CHAPTER 11

EXPERIMENTAL DETERMINATION OF THE PURPOSE OF A "BOX OVEN"

by

Paul T. Nicholson

During the last season of excavation at the Workmen's Village a rectangular structure, apparently associated with some aspect of bread making, was discovered in the Chapel 556 complex (*AR* IV: 73–76). This structure was designated as a "Box Oven". It had been built into the north-east corner of a courtyard on the eastern side of Chapel 556, and utilized two of the walls of the courtyard in its structure. It was roughly rectangular in plan, measuring 66/64 x 75 cm, with an opening in its badly preserved west wall. At the back there was a slight ledge or step; in front of the opening was a round pit [2798] which, like the structure itself, contained ash. Within the structure, and scattered outside it, was a total of 64 bread moulds and bread cones. Of these, 30 were of elongated conical type, while the remaining 34 were of a hemispherical type with a knob at the base, not previously found at Amarna (Rose 1987: 76). Those of conical type had been arranged at the rear of the structure in three rows of ten and were leaning on the east wall, while the hemispherical type had been at the front of the structure. Some of these had been scattered into the pit outside in antiquity, when a piece of basalt had been thrown in, breaking one of the moulds at the front.

The structure is of the same type and general appearance as that excavated at Mirgissa in Sudan and dated to the Middle Kingdom. This one was preserved to a height of 50 cm and measured 70 x 90 cm in plan. In front of it was a clay-lined pit or basin showing signs of exposure to fire, with bread moulds of conical type lying alongside (Holthoer 1978: 16 and Plate 72.2). Similar structures are recorded from North Karnak (Jacquet 1983: 82–83).

11.1 Function of the structure

In discussing the structure found at Mirgissa, Holthoer (1978: 16) considers it to have been for baking, whereas at Amarna discussion moved from this to the possibility that the structure might have served for the firing of the moulds, rather than for baking loaves within them (*AR* IV: 76), that is, it may have been a simple form of kiln, rather more developed than an "open" (or "bonfire") firing, but less sophisticated than a true updraught kiln. It might best be regarded as a "firing structure". The principle by which such a structure might operate is found in Drews (1979: 34, Figure 5). The presence in the same courtyard of Chapel 556 of a conventional round bread oven is then more easily explained, disposing of the oddity of having two differently shaped structures in close proximity serving identical purposes.

The opinion at the end of the 1986 season was summed up (*AR* IV: 76) as follows: "there is ... still much to be learned about the details of baking ... technology before the archaeological evidence can be fully and rationally explained." To this end it was decided to recreate this structure and experimentally determine whether or not it might have been capable of firing pottery.

In order to assist with this work, during the period between the close of the 1986 season and commencement of that for 1987, re-firing experiments were undertaken on fragments of the bread moulds at the University of Sheffield. These experiments yielded temperatures (based on the rate given above) of above 400 but below 800°C, and most in the 450–600°C bracket. Testing sherds in water proved that they were truly ceramic, and that the moulds found in the structure had therefore been fired at the time it was abandoned. This does not mean, however, that they were fired at the time they were placed in the structure.

11.2 An experimental "box oven"

The recreation of the "box oven" was carried out in the corner of an abandoned building a short way to the south of the present expedition house which had been used in the 1920s apparently to house Qufti workmen and thus remained in reasonably good condition, with walls standing to their original height in most places. The firing structure was built on the same orientation as that at the Workmen's Village, and had the same dimensions. Since the original height of the structure was not known, the reconstruction was made to the preserved height of that at the village, which was believed to be close to the original height of the structure. The brickwork at this height seemed relatively unburned, and it was believed that a taller structure would have been unnecessary. The total reconstructed height was therefore 75 cm. The western end of the structure had been that most damaged in antiquity so that the full height of the opening was not known, but it was thought, on the basis of the Mirgissa example, that this was considerably less than the height of the structure. The reconstructed height was therefore made at approximately that of two courses of brickwork, or approximately 25 cm. The only major difference was that the structure was located near a door in the northern wall of the house, and this had to be blocked during firing.

