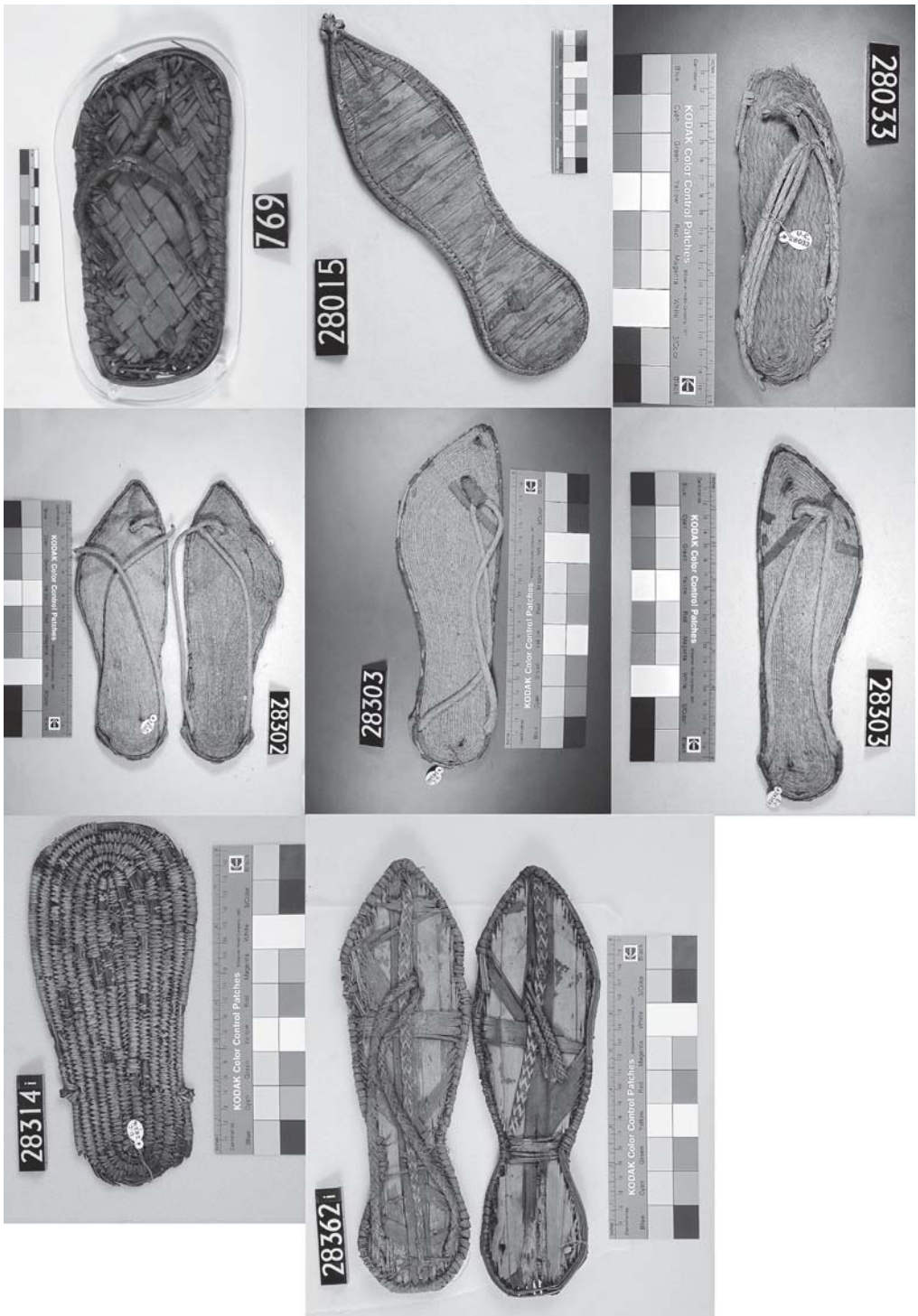

Figure 3. The footwear in the Petrie Museum of Egyptian Archaeology, University College London. Photography by the Petrie Museum.

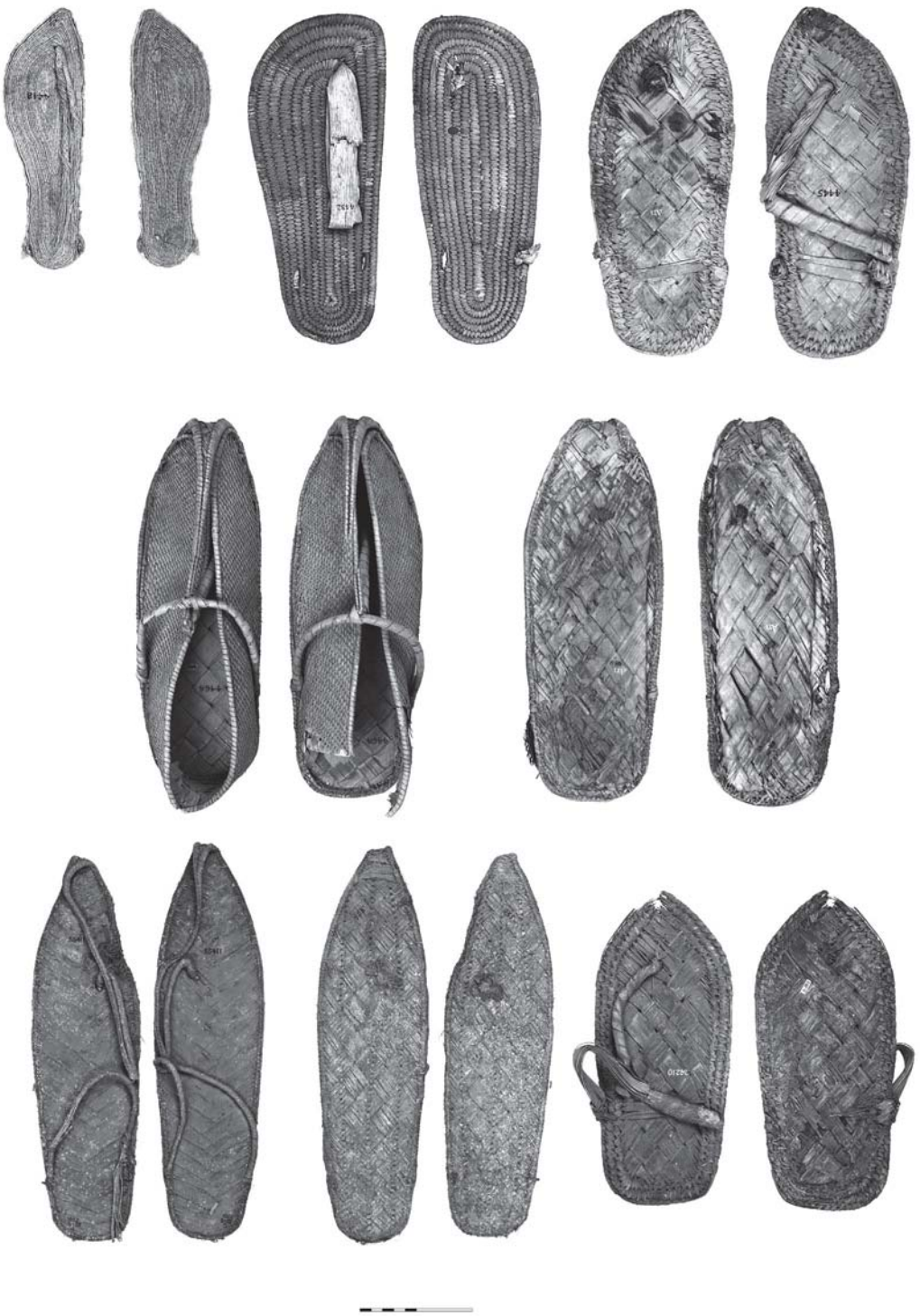

Figure 4. The footwear in the British Museum, London from which examples were taken. Photography by A. 't Hooft/A.J. Veldmeijer. A) EA4418, dorsal and ventral view; B) EA4432, dorsal view; C) EA4445, dorsal view; D) EA4465, dorsal and ventral view; E) EA55411, dorsal and ventral view; EA36210, dorsal and ventral view. Scale bar in cm.

