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Water-Mills in Jordan: Technology, Typology, Dating and Development

The occurrence of water-mills represents a stage in the development of the human search to convert "natural energy into motive power" (Forbes 1955: 78), that is, for running other machinery involved in the production or processing of material. Forbes identifies five power stages which Smith (1977: 215) neatly summarizes: an opening stage in which mankind uses only its muscles; a second stage which harnesses the power of animals; a crucial third stage which exploits the energy of wind and water; fourthly what might be called the heat engine stage, a complex phase embracing the reciprocating steam engine, internal combustion engines and the steam turbine; and lastly the currently emerging atomic power stage. These "power stages" are not successive — often several stages existed together and were used to meet the same or varying demands in spite of different technology.

In milling the demand is that of efficiency in producing greater quantities of the end-product more quickly. In effect, water-mills for grinding flour brought mechanization to the rotary quern which was used in Bilād ash-Shām for grinding flour from the second millenium BC (Forbes 1955: 141). Rather than producing greater quantities of flour for the export market, it is the belief of the author that the watermills so common in the *widyān* of Jordan are a case of appropriate technology for an essentially rural society. Their apparent conservatism can be directly related to the fact that they served their purpose and that there was no need for any further development as they performed their function perfectly adequately. This type of use did not change with the introduction of steam-mills which were also used by a primarily subsistence economy.

The aim of this paper is to describe the various types of water-mills and their technology; to consider several examples from Jordan in more detail; to refer to the problems of dating and to comment on the appearance of steam-mills.[1] The article is based on field-work that was conducted in 1983 during the Wādī al-'Arab survey. Since then several water-mills in Wādī Ḥisbān and in Wādī Ibn Ḥammād[2] have been recorded. The enclosed map (FIG.1) shows the sites which will be referred to in the text.

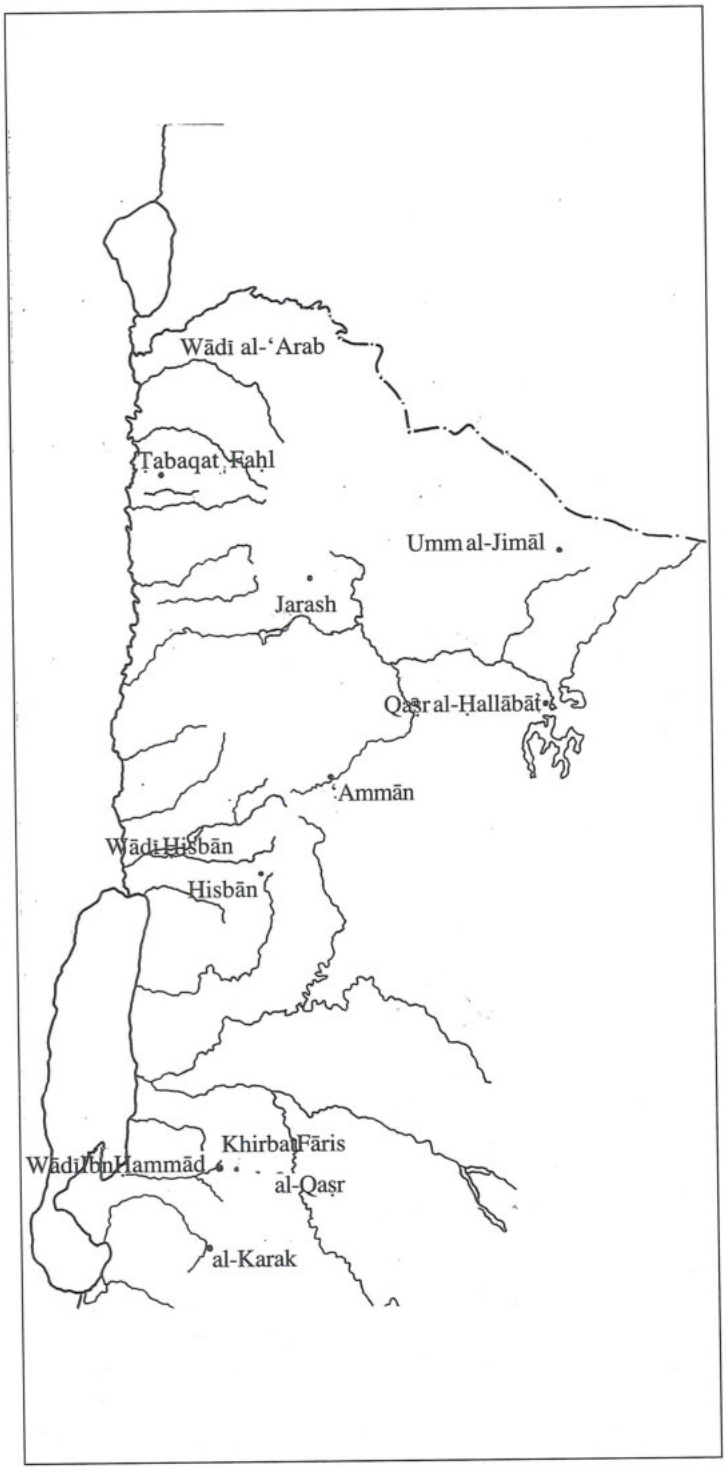
Typology (FIG. 2)

