Notes on Traditional Hydraulics and Agriculture in Oman
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Paolo M. Costa

Introduction

About three decades of archaeological research in Arabia have produced an impressive collection of data which begin to define the identity of the civilization of the peninsula and its position and role within the ancient world. The 'discovery' of Arabia started, of course, many years before but remained the concern of a handful of specialists, mainly epigraphists, besides becoming the subject of many travel and political books. It is widely known that the rapid modern development of Arabian and Gulf states, which in the 1950s followed the discovery of oil, posed a dramatic threat to the conservation of a world which had remained secluded for centuries, virtually untouched by alien technology. What is less acknowledged is that later the oil wealth funded also scientific research on the region, becoming indirectly responsible for the re-evaluation of its traditions and history. Gradually all the Arab states, reorganized according to modern administration, established departments and institutes for the study and preservation of their cultural heritage. The bureaucratic machinery was unfortunately (and not surprisingly) slow in the practical implementation of the principles of conservation. Hit by waves of 'modernisation' and 'development', the architectural heritage paid the highest toll: not only were single historic monuments destroyed but sometimes the built environment of entire areas was obliterated. Besides producing vast damage and irreparable loss, however, the modern development of the 'oil states' brought forth also an ever-growing interest in the scientific study of Arabian civilization which indeed opened new chapters in the history of the ancient Near East.

What had appeared before mainly as the 'Nabataean region', after the best or only known Arabian civilisation, now became known also for the early contacts of Eastern Arabia and Bahrain with Mesopotamia and for the art and architecture of the pre-Islamic southern kingdoms, where influence from archaic and Hellenistic Greece and from the Roman world could be traced. The boost of research in the last ten years has brought to our knowledge the early Islamic architecture of the Yemen and the mining and trade of copper from ancient Oman. The discovery of the latest studies has been, in a word, the Arabia of settled life by contrast with the Arabia of the nomads; the Arabia of the great urban centres, with its amazing architecture, in opposition to the stereotyped Arabia of the desert and the tent.

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Hydraulics in ancient Arabia

The mythical Arabia Felix appeared to have been economically based not only on trade in incense and spices but also on a well-developed agriculture almost totally dependent, as in all arid lands, upon irrigation.

Not surprisingly, therefore, field-work and systematic exploration soon revealed the amazing extent over many areas of the peninsula of sophisticated systems for the catchment, storage and distribution of water. The dam of Mā'rib, cited in the Quran and traditionally regarded as the wonder and symbol of the South Arabian civilization, appeared now to be only the most famous of hundreds of similar hydraulic works to be found widely in the south-west of the peninsula. Mā'rib is certainly the most gigantic of all, but the dams of Wādī Shalālā, Marēb (near San'ā), Tan'am, Hāker and Ẓafār (to quote only a few) are no less impressive. Nor are giants like the cistern of Na'it – 100m long and 10 × 10m in section – or the majestic reservoir of Kawkaban.

Size, on the other hand, is not the most interesting aspect of these hydraulic systems: the ingenuity of their builders is reflected more in the technical solutions which can be seen implemented in thousands of cases, in the preparation and use of special mortars and building materials and in the skill required to carry out hydraulic surveys and the levelling of fields. Irrigation in fact does not simply involve the location and exploitation of an aquifer, but also the transportation and distribution of water. This is done by means of the *ghayl* or water-channel present almost everywhere in the valleys of Arabia and most common in Oman, where it is called *falaj*. The *ghayl* or *falaj* transports and distributes water by gravity. It may run a long distance from the take-off point and this for two reasons: it needs to reach the surface with a gentle and constant gradient and it must transport the water where fields and settlement can be most suitably located.

The location of a traditional agricultural settlement is principally determined by the availability of good soil which in Arabia is sometimes more difficult to find than water. Other factors are obviously relevant: land tenure, defence, safety from flash-floods and easy connection with the main caravan routes. Not all these requirements are always met by a chosen site, and of course sometimes particular considerations prevail. The main concern after the definition of tribal boundaries and problems of ownership is obviously defence, and this leads the settlers to select a prominence on which to build their houses; this makes the village safe also from the danger of floods. One of the most characteristic settlement patterns throughout Arabia is the concentration of the main built-up area on a rocky outcrop surrounded by a cultivated flood-plain. The problems of irrigation and their implications in the physical layout of settlements will be examined later in relation to the distribution of water to the writer's observations in Oman.

A considerable amount of research has been done on ancient agriculture and exploitation of water resources in arid lands, particularly in relation to extraction techniques and social organization. Most of these studies concentrate on Mesopotamia, Iran and North Africa; with a few exceptions they ignore the Arabian peninsula. Many scholars have examined the problem of the origin of the underground water-channel or *qanat* (correctly *qanā*, Arabic singular for canal or conduit; plural *qinā'* or *qanawāt*) in the Near East. Written evidence as early as an Assyrian inscription of Sargon II (721-705 BC) has been found on the existence of *qanat* in ancient Urartu, near Lake Urmia.

The problem of the origin of the *qanat* is not one easily to be solved, if at all, and certainly cannot be examined in any detail here, but a few remarks would perhaps be appropriate. The development of a particular method of water exploitation is obviously dictated by the hydrogeological environment. In the plains of Mesopotamia, for example, Assyrians and Babylonians built a network of surface canals taking water from the Euphrates, the Tigris and its tributaries. Though possessing an advanced technology they never developed anything like the *qanat* simply because, in that terrain, an underground channel would never have reached the surface. The Assyrian king Sennacherib, on the other hand, constructed underground water-channels to supply the town of Arbil, which is located near the mountains of Kurdistan where the hydrogeological environment is more suitable (Safar 1947; Oates 1968: 81, n. 1). Struck by the great development of irrigation under the powerful and well-organized Achaemenian rule, many scholars do not hesitate to identify Persia as the region where the *qanat* was first constructed. Clearly this sort of 'Iranian syndrome' arises from the fact that a considerable amount of archaeological work has been carried out in Iran, far greater than in any other Near Eastern country, perhaps with the exception of Iraq. None the less, the origin of this system somewhere in the hills of Armenia or Kurdistan seems not unlikely.

We have seen that ancient hydrology in Arabia has only recently been investigated; even more recently acquired is knowledge of copper mining and smelting in mid-3rd millenium BC Oman (Weisgerber 1981). It is largely recognized that mining techniques are the same as those used in the exploitation of underground water (Forbes 1964: 157; J. C. Wilkinson 1977: 76). It is also true that in Oman there could hardly be settlement without a *falaj*. So far there is limited evidence of 3rd–2nd millenia BC settlements in Oman, but their existence is indirectly indicated by the hundreds of thousands of tombs of that date which dot much of the northern part of the country. Settled life in south-west Arabia could not have existed without the terraced fields which now cover most of the highlands of Asir and North Yemen. Arabia, therefore, should be included among the so-called 'hydrological countries' of the Near East in which settlement depended on the building of hydraulic constructions.

The notes which follow are essentially meant to report on work in progress in the territory of Oman and deal with the architectural aspects of traditional hydraulic works and land use. Where life is hard and difficult, sometimes reduced to pure survival, the *objet d'art* tends to be absent: this, of course, does not mean that in those areas art is absent. Aesthetic values, taste and imagination find their ways of expression in the building styles, in the design and decoration of tools and weapons, in the patterns of weaving and basketry; they are also expressed in the design of the hydraulic works. Strictly functional and related to the very existence of settled life, the irrigation systems are often artifacts of surprising beauty, reflecting in their architectural quality the interest and care of their builders.