The structure was built from mud bricks collected from tumble from the building mortared together with straw-tempered dung plaster. A pit corresponding in size to that at the village was also dug into the floor of the building. The whole operation took approximately half a day, after which the structure was allowed several days to dry whilst other operations were performed. The finished structure is shown as Figure 11.1. A small hole was left in the wall of the kiln for the insertion of the thermocouple, used to measure kiln temperature during the firing.

Figure 11.1. The reconstructed "box oven" and pile of *gereed* fuel.

11.3 The clay for the moulds

The next stage of the experiment was to obtain raw material for the making of moulds. This was collected from a large surface deposit of pale-buff silt derived from slope wash which had built up behind a modern flood barrier embankment which runs around the southern and western slopes of the plateau in which the Workmen's Village lies, and in fact separates it from the main city (it is marked on the map in *AR* IV: 125, Figure 9.6). This clay had been naturally refined by being washed from the slopes and then having stood as puddles until the water evaporated. This has left a large area covered in clay pans in much the same way as Arnold (forthcoming) has suggested for Nile alluvial clay used by ancient potters. In this case, however, the clay was a marl type derived from the calcareous rocks. It was relatively easy to collect from the surface, often coming away in quite large curved pieces resembling sherds. Large pointing trowels were used to scrape the surface, the clay being collected in buckets and then taken back to the excavation house for processing.

Processing involved firstly tipping a quantity of the clay into a large shallow metal bath tub (*tisht*) and removing fragments of organic matter, mainly pieces of twig. The clay was then returned to buckets. Next, sand was collected and sieved through a conventional agricultural riddle (*korbal*) with a mesh size of about 4 mm. Such devices are to be seen in use among contemporary potters in Egypt, for example at Ezbet Makhmal, near Badrashein (south of Cairo). Stones and large fragments of organic matter were thus removed from the sand. The first mixture of clay was then prepared. A metal can was used as a measure by which quantities of material could be judged. This was felt to be a more realistic method than weighing the quantities since ancient, and most contemporary traditional, potters would not have had access to weighing apparatus.[1] However, for comparison, the approximate weight of one measure of each substance was obtained as follows: clay: 2.5 kg; sand: 3.3 kg; water: 2.0 kg.

For the actual mixing, 6 measures of clay were put into the bath and 1 measure of water added along with 1 of sand. This was stirred with a stick for the first few minutes but soon became stiff enough to require trampling. In the absence of buffalo (commonly used to help trample clay) members of the team undertook this task. During the trampling further measures of sand and water were added to give a total of 6 measures of clay, 5.5 of sand and 3 of water. After some 40 minutes of trampling this produced a paste of smooth consistency which was judged to be suitable for mould making.

11.4 Forming the vessels

The moulds were made over a wooden form, known as a *patrix* or *archetype*, which corresponded to the interior dimensions of the moulds found at the Workmen's Village (Figure 11.2). For the conical type the patrix was designed to produce vessels c. 20 cm long with a rim diameter of approximately 5 cm, while for the hemispherical type the diameter was 10 cm and the height 10.5 cm. When applied to the patrices the clay mixture gave a satisfactory result, despite being rather deficient in plasticity and not easily worked, though smoothing with wet hands helped considerably.

A second mixture intended to give greater plasticity was, therefore, prepared. This involved the addition of a further 2 measures of clay and 1.5 of water, thus giving a total of 8 measures of clay to 5.5 of sand and 4.5 of water. This gave a much more workable mixture, though it still cracked if rolled thinner than 0.5 cm. It was known from observation of the ancient moulds that a sandy texture was characteristic of these vessels, and our preparations seemed to match this requirement quite well.