Water-mills fall into two main types — those with a horizontal wheel and those with a vertical wheel. In current literature this distinction is not always brought out. In fact the two groups share a technological concept but the execution is different.

The mills powered by vertical wheels involving the use of gearing again fall into two groups: 1. the under-shot wheel; and 2. the overshot wheel. Vitruvius describes a vertical wheel with horizontal shaft and gears in his *De Architectura X/V,* showing that the under-shot vertical wheel was in use by 25 BC. The vertical wheel was the type widely adopted in the Classical World and is known from a Byzantine mosaic in Constantinople (Tölle-Kastenbein 1990: 163) as well as from excavations, e.g. the Roman mill near the Mithraeum in the Baths of Caracalla, Rome, re-excavated in 1980 by Wikander and Schiler (Schiler 1989: 138), and Ephesos in western Turkey (Wikander 1984: 161). These vertical water-mills were those chosen for "research and development" during the Industrial Revolution in Europe. Vertical water wheels for lifting water are well-known from Bilād ash-Shām, e.g. Ḥamā and Antioch on the Orontes, but not vertical water-wheels with gearing for producing power to run machinery.

[1] I would like to acknowledge the support of the Raymond Carr Fund and the Committee of Graduate Studies, University of Oxford for contributing to the cost of attending the conference.

[2] The Wādī al-'Arab Survey was directed by Dr. J. Hanbury-Tenison. The water-mill study was carried out by the author and Mark Gardiner and its results can be found in Gardiner and McQuitty 1987. The Wādī Ḥisbān mills were recorded with the help of Ms. Suzanne Kerner, Dr. Cherie Lenzen and Dr. Kay Prag. The Wādī Ibn Ḥammād mills were explored during the course of the Khirbat Fāris excavations.



1. Map of Jordan showing places mentioned in the text.

Distribution of Vertical Mills in Jordan

Evidence for vertical water-mills in Jordan is confined to the wadi linked with the Roman fort of al-Lajjūn, which also provided the military population with their daily water requirements. Parker reports finding five undershot mills and a possible overshot mill (1983: 226) and de Vries has supplied a convincing reconstruction of the system in use (de Vries 1987: 399-428). However, excavation and oral history have shown that these structures date from the recent 19th century Ottoman use of the area and its spring (pers. comm. B. de Vries).

