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The Middle Bronze Age furniture from Tomb P19 at Jericho: wood identification and conservation challenges

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Summary Kenyon's excavations of Tomb P19 at Jericho revealed wooden furniture and funerary artefacts of high quality that provide an accurate reflection of the esteem in which the individuals buried within it were held. Unusual conditions of desiccation had preserved the tomb's organic materials, but upon excavation deterioration of the organic remains set in very quickly. Despite considerable problems for wood identification and the study of wood technology caused by deterioration during burial and brought about by the conservation methods and materials used at the time, particularly the liberal application of now-discoloured wax, a variety of timbers has now been securely identified. The most recent conservation assessments and treatments of the Tomb P19 wooden artefacts and furniture are described, including a preliminary assessment of the use of laser ablation to remove the disfiguring wax layer, and the implications of this study for the Jericho material on display in the British Museum are evaluated.

INTRODUCTION

The Jericho tell (Figure 1) consists of a large city mound that was occupied from the proto-Neolithic through the Early, Middle and Late Bronze Ages to the Iron Age. It is situated near a spring in the southern Jordan valley, 244 m below sea level and west of the River Jordan. Extensive excavations undertaken by Kathleen Kenyon from 1952 to 1958 revealed domestic housing, fortified structures and an extra-mural cemetery [1–7]. The last of these contained shaft tombs, mostly Early to Middle Bronze Age in date, many of which, through unusual conditions of desiccation, had preserved organic materials such as wood, basketry, fruits and foodstuffs, so that Jericho remains one of the best examples in the Levant of this type of organic assemblage. Kenyon explored 27 shaft tombs of the Middle Bronze Age (*c*.2000–1480 BC), one of the most impressive being Tomb P19 [3; pp. 388–410; Figure 193 and Plate 18:1]. Most of the P19 wooden tomb furniture, human and animal bones and accompanying funerary objects are in the British Museum collections and have, therefore, been the subject of scientific study and conservation condition assessments. This contribution explores the importance of Tomb P19 and how the remarkable survival of the wooden funerary items has presented scientific and conservation challenges.

TOMB P19

Tomb P19 had a very large chamber and, in common with many of the Middle Bronze Age tombs, was constructed and first used in the preceding Early Bronze IV (EBIV) period (*c*.2400–2000 BC). Remains of the earlier EBIV burial consisted of a single jar, some bronze scraps and fragmentary human bones that had been pushed to the front of the chamber and covered by an earth ramp. During the Middle Bronze IIB period (*c*.1750–1650 BC), after a gap of around 300 years, the chamber was reused to inter seven individuals. These were found arranged in a row with their heads to the west of chamber. Six of the skeletons were intact, but one (skeleton *E*) was much disarranged, apparently disturbed when the other six were introduced. The excavators concluded, therefore, that two phases of burial had occurred within the Middle Bronze Age use of the tomb [3]. Of the seven Middle Bronze Age individuals (designated *A*–*G*), skeleton *E* was a female,

FIGURE 1. Jericho tell. Image: Jonathan Tubb

aged about 28 years and around 1.55 m tall who was said to be "powerfully built". Three of the remaining six skeletons were male: skeleton *B*, aged about 26 years, around 1.73 m tall and of normal build; skeleton *F*, aged about 24 years, around 1.75 m tall and of "particularly robust build"; and skeleton *C*, a boy aged about 11. The three females (skeletons *A*, *D* and *G*) were aged approximately 15, 11 and 17 respectively.

One or more violent blows to the skull had killed all six individuals and they had been buried simultaneously some time after the interment of individual *E*. Males *B*, *F* and *C* were missing their right hands. Kenyon, interpreting this as evidence for a mass execution, suggested that the six were thieves caught robbing the tomb of individual *E* [3]. This might, according to her, explain the "kicked about" condition of skeleton *E* and the missing right hands of the three males. She therefore proposed that males *B*, *F* and *C* were tomb robbers caught in the act, and that they and their family had been executed and entombed. Kenyon's explanation seems highly improbable, as it is difficult to imagine a situation in which apprehended criminals would be interred in the very tomb they had desecrated. More significantly, her theory seems entirely contrary to the lavish nature of the burial offerings: pottery storage jars; bowls; vases; juglets and lamps; alabaster vessels; wooden tables, stools, platters and boxes with delicately carved bone inlay; baskets; beads; scarabs; and a decorated ostrich eggshell. If Kenyon's 'tomb robber' hypothesis was correct, all these should be assigned to individual *E*, since it does not seem likely that robbers would have been provided with grave goods. Examination of the tomb drawings makes the situation quite clear, as two distinct phases of deposition are present. Some pieces of furniture, presumably those interred with individual *E*, were already decaying when the later burials were made, as they were considerably disarranged. Other tables and stools, however, were found in the positions in which they ultimately deteriorated, and it would make sense to associate these items of furniture with the later burial of the six executed individuals. Such fine and expensive furniture would hardly be appropriate grave goods for disgraced tomb robbers. A further point of incongruity lies in the fact that three of the 'tomb robbers' (*B*, *C* and *D*) had been laid out on rush mats, in two instances with clearly associated personal ornaments; again, improbably benevolent for the burial of criminals. A much more plausible explanation for Tomb P19 is that the six simultaneously interred individuals were killed in an enemy raid and, being of the same family as individual *E*, were buried in the same tomb. The extensive and lavish nature of the grave goods, the majority of which are clearly associated with these six, strongly indicates this. The food remains found in the tomb, which included two complete lambs together with other joints of meat in bowls and wooden platters, represent the remains of a burial feast held in honour of the deceased. Although it is undeniable

