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The Sugar Industry in the Ghawr aṣ-Ṣāfī, Jordan

The remains of at least 38 *Ṭawāḥīn as-Sukkar* ("sugar mills") or, more accurately, *maṣāni' al-sukkar* ("sugar factories") have been found throughout the Jordan Valley and southern Ghawrs, a region south-east of the Dead Sea. The *maṣna' as-sukkar* ("sugar factory") in Ghawr aṣ-Ṣāfī is the largest of these early industrial complexes. The adjacent sites of Khirbat ash-Shaykh 'Īsā and al-'Amarī / al-Rujum have been identified as Zughar, a major commercial centre which marketed sugar during the mediaeval Early and Middle Islamic periods. Recent archaeological field research has identified the function of various components of the site and elucidated advances in industrial technology, irrigation and land-use strategies related to sugar production.

What is Sugar?

Sugar belongs to the large family of carbohydrates. Some types of sugar are sweeter than others. Cane sugar contains highly-sweet sucrose, whilst honey and fruits contain other sugars such as glucose and fructose. These are made by the chemical process of photosynthesis in leaves where carbon dioxide from the air combines with water under the stimulus of sunlight to form sugar (Hugill 1978: 11). Extra light increase the sugar concentration. Being water-soluble, sugar travels in the sap of the cane plant from the leaves to its extraordinarily long (up to 5 m) stem where it is stored. Sugar cane plants therefore require plenty of sunlight and abundant water to flourish. When processed and refined, sugar from the cane has a greater yield than naturally produced honey and fruits.

Sugar cane is a versatile tropical grass originating in south-east Asia, which can be sucked raw or cooked. Its juice can be drunk or boiled to produce syrup out of which red, brown or yellow sugar crystals can be extracted and refined to produce white sugar.

When sugar is eaten, enzymes and other complex processes in the body convert it to blood sugar, providing energy. The human body's response to drinks and food sweetened with sugar is to imagine that they taste better. Its attractive flavour has also made sugar a desirable additive for making distasteful medicines more palatable.

The proportions of the constituent parts of sugar cane vary considerably, not only according to climate and soil, but also from factors such as the ripeness of the cane at the time of harvest. Average fractions are: water 69 - 75%, sucrose 8 - 16%, uncrystallisable sugar traces up to 2%, fibre 8 - 16%, ash 0.3 - 0.8%, organic matter other than sugar 0.5 - 1% and nitrogen 0.005 - ~0.02% (Jones and Scard 1909: 11).

Origins of the Sugar Industry

The method of extracting sweet juice from sugar cane originated over 2,500 years ago in south-eastern Asia (Watson 1983: 24-26, 159 n. 4), but this was essentially as a small-scale 'cottage industry'. In the western classical world, fruits (such as dates and grape must) and honey were used as natural sweeteners (Singer *et al.* 1957: 6). It wasn't until the 4th century BC when Nearchos, admiral of Alexander the Great, reported the existence of "reeds [which] yield honey, although there are no bees" in India (Strabo XV: I, 20). In the Graeco-Roman world this product came to be known as *saccharum.*

During the 7th to 9th centuries AD, Arab scholars advanced their study and development of ancient Greek science, particularly in chemistry (Hassan and Hill 1986: 6, 27). This was partially linked to the development of a nascent chemical industry. Combined with knowledge of processing sugar cane acquired from India via Persia, the Arabs perfected its large-scale production. Consequently, wide-spread cultivation of sugar cane gradually became established in Egypt, Palestine, Jordan and Syria (Singer *et al.* 1956: 373).

Further interactions with Asia, particularly India, and advances in engineering and irrigation led to an agricultural revolution in the early Islamic world during the 8th century (Watson 1983: 6). One result of this was the advent of large-scale sugar production, which needed substantial (state) capital investment to build sugar factories and maintain sugar cane plantations, as well as abundant cheap labour.

Sugar cane was crushed using animal- or water-powered installations; the resulting product was pressed to extract the juice. The extract was then boiled for evaporation and subsequently poured into conical-shaped, perforated pottery drip-jars; it gathered in separate residue-collecting jars placed underneath. Large-scale production of sugar required a huge number of these specialised pottery vessels, as well as *dusut* – unusually large metal bowls needed for the boiling process (see below).

The processes of cane sugar manufacture include: (1) 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, (2) boiling of the juice to evaporate the water and produce syrup, (3) syrup clarification to remove both colour and non-sucrose substances using various chemical reagents, (4) sugar crystallisation from this melt and the draining of excess juice (molasses), originally by gravity, by using conical-shaped sugar moulds inserted into molasses jars for draining.

Considering that about 85 - 90% of desiccated sugar cane is residual fibre (*bagasse*) and an average of 10% fresh sucrose, the process needs to be carefully monitored both with regard to the type of clarifiers used and the temperature at which the juice is to boil (Bremner 1869). Overheating destroys the crystallising properties of sugar and converts it to a sticky mass or 'treacle'. The development of mineral clarifiers that were added to the syrup facilitated the production of pure crystals of sucrose, which led the transition to industrial-scale production (Stern 1999). These clarifiers included wood-ash, lime, alum and even certain herbs (Watson 1983; Clow and Clow 1952: 519; Peled 1999). It has been suggested that sugar may have been refined through use of wood-ash in southern Iraq as early as the 8th century AD (Hamarneh 1977-8: 12).

Lime (CaO) dehydrates the melt and neutralises the acidity of the juice, in addition to removing some of the non-sugar components. Lime kilns therefore became part of the sugar industry (Kelly 2004: 5-6). Regenerative animal bone charcoal, which returns to its original state when heated, was also used to remove any colour, resulting in white crystals of sugar.

Although most of the sugar cane plant constituents are water soluble, the fibrous *bagasse* can be used as fertiliser in the sugar cane fields, fuel for the boiling process or even as animal fodder.

Sugar in the Jordan Valley

There is documentary evidence in both European and Arab sources of the 11th and 15th centuries regarding an incentive by Ayyubid / Mamluk rulers to promote sugar crop plantation in the Jordan Valley by undertaking major irrigation schemes (Hamarneh 1977-8; Stern 1999). However, it seems clear that an understanding of how to carry out and control processes (2) and (3) as outlined above must have been in place before sugar manufacturing could be carried out on an industrial scale.