The falaj

Three types of *falaj* are to be distinguished according to three different types of extraction:
(a) channelling surface flow,
(b) tapping springs,
(c) draining water-soaked subsoil.
The first type normally runs open and on the surface for its total length, whereas the second

and third types are partly underground. Surface flow channelling is perhaps the oldest known method of irrigation: in Arabia it is common in North Yemen, Asir and Oman where perennial streams exist. In Oman water is diverted into the channel by means of a weir (*ma'qad*) or is tapped from a pool artificially created by damming the stream (*qabīl*).

The first method is adopted when limited amounts of water are required for the irrigation of separate plots of land situated on the banks of a wadi. Several weirs are usually built along the course of one stream: their location and the length of the channels depend on the position and level of the fields, which in most cases are artificially terraced. This method allows a fair share of the water by all the inhabitants of the area in accordance with the customary laws on water rights. The *qabīl* is normally used for a multi-purpose supply of water to one single village. Although the barrage is not a permanent structure and does not necessarily use the whole flow of water, a *qabīl* is built only if there are no other settlements for a short distance downstream.

The second type of *falaj* conveys water from springs to places of use. Construction may be as described for the first type, i.e. entirely above ground. Part or most of the *falaj* may also be subterranean and constructed as described below.

The third type of *falaj* originates from a 'mother well' (*umm*) dug on a spot chosen after consultation with a diviner (Birks & Letts 1976: 94–5). In some cases there can be more than one well: this is either because secondary wells have been added to the mother well in order to increase the supply or because trial wells have been excavated in order to find the best aquifer. Often the trial wells are linked to form a combined water-producing system. The depth of the mother well depends of course on the location of the water source and can vary considerably, from a few metres to 50 or more. From the point where the water is tapped, a tunnel is excavated in which the water flows at a gradient of from 1 to 3 per cent until it meets the ground surface where it continues, generally as an open channel, to where it is required. The underground channel is cemented wherever necessary to prevent erosion and seepage. Thus the function of the *falaj* of this type is to convey ground water that is extracted at depth, and it is therefore a subterranean structure. [The *qanat* has been brilliantly defined as a 'horizontal well' (J.C. Wilkinson 1977: 267).] The fact that it runs partly underground has the additional benefit of reducing evaporation and pollution, but this is a consequence and not the reason for its subterranean construction.

At suitable intervals vertical shafts are excavated to ensure ventilation and allow the removal of débris. Contrary to what is often said, these service shafts are not always excavated at regular intervals; their distance may in fact vary from a few metres to 100 or more, depending on various factors such as soil conditions, the depth of the *falaj*, and the ground morphology. The shafts tend to be sunk at regular intervals where, for example, the *falaj* crosses a uniform gravel plain. In this situation the typical pattern of a line of regularly placed wells is strikingly visible in aerial photographs. It is for this reason that uniform spacing is often assumed to be a consistent feature along the course of the whole *falaj*.

In order to protect the *falaj* from damage caused by run-off or flash-floods, the spoil is arranged around each shaft mouth; at some places the latter are capped with large stone slabs. Wherever the workmen meet unsafe loose soil, they roof the tunnel, in some instances with pairs of stone slabs, skillfully perched at a 90°-angle to form a self-supporting roof, without uprights. Another part of the *falaj* liable to damage or collapse is where the conduit approaches the ground surface. Here the *falaj* can no longer be tunnelled; it is instead excavated from the surface and then roofed with stone blocks or slabs laid flat and at a short distance above water-level. The trench is then backfilled.

Variants of this third or subterranean type of channel are normally found in catchment areas with thick gravel deposits which form a water-bearing stratum. These catchments are generally located in the *bajada* zone along the foot of the mountains. To the writer's knowledge, this type of *falaj* is present at least in the Yemen and Oman; the following description is based on research done in North Yemen. The water is drained from the water-soaked subsoil by means of wells of a typical conical shape, narrowing at the bottom where the conduit is built. From top to bottom, the wells are lined with rough stones, generally large wadi bed pebbles. The wells can be very numerous; they are all linked directly or indirectly to the main water-channel. An outstanding example of this type of system is the 'Ghayl Alāf' in North Yemen. Formerly supplying water to the city of San'ā, this *ghayl* originates about 7 km south of San'ā with a catchment system of forty-eight wells.

The architecture of the open channel

The two main problems faced by the *falaj*-builders – besides the location of a suitable source of water and the tunnelling of the underground section – are to ensure a proper velocity all along the channel and to negotiate the crossing of wadis and other physical obstacles. The first task requires a remarkable surveying skill because the builders must balance the gradient of the channel and the average flow-rate, taking into consideration also its seasonal variations. The construction of the open channel, which may run for several kilometres through rugged terrain before reaching its destination, is often a very difficult task which requires both experience and skill and is perhaps much more of a technical challenge than the excavation of the underground section itself. It is in a way surprising that all the major studies on *falaj* construction give special emphasis to the water-collecting and tunnelled sections and tend to overlook the other parts of the system which ensure the long-distance transportation of the water and its distribution. Symptomatically in those studies the *falaj* is normally referred to as the work of '*falaj*-diggers' rather than '*falaj*-builders'.

We have seen that the route of a *falaj*, especially through the mountains, must be carefully planned in order to avoid areas liable to create maintenance problems. The most usual route therefore is along the main wadi on the side nearer to the water source. The channel is built at a convenient gradient against the side of the mountain and follows it like a contour line, gaining height progressively from the level of the wadi. The *falaj*-builders make use of any irregularity or natural ledge on the mountain side in order to support the channel's structure but, when necessary, they carve the side of the cliff to accommodate it. Short cuts are often tunnelled through rocky spurs or consolidated gravel terraces. At some points, especially through narrow gorges where sudden drops of level cannot be avoided, the channel is shaped into a small tank, which acts as a flow regulator (Plate 1).

Sometimes the *falaj*-builders judge it unsafe to build the channel directly along the bluff side of a wadi, either because of the crumbling nature of the rock or because it is just a terrace of uncemented gravel. In both cases the channel is supported with a well-constructed stone wall founded directly on the side of the wadi bed. Sometimes the supporting wall may be of huge proportions, as for example at Tanūf, near Nizwa, where the wall is about 10 m high (Plate 2).

Plate 1 *Falaj* in the mountains of Wadi al Hijr. A flow-regulating tank.