For the fashioning of moulds from this mixture a rather different technique was employed. A lump of clay weighing approximately 2–3 kg was taken from the tub and moistened with the hands. It was then pounded several times on a hard, flat surface, the lump being struck with the heel of the hand each time it hit the surface, so further compressing it. It was next divided into two and the halves slammed together and the pounding repeated, and this was followed by a further division and so on. Finally the block was split into about three smaller lumps and the

[1] In another context Rye (1977) has observed that quantities are judged by volume not weight.

Figure 11.2. Bread moulds from Chapel 556 alongside replica wooden *patrices.*

process repeated again, the total preparation time for the 3 kg taking about 5–10 minutes. This form of "wedging" made the clay much more readily workable (Figure 11.3).

The small block was then slammed into an elongated rectangular shape and pressed out with the fist into an oval. This was then wrapped around a patrix (Figure 11.4), which had been dusted with ash to prevent the clay sticking, and the edges of the sheet of clay moistened to facilitate joining when pressed together. The clay was then pressed while rotating the patrix (Figure 11.5), so that the pressure was applied in a spiral fashion. This not only served to remove air from the mould but also thinned the walls to the desired thickness of c. 1.0 cm. The excess length created by this thinning of the walls was then removed and the rim evened out with the fingers. The shaping process took about 2–3 mins., after which the vessel and patrix were left to dry for about 10 minutes while other moulds were produced. The process of manufacture left the characteristic pattern of spiralled finger impressions exhibited by the ancient moulds. Removal of the mould from the patrix was achieved by slightly twisting the finished mould and pulling the patrix out. The completed mould was sufficiently dry to stand on its rim until truly leather hard.

Making the hemispherical moulds required a different technique. The clay was wedged in the same way as for the cones, and the patrix dusted with ash, but this time the clay was pressed out into a more circular shape. This was slammed against the top of the patrix whilst it was rotated (Figure 11.6). At the same time the clay was pressed around the patrix and any excess removed from the rim area, which was finished as for the conical moulds. The knob or foot was then pinched up from the surplus clay on the bottom of the mould (Figure 11.7). The weight of the clay had to be carefully judged, since, if it was too heavy, the walls stretched and tore. The vessel was then left to dry for a few minutes while another conical mould was produced. After this time it could be rotated slightly on the patrix and again left while a further two conical moulds were produced. This done, it was removed and left to dry standing on its rim. Care was needed not to remove this hemispherical type of mould from the patrix too quickly since its