In Palestine and Transjordan, 43 sugar factories have been identified, 34 of which are in the eastern Jordan Valley (Abu Dalo 2010: 27, fig. 2; Hamarneh 1977-8; Abu Dalo 1995; Stern 1999), with an additional three in the southern Ghawrs (*viz.* Ṣāfī, Mazra'a and Fīfā) and one at Jericho (Taha 2009: 181-191; Taha 2004: 73-78). These sites are usually erroneously referred to as *ṭawaḥīn* (see above) which literally implies "grinding" or "pulverising" (e.g. wheat into flour). However, the correct term is *ma'asir* meaning "crushing" or "pressing" of olives or sugar cane (Nashef 2011; Abu Dalo 1995). Furthermore, the presses are only one part of the sugar manufacturing process, making *maṣāni' as-sukkar* (see above) the most accurate term for describing the overall function of these sites.

Sugar cane plantations require abundant water and sunlight, which made the Jordan Valley and Dead Sea littoral particularly suitable for this crop. Today, as in the past, the soils in this area are relatively saline which can cause complications for agriculture. However, sugar cane is a salt-tolerant plant (Milwright 2005: 10) which flourished in these well-watered and sun-drenched regions.

The Jordan Valley sugar industry reached its peak during the Mamluk period of the 12th to 15th centuries; it proved to be a highly profitable trade as the product was deemed to be of the finest quality (Hassan and Hill 1986: 222). Sugar factories and plantations were declared royal property and the Sultan appointed a special supervisor for the Jordan Valley, known as *astadar al-aghwar*, to collect the sugar products and manage finances (Abu Dalo 1991: 8). Some of these factories were notably placed under the control of the *nā'ib* (representative of the Sultan) of Damascus who travelled to the Jordan Valley during the sugar cane harvest for inspections and to promote irrigation projects for the plantations.

At Manueth, a sugar production centre mentioned in Crusader texts, "sugar pots" were also discovered in 17th century contexts and listed in Ottoman tax registers (Stern 1998: 10-11, fig. 23). This is the last record of the sugar industry in Palestine and Transjordan.

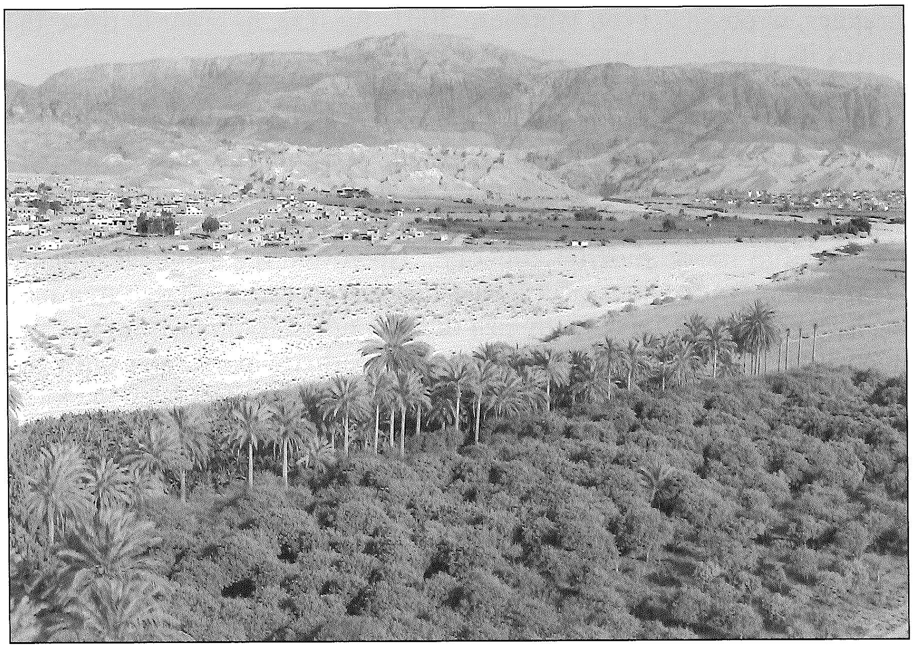
Archaeological Research at Ghawr aṣ-Ṣāfī

The earliest field work conducted at Ghawr aṣ-Ṣāfī revealed Roman, Byzantine and mediaeval Islamic remains (Albright 1924: 4; Kyle and Albright 1924: 283-91). In the early 1930s several ancient features were visible on the surface and at a depth of 2 m: wall foundations, remains of fortification walls, column fragments, a "large water pool" and piles of copper-slag associated with the remains of ancient furnaces (Frank 1934: 15-16). Systematic surveys were conducted by King *et al.* (1987) and MacDonald *et al.* (1992); limited excavations revealed part of a south-west city wall (Waheeb 1995: 555). More recent surveys (Politis 1998) and excavations (Politis *et al.* 2004, 2007 and 2009) revealed a remarkably well-preserved mediaeval Islamic period (9th – 15th centuries AD) sugar factory complex and an adjacent walled urban centre. It also became apparent that Ghawr aṣ-Ṣāfī originally had extensive Iron Age (Politis 1999a) and early Byzantine farming settlements (Politis 2012). Their agricultural success stemmed from their location close to the perennial Wādī al-Ḥasā stream, which provided a steady supply of water and fertile soil deposits to the Ghawr aṣ-Ṣāfī alluvial fan (FIG. 1).

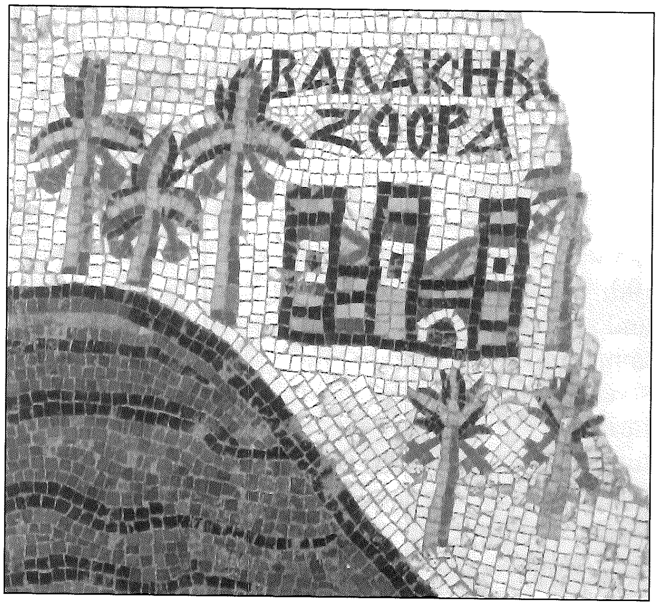
Ancient Agriculture in Ghawr aṣ-Ṣāfī

Roman and Byzantine sources indicate that Zoara (Ghawr aṣ-Ṣāfī) was a city based on an agricultural economy broadly similar to that of 'Ain Gedi and Jericho, with date palm groves and balsam vines (Jerome 108: 11). In the 2nd century AD Zoara is also mentioned as a farming centre (Bowersock 1983: 76-77). It is depicted on the 6th century AD mosaic map at Mādabā, surrounded by date palms and named Zoora (Politis 1999b: 227) (FIG. 2), a derivation of the Old Testament Zoar (Genesis 19).