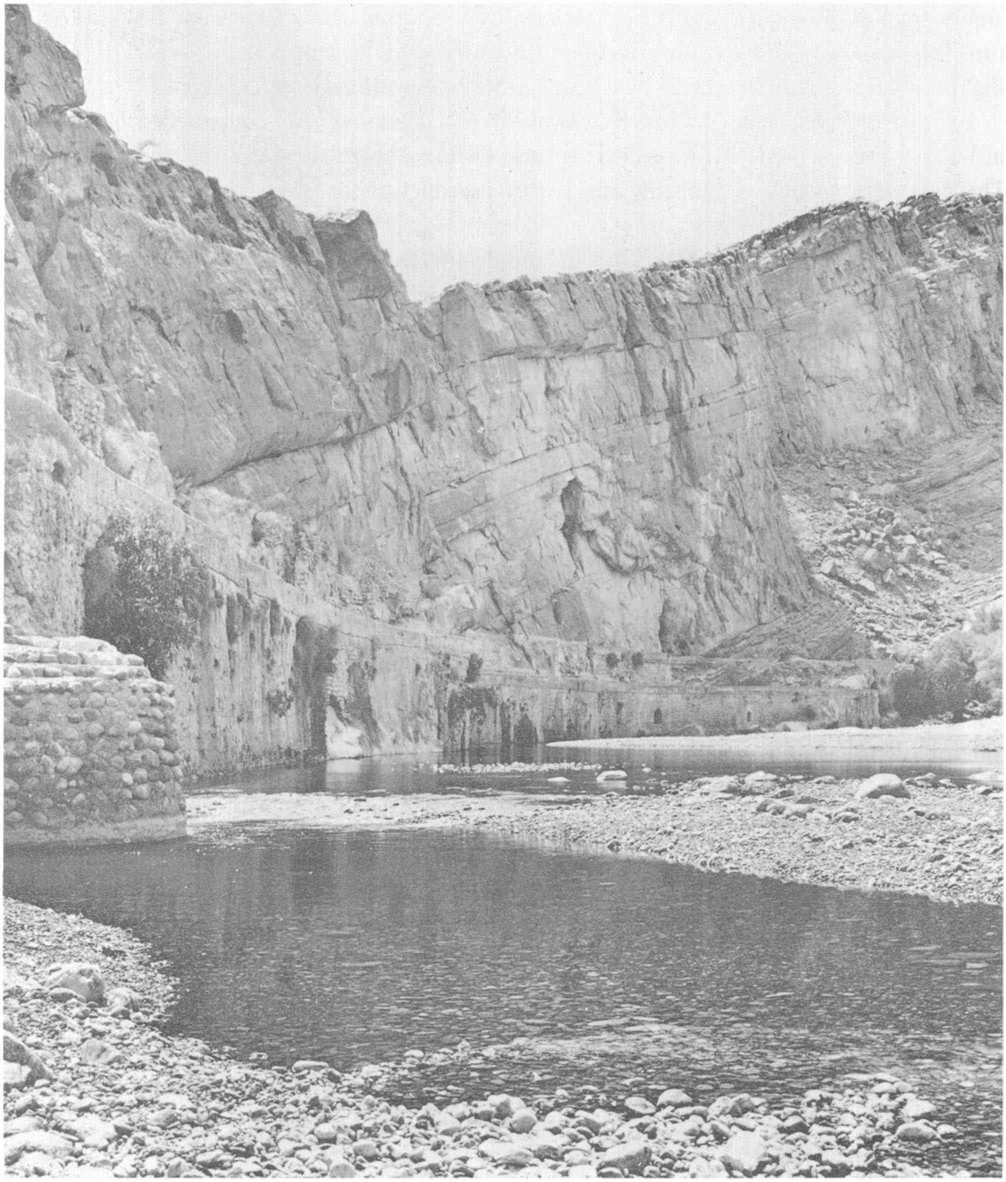

Plate 2 Water supply to the town of Tanūf. The channel which is still in use runs along the mountain on massive foundations; above it are visible the remains of a previous *falaj* and in the foreground part of the *fallāh* of a third *falaj*.

A major problem faced by the *falaj*-builders is how to cross tributary wadis which, although dry most of the year, may convey ravaging flash-floods during the rainy season. If the wadi is not very wide and the *falaj* flow is small, the builders may decide to lead the water across by means of a hollow palm-log which can easily be replaced if swept away by an exceptional flood. In the case of a more substantial *falaj*, with a wider span to cross, a permanent structure is built, strong enough to resist an average flood. Such masonry aqueducts rest normally on arches supported by piers protected upstream by buttresses. One of the most beautiful structures of this kind, built possibly in the 17th century AD, is still in use at Nakhl; it has two slightly pointed arches supported by a huge but well-proportioned column (Plate 3).

A more complex aqueduct showing two different phases of *falaj* construction can be seen in Wadi al-Sirrayn (Plate 4). Aqueducts are also common in the systems of the Jabal al-Akhḍar. The imposing remains of probably the largest aqueduct of the whole Jabal are still visible in Wadi Bani Habīb.

Another method of negotiating a wide and deeply eroded wadi with a steep gradient is to build a 'U'-shaped closed channel with its lower side incised in the wadi bottom and roofed or tunnelled beneath the wadi (Fig. 1). Water flows through such an 'inverted siphon' on the physical principle of hydrostatic head. This method of underpassing a wadi is prominently used in Oman, where it is called *gharrāq-fallāḥ* after the names of the two vertical shafts. The horizontal section which runs under the wadi is imaginatively called *jisr* (bridge) because, though underground, it 'spans' the river. The *gharrāq-fallāḥ* is also used when the *falaj* must be led across the main wadi either in order to water fields located on the opposite side or to reach its final destination.

The only visible parts of the *gharrāq-fallāḥ* are of course the vertical shafts which are often of regular and substantial construction: each has the appearance of a squat chimney, with a large squared base and a slender and taller cylindrical shaft. Plate 5 shows a *gharrāq-fallāḥ* built at Mulayyina, on a small tributary of Wadi al-Jizzi, in the mountains of North Oman. The structure belongs to a 9th century AD *falaj*, one of the longest and most important in the area; it was possibly reconstructed or considerably repaired in the 17th century AD. It measures about 7 m from the top of the shafts to the level of the wadi bed; the inner section of the cylindrical pipe measures about 1 m across. This large size, obviously ill-proportioned even to the maximum flow of the *falaj*, is needed to allow easy access to the shaft for the construction and maintenance of the system. The pipe must be smoothly plastered on its inner surface in order to avoid loss of velocity through friction and also seepage of water into the masonry.

The *gharrāq-fallāḥ* is used also to avoid trespass on caravan routes or other areas subject to rights of transit or public use. An example of a *gharrāq-fallāḥ* built under an old caravan track is shown in Fig. 2, a pictorial view of the Falaj al-Siḥāma in the Wadi Ḥalfayn, on the eastern side of the Jabal al-Akhḍar. A miniature *gharrāq-fallāḥ*, measuring no more than 1 × 2 m, is still in use to lead the water of a small distributary channel under a foot-path in the garden of a rich 18th-century house in the village of Sawāqim, near Quriyat.

Water mills

Ancient *falaj*-builders were not unaware of the potential source of power represented by water conduction as is proved by recently discovered *falaj*-powered mills (T. Wilkinson 1976; 1980).

Plate 3 Aqueduct at Nakhl.

Plate 4 Aqueduct in Wadi al-Sirrayn.

