Proceedings of the First International Congress on Construction History, Madrid, 20th-24th January 2003,
ed. S. Huerta, Madrid: I. Juan de Herrera, SEdHC, ETSAM, A. E. Benvenuto, COAM, F. Dragados, 2003.

Early Islamic lime kilns from the Near East. The cases from Amman Citadel

Ignacio Arce

The aim of this paper is to discuss the lime production methods in the Near East during the Umayyad period, with special attention to the relationship between kiln design, production processes, local conditions (in terms of resources availability), and the characteristics of the final outcoming product.

The analysis includes a review of the tradition of lime production in the region from Roman to Medieval period. Several aspects will be analyzed in detail, among others the differences in kiln design according to its use, comparing several samples found at Amman Citadel, Jerash (Jordan); St Anne Church complex in Jerusalem, the Herodion palatine complex (Palestine), etc. This will permit to establish a sound basis for the future study of the diachronic evolution of production as well as the synchronous comparision of different kinds of kiln according to their use.

The research conducted is part of the campaigns of excavation and restoration of several Umayyad monuments in Jordan carried out by the Spanish Agency for International Cooperation (AECI) and directed by the author since 1995, namely, the Umayyad Medina and Palace at Amman Citadel and the Qasr Halabat-Hammam As-Saraj complex. This research includes an ongoing regional sampling campaign of mortars, plasters and renders, that covers the whole region and spans from Roman-Nabatean times till Islamic and Crusader period.

Umayyad Lime mortars. The problem of the mortar composition

During the Umayyad period the most usual lime mortar used is characterized by its greyish colour, due to the presence of big amounts of ashes. These ashes are from vegetal origin and their presence is rather odd as this kind of ashes are quite hygroscopic and tend to debilitate and decompose the mortar, instead of reinforcing it. The presence in the region of Roman lime mortars with *pozzolanic* ashes (for instance in the Roman North Temenos wall at Amman Citadel itself), would mislead to the hypothesis of a failing attempt to reproduce the Roman mortars during the Umayyad period, without knowing the precise sort of ashes required to be added to the mix, in order to achieve the desired results.

Nevertheless, this idea does not fit with the evidences: On the one hand we can find also in Umayyad period fine lime mortars mixed with other hydraulic additives: For instance, pure white lime mortar with «*cocciopesto*» (i.e. crushed bricks as hydraulic additive), that can be found in the Umayyad hydraulic system at Amman Citadel, in the floor of Amman Citadel and Halabat mosques, as well as in many other Umayyad sites (Arce 1999 —in press—; Arce 2000 —in press—). Furthermore, as part of the systematic sampling of mortars carried out at Amman Citadel and throughout all the Near East, new kinds of Umayyad lime-based hydraulic mortars have been

identified, as the one from the walls of the mosque at Halabat. In this case, a lime mortar mixed with volcanic ashes (that certainly provide the mix with hydraulic properties) was found. This, as well as the mentioned samples of lime with «*cocciopesto*» prove undoubtedly that a precise knowledge of hydraulic additives was available to the masons working during the Umayyad period. Besides, and also as a result of this regional sampling, it has been found out that this kind of greyish mortar with charcoal and vegetal ashes[1] was used also in monuments and structures from the Roman and Byzantine periods (for instance in the foundations of the Roman colonnated street at Biblos in Lebanon).

These evidences, specially the fact that this kind of mortar was not devised in Umayyad times but earlier (although its use would be widespread during this period), corroborate the survival of Roman-Byzantine building techniques and know-how during the Umayyad period in the region (something suggested by many other evidences, see Arce 2000 & Arce 2001). Thus, another *raison d'être* should be sought for this kind of mortar, as the presence of ashes in this characteristic «Umayyad» lime mortar would not be the result of a deliberated addition of a component with specific properties, but the result of certain production process that could not avoid several by-products in the lime itself. This became more clear when, during the excavation of the East street of the Umayyad Medina at Amman Citadel, a singular lime kiln was found.

The Umayyad Lime Kiln from the Umayyad Medina at Amman Citadel

Location

During the 1998 campaign, the remains of a lime kiln from Umayyad period were found at the northern end of the East street, close to the Roman Temple dedicated to Hercules.

