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POTTERY FIRING STRUCTURES (KILNS) OF THE INDUS CIVILIZATION DURING THE THIRD MILLENNIUM B.C.

Heather M.-L. Miller, Anthropology, Univ. of Wisconsin-Madison,
1180 Observatory Drive, Room 5240; Madison, WI 53706-1397
heatherm@macc.wisc.edu

ABSTRACT

The Indus Valley ("Harappan") craftspeople developed a variety of ways to fire clay objects. This paper illustrates the technology of pottery and terracotta object firing in the greater Indus region during the third millennium B.C., drawing on scattered and unpublished evidence for a range of firing structures. "Open-air", single-chamber ("oven" and "pit"), and double-chamber updraft firing structures are discussed, with examples from the sites of Mehrgarh, Nausharo, Harappa, and Mohenjo-daro. I particularly stress the contemporaneous use of different types of firing structures and the continuum nature of firing structure "types".

INTRODUCTION

The Indus civilization was located in what is now Pakistan and northwest India during the third millennium B.C. Although it covered a far greater area than contemporaneous civilizations in Mesopotamia and Egypt, it has been the focus of much less research. It is chiefly known for its planned cities, particularly their well-developed water and waste-disposal systems, and for its highly talented craftspeople, who were particularly creative with various pyrotechnologies.

But Sophie Méry (1994) rightly points out that much of the published research on Indus craft industries has focused on prestige and luxury ornaments, such as long-barreled carnelian beads, steatite stamp seals, glazed steatite beads, and stoneware bangles. In contrast, this paper will focus on the production of terracotta pottery, rather than on "prestige" ceramic materials produced by Indus artisans, such as

stoneware, siliceous faience, and talcose paste and faience. (The Indus peoples did not make glazed clay objects, but did glaze talcose and siliceous objects.) Pottery has always been a topic of interest in Indus research, but primarily for chronological reasons. However, the past decade or so has seen a great increase in the interest in pottery production sites, particularly with the recent spectacular finds of potters' workshops and a range of firing structures. These new data have allowed me to interpret firing structures from early, incompletely published excavations, and to begin to characterize the variety of Indus firing structures used for pottery and/or other terracotta objects.

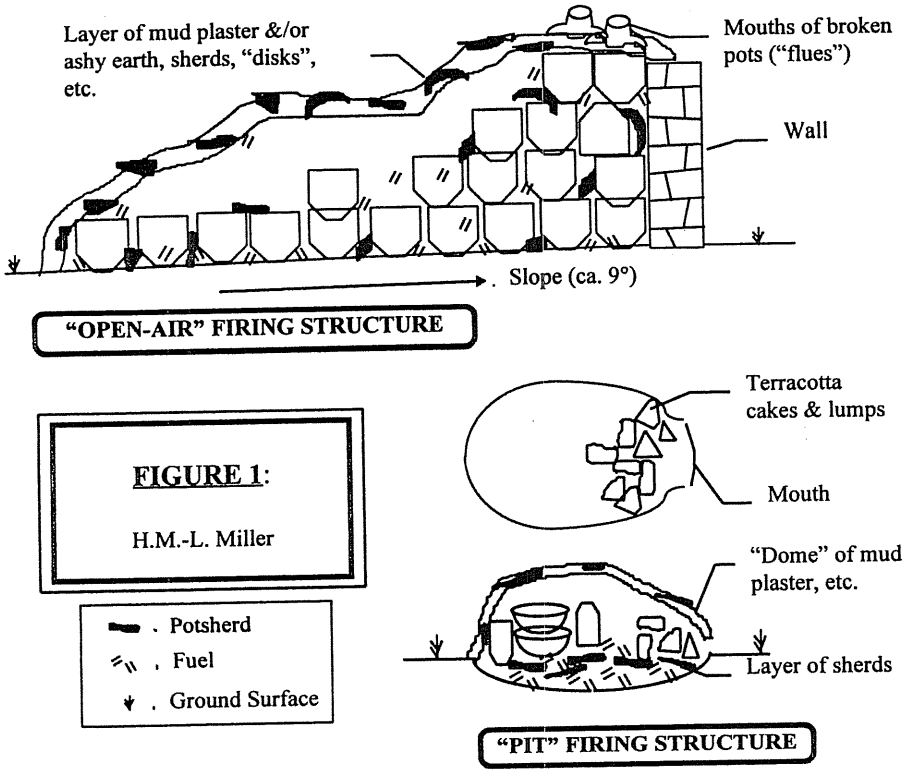
This paper is not a gazetteer of all known firing structures, but rather examines the range of firing structures and technologies used by Indus. (The relation between firing technologies and the economics—and politics—of pottery production will not be discussed in this paper, due to lack of space.) I have chosen only the best described and/or most common types of firing structures, but have tried to portray the variety of types of structures found. Most of my evidence comes from three groups of sites: (1) Mehrgarh, Lal Shah, and Nausharo in the Kachi Plain of southern Baluchistan; (2) Harappa, on the Ravi River in the flood plains of the Punjab; and (3) Mohenjo-daro, in the southern flood plains of the Indus River itself, in Sindh. The mounded urban sites of Harappa and Mohenjo-daro are the two best-known of the half-dozen largest Indus centers and the only ones to have been excavated, while the sites in the Kachi plain have revolutionized our knowledge of the earlier periods of this region. But these are by no means the only places where possible pottery firing structures have been found, but they are by far the best published, and firing structures found at other important sites are noted wherever possible.