During the 'Abbasid and Fatimid periods, Zughar (Zoara) was described as a busy market



1. Wādī al-Ḥasā alluvial fan deposits (J. Taylor).



2. Zoara depicted on 6th century AD Mādabā mosaic map (M. Piccirillo).

town renowned for its indigo and date production (Ibn Hawqal 184.17-185.3; Maq. 178.5). Ayyubid - Mamluk Zughar has been also been described as a flourishing commercial town by Walmsley (2001: 518, 542), who described an economy based on sugar production. Indigo, which is known to have grown in Ghawr aṣ-Ṣāfī (Walmsley 2007: 116; Schick 1997: 75), was an important agricultural precursor to sugar cane with close similarities in its processing requirements (Whitcomb 1992: 117), comparable to the advanced techniques of later centuries (Kelly 2004: 7).

Yaqut, the 11th century AD geographer, wrote: "The little Jordan is a river which derives its water from Tabariyya Lake and flows through the valley towards the south where it irrigates the villages, mostly harvesting sugar, which is carried from there to all countries of the East..." (Yaqut 1984: 216). The well-watered Jordan Valley, specifically the spring at Zughar which "the people used to irrigate the land", is mentioned in the *ḥadītha* report of Fatimah (Ibn Majah 1999: 438, no. 4074) which highlights its importance. The mediaeval Islamic name of Zughar derives from the Roman - Byzantine Zoara, alluding to a long period of uninterrupted occupation in Ghawr aṣ-Ṣāfī which is also attested to by recent archaeological excavations (Politis *et al.* 2007: 205-208; Politis *et al.* 2009: 303-307).

During the Crusader period, two chroniclers of Baldwin of Jerusalem's winter campaign of 1100 - 1101 refer to Ghawr aṣ-Ṣāfī (Zoara). William of Tyre mentions that the town was on the route leading east from Hebron and Dead Sea, noting that it was then named Palmer (William of Tyre: ch. 412). Foulcher of Chartres, who accompanied Baldwin on this campaign, was both more detailed and more impressed: "...we came upon a most pleasing villa they call Segor, of the fruit of the palms, which are called dates, exceedingly abundant, for which for provisions all day we took our fill. We came upon other rare things in the same place." (Historia: ch. 5). Presumably sugar was one.

The Ghawr aṣ-Ṣāfī Sugar Factory

General Description

The standing structures at the *maṣna' as-sukkar* (formerly known as *Ṭawāḥīn as-Sukkar*) in Ghawr aṣ-Ṣāfī can, for convenience, be divided into two areas (FIG. 3). The northern part, consisting of a vaulted room made of stone and lime mortar with adjacent mud-brick walls, was originally referred to as Qaṣr aṭ-Ṭūba or Qaṣr aṣ-Ṣāfī (Glueck 1935: 7, n. 19). The southern part consists of the remains of three presses with an arched aqueduct, water-channels, crushing chambers and subterranean vaulted rooms. These would have contained some type of overshot water-wheel (for a 6th century representation, see Siegne 2009: 436, fig. 3; for a hypothetical Ayyubid - Mamluk model, see Abu Dalo 2010: 29, fig. 4) operating a horizontal press base through a gearing mechanism (Hassan and Hill 1986: 52-53), possibly vertical such as that at Kouklia in Cyprus (von Wartburg 2001: fig. 15), in order to drive the cane-crushing machinery.

It has been suggested that the *qaṣr* area in the north and the presses in the south date to two different periods (King *et al.* 1987: 446). This may be true, in view of the fact that the vaulted room does not immediately appear to have had an industrial function. However, the large accumulation of ash and cinders spread over the area east and south-east of the vaulted room testifies to low-temperature heating, perhaps associated with the boiling of sugar syrup. It might have been the location of a *dār al-qaṣab* ("house of cane"), where the sugar cane would have been cleaned and chopped (Nashef 2011) into 'fingers' (Peled 1999: 252) and then stored.

The surviving architecture at the Ghawr aṣ-Ṣāfī sugar presses consists of two parallel edge-runner water-presses (with oblique penstocks) operated