To assist readers who might wish to refer to the conditions of SEM operation associated with the SEM images in the Figures accompanying this report, attention is drawn to the information provided in the data bar at the foot of each image. Reading left to right, the data bar information gives the model of the SEM, (sometimes) operator initials (S3700CRC or S4800), accelerating voltage (kV), working distance (mm), electron detector and mode (BSE3D or SE), signal (M = mixed), partial evacuation status (Pa), magnification (x) and scale (in micrometres or millimetres).

VP-SEM analysis of comparative reference specimens of Egyptian plants was crucial to the identification process (Cartwright, 2015). The advantages and drawbacks of using plant/wood anatomy atlases, online image databases and descriptive texts as references have long been the subject of debate, and key points relevant to this study are reiterated here. Online and printed atlases frequently contain light microscopy (LM) images of thin-sectioned plant specimens (including wood). Whilst these are extremely useful for modern material (e.g. Watson & Dallwitz, 1992: Figure 7), it is always difficult to try to compare with, and attempt to match key features on, historical, aged or archaeological plant remains, many of which have been altered through burial and/or through use, wear and tear, and the natural processes of ageing and deterioration. 'Textbook' images of clean, recent plant parts, whether using LM or SEM, cannot replicate the complex characteristics visible on historical or archaeological plant remains, many of which are clearly apparent in the Figures (images) accompanying this report. Although the following observation by Carr et. al. (2008: 252) refers to a different dataset entirely (that of plant fibres from New Zealand and the Pacific), a useful fundamental principle emerged that can be applied much more widely in time and space. They noted that such databases may assist in identifying plant materials but "should not be regarded as a substitute for a confirmed identification by a plant scientist," hence the collaboration of the two authors of this report.

3. *Results*

3.1. Introduction

Before discussing the results, mention needs to be made of the use of the words 'fibre' and 'fibres'. In plant anatomy the term 'fibre' refers to a particular type of cell, which functions as support. However, the term has acquired a more general usage (*sensu lato*) in literature, which can be confusing – particularly when the plant parts actually represent the external surface of a leaf or stem (so, strictly speaking, should not be termed 'fibres'). In this report the word 'fibre(s)' has only been used (*sensu stricto*) to refer specifically to the particular type of cell that functions as support, e.g. in the case of *Linum usitatissimum* (flax), but not to describe cells that occur adjacent to fibres such as parenchyma, collenchyma, phloem or xylem. If it has been possible to identify more specific details – e.g. the epidermal surface of a leaf, or parts of a stem – that information has been provided in the Figure (image) captions. In some instances, where the sample had been termed 'fibre' already (and there are other cells present besides fibres [*sensu stricto*]), the term has been retained for ease of reference[6] but placed in single inverted commas i.e. 'fibre'.

[6] Since the AEFP uses the term.

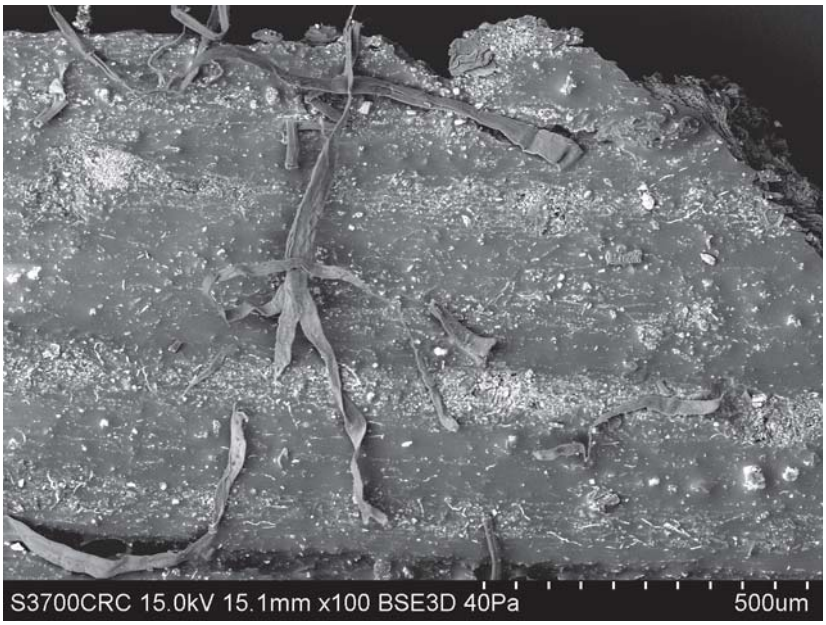

Figure 5. VP-SEM image of 6992/1 core sole edge showing how the widespread adhesive or conservation consolidant and modern cotton (and other) fibres adhering to its surface have masked the key features needed for plant identification. Image: C.R. Cartwright. © The Trustees of the British Museum.

Figure 6. VP-SEM image of 6992/1 core sole edge showing fungal hyphae and areas of frass, some of which are marked by white rectangles. Image: C.R. Cartwright. © The Trustees of the British Museum).

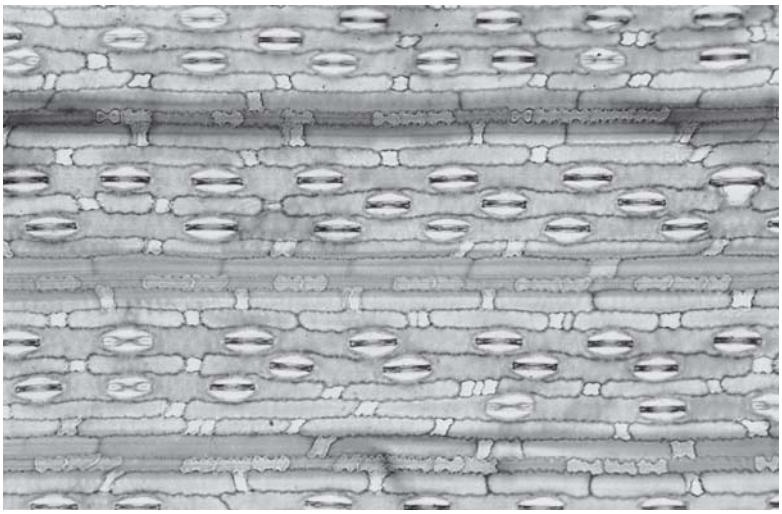

Figure 7. Light microscope image showing the epidermis of a modern leaf blade of *Imperata cylindrica* (halfa grass).
Image: © L. Watson & M.J. Dallwitz.

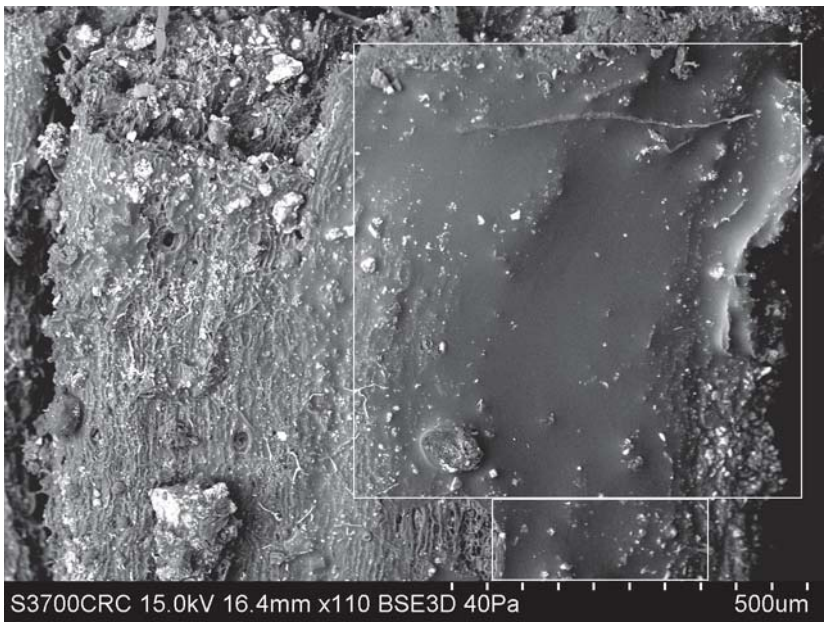

Figure 8. VP-SEM image of ÄM 6992/1 core sole edge showing areas of adhesive or conservation consolidant marked by white rectangles.
Image: C.R. Cartwright. © The Trustees of the British Museum.