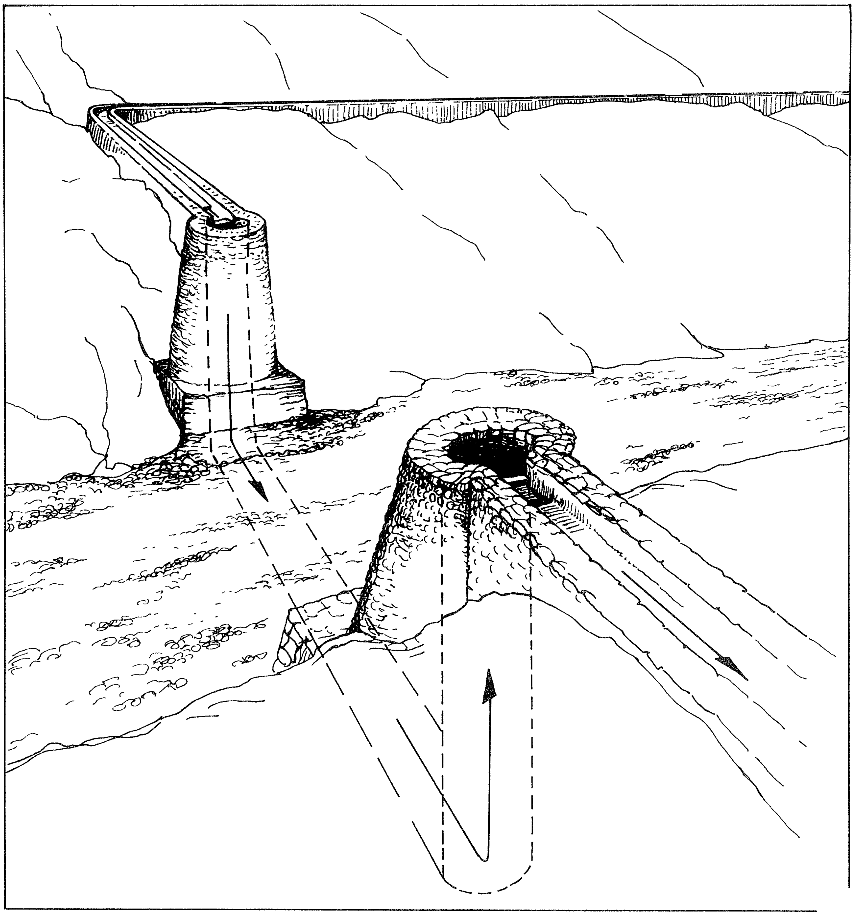

Figure 1 Diagram of a *gharrāq-fallāḥ*.

All the mills so far located (twelve) belong to the vertical or Norse type (Forbes 1965: 88). Depending on the channel level and the ground morphology these water mills may be built either above or underground. One underground mill has been partly excavated (T. Wilkinson 1977). This mill was one of a series of four located on the *falaj* mentioned above in relation to the *gharrāq-fallāḥ* of Mulayyina (Plate 5). The channel, long since disused, originated from a permanent pool in the Wadi al-Jizzi and ran above ground for about 35 km with the exception of a few hundred metres east of Mulayyina where it was tunnelled under a hill. In its final section, the *falaj* crossed the main wadi with a huge *gharrāq-fallāḥ*, possibly the biggest ever build in Oman, and then ran across the plain to a vast cultivated area to the west of the town of Sohar.

Excavation confirmed the hypothesis advanced at survey stage by Mr Wilkinson that both penstock and mill chamber were underground and revealed various details of the mill construction. In order to increase the water head and reduce the length of the penstock the mill-builders gradually raised the channel above ground-level to a maximum of 1.5 m at the point of entering

Figure 2 Sketched bird's-eye view of the Falaj al-Siḥāma.

Plate 5 *Gharrāq-fallāḥ* at Mulayyina (Wadi al-Jizzi) (from upstream).

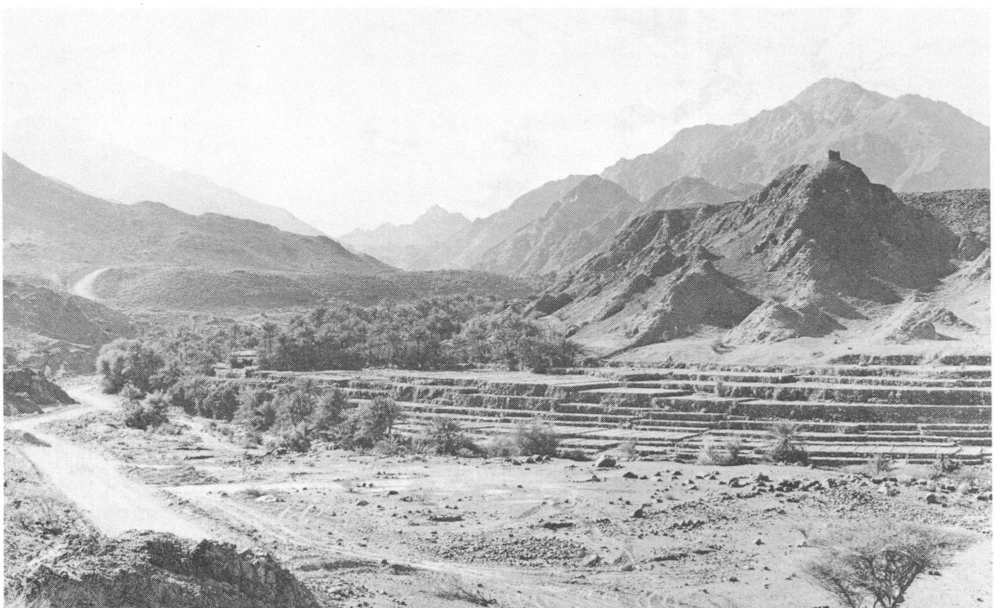

Plate 6 Patterns of cultivation at Raḥab (Wadi Bani 'Umar al-Gharbi) showing the oasis and seasonal terraced cultivation; in foreground are abandoned fields.

the vertical pipe, which measured 0.8 m in diameter. The pipe is 4.5 m long and ends with a large stone block pierced by an opening measuring 25 cm in diameter. The water filled the penstock and through the narrow opening at its bottom formed a jet which caused the rotation of a horizontal bladed wheel which turned a vertical shaft connected to the millstone. At the bottom of the mill chamber the water was funnelled into a channel which ran underground until it met the sloping ground surface to become an open channel again. This same cycle could of course be repeated several times on the same *falaj*.

The results of the field-work conducted in the Sohar area suggest that in some instances a mill 'provided a dual function for the system, firstly as a power supply and secondly as a means of negotiating wadi beds' (T. Wilkinson 1976: 76). This brings us to the interesting point of the analogies between water mills and the *gharrāq-fallāḥ*. In the mill penstock, as in the *gharrāq*, the discharge point is considerably below the entrance to the intake and sufficient head is developed to turn the mill; then the water runs underground as in the *jisr*. Where power is not needed and the aim is only to provide an underpass, the hydrostatic balance is re-established by the *fallāḥ*. Architecturally the *gharrāq* and the mill, when the mill penstock is located above ground, appear strikingly similar, as in the case of the mill near the medieval mining village of 'Arja (Costa 1978: Pls 8b and 9).

It is possible that the apparently odd distribution of water mills in Oman, concentrated in two groups in the Batina, is only the result of limited field-work. The fact that within the small number of identified mills both the above and under ground types are present would appear to lessen the importance of hydrogeological conditions as a limiting factor. Only further research will clarify whether other factors are relevant, for example the agricultural development in particular areas and periods. Certainly one must not forget that a mill is built not only where hydraulic power to turn its grinding stone is available but also where there is enough grain to grind. In this respect the concentration of mills in the Batina corresponds with the exceptional agricultural development of that region in medieval times (Williamson 1973).

Architectural features of the distribution system

In its final section, the *falaj* becomes part of the settlement as well as one of the main factors affecting its physical layout and development. We have seen that the *falaj* is a very flexible structure which can easily be led wherever necessary: seen in plan therefore the problem of the location of the settlement can easily be solved. Seen in section, on the contrary, the location of fields, gardens, ablution areas and water points is limited by the controlling factor of the highest feasible level of the water channel. If the *falaj* is already on the surface, and its level lies above the surrounding ground, the preparation of fields can be executed by simple clearing and levelling. But if when it reaches the settlement site, the *falaj* is still considerably below the average ground surface, the plots to be irrigated must be lowered to the required level. In some cases 4 or more metres of soil must be removed. Such excavations, sometimes of enormous proportions, have produced all around the consequent sunken gardens the accumulation of huge spoilheaps which are one of the most striking features of many settlements in Oman.