3. Aerial view of sugar factor complex in Ghawr aṣ-Ṣāfī from north (K.D. Politis).

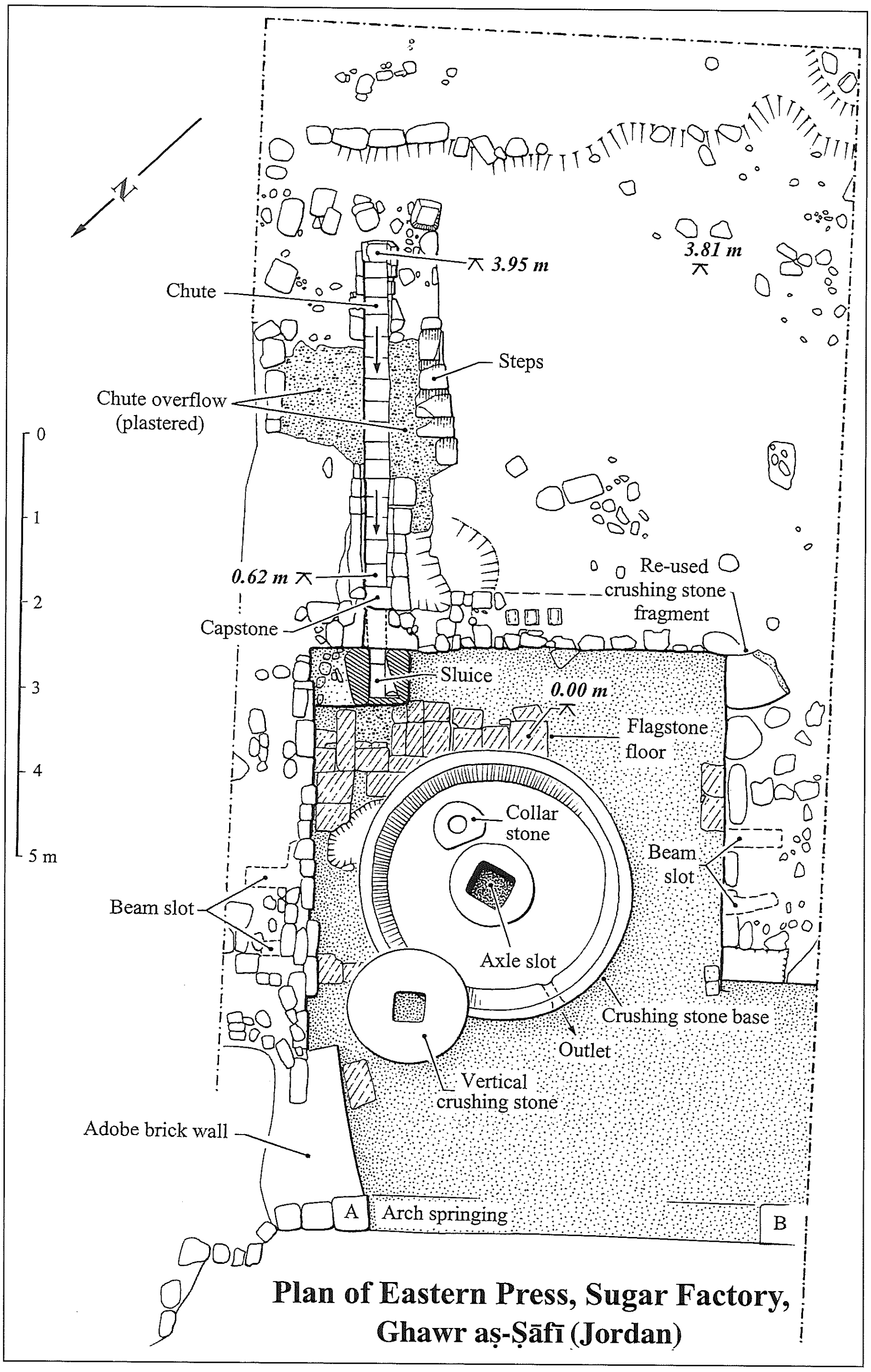
using high-powered water jets and a third water-press (with a vertical penstock) to the west. The third press, with the vertical penstock, is somewhat smaller than the edge-runner examples (generating a smaller head), is sequentially the last to be fed by the aqueduct and may therefore have been less important than the parallel arrangement. Its construction post-dates that of the two parallel edge-runner water-presses.

The sub-structure walls of the two parallel leats still stand to a height of *ca.* 4m in places. The channels are still visible along the tops of both leats, where they are defined by finely-cut sandstone blocks. The sub-structure walls are constructed of a mortared-rubble core faced with rough courses of natural stones of similar size and shape. Each of the parallel leats incorporates a single arch with a height of approximately 2m. On approaching the press-house installation, the leats descend sharply and obliquely, and the channel narrows to increase the force of the water. Both channels are lined with series of U-shaped sandstone troughs along this sharp descent into the installation. Although it is conceivable that the water could be stopped at the base of the chute by a sluice (as previously suggested by Photos-Jones *et al.* 2002: 602), it is more likely that the water flow would have been cut off (and thus controlled) along the main branch of the channel behind the parallel leats, allowing it to be diverted to whichever press-house was in operation. Such an arrangement has been described by Jones *et al.* (2000: 527), who refer to four distinct elements along the main aqueduct branch behind the parallel leats. These channel divisions were supported by substantial buttressing, which may have supported sluice devices at this point.

Eastern Press (FIG. 4)

The northern extent of the upper press chamber measures 6.90 m north - south by 4.80m east - west. The centre of the room was occupied by a substantial basal crushing stone 3.10m in diameter. The upper crushing stone has fallen over the north-eastern lip of this base stone but would have originally sat on edge and rotated over the base stone with the aid of wooden beams and a securing collar-stone. The floor of the entire room was originally paved with flagstones, now mostly surviving *in situ* in the south-eastern corner of the room. Isolated examples survive at the base of the eastern and western walls of the room.

Directly below the lower, basal crushing stone, there was a vaulted chamber which would originally have housed a gearing mechanism and gear-wheel emplacement similar to those found at the second complex at Kouklia in Cyprus (TST 1) (Maier and Karageorghis 1984: 334), Jericho (Taha 2009: 186, fig. 4) and Tall as-Sukkar (Abu Dalo 2010: figs. 4-5, 9-10). Similarly, the gravity-fed aqueduct system would have terminated in a covered pressure channel tapering narrowly towards a spout to greatly increase the power of the water. The water jet issuing from this spout would have operated a horizontal wheel which would have driven the



4. Plan of eastern press of Maʻāṣir as-Sukkar in Ghawr aṣ-Ṣāfī (J.M. Farrant).

upper crushing stone by means of a wooden vertical shaft and cross-beam. The shaft may also have engaged with some kind of wooden gear, as indicated by corresponding sockets in the elevation of the eastern wall of the upper storey. The tail-stream exited the complex through a subterranean conduit which runs northwards from the complex. The room was accessible via an arched doorway in the northern wall measuring 2.05 x 1.90 m, which allowed access for maintenance and monitoring of the wheel mechanism.

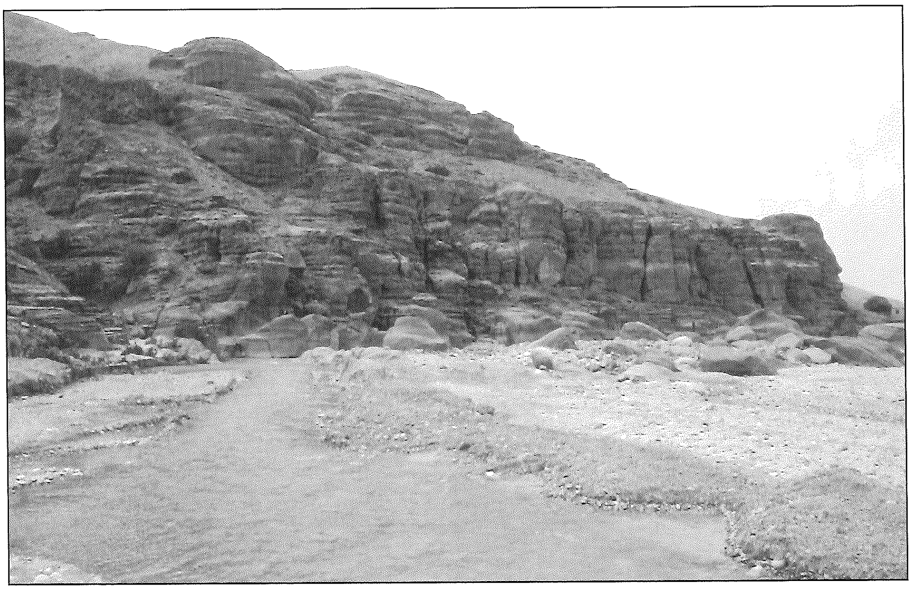
At the base of the northern wall of the eastern press, immediately north of the arched doorway, many hundreds of sugar pot fragments (mostly consisting of the upper cones) were found. These identify the area as that where the upper sugar pots or cones were smashed at the production site. This action was necessary to remove the sugar-loaf from the upper cone-shaped vessels which sat in the mouth of the lower molasses jar. The density of sugar pots in this layer concurs with the contemporary estimate that 2,500 - 3,000 vessels were needed as basic stock for a sugar refinery (von Wartburg 1983: 309).