I focus on the third millennium B.C., preceding and during the florescence of the urban Indus ("Harappan") civilization. As the chronological terms for the Indus region vary widely, and are still being extensively revised with new excavations, I will provide broad dates as currently known, but will also include the period/phase assignments. The most important point about chronology for this paper, however, is that there is <u>not</u> an evolutionary progression of firing structure types, as far as I can tell at this point. While increasingly more complex firing structures do appear over time, variants of the older structures apparently continue to be used.

Classifications are made for different reasons; my rough classification of firing structures in this paper focuses most on the ways in which structures dealt with the flow of air or heat (draft). It matches most closely Rye's (1981:96-100) classification of *open* vs. *kiln* firing, with pit structures and ovens as variants of open structures, and "kiln" restricted to structures with separate chambers for fuel and for products. Sinopoli's (1991:31-33) classification of *hearth (open-air)*, *pit*, *oven* and *kiln* structures is also similar. Rice's (1987: 153-163) classification of *nonkiln* vs. *kiln*, where "kiln" includes pit, bank, updraft and downdraft structures, is quite different. In this paper, I will discuss three categories of firing structures: *"open-air"*, *single-chamber*, and *double-chamber updraft kilns*. There are a number of other types of firing structures, including short "cylindrical kilns" from Mohenjo-daro and Harappa (Mackay 1938:49-50; Vats 1940:470), and "jar kilns" from Harappa (Dales & Kenoyer 1991:230, 1992:60; Wright 1991:78; Vats 1940:470), which will not be described in this paper.

To date, no true "bonfire" firing structures have been recognized for the third millennium B.C. in the Indus. All of our *"open-air" firing structures* involve some type of fairly substantial covering in addition to fuel, including potsherds, earth, and/or mud plaster. My category of *single-chamber firing structures* comprises slightly more permanent structures, including both "pit" structures and "ovens". *Double-chamber updraft firing structures/kilns* are found at a large number of sites during the Integration Era or "Mature Harappan" period, *ca.* 2600 to 2000/1900 BC. Double-chamber updraft kilns are a well-known type of firing structure, and there seem to be a number of different variants in use in the Indus. I have provided general renditions of the various types of structures (Figure 1), primarily to clarify the terminology I use (this is particularly a problem for double-chamber updraft firing structures). There are almost no drawings or plans published of the excavated structures, so these renditions should <u>not</u> be taken as exact drawings of the structures—these are based on educated guesses using the published descriptions and photographs, and some are generalized compilations of various structures excavated at different sites.