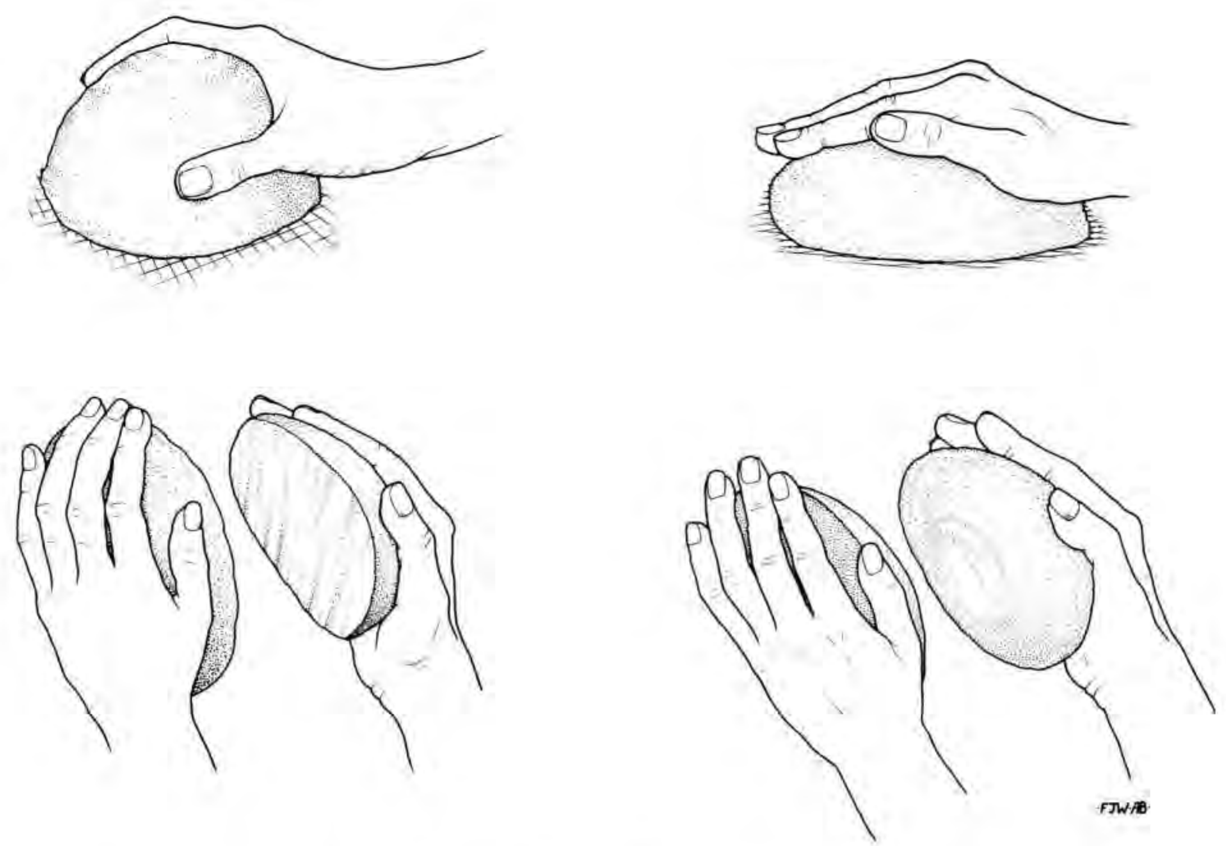

Figure 11.3. Diagram of the method of "wedging" clay (drawings by A. Boyce).

greater width-to-height ratio made it liable to collapse.

One point of particular interest emerged from the experimental manufacture of this hemispherical type of mould. It was found that the knob made it unnecessary to handle the walls of the vessel (which were more fragile than those of the taller moulds) while removing it from the patrix. Since the knob cannot have served as a foot it must have been designed for this purpose, and perhaps as a convenient handle for use while pre-heating the moulds for baking.

A total of 36 conical and 9 hemispherical moulds were produced from the tub of clay of which all but four were made from the modified second mixture. These were set to dry initially in the sun, but each time a further four moulds had been produced the first four were put into the shade to prevent them drying too quickly. Two blocks of clay of the same mixture were also prepared and incised with lines of measured length so that shrinkage could be measured after both drying and firing. After one and a half days of drying no shrinkage at all was recorded from the first block, while the second had shrunk from 10.0 to 9.5 cm on the long axis, but remained at the original length of 2.0 on the short.

Examination of the ancient vessels showed them to have a powdery, smooth interior, and it was thought that this might be a slip.[2] Thus, once completed, the vessels were coated with a slip made from the same clay. A slip is simply a very liquid clay, and so a lump of the prepared clay was taken and mixed with a large quantity of water until a consistency like that of cream was achieved. This suspension was poured into the moulds until they were full and then poured back into a container. This left a fine coating on the inside of the moulds like that of the originals.

[2] As suggested, e.g., by Larsen 1936: 53.

Figure 11.4. Wrapping clay around a *patrix.*

However, it should be noted that the moulds already showed a coating, somewhat like that of the originals, derived from the ash spread over the smooth surface of the patrix, contact with which had the effect of bringing the fine particles to the surface. It may not therefore have been necessary to use a separate slip at all.

For the actual firing, dried date-palm fronds (including the hard central ribs, *gereed*), were used. Each frond was cut into three or four lengths of about 60–90 cm. No measure of the quantity of fuel used was kept on this occasion. Palm fronds were thought to be a suitable fuel for several reasons. It was a substance which would have been available anciently and burns well, giving an intense heat though of short duration. In tests on other fuel, dung had been found to burn well only when used on a fire started with something else, and then gave a temperature of only 100°C and burned only partially. However, in bread-baking experiments, in a small circular oven, dung was found to be very satisfactory, burning slowly and maintaining a high temperature (see Chapter 12). Straw, which could have been used anciently, was not available during the season in which the experiments were conducted whilst *durra* stalks were not tried since this was a plant which would not have been available to the ancient Egyptians.