that the severing of the right hand was (and occasionally still is) a punishment for robbery in some areas of the Middle East, some ancient Egyptian peoples practised a similar mutilation in order to keep a tally of the dead. An illustration of this practice can be found in the scene depicted on the wall of the mortuary temple of Ramses III at Medinet Habu, in which Egyptian scribes are recording the numbers of severed hands recovered from enemy victims [8]. A punitive attack on Jericho could well account for the condition of the six individuals and their simultaneous interment in P19. The three executed girls (*A*, *D* and *G*) were buried with their right hands intact, suggesting that, as in the case of Egyptian tallying procedures, only 'men' or 'warriors' were counted.

A re-examination of skeleton *E* prior to its inclusion in a reconstruction of part of P19 in the British Museum's Raymond and Beverly Sackler Gallery of the Ancient Levant has added an additional interesting dimension. Preliminary analysis of this skeleton has revealed that the woman had a deformity of the left leg, sufficiently pronounced enough to have impaired mobility [9]. This observation helps to explain the presence of two wooden staves found beside skeleton *E*, interpreted by Kenyon as a "sign of rank" [3]. The two staves in question were found not just beside skeleton *E* but were quite clearly tucked beneath the left shoulder and, in this position and given the leg deformity, they should properly be interpreted as the constituent elements of a crutch. The new evidence makes it possible to state that the first interment in Tomb P19 in the Middle Bronze Age was of a disabled woman, aged about 28, who probably died of natural causes. She was buried not only with her crutch but also with a rich assemblage of grave goods, suggesting she was a person of high social status within Jericho society.

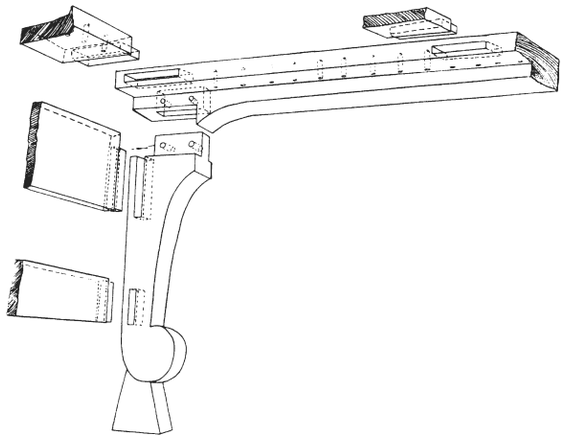

FIGURE 2. A sketch from the unpublished Jericho archive showing how a wooden stool might have been constructed (redrawn by Antony Simpson)

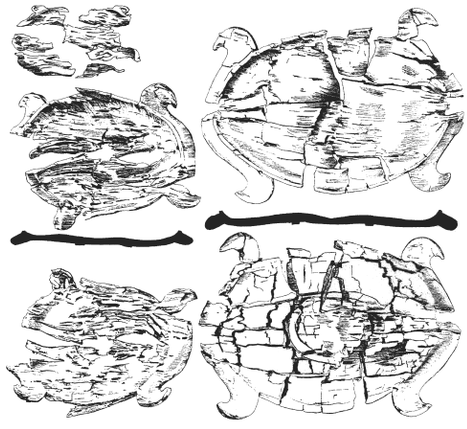

FIGURE 3. Sketches from the unpublished Jericho archive showing the construction of wooden platters (redrawn by Antony Simpson)

IDENTIFYING THE WOODEN FURNITURE AND ARTEFACTS FROM TOMB P19

Understanding the problem

It is extremely fortunate that detailed drawings and photographic records were made after opening Tomb P19. They remain the main source of information, along with the descriptive text [2, 5, 7], on the form, relative positions and condition of the grave items. They also provide the best technological evidence for the construction of the wooden funerary furniture and artefacts, Figure 2. In theory, the exceptional burial conditions of the Jericho wood suggest that the assemblage should be an outstanding resource for the investigation of Bronze Age carpentry and wood use. Unfortunately, as soon as the tombs were opened, deterioration of the organic remains set in very quickly. Despite the best efforts of the excavators, the conservation and lifting techniques available at the time were insufficiently advanced to prevent further fragmentation of much of the rich assemblage, as the drawings of the time show, Figure 3. In 2005 the first major study of the wood from the Bronze Age tombs at Jericho was published [10]. The long gap between excavation and identification is indicative that the microscopic techniques available in the 1950s were insufficient to overcome the difficulties presented by the state of preservation of the bulk of the material and reliable identification was not possible.