As will be apparent from the descriptions, these major types form a continuum of firing structures, of which these described types are only the "average" examples. This continuum exists even for perfectly preserved archaeological structures and/or modern ethnographic examples. With the added complication of poorly preserved archaeological structures (for example, usually only the base of a structure is preserved), assignment to a "type" can be a difficult task. It can even be counter-productive; it is much more helpful to publish even brief descriptions of excavated firing structures than simply noting that a "pit kiln" was found, especially given the number of different definitions of "pit kilns". More detailed descriptions are even more useful, such as:



- Dimensions and shape of preserved structure;
- Materials used in construction (mud bricks, perhaps baked *in situ*, pre-baked bricks, stone, plaster of various types with various tempers, specially made elements such as arches or stretchers for suspended floors);
- Any associated firing "furniture" (setters, separators, saggars, suspended floor elements, etc.) and the exact location within the structure where found;
- Fuel materials found (charcoal/ash from straw, brush, twigs, large pieces of wood, dung, etc., including species used)—or at least notes about the type of material (wood, straw, dung) and size of charcoal (twigs, large wood);
- Radiocarbon dates on fuel materials, palaeomagnetic dates on clay walls;
- Temperatures reached (based on analysis of structure itself or its products);
- Location (on slopes or flats or in hollows; orientation to prevailing winds; near roads or rivers (transport); within or outside of buildings, residential areas, and/or settlements);
- Any associated object production tools (chucks/molds, burnishers, etc.) or other evidence for object production in the vicinity of the firing structure;
- Products fired (based on wasters and/or unfired objects found in or near the firing structure). For the Indus the products fired are important for dating as well as production information, because with the lack of direct radiocarbon dates for most of the structures excavated, the products fired will have to supply the chronological information to date the structure.

Another line of evidence for the technology of pottery production is analytical studies of the finished product, and several Indus researchers have made use of this approach, particularly Wright (Wright 1985, 1986, 1989a,b,c; also Jenkins 1994; Méry 1994). As this is a paper focused on the firing structures themselves, I will not discussed this approach except in passing, but it provides a wealth of information about the technology of production, including firing.

Finally, for many of the firing structures excavated in the Indus region, it is difficult to say what was fired in the structure. Especially for early projects, excavators often did not provide information about wasters in or around the firing structures. But beyond this, the overlap in the characteristics of pyrotechnological structures used for many different functions makes it difficult to determine, for instance, whether a structure was used for craft production or for cooking (C. Jarrige 1994:288; C. Jarrige *et al.* 1995:511). This has led to widely different interpretations of almost identical features. For example, a group of structures found at numerous Indus sites are all described as shallow ovate pits (ranging from 0.35 to 1 m in length), showing traces of firing, with a cylindrical or rectangular block/pillar in the center (sometimes made from a single brick coated

with clay), and usually containing terracotta cakes or lumps as well as ash and charcoal fragments. These apparently identical structures are variously interpreted as ritual "fire alters" at Kalibangan (Lal 1979:77; Thapar 1973:101), as "cooking hearths/ovens" at Harappa (Meadow & Kenoyer in press), and as "fire-pits" related to domestic use (but also compared to pottery kilns) at Nausharo (C. Jarrige 1994:288).

However, the vast majority of the firing structures presented here have quite good evidence for their use in firing terracotta vessels. A variety of other terracotta objects, such as figurines, bangles, and beads, were probably fired in some or all of the firing structures described, either with pottery vessels or separately, but there are few references to finds of such objects as wasters or in firing structures. Like the vessels, other terracotta objects come in a range of qualities, so that a range of firing regimes from expedient to elaborate could have been used.