3.2. The Samples from the Ägyptisches Museum und Papyrussammlung, Berlin (Figures 2, 5, 6, 8-17)

Table 1 provides the identifications of the selected material. Consequently, selected aspects relating to the SEM examination and identification phase will be highlighted in this section. Despite being challenging and time-consuming on account of their condition, a large proportion of the 54 samples (some comprising more than one type of plant) have been identified to taxon. Six main taxa have been identified: *Cyperus papyrus* (papyrus sedge), *Desmostachya bipinnata* (halfa grass), *Imperata cylindrica* (halfa grass), *Hyphaene thebaica* (dom palm), *Linum usitatissimum* (flax) and *Phoenix dactylifera* (date palm). There is also an 'unidentifiable' category, as some of the samples were covered with adhesive or a conservation consolidant, which masked the diagnostic characteristics of the leaf or stem epidermis (Figures 5, 6 and 8-10).

In the case of samples taken, for example, from the core or sole of the sandal, there may be more than one type of plant present (see Table 1).

Hyphaene thebaica (dom palm)

The most frequently represented plant amongst the sandal components is *Hyphaene thebaica* (dom palm), present in twenty-two out of fifty-six items. *Hyphaene thebaica* (dom palm) was used for the insole strips (ÄM 3324; ÄM 18473), the edge sewing (ÄM 3324), the braids under the treadsole (ÄM 3324), the strip of the treadsole (ÄM 3324), the cladding of the strap (ÄM 17081; ÄM 18448), the strips tying the front strap (ÄM 18473), the sewing of the edge (ÄM 20471; ÄM 26547; ÄM 18448; ÄM 6992/1), the core of the strap (ÄM 18448), the outer surface of the upper (ÄM 6992/1), the soles (ÄM 6992/1; ÄM 6992 [Z-346]; ÄM 1397), the sewing of the edge of the upper (ÄM 6992 [Z-346]), the sewing strip of the sole (ÄM 6994/2), the outer layer of the strap (ÄM 6994/2), the cladding of the front strap (ÄM 1397), and the core of the strap (ÄM 620).

Desmostachya bipinnata (halfa grass)

Several examples of the grass family (Poaceae) have the common name of 'halfa grass' (which can lead to some confusion in publications if the Linnaean binomial term is not used as well). *Desmostachya bipinnata* (halfa grass) has ten entries (out of fifty-six) in Table 1. It has been used for the braids under the treadsole (ÄM 3325; ÄM 20471), the braid on the insole (ÄM 3325), the insole strips (ÄM 17081; ÄM 26547), the 'fibre' sole (ÄM 18473), the outer surface of the upper (ÄM 6992 [Z-346]), the inner layer of the upper (ÄM 6992 [Z-346]), the core of the sole's bundle (with *Imperata cylindrica, halfa grass)* (ÄM 6994/2), and the core of the strap (ÄM 6994/2).

Imperata cylindrica (halfa grass)

Present in seven entries (out of fifty-six), *Imperata cylindrica* (halfa grass) was used for the insole strip (ÄM 3325), the strip treadsole (ÄM 17081), the 'fibre' sole (ÄM 18473), the upper fabric (with *Linum usitatissimum*, flax fibres) (ÄM 18448), the inner layer of the upper (ÄM 6992/1), the core of the sole's bundle (with *Desmostachya bipinnata*, halfa grass) (ÄM 6994/2), and the sole strip (ÄM 620).

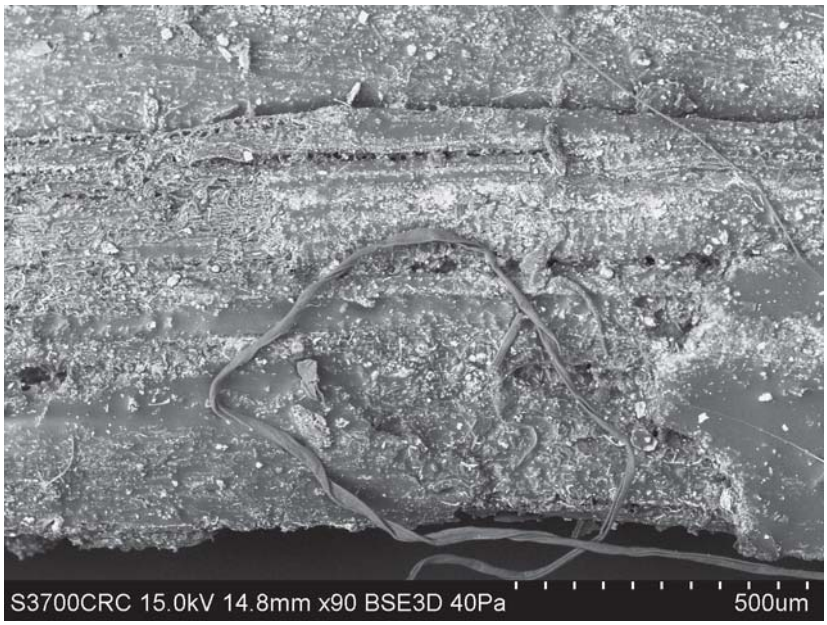

Figure 9. VP-SEM image of ÄM 6992/1 core sole edge showing widespread adhesive or conservation consolidant and modern cotton (and other) fibres adhering to its surface.
Image: C.R. Cartwright. © The Trustees of the British Museum.

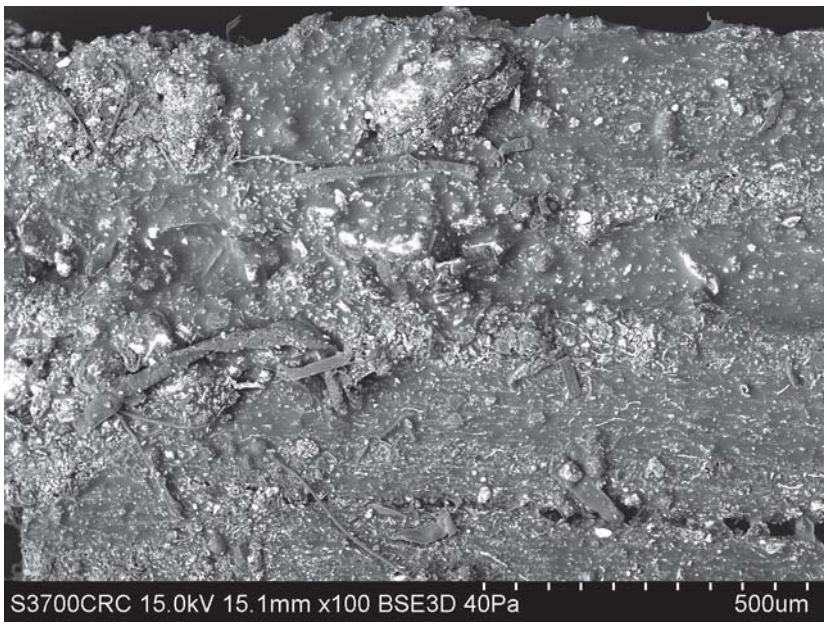

Figure 10. VP-SEM image of ÄM 6992/1 core sole edge showing widespread adhesive or conservation consolidant and modern fibres within it and adhering to its surface. Image: C.R. Cartwright. © The Trustees of the British Museum.