That the removal of the crystallised sugar loaf from the cone was a difficult operation which often resulted in breakage of the ceramic cone is also well-attested at Kouklia in Cyprus, where the ratio of cones to jars is remarkably uniform, with cones consistently predominating (von Wartburg 1983: 309). In the light of this, it was particularly significant to discover complete cones during excavations at Khirbat ash-Shaykh 'Īsā (Politis *et al.* 2004: 319, 2007: 207, fig. 17). This discovery securely links the urban site with the adjacent sugar factory. Furthermore, these complete cones and pottery kiln wasters (see below) indicate that they were produced there as complete pots. They rarely survive at industrial sites and are usually found only as fragments, owing to the nature of their function and use.

These sugar pot cones are similar to Type IV from Kouklia (von Wartburg 1983: 313, fig. 10, plate LII 2 and 3). Large cones of this type are thought to have been used for the production of crystal sugar, as opposed to the high quality sugars formed in the smaller cones (von Wartburg 1983: 314). Luttrell (1986: 165) deduces that the predominance of pottery cones used for making crystal sugar, rather than moulds used for the more expensive sugar loaf, at both Kouklia and Episkopi in Cyprus indicates that the cheaper variety was more important at these sites. This may also have been true at Ghawr aṣ-Ṣāfī.

Aqueduct

All three presses within the complex were fed by a substantial contour-line gravity-flow aqueduct which was fed by Wādī al-Ḥasā and descended along the south-west slope of the wadi mouth, using gravity-flow to reach the press. High in the mouth of the wadi is a substantial stone-carved conduit (Politis *et al.* 2004: 320, fig. 13) with a stone-carved *specus* 1.5 - 2 m wide. A Nabataean inscription and niche on the southern escarpment of this length of channel may mark the point at which the water was originally tapped, perhaps by a dam which has subsequently been washed away (FIG. 5). Smaller, early 20th century dams to the west were visible after a flash flood in 2007. The width of the aqueduct's channel, directly behind the parallel leats, is 1.35 m while the channel widths of the parallel branches are 0.95 m. The substantial dimensions of the channel itself (both in the wadi and directly behind the crushing installation), the presence of three large water-driven presses and archaeological evidence for a high degree of industrial activity at the site all suggest that a substantial amount of water was required for the installation to operate at its full potential. The scale of the facility as a whole is comparable to the second press at Kouklia in Cyprus. The main difference between the two instal-



5. Dam location in Wādī al-Ḥasā from east (K.D. Politis).

lations is that at Kouklia, the press is divided into two main parts: the pressing chamber and 'grinding hall'. Only the former was water-powered, whereas the latter was animal-powered (von Wartburg and Maier 1983: 303). At aṣ-Ṣāfī, the indications are that all three presses were water-powered.

Sinter build-up, a calcareous encrustation which is estimated to grow at a rate of *ca.* 1mm per year (at least in Roman aqueducts; see Kessener 2000: 111), is evident in places along the sub-structure walls of the leats and on the soffits of the *voussoirs* of the western arch. This evidence either reflects a degree of leakage during the operation of the press or, more likely, marks the point at which the press fell into permanent disrepair.

The vast amount of water directed towards the site was also used to irrigate the surrounding agricultural fields, where sugar cane was presumably cultivated. In 1997 the corbelled vault of the underground water channel coming down from the western press had partially collapsed at its north end and the author was able to descend into it to record it (FIG. 6). The channel was more than 1.5m wide and 2m deep, and was plastered on its lower part. A length of more 100m running on a north - south axis was provisionally identified, but presumably it ran much further towards the town centre and into the plantations.

