CHAPTER 8

CONSTRUCTION AND FIRING OF AN EXPERIMENTAL UPDRAUGHT KILN

by

Paul T. Nicholson

8.1 Introduction

[Note that Tables 8.1–8.14, and the corresponding Figures 8.18–8.29, are placed at the end of the Chapter].

During the 1986 excavation season two kilns were discovered in building Q48.4 of the Main City (Kirby 1987, Nicholson 1987). One of these was a large heavily used structure [2984] in square G4, while the other was a partly finished and smaller kiln [3052] presumably intended to replace the former (Figure 8.1). It was clear from the excavated evidence that these were pottery kilns and that they were of updraught type, that is, the fire was placed below the vessels which were fired by the rising gases, or "draught", from the fire. In such a kiln the vessel stack is usually separated from the fire itself by a perforated floor.

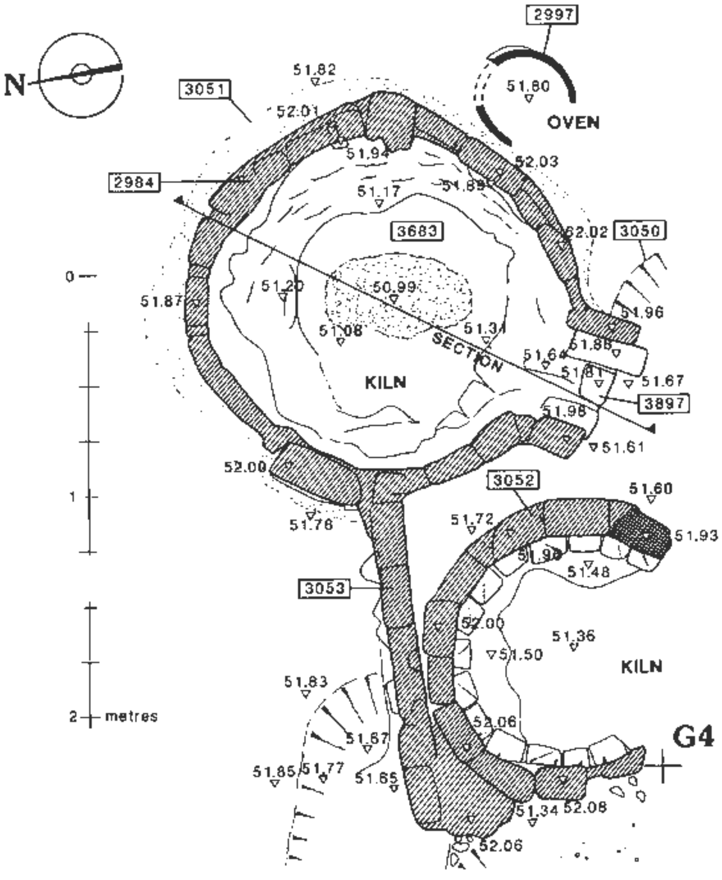

Figure 8.1. The excavated kilns in square G4 (cf. *AR* V:70, Figure 3.7). The experimental reconstructions are based on the larger one [2984]; the smaller [3052] was never finished.

Unfortunately, no traces of such a perforated floor were found, and evidence for the manner in which a floor of this sort might have been supported was slight, although certain features of the brickwork suggested that the floor had been supported around the edges by protruding bricks. Whether the centre was supported on a pillar, as in the copper furnaces at Buhen (Emery 1963:117, Fig.1; Adams 1977: 172–3, and note 20),[1] or was self-supported, having a low dome-like structure, could not be ascertained.

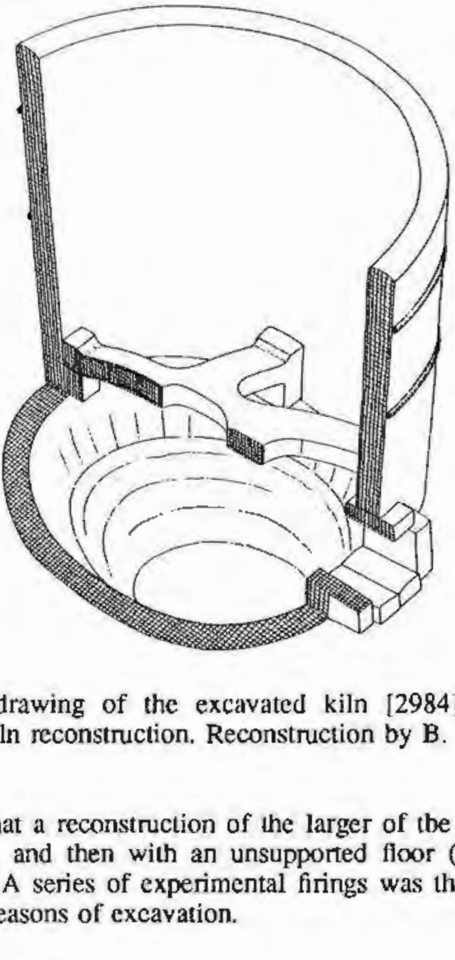

Figure 8.2. Reconstruction drawing of the excavated kiln [2984] with a low vaulted floor inserted, based on the 1990 kiln reconstruction. Reconstruction by B. Kemp.

It was therefore decided that a reconstruction of the larger of the two kilns be built, first with a floor supported by a pillar, and then with an unsupported floor (Figure 8.2). This work was begun by the writer in 1988. A series of experimental firings was then undertaken between 1989 and 1993, during the Spring seasons of excavation.

8.2 The reconstruction

The site of the kiln reconstruction was immediately to the east of the current Excavation House at Amarna. The reconstruction maintained the north–south orientation of the excavated example.

The structure of the first reconstructed kiln was made using experimentally produced mud bricks, intended to be more resistant to weathering than those produced by the current village technique. These were not specifically intended for use in the kiln reconstruction, but were used since they were readily available from the work at the Small Aten Temple, and could easily be manufactured to the correct size. Unfortunately, this particular batch of bricks was not produced exactly according to the specification laid down by Richard Hughes, the expedition's adviser on mud-brick conservation, and so were considerably weaker than intended. It was, however, believed that they would be strong enough for the intended reconstruction.

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1 Though it has become accepted that the Buhen kilns were for pottery, it seems that their original designation as copper furnaces may be correct. An analysis of slag from the kiln, to be published shortly (O'Connor, et al. forthcoming) is believed to confirm this view. I am indebted to Prof H.S. Smith for this information.

The kiln was built according to the reconstruction suggested in *Amarna Reports* V, that is, with the perforated floor supported partly by a central pillar. The preserved portion of the excavated kiln was reproduced as faithfully as possible, and the above-ground brickwork built to a height of 1.0 m, thus nine courses (Figure 8.3).

Figure 8.3. The experimental kiln as first built in 1989.

The perforated floor of the kiln would have been too weak had it been built of the experimentally produced bricks, and so was made using concrete (or gypsum and cement) lintels for some spans, and mud bricks from an abandoned modern building near the expedition house for others. These lintels, however, depended for their support upon the central pillar and on projections from the kiln walls on the north, east, and west sides of the kiln. Two other lintels rested in sockets in the brickwork on the south-east and south-west, so that the kiln had five permanent bars arranged as a five-pointed star. The upper surface and sides of these five arms were roughly plastered. Two movable lintels, the western one of concrete, the eastern of gypsum and cement, spanned the distance between the northern and eastern and northern and western points of the cross. The completed floor therefore consisted of two roughly equilateral triangles in the northern half and two arms in the southern. The kiln floor level was fairly clear from the excavated structure, and must have rested at a level approximately half-way up the stoke hole, so that this had to have a chute-like construction for access. This makes the reconstruction of the floor at the southern (stoke hole) side problematical (see *Amarna Reports* V).

The finished structure had a fire lit in it at the end of the 1988 season with a view to hardening the brickwork and testing the capability of the flooring to withstand heat. A fire of palm-leaf ribs (*gereed*) was maintained for about half an hour and a temperature of c 600°C achieved. Despite the short duration and relatively low temperature of this fire (Table 8.1), the lowest courses of bricks were observed to have changed colour from a cement grey to a pinkish red.

8.3 The vessels

Because of the time which would have been involved in producing at the expedition house sufficient vessels for a kiln of this size, the charge was purchased from a local potter at Deir Mawas. It consisted of twenty large *gidr* (water-cooling vessels) and twenty large open bowls, common in the repertoire of the Deir Mawas potter (for the Deir Mawas potter and his vessels, see this volume, Chapter 9).

8.4 Firing 1, 11-3-1989

Firings by the Deir Mawas potter had already been observed and recorded using thermocouples, so that some idea of the duration and peak temperature achieved in firing these siltware vessels could be obtained (Nicholson, this volume, Chapter 9). It was discovered that firings at the Deir Mawas pottery were much less highly organised than those to be seen amongst the marl-ware potters at Deir el-Gharbi, near Ballas (Qena Governorate, Upper Egypt) (Nicholson and Patterson 1985, 1989), and used substantially less fuel. Lower temperatures were reached at Deir Mawas than was usual among the marl potters, despite the smaller size of the former's kiln.

However, although the fuels used (sugar-cane waste — *boosa* — and sawdust soaked in old engine oil) were of a type unavailable in Pharaonic times, or even early in this century (cf. Blackman 1927: 150), the Deir Mawas pottery produces serviceable vessels while using a very small quantity of fuel. Unfortunately, the exact quantity used in each firing is not readily ascertainable since it does not come in discrete units (i.e. bales or sacks), but is drawn from a pile of rubbish and thrown in by the handful. The fuel pile can be difficult to differentiate from the floor of the workshop courtyard. Given that fuel is frequently a limiting factor in pottery making (Rice 1987: 173), it seems probable that ancient potters, like their modern counterparts, attempted to minimise the amount used, thus minimising their costs (however defined). Around the kilns excavated at Amarna there are no mounds of overfired waster vessels, though soft underfirings can be found around kilns as well as elsewhere. It would seem that these underfirings were generally felt to be saleable, and it is tentatively suggested that firing temperatures were kept to a minimum, thus minimising fuel use.

For the purposes of the experimental firing, *gereed* was used, chopped into lengths of approximately 30–40 cm as this had been found to be a convenient size for stoking the kiln. *Gereed* was chosen since it would have been available in ancient times, and so would not prejudice the validity of the experiment. However, in the absence of charcoal analyses from the excavated kilns, it is entirely possible that some other fuel was used instead of, or in addition to, this.

The first firing began at 15.35 hours on March 11th, 1989, a warm day with virtually no breeze (Table 8.2 and Figures 8.18 and 8.19). Prior to loading, the vessels had been allowed to stand in the sun and so their surfaces became very warm (air temperature 26°C). Only a part load of vessels had been purchased for this first firing, and, in loading, it was found that this was inconvenient since the area above the stoke hole could not be fully covered by the number of vessels in the firing. This left a large gap at the southern end of the kiln through which it was obvious that much heat would be lost. The vessels were loaded with the *gidr* to the bottom and the bowls on top, and were inverted in the kiln, the bowls forming part of the covering along with a layer of sherds. In this the stacking resembled that seen at both Deir Mawas and Deir el-Gharbi. The principle of this kind of stack is that the inverted vessels act as barriers to the hot gases, becoming filled with heated gases and thus firing. The inverted bowls on top of the stack cover the gaps between the *gidr* (Figure 8.4) and so prevent heat being immediately lost. In so trapping the heat they become fired. In addition, the vessels are packed in such a way that there is overlap between the layers, rather like brickwork, so preventing any gaps which might run straight through the pack. These gaps act as "chimneys" (hence their technical name) and allow the rapid escape of hot gases. This causes the overfiring of the vessels between which the chimney passes and is also wasteful of fuel.

The vessel charge, once loaded, was covered in a layer of sherds (Figure 8.5). This layer not only serves to insulate the vessels slightly and to help prevent chimneys, but is more importantly a kind of "soot trap". The carbon deposited during firing builds up on this uppermost layer rather than on the vessels themselves. At the end of a firing by contemporary potters clean straw is thrown on to the kiln top. This burns off the accumulated carbon from the sherds, but, more importantly, from any parts of the vessels which may have been exposed between the sherds. Thus the fired charge is a clean red colour throughout.

Within five minutes of lighting the fire, one of the gypsum and cement lintels comprising the north-eastern quadrant of the kiln floor gave way, presumably having become hydrated over the previous twelve months. Since this material was being used, along with concrete, as a substitute for mud brick or stone, it did not affect the validity of the experiment except in so far as it damaged one of the *gidr*, which fell through into the fire and had to be broken up and removed

Figure 8.4. Catherine Powell loading the 1989 kiln for firing 1. Bowls are being placed in an inverted position over the inverted *gidr* below.

through the stoke hole. Fortunately, the rest of the vessels had been sufficiently well packed for the collapse not to affect them, save that a chimney to the rear of the kiln had now been created.

The fire was allowed to go out and was relit at 15.45. This time there were no difficulties, and the thermocouple placed on the north (T1) side of the kiln at the level of the gridded floor recorded 145°C after only five minutes. The thermocouple on the eastern side (T2), and at a similar level, was near the front of the vessel stack and so in a colder spot, hence recordings from this lagged well behind that to the north. All temperature readings are given without correction for air temperature, which should be subtracted from them to give the actual reading.

The fuel had been divided into piles according to which part of the palm branch it came from. The most rapidly burning were the middle and end fronds of the leaves which, because of their shape, could be thrown into the fire like darts, and so reach the required areas of the kiln. The large fibrous "shoulders" which joined the branches to the tree were less readily positioned and burned more slowly. These were used as a means of maintaining the temperature after rapid stoking with the fronds. Intermediate parts of the branches were less useful, and the very spikey lower portion of the branches was difficult to handle, though could be used as slow-burning fuel. Occasionally, the fuel was raked using a wooden poker to ensure maximum combustion and minimal build-up of ash.

A maximum of 730°C (not corrected for initial air temperature of 22°C inside kiln) was achieved by this means (Table 8.2). It had been hoped to reach 800°C or more but, given the incomplete vessel load and the difficulties which this created, it was felt that the temperature achieved was satisfactory. It was clear that this temperature was not representative for the entire kiln interior, and that non-ceramic vessels might remain in some areas, but it was expected that

Figure 8.5. The part-load of vessels, used in firing 1, covered in a layer of sherds.

this would be rectified in a firing with more vessels. At 17.20, close to the end of the firing, a further part of the vessel load collapsed, perhaps prompted by cracking of the kiln structure (Figure 8.6). Only one vessel was broken by this collapse. The stoke hole was blocked at 17.30, though this is unlikely to have been effective in decreasing the rate of cooling significantly because of the gaps in the vessel stacking caused by collapse and lack of vessels.