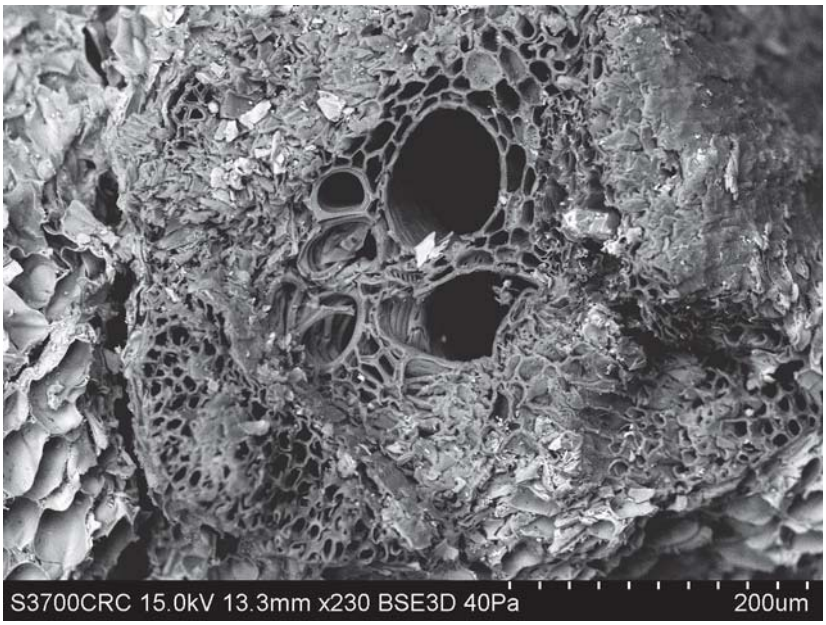

Figure 11. VP-SEM image of ÄM 6992 [Z-346] showing remnants of a small stem of *Hyphaene thebaica* (dom palm) used in the sandal sole. Image: C.R. Cartwright. © The Trustees of the British Museum.

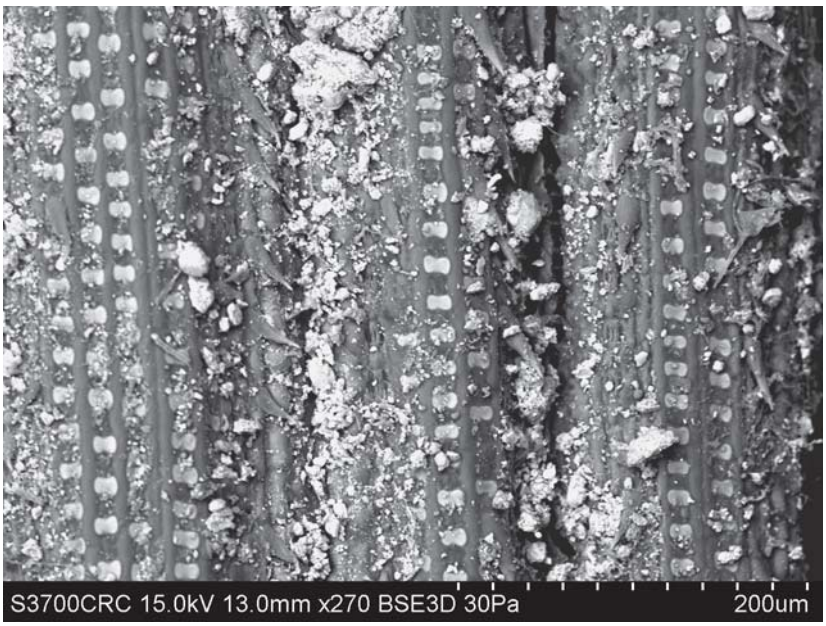

Figure 12. VP-SEM image of ÄM 6994/2 sole core sample showing the epidermal leaf surface of *Desmostachya bipinnata* (halfa grass) with its characteristic phytoliths (silica bodies) and hairs, as well as larger extraneous calcareous adhesions. Image: C.R. Cartwright. © The Trustees of the British Museum.

Linum usitatissimum (flax)

Linum usitatissimum (flax) fibres (*sensu stricto*) are represented in four samples: the red insole strips (ÄM 20471), the attached cloth (ÄM 20471), the upper fabric (with *Imperata cylindrica, halfa grass*) (ÄM 18448), and the outer surface of the upper (with *Desmostachya bipinnata,* halfa grass) (ÄM 6992 [Z-346]).

Cyperus papyrus (papyrus sedge)

Cyperus papyrus (papyrus sedge), from the sedge family Cyperaceae, is represented in four samples: the core of the front strap (ÄM 26547), the cladding of the pre-strap (ÄM 6994/2), and cladding of the straps (ÄM 1397; ÄM 620). As the sample of the cladding of the pre-strap from sandal ÄM 6994/2 was vestigial and very fragile, the Hitachi S4800 field emission scanning electron microscope (FE-SEM) was used with the secondary electron (SE) detector at the very low accelerating voltage of 5 kV in order not to damage the sample with an intense electron beam, while still achieving an identification. Figure 14 shows that remnants of *Cyperus papyrus* stem fragments are present.

Phoenix dactylifera (date palm)

In some samples, where the epidermal surface was masked by calcareous deposits – e.g. the core of the edge of sandal ÄM 3325 (Figure 15) – it was possible to sub-section the sample longitudinally. This permitted the displaying of anatomical characteristics that thereby enabled identification by revealing diagnostic cells of *Phoenix dactylifera* (date palm) (Figure 16). *Phoenix dactylifera* (date palm) was also recorded from three other core edge samples: ÄM 3324; ÄM 20471; and ÄM 26547.

Unidentifiable

In other samples, such as the winding strap from ÄM 18473 (Figure 17), the epidermal stomata have a calcareous filling masking their conformation. Whilst some of the other visible features in this sample resemble key traits of *Imperata cylindrica* (halfa grass) reference specimens, there is insufficient diagnostic detail present to make a secure identification. This raises an important issue in this identification process: the VP-SEM has been an extremely useful tool for assessing difficult samples, but in many instances, diagnostic details had to be pieced together from different views, and it was often not possible to obtain a single image displaying all key features.

3.3. The Samples from the Petrie Museum of Egyptian Archaeology, University College London (Figure 4)

Table 2 provides the identifications of the selected material. The seventeen samples (some comprising more than one type of plant) have been identified to taxon and the following plants are represented: *Phoenix dactylifera* (date palm), *Hyphaene thebaica* (dom palm), *Desmostachya bipinnata* (halfa grass), *Imperata cylindrica* (halfa grass), *Cyperus papyrus* (papyrus sedge) and *Linum usitatissimum* (flax). See above for examples of these taxa imaged in the SEM.

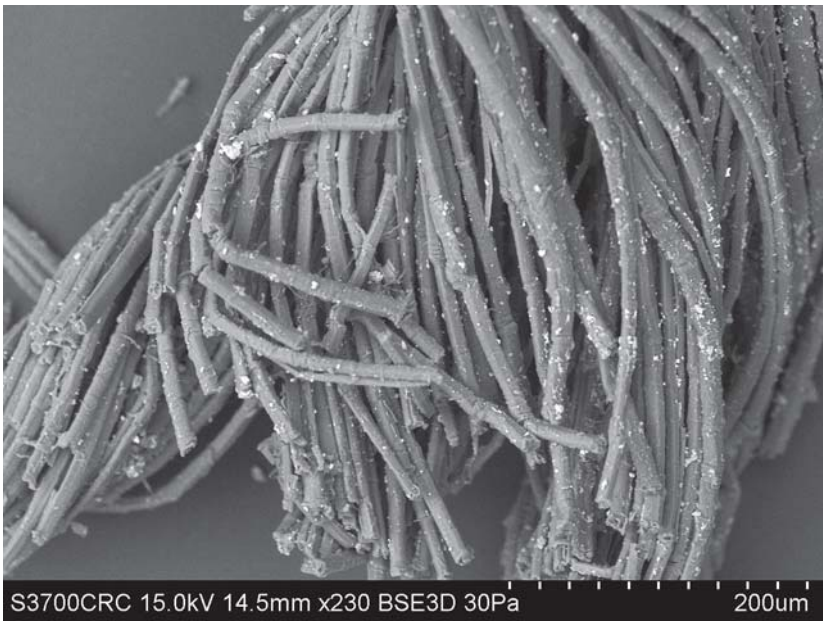

Figure 13. VP-SEM image from a sample of cloth attached to ÄM 20471 showing *Linum usitatissimum* (flax) fibres.
Image: C.R. Cartwright. © The Trustees of the British Museum.