It is interesting to clarify the reasons for the location of the kiln, as it could be regarded apparently, as an unusual place for building a lime kiln: The location was determined by the proximity to the «quarry» (actually, the Hercules Temple was used as a quarry providing pre-cut stone and marble for the lime production), and to the worksite itself (the palace and the palatine city). It must be pointed out that during the Byzantine and Islamic periods no structure was built over this Temple and its immediate surroundings due to the sacking and reuse of its building materials (the nearby Byzantine Church —6th.C.AD—, for instance, was built almost entirely with *spolia* from this Temple). Meanwhile, its location in the eastern side of the hill is most probably conditioned by the prevailing winds —coming from the West— so that the smoke would not annoy any existing building (at Jerash can be traced a similar pattern in the location of the Early Islamic lime and pottery kilns —personal comunication of Dr. Alan Walmsley during the 3rd International Conference on the Archaeology of the Near East. —3ICAANE— Paris Sorbonne, April 2002). These lime kilns from Jerash prove that the location of such a polluting infrastructure within the premises of a city, was not unusual in the region at that time. In Pompeii can be found an interesting example within the «house of the Iliaque chapel» (Adam 1984, 75). Also in Medieval western Europe, lime kilns are placed, when possible, in the worksite itself (usually within the city). For instance in 1347, during the construction of the Dome at Orvieto (Central Italy), a lime kiln was built «nel chiostro dell'Opera, al di là della piazza, successivamente destinata ad uso della bottega —pontica— posta *"ne la piaçça de la chiesia nel cantone de la strada che va de a Sancto Francesco ne la quale se fa la colla per lo musaço"*» (Riccetti 1988, p. 164). Otherwise, in most cases, the kiln is placed as close as possible to the quarry. In our case both conditions are given, as the remains of the Hercules Temple was the actual quarry for both the already-cut ashlars for building, and the marble for lime production: Few remains of a monumental statue of Hercules coming from the Temple (just a hand and a fragment of an elbow) survive. Most probably, the rest of the statue, toghether with the Temple marble veneer, were burnt in this kiln.

Description of the kiln

It was built with bricks (30 × 30 × 7,5–8 cms) within a cylindrical ditch excavated in the sloping ground of the hillock placed in the center of the Citadel. It has an inverted tronco-conical shape (1,60m in height; 3,10 m upper diameter; 2,10 m lower diameter), with a flat circular base. The top of the perimetral wall has

a smooth transition, opening and reaching the ground floor level (no traces of any structure built over the ground are ascertainable). At the top of the west side of the perimetral wall there is a built-in hooper or chute (Figs. 1–3), that tappers off down into the kiln (lenght: 90 cm; external width: 60 cm aprox.; internal width: 50 cm). At the base of the kiln there is no opening apart from what seems to be a small flue between two bricks (8 cm in diameter, most probably an air inlet). The kiln presents evidence of use even after the 749AD earthquake (i.e. during the Abbasid period) that destroyed the Citadel: It presents several refurbishments, specially in its eastern side, where missing bricks have been replaced by stones. It is clear that it has been in use for a long time, although in the lattest periods the floor was raised, and probably it was not used just for burning limestone, but also for melting metal, as some metal slag was found in the lattest layer of use (corresponding to the Fatimid period). Near to it, there are the remains of a cistern cut in the bedrock (most probably from Byzantine period) that could have been used as a slaking pit. This cistern was originally covered by a barrel vault of masonry that during the Umayyad period was not standing anymore (Arce1999 —in press—).

Figure 1
Amman Citadel. Umayyad lime kiln. General view

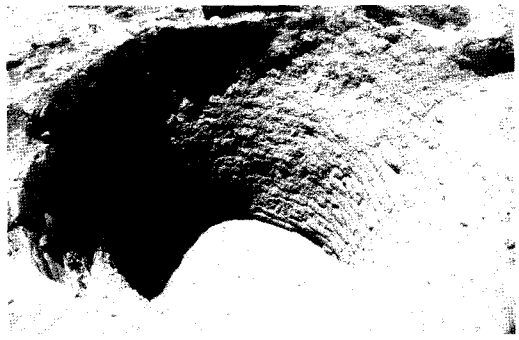


Figure 2
Amman Citadel. Umayyad lime kiln

Operational hypothesis [2]

At first, the lack of a lower mouth or opening for feeding with fuel the burning chamber, raised doubts about the use of this structure (this led to think that it was not a lime kiln, but perhaps a slaking pit), but the traces of slag, ashes and lime, mixed with lumps of partially cooked lime and marble, found at the base of the structure confirmed its use as a kiln. Thus, apparently the operating process of this kiln was different from the usual ancient process of lime production known. Regarding the operation of this kiln, two hypothesis can be raised :

According to the first, this kiln would be a version of the traditional system («high flame» firing kiln), and consequently operated in a similar way: A sort of dome or pile would be built with the stones to be burnt on top of the furnace chamber, that would be feeded with fuel from the hooper. Once the limestone was fired, the pile of burnt stones (already transformed into quicklime) would be dismantled and removed to the

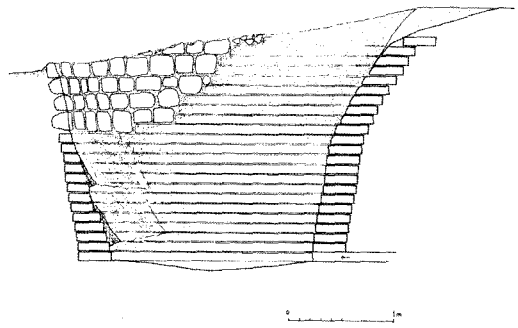


Figure 3
Amman Citadel. Umayyad lime kiln. Section

slaking pit. But in the standard kiln of this kind the opening for feeding the fire is placed at the bottom of the furnace, not at the top. This is the case, for instance, of the kiln from the Herodion fortress near Bethlehem dated in the Byzantine period, and the Crusader lime kiln from Saint Anne Church in Jerusalem (Fig. 4), both in Palestine. These two kilns also present at the top of the furnace chamber, the typical perimetral step required to built this sort of «dome» over it. But in our case this perimetral step does not exist, something that would stand against this hypothesis. At Amman Citadel, there is a second lime kiln, from Fatimid period (apparently kept in use till the Ayyubid-Mamluk period) with this «standard» design (mouth at the base of the furnace chamber and perimetral step at the top), and operational concept (see below), showing that it was well known in the area even at a later date.