As detailed below, the principal consolidant used on the Jericho wood around the time it was excavated was paraffin wax, which was liberally and extensively applied *in situ*. In most instances, the thick wax covered the wooden fragments to such an extent that carving, shaping, and any decorative marks were obliterated. The high level of fragmentation, particularly of the large items of wooden funerary furniture such as tables and stools, was a major handicap to establishing the precise and detailed relationship between artefact type and wood identification [10]. Many fragments of wood examined could not be attributed to a particular part

of a piece of furniture, such as a table leg, or even specifically to a table. Meaningful quantitative estimates of the woods used for specific types of furniture or artefact in the Jericho funerary assemblage are not possible because of their highly fragmented state; counting fragments simply gives an index of fragmentation.

Techniques of wood identification

Standard techniques of wood identification and terminology as set out by the International Association of Wood Anatomists (IAWA) are adopted for the identification of modern wood [11, 12]. For each sample, the key features are compared with reference collection specimens and textual descriptions [13, 14]. This methodology can often be applied to archaeological wood, providing it is modified to accommodate the effects of the conditions of preservation, e.g. desiccation or charring. Each sample needs to be prepared to expose transverse, radial longitudinal and tangential longitudinal sections for identification. For modern and certain types of archaeological wood, thin sections of approximately 12–14 µm are cut on a microtome, mounted on glass microscope slides and examined by transmitted light optical microscopy. Variants of these standard techniques were applied to the Jericho wood fragments in an attempt to overcome the problems created by the original conservation treatments. In order for wood identification to be carried out successfully, sampling had to take place on an area that had been damaged and was free from wax, as this material penetrates and fills the wood cells, preventing the recognition of diagnostic cellular characteristics. Heavy waxing typically penetrated up to 3 mm into the wood, seldom in a uniform manner, Figure 4. Scanning electron microscopy (SEM) was not practicable for the 2005 study, on account of the very large number (3100) of fragments involved [10], and the method adopted in that study was that used for charcoal identification, reflected light optical microscopy [15]. For the P19 wood, SEM was vital, particularly using the variable pressure (VP) SEM. Both fractured and unfractured surfaces were examined directly in the Hitachi S-3700N VP-SEM or Hitachi TM-1000 SEM. Using the VP-SEM significantly improved the preparation process for examination, as it was not necessary to employ many of the sampling steps described in the previous study [10]. It is worth re-emphasizing, however, that the number of features available for characterization was still restricted because of the high shrinkage, distortion and impregnation by paraffin wax, Figure 5. The extreme shrinkage of the wood was estimated by comparing it with inlaid bone ornamentation that retained its original form in composite artefacts. At least 25% shrinkage was present along the radial plane and 16% along the axial, similar figures to those reported by Baker [16]. Despite all these obstacles, a surprisingly diverse array of timbers could be reliably identified.

The wood identification of P19 furniture and artefacts: results and discussion

One of the main objectives of the 2005 study had been to establish whether particular woods had been used preferentially for specific types of funerary furniture and small portable artefacts, such as platters, combs and juglets. The results showed that the Jericho funerary carpenters did not simply rely on whatever wood was most readily available or common locally, irrespective of its particular properties, but that the main woods used were selected principally because their properties matched carpentry and design requirements. The Jericho carpenters clearly made informed, careful and specific choices from the different

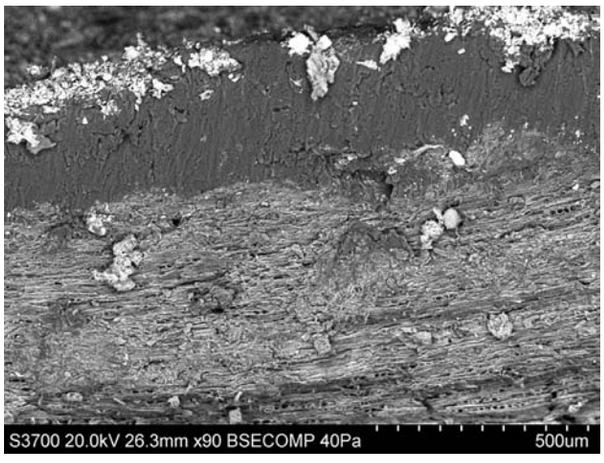

FIGURE 4. Backscattered electron image of a tangential longitudinal section through a table fragment made from *Cedrus libani* (cedar of Lebanon) wood, showing the soil present in the surface wax layer and the extent to which the wax has penetrated into the cellular structure. Image: Hitachi S-3700N VP-SEM