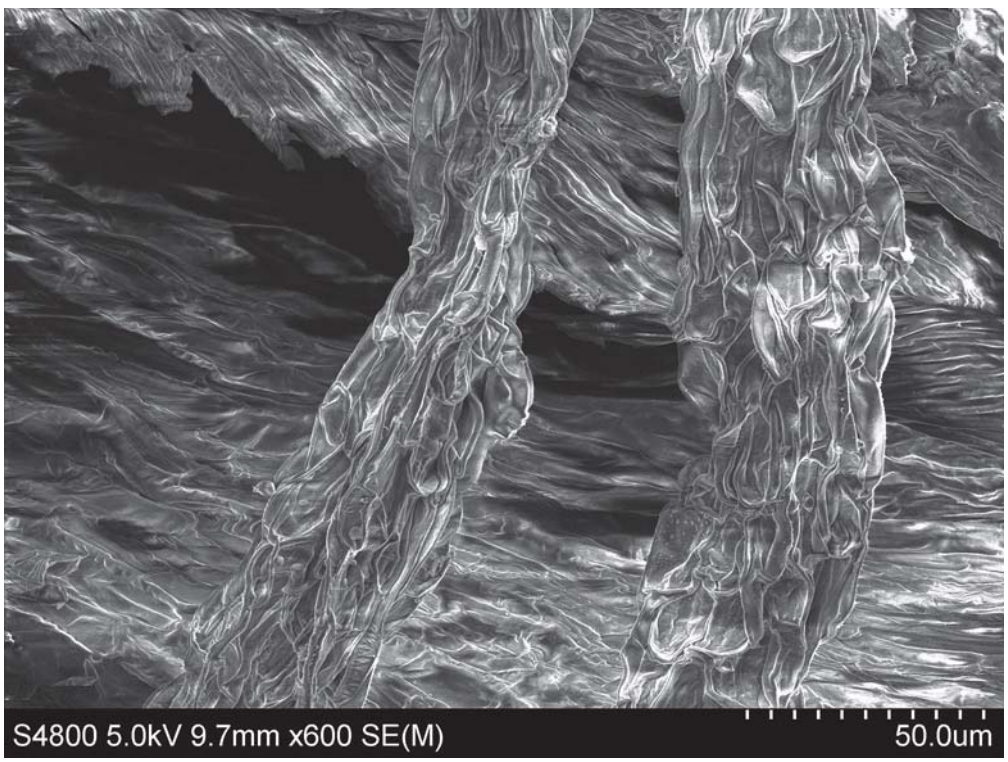

Figure 14. FE-SEM image of a sample of the cladding of the strap fastened to the sole of sandal ÄM 6994/2 showing *Cyperus papyrus* (papyrus sedge) stem remnants.
Image: C.R. Cartwright. © The Trustees of the British Museum.

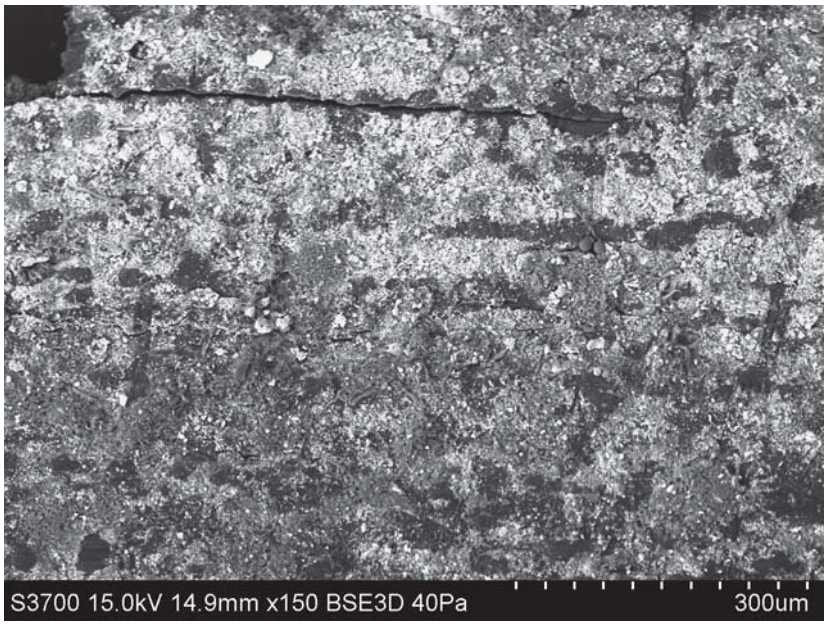

Figure 15. SEM image of a core edge sample of sandal ÄM 3325 showing the epidermal surface masked by calcareous deposits.
Image: C.R. Cartwright. © The Trustees of the British Museum.

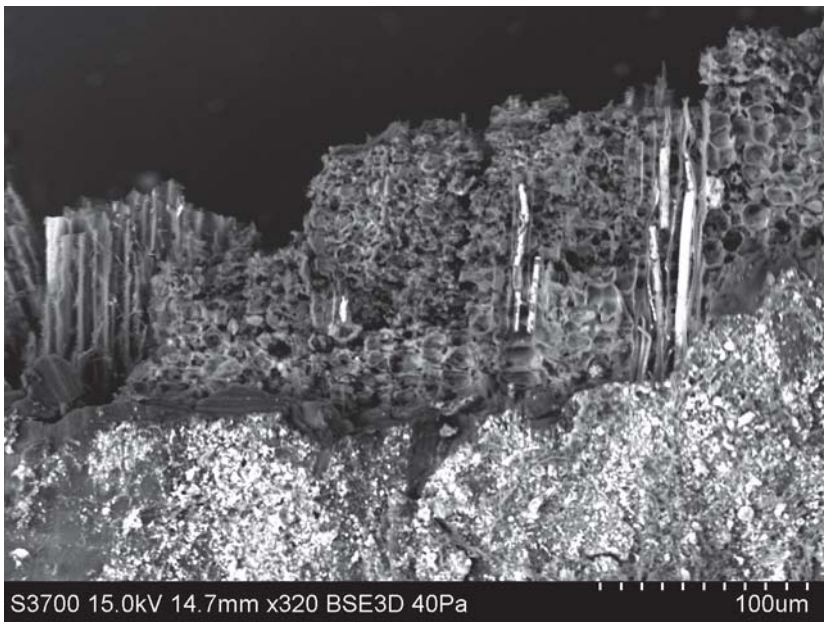

Figure 16. SEM image of a core edge sample of sandal ÄM 3325, partly sub-sectioned, which enabled identification of *Phoenix dactylifera* (date palm).
Image: C.R. Cartwright. © The Trustees of the British Museum.

3.4. The Samples from the British Museum, London (Figures 3, 18-22)

Table 3 provides the identifications of the selected material. The twenty samples (some comprising more than one type of plant) represent the following plants: *Phoenix dactylifera* (date palm), *Hyphaene thebaica* (dom palm), *Cyperus papyrus* (papyrus sedge), *Desmostachya bipinnata* (halfa grass) and *Imperata cylindrica* (halfa grass).

4. Discussion

Taking the decision to examine the samples in the VP-SEM without first cleaning and preparing them or using the alternative method of thin-sectioning them for LM examination, has yielded significant additional information about the condition of the sandals themselves. Many of the samples of sandal components display adhesives and/or conservation consolidants, encrustation (possibly from the historical use of pesticides), (non-active) fungal hyphae, frass, loose particles (dirt), abrasion, wear, and deterioration. Figures 5, 6, 8-10, 15 and 17 show typical examples of each of these. Despite the fact that sometimes these features have masked anatomical characteristics or hindered secure identifications, only a small percentage was ultimately unidentifiable. These results can be seen as adding to the body of knowledge about the effects of the preparation of the specifically-selected plant parts for the manufacture of the sandal or shoe, the use by its owner, as well as its subsequent storage. They can also inform active conservation and the care of the museum collections.