The weight of fuel used in the firing, calculated from the mean weight of ten *gereed* branches selected at random, was 208.59 kg. This may be a slight over-estimate, though the formula corresponds well to the amount of fuel used in the 1990 firings, all of which was weighed.

The kiln was then allowed to cool overnight and was examined again on the morning of March 12. At this time it was discovered that the major lintel running north–south from the rear of the kiln to the central pillar had given way, taking with it the new concrete lintel and all those vessels stacked upon it. Thus the entire northern section of the kiln load had fallen. The vessels themselves were cool enough to be unloaded, although the embers in the bottom of the kiln still glowed red when raked. It was thus necessary to remove all the vessels from the top, or allow the kiln to cool further and then stand in the ash. It was when removing the ash that it was decided that its weight should be measured on future occasions for comparison to the amount of fuel.

8.5 Conclusions from the first firing

It will be obvious from the above that the main difficulties with the first firing were related to the kiln structure. The blame for this must partly rest with the incorrectly made bricks, which did not harden over time as had at first been expected. These should have been supporting the north–south lintel, the collapse of which caused most of the damage during the firing.

Figure 8.6. The collapsed section of the first reconstruction after firing 1. North is to the right.

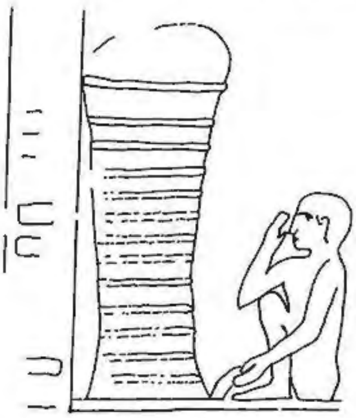

Figure 8.7. Ribbing on a kiln. From the tomb of Ti at Saqqara.

The cracks in the kiln walls were not of any great significance and are something commonly experienced in pottery kilns. They may have been accentuated by the poor quality of the bricks, but would have been expected in any case. This, however, yielded useful results in that it prompted the suggestion that the exterior of the kiln be plastered to add a little more strength to the structure and to show up cracks better when they occurred. It was also decided that, for future firings, ropes be bound around the kiln.

Rope binding was suggested for two reasons. Firstly, "bands" can be seen around representations of some kilns such as those in the Old Kingdom Tomb of Ti at Saqqara (Holthoer 1977), and may represent reinforcing hoops or ropes (Figure 8.7). Secondly, ropes or hoops were, and are, often used on updraught kilns for brick or pottery manufacture in order to help cope with the cracking which can occur due to thermal expansion (e.g. the wire ropes excavated from a nineteenth century brick kiln at Roystone Grange, Derbyshire, England, Probert 1988).

The kiln itself was found to draw the flames well and to be fairly simple to fuel and control. The vessels produced were on the whole adequately fired, and the main faults were breakage from collapses of the kiln floor and sooting on vessels which either fell into the embers or were sooted as a result of the flow of gases being altered where gaps in the stacking appeared due to collapses. In short, the firing itself can be regarded as a qualified success, while the difficulties experienced stem from the materials used in kiln construction. With this in mind, it was decided to replace the entire kiln floor, including the central pillar, before undertaking a second firing. After this the whole kiln was due to be demolished and rebuilt, with a vaulted floor, for comparison.

8.6 Other results

Once the kiln had been emptied of vessels and debris, and especially once the floor was removed, it was very clear that the broken remains of floor supports replicated closely the brickwork of the ancient kiln [2984] at site Q48.4. Naturally this was not surprising, as these formed the basis for the reconstruction, but their state of preservation relative to that of the surrounding brickwork was of interest, and suggested that these features had been correctly interpreted as kiln floor supports.

Equally interesting was that, three days after the firing (i.e. on March 15th), it was noted that the brickwork and mortar in those areas which had been oxidised during the firing were showing white patches. These were seen to be calcareous inclusions (pieces of shell, small limestone chippings, etc.) which had hydrated after the firing and spalled away the surfaces of the bricks and mortar which had formerly covered them. Such hydration may have been accentuated by the heavy rains of March 14. This pattern of white speckles was particularly apparent in the brickwork of those kilns excavated at Amarna, and doubtless has the same cause. Over time this would lead to the deterioration of the kiln and to its replacement, a process which was almost certainly in progress in the excavated pottery workshop in the Main City, where kiln [2984], on which the reconstruction was based, was evidently being replaced by kiln [3052].

8.7 Firing 2, 25-3-1989

For this firing, the kiln had been plastered outside with a mud and straw plaster, and bound round with two ropes, one near the rim, the other immediately above the stoke hole. Each rope was fitted with a simple adjuster. This consisted of a wooden lath about 30.0 cm long, with a hole of about 3.0 cm diameter bored near each end. One end of the rope was passed through each hole and knotted so that it could not be pulled out from the lath. The rope was then placed around the kiln and one knotted end of the rope pulled, the other being pulled tight against the lath as a result. Once the rope was pulled tight around the kiln, the end of the rope being pulled was passed behind the block where the tension on the rope gripped it tightly (cf. Figure 8.12). The ropes used were nylon; natural fibre would have been preferable since these could have been soaked before the firing and allowed to dry more tightly as firing progressed. Nonetheless the ropes were easily and efficiently positioned and adjusted.

This time the kiln was completely filled with vessels stacked in the same way, namely, inverted *gidr* making up most of the load, with inverted bowls on top of these and the whole covered by a layer of sherds.

The fire was lit at 16.35 hours (Table 8.3 and Figures 8.20 and 8.21), and no major problems occurred until 17.27, when there was some slumping of the kiln load; this was followed at 17.40 by a true collapse which increased in severity until 17.55. The problem area was the north-west quadrant of the kiln, and on unloading it was discovered that the movable lintel had completely broken, leaving only its south-west end resting on the cross beam. The lintel was probably too heavy as well as being prone to hydration. Nonetheless, the kiln was easier to operate with a full load of vessels, and a peak temperature of 890°C was achieved (not corrected for the 28°C air temperature inside the kiln before firing) (Table 8.3).

The amount of fuel used in firing 2, based on the average weight of a palm branch, totalled 230.43 kg. After the firing the amount of ash left from the fuel was weighed and totalled 40.80 kg, which represents 17.7% of the original fuel weight.

8.8 Conclusions from firing 2

This firing was judged to have been successful, since collapse occurred only in the late stages, by which time the point of the exercise had already been proven, namely, that the kiln was capable of temperatures in excess of 850°C and that controlled stoking was possible with the central pillar present. The vessels produced from firing 2 were generally well fired. No vessels were lost due to firing faults, although 1 *gidr*, 1 bat (for the experimental potter's wheel), and 4 bowls were broken as a result of the floor collapse.

The greater amount of fuel used was attributed to the higher temperature achieved since the length of the two firings was similar. Unfortunately, the importance of the weight of ash was not realised until it had been removed following firing 1; consequently no comparison of ash was possible. However, fuel consumption and weight of ash as a percentage of fuel weight were thought likely to prove useful means of comparison with the proposed experiments for 1990.

The main failings of the firing were again due to materials. Since stone was not available for use as a flooring material, concrete had again been used, albeit with reinforcement in the form of wire mesh. Although it was realised that this would not survive for long, given its tendency to hydrate between firings and lose strength during firings, it had been hoped that it would provide a suitable short-term substitute. This was clearly not the case. Experiments should ideally be undertaken using stone kiln bars. It would be particularly interesting to examine whether the readily available local limestone would be suitable, at least for short periods, as flooring material.

The provision of ropes around the kiln seemed to be of some benefit. Although cracks again opened in the kiln walls, they were prevented from spreading sò widely as in the previous firing. Consequently there was less opportunity for the vessel stack to move or settle as the cracks opened and then gradually closed on cooling. It was observed, too, that the kiln pit had deepened slightly over the course of the two firings. This may be attributed to the effect of heat on the compacted *gebel* surface and to the actions of poking the fire during the firing, and raking the ash out afterwards.

At the end of the season the kiln stoke hole was blocked with unmortared bricks to prevent sand and rubbish accumulating in the kiln pit.

8.9 Reconstruction 2, 1990

At the beginning of the 1990 excavation season the first reconstruction remained in good condition, save that the concrete bars of the floor bad hydrated and become brittle, so much so that they would not withstand being stood on. The kiln was photographed and then carefully demolished.

The experimentally produced bricks had not become fire hardened, and many crumbled to powder on removal from the structure. Some of the surviving bricks were examined to gain some idea of the depth of fire reddening on the material. This extended up to 2.0 cm into the brick. Of particular interest were the mud bricks used as projections on which the floor rested. These had reddened where they protruded into the kiln, but remained unaffected where they had been built into the thickness of the structure. The limestone chippings which were included in these bricks stood out most clearly in the reddened part of the bricks where they had hydrated and were beginning to break down. This was a feature observed on the walls of the excavated kiln [2984] in square G4 of site Q48.4.

The kiln pit, however, was to be re-used since it maintained the correct circumference. However, the depth of the pit had increased slightly and since it was desirable to maintain the stoke hole and floor supports in the same position as in [2984], the brickwork was extended below it for an extra 10.0 cm. This meant that the final version of this kiln maintained the same distance between firing-pit floor and gridded floor as in the final firing of 1989. Thus the last firing of 1989 and first of 1990 may be said to be the most directly comparable.

In building the 1990 reconstruction a correctly produced batch of experimental bricks were used for the lower courses, the floor, and floor supports of the kiln. These were much denser bricks than the previous ones and had been allowed to dry and harden more slowly. The remainder of the poorer quality bricks from 1989 were used in the superstructure. Nonetheless, these new bricks were not as strong as those removed from the decayed modern house, nor those in ancient structures in the city, although not too much should be read into this in comparing ancient and modern kilns and other structures, since it is thought (opinion of R. Hughes) that over a period of time precipitation of calcium carbonate in local mud bricks exposed to the elements increases their hardness naturally. The brickwork of ancient kilns at Amarna which we have examined and which, having been buried, has not been exposed to the effects of chemical weathering, we have found also to be of poor quality (see this volume, Chapter 7, section 7.3).

Figure 8.8. Making the *gereed* former for the fenestrated dome of the kiln floor.

The construction followed the same course as the 1988 reconstruction, except that the floor was supported wholly on projecting bricks rather than being partly let into the kiln, at the south-east and south-west, and this time there was to be no central pillar. The absence of this central supporting pillar meant that certain technical difficulties had to be overcome. Foremost amongst these was the construction of a self-supporting perforated floor made using only techniques which could have been employed anciently. The solution adopted was to take lengths of *gereed* with all the foliage stripped from them and cut them to lengths slightly greater than the width of the kiln at the points for which they were intended. One end of these was then placed beside the projecting floor supports and the rest bent, in the manner of a bow, until the other end could be placed beside the opposite support, or, where no opposite support existed, on the opposite kiln

Figure 8.9. The completed fenestrated dome before plastering and burning out the former.

wall. The tension exerted by this bending kept the *gereed* in place. The individual lengths were then tied together where they crossed to prevent any lateral movement and to minimise the risk of injury should any of the pieces spring out of position. This technique produced a very strong former. Bricks were then laid on top of this *gereed* former, most of them with their broad faces resting on the *gereed* (Figures 8.8 and 8.9). This allowed the floor to be relatively thin, so that heat would not be wasted in heating thick brickwork. The gaps between the bricks were "chinked" with sherds, a process still observed in the building of vaults by contemporary Egyptian builders. At the centre of the kiln the bricks were shaped into truncated triangles. This enabled them to butt on to one another directly or allowed extra, shaped, bricks to be used between them. The five arms of the floor thus distributed their thrust on to a distorted ring-shape (provided by the kiln wall) which had its centre spanned by a half brick. The kiln floor thus became a very shallow fenestrated dome.

The floor was next carefully plastered over, on all sides. The plastering included the *gereed* former where it touched the underside of the brickwork. The kiln structure was then built to the same height as its predecessor, with about nine courses of brickwork above the uneven ground surface. Finally the outside of the kiln was plastered using mud and straw (*tibn*) plaster. It was found that the best way to apply this was to mix it thoroughly with the hands and apply it in the same way, dashing a handful at a time against the kiln walls and then smoothing it down.

This done, a small fire was lit in the fire pit to burn out the former and to harden the bricks and plaster (Figure 8.10). Although this could have been done as part of the first firing, it was considered safer to ensure that the kiln floor was adequate and that it would stand without any support. After the firing the bricks were observed to have reddened as before, and the structure showed no signs of damage.

Figure 8.10. Burning out the former from the new fenestrated floor.

8.10 Firing 3, 12-4-1990

For this firing, *gidr*, *fakshia* (small *gidr*), and bowls were again commissioned from the potter at Deir Mawas. As part of the further documentation of the firings, all of these vessels were weighed and their rim diameters recorded before firing (Table 8.6). The vessel load consisted of 4 small *fakshia*, 6 ordinary *fakshia*, 26 *gidr*, 11 large bowls, 26 small vessels, and 2 large bats produced experimentally by Catherine Powell, as well as 8 bowls already fired in the 1989 season and re-used to make up a full load for this experiment (Figure 8.11). The total clay weight of these pieces was 290.20 kg. The vessels were stacked as before, inverted with the bowls uppermost, and the whole covered with sherds. The kiln was again bound with rope tensioned using the wooden blocks (Figure 8.12).

The fuel for the firing was carefully weighed and put in piles of known weight. Palm ends, fronds, and spikey sections were each put in separate piles. The total weight of fuel used in the firing was 153.30 kg. As in the previous season, two thermocouples were used, although this time they were at the north (rear) of the kiln and on the eastern side (rather than the western as before).

Firing began at 15.24 hours and lasted for 1 hour and 46 minutes, immediately before which the air temperature inside the kiln was 31°C (the temperatures given include this). A peak temperature of 962°C was reached in the 91st minute of firing, although temperatures in excess of 800°C were maintained for 28 minutes, and temperatures in excess of 600°C were maintained over at least 70 minutes (Table 8.4 and Figures 8.22 and 8.23).

Figure 8.11. The vessels for firing 3, before being covered with sherds.