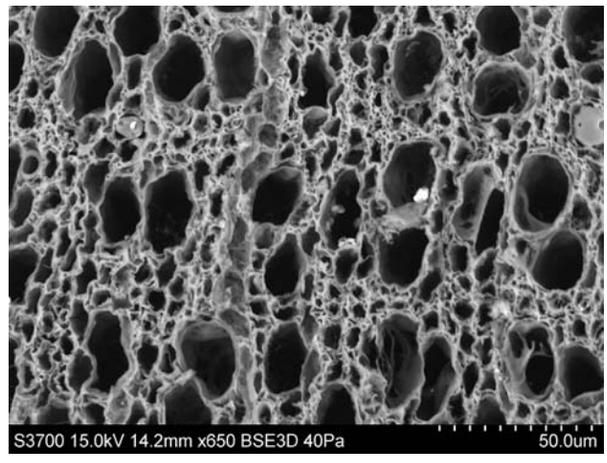

FIGURE 5. Backscattered electron image of a transverse surface of a fragment from a wooden artefact from P19 made of *Crataegus* sp. (hawthorn), showing severely shrunken and distorted vessels, fibres and parenchyma cells. Image: Hitachi S-3700N VP-SEM

vegetation types available locally, selecting for use prime timber from the Mediterranean vegetation, riverine gallery forest or the wadi slopes. For very special artefacts, timber was imported or cultivated locally [10].

Parr records that among the 57 identifiable items of wooden furniture documented from the Jericho tombs, there is a total of 28 tables [17]. Table 1 contains details of the P19 furniture and other artefacts and Figure 6 shows the most intact table from P19, presumably three-legged to be stable on an uneven floor. The following woods have been found in the manufacture of funerary tables, surviving either as intact items or recognizable fragments: *Acacia* sp. (acacia); *Ceratonia siliqua* (carob); *Ficus* sp. (fig), *Fraxinus* sp. (ash); *Olea europaea* (olive); *Quercus* sp. (oak); *Salix* sp. (willow); and *Tamarix* sp. (tamarisk). Some of the smaller fragments were labelled by the excavators as belonging to the 'tables' category and their identifications are: *Crataegus* sp. (hawthorn); *Populus* sp. (poplar); *Ziziphus spina-christi* (Christ's thorn); *Phoenix dactylifera* (date palm); and *Cedrus libani* (cedar of Lebanon). The timbers used for tables and table components seem to fall into four groups. Group 1 comprises ash and oak woods, ideal for the larger elements of tables. Group 2 contains woods that are soft, such as willow, light and fibrous, such as fig and tamarisk, or light but relatively tough, such as poplar (although poplar is not resistant to insect attack). While care would be needed if these woods were used as load-bearing components, they could have been incorporated in other elements in the tables. Group 3 includes woods used to make the finer features, such as the legs, which need to be suitable for carving or turning, but also require strength and durability. Such qualities can be found in acacia, carob and hawthorn woods, although ash and oak are also sufficiently all-purpose to be used for finer, as well as major, elements. Group 4 comprises those woods that were most likely to have been used for elements of decorative carving, inlay or veneer work on the tables. These include olive, Christ's thorn, date palm and cedar of Lebanon [10].

TABLE 1. Wooden furniture and funerary artefacts from Jericho Tomb P19 in the British Museum