Horizontal Wheeled Mills

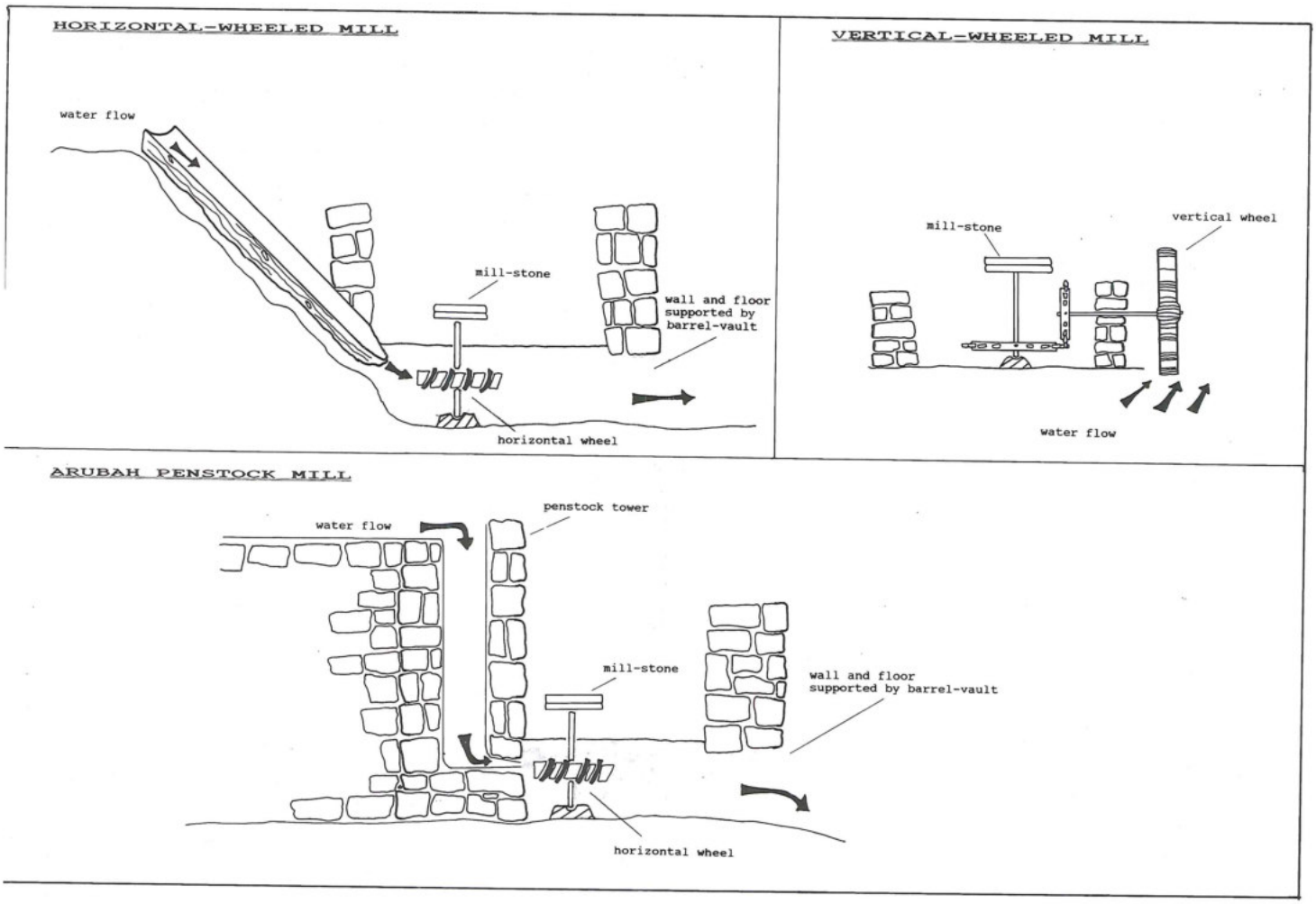
The mills driven by a horizontal wheel can again be considered in two main groups which are based on the differing methods of water delivery and associated superstructure.

1. The "Greek"/"Norse" mill which is driven by the force of flowing water hitting horizontal paddles and producing a slow rotation. As FIG. 2 shows, the water delivered to power this wheel can be down a simple chute, e.g. a hollowed-out log.
2. The horizontal wheel which operates under pressure of water delivered down a constructed tower and which exits through a narrow nozzle. This is the precursor of the turbine and not surprisingly produces more power (FIG. 3).