The fire was found to be easy to control, more so than in the previous kiln, and stoking was considerably easier without the central pillar. During the firing a breeze blew up from the west necessitating a small windbreak of four bricks, placed on the eastern rim of the kiln. This method of making a windbreak is employed by the potters at Deir el-Gharbi and elsewhere. In the 72nd minute the rear wall of the kiln developed a crack which ran down as far as the hole bored for the thermocouple; this was followed shortly afterwards by a crack on the western side. Both of these events were accompanied by the sound of the settling of the vessel stack. However, the ropes around the kiln prevented excessive cracking and vessel movement.

The soot deposit which built up on top of the sherds, and the uppermost layer of pottery where exposed, was finally removed by throwing clean straw on top of the kiln. The kiln was then allowed to cool until April 15.

8.11 Conclusions from firing 3, 1990

The kiln was deliberately fired to a higher temperature than that normally employed in firing the Deir Mawas vessels, as a test of how easily very high temperatures could be achieved. Nonetheless, there were no actual firing losses. Two *gidr* distorted badly (though had they been fired at Deir Mawas they would probably have had any cracks plastered, given a fugitive slip — an unfired and water-soluble slip — and sold), one *fakshia* had a cracked rim, and two of the small experimental bowls broke, though this was probably as a result of drying cracks. Two of the small bowls had become reduced and blackened, but these had fallen through the stack during the settlement when the cracks appeared, and had been buried in the soft ash. Several vessels showed clear evidence of "flashing" marks left where they had been in close contact during the

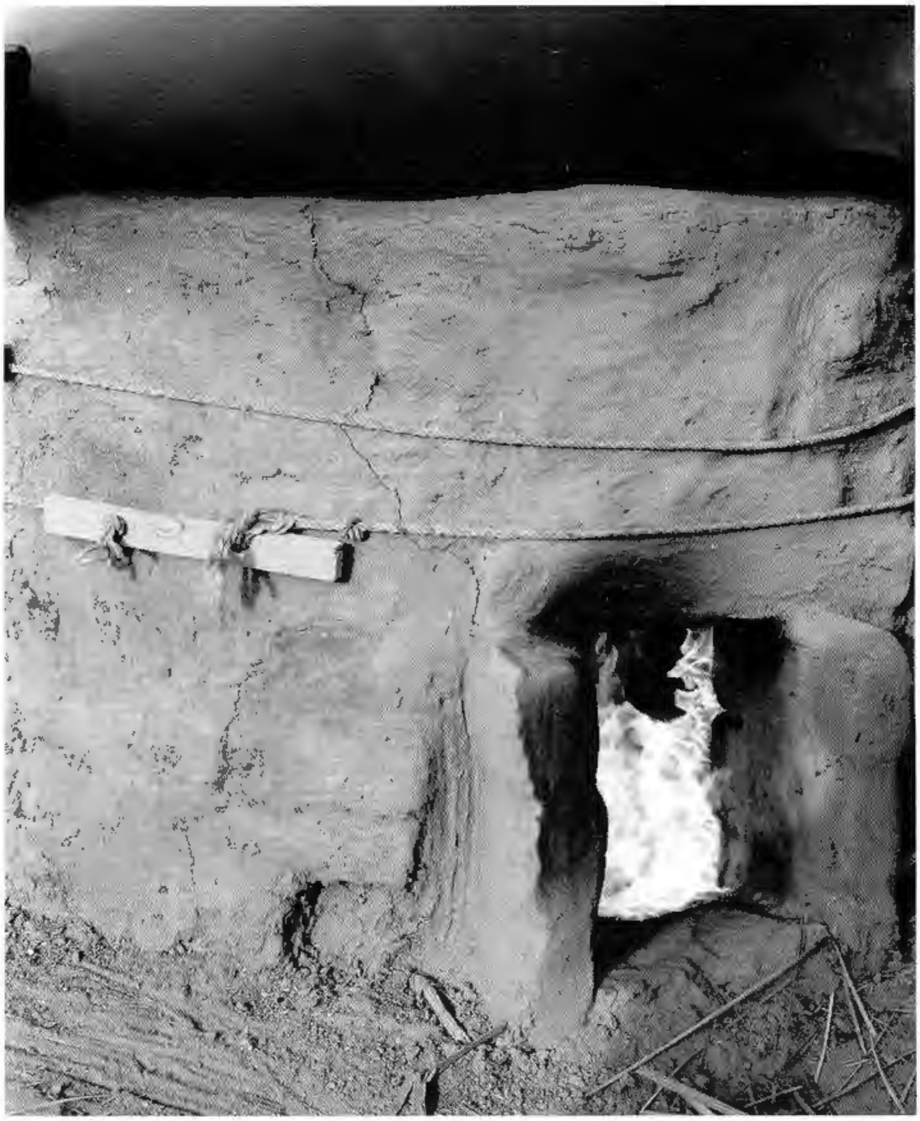

Figure 8.12. Firing 3 in progress. Note the wooden "cleat" for securing and adjusting the rope.

firing.

The kiln floor was found to have survived the firing extremely well, though some of the mud plaster had cracked. In several places inclusions of lime had burst through the plaster and were crumbling away as a powdery efflorescence, the result of hydration. The floor, like the walls, was fire-reddened, and some of the walling showed a colour change to a whitish bloom.

The ash, still at a temperature of 421°C at 07.00 on April 15, was removed later that day and weighed. The total weight of ash was 20.00 kg, which represents 13.05% of the fuel weight. In weighing the ash it was noted that the buckets got heavier as the ash from lower down the kiln was removed, and this led to closer observation in the next firing. The volume of ash was approximately 71.5 litres. Since both the weight of fuel used and the weight of clay fired had been accurately recorded, it was possible to calculate a clay/fuel ratio (Sheehy 1988) for this firing. This gives a ratio of 1:1.89, that is 1 unit of fuel fires 1.89 units of clay.

The mean clay/fuel ratio quoted by Sheehy (1988: 213), in his study of South American potters for bisque firing in a medium-sized kiln, is 1:2.16, a more effective rate than that achieved in the Amarna reconstruction. However, the Amarna kiln was fired to a higher temperature than for the bisque firings observed by Sheehy (1988: 215) which probably accounts for the difference. In fact, the Amarna reconstruction is more efficient than some of the ratios used by Sheehy in calculating his mean figure.

The vessels were weighed after firing and their rim diameters measured (Table 8.7). The greatest percentage weight loss (Table 8.9) was recorded for the *gidr*, vessels which lost 17.40% of their weight. This probably represents the burning out of the large quantity of chaff included in the matrix along with organic matter naturally occurring in the clay. The mean weight loss for all classes of vessels (including *gidr*) was 11.24%. The greatest shrinkage in rim diameter was also recorded for the *gidr* at 4.89% whereas the mean shrinkage (including this figure) was 3.96%.

8.12 Firing 4, 18-4-1990

For this firing, the already fired vessels were re-used along with two unfired *gidr*, experimental tiles, and experimentally made bowls (Table 8.8). The two *gidr* were placed, one near the stoke hole and the other in the top row so that it could be determined whether firing had been effective. In all other respects the vessel stack was as in the previous firing, and a sherd covering was used over the whole.

Firing began at 16.40 hours and had a duration of 1 hour and 22 minutes, the peak temperature of 885°C being achieved in the 75th minute (Table 8.5). This was recorded on the western thermocouple (T2), the northerly thermocouple recording its peak of 867°C in the 72nd minute.

During this firing, periods of reduction were specifically recorded (shown as "R" on Table 8.5, see also Figures 8.24 and 8.25). It was found, however, that defining these periods of reduction was difficult, since the change from oxidising to reducing atmosphere is very fluid and only the peak is readily observed. Where reduction is at its peak, the flames can be seen to "roll" along the underside of the perforated floor toward the stoke hole, and carry with them some of the smoke. Black smoke can be seen on the kiln top also.

8.13 Conclusions from firing 4, 1990

This fourth firing confirmed what had been apparent in the third one, namely, that the reconstruction without central pillar was easier to work with. Control of the fire was simpler than in the previous reconstruction, and stoking was a fairly simple matter, too. The absence of the central pillar also meant that one did not need to worry about a "cold" spot developing behind the pillar where raking was not possible, and where fuel could only be placed by skillful stoking.

As previously, the fuel used was recorded and the amount of ash remaining weighed at the end of the firing. It was found that a total weight of fuel of 120.60 kg was used and that the remaining ash, 18.6 kg, represented 15.42% of this. This indicates that the combustion was more complete during the previous firing. The greater density of ash at greater depth in the fire pit was also confirmed indicating the ease with which the ash can be compacted. The clay/fuel ratio, at 1:1.94, is more efficient than in the third firing. This is much closer to Sheehy's mean figure (1988: 213), and, given the differences between the fuel used and the differences in kiln size and construction, is very acceptable. Once again the temperature was in excess of that achieved by Sheehy's potters, so that the two sets of figures are still more comparable.

8.14 The third reconstruction, 1992

During the 1992 season it was decided to make a third and final version of the kiln. This involved the addition of an extra metre to its height (Figure 8.13). The rationale for this was to make it more similar to the representations of kilns known from tomb scenes of both the Middle and New Kingdoms, where kilns have a distinctly chimney-like appearance. It was thought that such a structure might draw well and so fire vessels more efficiently. The kiln floor had remained intact since the firing of 1990 and was judged to be in sufficiently good condition not to warrant any replacement. The mud plaster with which it was covered had fired hard, though was badly cracked in places.

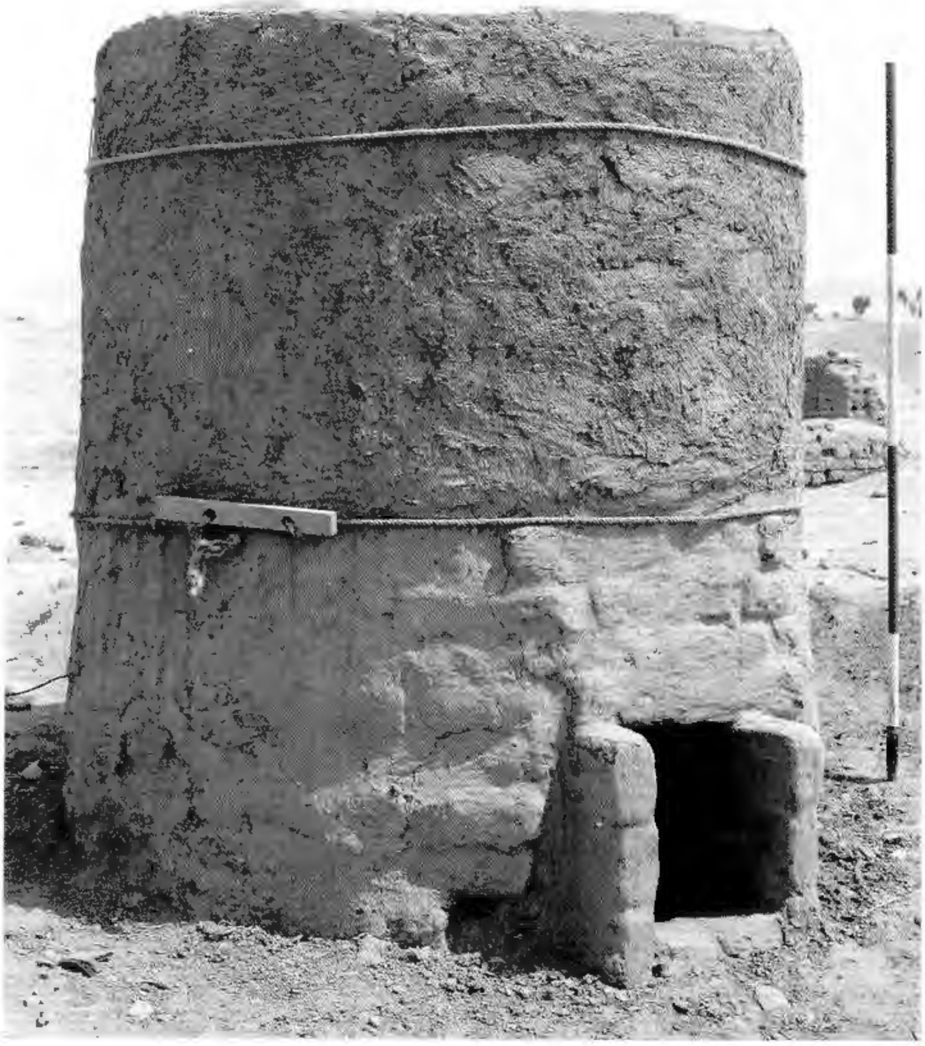

Figure 8.13. The final reconstruction of the kiln in 1992. As well as being a metre higher than its predecessors this kiln maintained the low vaulted floor from the 1990 reconstructions. The rope fastenings can be clearly seen.

8.15 Firing 5, 19-3-1992

Once again fuel for this firing was weighed out and placed in distinct piles according to which part of the palm branch it came from (Figure 8.14). The total fuel weight was 191.55 kg. The kiln contained a mixture of fired and unfired vessels (Table 8.10), since it would have been both expensive and impractical to fill a kiln of this size with unfired vessels for each experiment, and we already had, in storage, a large number of fired vessels from previous experiments. The charge thus comprised 25 unfired *gidr*, 26 fired *gidr*, 18 fired *fakshia*, 10 small unfired *fakshia*, 2 small fired *fakshia*, 9 fired bowls, 2 unfired experimental hearths, and 1 experimental bottle, also unfired. These gave a total clay weight of 391.90 kg. Since the kiln was taller than previously, three binding ropes were used around it rather than the usual two (Figure 8.15).

Firing (Table 8.11 and Figure 8.26 and 8.27) began at 16.05 hours, at which time the air temperature was 21°C. However, within ten minutes a wind blew up from the north and grew stronger throughout the firing. This breeze blew directly toward the stoke hole, and though this

Figure 8.14. The 1992 kiln just before firing. The fuel can be seen in the foreground, divided into weighed piles according to which part of the branch it came from.

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could have been narrowed by placing bricks near it, the effect of the breeze would still have been considerable. It was, therefore, thought better not to attempt to narrow the opening, which would anyway have made stoking more difficult and comparison with previous firings less valid. The peak temperature reached was 918°C in the 68th minute (uncorrected for air temperature), though this was not held, since a temperature of 850°C was all that was required on this occasion. However, a temperature of this order was not reached until the 65th minute and was only maintained for four minutes, so great was the cooling effect of the wind.