Nevertheless we have local examples of «high flame» kilns with this same kind of furnace chamber with upper feeding (like the Abbasid pottery kiln found also at Amman Citadel, and feeded from two hoopers or chutes) that, on the contrary, would support this operational hypothesis. Similar samples can be found also in other areas of the Mediterranean basin, like the Early Medieval example from Crypta Balbi at Rome (Fig. 5). The latter consists of two separate sections: On the one hand, there is the big cylindrical lower furnace chamber excavated in the ground, 3m deep, lined with reused bricks, and pointed with clay as bonding/insulating agent. Also in this case it is very clear the perimetral step to built the stone «dome» over it,[3] but the mouth of the kiln is at the top of the furnace chamber (as in our case). On the other hand there is the upper chamber, built over the ground level, and almost lost. Nevertheless a sort of *praefurnium*, defined by two walls built with bricks

Figure 4
Jerusalem. Crusader lime kiln from Saint Anne Church

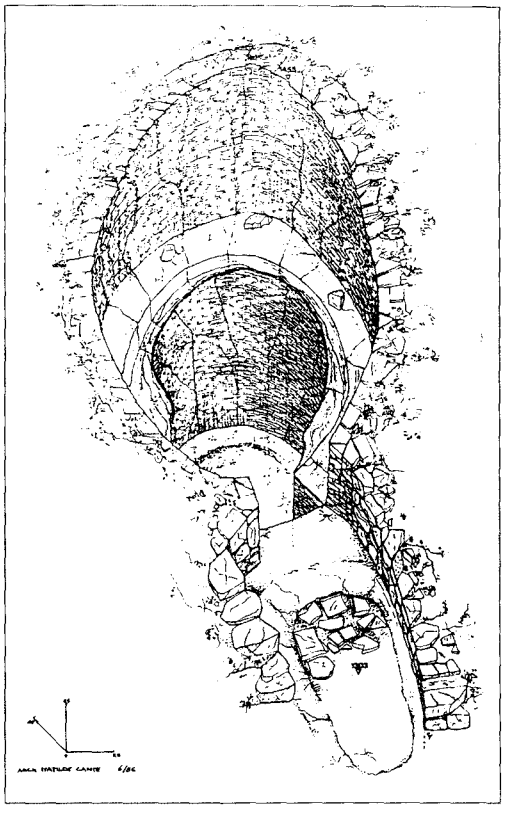


Figure 5
Rome. Early Medieval lime kiln from Crypta Balbi (Sagui 1986)

and stones is located at the mouth of the underground furnace chamber.

Also in favour of this first hypothesis there is the description of the way lime kilns were operated in Palestine up to a few decades ago. The description, according to a second hand account of how it used to work, corresponds to a kiln from a village near Ramallah, in use before 1967:

> A cylindrical ditch with a diameter of 3–4 meters and 3–5 meters deep is cut in the earth (see A in the sketch). A wall (E) about one meter thick and 1.25 m. high is built around the edge of the ditch. There must be two openings in this wall, a large one (C) 80 × 50 cms and a smaller one 40x30 cms. opposite to the first. The larger hole is used to supply wood to the fire while the smaller one serves as a smoke hole. The stone (F) to be burnt for lime is placed in several layers on a roof *[sic]* (G and H). The roof is formed of *[supported by]* long poles of wood (B) which support a layer of branches (G) over which is placed a layer of mud (H) at least 10 cm. thick [!]. The stones to be burnt are laid in a dome without mortar so that they will not fall into the pit after the wood is burnt. This same method of dome construction can still be seen in old villages houses . . . (Khadijah 1971: 107).

However, this description present some problems, specially regading the thick mud bedding on top of which the stones would be placed. Most probably it is a mistake, as this would prevent the stones placed over it from being burnt. Most probably this layer of mud was placed on top of the pile of stones in order to insulate the whole and prevent heat losses.

Still, this operation process does not explain the (undesirable) massive presence of ashes in the standard Umayyad lime. The kilns with an opening at the bottom of the furnace chamber, appart from a more convenient fuel feeding, permit also to remove easily the ashes once the firing is finished, (and before the «dome» is dismantled), in order to prevent the eventual mixing with the quicklime. This would led to the idea that in the kilns with upper feeding furnaces, it is impossible to remove the ashes and consequently to prevent the «dirting» of the lime, but this is not the case, because an adequate cleaning can actually take place, and the lime lumps can be sieved to eliminate the bulk of the ashes (even a layer of sand can be laid over the ashes remaining before the quicklime dome is dismantled). An interesting description of the Roman lime kilns and the way they were brought into operation was recorded by Caton in *De Agricultura*.[4] In this treatise, among other comments, it is said that . . . «if a sole opening is to be used, a big cavity must be left inside, enough to contain the ashes, so that it would not be necessary to remove them out [during the process] . . . If two mouths or openings are used, no space left inside is required, when needed, the ashes will be removed from one of the openings, meanwhile the feeding will continue through the other one» . . . Unfortunately it is not clear the exact position (at the bottom or at the top of the furnace) of these openings.