"OPEN-AIR" FIRING STRUCTURES

The "open-air" structures were found primarily at the site of Mehrgarh. The time depth of the Indus civilization was radically changed in the 1970s by the French Mission discoveries at the site of Mehrgarh in the Kachi Plain, with sequences from the seventh millennium B.C. to the third millennium B.C. at Mehrgarh and the nearby later site of Nausharo (C. Jarrige *et al.* 1995). The finds at Mehrgarh and Nausharo have played a pivotal role in research into the production of many materials, including pottery. Among the most spectacular have been finds of several potters' workshops, including several at Mehrgarh and one at Nausharo, as well as a number of separate pottery firing structures from various time periods, some within the settlements and some outside them. Finds from the workshops include unfired and fired pottery of a wide variety of types; clay scraps from the shaping of vessels and scraping of leather-hard vessels; stone, bone, and fired clay tools from both of these operations (which have different microwear patterns); fired clay chucks/molds; grinding stones, and a variety of other objects from various production stages. (See Anderson-Gerfaud *et al.* 1989; C. Jarrige *et al.* 1995; Méry 1994; Quivron 1994; Russell 1995; Santoni 1989)

The most detailed descriptions of any of the firing structures from Mehrgarh/ Nausharo are of an "open-air" firing structure, a very simple structure which nevertheless resulted in some rather sophisticated uses of heat and air flow. (Figure 1) The most spectacular example is from Mehrgarh Period VI, from the first half of the 3rd millennium B.C. (prior to 2700 B.C.), in Mehrgarh Area 1, MR.C, Square 9H. (Audouze & C. Jarrige 1979; C. Jarrige & Audouze 1979; C. Jarrige *et al.* 1995:109,136; J.F. Jarrige 1979) The Period VI structure consisted of some 140 jars piled on a south-to-north sloping surface (sloping 9°, downhill to the north), in an oval shape 6 m long (NW-SE) by 4 m wide. The bottom of the structure consists of the remains of a mud-brick wall from the previous period on the southern end (upslope), and perhaps a paving of limestone cobbles. Above this, the excavators note that the jars seem to be set on or in a layer of clean, hard clay. The intact eastern profile of this structure revealed that the jars were piled up in as many as 4 layers, some piled one inside another, others stacked in alternate rows, and at least two jars upside down. The jars are poorly fired, some showing blistering, vitrification, or crazing. Although most were complete, they are cracked and broken in place. Numerous sherds are packed among the jars, many apparently fragments of older, broken vessels "used to stabilize the unfired jars as the layers were built up" (Audouze & C. Jarrige 1979:215). The uppermost layers of this structure consist of an ashy, powdery sediment containing "a large number of jar fragments, sherds of a finer variety of pottery, and fire-cracked limestone pebbles" (Audouze & C. Jarrige 1979:215), with increasing amounts of ashes and charcoal towards the bottom of the structure. The sherds probably functioned as coverings for the top of the firing structure. The pebbles may have functioned for heat retention (see below, "pit kiln"), or were included to take advantage of the heat of the structure rather than fired separately for lime production, or both. (See Audouze and C. Jarrige (1979:219) and C. Jarrige *et al.* (1995:184) for a description of lime production near this structure.) Around the margins of the structure, and stuck onto some of the jars or fragments of jars at the top of the structure ("especially along their mouths"), were fragments of baked clay mixed with straw (Audouze & C. Jarrige 1979:215). Most of this straw-tempered clay mixture is undoubtedly the remains of a covering plastered over the jars during firing, to retain heat within the structure. However, the straw-tempered clay around the mouths of the jars may relate to their possible use as containers, as suggested by Méry (below).

The vast majority of the jars are standardized in shape: wheel-made, with a flat base of 10-14 cm diameter, slightly rounded walls, and a wide mouth forming the maximum diameter of the vessel (around 30 cm). They are undecorated, but their color ranges widely from brick red to bottle green, both from one jar to the next and within a single jar, due to uneven firing. There are three groups of exceptions: (1) a few jars of the above type, but decorated with geometric patterns in red, black and white, (found in three different parts of the firing structure); (2) a few jars clearly larger than the rest, and (3) a dozen small jars with a ring base, carinated underside, and straight walls. (Audouze & C. Jarrige 1979:216) At least some of the painted vessels and finer vessels were found in

the northern area, where the fire was probably first lit (C. Jarrige *et al.* 1995:136). Some of the jars bear different "potter's marks" (J.-F. Jarrige 1979:83).