Greiss (1949) identified the materials in five sandals, but only two were illustrated. This limited our ability to verify his identification of the type to only these two, thus only they will be discussed here. The Sewn Sandal (383 C.M.) is made of *Hyphaene thebaica* (dom palm) and *Imperata cylindrica* (halfa grass), but it is not specified which parts of the sandal were sampled. The Sewn Sandal in the Berlin collection includes, besides these two materials, also *Cyperus papyrus* (papyrus sedge) and *Desmostachya bipinnata* (halfa grass). Although the material of the sandals from the tomb of Tutankhamun has been identified as halfa grass[7] for the core of the transverse bundles, *Hyphaene thebaica* (dom palm) for the sewing material that wraps them, and *Cyperus papyrus* (papyrus sedge) for the straps (Veldmeijer, 2010a: 145-146[8]), here too a larger number of samples from various parts of the sandals (cores of the edge or core of the straps, for example) would probably point to additional materials being used. Reed(?) cores are suspected to have been used as cores in the Sewn Sandals from the tomb of Yuya and Tjuiu, as well as in an example from the Petrie Museum of Egyptian Archaeology, University College London (Veldmeijer, 2010a: 145). El Hadidi & Hamdy (2011) published the results of the identification of various pieces of footwear, including a Sewn Sandal from Deir el-Medinah. Remarkably, the bundle of this sandal is made of *Cyperus papyrus* (papyrus sedge), rather than reed or grass; the wrapping strips are made of *Hyphaene thebaica* (dom palm). The use of *Hyphaene thebaica* (dom palm) for the sewing was registered in all Sewn Sandals that have been sampled for material identification, and

[7] Not further specified, as this would need a comparable strategy to the material that is presented here; this was not done.

[8] These identifications, made by means of macroscopic investigation and assisted by magnifying lenses up to 20 times, have been confirmed by the identification of one sandal by the Grand Egyptian Museum Conservation Lab (Morshed & Veldmeijer, 2015: 93-94).

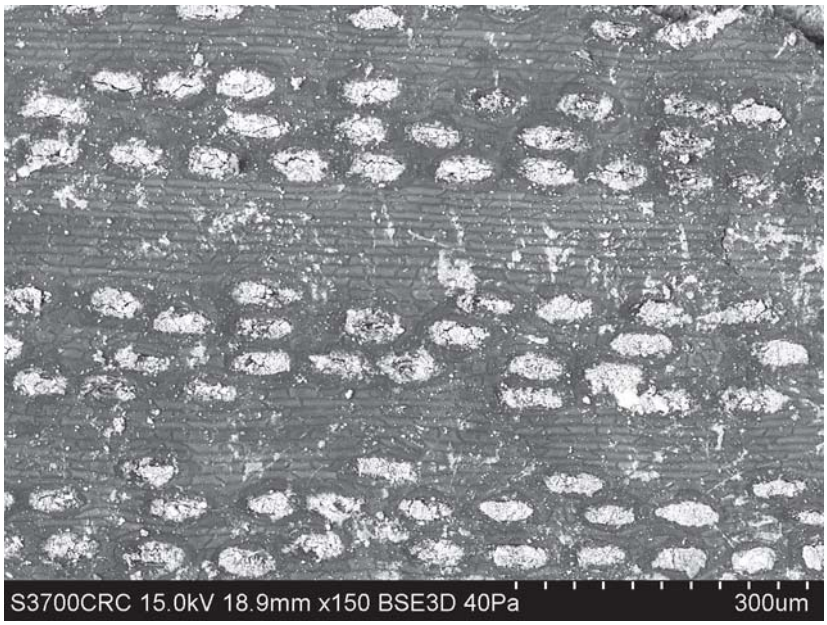

Figure 17. SEM image of the winding strap of ÄM 18473 showing how the rows of epidermal stomata have a calcareous filling that masks their morphology. Image: C.R. Cartwright. © The Trustees of the British Museum.

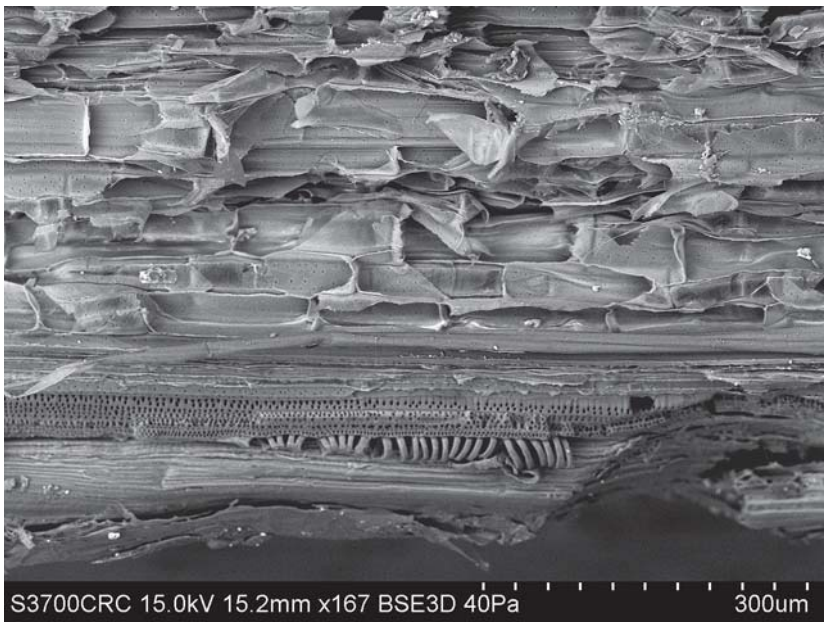

Figure 18. VP-SEM image of a longitudinal section of a small stem of *Arundo donax* (giant reed) from the core of the right sandal strap of EA4445. Image: C.R. Cartwright. © The Trustees of the British Museum.

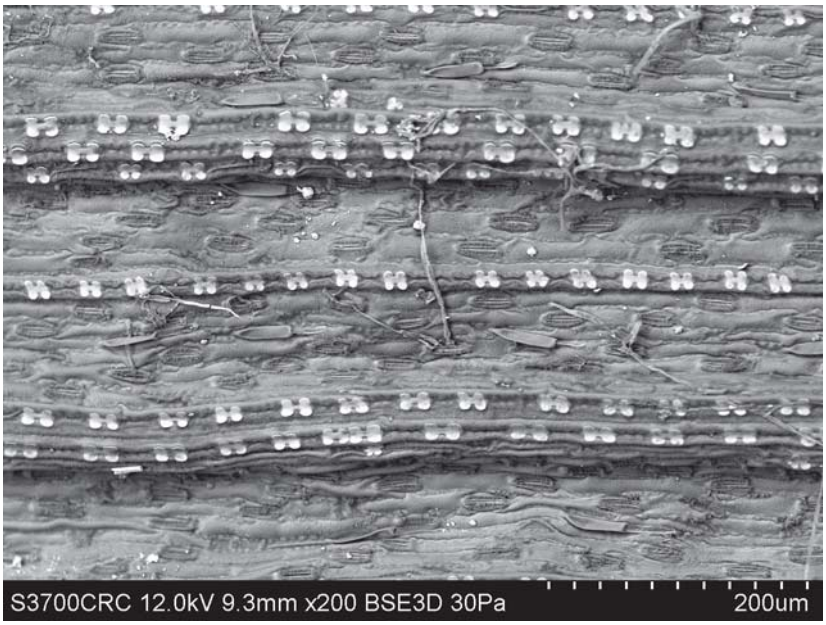

Figure 19. VP-SEM image of a longitudinal section of a leaf of *Arundo donax* (giant reed) from the insole of the right sandal of EA4445. Image: C.R. Cartwright. © The Trustees of the British Museum.

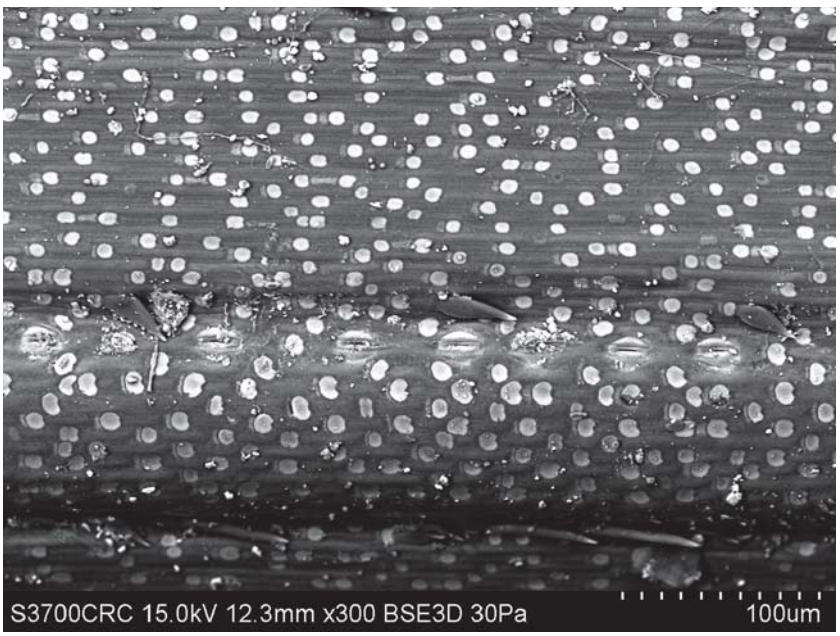

Figure 20. VP-SEM image of a longitudinal section of *Desmostachya bipinnata* (halfa grass) from sandal EA5411. Image: C.R. Cartwright. © The Trustees of the British Museum.

