THE SUGAR INDUSTRY IN THE SOUTHERN JORDAN VALLEY: AN INTERIM REPORT ON THE PILOT SEASON OF EXCAVATIONS, GEOPHYSICAL AND GEOLOGICAL SURVEYS AT ṬAWĀḤĪN AS-SUKKAR AND KHIRBAT ASH-SHAYKH ʻĪSĀ, IN GHAWR AṢ-ṢĀFĪ

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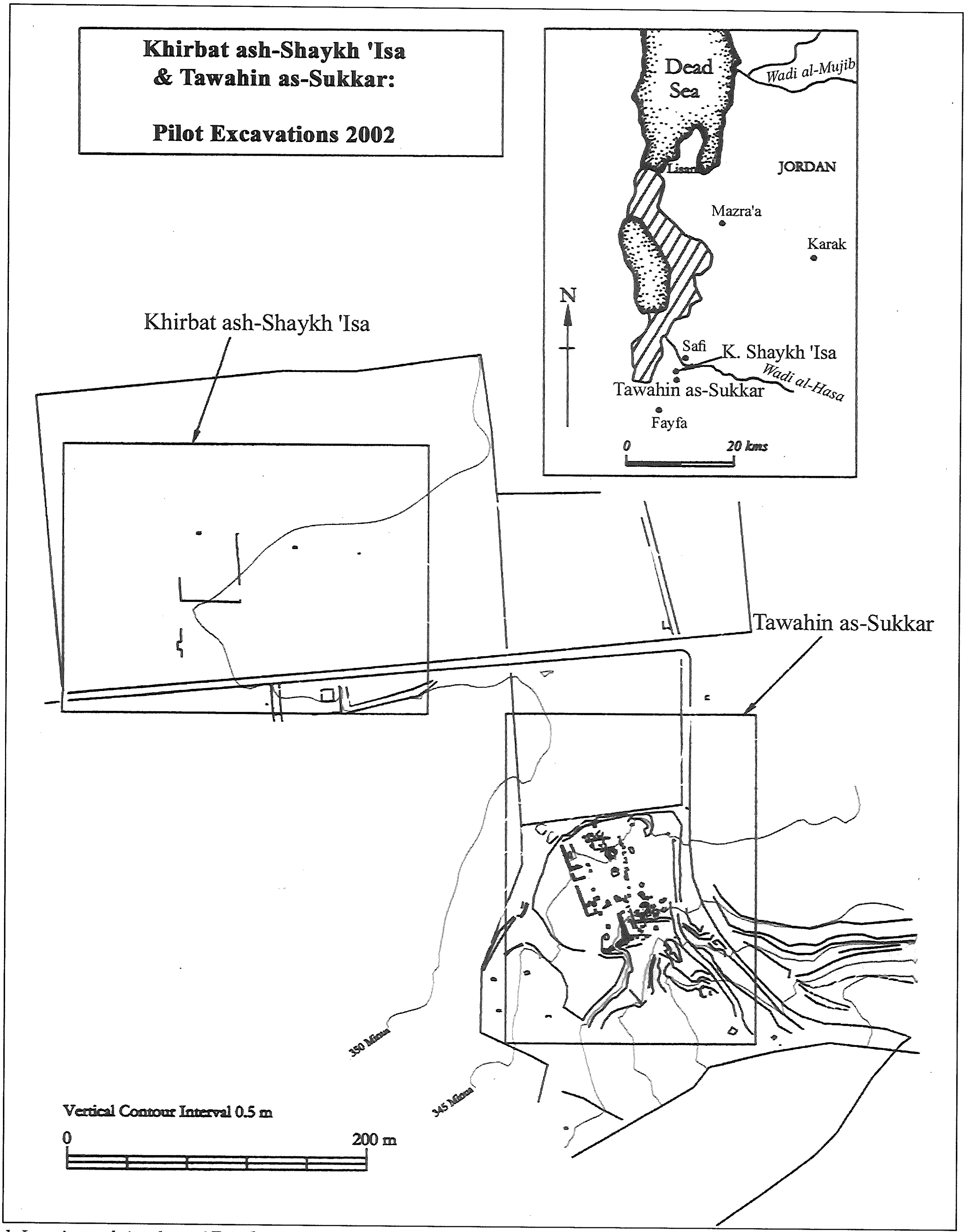
1.0 INTRODUCTION

1.1 Setting the Scene

In January 2002, a pilot season of excavations accompanied by a limited geological survey took place at and around the neighbouring sites of the Ṭawāḥīn as-Sukkar طواحين السكر (TES) and Khirbat ash-Shaykh ʻĪsā خربة الشيخ عيسى (KSI) in the Ghawr aṣ-Ṣāfī غـور الصـافي , southern Jordan (**Fig. 1**). The general aim of the pilot phase was to assess the level, quality and state of preservation of the material evidence at key areas within the sugar mill and the KSI, and to place the sugar industry in the context of the landscape that generated and sustained it. Prior to January 2002, two seasons of geophysical survey were carried out, one in April 1999, the results of which have already been published (Jones *et al.* 2000), and a second in April 2000, the results of which are presented here. A general assessment of the surface evidence had been carried out in the late 1990s (Politis 1998). A detailed account of the excavations has been submitted to the Department of Antiquities (James 2002).

Our current research into the organisation of the sugar industry in the Jordan Valley during the Ayyubid/Mamluk (12th-15th centuries) or earlier periods is focused firmly on two sites: TES, the industrial complex proper, with standing remains, one of a number operating in the Jordan Valley between the 12th and 15th centuries AD (Hamarneh 1977-8; Khouri 1988; Stern 1999) and KSI, a settlement site, originally a mound, but now levelled, known since the 1930s, and for which it has been stated that "there is little doubt that (it) ... was Byzantine-Early Islamic Zoar(a)/Zughar or Sughar" (MacDonald 2000: 57-58); this is the fortified 'city' depicted on the Mādabā floor mosaic map, surrounded by date palms and labelled in Greek, namely 'Valak and/or Zoora'. Given the proximity of the two sites (KSI lies 150m to the NW of TES) and the large collection of sugar industry-related pottery recovered at both, we are presently assuming they were linked to each other as an industrial complex with its associated settlement during one or more chronological periods. However, it is possible that at some point in the future, depending on the nature of the emerging evidence, the incentive for a full-scale excavation at KSI may be directed towards establishing whether it was indeed the site of the biblical Zoar, Byzantine Zoara or Islamic Zughar rather than its capacity either as a settlement for the workers at the *ṭawāḥīn* or a pottery manufacturing centre within a market town. Therefore 'the industrial complex with associated settlement' model is merely a working scenario, almost certainly to be refined or altered as the investigation progresses.

This research project has been driven by two motivating forces: on the one hand, the benefits of integrating scientific analysis into the examination of the building materials, artefacts and the products and waste of the industrial processes; and on the other, the realisation that an industrial complex is more than the sum of its parts, and in particular the parts referring to issues of technology. Therefore, parameters, both natural and human-made, contributing to the industry's development in the Jordan Valley are considered. These include soil suitability and water availability, the planting and irrigation of sugar cane crops, the management of the water-power needed for the milling of the harvest, the methods developed for the processing of the product(s), the ancillary industries (pottery, iron working) necessary for its smooth operation, the nature, extent and social stratification of the labour force required in the fields and within the mill, the location, nature and extent of the settlement supporting the industry both as a home for the workers, as well as a market for their product, the trade routes and the markets for which sugar was destined, to mention only a few. All these parameters are expected to be recovered to a greater or lesser extent from the archaeological record, deduced by the application of the combined methodologies of excavation, documentary research and scientific analysis and complemented by similar information derived from other sites. Archaeological evidence — even at this initial stage — points indisputably



1. *Location and site plans of Ṭawāḥīn as-Sukkar and Khirbat ash-Shaykh ʿĪsā, January 2002.*

to an industrial complex which would have required a substantial initial outlay of capital for its establishment; it would also have needed a 'large' workforce — slave or freeman — for its running, and have required a well-established trade network for its products. Regarding KSI, it is clear that the size and layout of the walls exposed so far, the complexity of its stratigraphy and the richness of the finds point to a substantial settlement with a long history of occupation. There is also evidence for pottery manufacture on site, but its relation to the main phases of occupation is at this stage unclear. Nevertheless, the elucidation of this relationship may form the starting point for future excavation.

This report presents the results of three weeks of excavation, one week of geological and two weeks of geophysical surveys, each section of the work being carried out by a specialist team. A brief introduction into the general principles of sugar manufacture is included while the discussion section focuses on a selection of the themes outlined above.

1.2 Sugar Production: some general principles

It is suggested that sugar may have been refined with the use of wood ashes in southern Iraq as early as the eighth century AD (Hamarneh 1977-8) before it became an important industry in the Near East between the 11th and 15th century in Egypt, the Syrian Coast, Palestine, the Jordan Valley and later moved westwards to Cyprus, Venice and beyond. In reference to the sugar mills in the Jordan Valley, a substantial number have been recorded although with varying degrees of archaeological evidence. A total of thirty-two sites are thought to belong to the Ayyubid/Mamluk periods (Hamarneh 1977-8; Abu Dalu 1995; Khouri 1988; Stern 1999).

It is almost certain that the sugar cane was cultivated well before that period in Persia and India and it is important to note that knowledge and cultivation of sugar cane does not necessarily imply knowledge of sugar manufacture. This is because of the versatility of this tropical grass which can be sucked raw or it can be cooked; the juice can be drunk or boiled to produce a syrup out of which red, brown or yellow sugar crystals can be extracted; and finally refined to produce sugar crystals.

Sugar cane, *saccharum officinarum* often reported as the "Middle-Eastern variety" is only one of the many cultivars presently available. It requires abundant water and sunlight, making the Jordan Valley and areas near the southern Jordan wadis particularly suitable for crop plantation. The chemical formula of sugar is essentially sucrose ($C_{12}H_{22}O_{11}$), a saccharide like glucose and fructose, which belong to the family of carbohydrates. The plant manufactures sucrose from carbon dioxide in the atmosphere and water from its roots and stores it as energy. The proportions of the constituent parts of sugar cane vary considerably, not only according to climate and soil, but also upon other parameters such as ripeness of the cane at the time of harvest. But for purposes of reference they can be summarised as follows (after Jones and Scard 1909: 11):

Water	69-75%
Sucrose	8-16%
Un-crystallisable sugar	trace to 2%
Fibre	8-16%
Ash	0.3-0.8%
Organic matter other than sugar	0.5-1%
Containing nitrogen	0.005-~0.02%

From the above it is clear that about 85-90% is waste material only, an average of 10% being sugar. Although most of the plant constituents are water soluble, it is expected that some like fibre and other inorganic matter may be retrievable in the archaeological record (see Trench VI, *The Mill Room*).

Overall, the same general processes applied in the past are still followed today in cane sugar manufacture. These include: a) crushing the sugar cane to extract the juice, a process originally carried out in two steps, pulp formation and subsequent pressing of the pulp to extract the juice; b) boiling of the juice to evaporate the water and produce syrup; c) syrup clarification to remove both colour and non-sucrose substances using different types of 'reagents'; d) sugar crystallisation from the melt and draining of excess liquor originally by gravity — with the use of the conically shaped sugar moulds inserted and draining within molasses jars, used in the Near East and Europe — and later, in the 19th century, centrifugal force where the contents were spun.