The change from plastic clay to ceramic takes place at temperatures of above 600–650°C, and temperatures above the higher of these figures occurred from the 39th minute until the end of the firing, a period of some 56 minutes. Indeed, the kiln temperature remained above this even after recording ceased, so that all the vessels were properly fired.

However, the cooling effect of the breeze meant that all of the fuel was used, and that stoking was rather more rapid than on previous occasions. As usual in firing, the stoke hole was blocked and clean fuel thrown on the kiln top at the end of the firing (Figures 8.16 and 8.17). The ash was removed from the kiln in the morning of March 21 and found to total 54.7 kg (192 litres). This represents 28.5% of the fuel, less efficient than the previous two firings. Unfortunately, the effect of the strong breeze cannot be quantified, so that, though this firing was less efficient, and the experiment is valuable in demonstrating the effect of such a breeze, not all the aims of the experiment were satisfied. Thus, although it could be demonstrated that the kiln worked well and that all the vessels could be fired, it was not possible to ascertain whether the kiln would normally have burned its fuel more efficiently than on this occasion. The experiment should be repeated on another occasion when there is no breeze in order to ascertain the fuel-to-ash percentage and the clay-to-fuel ratio under more directly comparable circumstances.

The total weight of fuel used was greater than in the previous two firings. However, the total weight of vessels (accounting for the fired examples as well as the unfired) was 391.90 kg, and this gives a clay to fuel ratio of 1:2.04, which is still more efficient than any of the other firings for which such records were kept. It might be objected that a false impression of the firing is given as a result of using pre-fired vessels. However, the unfired vessels were strategically placed

Figure 8.15. Firing the 1992 reconstruction. Note that for this firing three rope bands were used to help cope with the expansion of the kiln.

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to ensure that firing was complete from bottom to top and front to back of the kiln. All fired properly, thus validating this view. It is possible that the ratio might have been slightly lower had the charge comprised entirely unfired vessels. I do not feel, however, that it would have been lower to a substantial degree, and, were firing undertaken on a windless day, the ratio might well have been substantially improved.

It should be noted that, although the vessels fired well, there were breakages during the unloading of the kiln. These were a product of the kiln structure in that the bricks used for the floor, though adequate for the firings, were judged to be too weak to stand on for loading and unloading. This meant that the unloading operation took place from the top of the kiln using a hooked pole. Several vessels were damaged in this way. The ancient kiln, with stronger bricks, would have been loaded, as are contemporary examples, by a worker standing on the floor and then on the vessels as the floor became covered, and unloading would have been the reverse of this process.

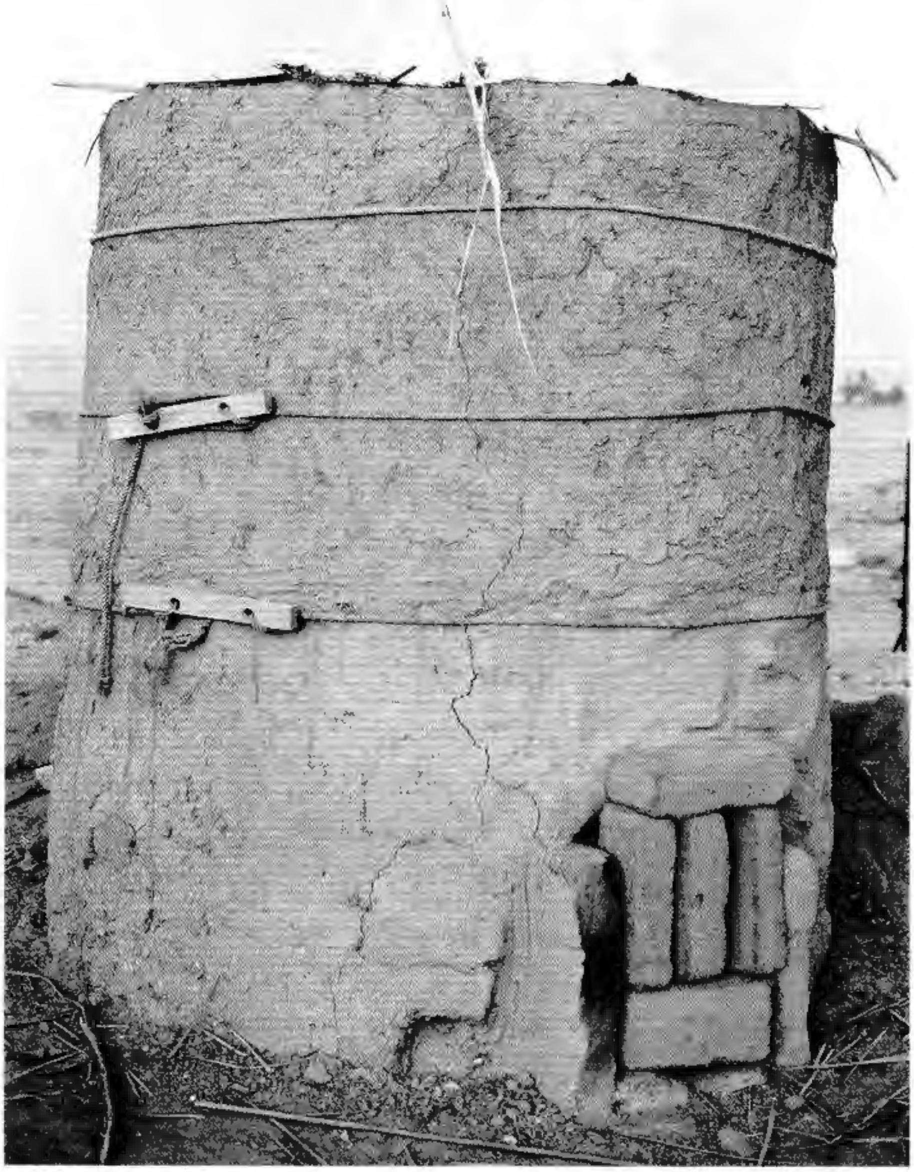

Figure 8.16. The kiln stoke hole is blocked during decarbonisation of the kiln top.

8.16 Firing 6, 11-4-1993

This, the sixth firing of the present experimental kiln, and the second in its heightened version, took place during the 1993 Amarna season. The kiln fabric at the beginning of the season showed no marked signs of deterioration, although it was necessary to undertake a minor repair to the northernmost (rear) arm of the kiln floor. This had been damaged in previous firings and become badly worn underneath. The repair was made by Catherine Powell using some of her potter's clay heavily mixed with *tibn* (chopped straw). This was allowed to dry for several days before the kiln was used.

Figure 8.17. Throwing clean fuel onto the kiln top in order to decarbonise it. This marks the final stage in the firing of the kiln.

This firing incorporated most of those vessels fired on previous occasions plus ten experimentally produced beer jars and three bowls also experimentally produced. This means that although the weight of clay in the kiln was 394.75 kgs, the actual unfired weight was much less. These unfired vessels were, however, placed at widely spaced points in the kiln profile from lowermost to uppermost layers. In this way, the success of the firing could be judged. The three bowls were fired in a stack in a saggar made from two of the large bowls which had previously been made and fired at Deir Mawas. Since Ms Powell wanted to examine her vessels when fired below 750°C, in order to prevent lime spalling, this was intended to be a low temperature firing.

Firing was undertaken on the afternoon of April 11, 1993 (Table 8.12 and Figures 8.28 and 8.29). The wind initially blew steadily from the north, but changed to a south wind about 15 minutes into the firing. It was not sufficiently strong to influence the firing significantly. The fuel, totalling 113.7 kgs, had been chopped into lengths, and separated into weighed piles as usual.

Firing proceeded without difficulty, and a temperature (recorded on T1, the thermocouple on the lowest level of the kiln) of over 700°C was held for about 12 minutes, and over 600°C for twenty minutes in order that the vessels should be thoroughly fired. The firing was largely an oxidising one with very few periods of reduction. With a firing temperature in the low range of this one the pots do not become sufficiently hot to glow visibly, so that judgement of when to stop firing has to be a matter of experience/educated guess.

The stoke hole was blocked in the 87th minute of firing, and clean *tibn* thrown on to the kiln top. The blocking of the stoke hole took place before the fire had been allowed to die down very much. The kiln was allowed to cool overnight and was unloaded during the next day. It was found that the vessels around the circumference of the kiln, and on the top layer, were covered in a very fine grey ash, rather like a bloom. This could be wiped away with the hand, but has not been noticed previously. It may be that this is the result of blocking the stoke hole before the fire has burned as low as usual. Alternatively (or additionally), it may be the effect of stacking the kiln to slightly above wall level, thus — perhaps — increasing the chimney-like effect of the stack and tending to draw up dust. As yet the reason remains speculative.

8.17 Conclusions for firing 6, 1993

All of the experimental vessels fired well, and will be discussed by Ms Powell elsewhere. The already fired vessels did not deform since the firing was at a relatively low temperature, nor did the appearance of most of them vary significantly. A few, however, showed some traces of overfiring, having been used on several occasions.

The repaired kiln floor survived the firing, though the rear arm did collapse during unloading, without causing any damage to the pots. This was probably the result of hydration of lime inclusions in the bricks and mortar, and it is likely that in an industrial situation where the kiln was being regularly fired many more firings than those undertaken could have taken place, whereas the floor had withstood several years of weathering with only occasional use. The cracking of the kiln walls was again noted, though the cracks virtually closed again on cooling.

The fuel/ash percentage was 24.80%, slightly more efficient than firing 5, while the clay/fuel ratio was the best so far recorded, at 1:3.47 (Table 8.13). It should be borne in mind, however, that the lower-temperature firing might be expected to use less fuel and that the high percentage of already fired vessels may have had some effect on the figures. This effect is not, however, thought to be very great.

It may be concluded that the kiln floor reconstruction is easier to use than the first version, which used a brick pillar, and that the greater height of this kiln makes for greater efficiency. The height did, however, make the kiln difficult to unload. This would not have been a problem for the ancient potters whose bricks were stronger than those used experimentally, and who could therefore have stood on the kiln floor during unloading, as do their modern counterparts. The experimental kiln was unloaded using a long pole with a hook on one end, by which the handles of the pots could be caught.

8.18 General conclusions

From the experiments undertaken, it can be suggested that the kiln would operate at sufficiently high temperatures and without undue difficulty with either a central pillar to support the floor or with a low vaulted floor. It should be borne in mind that the failings in the 1989 firings were largely due to the failure of the floor bars themselves as a result of using substitute materials. Mud brick or stone would probably have given no such difficulties. This apart, however, the kiln without a central pillar was easier to fire, although it did require more careful construction of the floor, which took about 24 man-hours to complete. Although it cannot be proven that this more sophisticated design was the one employed (simplicity of construction may have been paramount), it would certainly have been the most efficient design in terms of ease of use.

Calculations were also made to determine the amount of ash which could have been contained between the bottom of the fire pit and the lip of the stoke hole. This calculation was made in order to investigate the maximum length of time a firing could have continued. In fact, the volume of ash which could be contained in this part of the kiln, as deepened, is 1,103.9 litres, 10.6 times the amount from firing 4, which here would give a maximum firing time of 8.9 hours. There is, therefore, no significant relationship between the depth of the kiln pit and the length of firing (assuming the fuel was *gereed*). This conclusion was not expected, since the pit seemed to fill quite rapidly. It seems that the ash is readily packed down by the weight of new material on top of it so that, after apparently filling quickly, it reaches a plateau as the material at the lowest levels is packed. Clearly this accounts for the greater density of ash observed at the lowest level of the kiln pit.

With the figures for clay weight, fuel weight, etc. derived from the experimental firings, it should be possible to make some suggestions regarding the output of the ancient kiln excavated. With this in mind, the unfired sherds excavated in 1987 from the area of the kiln in building Q48.4 were weighed, and a total of 13.85 kg arrived at (Table 8.14). This figure is, of course, to be treated with caution since the whole area has not been excavated, and not all the sherds need be from the same production batch.

It is known from firing 3 of 1990 that the kiln as then reconstructed could hold at least 290.00 kg of unfired clay. Since the ancient kiln is unlikely to have had a lesser height, and may well have stood still higher, as in firing 5, the figure of 290.00 kg can be used as a "minimum". It is not known how many times a week[2] the ancient kiln would have been fired, but it is not unreasonable to assume that two loads per week could have been fired. Certainly the modern potter at Deir Mawas is able to fire as frequently than this, if not more so.

One is left with the question of what percentage of the total weekly production is represented by the 13.80 kg of unfired sherds. For convenience it will be assumed that all the sherds are from the same batch and that all would have been re-used in the clay mixture in the next batch had it ever taken place. At two firings per week, therefore, this material only represents half of a week's unfired waste. If it assumed that all of the unfired material was excavated, then in a week there must have been 27.60 kg of unfired wasters. This represents 4.76% of the weekly weight of clay actually fired (taking that weight as 580.00 kg).

This raises the problem of "wasters". Normally wasters are those vessels which become badly overfired and distort or burst during firing. At the excavated workshop there were no clear wasters, and certainly no waster heaps. I am, therefore, assuming that firing faults tended toward underfiring rather than overfiring, and that these underfired vessels were also sold.[3] A tendency toward underfiring is likely in an area where fuel must always have been at a premium. Therefore, the greatest loss to a batch would be at the unfired stage, where sherds could always be re-used, making the industry very efficient. At Deir el-Gharbi (Nicholson and Patterson 1989) the percentage of waster vessels is 4.78% which would correspond well to the percentage of unfired sherds from the Amarna workshop. For the present purposes I will assume that, at Amarna, no overfirings were produced and that, to all intents, waste vessels are represented by unfired sherds.

We have no certain evidence for the duration of the workshop, and it seems likely that the kiln would have been replaced several times during the life of the establishment. However, for the present calculation I have assumed a life of ten years for the workshop, with the kiln maintaining the same size as that reconstructed for firings 1 to 4. The fuel used in firing 290.20 kg of clay was 153.3 kg. However, that was for a temperature of 962°C, which is probably higher than the normal achieved in the workshop. The lower fuel figure of 120.60 kg has, therefore, been used. This fired a clay weight of 234.48 kgs, though again to a high temperature (885°C), and there is little doubt that it would have fired the greater weight of clay, especially if the temperatures were lower. The amount of ash is also that from this fourth firing. This would allow the following, highly speculative, set of figures for a ten year period.

Unfired clay used (not counting 13.80 kg residual waste after each week for re-use the next): 301,600 kg.

Fuel: 125,424 kg.

Ash: 19,344 kg, or 108,160 litres.