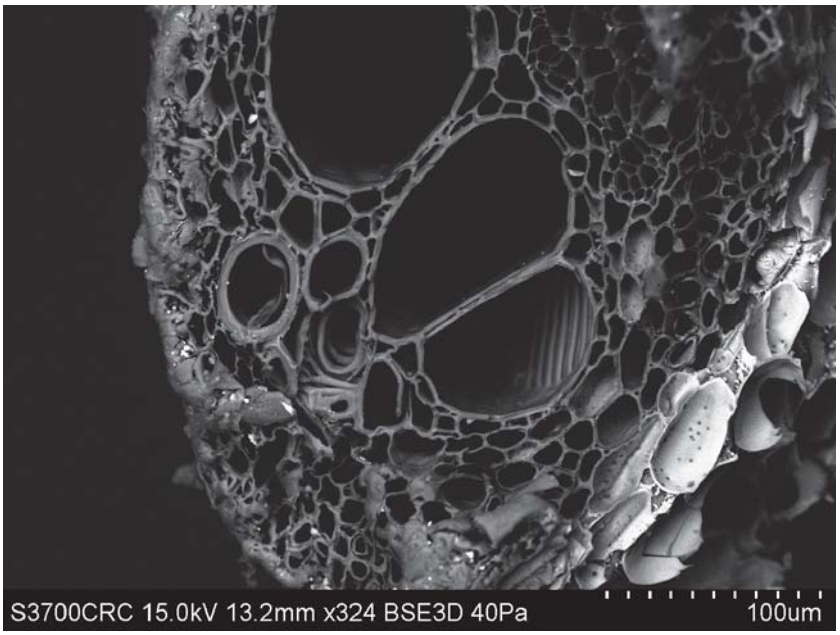

Figure 21. VP-SEM image of a transverse section of *Hyphaene thebaica* (dom palm) from the edge of the core of sandal EA5411. Image: C.R. Cartwright. © The Trustees of the British Museum.

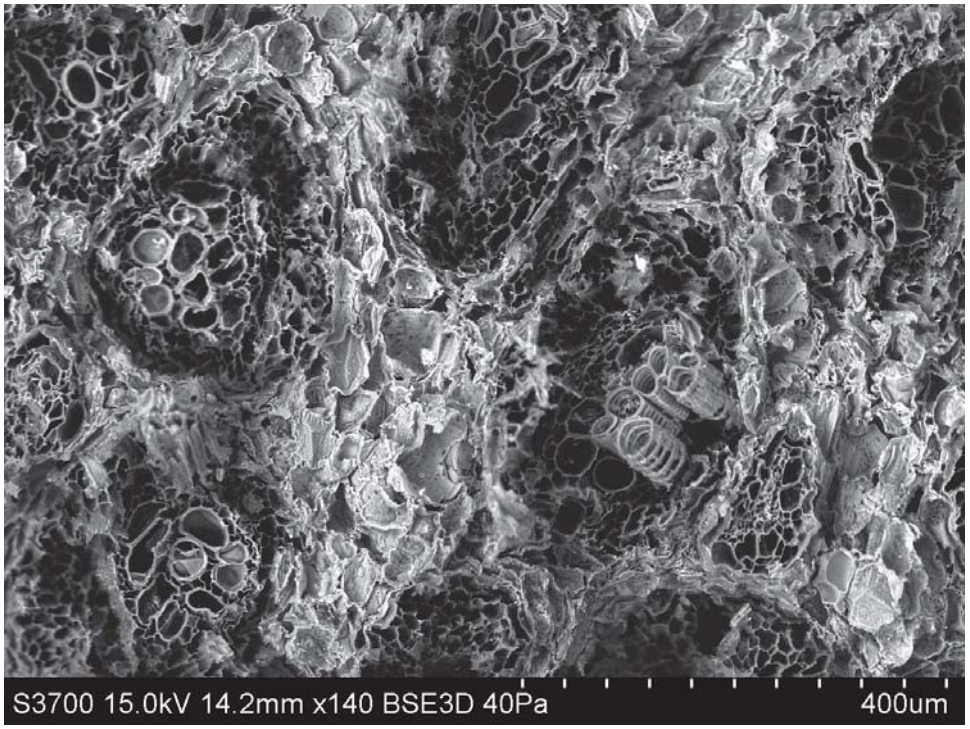

Figure 22. VP-SEM image of a transverse section of *Phoenix dactylifera* (date palm) from the edge of the core of sandal EA36210. Image: C.R. Cartwright. © The Trustees of the British Museum.

where the sampled area was specified. Montembault (2000: 38; Dupéron-Laudoueneix, 2000) mentions *Hyphaene thebaica* (dom palm) leaf too, but it was not specified from which part the identification was made; the same can be said about the Sewn Sandals published by Gourlay (1981a: 62; 1981b: 56, pl. xxb).

A comparable problem can be seen in the identification of the materials of other types of sandals and shoes: one should not assume that all elements were made of the same material as the identified sample. The Sewn-Edge Plaited Sandals from the three collections that were sampled for the present work were made of two, three, four or even five materials, including *Cyperus papyrus* (papyrus sedge), *Desmostachya bipinnata* (halfa grass), *Hyphaene thebaica* (dom palm), *Phoenix dactylifera* (date palm) and *Arundo donax* (giant reed). Greiss (1949) identified *Hyphaene thebaica* (dom palm) for a Sewn-Edge Plaited Sandal and its border (we assume that by 'sandal' he meant the sole alone). El Hadidi & Hamdy (2011: 1052) identified *Hyphaene thebaica* (dom palm) for the plaiting strips and the petioles in the bundles of the edge of the sandal that they examined. Although analysis of the Sewn-Edge Plaited Sandals published by Montembault (2000: 33-35; Dupéron-Laudoueneix, 2000) has the same problem the Sewn Sandal fragment from the Louvre collection (exactly what part was examined is not specified), *Phoenix dactylifera* (date palm) was identified. Gourlay (1981a: 55-64; 1981b: 45-59, pl. Vd-f; XXa, c) only mentions palm as the material, without any further specification. The Composite Sandals in the Louvre collection include *Phoenix dactylifera* (date palm) and *Cyperus papyrus* (papyrus sedge), but again, the region from which the sample was taken is not specified (Montembault, 2000: 39-43; Dupéron-Laudoueneix, 2000). Composite Sandals have not been sampled by El Hadidi & Hamdy (2011), nor were they mentioned by Gourlay (1982a, b); the examples shown in the present work, therefore, are the most precise representation of materials used in this type of sandal.[9] A single sandal can have two, three or four materials in it (note that in the case of four materials, one material was unidentified). The identified materials are *Desmostachya bipinnata* (halfa grass), *Imperata cylindrica* (halfa grass), *Hyphaene thebaica* (dom palm), *Phoenix dactylifera* (date palm), and *Linum usitatissimum* (flax).

In both of the open shoes that were examined by El Hadidi & Hamdy (2011), the plaiting strips (it was not specified which plaiting strips) and the insole were made from *Cyperus papyrus* (papyrus sedge), but the straps on one shoe were made from *Phoenix dactylifera* (date palm) and on the other from *Hyphaene thebaica* (dom palm). The shoes in the Louvre collection included *Phoenix dactylifera* (date palm) and *Hyphaene thebaica* (dom palm) (Montembault, 2000: 36-38, Dupéron-Laudoueneix, 2000). Again, a greater diversity of material was noted for the footwear presented here, but, as with all sampled footwear, more samples were taken from each shoe (in some cases as many as five) than in the other studies. The open shoes were made with two, three or four different materials (one shoe that was made of three materials, and the only example that was made of four, included one unidentified material). The materials that were identified are *Phoenix dactylifera* (date palm), *Hyphaene thebaica* (dom palm), *Imperata cylindrica* (halfa grass), *Desmostachya bipinnata* (halfa grass) and *Linum usitatissimum* (flax).