The second hypothesis implies a different concept of firing the limestone: All the above described kilns carry out to the so call «high flame» firing process. These kilns are the standard ones used in places where plenty of wood is available to be used as fuel. The combustion relies on the high flames produced by the fuel, but a high loss of heat also takes place, requiring a continuous feeding of the (lower) furnace. There is a second kind of combustion process, the so called «low flame» one, that up to now was thought to have been devised just in modern times. In this case there is not a proper furnace phisically separated from the stuff to be fired (below it), that would require recurrent fuelling. On the contrary, in this second case, the limestone and the fuel are placed piled in alternative layers, burning toghether, being required just a small amount of oxigen provided by small flues. This proccess is much more efficient in terms of fuel consumption and temperature reached. Furthermore, in this process are used nuts shells, pine cones and olive pits as fuel instead of timber, because of its higher heat-producing power (these nutshells, etc, are mixed with some kindling and oil to ease its ignition). This is the principle of the kilns developed in modern times: The so called *mixed feed vertical continuous draw kiln* (or *continuous vertical shaft kiln*). These kilns have a cylindric shape (Fig. 6), and have at their base a mouth used just to remove the ashes and retrieve the quicklime once it is ready. Feeding is done continuously through the top of the kiln with the aforementioned alternative layers of limestone and fuel that flow down slowly, once the lowest layers are already cooked and removed. In the upper zone the mix gets heated; The central one is the burning zone, where the actual combustion takes place thanks to the poking hole at the base of this zone (This small hole provides to the mix the required oxigen for the combustion. In order to help this air

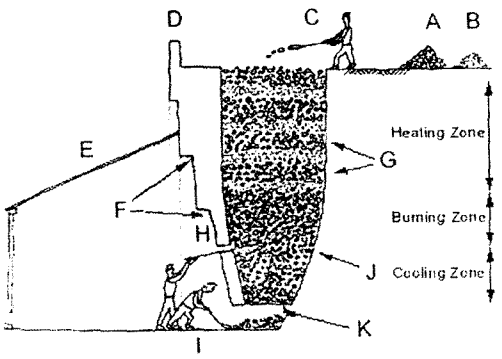


Figure 6
Modern mixed feed vertical continuous draw kiln (or continuous vertical shaft kiln). A: Lime for burning; B: Fuel (usually coal); C: Placing limestone and fuel in alternative layers; D: Parapet; E: Shelter; F: Arches; G: Alternative layers of lime and fuel; H: Poking hole; I: Burnt lime being removed; J: Brick or stone lining; K: Grate

entering, a long iron pole is introduced to poke the fire, opening cracks in the mix); The lowest section is the cooling zone, that ends at the bottom where the mentioned opening for retrieve the final product is placed (this allow to separate the layers of ashes and slag, corresponding to the fuel, from those of quicklime). This continuos process permit also to keep a more efficient production pace, as it is not necessary anymore the cyclic routine of mounting the piles or «domes» of limestone over the furnace, and dismantling them once the firing process is finished, nor to ignite and extinguish the furnace at each cycle, with an evident gain in time and fuel (preventing also damages to the kiln itself, avoiding the troubles from this cyclic heating and cooling process). Limestone is preheated above the burning zone and cooled below it, while also warming the incoming air. Utilising the waste heat to preheat the stone, providing warmed air to the burning zone, and ensuring the quicklime is cool when discharged, significantly increases energy efficiency.

In our case the continuous supply of fuel and stone, and the related benefits of continuos operation, do not exist (being an «intermittent fire kiln»), but the «low flame» combustion principle and its energy-saving conception would be the same: Alternative layers of fuel and stone or marble, with just enough air entrance from the small flue located at the base, would give as a result the same kind of «low flame» combustion. Thus this kind of kiln still would offer a better energy efficiency than the traditional ones, as no timber wood is required, just nuts shells, pine cones and olive pits. These are actually the sort of ashes found mixed with the lime in the mentioned «grey Umayyad mortar». This undesirable presence of vegetal hygroscopic ashes finds thus a *raison d'être*, as in this case it would not be possible to separate the ashes from the quicklime. Just some lumps of clean lime could be retrieved separately, meanwhile the bulk of it would be unfailingly mixed with ashes. This would also reaffirm our hypothesis that this mortar would not be the result of a deliberated addition of a component with specific properties, but the result of certain production process that could not avoid the presence of several undesirable but unavoidable by-products in the lime itself. Furthermore this would mean that this «low flame» combustion process and the related piling-kiln to cook the lime would have been devised much earlier that thought.