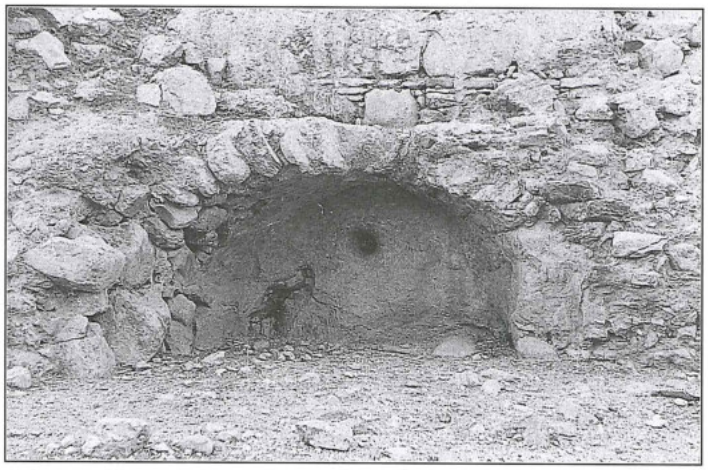
Horizontal-wheeled mills have a very wide distribution and in their most basic form (the so-called "Greek"/"Norse" mill depending on the preferred origin) were a common sight in agricultural communities. Such mills using a hollowed out tree-trunk down which the flow of water is directed, have been reported from Northern Europe (Strauss 1971: 22ff.), the Balkans (Wilson 1952: 2), Peru (Gade 1971: 44) and eastern Turkey (pers. comm. J. Hather). The original date of this type of mill is unclear — the earliest literary references to water-mills are to water-mills in general rather than identifying particular types. However, later Classical writers do refer to mechanisms which are to be associated with these horizontal mills, e.g. Pliny in the first century AD writes "in the greater part of Italy a roughened pestle is used, and wheels also that water turns round as it flows along; and so they mill" (*Nat. History* 18: 23).

An increase in this method of powering the wheel is introduced when the raised tower is constructed and the water exits the arubah penstock/water chute as a jet and hits the wheel at pressure. This is erroneously called a turbine *unless* the wheel operates in a closed-space. All the evidence from Jordanian examples suggests that this was not the case and that the water-jet exited freely from the wheel chamber rather than from a confined space.[3]

[3] It has recently been claimed by Schiler (1989) that he has evidence for Roman turbine mills on the Crocodile River near Caesarea Maritima, Palestine. However, as he himself points out, there is no proof for the turbine wheel and as far as I can tell it could equally well be a horizontal wheel turned by a jet of water. This in itself would be interesting since until now a Roman example of *this* type of wheel in Bilād ash-Shām has not been excavated. However, the Roman date of AD 345-80 was based on C14 analysis which is problematical for mortar, particularly in a limestone area (pers. comm. Dr. R. M. Hedges, Accelerator Unit, Oxford Research Laboratory). Another recent candidate for a Roman horizontal wheeled mill is that still standing at Wādī Faynān which is associated with the presumed Roman reservoir.



2. Watermill types.



3. Water outlet at the base of the penstock tower from which the water exits under pressure onto the mill-wheel.

Distribution

The distribution of this type of raised-tower mill is common throughout the Eastern Mediterranean. Those from Palestine have been catalogued by Avitsur (1960: 37-46) and Schiler (1989: 142), and Chehadé has reported on examples from Syria (1973: 241-273). Similar watermills are reported from Oman and are dated to the Islamic period and associated with *falāj*/irrigation systems dating to the 9th-17th centuries AD (Costa and Wilkinson 1987: 56-57 and PLS. 57-59). Wilkinson also refers to similar examples from the agricultural hinterland of Siraf, Iran (1975: 165-166). Dr. S. Roaf has recorded similar arubah-penstock mills from Iraq (pers. comm.). The chief variation of these southern examples from those of the Bilād ash-Shām seems to be that they are an integral part of a controlled irrigation system and do not rely on the mountain-stream aspect.[4] Doubtless the distribution of this simple horizontal-wheeled mill extends or extended all over the rural mountainous regions of South-West Asia. They occur as far east as Kashmir (pers. comm. B. Rehman).