There is ample documentary evidence both in European and Arab sources during the period between the 11th and the 15th centuries regarding the incentive by Ayyubid/Mamluk rulers to promote sugar crop plantation in the Jordan Valley by undertaking major irrigation schemes (Hamarneh 1977-8; Khouri 1988; Stern 1999). However, it seems clear that an understanding of how to carry out and control steps (b) and (c) must have been in place prior to that period before sugar manufacture could expand on an industrial scale. With an average of 10% sucrose in the sugar cane, the process needs to be carefully monitored both in the type of clarifiers used and the temperature at which the juice is to boil, as 19th century industrial reports amply testify (Bremner 1869). Overheating destroys the crystallising properties of sugar and converts it to a sticky mass or treacle. In reference to Palestine, Stern (1999) rightly suggests that it was development/invention of mineral clarifiers that were added to the syrup, facilitating the production of pure crystals of sucrose, which spearheaded the transition to industrial level. These clarifiers included wood ashes, lime, alum and even certain herbs (Watson 1983; Clow and Clow 1952: 519; Peled 1999). Present-day clarifier is lime, CaO, which apart from removing the non-sugar components, dehydrates the melt and neutralises the acidity of the juice. Regenerative charcoal, which returns to its original state when heated, from animal bone is used to remove the colour resulting in white crystals of sugar. The level of technological know-how practiced at the Ṭawāḥīn will be assessed with the scientific analysis of the recovered industrial waste (see Trench II).

1.3 Site Location and Topography

The two sites of Khirbat ash-Shaykh ʻĪsā and Ṭawāḥīn as-Sukkar are located approximately 150m apart, and about 0.5km from the present location of the village of aṣ-Ṣāfī to the southeast of the Dead Sea (**Fig. 1**). They are situated near the mouth of Wādī al-Ḥasā (وادي الحسا), a major channel bringing water and sediment to the southeast corner of the Dead Sea from the high plateau area that lies to the east (see **Figs. 2, 3**). A large (ca. 20km^2) alluvial fan has developed near the mouth of the wadi raising the ground level by a few metres above that of the saline flats, which extends southwards in the Dead Sea basin. The gently undulating topography of the alluvial fan with its agricultural development realised by irrigation, is in stark contrast to the barren saline flats to the west and north and to the high ground lying immediately to the east. Although the pebbly sands and silts of the alluvial fan provide good drainage and evidently a fertile soil, it is irrigation that makes it presently agriculturally viable for cash crops like bananas and tomatoes.

TES is situated on a convenient steep slope at a topographic 'corner' where the general N-S trend of the eastern side of the Dead Sea Basin meets the E-W trend of the southern mouth of the Wādī al-Ḥasā (**Fig. 2**). TES was built on compact pebbly to bouldery alluvial sediments that drape over the sedimentary rocks outcropping along the eastern side of the Dead Sea Rift valley.

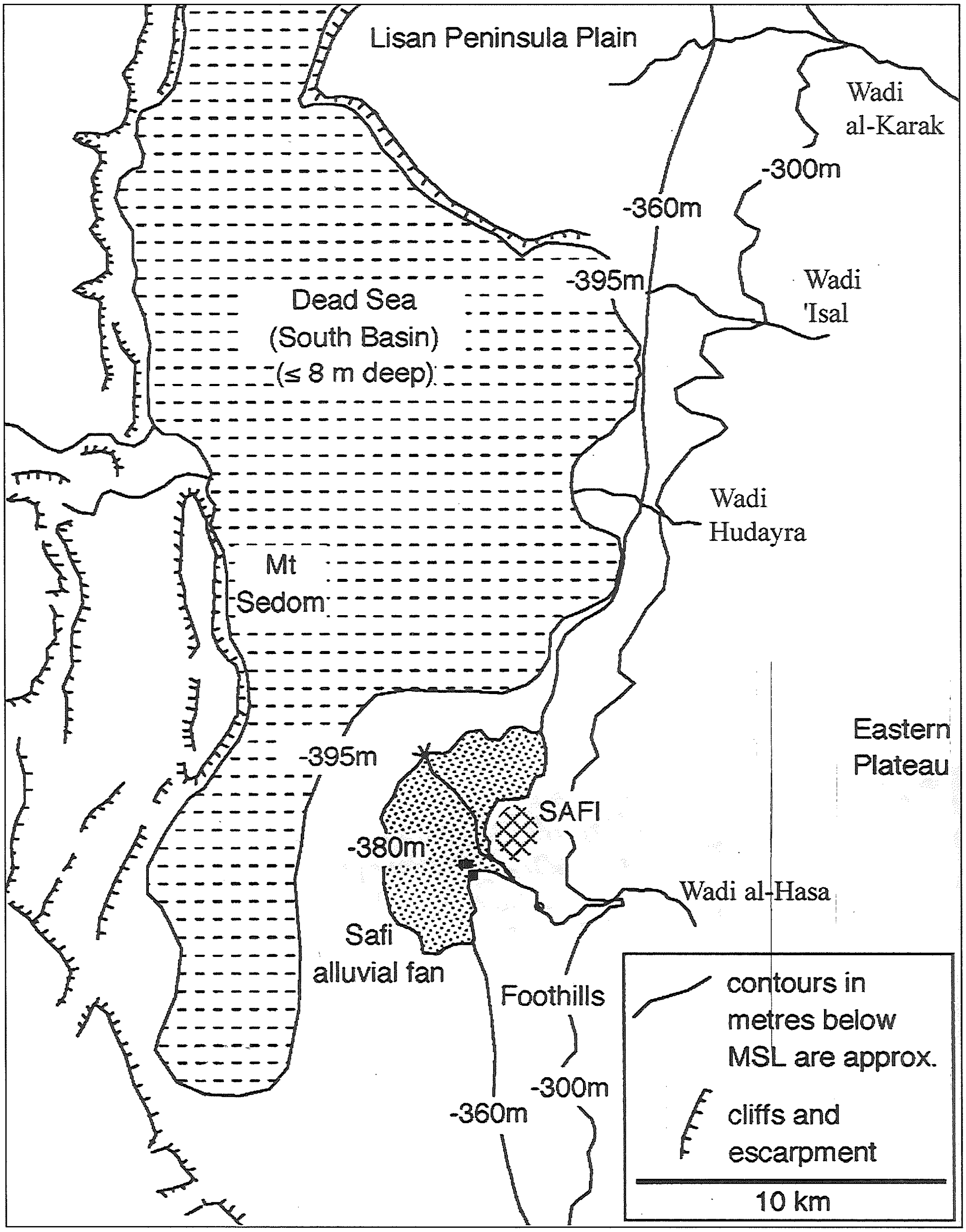
There must have been ample space for plantations of the sugar-crop, presumably cane sugar, all around the KSI including the fields between the KSI and the TES. TES lies to the SE of KSI and to the NW of an extensive Early Bronze Age cemetery (Waheeb 1995; Papadopoulos *et al.* 2001) now much robbed. The upstanding remains at the site consist of stone walls, a set of two parallel aqueducts and their associated water chutes at varying levels of preservation, subsurface water channels as well as adobe brick walls belonging to a later fort. These remains extend over an area of approximately 100m N-S and 50m E-W and are partly hidden beneath varying depths of wind-blown sand. Damage to these remains has been caused by natural erosion and by several deep robber trenches. The site, open until recently to goat and pedestrian traffic, was enclosed in 2000 by a wire fence on three sides and an adobe brick wall to the east (**Fig. 4**), which has subsequently been broken through. A preliminary phase of wall consolidation had started then and continued after the excavations of January 2002.

KSI appears to be situated on a broad raised area on the fertile alluvial fan, but it is impossible to say how much of the topography is natural and how much is human-made. The site is a rectangular area of uncultivated ground measuring about 140m (N-S) by 200m (E-W) and is approximately 340m below sea level. The topographic survey revealed that the southern part of the site forms a slight mound that straddles the road marking its southern boundary. It is surrounded by cultivated fields and is seasonally inhabited by Bedouins.

2.0 PREVIOUS ARCHAEOLOGICAL WORK

2.1 Surveys

There is a long history of archaeological survey in the region of Ghawr aṣ-Ṣāfī, both TES and KSI being included in those surveys (Albright 1924; Frank 1936; Glueck 1935; Rast and Schaub 1974; King *et al.* 1987; MacDonald *et al.* 1992). Ṭawāḥīn as-Sukkar was surveyed and planned by Frank in 1934. There has been limited excavation at KSI (Albright 1924: 4; Kyle and Albright 1924: 283-291; Waheeb 1995: 555). The 1924 excavation by Albright consisted of a single sounding, presumably a small trench up to 3m deep. In 1995 Waheeb (1995: 555) undertook a limited excavation (20 x 4m), which exposed a length of walling in the SW corner of the site (Wall 1 in **Fig. 5b**). Modern surveys have involved surface collection of sherds and artefacts (MacDonald *et al.* 1992: 104, 249; King *et al.* 1987: 448, 456; Politis 1998). The majority of the artefacts recovered from KSI were dated to the Byzantine period (4th-7th century AD) or later. Bulldozing of the site and the installation of underground irrigation channels in the early 1980's revealed "columns, capitals and even mosaic floors" at a depth of "several metres" below the current road that could also belong to the Byzantine period (Politis 1998). There is as yet no definite archaeological support for KSI being the



2. Sketch map of the aṣ-Ṣāfī alluvial fan and its physiographic setting at the mouth of Wādī al-Ḥasā on the eastern scarp of the Dead Sea graben. Topographic features based on fig. 8 of Neev and Emery (1967) and a satellite map (Hall 2000) of the southern Dead Sea area. The topographic boundaries and their contour values in the E/SE of the map are approximate. The shore of the Dead Sea has been receding northwards due to salt extraction and the entire southern basin of the Dead Sea is now subdivided into large salt pans. TES and KSI are indicated by black rectangles.

biblical Zoar, but this may be due to the lack — so far — of systematic excavations. Its proximity to the archaeological remains of the 6th-7th century Monastery of St. Lot (Politis 1999), also depicted in the Mādabā floor map, cannot be underestimated.

2.2 The Geophysical Surveys

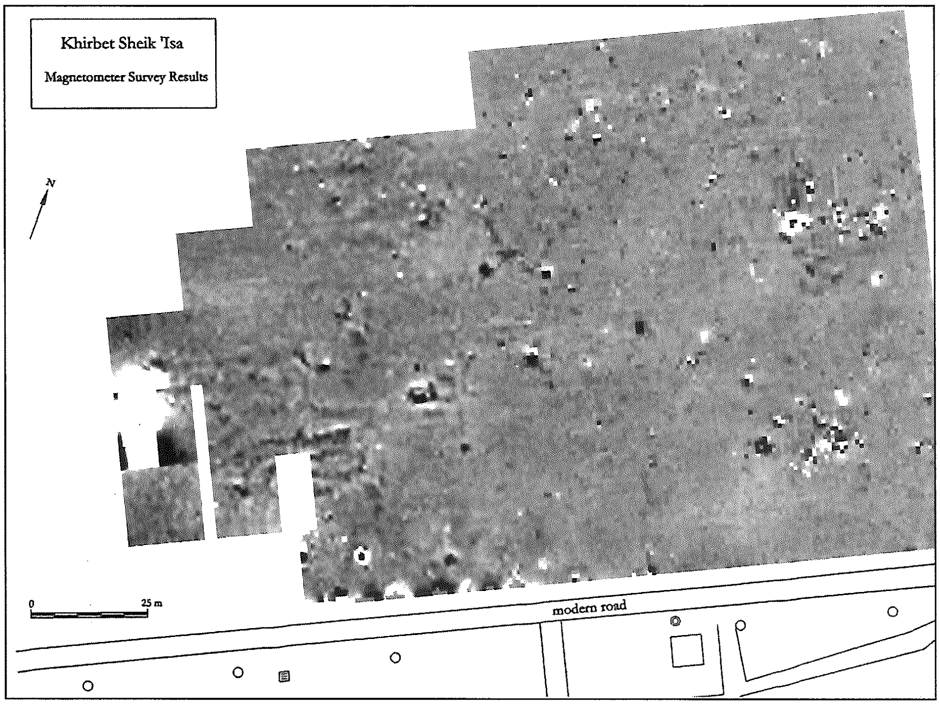
An exploratory geophysical survey with a FM36 fluxgate gradiometer at the western end of the mound at KSI, close to the previously excavat-