Given that the approximate fired weight of clay from firing 3 (1990) was 246.50 kg, the total over ten years would therefore be 256,360 kg of fired clay. Since the mean weight of a fired *gidr* is 5.22 kg, this is the equivalent of 49,111 such vessels. A more meaningful comparison might be with the large bowls which weigh 3.57 kg, of which 71,809 could have been produced. These are of a similar size to some of the hearths found at the Workmen's Village, which perhaps gives a better idea of the potential production of the workshop. These calculations are based on the kiln of smaller volume used in firings 1 to 4. If a taller kiln, as used in firings 5 and 6, had been used, the output could have been far greater. As for the large quantity of ash, it may have been mixed into the soil as a form of fertiliser, mixed with clay to help improve its working properties,

2 This is calculated using a week of seven days, rather than the ancient Egyptian "week" of ten days.

3 This is suggested by the high percentage of brown wares, which are noticeably soft, found at the Workmen's Village.

or simply have been piled up from where it would quickly be dispersed by the wind. However, it is not improbable that the workshop produced substantially less than this, as the Workmen's Village would soon have become saturated with pottery, even given frequent breakages; though it is quite possible that vessels were made for state workers on the west bank at Amarna also, and some may have been exported to other parts of Egypt.

Despite the rather artificial nature of these calculations, and the many and large assumptions on which they are based, it is nonetheless clear that the workshop could have produced a great deal of pottery. Given that our evidence is beginning to indicate that many private estates at Amarna also had pottery kilns attached to them, that there were probably other industrial establishments in the city, and that some pottery (notably the finer quality marl vessels) were probably imported to the site, the large quantity of pottery found at Amarna becomes easily explicable.

Finally, these experiments help to demonstrate the value of the experimental archaeological approach to problems of production and distribution. It has proved possible to suggest, and test, possible flooring constructions, to examine the amounts of fuel used and ash produced, to demonstrate the temperatures possible from kilns of this sort, and to examine the problems associated with them. The enigmatic "ribbing" seen on representations of ancient kilns has been examined, and a plausible explanation discovered. From these experiments it has also been possible to speculate, albeit very tentatively, on the output of a workshop of the sort excavated in Q48.4 over a number of years. Even such speculative calculations help to focus attention on the scale of the pottery industry at this time, and might lead us to think in new ways about how the industry was organised.

All of these findings could be little more than unsubstantiated conjecture without the use of experiment. Only the practical trial of such ideas can really test their feasibility, and many of the questions to which such trials give rise would have been far from evident from reconstructions produced on paper. For this reason, experimental archaeology, along with ethnoarchaeology, should be considered as integral parts of archaeological strategy (as they are at Amarna), rather than as interesting asides.

Acknowledgements

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References

Adams, W.Y. (1977). *Nubia: corridor to Africa*. London.

Blackman, W. (1927). *The Fellahin of Upper Egypt*. London: Harrap.

Emery, W.B. (1963). "Preliminary report on the excavations at Buhen." *Kush* 11: 116–20.

Holthoer, R. (1977). *New Kingdom Pharaonic sites: the pottery*. The Scandinavian Joint Expedition to Sudanese Nubia, Vol. 5:1. Lund: Scandinavian University Books.

Kirby, C. (1987). "Report on the 1987 excavations: the excavation of Q48.4." *AR* V: 15–63. London: E.E.S.

Nicholson, P.T. (1987). "Report on the 1987 excavations: the pottery kilns in building Q48.4." *AR* V: 63–81. London: E.E.S.

Nicholson, P.T. and H.L. Patterson (1985). "Pottery making in Upper Egypt: an ethnoarchaeological study." *World Archaeology* 17 (2): 222–39.

Nicholson, P.T. and H.L. Patterson (1989). "Ceramic technology in Upper Egypt: a study of pottery firing." *World Archaeology* 21 (1): 71–86.

O'Connor, D.B., W.B. Emery and T.G.H. James (forthcoming). *Buhen: The Old Kingdom Town.* London: E.E.S.

Probert, S. (1988). "Excavations at the Minninglow brickworks, Roystone Grange: 1981-86." *Derbyshire Archaeological Journal* 108: 48–53.

Rice, P. (1987). *Pottery analysis: a sourcebook.* Chicago: University of Chicago.

Sheehy, J.J. (1988). "Ceramic ecology and the clay/fuel ratio: modelling fuel consumption in Tlajinga 33, Teotihuacan, Mexico." In C. Kolb, ed., *Ceramic ecology revisited 1987: the technology and socioeconomics of pottery.* Oxford: B.A.R. S436 (2): 199–226.

[On the following pages]

Figures 8.18–8.29: Firing temperature graphs from experimental firings. These have not been corrected for air temperature. T1 = Thermocouple 1, T2 = Thermocouple 2.

Tables 8.1–8.14.

Fire lit 15.35

Minute	T1	T2	Comments
0	26	22	
3	33	26	
5	144	28	Floor collapse
8	76	26	
10	57	32	Fire relit
12	78	51	
15	145	47	
18	142	44	
20	167	52	
23	247	64	
25	217	60	
27	263	87	
29	314	73	
31	328	63	
33	354	64	
35	372	72	
37	392	72	
39	420	79	
41	468	85	
43	472	95	
45	486	116	
47	539	99	
49	533	112	
51	528	140	
53	535	160	
55	554	151	
57	565	215	
60	531	177	
65	517	127	
70	573	163	
			600
75	575	220	
80	636	315	
85	684	284	
			717
90	677	268	
			730
95	707	335	
100	733	325	T1 peak Major collapse at rear
105	603	278	
110	629	312	
115	628	251	End of active firing
120	467	130	
125	410	91	
155	223	49	

Duration of active firing 1 hr 55 mins
Peak temperature 733°C
Total fuel weight used 208.59 kg

Table 8.2. Firing 1 1989: 11-3-1989.

T1 = Thermocouple 1, northern wall of kiln
T2 = Thermocouple 2, eastern wall of kiln

Firing began 11.05

Minute	Temp.°C	Peak temp. between timings
0	28	
5	145	
		306
10	288	
		381
15	378	
		540
20	516	
		588
25	588	
		610
30	458	
		510
35	506	
40	359	
45	375	
50	320	
		338
55	282	
60	216	End of firing - fire out
65	188	
70	167	
77	157	
82	145	
87	133	
92	123	
98	116	
102	111	
107	105	
112	102	
117	100	

Table 8.1. Empty firing of 1988 reconstruction: 7-4-1988.

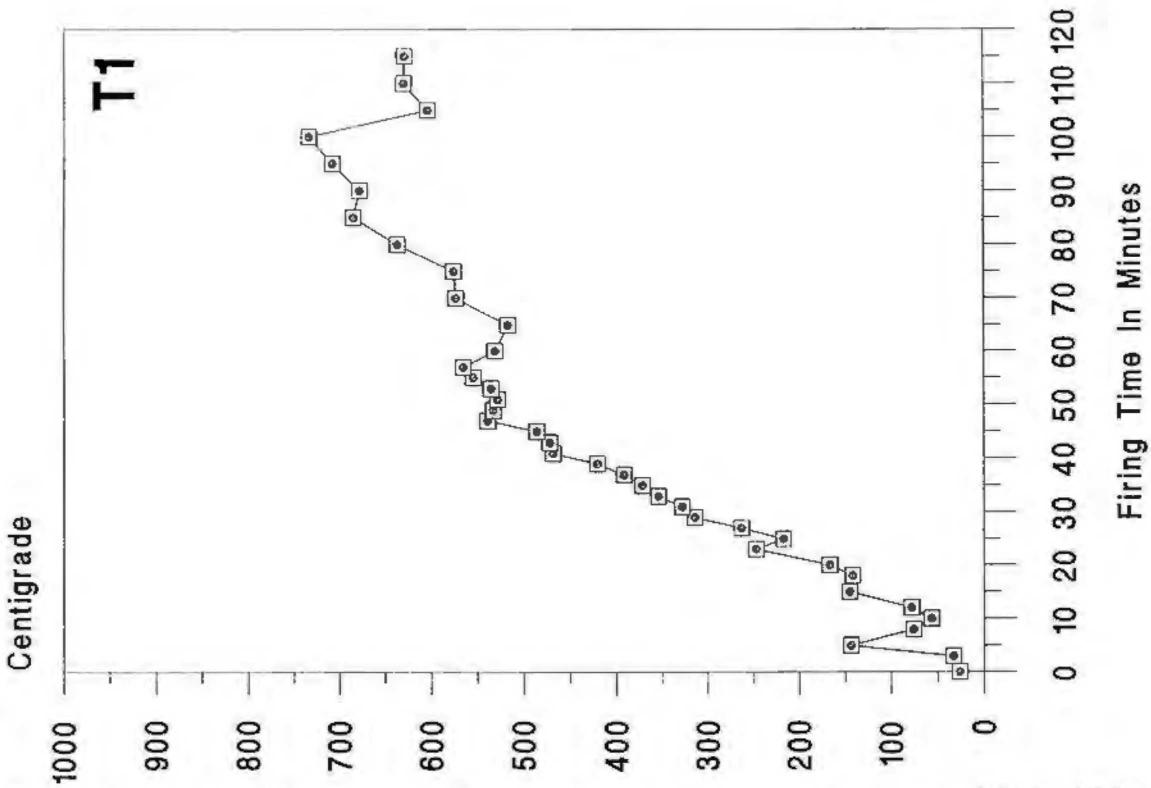

Figure 8.18. Firing 1. Thermocouple T1 on north side of kiln, extending into the kiln by 0.85m at level of gridded floor.

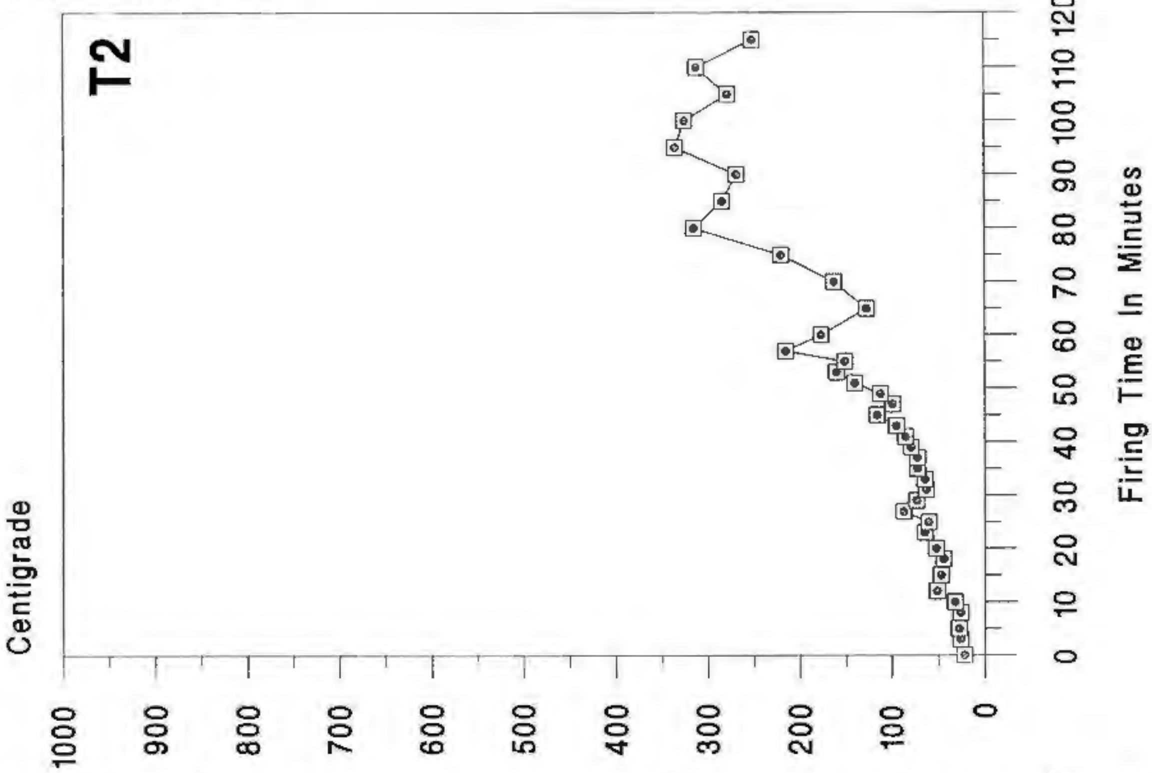

Figure 8.19. Firing 1. Thermocouple T2 on east side of kiln, extending into the kiln by 0.60m at 0.20m above gridded floor.

Fire lit 16.35

Minute	T1	T2	Comments
0	28	40	
2	72		
4	300		
5		183	
6	309		
8	446		
10	572	248	
12	634		
14	600		
15	627	276	
16	585		
18	651		
20	729	321	
22	714		
24	667		
25		392	
26	754		
28	787		
30	843	434	
32	848		
34	778		
35		462	
36	776		
38	704		
40	706	423	
42	795		
44	833		
45		488	
46	758		
48	847		
50	850	604	
52	890		Peak. Fall in kiln
54	850		
55		593	
57	839		
58	817		
60	819	600	
62	863		
65	806	585	Collapse
68	793		Collapse
70	740	564	
72	752		
75	742	588	
80	790	541	Collapse
85	828	521	
90	784	616	
95	764	730	
100	786	686	
105	787	788	
110	733	731	End of firing
115	688	636	
125	630	567	
235	191	228	

Duration of active firing 1 hr 50 mins
Peak temperature 890°C
Fuel weight 230.43 kg
Ash weight 40.80 kg
Fuel-ash % = 17.7

Table 8.3. Firing 2 1989: 25-3-1989.