Excavation No.	British Museum No.	Object details
P19/U	1958,0211.48 (138869)	Table fragments; two isolated fragments of border of table; tenons and bevelled edge; 28.0 and 24.8 cm
P19/01	1958,0211.66 (138887)	Nearly complete platter; four hooked lugs; low ring base; length (l) 34.8 cm × width (w) 22.8 cm
P19/02	1958,0211.46 (138867)	Table fragments forming the major part of the main board and three legs; 124.8 (l) × height (h) 42.0 cm
P19/04	1958,0211.62 (138883)	Roughly oval fragmentary platter; hooked lugs; rounded base; ridged rim; 30.0 (l) cm
P19/05	1958,0211.65 (138886)	Nearly complete platter; four hooked lugs; low ring base; 25.6 (l) × 16.8 (w) cm
P19/06	1958,0211.52 (138873)	Stool in many pieces; *c.*80.0 (l) × *c.*26.0 (h) cm
P19/07	1958,0211.76 (138897)	Staff; traces of a central longitudinal ridge; poorly preserved
P19/08	1958,0211.75 (138896)	Staff; traces of longitudinal ridge and grooves; broken, warped and decayed
P19/13	1958,0211.74 (138895)	Stick; tapering; fragmentary condition; circular section; plus a number of roughly rectangular pieces
P19/15	1958,0211.60 (138881)	Several lengths of slightly bevelled wooden strips
P19/17	1958,0211.77 (138898)	Toilet-box(es) fragments; 13 very thin and much warped pieces
P19/18	1958,0211.67 (138888)	Dipper juglet (upper half) with a recessed band with chevrons in relief above the junction; 66.0 (h) cm
P19/19	1958,0211.81 (138902)	Copper alloy knife found on table 2, beside joint of meat; curled tip; three rivets for handle; traces of wood; 22.0 (l) cm
P19/20	1958,0211.47 (138868)	Well-preserved table; fragments forming most of main board and three legs; 88.0 (l) × 44.0 (h) cm
P19/20A	1958,0211.53 (138874)	Stool fragments; poorly preserved
P19/20B	1958,0211.59 (138880)	Stool fragments; two stool feet; square section with bevelled edges, tapering to round peg foot
P19/21A	1958,0211.56 (138877)	Stool fragments; side rail with leg and shorter rail
P19/21B	1958,0211.57 (138878)	Stool leg; 18.4 (h) cm
P19/21C	1958,0211.55 (138876)	Four stool legs; 24.8 (h) cm
P19/21D	1958,0211.58 (138879)	Stool fragments; probably lower rails
P19/21F	1958,0211.49 (138870)	Table border fragment; bevelled edge; 42.4 (l) cm
P19/21G	1958,0211.50 (138871)	Table border fragment; bevelled edge; 32.8 (l) cm
P19/21H	1958,0211.51 (138872)	Table border fragment; bevelled edge; 22.4 (l) cm
P19/46	1958,0211.70 (138891)	Fragmentary comb; end bars and most of the teeth are missing, but preserved to full length; 5.4 (l) cm
P19/47	1958,0211.71 (138892)	Fragmentary comb; most teeth and upper bar missing; one side bar and a few teeth preserved to full width; 6.0 (l) cm
P19/50	1958,0211.61 (138882)	Many very decayed and twisted wooden strips
P19/53	1958,0211.54 (138875)	Stool fragments (53F is the leg fragment that may have been lathe-turned)
P19/54	1958,0211.45 (138866)	Table fragments; part of table top, one leg and the top of another
P19/71	1958,0211.63 (138884)	Platter; rounded base; bar handles with hooks at ends; ridged rim; 28.8 (l) × 24.0 (w) cm
P19/71a	1958,0211.64 (138885)	Platter; fragmentary and decayed; 25.6 (l) × 16.8 (w) cm
P19/77	1958,0211.72 (138893)	Comb; complete length of one side bar; two teeth remaining; teeth on both sides of central bar
P19/78A	1958,0211.68 (138889)	Comb; complete length; some teeth missing; 4.4 cm (l)
P19/78B	1958,0211.69 (138890)	Comb; complete length; some teeth missing; 4.7 cm (l)
P19/88	1958,0211.73 (138894)	Nail (dowel); polygonal in section

FIGURE 6. A relatively intact three-legged table from Tomb P19

In total, 27 stools have been recorded for the entire Jericho funerary assemblage [17]. One type is a rectangular bench-like construction with sturdy legs and paw-like feet. The second type is square with narrow legs and plain feet. Both types had seats made from woven withies of willow, tamarisk and *Prunus* sp. (plum/cherry/almond, etc.) [10]. Ricketts speculated whether a lathe could have been used [18], and a furniture leg fragment from P19 (number 53F) made of carob wood shows regular incised lines that suggest lathe turning of some kind [10; Figure 5]. Other woods identified for stools were: *Acacia* sp., *Crataegus* sp., *Populus* sp., *Prunus* sp., *Quercus* sp., *Salix* sp. and *Tamarix* sp.

The subdivision of use between legs, tops and decorative inlays dictated by the properties of acacia, willow, poplar and tamarisk described above for the tables applies equally well to stools and benches. In addition to providing soft, light but resistant wood, willow withies would also have been useful for furniture seats and basketry. Carob, acacia, hawthorn and various *Prunus* species such as almond or plum are best suited for the manufacture of furniture legs, not only on account of the dimensions of the branches frequently found on these trees, but also because these woods have common properties of hardness, strength, density and durability.

Wooden veneers, inlays and strips were mostly attached to tables, but were also applied to stools, juglets and boxes. The main woods used were *Crataegus* sp., *Olea europaea*, *Populus* sp., *Ziziphus spina-christi* and *Cedrus libani*, with the last two used for dowels. The choice of Christ's thorn was ideal, as the wood is hard, very dense and durable. The selection of cedar of Lebanon wood for dowels was made when other parts of the piece used the same wood, notably for the furniture inlay strips. Because of the current condition of the P19 assemblage, it is not possible to specify in detail the extent of wood veneering, i.e. the application of thin slices or slips of wood onto a surface, compared to wood inlaying, in which thin segments of wood (often of a different colour) would be set into the surface layer of an item of furniture.