3. *Topographic map of area around the sugar mill (TES) and the settlement site (KSI). The northern line shows the most likely route for a canal to take water from the wadi in the east to the aqueduct of the sugar mill. The southern route shows an alternative possibility but only if they had a reservoir to control it.*

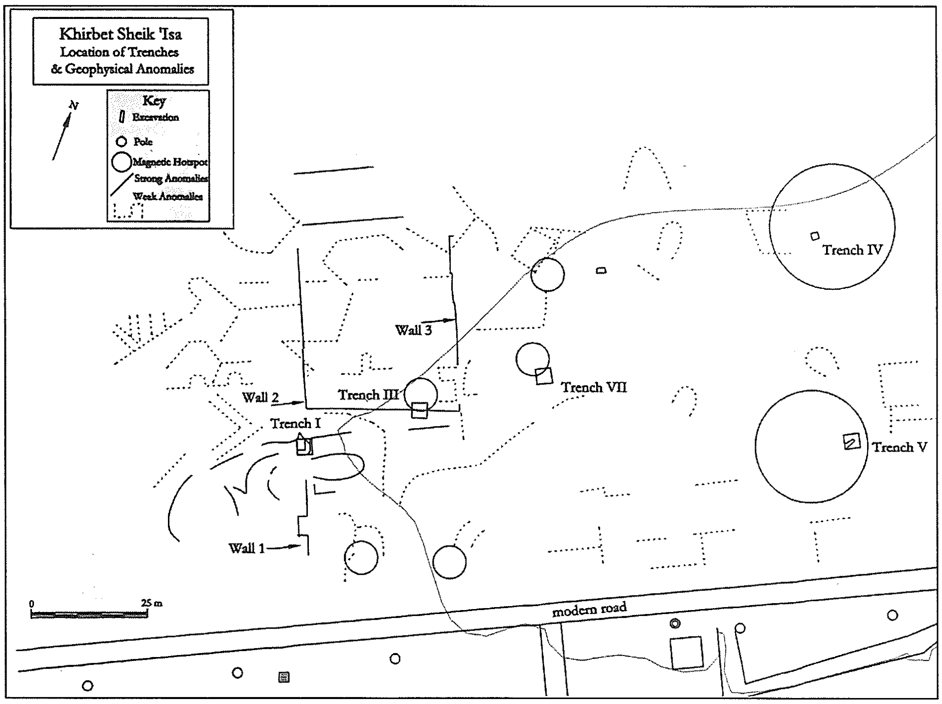
4. *View of TES prior to fencing (May 1997); view from southeast, with robber trench in the foreground.*

ed area, was carried out in 1999 and reported by Jones *et al.* (2000). Since the results were encouraging if not straightforward in interpretation, the survey was considerably extended in April 2000 by R.E. Jones and J. Hamer† using a Geoscan FM36 fluxgate gradiometer to encompass most of the mound, ca. 2.7ha in total. The purpose of the survey was, as before, to locate buried building structures and, in view of the surface scatter of industrial waste, possible furnaces or kilns; the depth of penetration of the magnetometer was not greater than 1m. It was the results of the 2000 survey that guided the selection of targets for excavation in January 2002 (see Trenches I, III, IV, V and VII in the following sections), although the detail within these results did not emerge until after the excavations. They are presented here as a guide to future work on the site.

Superficially, the site appeared well suited to survey: flat, smooth terrain, sloping gently to the north to an area where there had been some recent shallow tilling. As mentioned in the previous section, at the western end of the site was visible a stretch of wall (Wall 1 in **Fig. 5b**) exposed by Waheeb (1995). The transient nature of Bedouin encampments affected the terrain only superficially. However, the presence of modern metallic rubbish on or close to the surface proved to be problematic in interpreting the magnetic data; furthermore, a large partially-buried iron drum at the western extremity of the surveyed area prevented measurements being taken in sectors of two potentially very informative grids. As in 1999, readings were taken at 1m intervals along traverses 1m apart in 20 x 20m squares, and the data were processed with Geoscan's Geoplot 3.0. The survey baseline was the line of a former metal fence running parallel to, and ca. 2m from the modern road, and its relation to the topographic plan given in Jones *et al.* (2000: fig. 3) was determined manually with tapes and compass; as a result, there is a probable error of up to +/- 2m in transposing the geophysical sur-



5a. Results of the magnetometer survey at KSI in the form of a grey-scale plot (Geoplot 3: shade plot (clip), black and white tones are +17 nT and -17 nT respectively).



5b. Interpretation plan showing the locations of strong (continuous line) and weak (dotted line) magnetic anomalies. The medium and large-sized circles represent magnetic hotspots; poles for power lines are indicated by small circles to the south of the modern road. Walls 1, 2 and 3, which are visible close to the ground surface, and Trenches I, III, V and VII are shown.

vey area onto the topographic plan.

Fig. 5a shows the composite graphic from the magnetometer survey in the form of a grey-scale plot with high positive and negative values in black and white respectively superimposed onto the site plan. There is a remarkably rich mosaic of anomalies, most of which are of low intensity, distributed across the site. These anomalies are more abundant in the western half of the survey area where the soil is often dark and there are slight surface undulations; furthermore, this sector forms a slight mound with respect to the eastern sector which is flatter and whose surface consists for the most part of compacted earth. The major task of securely identifying all the anomalies in **Fig. 5a** is on-going, but for present purposes the emphasis is on drawing attention to a majority of them, and these can be conveniently, if subjectively, classified into major (full line) and minor (dotted line) in **Fig. 5b**.

Starting with the *western* half of the survey area, the main point to make is that the anomalies, all of them lying up to a depth of 1m, belong to at least three groups on the basis of their shape and orientation:

(a) Those that are essentially on the same orientation as the excavated sector of wall (Wall 1 in **Fig. 5b**). They are best represented by the substantial rectangular sequence of walling composed of Walls 2 and 3 that are visible close to the surface. Other walls of different length but on the same orientation are observed to the north and west. None of the anomalies in this group is strong in intensity, suggesting poor magnetic contrast between the sandstone masonry and the sandy soil.

(b) Those whose orientation is closer to east-west and which are likely to be walls varying in length up to 10m. In a few places they seem to overlie those of (a). Like those in (a), the anomalies are weak.

(c) The remainder which include those due east of Trench I that were first discovered in the 1999 survey (Jones *et al.* 2000: fig. 6c), and the bipolar ones, such as that at Trench III, which should be thermoremanent representing furnace-type structures. The very large bipolar anomaly at the western extremity of the survey area is, as explained above, due to a modern iron drum. Note that the haloes in **Fig. 5a** along the southern edge of the survey area by the main road are associated with the remains of the (modern) metal fence.

One preliminary interpretation of (a) and (b) is that they represent two grid plans of differing orientation superimposed one upon the other but belonging to different phases of the settlement. The curving nature of some of the stronger anomalies in **Fig. 5a** is puzzling, and the number of bastion-like features is intriguing since they correspond in shape if not in scale to those already excavated.

The *eastern* sector is no less interesting. Its most notable aspect is the host of hotspots of differing size and intensity, some of them connected by weak positive anomalies. Given the greater concentration of surface scatter of sherds, 'furnace' linings in this area of the site in comparison with the western sector, it is tempting to interpret the large hotspots at the eastern end (Trenches IV and V) as a series of ovens/furnaces/kilns and therefore to consider this sector, if simplistically, as an industrial quarter, notwithstanding the difficulty that remains in excluding the likelihood that some of the hotspots are due to modern metal or indeed modern bread ovens (*ṭawābīn*). Of the latter, there was plenty archaeological evidence (Trench V, James 2002). Attempts to relate the distribution of surface finds with the main anomalies proved unrewarding owing to its distortion introduced by modern presence at the site. At the southern and south-eastern sides of this sector are very faint anomalies, probably representing fragments of wall whose orientation is akin to (a) above. They seem to form a complex of related buildings. The remaining magnetic anomalies are less coherent and must for the present be regarded as miscellaneous.

2.3 The Geophysical Surveys: future work

Given the wealth of potential detail in **Fig. 5a**, there is a case for re-surveying particular areas of the site with the same instrument but at a smaller sampling distance, that is 0.5m rather than 1m. Furthermore, magnetometer survey should be continued to the north and west of the presently surveyed area in order to determine the limits of the site in the form of a wall or otherwise; the large oil drum whose presence has seriously distorted the western extremity of the survey area should be removed. Turning to the detection of more deeply buried levels, there are two options: either resistivity survey at 2m or greater electrode spacing, or ground-penetrating radar (GPR). The former would only be feasible in the season of maximum potential rainfall and even then would be slow, arduous work owing to the sandy soil conditions. The alternative, GPR, is attractive because it could combine the necessary depth of penetration with relatively rapid speed of survey, and using the time slice method could give 'images' at different depths [as for instance carried out recently at Petra by Conyers *et al.* (2002)]; on the debit side would be the difficulty of interpretation in areas of complex stratigraphy. GPR would also be valuable in identifying, in tandem with the magnetometer, the limits of the site. Wherever possible, geophysical survey should be combined with trial trenching.

3.0 EXCAVATIONS

3.1 Methodology

The excavations took place between January 12th and the 30th, 2002. For reasons of safety the areas of the underground channels at TES were not examined, and so only the chute base and waste heap were investigated (Trenches VI and II respectively). The emphasis was on revealing the building remains associated with milling (Trench VI) and on the recovery and characterisation of waste heap materials (Trench II); subsequent seasons will target other stages of the industrial process. At KSI five locations were selected based on the interpretation of the geophysical map available at the time. These included Trenches I, III, IV, V and VII, whose distribution (**Fig. 5b**) reflects what was thought at the time to be the civic buildings area of the site (Trenches I and III), the industrial quarters (Trench IV and V) and the area of the kiln and pottery wasters (Trench VII).

The trenches were laid out and each layer (context) was carefully excavated by hand with small picks and trowels. All the material removed from the trenches was sieved through a 5 x 5mm mesh and all finds were kept (James 2002). Only significant artefacts were recorded as registered objects, the remaining finds being recorded by context. A topographic survey was carried out using a Pentax model PCS2S total station to allow the locations of the excavation trenches, robber trenches and city walls to be placed on the overall site plan.

In the following sections the numbers in brackets refer to the context numbers assigned to the deposit in the field. Assigning of features to archaeological periods is provisional at this stage, until the pottery has been analysed and radiocarbon dates returned.