The known, extant water-mills in Jordan are all of the

[4] This is not to say that the Jordanian examples do not form part of irrigation systems which lead water to agricultural terraces and gardens — some of them do — but it is not the prime aspect.

horizontal-wheel type and of the second group, i.e. with an arubah penstock on average 4.00 metres high (FIG. 4). Their distribution is wide-spread — along most of the east-west *widyān* running into the Jordan River and the 'Arabah depression, [for examples from other surveys see the Wādī al-Ḥasā Survey, MacDonald 1988: 284-288; the Wādī Ḥisbān Survey, LaBianca 1990: 194; Northwest Arḍ al-Karak Survey (Wādī Ibn Ḥammād and its tributaries) Worschech 1985: 17-20, 67]. The mills under consideration here show no sign of having been used for anything but grinding grain, i.e. they are not surrounded by fragments of sugar-pots.[5] The requirements for these mills are not major —a stream of fast-flowing water, and knowledge of hydrological methods both for installing the machinery and for ensuring the flow of water. Arubah penstock mills are an ideal adaptation to situations where the flow of water may not necessarily be strong or constant. The high penstock results in the build-up of a head of water and the resulting pressure. This can be increased if a holding-tank is introduced into the system. This contrasts with the "Greek"/"Norse" mills which rely on the speed of the flow of the water itself without manipulation. The arubah penstock mills seem to be a considerable advance, taking environmental factors into consideration in their design; a fairly steep bank but a situation that does not preclude access for animals bringing the grain to be ground; knowledge of construction methods for both the penstock and the leats and channels leading to it and the mill-house.

The mills considered here are all located on perennial *widyān* — Wādī al-'Arab, Wādī Ḥisbān and Wādī Ibn Ḥammād. Given the present needs of the population in pumping out water for irrigation, it is hard to reconstruct the water-flow at the time when the mills would have been in use. However, certain technical adaptations could have been made for dealing with a low body of water, e.g. the size of the nozzle directing the jet of water from the penstock to the wheel could have been increased or decreased (Wulff 1966: 400). Measures taken to ensure a steady supply of water can be seen in the remains of channels leading water off from upstream to the mill tower. In one instance in Wādī al-'Arab a dam has been constructed c. 2 km upstream from which the channel leads, in Wādī Ḥisbān similar channels could be seen running along the "cliffs" above the wadi, a situation which is paralleled in Wādī Ibn Ḥammād although here the channels seem to be part of a more complex irrigation system (pers. comm. William and Fidelity Lancaster). The mills are constructed in "chains" along alternate sides of the wadi where the topography is suitable.

Distribution of Horizontal-Wheeled Types in Jordan

The mills of Wādī al-'Arab are of two types: 1. single penstock mills; and 2. double penstock mills (FIG. 5).

Two mills examined in Wādī Ḥisbān are again of both types and the remains of the third are too fragmentary to determine its type. Those of Wādī Ibn Ḥammād are just single penstock examples. I know from travelling

4. Single arubah penstock in Wādī Ibn Ḥammād.

5. Double arubah penstock in Wādī al-'Arab.

[5] Sugar-mills are well known from the Jordan Valley, cf. Hamarneh (1977: 19) and MacDonald (1987: 410). A sugar-mill dating to the 13th/14th century AD on ceramic grounds has been excavated at Stavros, Cyprus (von Wartburg 1983: 303-304). Here the horizontal-wheeled, arubah penstock mill was used to pound and crush the cane. From the surviving structure it seems as if this type of mill was also used in Jordan for crushing sugar.

around, that in Wādī az-Zarqā' and Wādī Kufranja there are examples of both types, while in Wādī Shu'ayb there are just single penstock mills. In addition, it seems that in Wādī al-'Arab there is one example of a simple "Greek"/ "Norse" mill, (no. 062, Gardiner and McQuitty 1987: 32). The water-chute adjoins the natural incline in the land so that the fall in water can be achieved without a raised tower. Until further fieldwork is done, it would be rash to say that the presence of multi-phase and multi-penstock water-mills in the north as opposed to the apparent single-phase and single penstock of the southern mills means anything. However, it does seem that double penstock mills are more common north of Wādī al-Mūjib. G. Palumbo has recently noted a six-wheeled mill near Jarash, and this may be related to greater grain production in the immediate area or greater demand (pers. comm.). As yet the sample is too small to allow such conjectures.