The head of the distribution section of a *falaj* is generally marked by a mosque which is preceded by the last point where drinking water can safely be collected (*shari'a*). Before this point the *falaj* is generally roofed for a few hundred metres to prevent pollution and to ensure that the prohibition of washing and of watering animals upstream of the *shari'a* is observed. The main feature of the distribution system is a large cistern (locally called *lājil* or *jābiya*, although the classical *birka* is also used). These cisterns are necessary for two main reasons:

(a) to build up a sufficient head of water to reach all parts of the oasis;

(b) to ensure a steady flow through the distributary system particularly when the *falaj* flow declines.

The increase in water head is required even when the *falaj* flows at its best because it is necessary to ensure a sufficient flow throughout the network of the irrigation channels which are built with little or no gradient and are mostly unlined.

Virtually no *falaj* in Oman has a constant flow throughout the year and the average flow-rate declines dramatically after periods of drought; a large reservoir is therefore necessary for a better controlled distribution of the water which is periodically stored and released according to flow variations and irrigation needs. Only a few *falaj* systems in Oman do not have this type of reservoir: not surprisingly these are locally reputed to originate from perennial springs. In fact they usually irrigate gardens lowered to such depth that an increase in water head is unnecessary.

Cisterns vary in design and proportions, both dictated by a number of technical factors. Capacity is obviously determined by water flow and irrigation needs. Depth, on the contrary, is determined by outlet level. A round cistern located above a complex of terraced fields in the medieval mining settlement of 'Arja measures 35 m in diameter and only 2 m in depth: the odd ratio seems due to the need to store a considerable amount of water while keeping the outlet at a relatively high level (Costa 1978: Pls 8a and 10), a requirement which clearly prevailed over the obvious need to minimize evaporation. The round cistern on the Falaj al-Siḥāma (Fig. 2) measures 20 m in diameter and approximately 6 m in depth (exact measurement requires excavation). The much more satisfactory design of this cistern was made possible by a steeper ground surface which allowed the outlet channel to re-emerge after running only 100 m underground.

Besides their main function, cisterns may serve other purposes, as in the case of a cistern in the Qat'a quarter of Nizwa (Fig. 3). The tank, fed by an animal-powered well, supplies water to a large garden stretching along the opposite side of the main street. From a small basin beside the well, the water is led either through a hole directly into the cistern or, alternatively, is funnelled into a small channel built in the thickness of the cistern's rim and running all along its top. At the point nearest the street the channel is enlarged to form a small trough whence a stone spout conveys the water into the cistern. On one side of the trough the channel runs under a small shelf built for the convenience of passers-by who may wish to collect some water. This curious and attractive cistern/fountain reflects the tasteful imagination not only of its builders but also of the traditional society to which they belonged. What inside a rich palace would have appeared just a simple water tank, next to an orchard and a dusty road looks a surprisingly refined construction. A cistern conceived for irrigation purposes as well as recreation is part of the compound of Masjid al-Luqta, examined later in this article.

Exploitation of temporary pools for irrigation

After an exceptionally long rainy season, large amounts of water are wasted because the wadi flow is too strong to be controlled. Only in particularly favourable circumstances and when the flood water starts decreasing can temporary channels be excavated to direct water to small

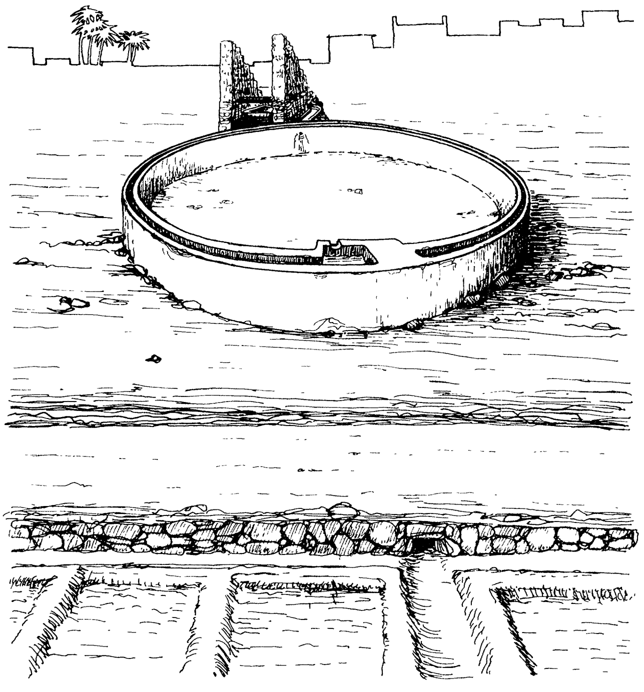

Figure 3 Sketched perspective of the cistern of Bir al-Qat'a (Nizwa). In the foreground, under the intervening road, the outlet of the irrigation channel into the fields.

plots of land prepared for seasonal crops. A more durable source of water is represented by large pools which form in wadi bends and may last several months. In areas with abundant rainfall, these pools tend to occur after every rainy season: this has encouraged the building of permanent structures to lift the water from a wadi and channel it to fields without other kinds of water supply. An example is provided by a site in the Wadi Ḥawasina, here illustrated by a sketched bird's-eye view (Fig. 4). The lifting structure, quite impressively built on a rocky spur overlooking the wadi, resembles a normal well and is called *zajara* (animal-powered well). From the well's basin runs a water channel which meanders in and out the gullies which furrow the side of the rock. The channel crosses on a small aqueduct the gap between the rock and the side of the wadi to water the fields created on the natural terrace.

Run-off agriculture

The opportunity of extending the cultivation of seasonal crops beyond the limits of the *falaj*-irrigated oases has never been overlooked in Oman. Since there are periods when water is plentiful, most settlements have fields specifically prepared to receive the water surplus. A common layout of agricultural land is here illustrated through the example of Raḥab, a village on Wadi Bani 'Umar al-Gharbi, inland of Sohar. The oasis, including a large number of date palms, is situated slightly above wadi level. Irrigation is provided throughout the year by two *falaj* channels which tap the wadi at two different levels a few km upstream (*qabīl* method described above). When surplus water becomes available, part of the flow of the higher *falaj* is diverted into a secondary channel to irrigate a vast area of terraced fields stretching along the northern side of the wadi (Plate 6). A further way to stretch the extent of the cropped

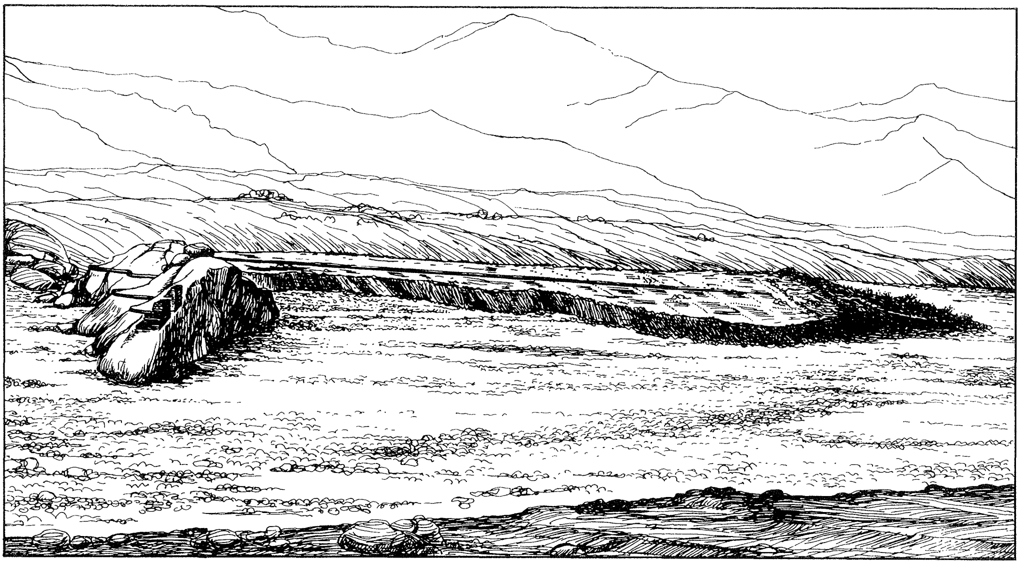

Figure 4 Sketched bird's-eye view of water-lifting and irrigation system in Wadi Ḥawasina.