3.2 The Excavations at TES

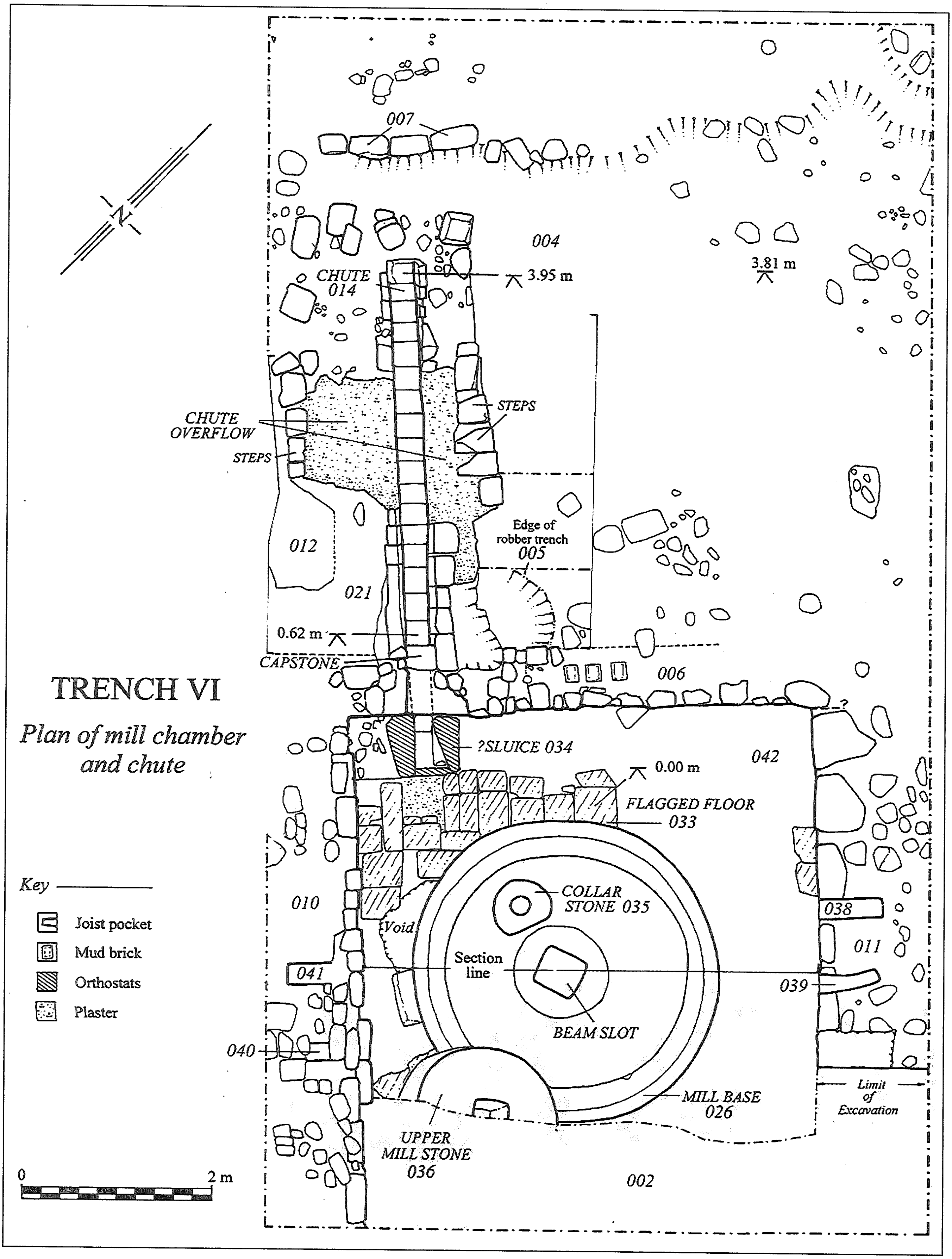
3.2.1 Trench VI

Trench VI roughly straddled the area to the NW of the space between the two aqueducts. The ground surface here sloped down steeply towards the NW. The trench measured 7 x 13m and was excavated to a maximum depth of 3.6m over a period of 17 days. Once the loose material was removed from the trench it became clear that its lower, NW, part consisted of deep, in-filled deposits enclosed by three stonewalls. These deposits were excavated down to the floor of the mill room (see **Fig. 7**). The higher, SE, part of the trench consisted of deposits associated with the construction and use of the mill, and excavation was concentrated in the NE half of the trench in the vicinity of the water chute (**Figs. 6, 7**).

The Mill Room **(Figs. 7, 8, 9, 10, 11)**

A mill base stone (026) was found to be lying *in situ* sitting on a partly flagged floor (033), within

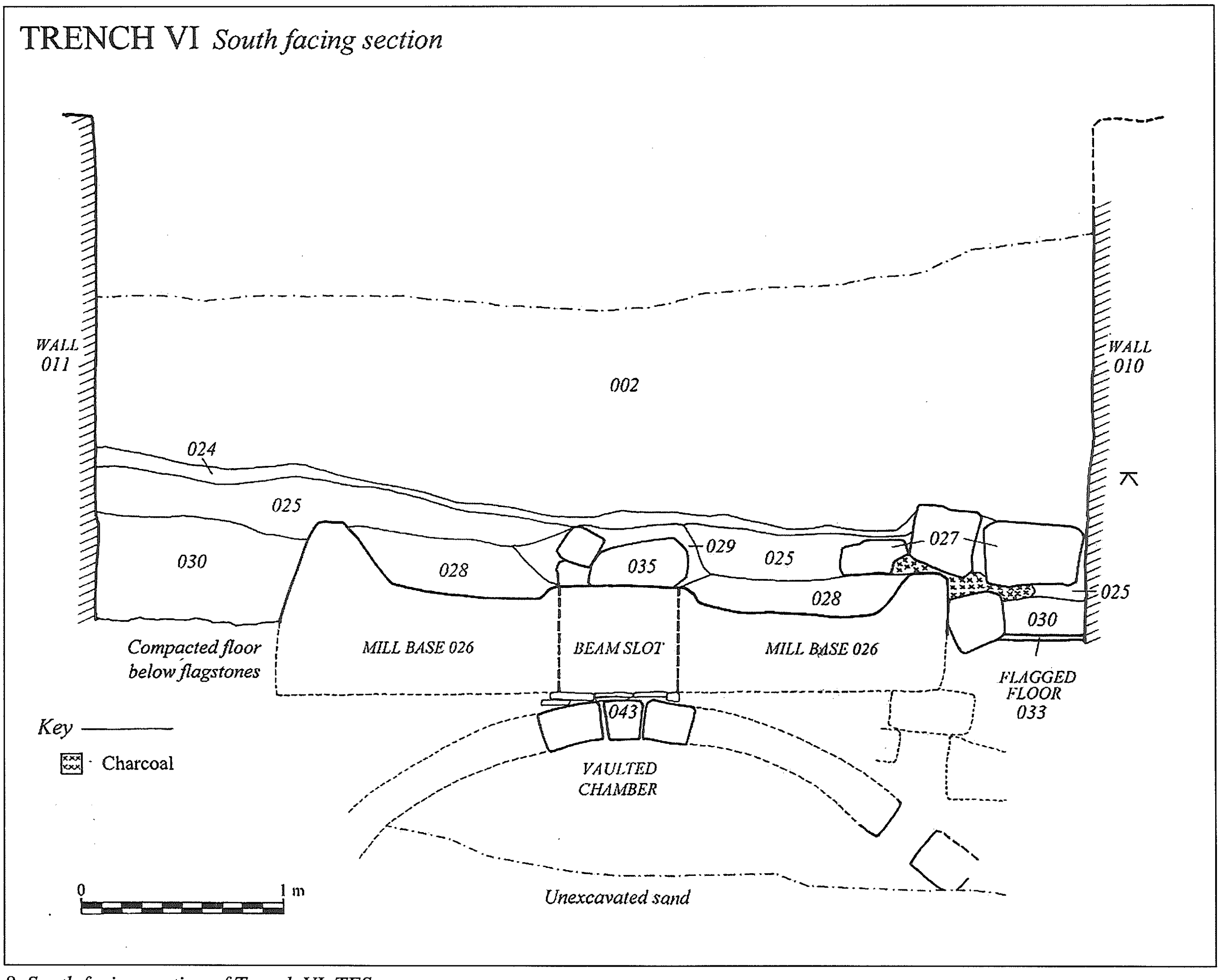
6. TES Trench VI. View from the northwest; the eastern and western aqueduct with the western wall of the room with the millstones.



7. Plan of the mill room and chute in Trench VI, TES.

the mill room (**Fig. 7**). The infill from the mill base was sampled but there was no obvious evidence for large fragments of botanical (charred or other) remains. The upper mill stone (036) lay on its side, resting on the edge of the mill base. The mill room had three walls, the back wall (006), E wall (010), W wall (011) and a floor (033 and 042). The NW end of the upstanding water chute (C3) had been truncated, but excavation revealed that, after a gap of ca. 2.5m, the stone-built chute (014) continued further on in the same direction, dropping down steeply to meet the back wall of the mill room (006). The chute continued through the wall, but the area where it entered the mill room was below the level of the floor (033). The mill base was supported by the vaulted ceiling (043) (**Fig. 8**) of a lower room into which the water chute would have entered. The lower room was full of sand and no workings within this wheel chamber were visible.

The mill base (026) was made from a single piece of limestone and measured 3.3m in diameter and the crushing base was 0.5m thick. There was a central square hole ca. 0.5m wide around which was a circular raised section that had several small holes, some with evidence of metal still within them. One half of a broken, 'donut-shaped' stone was found immediately above the square hole, and the other half had fallen through the hole in the mill base. This was retrieved so that the two pieces could be laid together. The 'donut-shaped' stone was interpreted as a collar stone that was slightly flattened on one side, and could have been attached to the mill base with metal. The flat crushing area of the mill base was 0.7m wide and the sides sloped up 0.2m forming a rim. There was a circular hole through the rim about 0.12m in diameter in the W side, which would have allowed the sugar pulp/syrup to drain out for collection. The mill base was tilted slightly towards the N where the upper millstone sat. The upper millstone (036) was



8. *South facing section of Trench VI, TES.*

9. Trench VI, TES, mill base (026), upper mill stone (036), collar stone (035), and the stone feature (034) in the top right corner.

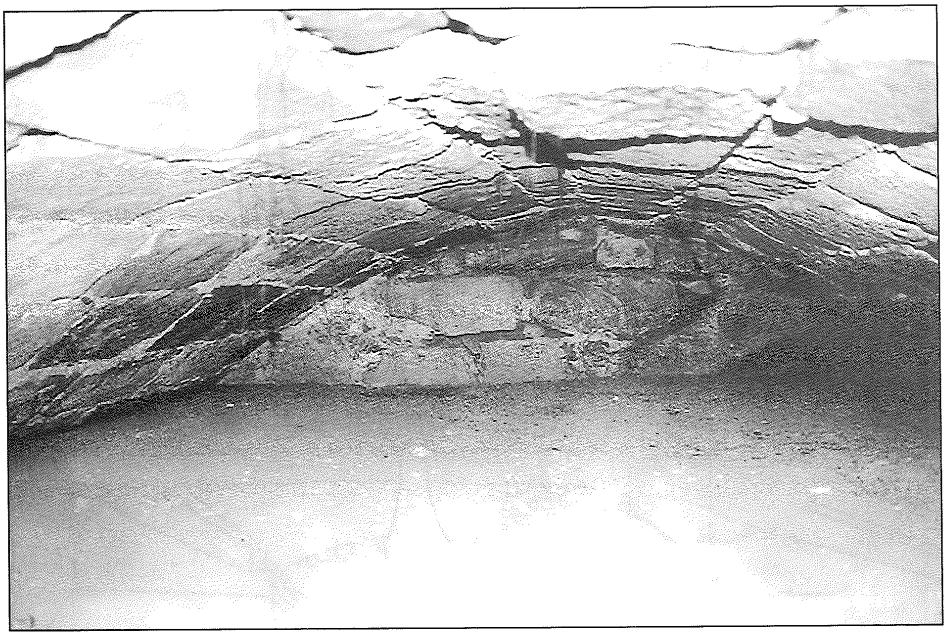
10. Trench VI, TES,. western wall of the room with upper and lower millstones.

not revealed fully during the excavation. It measured 1.4m in diameter and was 0.4m thick. It also had a central square hole 0.5m wide.