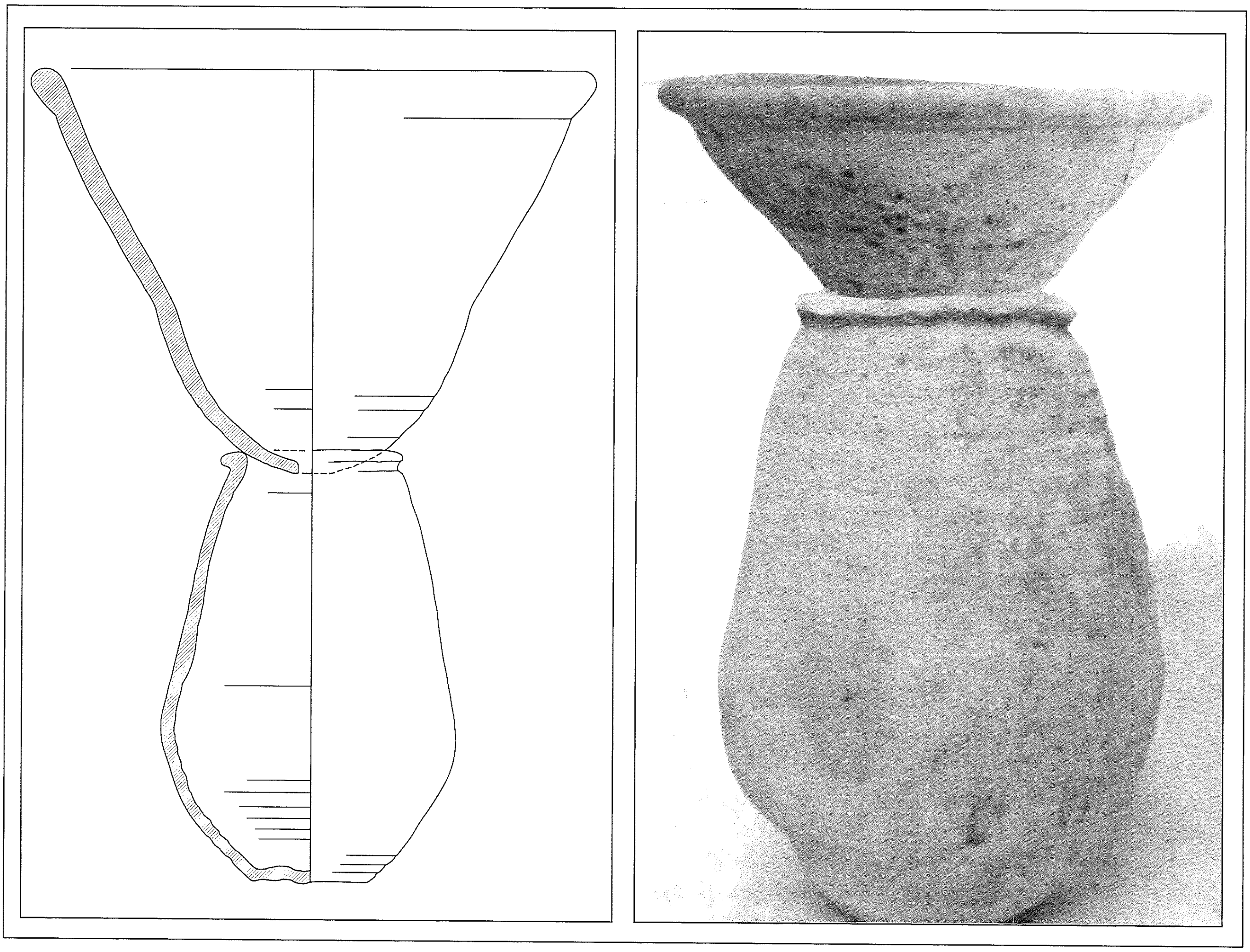
Archaeological Finds and their Dating

Archaeological surveys and excavations conducted between 2000 and 2008 at Ṭawāḥīn as-Sukkar and Khirbat ash-Shaykh 'Īsā in Ghawr aṣ-Ṣāfī resulted in the discovery of various finds related to the sugar industry, which help to date its establishment and period of operation.

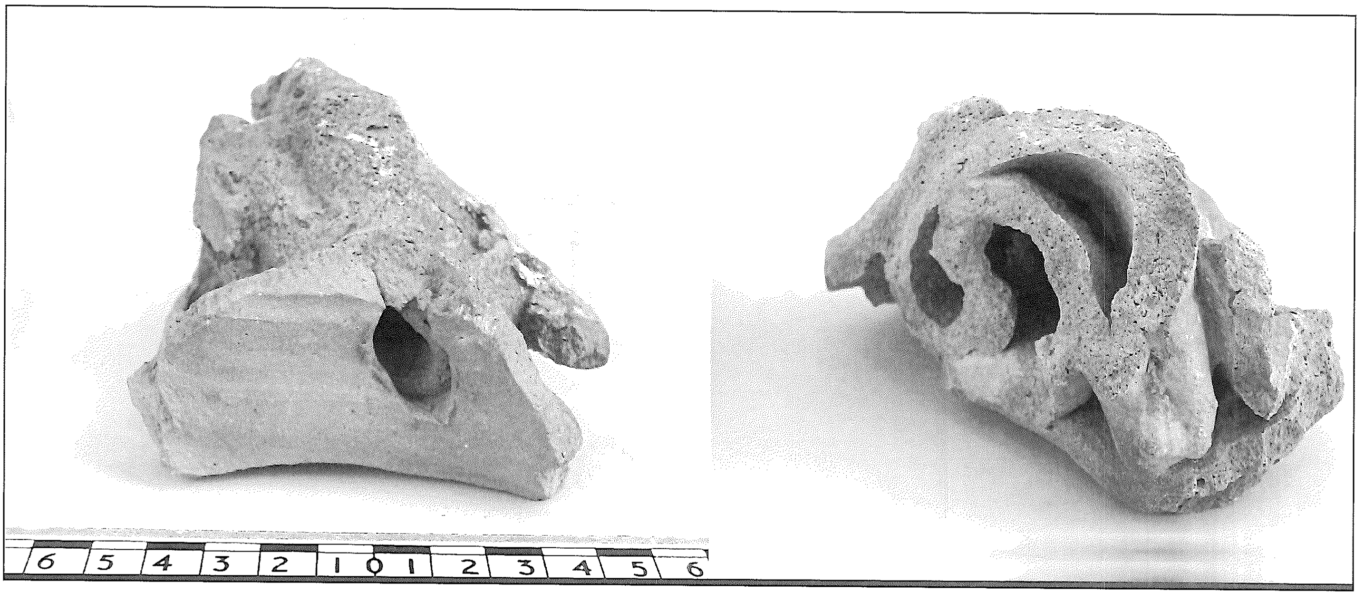
Pottery sherds recovered from the ground-surface as well as from excavations indicate that the sugar factory at Ṭawāḥīn as-Sukkar could have functioned from as early as the 8th or 9th centuries AD. However, the majority of sherds have been dated to the 12th to 14th centuries AD (Grey and Politis in Politis 2012). The most significant of these pottery finds are two related types of sugar pot, which are by far the most ubiquitous on the site, comprising 77% of all pottery finds. The upper pot has a conical form with a wide thickened out-turning rim and a perforated base. It was the container for the boiled sugar juice, where it solidified and crystallised. The lower pot was an ovoid-shaped jar with a dimple, or *omphalos*, at the centre of its base which collected the molasses syrup as it dripped down from the upper one (FIG. 7). These two types of sugar pot actually functioned as a single unit. Many of these sugar pots have been found on the surface and in stratified deposits at the urban site of Khirbat ash-Shaykh 'Īsā, along with large quantities of pottery kiln wasters (FIG. 8), and clearly attest to sugar pot production at that location (see above).

Three main sugar pot rim types have been distinguished: plain, angular and rounded for upper pots, plus a number of other types, such as flat and angled, for the lower collecting jars. Although rim

6. Underground water channel of western press of Ma'āṣir as-Sukkar in Ghawr aṣ-Ṣāfī (T. Springett).



7. Upper and lower sugar pots from Ghawr aṣ-Ṣāfī (photo K.D. Politis; illustration C. Schofield).



8. Sugar pot wasters from Ghawr aṣ-Ṣāfī (R.E. Jones).

diameters vary widely, smooth-bodied forms of the lower jars are an earlier, 12th century form, contrasting with much heavier (and later) ribbed forms. Differences in form may reflect differences in the grades of refined sugar, as well as differences in date. However, the industrial nature of these mass-produced pots means that the potters may not have paid too much attention to the finishing of rims and bodies of the vessels (de Haas *et al.* 1992: 338).