area is through the collection and distribution of rainwater. There is evidence that this very simple form of irrigation was used in settlements dating back to the 3rd millenium BC (Hastings, Humphries and Meadow 1975).

Even after more sophisticated and reliable methods of irrigation like the *falaj* came into widespread use, run-off agriculture was never completely abandoned, and this for two reasons. Economically it was regarded, and still is, as a complementary source of income. Technically, it appears that the principles employed in the construction of retarding and diverting structures such as gabarbands (low catchment walls), shallow dams and ditches, which allow the control and exploitation of the run-off, are also employed in the construction of the vital drainage systems (P. & G. Bonnenfant and S. al-Harthi 1977: 111). It should be noticed, however, that if run-off farming has only a minor role in the economy of the *falaj*-supplied settlements, in the mountains of Ra's Musandam, where ground-water exploitation is not feasible, it is the only possible method of cultivation. Thus it is because of the peculiar hydrogeological conditions of their homeland that the Shihuh tribes of the inner wadis and the high plateaux of Musandam migrate in summer to the well-watered coastal oases where they work at the date harvest and indeed often possess some palm trees. In winter the Shihuh move back to their mountain villages where, contrary to their unmerited fame as primitive cave-dwellers, they live in well-built stone houses. Water storage is effected by cisterns (Plate 7) and large earthen jars. Fields often consist of a cluster of terraced plots fenced against goats by drystone walls (Plate 8). The rainwater run-off is collected from the side of the mountains by low damming walls and then channelled to the uppermost part of the field through openings at the base of the fencing walls. Distributary channels then spread the water to other fields.

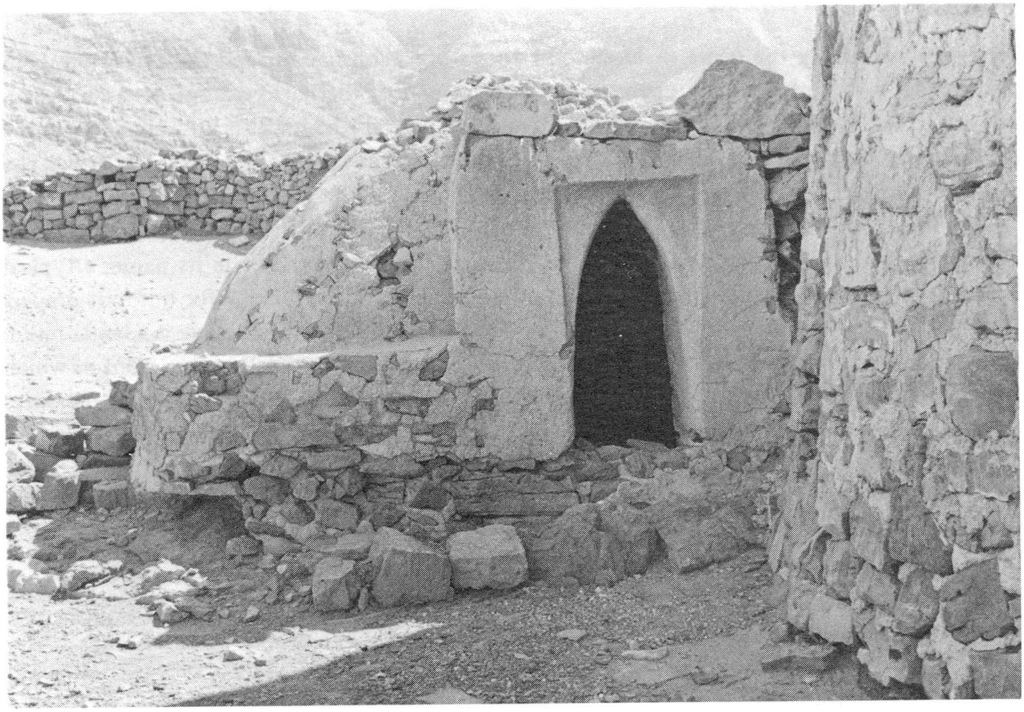

Plate 7 A cistern at Bukha (Ra's Musandam).

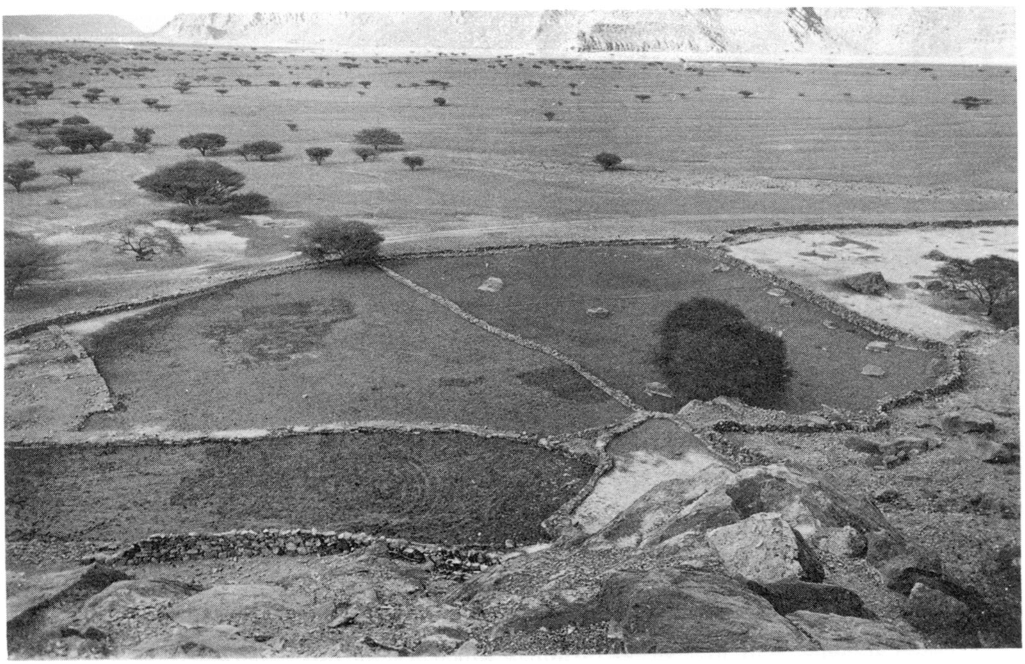

Plate 8 Run-off agriculture in Wadi Khasab (Ra's Musandam).