Other kilns from Amman Citadel

The Abbasid pottery kiln from the area behind the congregational Mosque

This kiln was placed in the entrance corridor of an Umayyad building (Fig. 7) located at the eastern end of the north *ziyada* (perimetral street arround a Mosque) of the Umayyad congregational Mosque (Arce 2000 —in press—). Only remains the furnace chamber: It has a cylindrical shape, and was excavated in the ground (between the lateral walls of the mentioned corridor), and lined with stones. The upper chamber was supported by means of three parallel diaphragm arches E-W oriented, and made out of reused bricks looted from the *hypocaustum* of the Umayyad bath (the brick dimensions varies from 29 × 29 × 6,5 to 28 × 28 × 6 cm, Arce 1999 —in press—). Only the springers of the southernmost arch still survives (Fig. 8). This lower furnace chamber was fed by means of two hoopers located one in front of the other, at the southern and northern sides. As in the case of the Umayyad lime kiln these hoopers tapper off slightly from the ground floor level. Any

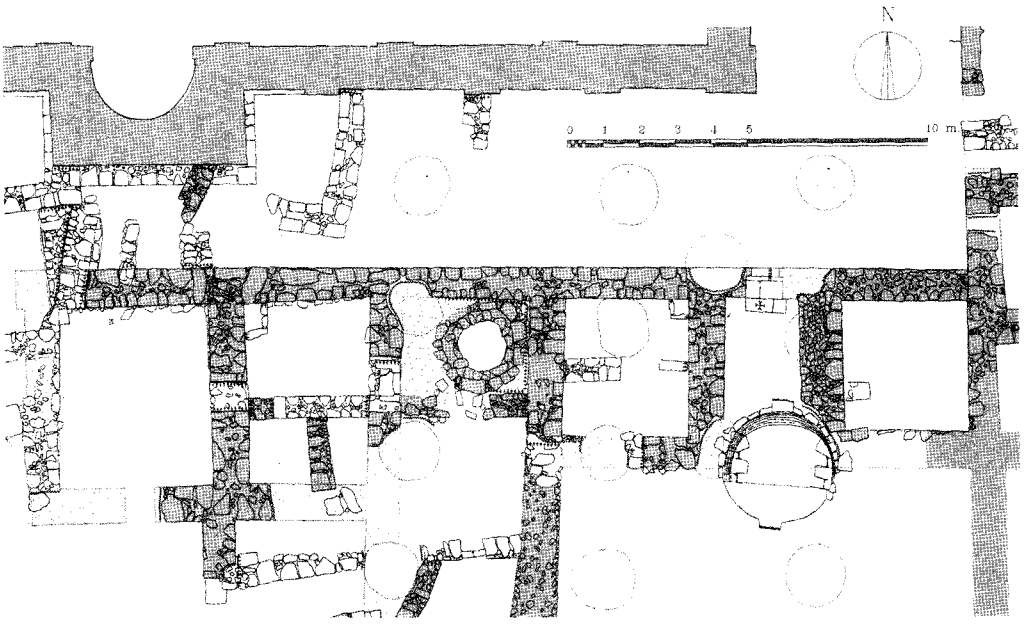


Figure 7
Amman Citadel. Location of Abbasid pottery kiln and Fatimid lime kiln

traces of the upper structure of the kiln have dissapeared. Nevertheless, it is quite clear that these arches supported the pierced floor of the upper chamber, where the clay objects (and eventually bricks) were placed for baking (Fig. 9a&b).

The Abbasid kiln from building «F» at the Umayyad Palace

This kiln was built in one of the buildings from the Umayyad palace itself, over the debris from the collapse of the structures that were destroyed by the 749 AD earthquake. It was built in the area were originally stood one of the *iwans* opened to the courtyard of the building. The original space was divided by two transversal walls, one at the edge of the court (blocking the *iwan*), meanwhile the second divides in two the original room (Fig. 10). Between both walls was placed the kiln and a small room, probably devoted to store the fuel. It was never finished nor used. Due to this fact and to its unusal shape, is difficult to say for what exact purpose it was built. It was designed as a small semispherical dome (2,24 m of diameter) on a flat surface, and built with small square bricks, the dimension of which varies from $20 \times 20 \times 6{,}5$ to $22 \times 22 \times 6{,}5$ cm (Fig. 11). It is noteworthy that these bricks do not seem to be reused (as it is the case of the above described pottery kiln), but built *ex profeso* for this structure. The mouth of the kiln is defined by big reused ashlars of limestone. The threshold of this opening was placed approximately one meter high over the Abbasid floor level (more than one meter higher, in its turn, than the original Umayyad floor, due to the deposit of debris). This threshold height is more or less the same of modern western bread kilns. This fact, besides its shape and the small dimension of the furnace chamber, could mislead to identify it as a bread oven, but this is, by no means, the case.[5] Most probably, it was an industrial furnace, for the production of metal or glass, although there are not enough evidences to assert undoubtedly which of the two choices is the correct one.

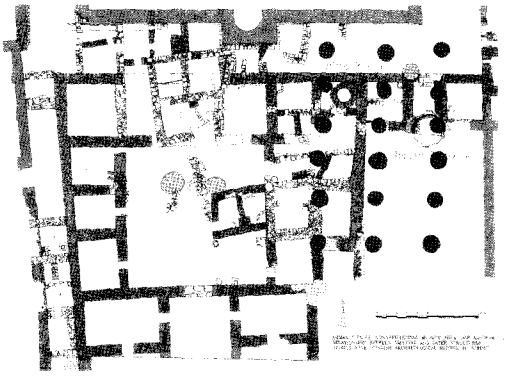
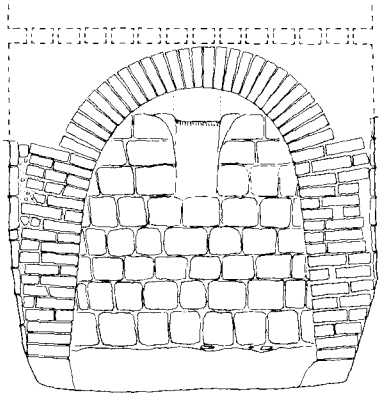


Figure 8
Amman Citadel. Abbasid pottery kiln. General view.