T1 = Thermocouple 1, northern wall of kiln
T2 = Thermocouple 2, eastern wall of kiln

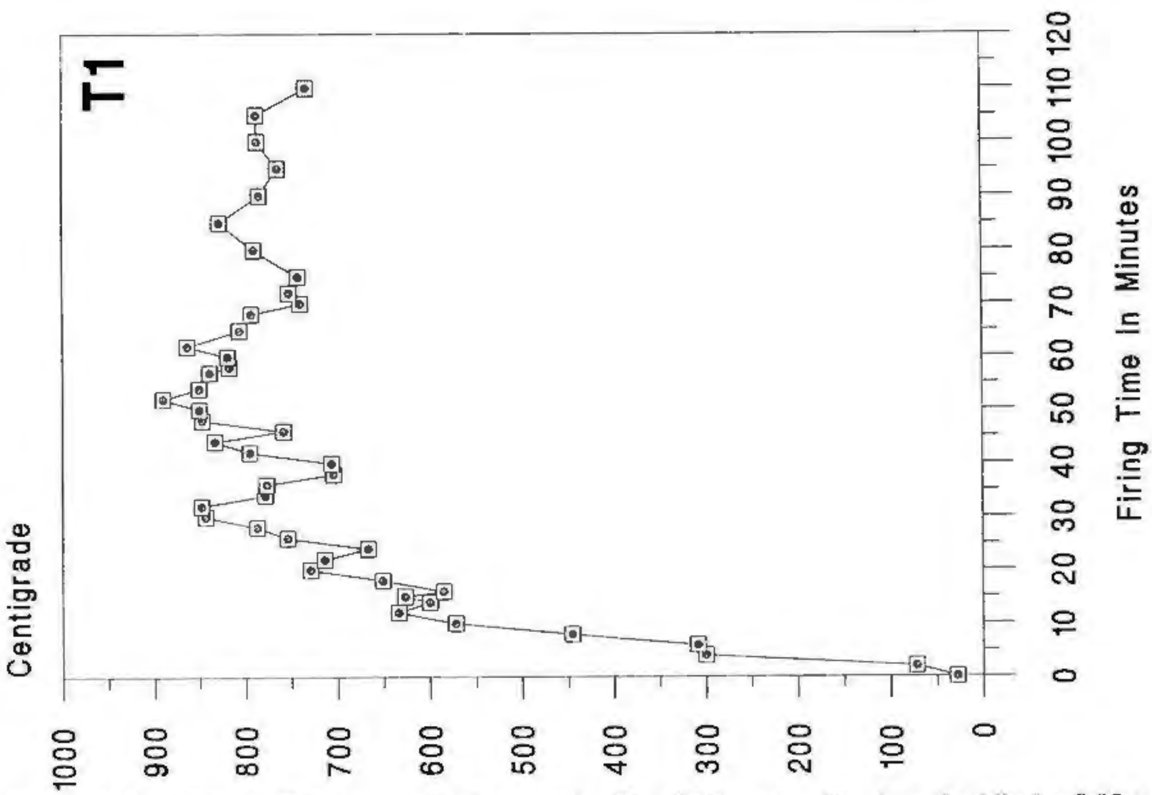

Figure 8.20. Firing 2. Thermocouple T1 on north side of kiln, extending into the kiln by 0.85m at level of gridded floor.

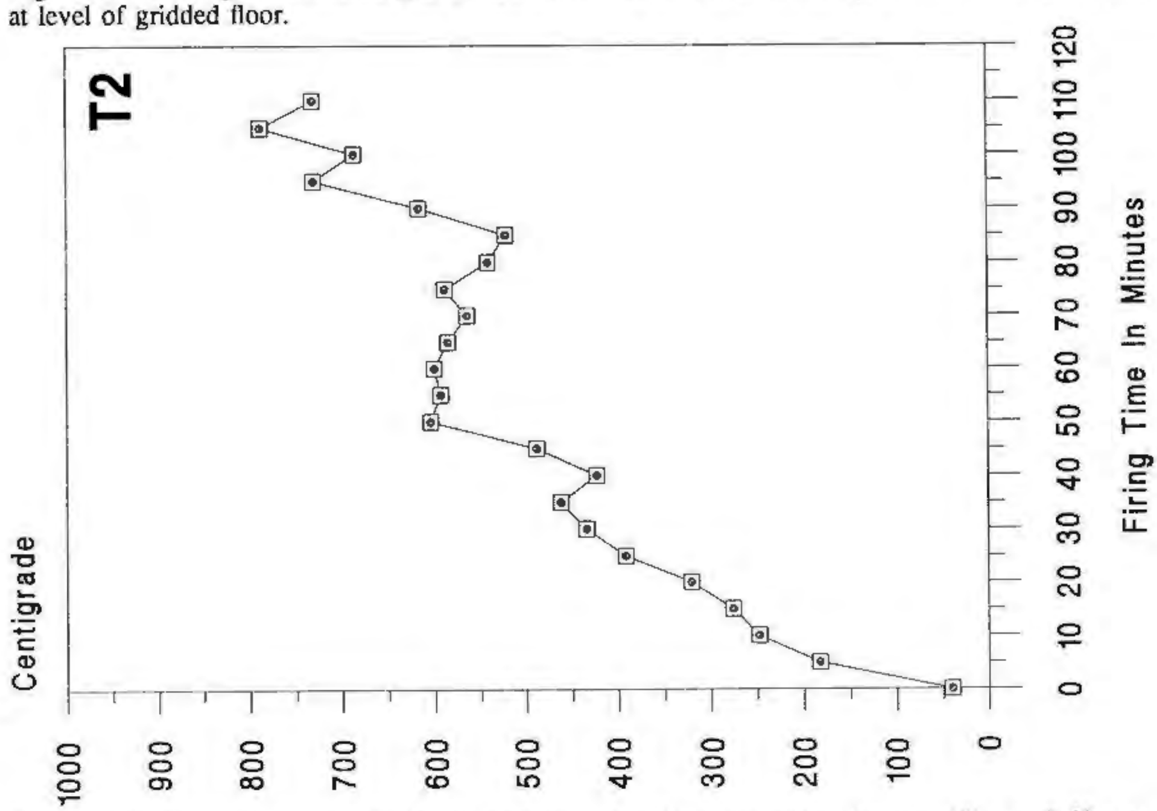

Figure 8.21. Firing 2. Thermocouple T2 on east side of kiln, extending into the kiln by 0.60m at 0.20m above gridded floor.

Air Temperature 31°C
Fire lit 15.24

Minute	T1	T2	Comments
2	54		
4	119		
6	142		
8	151		
10	159		
12	180		
14	185		
15		258	
16	200		
18	218		
20	245		
22	276		
24	321		
26	380		
28	394		
30		492	
32	440		
34	484		
36	523		
38	553		
40	564		
42	562		
44	555		
45		595	
46	550		
48	570		
50	620		
52	634		
54	645		
56	668		
58	675		
60	694	682	
62	720		
64	749		
66	775		
68	801		
70	805		
72	772		N. wall cracks
74	814		
75		770	
76	828		
78	833		
80	849	850	
82	869		
84	869		
86	887		
88	923		
89		890	W. wall cracks
90	942		
91	962		Peak
92	944		More W. cracks
94	948		
95	950		
96	931		
98	922		
100	901		Fuel on kiln top
102	841		
104	794		
105		764	
106	751		End of firing
108	767		
110	748		
112	734		
114	710		
116	687		
118	685		
159	421		
219	266		
279	202		
339	169		

Duration of active firing 1 hr 46 mins
Peak temperature 962°C
Fuel weight 153.30 kg
Ash weight 20.00 kg
Fuel-ash % = 13.05

Table 8.4. Firing 3 1990: 12-4-1990.

T1 = Thermocouple 1 northern wall of kiln
T2 = Thermocouple 2 western wall of kiln

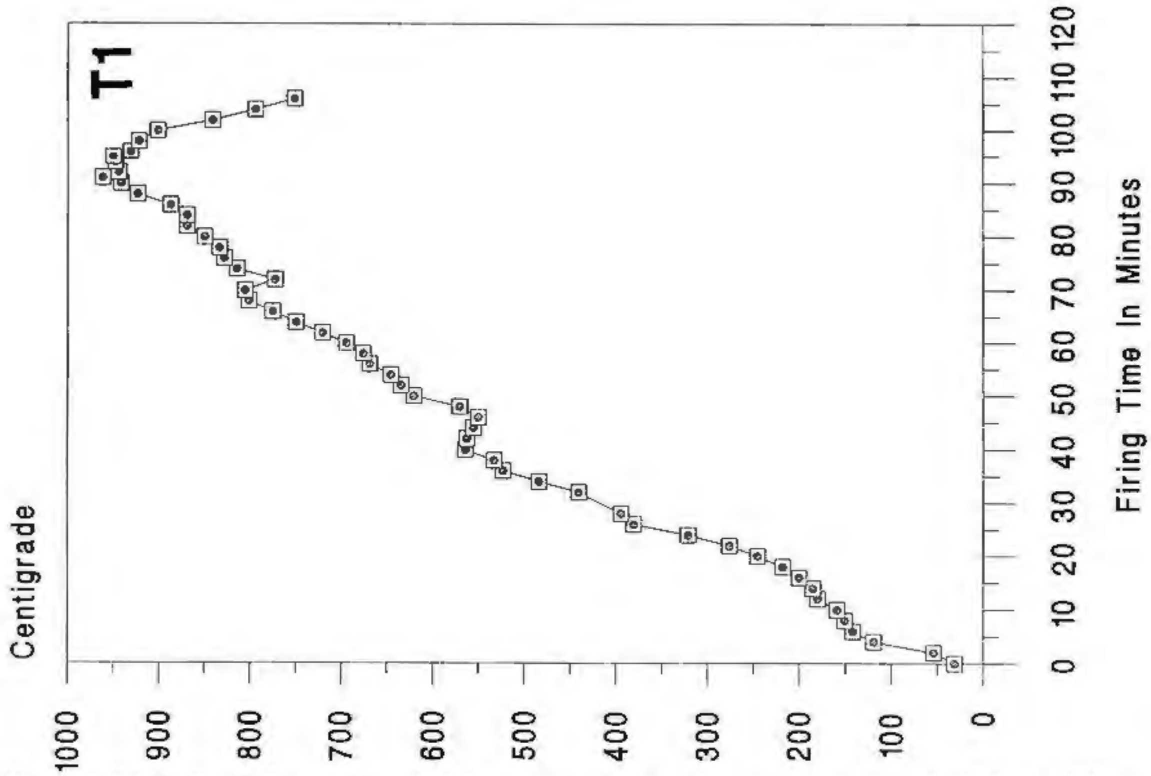

Figure 8.22. Firing 3. Thermocouple T1 on north side of kiln, extending into the kiln by 0.85m at level of gridded floor.

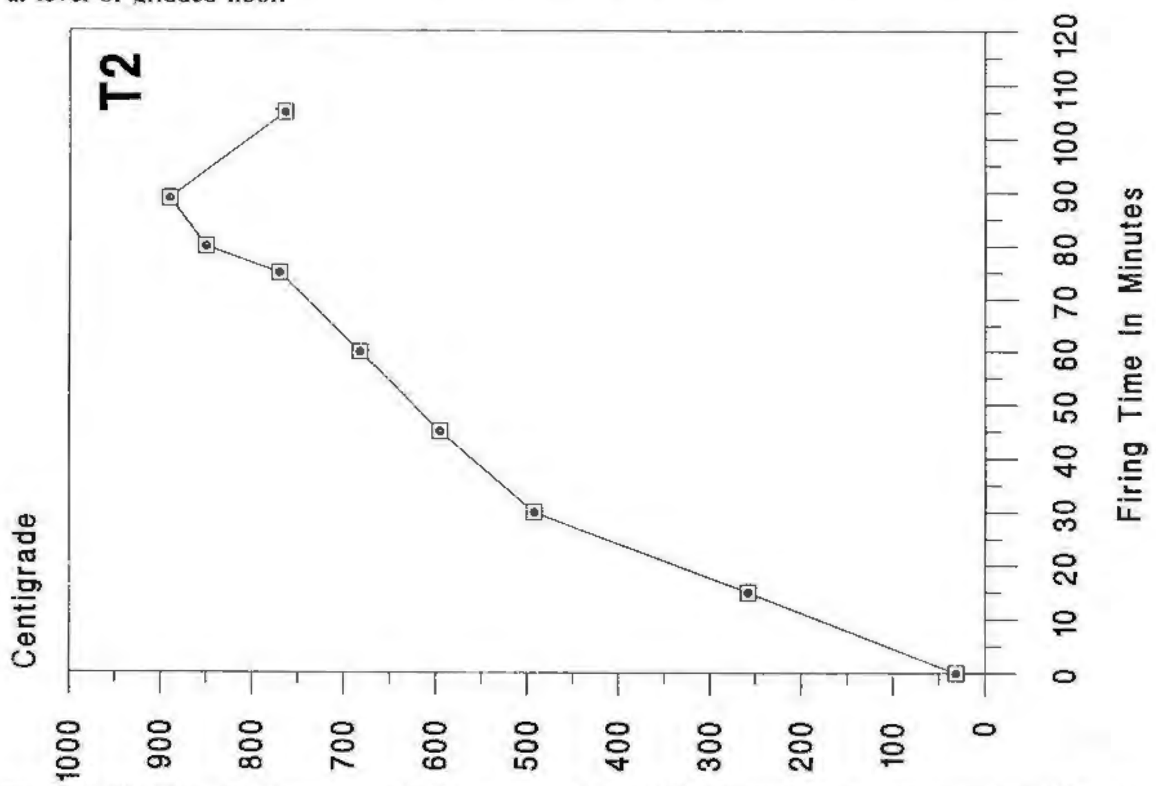

Figure 8.23. Firing 3. Thermocouple T2 on west side of kiln, extending into the kiln by 0.60m at 0.20m above gridded floor.

Air Temperature 40°C
Fire lit 16.40

Minute	T1	T2	Comments
0	40		
2	77		
4	124		
6	168		
8	214		
10	241		
12	280		
14	307		
15		405	
16	326		
18	343		
20	380		R
22	415		
24	434		R
26	472		R
28	495		
30	509	593	
32	511		R
34	534		R
36	543		
			R
38	553		
			R
40	591		
42	608		R
44	645		R
45		721	
46	663		R
48	689		R
50	725		R
52	728		
54	732		R
56	769		R
58	757		
60	768	800	R
62	808		
64	800		
66	834		R
68	847		R
70	849		
72	867		R
74	854		
75		885	R Peak
76	846		Fuel on kiln top
78	793		
80	748		
82	713		End of firing
84	702		
85		673	
86	687		
88	667		
90	648		
110	519		
140	371		
200	244		
255	193		

Duration of active firing 1 hr 22 mins
Peak temperature 885°C
Fuel weight 120.60 kg
Ash weight 18.60 kg
Fuel-ash % = 15.42
R indicates a reducing fire

Table 8.5. Firing 4 1990: 18-4-1990.