Provisional measurements on samples of unbaked local clay and on well-baked jar fragments gave firing temperatures of 850°C in an oxidizing atmosphere. Similar measurements of overbaked fragments and underbaked fragments gave results of up to 1000°C and only 750°C, showing the irregular distribution of heat in the structure. (The method of analysis is not given, but the low temperatures were attributed to a clay composition rich in illite and limestone.) (Audouze & C. Jarrige 1979:217; C. Jarrige *et al.* 1995:136; Note that C. Jarrige *et al.* 1995:184 gives ranges of 500 to 800°C, with a "correct" firing temperature of 600°C.)

This firing structure was interpreted with the aid of modern structures of startling similarity created by professional potters in the Kachi plain to fire large numbers of vessels. The modern potters set as many as 500 to 1000 vessels on a sloped surface covered with a layer of straw and other agricultural by-products (C. Jarrige & Audouze 1979:91), which is often terminated by a wall at the upper end. The vessels are then themselves covered by a layer of straw and other agricultural waste, then by potsherds, and finally covered over by ashy earth saved from previous firings and/or by a layer of clay plaster. The fire is lit from the lower end ("in a sort of open oven built at the lower end"), and the natural uphill draft passing between the jars is encouraged by using the mouths of broken jars to form ventilation chimneys at the upper end of the structure, rather like the principle behind East Asian bank kilns. The firing lasts 24 hours, with no addition of fuel, followed by a week of cooling. The firings are done during the summer months (April-Sept.) after the winter rains are over. (Audouze & C. Jarrige 1979:219-220; C. Jarrige & Audouze 1979:91; C. Jarrige *et al.* 1995:109) The advantages of the technique are that a huge number of vessels can be fired with a limited amount of fuel, and that there is no need to maintain a permanent firing structure. The disadvantage is that there is a fairly high percentage of failures during rain or winds. (J.-F. Jarrige 1979) Presumably the archaeological example represents such a firing failure, perhaps caused by a wind or storm leading to uneven heat and flare-ups of overly high temperatures within the structure. (C. Jarrige *et al.* 1995:136)

These modern structures seem to match the archaeological structure in almost all details, down to the wall at the upper end of the structure. Allowing for the gaps in the distribution of vessels where well-fired jars were apparently removed, the original archaeological structure must have contained some 200 jars (Audouze &

C. Jarrige 1979). At least in some cases, the jars may have been used as firing containers for smaller vessels, as well as being fired themselves. (Méry 1994: 479-480,481 ftnt. 5)

A number of other "open-air" structures are reported from Mehrgarh, dating to both "earlier and later levels" than the Mehrgarh Period VI example described above (Audouze & C. Jarrige 1979:219). Most were apparently quite ephemeral, due to the removal of the (successfully) fired vessels. An earlier example is dated to *ca.* 3300 B.C. (in Mehrgarh Period V), from the same location as the Period VI structure described above (Mehrgarh Area 1, MR.C, Locus CCXXXII), and associated with two rooms containing large amounts of a wide variety of pottery types. This Period V structure is slightly different, as its base was a shallow depression rather than a flat slope, but it also functioned to fire large numbers of vessels. The Period V vessels from this structure were almost identical to the Period VI structure jars in shape, but smaller (20 cm max. diameter) and made either of heavily-tempered coarse clay or of wet ware. (C. Jarrige *et al.* 1995: 321,344,374,425; J.-F. Jarrige 1995:78)

A later example from the nearby, later site of Nausharo dates to 2500-2400 B.C. (the Period II levels of sector NS.K, in the southern mound). In a room containing six or seven layers of refuse from a variety of forming and firing stages of pottery production, "glazed coating fragments" were found "in a primary position, on the facing of the western and southern walls" (Méry 1994:474). Based on this evidence, as well as finds of 40 cm of "white compacted ashy microlevels containing few potsherds and firing wasters" extending to the south of this room, the excavators suggest that Room 2 was used (or more likely re-used) for pottery firing in an "open-air" type of structure (Méry 1994:474). Méry also notes that, as for earlier periods at Mehrgarh, this would be just one type of firing structure among other contemporaneous types, as at least one double-chamber updraft kiln dating to Period II has been found within 100 meters of NS.K area.