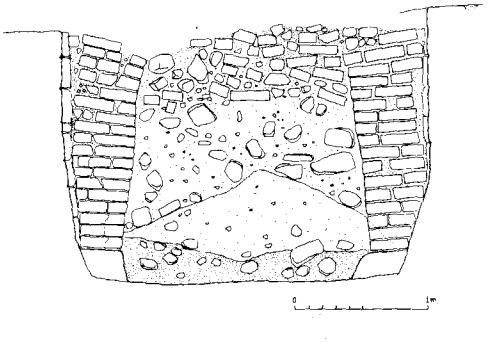


Figure 9a&b
Amman Citadel Abbasid pottery kiln. Sections. Present state and restoration

Figure 10
Umayyad Palace of Amman. Abbasid kiln from building «F» .General view

Figure 11
Umayyad Palace of Amman. Abbasid kiln from building «F» . Detail

The Fatimid lime kiln from the area behind the congregational Mosque

Only the lower furnace chamber of this small lime kiln survives (Fig. 12) It was placed in the corner of one of the rooms from the same building near the Umayyad congregational Mosque, where the Abbasid pottery kiln above described, had been found. When the former was built the latter was apparently out of use (the stratigraphy that would have related both structures was badly disrupted by the foundations of a modern concrete store built over them, see Fig. 8). It was built within the room defined by a late (Abbasid) wall that divides the original Umayyad room in two sections, so that it was contained by perimetral walls, being the space in between filled with earth. Actually, several lime kilns have been found not excavated in the ground, but built within previous existing built structures, like towers, or rooms, to offer a better insulation, and reinforce their stability, strenght and cohesion. The kiln furnace consists of two concentric rings of irregular stones masonry bound with earth: The internal one (1,3 m inner diameter; 0,9 m high) is lower than the external one (1,9 m inner diameter; 2,7 m external diameter; 1,4 m high), so that it defines the perimetral step required to built over it the «dome» of stones to be burnt (Fig. 13). At the bottom of the southern face of

Figure 12
Amman Citadel. Fatimid lime kiln from the area behind the Mosque. General view

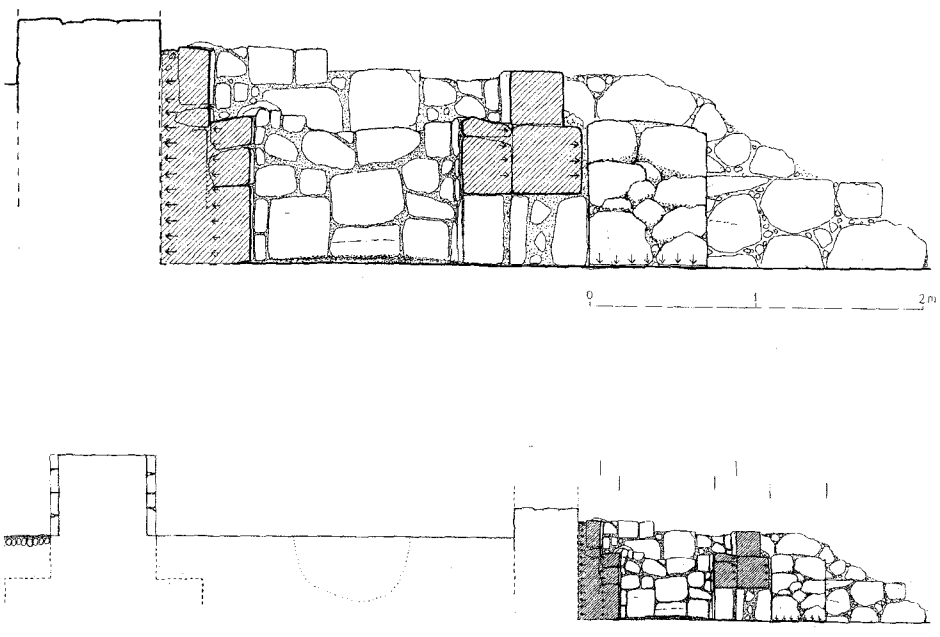


Figure 13
Amman Citadel. Fatimid lime kiln. Section

the furnace wall (in correspondence with the door of the Abbasid wall, there is the mouth to feed it (42 cm high; 30cm wide). Inside the chamber were found ashes and traces of lime, and partially burnt limestone. Among the pottery sherds found, a sample from Ayyubid-Mamluk period placed at the bottom of the kiln, on top of the ashes, would indicate the last period of use of the kiln.