The retreat of Masjid al-Luqta

The estate known by the name of Masjid al-Luqta was established around the end of the 18th century AD in the plain which opens at the western end of the narrow gorge of Wadi ‘Aday. The site is also known by the name of its *falaj*, al-Ḍankī, or al-Khaḍrā. It is now abandoned, the *falaj* dry, the buildings dilapidated and in the former gardens only wild acacia trees grow. The focal point of the whole site is the black outcrop chosen by the builders of Masjid al-Luqta as background to the main group of buildings, at the southern end of the gardens (Fig. 5). On the western side of the outcrop stands the small mosque which gives the site its name, a typical simple Ibadi mosque with a gravelled courtyard and a secondary *mihrab* for outdoor prayers (Fig. 6). Built against the rocky hillock and 1 m above the level of the mosque is a larger building which housed a theological school. It has three rooms along the back wall in front of which is a portico with five octagonal columns, now missing. The cell-like room in the middle measures only 2 x 2.5 m, but has a formal entrance from the portico.

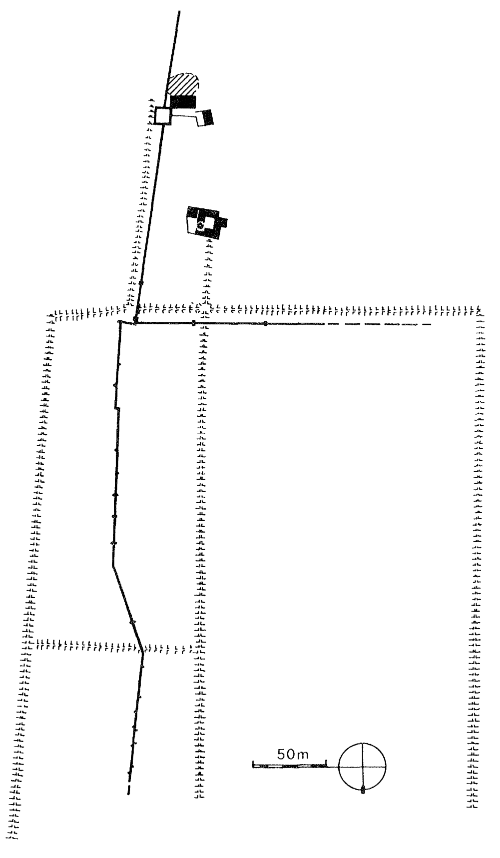

Figure 5 Masjid al-Luqta: general plan.

The *falaj* which supplied water to the estate originated from a wadi some 10 km to the south; it is now badly damaged or, in many places, completely destroyed. The main preserved feature is a well-built aqueduct with nine arched openings, which at some time superseded a *gharrāq-fallāḥ* in spanning a wadi some 400 m from the site. After skirting the eastern tip of the outcrop, the

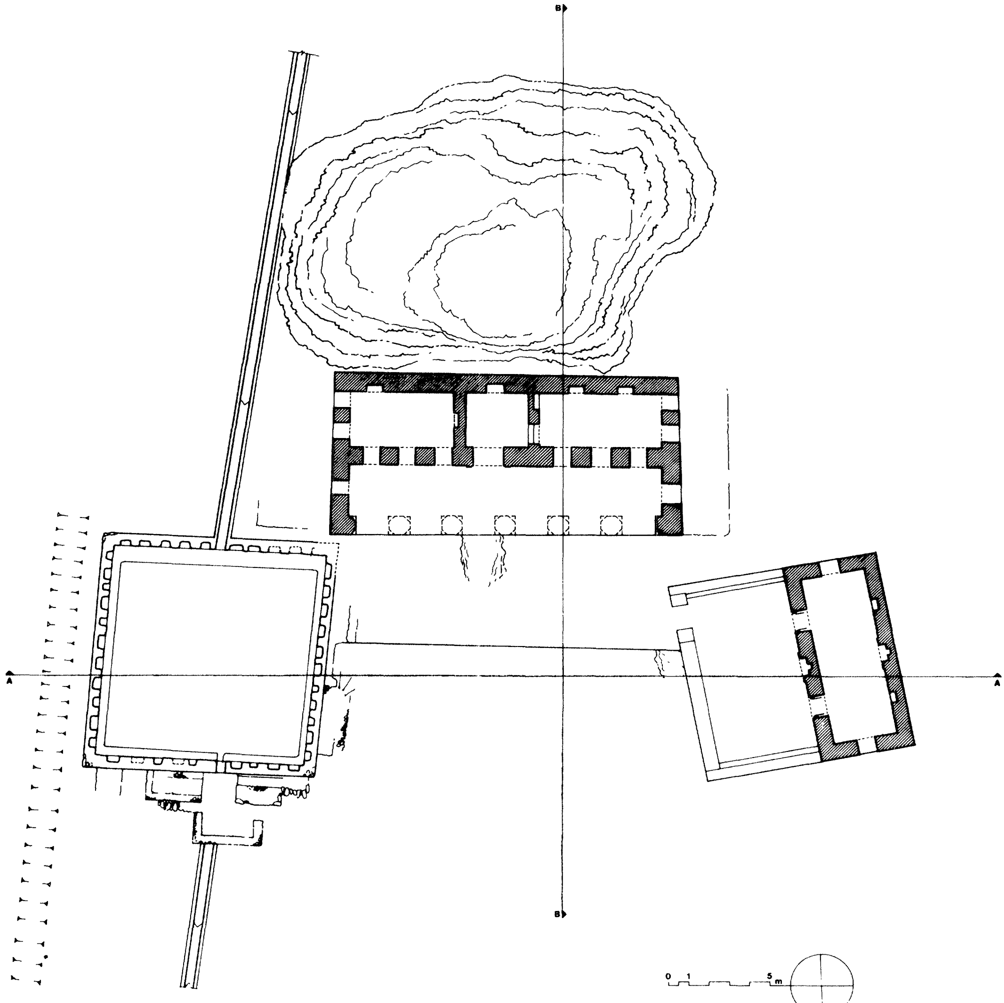

Figure 6 Masjid al-Luqta: plan of mosque, *madrasa* and ornamental pool.

channel flowed into a 10-m-square cistern, built as the main reservoir for the irrigation system and also as an ornamental pool for the mosque and the *madrasa*. The pool is built partly above ground; the basin is 1.2 m deep and at its bottom a step runs along the four sides. In the thickness of the wall are twenty seats with straight sides 55 cm above the step at regular intervals along the sides of the pool. These alternate with rectangular recesses at a slightly higher level, 95 cm above the step (Fig. 7). The highest watermark visible on the side of the pool suggests that these recesses were intentionally above water-level (Plate 9). From the pool, water was channelled to the irrigation system serving the main area of cultivation. On its northern side the pool also had a low-placed outlet and an overflow connected to a series of basins and what was possibly a small ablution area *cum* latrine. A minor ablution place seems to have existed against the western side of the pool but this area is too disturbed and obscured by debris to be examined.

The two diverging lines of the *falaj* and the *qibla* wall of the mosque generate the fanwise layout of these three buildings which are opened scenographically on a terrace connecting the pool and the mosque and overlooking a lower esplanade (Fig. 6). This led to a second group of

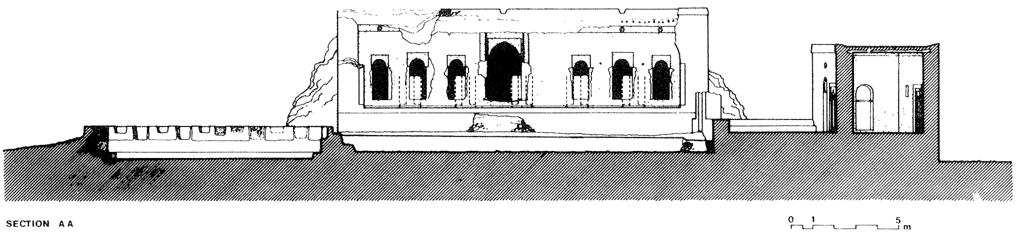

Figure 7 Masjid al-Luqta: east-west section of mosque, *madrasa* and ornamental pool.