Funerary boxes were made from *Olea europaea*, *Prunus* sp., *Punica granatum* (pomegranate), *Ziziphus spina-christi* and *Cedrus libani* woods. The 'boxes' category has yielded particularly useful and new information about the use of different types of wood on a single object. Not only were several different types of wood used to make up a particular box, but high quality, imported timber (cedar of Lebanon) was also selected. Of note is the very fine technological use of *Cedrus libani* for the P19 boxes; the wood has been split down the radial plane to form thin sheets that could be bent or dowelled into place to create the boxes. One of these (No. 3), described as a wooden box in a basket from Tomb P19, was made from both *Cedrus libani* and *Ziziphus spina-christi* woods. Although another box from Tomb P19 (No. 17) was constructed mainly from thin sheets of *Cedrus libani*, it has a base of *Prunus* sp. wood. In many respects, this gives some clues to what must have been the elaborate use of different coloured and grained woods, veneers and bone inlays for the larger funerary items such as the tables.

The staffs (or sticks), combs and juglet from P19 were made from *Olea europaea* (olive) wood. Apart from its hard, strong and dense properties that make it an ideal carving material, olive wood also has an attractive mottled figuring. It is seldom possible to obtain long lengths of olive wood timber. Carved wooden vessels found in the Jericho tombs were illustrated and described by Kenyon as "platters", "bowls" or even "dishes" and many had four handles carved as ram's heads or small lugs [2]; the P19 platters were made of olive wood.

The descriptions and drawings published by Kenyon [2–4], and the suggested joinery techniques that were discussed and illustrated shortly after excavation [16, 18], provide tantalizing glimpses into the sophisticated joinery techniques, decorative carving, inlay work and veneering of this furniture. But in their current state, the heavy layer of discoloured paraffin wax obscures much of the evidence for such details. Before a further study of the technology of these objects could be undertaken, or indeed the furniture made suitable for display, a technique to remove the disfiguring surface layer of wax without damaging the wood was needed.

CONSERVATION ASSESSMENTS AND TREATMENTS

Condition survey

During preparation for the new Levant galleries in 1998, several organic objects from the excavations at Jericho were examined to assess their condition and conservation requirements. This gave an insight into the unique state of preservation of this assemblage, but also underlined the fragile nature of these wooden artefacts and, as a result, a full conservation survey of the material was then carried out [19]. Those fragments that had not been treated with consolidants appeared to be in good condition with a natural brown colour, while several combs seemed to have been treated with a dark, glossy, pigmented resin. The majority of the wooden objects had, however, been consolidated with a thick wax that was identified as paraffin wax [20]. This

had made the surface very dark, which gave the misleading impression that the object, or at least the surface, had been burnt. It seems that the application of paraffin wax was a standard treatment for fragile objects from excavations in the Middle East from the 1920s to 1950s, particularly wood and bone. Woolley describes the application of boiling wax during excavations at Ur, where it was "ladled generously" over an object and the surrounding soil [21]. This wax coating has now darkened, giving the Jericho wood an unnatural appearance, and this has made it difficult to examine the surface. As stated above, the penetration of the wax is variable; on the pieces examined during the condition survey it appeared to have penetrated to an average depth of 1–2 cm and, although somewhat unsightly, the smaller objects appeared to be stable. There were, however, some problems with the large structural pieces, which were solid on the outside where the wood was impregnated with wax, but had very soft, friable interiors where the wax had failed to penetrate. This difference had resulted in some breakages. The survey recommended that many of the objects required cleaning to remove dirt and old consolidants and that such treatment should address the dark surface appearance and reveal further evidence of surface detail [19], allowing a more comprehensive study of the carpentry techniques.

Previous conservation treatments

Five very fragile wooden combs, which were covered with a dark glossy consolidant that was found to be a resin containing a brown pigment, had already been conserved for display. Acetone (propanone) had been applied on cotton wool buds to remove much of the surface resin and take down some very obvious old joins. As the wood was heavily impregnated with the resin, it was judged that further removal would have resulted in damage to the wood. Nevertheless, after treatment, the wood became a much more natural colour and surface detail was visible. As no new consolidant was introduced, the combs remained very fragile and were supported on a specially constructed recessed mount for storage and display [22].

As the condition survey revealed, the wax had only impregnated the outer layers of the wood and consequently did not completely consolidate it. In 1972 two methods that might remove the wax en masse were investigated, so that subsequent reconsolidation with another material could be attempted [23]. The first technique involved soaking representative samples of wax-impregnated wood in baths of toluene (methylbenzene) at room temperature; the solvent was changed daily. The second method involved the use of the so-called Soxhlet extraction technique; in a cyclical process hot solvent vapour condenses into a freely draining, permeable vessel containing the sample and the soluble material is extracted and carried into the reservoir of solvent that is being heated to provide the solvent vapour. Neither technique was found to be particularly controllable and although the colour of the wood samples was lighter after treatment they were very fragile; it proved impossible to remove the paraffin wax completely without the object disintegrating and any remaining paraffin wax impeded attempts to reconsolidate with other materials [23].