[9] The important publication of a burial with a pair of Composite Sandals *in situ* (Fiore Marochetti et. al., 2003) also mentions palm as material, without any further specification.

Several different plants are often used together in making footwear, and the main three of these that have been consistently found are *Phoenix dactylifera* (date palm) leaflets, *Hyphaene thebaica* (dom palm) leaflets (particularly for the stouter elements), and *Cyperus papyrus* (papyrus sedge) culms (which may be used for cladding and insoles as well as other components). These findings also suggest that, if only one material is mentioned as being identified for a sandal or shoe, this probably means that it refers to only one part (e.g. the sole or the straps, although even these can be made of different materials) rather than to all the different components. In scientific literature, these three materials are also most commonly mentioned. However, a combination of factors, including not identifying the part of the shoe or sandal from which the samples were made, and assuming that materials which were found in only one or two extracted samples are representative of all the materials used, has distorted our picture of the craft of footwear production. Even in the present work, the description of the samples is not always precise enough: in the case of a pair of sandals, for example, it was not specified which of the sandals/shoes were sampled. Other problems can occur if the type of sandal is not specified.

Thus, it appears that the people producing footwear, whether they were professional sandal-makers or not, used whatever material was available, and no specific preference existed. Still, a slight inclination for dom palm and papyrus sedge for certain uses can be seen; most obvious is the use of *Cyperus papyrus* (papyrus sedge) for the (cladding of the) straps in Sewn Sandals (although examples are known where these straps are made from other materials).

A short note on papyrus sandals: as has been mentioned elsewhere (Hagen, 2011: 195-197), footwear referred to as 'papyrus sandals' in texts, *if* this designation meant sandals made solely of papyrus, are not known from the archaeological record. This has led to the suggestion that the translation of the term should be reviewed. This suggestion is supported by the fact that no sandals were identified as crafted only from *Cyperus papyrus* (papyrus sedge) in the present study, although the material was certainly used for various elements.[10]

Acknowledgements

Grateful thanks are due to Alan J. Clapham for kindly providing and discussing some modern reference specimens of Poaceae from North Africa. Mike Dallwitz is acknowledged for permission to publish photographs of the epidermis of modern leaf blade of *Imperata cylindrica*. Further thanks are due to the collections for allowing us to sample the footwear and publish the photographs. We thank Ariel Singer for proof reading and correcting the text.

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[10] Note that in general "there is still much uncertainty about the identification of ancient Egyptian plant names" (Veldmeijer & Zazzaro, 2008: 27).

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TABLE 1. Identification of plant materials used for footwear in the Ägyptisches Museum und Papyrussammlung, Berlin.

Accession number and sample details	**Type of footwear**	**Sample Description**	*Cyperus papyrus*, papyrus sedge	*Desmostachya bipinnata*, halfa grass	*Imperata cylindrica*, halfa grass	*Hyphaene thebaica*, dom palm	*Linum usitatissimum*, flax (for linen)	*Phoenix dactylifera*, date palm	unidentifiable
ÄM 3324	sewn-edge plaited sandal, type D, variant i	insole strip				■			
		edge sewing				■			
		core of the edge						■	
		braid treadsole				■			
		treadsole strip				■			
ÄM 3325	composite sandal, type elongated straight, variant notched	insole strip			■				
		braid treadsole		■					
		core of the edge						■	
		braid insole		■					
ÄM 17081	composite sandal, type elongated straight, variant unnotched	insole strip		■					
		cladding of the strap				■			
		core inside the insole edge							■
		strip treadsole			■				
ÄM 18473	coiled sandal, type 1	‘fibre’ sole (woven sole layer)		■	■				
		strips insole				■			
		cladding of the strap							■
		strip tying the front strap				■			
ÄM **20471**	composite sandal, type elongated swayed	insole strip (coloured red)					■		
		insole strip (beige strip)							■
		sewing of the edge				■			
		attached cloth					■		
		core of the edge						■	
		braid treadsole		■					
				■					

				■					
ÄM **26547**	sewn-edge plaited sandal, type A	insole strip		■					
		core of the front strap	■						
		sewing of the edge				■			
		core of the edge						■	
ÄM **18448**	open shoe, full upper type, upright upper variant	upper fabric			■		■		
		sole strip							
		sewing of the edge of the sole				■			
		cladding of the strap				■			
		core of the strap				■			
ÄM **6992/1**	open shoe, partial upper type, short toe variant	outer surface of the upper				■			
		inner layer of the upper			■				
		sole				■			
		core of the edge of the sole							■
		sewing of the edge				■			
ÄM **6992** **(Z-346)**	open shoe, partial upper type, short toe variant	outer surface of the upper		■			■		
		inner layer of the upper		■					
		core of the edge of the upper							■
		sewing of the edge upper				■			
		sole strip				■			
ÄM **6994/2**	sewn sandal, type A	sewing strip of the sole				■			
		core of the sole's bundle		■	■				
		strap (outer layer)				■			
		core of the strap		■					
		cladding of pre-strap	■						
ÄM **1397**	sewn-edge plaited sandal, type C	cladding of the front strap				■			
		sole strrip				■			
		cladding of the strap	■						
ÄM **620**	sewn-edge plaited sandal, type B	sole strip			■				
		cladding of the strap	■						
		core of the strap				■			
		sewing of the edge							

Key: filled cell = plant part present

TABLE 2. Identification of plant materials used for footwear in the British Museum, London.

Accession number and sample details	**Type of footwear**	**Sample Description**	*Cyperus papyrus*, papyrus sedge	*Desmostachya bipinnata*, halfa grass	*Imperata cylindrica*, halfa grass	*Hyphaene thebaica*, dom palm	*Phoenix dactylifera*, date palm	*Arundo donax* giant reed
EA4418	coiled sandal, type 3 (looped)	left sandal				■		
EA4432	coiled sandal, type 4 (sewn)	core of the coil					■	
		sewing of the coil	■					
EA4445	sewn-edge plaited sandal, type A, variant 1	core of the strap						■
		cladding of the strap					■	
		insole strip						■
EA4464	open shoe, partial upper type, extended toe variant	outer layer of the upper (left shoe)					■	
		middle layer of the upper (left shoe)					■	
		inner layer of the upper (left shoe)				■		
EA55411	sewn-edge plaited sandal, type B, variant 4	four samples of the sole strips	■	■	■		■	
		sewing of the edge	■					
		core of the edge				■		
EA36210	sewn-edge plaited sandal, type A, variant 1	core of the edge					■	
		edge of core					■	
		core of the strap	■					
		cladding of the strap	■					
		Insole strip	■					

Key: filled cell = plant part present

TABLE 3. Identification of plant materials used for footwear in the Petrie Museum of Egyptian Archaeology, University College London.

Accession number and sample details	**Type of footwear**	**Sample Description**	*Cyperus papyrus*, papyrus sedge	*Desmostachya bipinnata*, halfa grass	*Imperata cylindrica*, halfa grass	*Hyphaene thebaica*, dom palm	*Phoenix dactylifera*, date palm	*Linum usitatissimum*, flax (for linen)
UC769	sewn-edge plaited sandal, type A, variant 1	sewing of the edge	■					
		core of the edge					■	
		woven material under the sole				■		
UC28015	composite sandal, type elongated straight, variant notched	sole strip					■	
		binding at the toe						■
UC28033	coiled sandal, type 2, variant 2	wrapping of the edge (heel)					■	
		cladding of the strap		■				
UC28302	coiled sandal, type 3 (looped)	cladding of the strap (right sandal)				■		
		looping material cores sole (right sandal)		■	■			
UC28303	coiled sandal, type 3 (looped)	strap (right sandal)				■		
		looping material cores sole (right sandal)		■	■			
UC28314i	coiled sandal, type 4 (sewn)	sewing of the outermost core (at heel)	■					
		core of the edge				■		
UC28362i	composite sandal, type elongated swayed	sole strip	■					
		plaited strip at sole						■

Key: filled cell = plant part present