T1 = Thermocouple 1, northern wall of kiln
T2 = Thermocouple 2, western wall of kiln

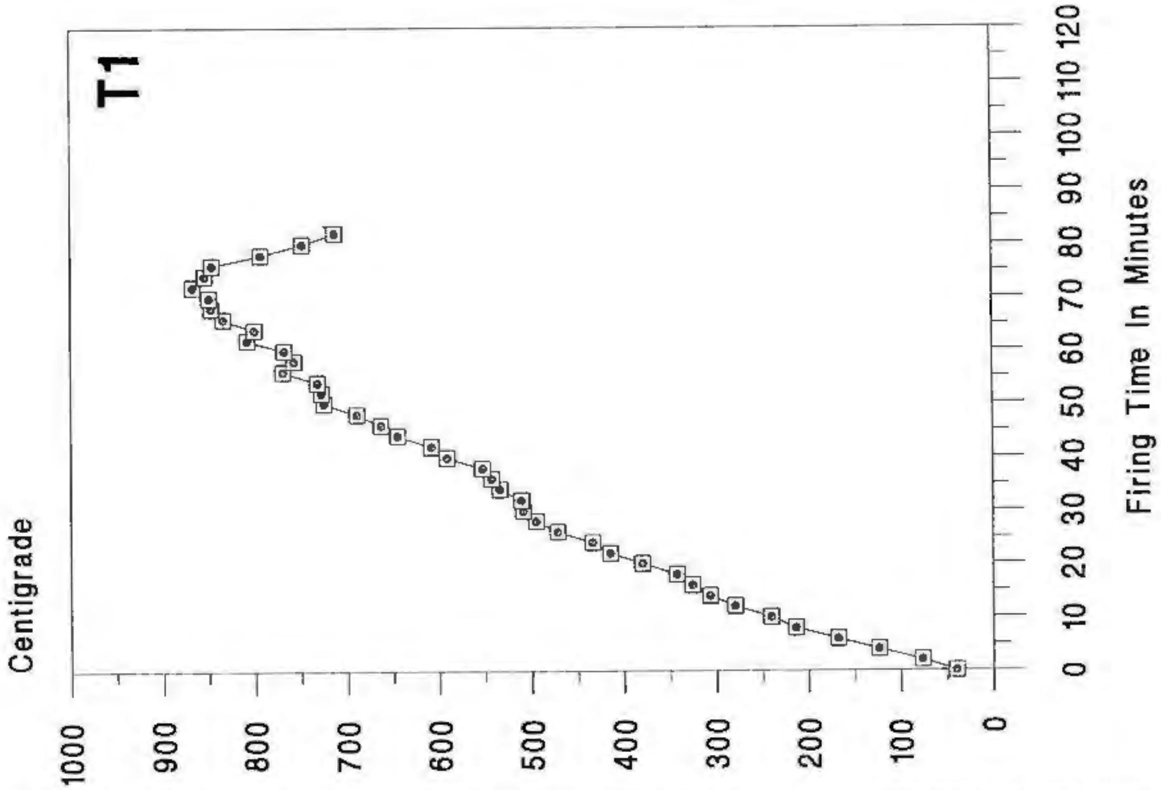

Figure 8.24. Firing 4. Thermocouple T1 on north side of kiln, extending into the kiln by 0.85m at level of gridded floor.

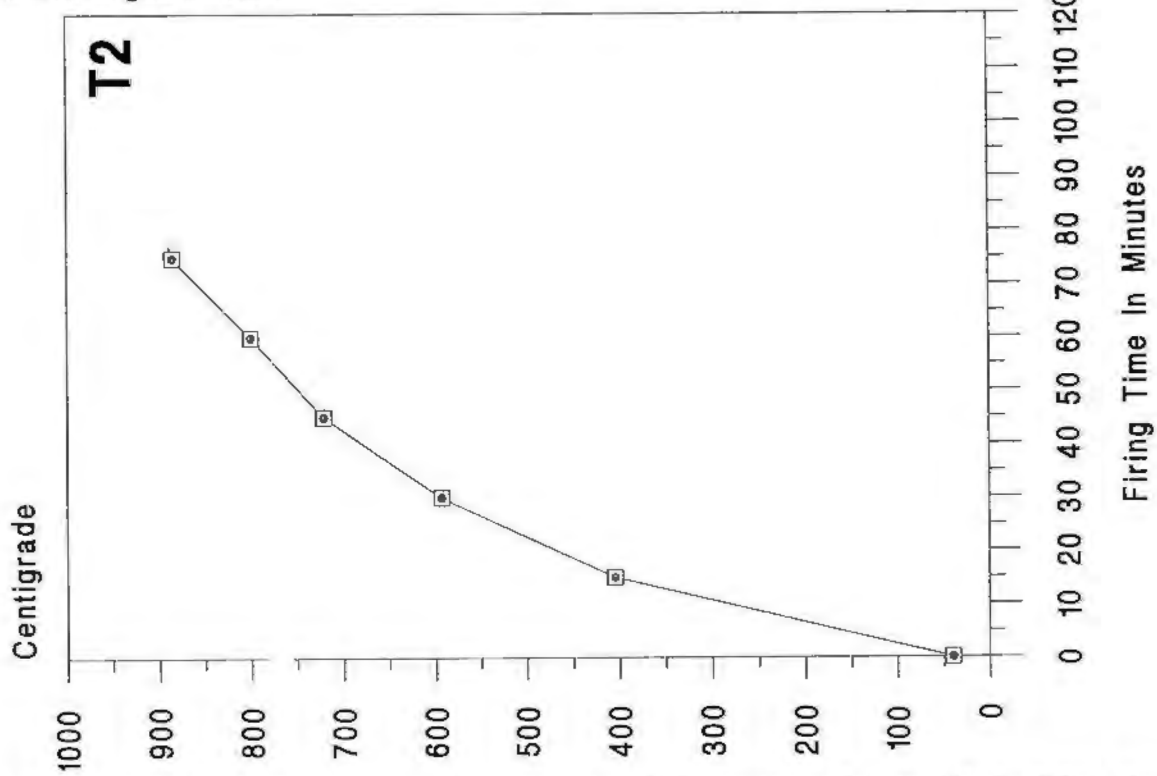

Figure 8.25. Firing 4. Thermocouple T2 on west side of kiln, extending into the kiln by 0.44m at 0.22m above gridded floor.

Vessel	Wt kg	Rim d.cm.
Small *fakshia* n=4	1.1	12.5
	1.2	12.0
	1.2	12.5
	1.0	11.0
	4.5	**48.0**
Fakshia n=6	2.2	17.0
	2.2	17.0
	2.6	16.5
	2.6	18.0
	2.4	15.5
	2.2	16.5
	14.2	**100.5**
Gidr n=26	4.5	21.0
	5.0	20.5 *
	5.0	18.5 *
	5.0	20.5 *
	5.6	20.5
	6.2	21.5 *
	5.2	20.5 *
	4.2	21.5
	5.0	21.0
	5.5	21.0
	4.9	20.5
	5.3	21.0 *
	5.3	20.5 *
	5.7	21.0 *
	5.0	20.5 *
	5.2	20.0 *
	5.1	19.5 *
	5.4	21.5 *
	5.6	21.0 *
	5.3	21.0 *
	5.1	20.0 *
	5.4	21.0 *
	5.8	22.0 *
	5.9	22.0 *
	5.2	22.0 *
	4.4	21.5
	135.8	**541.5**

Vessel	Wt kg	Rim d.cm
Bowls incl. 1989 n=19	3.9	21.5
	2.9	31.0
	3.7	34.0
	3.3	34.5
	3.6	34.0
	4.0	34.0
	3.6	33.0
	4.0	34.5
	3.3	33.0
	3.5	31.5
	3.9	32.0
	3.4	31.0
	3.7	33.5
	3.4	31.0
	4.2	34.0
	3.2	33.0
	3.1	32.0
	4.0	34.0
	3.2	31.5
	67.9	**613.0**
Experimental bowls n=26	4.8	-.-
	4.8	-.-
Bats n=2	10.2	-.-
	9.1	-.-
	19.3	-.-

Total No. of vessels = 83

Mean rim diameters & weights		
Small *fakshia*	12.00	1.13
Fakshia	16.75	2.37
Gidr	20.83	5.22
Large bowls	32.26	3.57
Small bowls	-.-	0.18

Notes: * *Gidr* with three handles; those not asterisked have two. Several vessels were distorted due to over firing and so have no true rim diameter so that here only an estimate is given.

Table 8.7. Vessels after firing 3: recorded 15-4-1990.

Vessel	Wt kg	Rim d.cm
Small *fakshia* n=4	1.4	13.5
	1.2	11.5
	1.3	12.0
	1.2	12.5
	5.1	**49.5**
Fakshia n=6	2.5	16.0
	3.2	19.0
	2.3	17.5
	2.2	17.0
	2.8	17.0
	2.7	18.0
	15.7	**104.5**
Gidr n=26	6.0	21.5
	6.4	21.0
	5.5	21.0
	6.5	24.5
	5.0	22.5
	6.7	23.5
	6.5	23.5
	6.9	21.5
	6.5	23.0
	6.0	19.5
	6.4	21.5
	6.5	21.5
	5.9	22.0
	6.5	21.5
	6.5	23.0
	6.5	22.0
	6.0	22.0
	6.0	22.0
	5.3	22.5
	7.4	22.5
	6.3	21.0
	6.0	22.0
	6.4	21.5
	6.2	21.5
	7.0	21.0
	6.0	21.0
	162.9	**570.0**

Vessel	Wt kg	Rim d.cm
Large Bowls n=11	4.1	34.0
	4.0	34.0
	3.7	33.0
	3.7	31.5
	4.0	33.0
	4.4	34.5
	4.6	33.5
	3.8	32.0
	4.1	35.0
	4.4	34.5
	4.0	34.0
	44.8	**369.0**
Experimental bowls n=26	4.9	-.-
	4.9	-.-
Bats n=2	14.9	-.-
	14.5	-.-
	29.4	-.-
Fired bowls from 1989 n=8	3.2	31.0
	3.0	31.0
	4.1	34.0
	4.0	31.0
	3.9	31.5
	3.2	32.0
	2.8	31.0
	3.2	31.0
	27.4	**252.5**

Total no of vessels = 83
Total wt of clay 290.2

Mean rim diameters & weights		
Small *fakshia*	12.40cm	1.28kg
Fakshia	17.42	104.50
Gidr	21.92	6.27
Large bowls	4.07	33.55

Notes: The mean figures given for *gidr* are based on the 26 vessels actually fired, though 30 were actually puchased. If these 4 are included, the mean weight becomes 6.32 kg and the rim diameter 21.90 cm. The Large bowl means are for the unfired bowls only.

Table 8.6. Vessels for firing 3: 12-4-1990.

Mean weights kgs

Vessel	Unfired Wt	Fired wt	Loss	% Loss
Small *fakshia*	1.28	1.13	0.15	11.71
Fakshia	2.62	2.37	0.25	9.54
Gidr	6.32	5.22	1.10	17.40
Bowls	4.07	3.57	0.50	12.29
Experimental bowls	0.19	0.18	0.01	5.26
				Mean 11.24

Mean rim diameter cms

Vessel	Unfired diam.	Fired diam	Loss	% Loss
Small *fakshia*	12.40	12.00	0.40	3.23
Fakshia	17.42	16.75	0.67	3.85
Gidr	21.90	20.83	1.07	4.89
Bowls	33.55	32.26	1.29	3.85
Experimental bowls	-.-	-.-	-.-	-.-
				Mean 3.96

Table 8.9. Vessel shrinkage in firing 3.

	Number	Weight kgs
Unfired *gidr*	25	158.0
Fired *gidr*	26	135.7
Fired *fakshia*	18	42.7
Small unfired *fakshia*	10	12.8
Small fired *fakshia*	2	2.3
Bowls	9	36.6
Hearth bowls	2	3.3
Small bottle	1	0.5
TOTALS:	93	391.9

Table 8.10. Vessels and clay weight for firing 5.

Before firing:		After firing:	
Vessel	Wt kg	Vessel	Wt kg
Fakshia n=6	14.22	*Fakshia* n=6	14.22
Gidr n=25	130.50	*Gidr* n=25	130.50
Unfired *Gidr* n=2	7.1 6.5 13.6	Previously Unfired *Gidr* n=2	5.8 5.5 11.3
Large Bowls n=18	64.26	Large Bowls n=18	64.26
Unfired Small bowls	4.6	Previously unfired small bowls	4.1
Unfired experimental tiles	7.3	Unfired experimental tiles	6.0
Total clay weight including Fired pieces: 234.48kg		Total fired weights: 230.38	

All pieces were fired from the first firing of 1990 unless otherwise stated. The weights for the fired pieces are calculated from the mean fired weights from that firing.

Table 8.8. Vessels before and after firing 4: 18-4-1990.