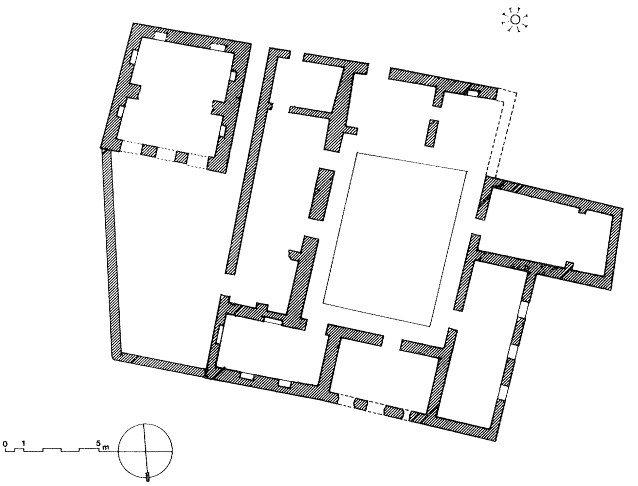

Figure 8 Masjid al-Luqta: plan of house and pavilion.

buildings (Fig. 8). One is a very dilapidated mud-brick house with six rooms of different size around a rectangular courtyard. There are two entrances on the southern side and one on the eastern. A small well has been found outside the house, near its south-west corner. Near the house and aligned to its southern side is a two-storey building, 6 m square in plan, constructed of rubble and mortar, with a plastered surface; the building is partly ruined and the southern wall completely missing. The ground floor is divided into an inner room without windows and a second room with three arched openings on its northern side. The upper storey is taller than the one below and has three wider openings with pointed arches supported by octagonal pillars. The arcade is open to floor-level and bears no trace of windows or fittings. This attractive loggia was topped by rounded crenellations, partly preserved on the eastern and western sides of the building (Plate 9). These features, together with the building's small size and simplicity of plan, give it more the character of a pavilion than of a house. This interpretation fits the architectural context of the site and explains why the pavilion, though next to the house, was not directly connected with it.

Built at the edge of the main garden, where a preliminary survey has yielded evidence of a plantation of at least 500 date-palms or similarly large trees, the pavilion was clearly meant to be a place of rest and recreation, overlooking the vast expanse of greenery and enjoying any available northern breeze, no doubt a great relief during the hot period of the date harvest. This pavilion can be considered a refined version of the garden kiosk which is a common feature in the oases of Oman and along the Batina where it is constructed with palm leaves.

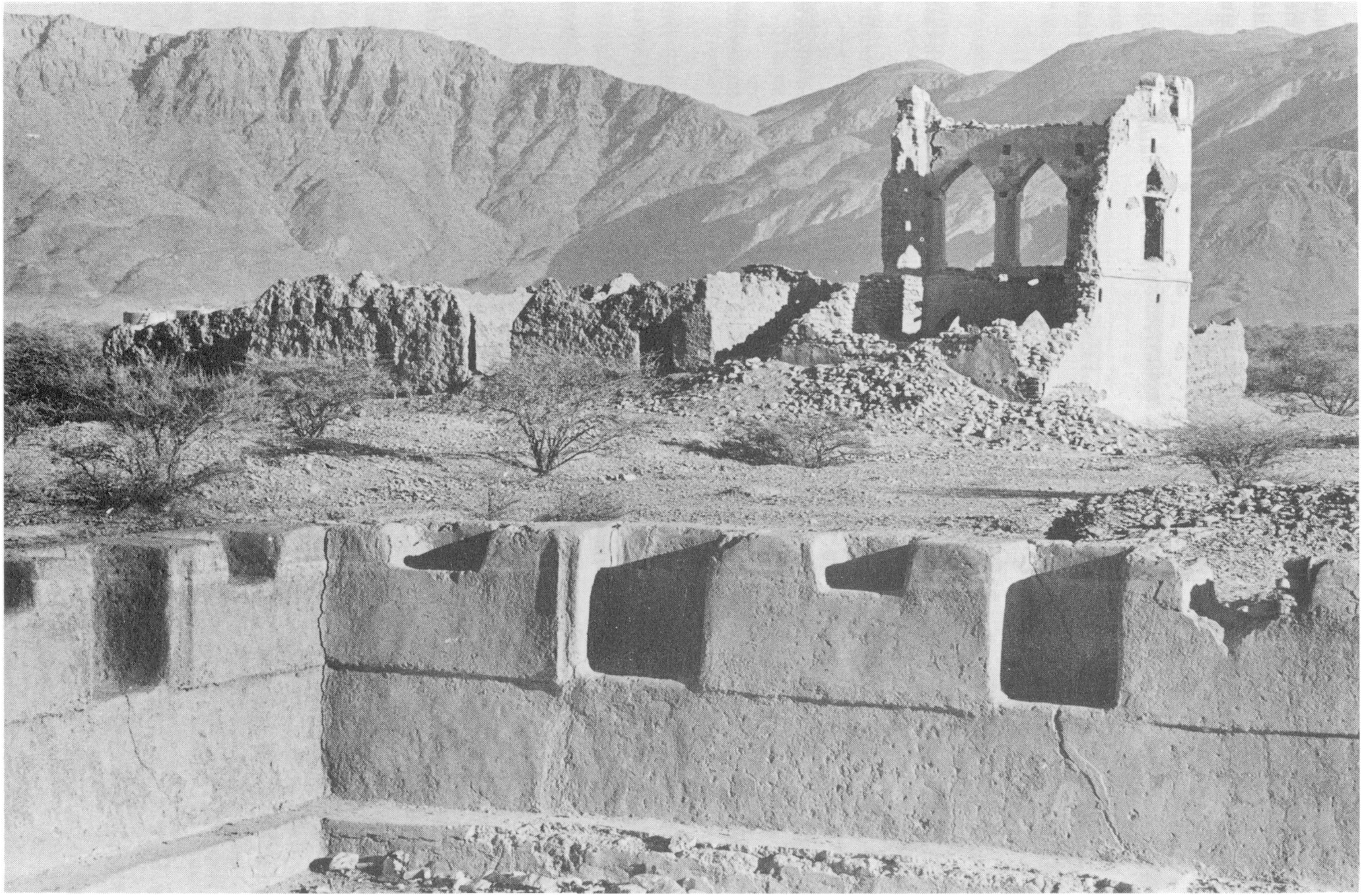

Plate 9 Masjid al-Luqta. Details of ornamental pool; in the background the ruined pavilion.

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Abstract

Costa, P. M.

Notes on traditional hydraulics and agriculture in Oman

The growing collection of archaeological data on water exploitation and agriculture in Arabia not only contributes to a wider knowledge of ancient Near Eastern hydrology and land use but sheds new light on Arabian art and architecture. Some features of water supply and irrigation works in Oman are discussed with a particular interest in their architectural values and their implications with regard to settlement patterns. Run-off farming is examined in relation to the economy of settled and semi-nomad communities. The architecture of an Omani garden is also presented, with a case study of Masjid al-Luqta, near Muscat.