Annex: Shared production of lime and bricks/pottery in the same kilns

In western medieval Europe, we know from written sources (legal norms and regulations) that the same kilns devoted to brick fabrication were producing lime as well. At Florence, during the medieval ages and the *Renaissance*, bricks and lime could be produced in the same furnace. The regulations of 1325 and 1415 from Florence make explicit the duty of brick kilns to produce lime as well. Furthermore the register documents of the related guild (*l'Arte dei calcinarii*) from the same city, do not make differences between the furnace workers of lime kilns from those from brick ones, as it used to happen in Bologna (Goldthwaite 1984, 267 cit. in Baragli 1998, 126). It make sence that due to economical reasons the same procedure would have been in use in the Levant. J. P. Adam noticed that in some areas of present day Tunis (Kairouan and Nabeul) the baking of bricks and lime is often made simultaneously, placing in the kiln («high flame» one) the bricks on top of the lime stones to be burnt. He mentions that no archaeological evidence, nor historical account of the use of this procedure in the Antiquity is recorded (Adam, 71; Fig. 154).

Yet, the «low flame» method, more energy-efficient, for lime production that apparently was devised in the Levant, would not allow a simultaneously baking of bricks. However, the same kiln could have been used for producing lime and baking bricks alternatively, just by changing the way the furnace was feeded and operated (in a similar way our Umayyad lime kiln might have been reused for melting metal in Fatimid period).

In our case, we have the evidence of two different kilns simultaneously in use, for lime and pottery production respectively (the first is Umayyad reused in Abbasid period, and the second one Abbasid). Apparently, it seems that each one had a very specific aim, and consequently a different design and operational system: The one for the lime would be a «low flame kiln», very adequate and efficient for lime production, meanwhile the pottery one would be a «high flame» kiln, required for pottery baking (the «low flame» ones cannot be used for this purpose). This would indicate that the bricks eventually baked at Amman Citadel during the Abbasid period should have been produced in the second kiln, or in the first one but using it as a «high flame» kiln. But they never could have been baked at the same time the lime was produced, if the mentioned «low flame» process was the one actually used.

Notes

1. The charcoal and ashes encased in this kind of mortar enables to date it with great accuracy by means of radiocarbon dating (Berger 1992; Gallo 1998). In collaboration with Dr. Ferran Alonso, and his team from the Institute of Physical Chemistry «Rocasolano» (CSIC), it has been foreseen the possibility of establish a research program to analyze and dating the samples collected by the Author. This would allow to test and calibrate the instrumental dating process, and at the same time to have a certain dating of these monuments. It must be taken into account that most of these Umayyad monuments were built in a very short and well defined period of time: the last years of the 7th C. and the first half of the 8th C. AD.
2. J. P. Adam distinguish three different kinds of operation process for burning the limestone: The kiln with furnace in the base («high flame» burning procedure), the «piling» kiln («low flame» burning procedure), and burning the lime in the open air. Regarding the second method («low flame»), Adam mentions the energy-efficiency but also the difficulty to separate the lime from the ashes, and the lack of known examples from the Antiquity. The last procedure, can just be used for gypsum production, due to the low temperatures reached. (Adam 1984, pp. 73–5).
3. «Il tratto superiore della muratura, che doveva essere costruito fuori terra, non è più conservato. Le pareti della zona inferiore della fornace sono costituite, per una altezza di cm. 170 circa dallo spiccato, da una muratura più spessa di cm 40 circa rispetto a quella della zona superiore. La differenza di spessore tra le due parti dà origine ad una risega che, avanzata verso l'interno della struttura, ne segue la intera circonferenza. La zona compressa tra la base della fornace e la risega, costituisce la camera di combustione della fornace L'alimentazione della fornace avveniva da

una zona posta inmediatamente all'esterno e comunicante con la fornace stessa: il prefurnio, costituito da una superficie ovale leggermente depressa e di modeste dimensioni (cm. 250x130 ca.), posta ad un'altezza quasi corrispondente alla risega della fornace (Sagui 1986, pp. 345–9).

4. The original text says: «Fornacem calcariam pedes latam X facito, altam pedes XX, usque ad pedes tres summam latam redigito. Si uno praefurnio coques, lacunam intus magnam facito uti satis siet ubi cinerem concipiat, ne foras sit educendus, fornacemque bene struito; facito fortax totam fornacem infimam complectatur. Si duobus praefurniis coques, lacuna nihil opus erit; cum cinere eruto opus erit, altero praefurnio eruito, in altero ignis erit. Ignem caveto ne intermittas quin semper siet, neve nectu neve ullo tempore intermittatur caveto. Lapidem bonumin fornacem quam candidissimum, quam minime varium indito. Cum fornacem facies, fauces praecipites deorsum facito; ubi satis foderis, tum fornacilocum facito, uti quam altissima et quam minime ventosa siet; si parum altam fornacem habebis ubi facias, latere summam statuito aut caementis cum luto, summam extrinsecus oblinito. Cum ignem subdideris, si qua flamma exibit nisi per orbem summum, luto oblinito. Ventus ad praefurnium caveto ne accedat; inibi austrum caveto maxime. Hoc signierit ubi calx cocta erit: summos lapides cocto esse oportebit; item infimi lapides cocti cadent et flamma minus fumosa exibit» (Caton, De Agricultura XLIV,1–4 *De fornace calcaria*).