The mill base was sunk into a partly stone flagged floor (033) that had partly collapsed in the area immediately over the water chute. These stones were seen in the E side of the room, and the rest of the floor was a compacted brown silt (042).

The Mill Room had three plastered walls constructed of large ashlar stone blocks. The walls survived to about 3.2m high and the room was 4.8m wide. Both sidewalls (010 and 011) abutted the back wall (006), but this was thought to be a construction technique rather than evidence of a later phase. Wall (011) was 4.0m long and was butt ended. Wall (010) continued beyond the end of the trench and was therefore at least 5.5m long. No wall was seen on the fourth side at this level. Patches of plaster were noted on the inside walls, some of which carried small fragments of charcoal, potentially providing dates for plaster manufacture and indirectly the building *per se*.

In the eastern corner of the upper room there was a stone feature (034) sitting on the flagstone floor directly over the water chute. It was 1.2m long, 0.7m wide and 0.65m high. Two upright stones, with a gap between them of 0.2m, sat directly over the open chute and solid masonry filled the corner. This may be a secondary feature inserted into the corner of the room. To the NW of this feature there was a square-shaped gap in the stone floor that had been filled with compact plaster, which may have been the primary aperture, providing access to the water chute below. The reason why this aperture was blocked is uncertain at this stage. These features may have acted as some kind of sluice controlling the flow of the water (Mario Rizos pers. comm.) or to provide access for cleaning debris from the chute.



11. Trench VI, TES. The vaulted room below, with arched passage in the northern wall (044), right hand corner.

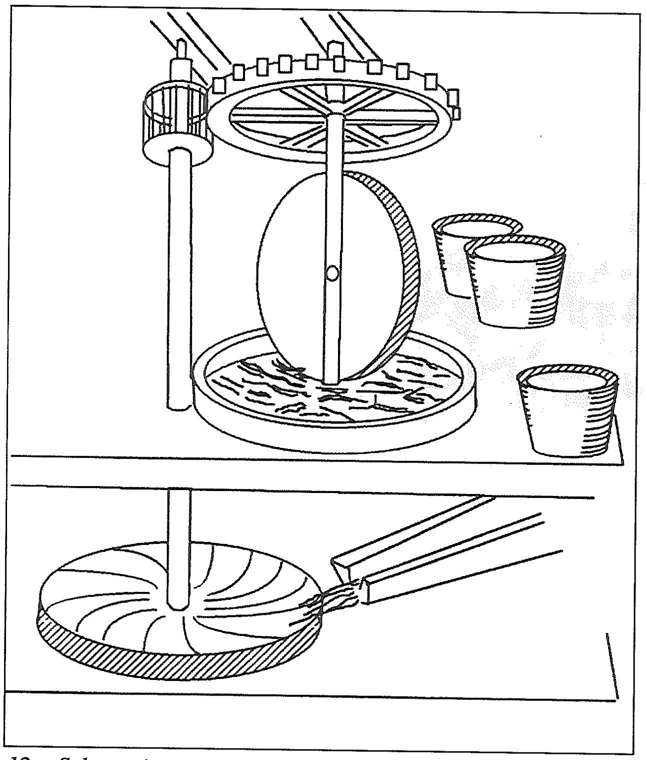
There are four probable beam slots within the sidewalls (038 and 039 in wall 011 and 040 and 041 in wall 010). These slots were 0.8 and 1.0m apart respectively and were about 2.8m above the flagged floor. They were in-filled with plaster that left cylindrical-shaped hollows extending back into the walls between 0.6m and 0.9m. At the back these were blocked by stone and plaster and so could not have been a water chute. The slots were not the same distance from the back wall 006 on either side of the room. Yet when a line was drawn from (041) to (039) and from (040) to (038) they passed directly over the centre of the beam slot. These features were therefore interpreted as beam slots that could have been used to support a bracing structure for the vertical mill-driving beam similar to the ones shown in **Figs. 12a and 12b** adapted from von Wartburg (2001: figs. 14 and 15) and deriving from two separate accounts dating to the late 15th and 16th centuries respectively. The hole in the flagged floor described as 'void' and originally thought to have been the result of robber activity, may actually have served as a passage for a beam rising from the Lower Room. However, until this is excavated (see below) this has to remain a conjecture. In brief, what **Figs. 12a and 12b** represent is two different positions for the gearing mechanism, one above the mill base and the other below the mill base. Gearing mechanisms are necessary if the revolutions/min. of the vertical stone are to be kept at a steady rate. Edge runner mills operating with the above gearing mechanism seem to have been the norm in sugar mills (von Wartburg 2001).

There was no evidence for water being supplied into the upper room, water being channelled under the flagged floor. However, this possibility cannot be ruled out because the section of the wall (006) had been destroyed by a robber's trench.

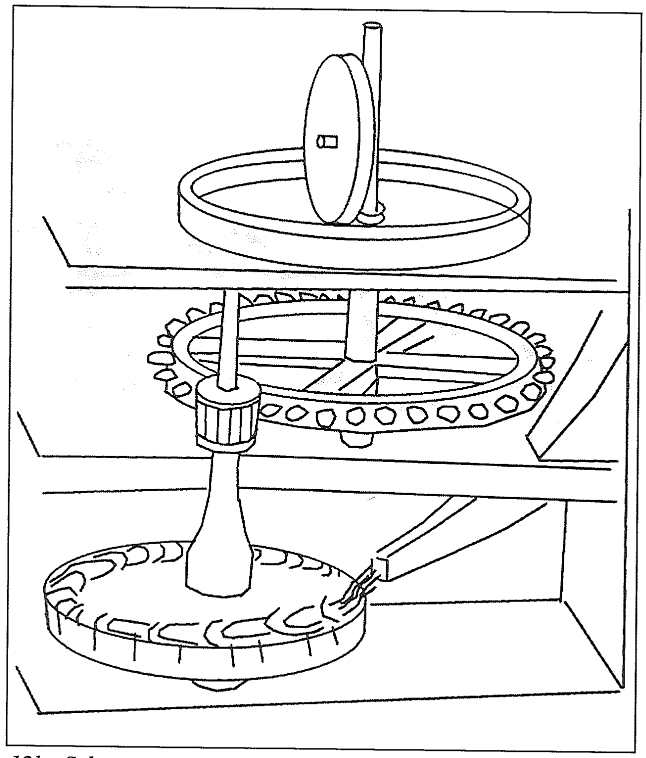
The Lower Room

The vaulted lower room was examined through the square holes in the mill base (**Figs. 8, 11**). This room had become filled with sand that had gradually fallen through these holes so that the entry of the water chute was not visible. The back wall (006) could be seen continuing down on the SE side, and to the NW another similarly built wall (044) could be seen, thus forming a lower room about 6.0m long. The top of an arch could be seen within wall (044), in line with the water chute, but could not be examined safely. There were two other gaps within the vaulted roof, both above the line of the chute. One was beneath the corner feature (034), but again it could not be examined safely. It perhaps related to the sluice above. The other gap, nearer to the mill base, measured 0.3 x 0.45m and was clearly part of the original vaulted structure. Although the roof of the vault was intact, the floor above this area had either collapsed or been destroyed.

It is clear that this vaulted room would have housed the wooden mill wheel, driven by water supplied through the chute. The mill wheel would turn a vertical beam, via a gearing mechanism. The vertical beam would have passed up through the central hole in the mill base and, in turn, driven the upper mill stone. The details of this mechanism will have to await further excavation to remove the sand and reveal any remains of the lower mill mechanism and gearing system. It is possible that all the wooden elements have been removed from



12a. Schematic representation of possible position for gearing mechanism lying above the mill base and driving the vertical wheel (adapted from von Wartburg 2001: fig. 15). This diagram accounts for the presence of two or more beams slotting in walls (010) and (011) respectively.



12b. Schematic representation of an alternative position for gearing mechanism lying bellow the mill base within the Lower Room (adapted from von Wartburg 2001: fig. 14). No overlaying beams appear to be necessary in this set up.

the site, but the stone floor, metal fixings, entry of the water chute and some indication of the architecture of the mechanism should be still intact.

The Water Chute

While the lower room housed the mill wheel mechanism, the water chute provided the water that drove it. The water chute (014) was constructed of a flat base and upright side slabs and plaster completing the channel (**Figs. 7, 10**). The chute was about 0.3m wide and 0.6m high (in cross section) and extended 4.2m from the back wall of the mill. There were no capstones over the chute except within the thickness of the wall (006). The central area of the chute was flanked on either side by two sloping areas of plaster about 1m wide and these were interpreted as overflow slipways. Up to five stone steps had been built into the sides of both slipways. A series of compact sand and gravel deposits (012, 021, 023, 022, 020 and 018) formed a wedge shape on either side of the chute, up against the wall (006). These may have been part of the construction of the mill or perhaps material deposited during the periods when water was running out of the chute over the slipways. The steps on either side of the chute would have provided access to the upper parts of the chute to deal with any blockages.

It is not clear the extent to which the combined drop of the chute from the top of the aqueduct to the mouth of the jet would be sufficient to drive the mill wheel.

Deposits post-Dating the Mill (**Fig. 8**)

Within the upper mill room a layer of compacted sand overlay the floor to a depth of about 0.4m (030) and in-filled the mill base (028). The hole through the mill base was packed with broken stones (including the half collar stone) and gravel (029). These layers were sealed by an extensive layer of sand and charcoal (025) that filled the room to a depth of up to 0.4m. A line of three stones (027) was seen above (025), in the N corner of the room. These stones, which appeared to be held together with compacted sand rather than being loose tumble, these may have formed the base of a small wall, or may be intentionally blocking the hole where the flagged floor had collapsed.

These deposits were then sealed by a thin layer of compacted sand containing mud brick and plaster (024). The surface of this layer sloped down slightly towards the N. The remaining deposit within the mill room consisted of a deposit of windblown sand (002) up to 2m deep. This sand contained dressed stones, plastic and foam packing. Two piles of collapsed dressed and undressed stones were found within the windblown sand (002) (008 and 009). The uppermost layer was a surface collection within the loose windblown sand (001) at a depth of between 0.1m to 0.5m. A large robber trench (005) about 2m wide and 3m long had been cut from the surface of (004) down through the deposits above the chute and removed much of the back wall of the mill (006) to just above the corner sluice (034).

A line of five rectangular stone blocks (007) were seen at the top of the excavated section of the chute which were thought to be the kerb of a modern path across the site.

The surface of the area between the kerb (007) and the surviving top of the chute (014) was strewn with collapsed debris consisting of sand, plaster, gravel, decayed mortar and sugar potsherds (003).