Recent attempts at surface wax removal

Although the dark coating of discoloured wax does not appear to be causing damage to the underlying wood, its dark, glossy appearance disfigures the objects and, following the reassessment of the material, it was felt that to enable the carved and inlaid surfaces to be seen or examined more clearly, the wood needed to be cleaned to remove excess wax where possible. Three techniques were tested on small unprovenanced fragments of Jericho tomb wood. The aim was to remove sufficient wax from the surface so that the natural surface colour was revealed and any evidence of technology could be examined, while leaving the surface of the wood intact. While a non-contact method would clearly be preferable, two of the techniques required some physical contact with the surface of the sample.

The first method tested was the use of solvents to remove the wax. It was found that if industrial methylated spirit was applied to the surface, the layer of dirt and wax was softened and that this softened wax could be removed with a scalpel. The latter step was difficult, since the underlying layer was highly irregular and great care had to be taken not to remove the surface of the wood. The process was further complicated by the presence of pieces of loose wood and soil in the surface layer of wax, Figures 4 and 7.

A second approach was to use a hot air tool (a pneumatic power pen) to soften the wax, which was then absorbed while molten with tissue paper. A potentially beneficial side effect of this process was that excess molten wax flowed into areas of weakness such as cracks. Although this offers additional support to the wood, the method leaves a thin,

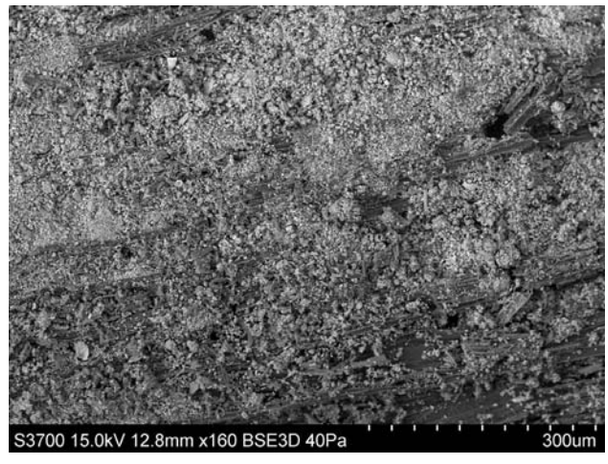

FIGURE 7. Backscattered electron image of a tangential longitudinal surface of a fragment from an artefact, showing loose pieces of wood, detritus and soil present in the surface wax layer. Image: Hitachi S-3700N VP-SEM

if reduced, layer of wax on the surface of the wood and dirt embedded in the wax will not be absorbed by the tissue paper and will remain on the surface of the object.

The third technique employed in these tests was laser ablation of the wax layer. Since 2005 the British Museum has been using a dual wavelength (532 and 1064 nm) Nd:YAG laser to treat dirt- and pollution-encrusted stone sculptures and has been evaluating its potential for use on a variety of other types of materials [24, 25]. While laser cleaning has been used successfully for many years as a method for the conservation of stone [26], its application to other substrates has yielded mixed results, although in the context of these tests on wood from Jericho it is worth noting that some success has been reported in the application of laser technology to the conservation of wood [27]. Research at the British Museum into the use of lasers has included trials in the conservation of organic materials and in the use of the laser in situations in which no other satisfactory cleaning method is currently available; these research strands meet in the case of the wood from Tomb P19.

The properties of lasers and the theoretical basis for laser cleaning are covered elsewhere [26], but for the method employed in these trials the laser beam is directed onto the surface of the object in short pulses through a pen-like handpiece within which a lens produces a diverging beam. The laser energy is absorbed close to the surface, causing rapid heating and expansion. If the expansion is sufficiently rapid, the resultant forces eject matter from the surface. The length of the pulse and resultant energy density (or fluence) are controlled so that ablation occurs before the heat gain can be transferred from the layer to be removed to the underlying substrate. The fluence, usually measured in Joules per square centimetre ($J.cm^{-2}$), must be high enough to remove surface deposits but low enough to ensure that the surface of the object is not damaged [28].

Experiments conducted on fragments of Jericho wood used both the 1064 and 532 nm lasers. The most promising results were achieved using the green laser (532 nm) set to an output energy of 20 mJ, with a ceramic ring inserted into the hand-piece to reduce the fluence by around 35% to *c.*1.33 $J.cm^{-2}$. The laser beam caused the wax layer to become opaque and to delaminate from the underlying wood. Smaller fragments of wax were directly ejected during laser exposure, while the larger detached fragments became loose so that they could be lifted away from the surface with forceps, Figure 8. An added advantage was that much of the excavation dirt and subsequent soiling had been incorporated into the wax layer and was removed with it, giving a wood surface that appeared clean and undamaged, Figure 8d. The surface was examined in more detail first using an optical microscope and then at higher magnification in a variable pressure scanning electron microscope (VP-SEM), Figure 9. Although preliminary, these results with laser cleaning show some promise, and further studies will be conducted, not least to investigate the longer-term effects of laser cleaning on wood.