Date

It seems clear that there is a history of such mills in Jordan, but as it has been so concisely and dampeningly put by Hill, "..the survival of an old mill does not necessarily tell us very much about its history. We cannot be sure, without further evidence, that there was a mill on the same site in mediaeval times, and in many cases milling installations were completely re-built on different lines in the eighteenth and nineteenth centuries." (1984: 130). Even scientific dating of the structures themselves is problematical; for the latest re-furbishment of these mills we can rely on documentary evidence (cf. Dr. E. Rogan's paper in this volume). For the *de novo* construction and the intervening use and re-use we cannot be so sure, and there was undoubtedly variation in periods of re-use throughout Jordan.

In Wādī al-'Arab two of the mill houses show several phases of use; in Wādī Ḥisbān one of the three mills examined showed an earlier penstock on the same site; the five noted in Wādī Ibn Ḥammād seem to be single phase but further investigation is needed to determine this. If the tentative dating of the mill in Wādī al-'Arab to the 18th century on grounds of tufa build-up is accepted,[6] and the reference of Conder that "At Sumieh and below 'Ain Hesban are the mills, which were erected by Dhiab of the Adwan in the year 1191 of the Hejirah" (AD 1777) (1889b: 129), it can be accepted that re-building took place in several *widyān* in the 18th century. Before that, perhaps there was another three hundred years of use on the same site. We know that mills existed in the 16th century because they were taxed (Hütteroth and Abdulfattah 1977: 72). But what of the period between the fourth and 16th centuries AD?

It is assumed that the 14th century AD sugar-mills of the Jordan Valley were horizontal-wheeled (Hamarneh 1977: 19). Hamarneh notes that al-Maqdisī, among others, speaks of the fame of the Jordan Valley for sugar-cultivation. This would push the date for production and processing back to the 10th century. Does one assume that horizontal-wheeled mills were also in use for grinding grain at this time? In the tenth century AD the Arab geographers refer to mills all over the Arab world (Hill 1984: 137ff.), but these seem to be references to more commercial mills. Before this date did hand-mills reign supreme? Were animal-powered Pompeian grain-mills in use? Was there a hiatus in water-milling between the fourth and tenth centuries AD? Excavation of some of these water-mills and certainly more detailed survey would help to contribute the answers to these questions.

Water-Mills and the Community

Would the environment in Jordan support production of a grain-surplus on a consistent basis or do these mills reflect processing for a subsistence rather than export economy? Grain keeps better than meal and flour and therefore "watermills would...tend to be positioned nearer to product consumers than corn producers" (Spain 1984: 173). Accounts of grain rather than flour being transported by camel and mule to Palestine are known from the 19th and 20th centuries AD and earlier. But in the case of rural Jordan for much of the past the main consumers were the producers. As shown by the following quote from Dalman writing in the 1930s, the water-mill was very important to the community: "Für Bauern und Beduinen ist die Wassermühle oft die wichtigste Art der Mühle im Grossbetrieb. Beduinenstamme schliessen zuweilen Waffenstillstand oder geben freis Geleit damit das Getreid zu einer Wassermühle geschafft werden kann." (1964: 243).

As to the ownership and use of these mills, Dr. Rogan's work sheds more light on this for the 19th century, detailing the considerable expense involved. The evidence from Conder (1889b: 129) and informal conversations about their use in the 20th century suggests that one or several were the property of one man. The names of the mills in Wādī Zahar as noted by Schumacher (1890: 143) suggest this and one of the mills on Wādī al-Kafrayn is recorded by Conder (1889a: 228) as "Tahunet Jodeh"; presumably originally belonging/used by the Jodeh tribe.[7] The Wādī al-'Arab examples show consistency in construction as do the Wādī Ibn Ḥammād examples, which suggests that they were all built at the same time, by the same craftsmen and probably at the in-

[6] The dating of the Wādī al-'Arab mill relies on the build-up of tufaceous deposits at a regular known rate (Gardiner and McQuitty 1987: 28). This same tufaceous deposit has been subjected to dating by the Oxford Research Laboratory for Archaeology and the History of Art; the results are as yet unknown.