Burials

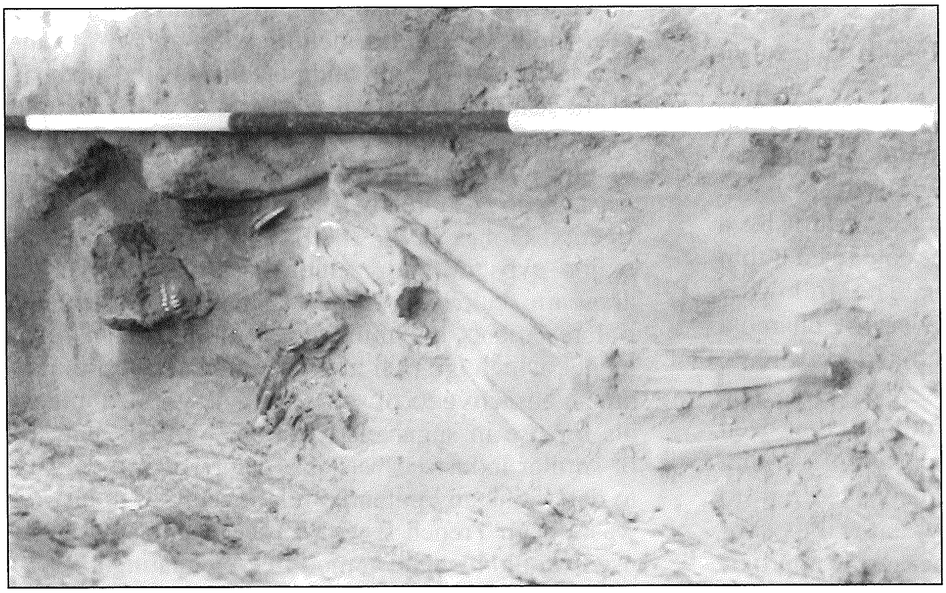
Burial (032) **(Fig. 13)**: As the sand layer (030) was being removed from within the mill room an adult, probably female, skeleton (032) was discovered lying up against the back wall and over the floor (033). The body was extended, parallel with the wall, aligned SW-NE and with the head in the SW, facing SE. A broken flagstone had been used as a headstone and another broken paving slab was found beneath the knees. The body was adorned with five glass bracelets, three of which were complete **(Fig. 14)**; several iron bangles, none intact; a finger ring and a bead necklace made up of several coloured beads of different shapes, including white, black, amber and green. This burial had to be excavated rapidly before the end of the day because of the threat of tomb robbers. The artefacts from this burial suggested that it might be 15th or 16th century in date (A. McQuitty pers. comm.).

Burial (031): The skeleton of a small child (031) was found within the sand (030) at the same level as burial (032), at a distance of 2.5m, to the NW. This skeleton lay parallel with (032) with its head against the side mill wall (011). Only a sherd of sugar pot accompanied the grave. This grave was broadly contemporary with burial (032).

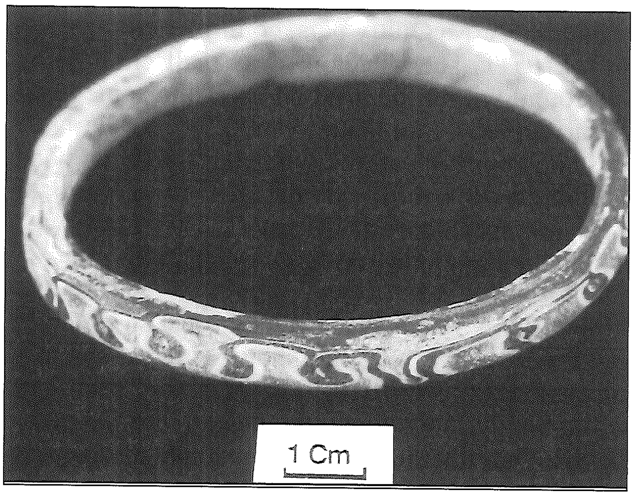
Burial (017): The partial skeleton of a small child was found to the S of the chute within a shallow cut made into layer (016). The body had been laid with a SW-NE alignment, the head to the SW, facing SE. Only the head and upper torso survived as it had been truncated below the third rib by a robber trench (005). The burial was sealed by layer (015), which contained charcoal and plastic and was thought to be fairly modern so it was re-buried nearby.

3.2.2 Trench II **(Figs. 15, 16)**

The purpose of Trench II was to investigate the nature and contents of the main waste heap in an attempt to shed light on the sugar production and refining stage. Trench II was located at the extreme northern end of a fenced off area around TES. The trench which extended an existing robber trench on the N-facing slope of a large waste mound with visible stratified remains, was orientated approximately N-S, measured 3.6m long by 1.2m wide and was excavated over 9 days. The depth varied from 1.7m in the S to 0.5m in the N because of the steep slope of the waste dump. Samples of pottery, charcoal, ashes and waste materials relating to refining were collected during excavation of the trench and also, once excavation was complete, from the east-facing trench section.



13. Burial (032), Trench VI; TES; skeleton of adult female.



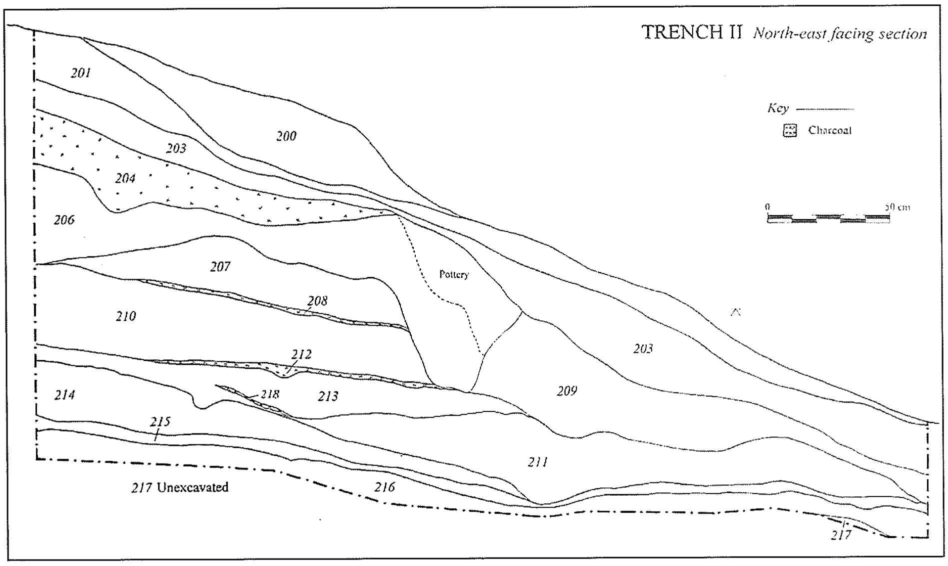
14. Trench VI, TES; glass bangle from burial (032).

15. Trench II, TES; the waste heap. View from the northeast

In general, the layers within the waste dump sloped down from the S to the N following the slope of the surface (see **Fig. 16**). The basal layer within Trench II (217) consisted of sand and gravel with very dense vein-like patches running throughout and extended over the entire length of the trench. This layer was not fully excavated and so its depth is unknown. It was sealed by a relatively compact ash layer (216), a thin compact deposit of industrial waste (215) and another layer of sand and gravel (214), which thinned out about 1.4m from the N end of the trench. A dump of exclusively sugar-pot sherds (211) up to 0.35m deep sealed these layers. Layer (211) was sealed in turn by a layer of industrial waste (213) that contained a thin lens of charcoal and ash (218). The following layers alternated between thin layers of charcoal and ash with thicker layers of sand and gravel and sugar-pot sherds (212, 210, 208 and 207). The southern edge of these layers had collapsed or been truncated. Layers of adobe brick with varying amounts of pottery were then deposited up to depths of 0.4m (209 and 206). A large block of compact white industrial waste, measuring approximately 0.3m by 0.25m, lay on the surface of (206) and was then sealed by a layer of charcoal and ash (204) which was noted in the southern half of the trench only. Overlying this was a compact ash and sand layer (203) containing a circular patch of charcoal and ash (202), probably the remains of a small fire that did not extend into the section. The upper layers (201) and (200) consisted of loose topsoil and the spoil from the robber trench respectively.

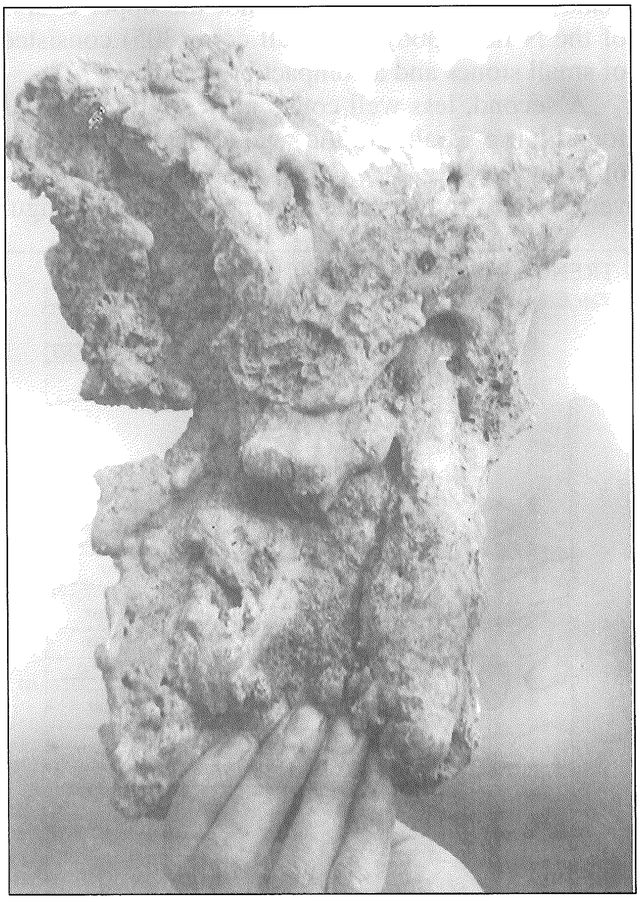
Excavation of Trench II revealed the following general groups of deposits: a) charcoal and ash layers; b) sugar pot sherds; c) clay-rich (of the mud brick type) layers with or without pottery; d) sand and gravel; e) off-white powdery materials identified as industrial waste and distinct from charcoal and ash layers. The pottery that was recovered from Trench II was predominantly from pots relating to the sugar production process in the Near East and Western Europe well into the 18th century (**Fig. 17**), sphero-conical shaped pots into which sugar crystallised and excess liquid with uncrystallised matter dripping in the jars below (Lagro and de Haas 1990). Sherds were found in nearly all of the contexts but were recovered in largest numbers from the potsherd dumps (206) and (211). They appear to have been broken up after use. Apart from the well-recognised two types, fragments of bucket-like ceramic vessels were identified. There were very few domestic artefacts. The pottery, both domestic and industrial, will in due course, be the subject of a separate investigation.

There was overall a large concentration of ashes and industrial waste confirming that this area of the site was being used primarily for dumping waste from the sugar production, or perhaps other industrial processes as well (a smithing hearth bottom was recovered as surface find from the waste heap in May 1997; see also **Fig. 18**). Analysis of charcoal (both for species identification and C-14 dating) is currently being undertaken as is the analysis of the ash and industrial waste contexts. A sample of unstratified white debris resembling the contents of (215) from a robber tomb to the south of the waste heap has already been analysed by X-ray diffraction (Jones *et al.* 2000), and found to contain major gypsum with minor bassanite, anhydrite, aragonite, calcite and quartz. This composite material resembles the mineralogy of the Lisān sediments, which are rich in aragonite and gypsum and are an attractive local source of fine-grained minerals for use in sugar clarification. Further analyses of similar industrial wastes are currently underway to determine any potential relationship of industrial waste from Trench II with Lisān sediments that, if used, would have been modified by heating.



16. Trench II, TES; the waste heap . Northeast facing section.

17. Sugar industry related pottery fragments; surface finds, Trench II, TES.



18. Kiln wall waster, surface find, TES Trench II.

3.3 The Excavations at KSI

3.3.1 The City Enclosure Walls

The substantial walls at KSI revealed by the excavations of Waheeb (1995), evident on the surface to the NW and N, were surveyed during Phase I of the project. In January 2002 a few days were spent clearing off loose sand and modern debris from these walls in order to expose more of their extent so that they too could be surveyed. These have been referred to in this report as Wall 1 and Wall 2 respectively (see **Fig. 5b**).