Other significant pottery finds included a 9th – 11th century Egyptian bowl from Fayyum, a Syrian under-glaze painted soft-paste bowl with blue vegetal motifs and a glazed slip-painted 13th century bowl imported from Cyprus, probably Paphos (FIG. 9). All these, but especially the latter, indicate connections with other sugar-producing centres.

The pottery typology from the Ghawr aṣ-Ṣāfī excavations, which consist predominantly of sugar pots fragments, did not produce a definitive date for the initial establishment of the sugar factory, but suggested that it was at its peak during the Ayyubid - Mamluk period.

Although the exact date of the earliest operation of the presses is not clear, their working-life was long enough for the upper crushing stone to have been replaced at least once. Several large building blocks of the western wall of the pressing chamber were identified as a fragments of arcs of an upper crushing stone, one with the squared edge of the central aperture and outer curving edge still preserved (see FIG. 4). Late 15th century AD burials placed within the eastern pressing chamber (Photos-Jones *et al.* 2002) (FIG. 10) confirm that it had ceased to function by that date, concurring with the ceramic evidence.

Most of the coin finds seem to be Late Roman,

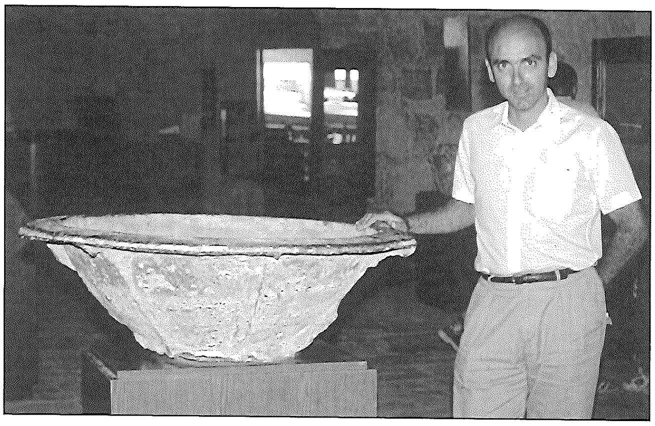
9. 13th century AD glazed bowl base fragment probably from Paphos, Cyprus (K. D. Politis).

10. Late 15th century AD glass bangles from burials at Ghawr aṣ-Ṣāfī (T. Springett).

mirroring those discovered at the nearby site of Dayr 'Ayn 'Abāṭa. These coins continued in circulation beyond the 4th century (Bowsher in Politis 2012). A few are early Byzantine, most were Islamic, but one (GS-KSI 401) is a Crusader issue of the Kingdom of Jerusalem (Metcalf 1995: pl. 12). This last coin is the most direct indication of a Crusader presence in or contact with Ghawr aṣ-Ṣāfī.

A *dusut*, or large mould-made copper cauldron (FIG. 11), found at Ghawr aṣ-Ṣāfī completed the evidence for the refining cycle of mashing, boiling, collecting and cooling being performed at the site. Such copper vessels are more energy-efficient because they distribute heat more evenly than iron equivalents. Their large size is further evidence of the industrial-scale metal production needed by the sugar industry.

It can be expected that *bagasse*, the waste matter from sugar cane crushing, was used to fuel the boiling process (see above). Such material is still used today as an alternative fuel as it is readily available and highly flammable. A limited chemical study of waste material sampled from test excavations failed

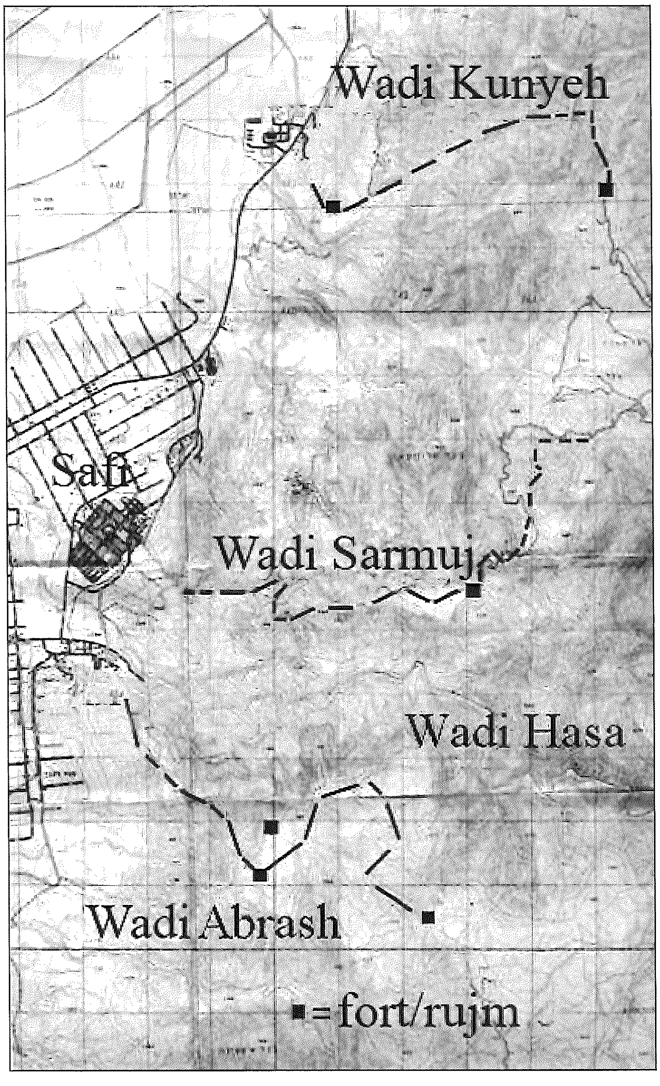


11. *Dusut* copper cauldron from Ghawr aṣ-Ṣāfī (T. Springett).

to identify any sugar cane elements, but instead revealed a high proportion of calcite and gypsum (Photos-Jones 2009: 227-228), both quite common in the highly saline soils of the region. However, more recent botanical analyses have identified actual charred sugar cane fragments (Politis 2012).

Study of the animal bones recovered from the excavations at the site has shown that zebu (*Bos primigenius indicus*), a cattle species usually employed for draught and tillage (as opposed to meat and milk production) was kept there during the Ayyubid - Mamluk period (Martin in Politis 2012). Furthermore, the zebu's Indian origins mirror the south Asian derivation of sugar cane, highlighting interrelations between the two regions.

The zooarchaeological investigation also focused on identification of potential pack animals,



12. Map showing the three eastern routes into Ghawr aṣ-Ṣāfī (G.A. Papaioannou)

which would have been used to transport agricultural and other products. Initial animal bone analyses indicate that camels were used at the site (Martin in Politis 2012). At Wādī Abrash, south-east of Ghawr aṣ-Ṣāfī, a narrow track is still used by camels today (Politis *et al.* 2007: 203, figs. 9-10) as evidenced by fresh camel dung and graffiti. Camels as work animals are also depicted on the Umayyad-period wall paintings at Quṣayr ʻAmra (Walmsley 2009: 465).