5. The typical unleavened bread of the Middle East, is baked since the Antiquity in small clay made ovens: The *Taboun* and the *Tannour*. In the first case the oven (*Taboun*) has a rounded spherical shape that houses inside it the fire (feeded through an small opening at the base of its lateral wall). In this case the thin forms of unleavened bread are baked by placing them on top of its external surface, being the most widespread and usual method. The second kind of oven *(Tannour)* is slightly bigger and has a cilindrical shape opened at its top, housing the fire inside it at its base. It is used for cooking with pots or pans that are placed on top of it. Eventually (although quite rarely) it can be also used for baking bread: In this case the forms of thin bread are baked being adhered against the inner face of these ovens. More conventional stone built ovens exist: The so called *furun*.

Reference list

Adam, J.P. 1984. *La Construction Romaine. Materiaux et Techniques.* Paris: Picard Ed.

Almagro, A. & Arce, I. 1996. El Alcázar omeya de Amman, crisol de técnicas constructivas. In proceedings of *I Congreso Nacional de Historia de la Construcción.* Pp. 25–30. Huerta, S. ed. Madrid: Instituto Juan de Herrera, CEHOPU & CEDEX.

Arce, I. 1996. Elementos y sistemas constructivos antisísmicos en la antigüedad. Aplicación a la restauración de estructuras históricas. In proceedings of I *Congreso Nacional de Historia de la Construcción.* Pp. 39–47 Huerta, S. ed. Madrid. Instituto Juan de Herrera, CEHOPU & CEDEX.

Arce, I. 1999 (in press). The Umayyad Hydraulic System at Amman Citadel, in *Men of Dikes and Canals: The Archaeology of Water in the Middle East.* (Proceedings of the International Conference held at Petra in June 1999) German Archaeological Institute (Oriental Section). Berlin.

Arce, I. 2000. Un tipo inédito de trompas en la arquitectura omeya. In proceedings of *III Congreso Nacional de Historia de la Construcción.* Pp. 37–47. Huerta, S. ed. Madrid: Instituto Juan de Herrera, CEHOPU & CEDEX.

Arce, I. 2000b (in press). The Umayyad Congregational Mosque and the Souq Square complex at Amman Citadel. Architectural Features and Urban Significance, in *Proceedings of the 2nd. International Conference on the Archaeology of the Ancient Near East —2ICAANE—* (Workshop on «Strategies for Islamic Archaeology in Bilad al-Sham and the Jazira» May 2000). Walmsley A. Ed. Carsten Niebuhr Institute. University of Copenhagen. Copenhagen.

Arce, I. 2001. The Early Islamic Stucco Techniques and the Parto-Sassanian tradition. Continuity and Change. In *Lo Stucco, Cultura, Tecnologia e Conoscenza* (Proceedings of the XVII International Conference «Scienza e Beni Culturali». Pp. 107–129. Biscontin, G. & Driussi, G. eds. Padova: Edizioni Arcadia Ricerche.

Baragli, S. 1998. L'uso della calce nei cantieri medievali (Italia centro-settentrionale): Qualque considerazione sulla tipologia delle fonti, in *Archeologia della Architettura III* (supplemento a *Archeologia Medievale XXIV*). Pp. 125–139. Firenze: All'insegna del Giglio.

Berger, R. Dating Mortar in Ireland, in Radiocarbon, Vol. 34, N°.3, pp. 880–889. (Proceedings of the 14th. International C^{14} Conference Department of Geosciences, University of Arizona. Tucson.

Cortonesi, A. 1986 Fornaci e Calcare a Roma e nel Lazio nel Basso Medioevo, in *Scritti in onore di Filippo Caraffa, Biblioteca di Latium, 2,* pp. 277–307. Istituto di Storia e di Arte del Lazio Meridionale, Centro di Anagni.

Gallo, N. 1998, 14C e Archeologia: Il problema delle malte, in *Archeologia della Architettura III* (supplemento a *Archeologia Medievale XXIV*). Pp. 87–8. Firenze: All'insegna del Giglio.

Goldthwaite, R.,A. 1984. *La costruzione della Firenze Rinascimentale.* Bologna.

Khadijah, M.M. 1971. Lime kilns. in *Annual of the Department of Antiquities of Jordan XVI.* Pp. 107–9. Amman.

Marino, L. & Lodino, M. 1999. *La casa tradizionale nei villaggi della Giordania.* Verona: Cierre Edizioni.

Saguì, L. 1993, Crypta Balbi (Roma): conclusione delle indagini archeologiche nell'esedra del monumento romano. Relazione peliminare in *Archeologia Medievale XX*, pp. 409–418.Firenze: All'insegna del Giglio.

Riccetti, L. 1988. Il cantiere edile negli anni della Peste Nera, in *Il Duomo di Orvieto,* L. Riccetti, ed. pp. 139–215. Roma-Bari.

Vecchiattini, R. Unità produttive perfettamente organizzate: Le calcinare di Sestri Ponente —Genova—, in *Archeologia della Architettura III* (supplemento a *Archeologia Medievale XXIV*). Pp. 141–152. Firenze: All'insegna del Giglio.