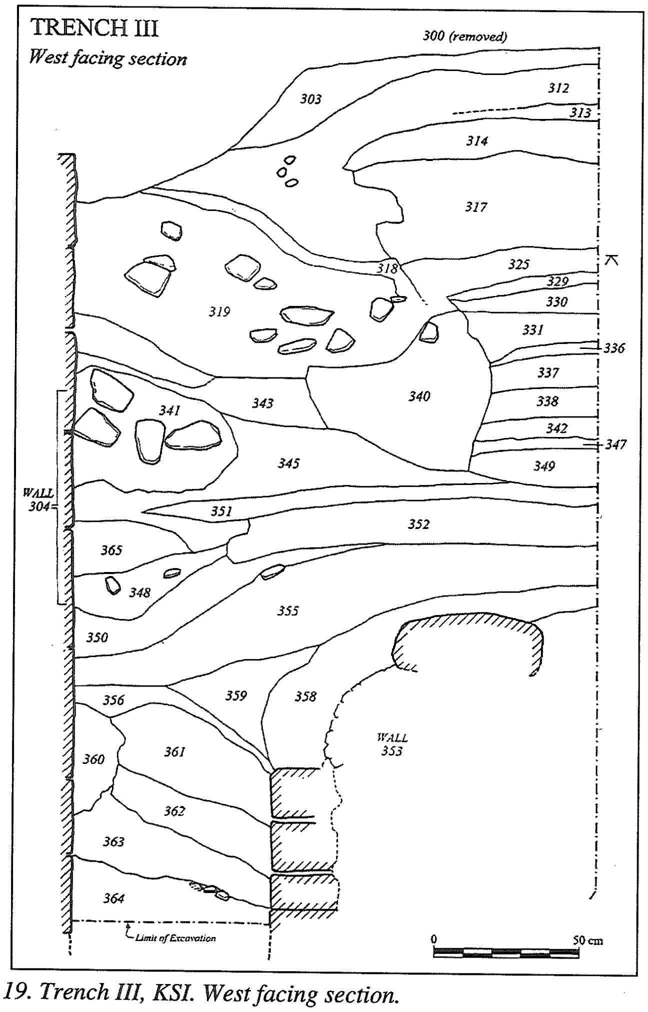
A corner was identified just east of Trench III and a new line of walling was uncovered approximately parallel with Wall 2 (Wall 3, see **Fig. 5b**). In the N part of the site the walls appeared to continue beneath an increasing depth of deposits and so could not be examined further. No substantial walls like those in Trench I and III have yet been found at the E end of the site, the walls within Trenches IV and V being much narrower and of less massive construction. So while Walls 1 and 2 may constitute external city boundaries, the east and northern extents of the city have not been defined.

3.3.2 Trench III

Trench III was located at the E end of a visible line of walling which corresponded with an anomaly noted in the geophysical survey. Trench III, measuring 4 x 4m, was dug to a maximum depth of 3.2m over a period of 17 days. Initially the whole trench was excavated, but when the full width of a substantial wall (304) was revealed, the excavation continued on the S side of this wall, leaving the N side unexcavated. In order to reach the deepest layers possible within the time available, it was later decided to excavate the SW corner leaving the SE corner as a higher step.

The most remarkable feature of this trench was the massive stone wall (304), 1.5m wide, that extended across the whole width of the trench equivalent to Wall 2. Wall 304 was constructed of large squared blocks, some up to 0.9m long, in nine well-laid courses, which were exposed to a maximum height of 2.95m. The face of the two basal courses of this wall was rougher than the upper courses, and they were covered with patches of plaster. There were no architectural features within the revealed face of the wall (304) nor the upper course of the N face (306). The wall core (305) consisted of small stones and a compact brown matrix.

A second, less well constructed, wall (353) was found lying parallel to the wall (304), at a distance of 0.7m (see **Fig. 19**). One face of the wall was revealed up to five courses high constructed of angular and rounded stones topped with rubble. This wall was about 1m high and at least 1.5m wide. It was seen for a length of 1.5m. The bottom of the wall was not excavated, and there was no evidence to suggest the relationship between these two walls.



19. *Trench III, KSI. West facing section.*

The gap between the walls was filled with five layers of compact soil varying in colour from grey to yellow brown (364, 363, 362, 361) to a depth that varied from 0.5m in the W to 0.75m in the E. These layers abutted the walls on either side and sloped slightly towards the wall (353). Within layer (361) there was a linear feature, probably an animal burrow (360), consisting of a loose brown soil against the wall (304).

These deposits were sealed by a layer of dark brown and grey layer of ash and charcoal (356) up to 0.1m thick, which in turn was sealed by layers of compact yellow soil (358) and loose stones (359), which appeared to be spreading from the wall core.

The wall (304) is part of a more extensive line of walling (Wall 2), extending from what may be an entrance to the W, with an E-W alignment (**Fig. 20**). The wall was found to continue to the E of Trench III just beneath the surface. There were no architectural features that could help to date the wall, but it probably belongs to the middle Islamic

20. *Trench III, KSI: Wall 2 with ashlar masonry, view from the south.*

period of the town, perhaps forming the north side of the main street through the city. This wall could be the outer wall of a substantial building, but because its interior has not yet been examined the nature of occupation remains unknown.

The relationship between the two walls (304) and (353) was not resolved within this trench. If the wall (353) predates the construction of the city wall (304), then it is possible that the surface (355) forms a street level, and the courses of wall (304) below this are foundation, with intentional infilling of the space between the two walls. The compact nature of the deposits between the walls does suggest intentional infilling rather than natural silting. However, if the wall (304) predates the wall (353), it would suggest an alteration to the original town layout, with the construction of a structure right across what would have been the street. It is also possible that these walls were in contemporary use, the gap forming a passageway only 0.7m wide.

The upper layers are likely to be deliberate deposition of occupation debris consisting of wood ash, charcoal, carbonised seeds and midden material, especially mammal bone with some windblown element. These deposits are consistent with the use of this area as an open space, perhaps a yard, rather than the interior of a house. In particular the burial of disarticulated camel bones and the complete body of a small mammal, probably a dog, also supports this interpretation. The pottery will help to provide a chronological framework for this period of deposition. This trench has highlighted the excellent survival of the massive walls, which are of middle Islamic date and another less well-built structure at depths of up to 3.2m below the surface.

The trench did not uncover the anomaly produced by the geophysical survey. However, there was a wall constructed of rounded boulders just at the N edge of the trench, at a depth of about 0.6m below the surface. This wall contained plastic, which would suggest that it is relatively modern. All the deposits within the trench, above and below this wall, consisted of silt with pottery and small amounts of other domestic debris, which suggests that these are layers of occupation debris. All layers excavated within this trench are thought to be modern (i.e. post 1918).

3.3.3 Trench I

Trench I was located about 50m to the N of the main road (**Figs. 5b, 21**). The trench location corresponded to a geophysical anomaly and was also in line with Wall 1. The trench measured 4 x 4m and was dug to a maximum depth of 1.1m over a period of 17 days.

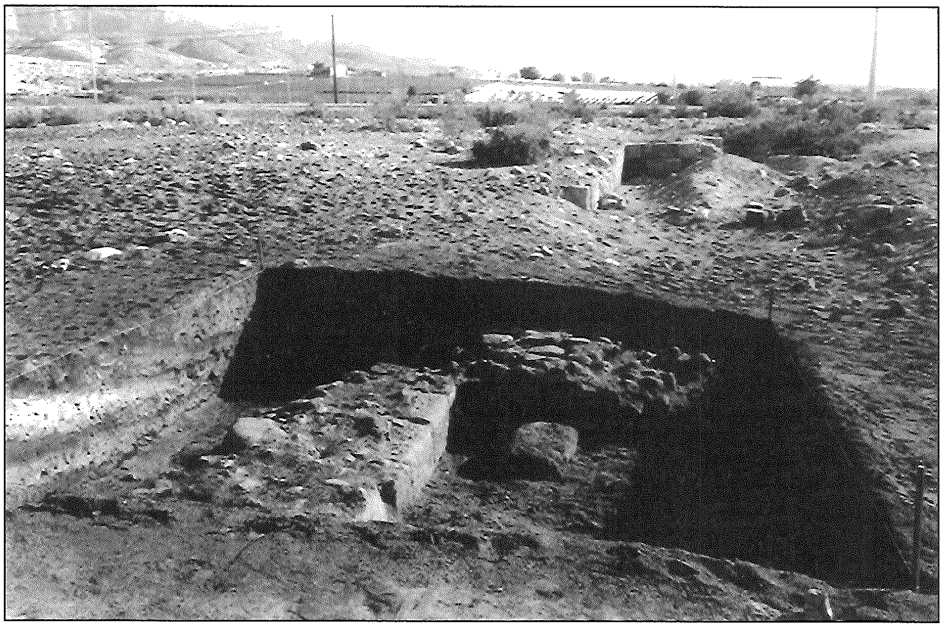
The earliest feature within this trench was a substantial L-shaped wall (109 and 108), the N-S element of which (109) continued the line of Wall 1. Its two outer faces consisted of two courses of rectangular stone blocks with a rubble and mortar core. It measured 1.5m wide and was exposed to a height of 0.7m. A single face of a perpendicular arm of walling (108) was exposed for at least 2.2m to the W of (109). The foundation levels of these walls were not exposed within this trench. This corner of walling formed by (108) and (109) could have been part of a square foundation for a bastion, tower or the entrance to a substantial building.

Several layers of ash had been deposited within the corner formed by (109) and (108). These layers sloped gently downwards towards the W part of the trench. The lowest layer excavated was a loose brown ash (114) with a circular bread oven (*tābūn*), on its surface (115). This oven was 0.6m in diameter and was 0.1m deep. The base of the oven consisted of small pebbles. These types of small quartz pebbles originate from the bottom of wadis and are chosen especially for bread oven construction as they do not crack when heated (H. Hijazeen, pers. comm.). The domed-shaped sides of the oven had collapsed. This feature was sealed by further ash deposits to a depth of 0.6m (113, 111 and 112). To the E of wall (109) a single layer of ash (105) was identified. These ash layers and the top of the wall (109) were sealed by a layer of brown ash and plaster fragments (107). Further layers of ash then sealed both ash layers and the wall up to the present ground surface (110, 106, 104, 103, 102, 101 and 100). Two of these layers consisted of white/grey ash (102 and 104) while the rest were brown.

This trench has provided evidence that the line of Wall 1 continued further north beneath layers of ash. It has also shown that there is a possible bastion, tower or substantial entrance located here. A similar square feature was exposed during the earlier excavations of Wall 1 and this protruded about 2m W of the wall line and was approximately 5m long. Wall 1 and Wall (109) are not in line with the north-south Wall 2, which is located further N. Wall 2 is also aligned N-S but about 2m further E. Wall (108/109) here in Trench I was of the same construction and width to Wall 2 exposed in Trench III.

These excavations did not provide any direct dating evidence for the construction of these walls, as the foundations were not exposed and there were no distinctive architectural features, however it is thought that they are probably Islamic.

The presence of the oven within the corner of



21. Trench I, KSI,: corner of walls (108) and (109) with Wall 1 in the background.

the wall indicates a definite occupation horizon, probably dating from the middle Islamic to Modern times. This indicates that the massive walls were still being used within the later settlement. After the buildup of several layers of ash and occupation debris (layers 113, 111, and 112), there was an episode of destruction (107), perhaps when the walls were bulldozed in the 1980's. Further ash layers were then spread over the area from the NE, perhaps by bulldozer, in order to level the site for agricultural use (layers 110, 106, 104, 103, 102, 101 and 100).