11.5 Firing

After the insertion of the thermocouple, the kiln was set as follows. Firstly, four of the leafy, thin ends of palm branches were laid longitudinally inside the kiln, then four more across with some dung fuel sprinkled amongst them. This procedure was intended to allow the hot gases to circulate under the vessels during firing while the dung fuel was thought to be a suitable way of maintaining temperature during the latter stages of firing. This was later found to be unnecessary. On top of the lattice of fronds were placed some fragments of reed matting, which also subsequently proved to be unnecessary. This layer of fuel was then compressed by treading. It

Figure 11.5. Pressing clay around a *patrix* whilst it is rotated.

was noted that the height of the structure was the maximum at which a man of average height could easily step inside. Though the lattice covered the whole floor area of the structure, the matting covered only the rear 40 cm, while at the front some of the fibrous material from the limb of the branch was allowed to protrude into the fire pit. This was to allow the fire to spread more easily into the kiln itself. On top of this arrangement of fuel were placed the vessels themselves. Approximately thirty-five of the conical moulds were placed in three rows with about five vessels lying flat on top of them. The thirty stood with their open ends uppermost as in the excavated example. The nine hemispherical moulds were placed on their sides at the front of the kiln, openings facing the rear of the kiln. The two blocks designed to measure shrinkage were placed amongst these. Over the moulds was placed a layer of broken sherds. It is not known whether this practice had been employed originally since the upper part of the excavated structure had been destroyed, and sherds may have been removed. It is, however, a practice well known ethnographically from many countries including Egypt (Nicholson and Patterson 1985). At the

Figure 11.6. Putting clay on to a hemispherical *patrix*.

front part of the kiln were placed some of the finer fronds from the branches, and these overlay the vessels. Over the whole were placed three large limbs from the branches which it was felt would serve initially as a good insulating layer, keeping the heat in the vessel stack, and later burn away with some positive effect, though most of their heat would be lost to the air.

A random selection of palm branch cuttings was next placed in the pit until slightly heaped. The fire was lit at the point furthest from the kiln itself. It was hoped that this would allow a more gradual spread of the fire into the structure and would allow some pre-heating of the vessels, so that any trapped water could be driven off. In a conventional updraught kiln a period of "water smoking" (Hodges 1981: 39) is usually allowed while this moisture is given off, but a structure of this simpler kind is more akin to open firing, and it was thus felt that this method would prove most satisfactory. In retrospect it is likely that this procedure was unnecessary since the coarse nature of the vessels would largely obviate the need for "water smoking". The fire burned quickly and after only a few minutes was in the kiln. It soon became apparent that the stoke-hole arrangement provided an excellent updraught, and the fire was drawn from the pit and through the kiln very satisfactorily. During the firing the doorway to the courtyard was blocked so as to reproduce conditions at the Workmen's Village. There was no breeze at the time of firing.

Throughout the firing the pit was kept stoked and fronds inserted from it into the stoke-hole part of the kiln so that it was possible to keep a certain amount of the fire inside the structure. A small quantity of the leafy fronds was also thrown in through the top of the kiln, but these numbered no more than fifteen and may not have had any significant effect.

When the fire in the pit dropped in intensity it was poked and then fanned using a large wooden fan (Figure 11.8). This seemed quite effective and, combined with the updraught through the stoke-hole, drew the flame well into the kiln. After this more branches were added to the pit fire. It was found to have been a mistake to cut the branches into segments of up to 90 cm long, as these tended to mound up in the pit to such an extent that much heat was wasted. During the

Figure 11.7. Forming the knob on a hemispherical bread mould.

firing three loud cracks were heard, and it was expected that some damage had occurred to some of the vessels.