During the Umayyad period, a road network with regular stations was established in Bilād ash-Shām, some along Roman - Byzantine Imperial roads, thereby ensuring good access for both pilgrims and trade. These are known to have passed through Zughar (Walmsley 2009: 463). Recent surveys have identified three routes from the eastern plateau down to Ghawr aṣ-Ṣāfī (FIG. 12), including a main, former Roman - Byzantine Imperial road with three open-air mosques (Politis *et al.* 2007: 203, figs. 9-13). A route west of Zughar led to the Mediterranean port of Gaza via Mezad Zohar, just below Ma'ale Zohar (= Zohar ascent), which may have been a kind of weigh-station for sugar on the basis of the sugar pot fragments found there (Erikson-Gini 2011). This may be the same road mentioned by the Crusaders (William of Tyre: ch. 412). These routes could have been sections of a more extensive *darb as-sukkar* transport network.

Identifying the people involved in the sugar industry is more problematic. Mediaeval population studies have not been conducted and physical anthropology is restricted because of modern religious sensitivities. However, a small group of late 15th century AD human skeletons recovered from Ghawr aṣ-Ṣāfī which is currently under study clearly shows that their diet was heavily reliant on the consumption of carbohydrates, including sugars (Gasperetti in Politis 2012). Indications of an influx of new populations into the Jordan Valley also need to be investigated, in view of accounts describing the importation of slave-labour from Africa for the sugar industry.

Discussion

Excavation of the sugar factory at Ghawr aṣ-Ṣāfī has revealed a high degree of press sophistication in the area south-east of the Dead Sea. Von Wartburg and Maier claim, when describing the sugar press at Kouklia in Cyprus, that technical improvements (e.g. an increase in motive power derived from use of a high pressure water jet, or the use of specially-constructed wheels) resulted in a Cypriot type of press that was more advanced than the type normally used in Bilād ash-Shām / the Levant. This was powerful enough to operate heavy edge-runner presses (1989: 179). While this argument is valid, the fact that these features are present at Ghawr aṣ-Ṣāfī refutes any notions of retardation in the Levantine industry, as is often suggested. Luttrell (1996: 166) attributes the decline of the Bilād ash-Shām / Levantine sugar industry to the supposed absence of technical features such as gearing, which was most probably present at Ghawr aṣ-Ṣāfī. Ashtor (1992: 111) also makes much of the stagnation of the sugar industry in Bilād ash-Shām / the Levant and claims that most presses were driven by animals. At Ghawr aṣ-Ṣāfī, all three presses are water-powered and water-powered presses are evident throughout the region, e.g. at Mazra'a and Fīfā.

The sophistication of the sugar factory at Ghawr aṣ-Ṣāfī is attested by the fact that nearly all the refining processes are evidenced on-site. The degree of industrial competence here is not surprising considering that the refining process was perfected in Bilād ash-Shām / the Levant, with Syrian specialists of high repute in charge of refining the entire sugar production of Cyprus until July 1468 (Maier and Karageorghis 1984: 329). The presence of three presses, the vast quantities of water channelled to the complex and the sheer quantity of broken sugar pots on-site are all indicative of a highly-developed factory whose progressive technology should prompt a reassessment of the sugar industry not just in Transjordan, but in Bilād ash-Shām / the Levant as a whole.

Analysis of the pottery finds suggests that the sugar factory may have been established as early the 8th or 9th centuries AD and was certainly fully operational by the Crusader and Ayyubid - Mamluk periods. The late 15th century AD burials found within the crushing chamber demonstrates that operations there had been abandoned by this time.

This evidence accords with developments in the wider trading world. In the 15th century, the Spanish and Portuguese introduced sugar cane to the islands of Madeira, the Canaries, Santiago and Sao Tome. By the later part of the 15th and early 16th centuries, sugar from these islands was flooding European markets, with ruinous effects on the sugar industry of both the Christian and the Muslim Mediterranean littoral (Watson 1983: 145).

Alternatively, Luttrell (1996: 169) has argued that the Mamluk sugar industry fell into decline before such competitive market forces were introduced to the Mediterranean, pointing instead to over-arching crises caused by recurrent plagues and civil wars which led to dramatic depopulation, a situation aggravated by government interference, over-taxation and technological stagnation. The palaeo-environmental record of the Dead Sea region clearly demonstrates a marked decrease in rainfall after 1400 AD (Bookman *et al.* 2004: figs . 5, 8), which may also have contributed to agricultural and economic decline.

Conclusions

Recent archaeological evidence indicates the possibility that the sugar industry was established in the Jordan Valley as early as the 8th or 9th centuries AD, substantiating contemporary Arab accounts. In the 11th century, European Crusaders conquered the Holy Land and soon acquired a taste for the new sugar substance, maintaining large factories to produce it and exporting much of it to Europe. When Arab control of the lands was regained by the Ayyubids - Mamluks in the 12th - 13th centuries, they expanded these complexes, especially in the well-watered Jordan and Nile river valleys, and profited enormously from the trade in sugar until approximately the 15th century. By this time, Europe had become so dependent on sugar that it began building its own factories to produce it, such as those on the Mediterranean islands of Cyprus, Rhodes, Crete and Sicily, and eventually Madeira (Ouerfelli 2008). These refineries introduced a further process involving the addition of lime-water and blood, the whole mixture being boiled until the solution was clear. It was not until the 19th century that refining with charcoal and decolourising agents was introduced (Singer *et al.* 1957: 8) which enabled production of the pure white sugar we are familiar with today.

The Maṣna' as-Sukkar in Ghawr aṣ-Ṣāfī is important because it is the largest in Palestine and Transjordan. The nearby sites of Khirbat ash-Shaykh 'Īsā and al-'Amarī / al-Rujum were integral parts of Zughar, the major market centre in southern Bilād ash-Shām from which sugar was traded and exported via an east - west road network to leading to Gaza and thence to the European markets. Because sugar was so closely associated with the city of Zughar, it is likely that it gave sugar its name.

The international impact of the sugar industry cannot be overstated. Not only did it represent the apogee of mediaeval Arab science and technology but was also keenly sought after and eventually emulated by Europeans. Sugar thus became a major world commodity. Ultimately, sugar production and its industrial by-products became important components of the Industrial Revolution in 18th century Europe.

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