[7] I am grateful to Dr. Kay Prag for bringing this to my attention.

stigation of one person or tribe. It seems clear that they were used by the local community although this may have been made up of several tribes. The arrangements regarding the water used to power these mills appear to have been customary involving negotiation between the various families/tribes who held sway in the area (pers. comm. W. Lancaster).

Construction

The construction techniques of the towers are fairly standard — well-built stone structures using both re-used blocks from antiquity sites and presumably locally quarried stone. The techniques required for building the arubah penstock and wheel-chamber were specific and it seems likely that there were groups of masons specializing in building the mechanism of water-mills as there were in building arches for houses. However the exterior of the towers shows no great variation from the stone vernacular house architecture of the last 150 years. There is much more variation in the mill-houses which would have held the grinding-stones. Some are as well-built as the towers; some are very shoddy and hardly deserve the term house; in many cases there is no trace of a mill-house. One presumes it was either made of impermanent material, e.g. mud-brick, that has been washed away by subsequent wadi flooding or did not exist in the first place.

Steam Mills

These mills were gradually replaced in the 20th century by steam-mills. The buildings housing the steam engines were of grand dimensions and although they were noted as early as 1886 by Schumacher in Ḥawrān (1886: 163), the greatest influx seems to have been in the 1940s when individuals imported them from Britain and France. Sometimes a village boasted more than one. The greatest contrast between these water-mills and the later steam-mills lies in their efficiency[8] and their siting, since the steam-mills were constructed in the villages up on the plateau very near the consumers. Water-mills still continued to be used after steam-mills had been introduced and sometimes there is an odd combination of imported and local technology, e.g. mill 003 on Wādī Ḥisbān is a single penstock stone and mud-brick construction with concrete foundations containing an imported conglomerate mill-stone bearing the words "Société Générale Meuliére France". Concrete was not in general use in Jordan until well after 1918, which would imply that this mill was refurbished at a late date. The introduction of steam-mills does not necessarily imply flour-production for the export market — it seems more probable that they were still used for the local market — for subsistence.

Conclusions

There seems to be no doubt that the "Greek"/"Norse" mill is represented in a more developed form in Jordan (and elsewhere in South-West Asia). The arubah penstock mills are more efficient and well-suite to an environment and topography which offers fast-flowing but seasonally varying water flow or an environmental situation which can be manipulated to produce the same conditions. In areas of permanently fast-flowing water, e.g. the Alps, there would have been no need to make such an adaptation. In Oman the mills were an integral part of the irrigation systems of the 9th-17th centuries AD — it would seem that the mills were the product of a culture that had the knowledge and skills of manipulating water. The wider distribution of arubah penstock mills shows a marked preference for the Arab/Islamic World. Examples from Europe appear to be confined to Spain and Sicily — both subject to Arab hegemony. Technical drawings of horizontal-wheeled mills are extant in Spanish documents of the 16th century (Reti 1967: FIG. 3) but all the information regarding other European late Medieval horizontal-wheeled mills points to the more primitive "Greek"/"Norse" mill. Apart from the possible Roman candidates mentioned above, the documentary and archaeological evidence for arubah penstock mills seem to date from the ninth century AD onwards. Could these mills have been introduced from the East along with the new agricultural crops of the Islamic "Green Revolution" (Watson 1981)? The mills may not always have been the tools of subsistence agriculture; certainly their role in the 13th century sugar production was not. However, this was the final result.

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[8] Efficiency in water-mills is measured by the number of times the grinding stones rotate compared to the number of times the water wheel turns. Forbes calculates that two slaves or a donkey move the querns at a rate of 0.4-0.5 HP; that the "Greek"/"Norse" mill moves the querns by 0.5 HP and that the Vitruvian mill produces an output of 3 HP (1955: 81). For an arubah penstock mill in Iran with a similar height tower to those encountered in Jordan but with larger grinding stones, Wulff calculates an output of 8.5 HP (1966: 400). The mechanism of one of the Jordanian mills would need to be reconstructed to settle this matter but there is no doubt they are more efficient than hand-grinding.

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