The firing lasted for 30 minutes, the fuel being exhausted after 20, and fanning being ceased after 25. The thermocouple readings were as given in Table 11.1. The chrome-alumel thermocouple was protected using an AMAL aluminous porcelain sheath which may mean that 10–20°C can be added to these temperatures, making the peak temperature, reached in the twelfth minute, about 540°C.

It is felt that this structure does allow rather more control than would an open firing, since it is possible to allow the fire to burn into the kiln and give a brief period of firing below 200°C (c. 6 minutes) before full firing begins. This period could have been prolonged had it been felt necessary.

After 1hr. 40mins. the kiln temperature had fallen to 40°C and a spall from a damaged vessel was picked from the ashes and examined. It appeared to be well fired, and to test this it was placed in water for 24 hours, along with a sherd from one of the ancient vessels. The spall remained hard and was therefore truly ceramic, as was the ancient sherd.

The vessels could have been removed from the structure later the same day, but instead they were left for a further day while other work was undertaken. On removal it was found that all but two vessels were complete and usable, the two damaged ones having suffered spalling either from too rapid initial heating or from large calcareous inclusions left in the clay. It was found to be the hemispherical moulds, placed near the front of the kiln, which had suffered this damage. All the vessels had fired well and resembled the ancient ones quite convincingly, though some were rather more blackened than the originals. Traces of ash were stuck to some of the vessels and this was also observed on some of the ancient ones when re-examined. It was found that the matting had not been burned and was therefore unnecessary, as was the dung fuel placed between the lattice of *gereed*, which had burned except where the matting covered it.

Figure 11.8. Using the wooden fan during a firing.

Minutes	Centigrade
3	80
5	150
7	350
10	500
15	470
20	400
25	340
30	280

Table 11.1. Temperatures of the first firing.

11.6 A second firing

In order to replicate more exactly the heat-loading of the original structure it was decided to undertake a second firing using the same number of vessels as those found in the excavations. Thus thirty of the elongated and thrity-four of the hemispherical moulds were made using a third mixture of clay, intended to be the same as that of batch 2. However, in preparing the clay mixture, the proportions of which were known from the previous batch, the mistake was made of adding all the water at once which proved too much for the clay, the difference in volume evidently having required a slightly lesser amount. It was thus necessary to prepare twice the quantity used in batch 2. It was found that twice the quantity required less than twice the amount of water, so that the final mixture was as follows: clay: 16 measures; sand: 11 measures; water: 8 measures.

The mixture was again prepared in the *tisht*, but the larger quantity made mixing more difficult so that it was felt that this batch of clay was of poorer quality than the previous one. Had mixing been easier, it might further have been improved by the addition of another half measure of clay, which might have been "lost" as a result of measuring quantities by volume rather than weight. The sand used in this mixture was somewhat coarser than in the last and contributed to the diminished workability of this clay mixture. The technique used to form the vessels was the same as that used previously, except that this time a more sophisticated wedging technique was employed, consistent with that used by professional potters. The required number of vessels was produced after about 21 man hours.

The conical vessels were stacked at the rear of the kiln as before, in three rows, while the hemispherical ones were arranged in three lines, two on each side wall and a shorter one in the opening, and these three rows were then "vaulted over" with other vessels to form two flues running from the opening toward the stacked conical vessels, and so directing heat into the kiln. It was not known exactly how the hemispherical vessels had stood, so this method was adopted as one possibility.

It had been noted in loading the kiln for an attempted firing on 23 March that the increased vessel load required increased sherd covering and that, as the stack of pots sloped away toward the opening, so must the sherds slope downward. It was observed that the sherds were likely to act as a heat deflector in this instance, preventing heat from penetrating the stack. For this reason no sherds were used to cover the vessels during this firing, something more consistent with the archaeological evidence from this structure. Only the thick limb ends of palm branches were used on the top of the pile. This time the fuel was cut into shorter lengths averaging 40–50 cm, and this made the fire more controllable. Still shorter lengths might have been desirable, but these proved difficult to cut with the tools available (which were steel adzes).