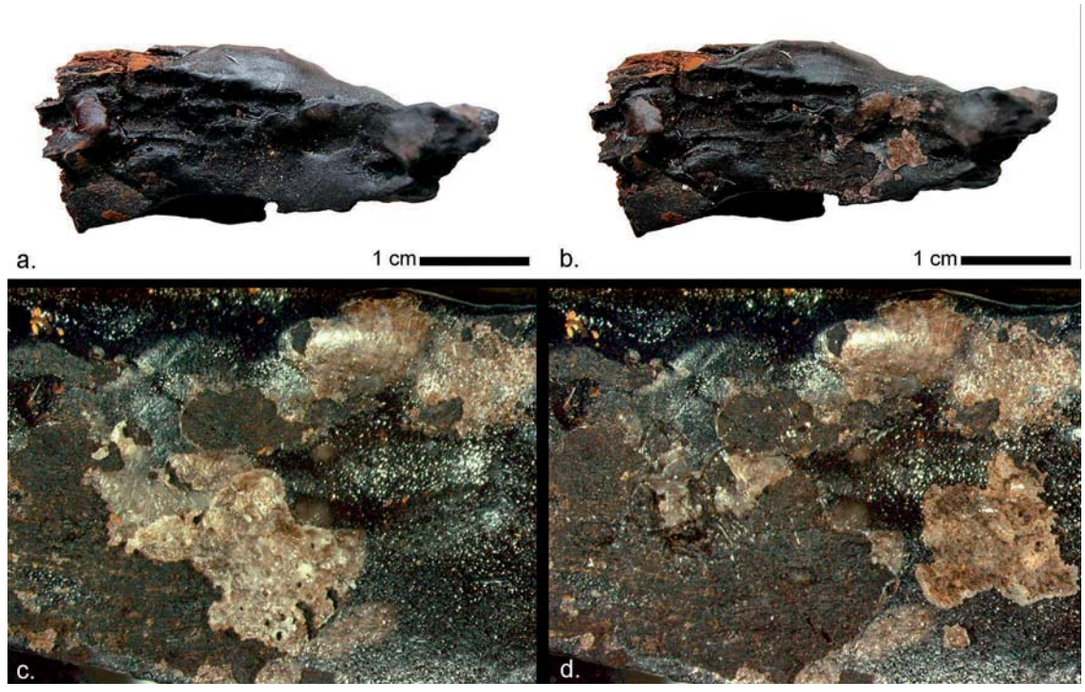

FIGURE 8. An unprovenanced sample of Jericho wood selected for laser treatment: (a) before treatment, showing the darkened wax layer on the surface; (b) after laser treatment of part of the fragment, showing a cleaned area near the centre and an opaque loose flake of wax to its right; (c) a detail at higher magnification showing the laser cleaned area to the lower left and an opaque wax flake at the centre; (d) the same detail with the wax flake turned over so that its underside, with embedded debris, is visible

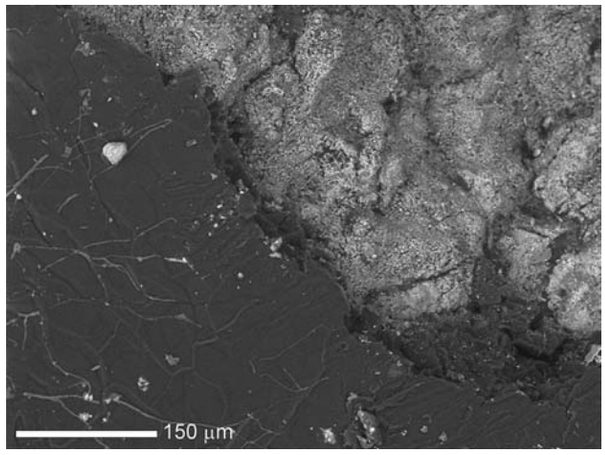

FIGURE 9. An unprovenanced sample of Jericho wood, showing thick wax deposits to the lower left and the area cleaned by the laser to the upper right. Image: Hitachi TM-1000 SEM

CONCLUSIONS

Kenyon's excavations of Tomb P19 at Jericho revealed an array of high quality wooden furniture and funerary artefacts that provide an accurate reflection of the esteem placed on all the individuals buried within the tomb. Although unusual conditions of desiccation preserved the tomb's organic materials, it is still proving difficult to gather evidence of the sophisticated carpentry techniques from the material as its present condition is adversely affected by the thick coating of paraffin wax that was applied during the excavations, masking surface detail and creating obstacles to wood identification. Recently introduced methods, such as examination in the VP-SEM, have improved the number of accurate wood identifications that are possible, increasing the number of different timbers characterized. Recent condition assessments and new approaches to removing the wax coating from Tomb P19 wooden artefacts and furniture, particularly the preliminary tests with the laser, have not only increased the possibility that new technological information may be retrieved, but have also offered methods by which the appearance of this important material may be significantly improved, allowing it to be displayed to the public to its best advantage.

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