3.3.4 Trench VII

Trench VII was excavated at KSI approximately 60m north of the main road to investigate a surface spread of kiln wasters and an anomaly noted by the geophysical survey. Trench VII measured 4 x 4m and was excavated to a maximum depth of 0.9m. The presence of the dumps of sugar pottery fragments at the W end of the trench are interesting as this material is associated with the sugar processing and it is likely that they were dumped here after use. It is possible that they are wasters that were never used, however the excavators did not notice any particularly misshapen or badly fired sherds to support this. Closer examination of the sherds and comparison with the sugar pot recovered from Ṭawāḥīn as-Sukkar will help to resolve this. Of equal importance were the kiln wall wasters recovered in association with the sherds suggesting that a demolished kiln had been somewhere in the vicinity, but unfortunately, the site was not located within this trench.

Two more trenches (Trenches III and IV) were excavated at KSI, and the results presented in the Data Structures Report (James 2002).

4.0 DISCUSSION

Having set forth the results of this pilot season of excavations and those of the geophysical surveys, a select number of themes relating to the industry are now explored.

a) Energy Resources and Water Management

Assuming that there has been no significant climate change in the last few thousand years, the only viable source of water for power and irrigation would have been Wādī al-Ḥasā, which provides the present-day source of water for domestic and irrigation purposes. Assuming that the wadi was tapped, probably with the aid of a reservoir at about the same altitude as the present reservoir, the water would have to have been conducted in a channel that followed the contours of the southern slopes of the broad mouth of the Wādī al-Ḥasā westwards to the sugar mill. This is possible, via two routes whose channels are nowhere evident in view of the extensive road, housing and water management development in the area, not to mention tomb robbing.

The water from the wadi would have been required to arrive at the same elevation as the two aqueduct channels. It could have come around the small knoll to the south of TES on either side (the south or the north aqueduct channel), but the northerly route seems to be more likely unless there was a reservoir required to control the flow rate, in which case the water would have been better provided around the southern side of the knoll (see **Fig. 3**). Accurate surveying of elevations at key positions will be required to assess the route of the channel and the hydraulic head. In any case it is unlikely to be more than a few metres. The waterpower for the mill would presumably have depended almost entirely on the drop between the top of the aqueduct at the mill and the horizontal wheel that was water-driven. Assuming there was an ample supply of water in the channel or canal from the wadi, the feed down the aqueduct chute could have been controlled by diverting the water at the top (inlet) of the mill.

b) Soil Parameters Affecting Crop Cultivation

The sitting of the sugar mill was evidently influenced by the topographic break occurring close to an area on the alluvial fan, with soils rich enough and well drained for sugar plantation development and presumably close to an already established settlement site at KSI. But other considerations would have been the availability of waterpower and other natural resources required for the sugar industry.

Regarding agricultural potential in the area, this can be assessed in relation to three distinct physiographic sub-divisions corresponding to those recognised in the area of the southeast Dead Sea by Shammoot and Husseini (1969): Upland or Old Alluvial Fans; Recent Alluvial Fans and Flood Plains; and Basin.

The higher ground especially to the south of the present-day aṣ-Ṣāfī plantations is underlain by bouldery/pebbly alluvium of 'Old Alluvial Fans' and is either wasteland, burial grounds for the Early Bronze Age cemetery or currently used for building development. The soils here, of the Grey Brown Desert Soil Group, are loose and permeable but in general not suitable for agriculture because of the steep topography.

The large 'Recent Alluvial Fan' on which the irrigated plantations of aṣ-Ṣāfī are currently situated (**Fig. 2**) has soils that are also of the Grey Brown Desert Soil Group. These are medium to light textured, well drained with fair to moderate water holding capacity and are the best agricultural soils in the area (Shammoot and Husseini 1969). The topography is slightly undulating and gently sloping. We can therefore assume that the extensive area of the alluvial fan was available for agriculture at the time of the sugar industry but plantations would have required an ample water supply. Lower ground closer to the wadi would therefore presumably have been more convenient for development of the plantations. The plantations could have been situated conveniently, near the wadi to the east and north of the mill, their precise location being decided by the irrigation pathways existing at the time.

Finally the 'Basin' soils range from loamy sand to heavy clay, with permeability from slow to rapid; they are strongly saline, alkaline and black and they are not suitable for current irrigation procedures (Shammoot and Husseini 1969). The low ground between the large alluvial fan developed at the mouth of Wādī al-Ḥasā and the Dead Sea shore (**Fig. 2**) belongs to this category. This flat shore of the Dead Sea has increased in area due to exploitation of salt to the extent that the southern Dead Sea basin is now almost entirely composed of human-made salt pans. The proximity of the Dead Sea shore to the fertile alluvial fan during the lifetime of the sugar industry is currently unknown.

c) Industrial Minerals Potentially Used in the Sugar Industry

The fine-grained gypsiferous and calcareous Lisān sediments provide a substantial source of minerals with industrial potential. X-ray diffraction analyses of several samples confirmed major aragonite, $CaCO_3$, with minor calcite, $CaCO_3$, gypsum, $CaSO_4.2H_2O$ and quartz, SiO_2. Calcium carbonates and sulphates have a use in sugar processing as well as in wine clarification. Furthermore, gypsum is a natural anti-caking agent and is used in cement for example to prevent setting. Sugar probably also would have benefited from an anti-caking agent during transport if in powder form. Gypsum was observed to occur in small veinlets but is also reported to occur in distinct beds in the Lisān sediments. Salt from the Dead Sea was obviously readily available for local use, but we do not know of any special use of salt in the sugar industry.

d) Clay for the Pottery Industry

Clay for the large amounts of specialised pottery and building stones for the sugar mill and related structures are obvious important requirements for the establishment and functioning of the sugar industry in Ghawr aṣ-Ṣāfī. Regarding clay resources, there was an ample convenient source of alluvial soil for pottery and bricks in the main channel of Wādī al-Ḥasā, that would usually have been occupied by a small stream or isolated ponds of standing water replenished during flash floods. This type of clay deposit can still be seen in the wadi in places and is also likely to have been available within the al-Ḥasā alluvial fan whenever major irrigation channels were produced, as these would have allowed ponding of floodwater and accumulation by settling of fine sediments. One such deposit lying one kilometre due west of TES and favoured by the local inhabitants for constructing bread ovens was sampled.

e) Kiln and Hearth Wall Wasters and Sugar Industry Pottery Wasters

Two trenches (II at TES and VII at KSI) produced most of the pottery wasters. Trench VII not only revealed a substantial amount of sugar mould pottery fragments (James 2002) but also intriguingly, kiln wall wasters. A distinction should be made between the kiln wasters in Trench II, which derive from the lining of the hearths in which the juice boiled and those from Trench VII at KSI, which appear to belong to a proper pottery manufacturing kiln. The raw materials used for the two different structures are expected to be similar.

f) Building Stone Source

The sugar mill and the stonework of the buildings of KSI required building stones of a substantial size. Boulders of a convenient size for building, though rather rounded and hard, appear to be scattered through the sediment of the alluvial fan of the al-Ḥasā but are abundant and readily available in the dry riverbed itself. Larger blocks of sandstone and limestone, more convenient for shaping into dimension stone are also present in the alluvial sediments. The reddish 'Nubian' sandstone outcrops in the walls of the Wādī al-Ḥasā and would have been easy to quarry if shaped and dressed blocks were required. Limestone for mortar is available in the higher areas to the east as well as in blocks washed down the wadi. However, the calcareous Lisān sediments outcrop not far away at the southern end of the Lisān peninsula and probably elsewhere even closer along the eastern shore of the Dead Sea. These are easily worked soft, fine-grained, homogeneous sediments providing a supply of calcium carbonate that would have been suitable for producing lime for mortars and plasters. Since the sediments also contain gypsum, they may have been particularly suited to this purpose.

g) Sulphur and Geothermal Energy

Since other minerals could well have been required, consideration has been given to materials known historically to be associated with the southern Dead Sea or were potentially locally available such as sulphur, bitumen and evaporitic minerals. Elemental sulphur has had a long historical association with the Dead Sea area and was found as pellets evidently weathering out of the Lisān sediments of the Lisān plateau. The pellets were not observed *in situ*. They probably occur scattered through certain layers rather than as substantial concentrations, and so only small amounts of such sulphur would have been available for exploitation. The sulphur could have been used for lighting and medical applications, and it may have been employed in sugar refining. Bitumen is similarly well known historically to have occurred as seepages into the Dead Sea, but we did not observe any signs of bituminous seepages or residues. The Dead Sea graben is geothermally active with warm springs and rocks exposed along the eastern coast show localised evidence of hydrothermal alteration. These areas are potential sites of small deposits of sulphur and sulphates including alum group minerals: yellow crystals of tamarugite, sodium-alum, $NaAl(SO_4)_2(H_2O)_6$ was recovered from one locality and identified using powder X-ray diffraction.

h) Mill Construction

It is with the excavation of the Lower Room that the mechanism of operation of the vertical mill stone will be clarified. "Blueprints" from 15th and 17th century plans of sugar industry establishments provide a frame of reference for the possible location of the gearing mechanism. This could have been placed either above (**Fig. 12a**) or below (**Fig. 12b**) the mill base. Both options are presently viable for TES although the former may be favored on account of the beam slots in walls (010) and (011). The waterpower available to drive the wheel will be assessed once the total drop can be measured, from the top of the mill chute to the floor of the Lower Room.

i) City Boundaries and Type of Buildings

Geophysical survey revealed the location of a number of wall sectors at potentially two different orientations, E-W and NW-SE. The examination of the rich artefactual evidence from KSI with particular reference to the pottery, metal, glass, botanical and animal bone remains will be studied in the post-excavation phase. In setting in perspective the archaeological evidence, KSI has certainly produced evidence commensurate with the famed importance of historical Zoara/Zughar. Perhaps it is important to remember that in medieval times the Dead Sea was called the Sea of Zughar.

j) The Sugar Mill

A materials oriented industrial archaeology approach to one of the most important industries in the Near East, i.e. sugar manufacture, is undertaken here for the first time. The results of the pilot season of excavation revealed very good state of preservation of the 'Mill Room' and potentially of the

Lower Room as well. The aim is to excavate and study each stage in the sugar making process in a stepwise manner, as outlined in the introduction. The sugar refining stage is tackled by the scientific analysis of the stratified contents of the waste heap (work in progress). However, apart from the study of the industry, a number of other issues have to be taken into consideration. The upstanding adobe brick walls of the later Ottoman fort are in need of consolidation, while the numerous robber trenches need to be filled in since they undermine the foundations of both stone and adobe brick upstanding walls. A parallel course of consolidation, excavation, study and restoration is therefore advocated and, assuming funding and relevant permits are in place, will be set in place. A preliminary phase of conservation work has started with the filling-in with windblown sand of robber trenches within TES. The locations of all robber trenches had already been recorded on the site plan in the course of the excavations, for future reference. A preliminary phase of experimenting with materials to be used for adobe brick wall conservation is already implemented; a summary is given below.

Conservation Programme

The conservation of the substantial standing remains at Ṭawāḥīn as-Sukkar was undertaken immediately after our excavation season. First, robber trenches that undermined foundations of both stone and adobe structures, were filled in with the top layer of wind-blown sand cleared from Ṭawāḥīn as-Sukkar. Most vegetation growing, and consequently damaging the site, was also removed.

The second, more long-term work begun was the consolidation of all standing and/or exposed structures (as a result of archaeological excavations). Adobe brick and mortar samples were taken, and after a series of experimental mixtures made by conservator Stephania Chlouveraki, they were tested and finally chosen to be used on Ṭawāḥīn as-Sukkar. Four local workers trained at the Sanctuary of Lot project were employed to carry out the consolidation work during 2002. The costs for this were covered were covered jointly by the Department of Antiquities and our project.

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