Firing of this batch took place on 4 April, 1987, an initial attempt made on 23 March having failed due to a change in wind direction, heat and flames being driven away from the kiln and toward the experimenters. The temperatures recorded during this firing are given in Table 11.2.

11.7 Conclusions

The results of the firing were encouraging. All of the hemispherical vessels fired adequately, as did the front row of the conical vessels, and a few of those on the rear two rows. The rest were much underfired. There were no breakages during firing. The reason for the failure of heat to penetrate the rear of the kiln was probably the way in which the vessels at the front were stacked. It may be that the flue arrangement ought to have consisted of one large flue only and that a little more space should have been left at the point where the rows of hemispherical vessels met those of the conical. Furthermore, most of the fuel was thrown into the pit at the front of the kiln, whereas it would have been possible to throw more into the structure itself. Some fuel was burned in this way, but this was a relatively small quantity. Nonetheless, the fact that over half of the vessel load fired correctly on what was, after all, only the third attempt by unskilled experimenters, does tend to lend weight to the suggestion that this structure was a kiln, rather than an oven, for firing the bread moulds prior to their use. It is known, from the first experiment with fewer hemispherical moulds, that it is possible to get heat to the back of the structure, and it is therefore believed that a better stacking arrangement for the hemispherical moulds would lead to a better result overall.

Time	Temperature	Time	Temperature
11.10	Fire Lit	11.44	540
11.15	40	11.45	510
11.20	60	11.47	521
11.21	100	11.49	490
11.22	120	11.51	610
11.23	200	11.55	480
11.24	240	11.57	450
11.25	300	11.59	440
11.26	340	12.00	430
11.28	350	12.01	460
11.29	360	12.02	440
11.30	400	12.03	440
11.31	440	12.05	440 Firing ceases
11.33	480	12.06	400
11.34	500	12.09	380
11.35	460	12.13	340
11.36	480	12.16	310
11.38	410	12.20	280
11.39	520	12.23	260
11.40	560	12.27	210
11.41	520	13.05	100
11.42	500	14.00	60

Table 11.2. Temperatures of the second firing.

Acknowledgements

I wish to express my thanks for the help of members of the Amarna expedition in this experiment, particularly Pamela J. Rose, Ann Cornwell, Maire Brison, Wilhelmina Wendrich and Andrew Boyce. Pyrometric equipment was kindly loaned by the Department of Ceramics, Glasses, and Polymers, Sheffield University, and I am especially grateful for the advice of Dr P.F. Messer and Mr A. Gregory of that department. My work over the last two years has been supported by a grant from the Leverhulme Trust and has been supervised by Dr Richard Hodges (Sheffield University, Department of Archaeology). To both of these I am most grateful.

References

Arnold, Do. (forthcoming). "Potters in their setting." In J. Bourriau, ed., *Introduction to ancient Egyptian pottery*.

Drews, G. (1979). "Entwicklung der Keramik-Brennöfen." In A. von Müller, G. Kutscher, and S. Waetzoldt, eds., *Acta Praehistorica et Archaeologica*. Berlin (Volker Spiess). 33–48.

Hodges, H.W.M. (1981). *Artifacts*. London (Baker).

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

Jacquet, J. (1983). *Karnak Nord* V: Le Trésor de Thoutmosis Ier. Cairo (IFAO).

Larsen, H. (1936). "On baking in Egypt during the Middle Kingdom." *Acta Archaeologica* 7: 51–57.

Nicholson, P.T. and H.L. Patterson (1985). "Pottery making in Upper Egypt: an ethnoarchaeological study." *World Archaeology* 17 (2): 222–239.

Rose, P.J. (1987). "Description of the bread moulds." In *AR* IV: 76–79.

Rye, O.S. (1976). "Keeping your temper under control: materials and the manufacture of Papuan pottery." *Archaeology and Physical Anthropology in Oceania* 11 (2): 106–137.