Air Temperature 21°C
Fire lit 16.05

Minute	T1	T2	Comments
0	21		
5	130		
7	166		
9	208		
11	208		
13	260		
15	288	158	
17	328		
19	348		
21	350		R
23	376		
25	414		
27	482		
29	499		
30		299	
31	548		R
33	607		
35	611		R
37	613		
39	656		
41	634		
43	628		
45	695	466	R
47	718		
49	706		
51	776		R
53	802	557	
55	779		
57	778		
59	761		
61	797	620	
63	793		
65	862		R
67	874		R
68	918		
69	876		
71	800		
73	775		
75	796	683	
77	728		
79	730		
81	798		
83	843		
85	855		
87	798	712	
89	758		
91	760		
93	817		
95	790		End of firing
98		706	
99	755		
101	736		
103	715		
105	694		

Duration of active firing 1 hr 45 mins
Peak temperature 918°C
Fuel weight 191.55 kg
Ash weight 54.70 kg
Fuel-ash % = 28.50
R indicates a reducing fire

Table 8.11. Firing 5 1992: 19-3-1992.
T1 = Thermocouple 1, western wall of kiln
T2 = Thermocouple 2, northern wall of kiln

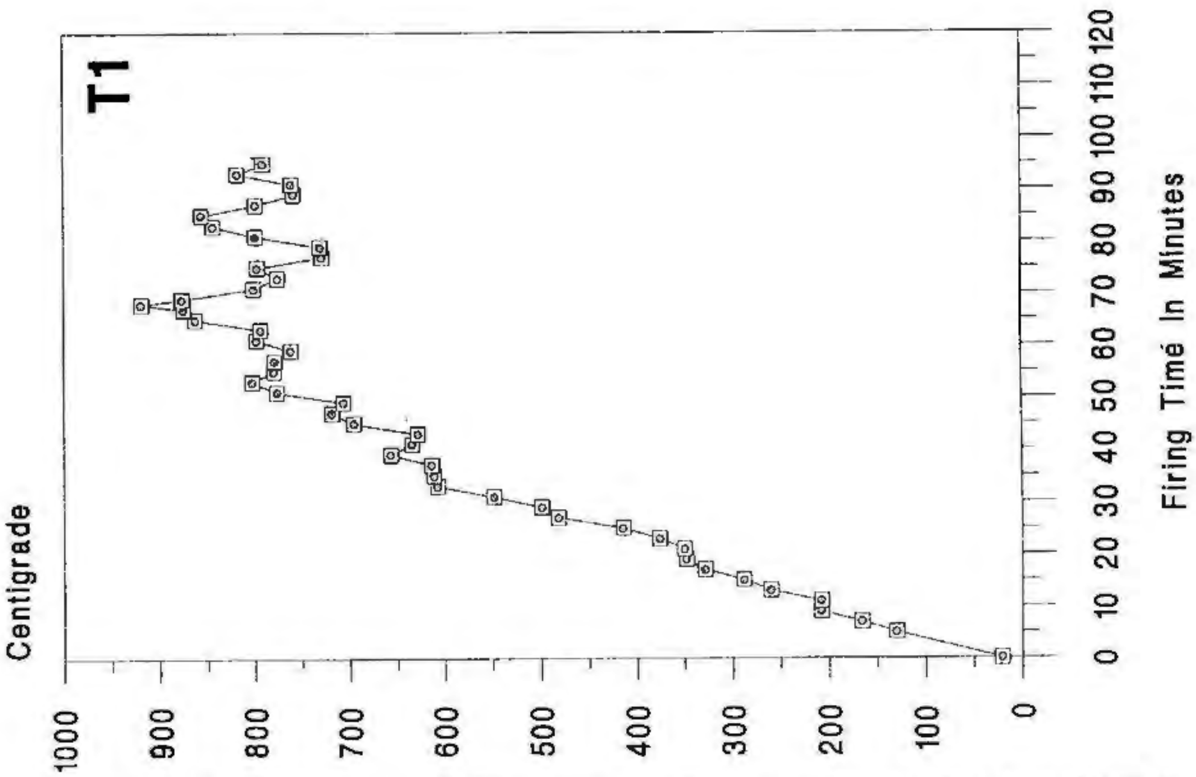

Figure 8.26. Firing 5. Thermocouple T1 on west side of kiln, extending into the kiln by 0.90m at level of gridded floor.

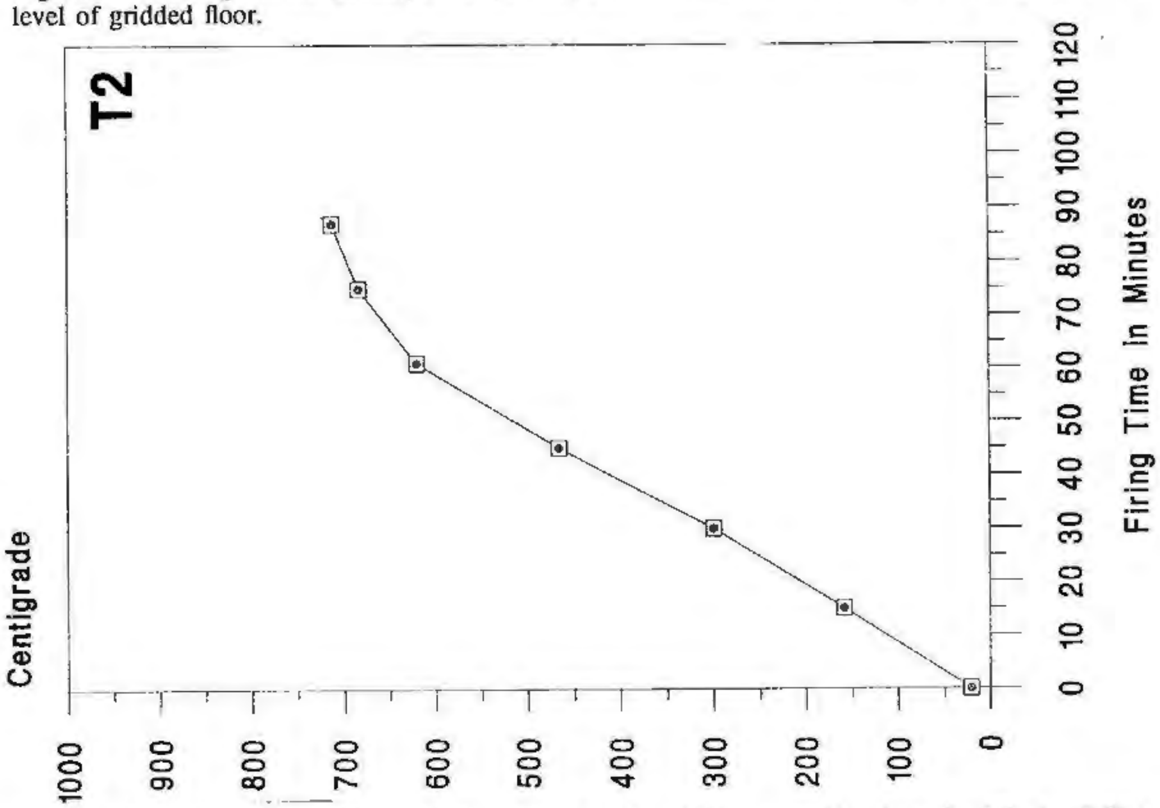

Figure 8.27. Firing 5. Thermocouple T2 on north side of kiln, extending into the kiln by 0.68m beneath sherd covering and bent into kiln stack by 0.34m.

Fire lit 17.13

Minute	T1	T2	Comments
0	26		
3	89		
6	125		
9	148		
10		66	
12	184		
15	193		
18	260		
20		122	
21	274		
24	367		
27	408		
30	413		
31		205	
33	469		
36	535		
39	547		
40		273	
42	612		
45	523		
48	625		
50		346	
51	630		
54	565		
57	649		
60	739		
61		424	
63	713		
66	705		
69	712		
70		482	
72	768		T1 peak (actually 780 between readings)
75	698		
78	686		
80		502	T2 peak
81	694		
84	628		
87	606		End of active firing
90	572		
91		473	
96	512		

Duration of active firing 1hr 27mins
Peak temperature 768°C
Total fuel weight used 113.7 kg
Ash weight 28.2 kg
Fuel-ash % = 24.80

Table 8.12. Firing 6 1993: 11-4-1993

T1 = Thermocouple 1, western wall of kiln
T2 = Thermocouple 2, northern wall of kiln

	Number	Weight kgs
Fired *gidr*	60	313.2
Fired *fakshia*	7	16.59
Small fired *fakshia*	11	12.43
Experimental bowls	3	2.1
Beer jars	10	18.3
TOTALS:	**91**	**394.75**

Clay/fuel ratio for firing 6 1:3.47

Table 8.13. Vessels and clay weight for firing 6.

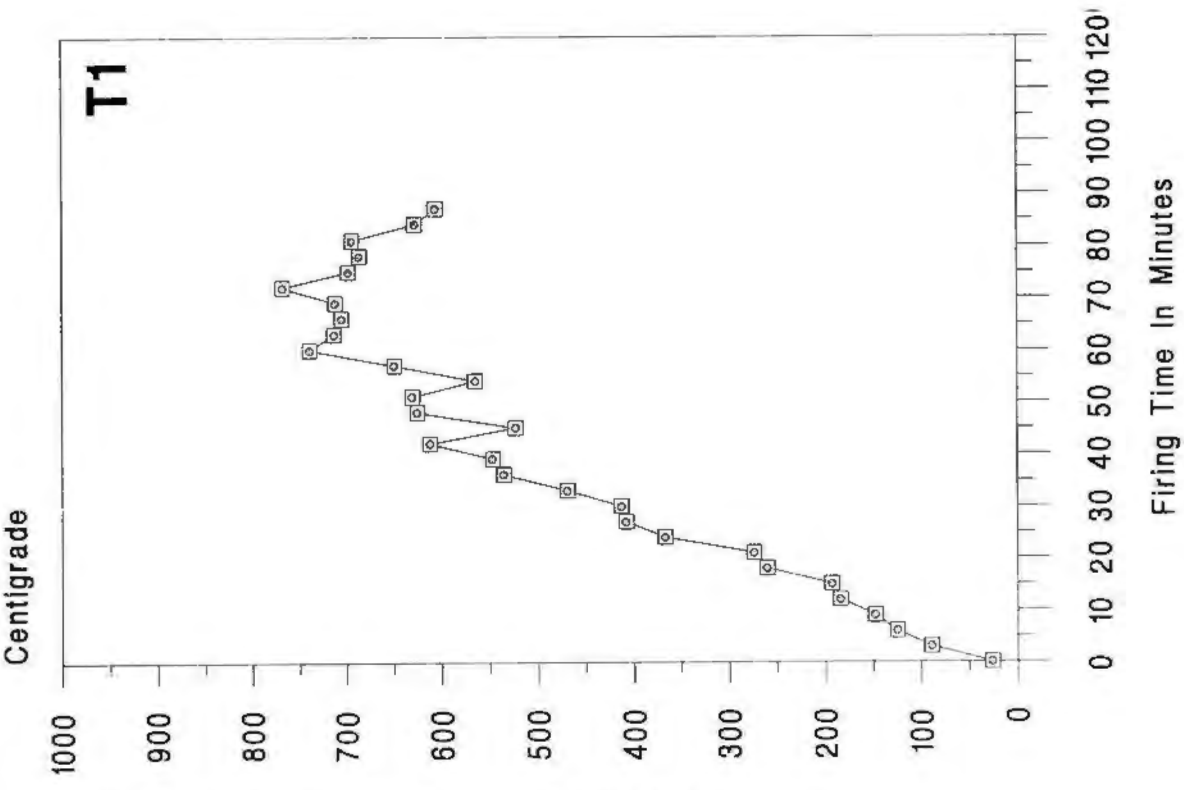

Figure 8.28. Firing 6. Thermocouple T1 on west side of kiln.

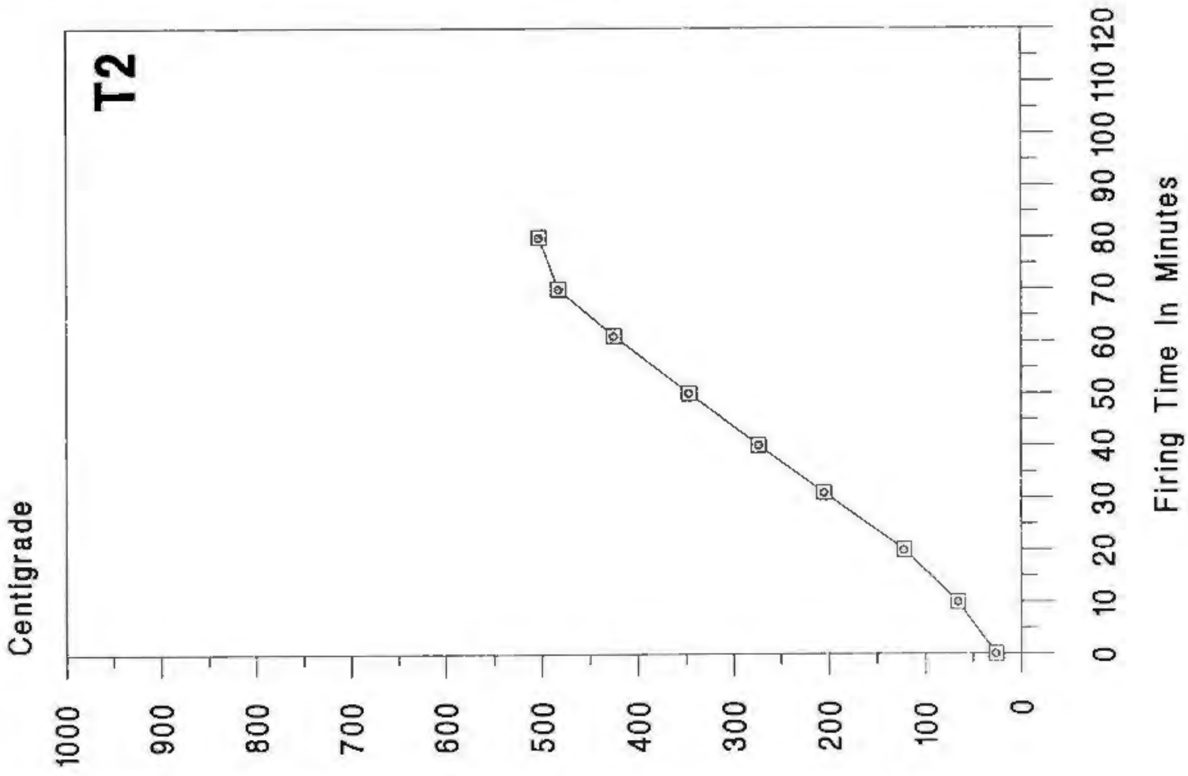

Figure 8.29. Firing 6. Thermocouple T2 on north side of kiln.

Square	Unit	Wt grams
D3	3713	120
D3	3372	330
D3	3720	150
D4	3154	720
D4	2903	430
D4	3162	250
D4	3156	880
D5	3785	2790
D5	2902	580
D5	2984	50
D5	3784	(2 sherds)
E3	3165	50
E3	3123	190
E3	3220	10
E4	2903	10
E4	2942	(1 sherd)
E4	2941	20
E4	2979	(Clay lump)
E4	3007	120
E4	3014	90
E4	2946	10
E5	3014	1544
E5	3722	1955
E5	3785	60
E5	3759	50
E5	3744	60
E5	3743	40
E6	3029	(1 sherd)
E6	3045	440
E6	3038	270
E6	3785	580
E6	3036	60
F3	2949	50
F3	2954	220
F3	2940	75
F3	2953	100
F3	2962	30
F3	2938	530
F3	3089	20
F4	3084	50
F4	3091	20
F4	3063	25
F4	3086	170
F5	2998	30
F6	3328	20

Square	Unit	Wt grams
G3	2929	80
G3	2927	110
G3	2885	20
G3	2886	70
G3	2928	25
G3	2934	150
G4	2983	10
G4	2987	20
G4	2991	80
G5	3354	70
G5	3394	20
Total weight		**13.85kg**

Small individual sherds not included in total.

Table 8.14. Weights of unfired sherds excavated in 1987 from the area of the kilns in building Q48.4 (*AR* V).