Another important group of firing-related objects from a different layer in Room 2 are fragments of flat, rounded clay "disks" made of a mixture of straw and clay (25-30 cm in diameter, 3-4 cm thick). More of these objects have been found in a Nausharo Period III potters' dump (*ca.* 2400 to 2100 B.C.). (Méry 1994:479) Méry suggests that, based on modern Baluchi firings, these may have been used to cover the "open-air" firing structures. Similar objects at Harappa (although somewhat thinner) have been interpreted in similar ways (J.M. Kenoyer, personal communication), and could be used to cover/roof any of the firing structure types discussed in this paper.

In sum, these "open-air" structures are a clever use of simple physical principles (a slope to increase the draft) and low-cost materials (including the use of agricultural wastes) to achieve maximum temperatures and minimal fuel use. So why was this technique not used elsewhere in the greater Indus region? It probably was, and the ephemeral nature of a successful firing has precluded its recognition. For example, Mackay (1938:109) found at Mohenjo-daro "a mass of debris several feet high" that was "evidently plastered over, for one or two patches have been preserved by the fire that also baked part of the plaster on the courtyard walls". (See also Mackay 1938:49,121 for other finds at Mohenjo-daro of burnt mud-plaster found in areas with burnt walls.) This is much like Méry's description of the remains of an "open-air" structure at Nausharo (above). However, this is not to deny the possibility of regional variation in firing techniques; perhaps at sites in other parts of the greater Indus region, pit structures were used instead of "open-air" structures. Indeed, such regional variations are quite likely, given the vast size of the Indus civilization, but at present the data is not sufficient to even speculate on regional differences.

SINGLE-CHAMBER FIRING STRUCTURES

As noted above, we are dealing with a continuum of structures; in fact, Rye (1981) refers to pit and other types of single-chamber firing as a variants of "open firing". The Mehrgarh Period V "open-air" firing structure described above might be classified as a "pit firing", given the presence of a shallow depression. Another type of single-chamber firing structure, from Mohenjo-daro, might be better classified with the open-air structures above, since it employed the use of a draft created by a sloped floor and "flues" at its rear.

Sub-Triangular Single-Chamber Structure from Mohenjo-daro

Quite different from the Mehrgarh and Harappa examples below, one of the best described single-chamber firing structures from an Indus site was found at Mohenjo-daro (south of DK-B,C area) by the IsMEO surface surveys (Pracchia *et al.* 1985; Pracchia 1987). Unfortunately, due to its proximity to the surface, it can only be dated vaguely to the "Mature Harappan" (*ca.* 2600 to 2000/1900 B.C.). However, due to careful observation and reporting, a great deal of information is available about its operation in spite of its poor preservation. Only the very base of this sub-triangular structure was found, measuring 1.40 by 1.50 m, with walls delimited by a single row of almost complete re-utilized bricks. It was possibly surrounded by a filling, perhaps indicating that it was originally semi-

subterranean, but too little of the structure remains to be sure. Pracchia compares its shape to Vats' "pear-shaped kilns" from Harappa (see below). (Pracchia 1987: 153; Pracchia *et. al* 1985:219) The structure contained drops of vitrified clay from melted mud plaster, a layer of ashes, and a group of vessels in front of the stoke-hole/fire tunnel which were probably from later dumping after the structure's abandonment (Pracchia *et al.* 1985:219). There is no sign of a pillar, nor of any vitrified material from a suspended floor (Pracchia 1987:153). There are two unique aspects of this structure which support the notion of a single-chamber firing structure with a draft. One is the presence of two blocks of clay melted into place on the back corners of the structure, which appear to indicate the existence of two exterior flues or chimneys at these points (Pracchia *et al.* 1985: 215; Pracchia 1987:152,Fig. 5). The second aspect is the inclined floor of the structure, sloping upwards from the stoke-hole/fire tunnel to the back of the structure (Pracchia 1987:153,Fig. 6), perhaps to create a draft as in the "open-air" firing structures from Mehrgarh/Nausharo. This structure is thus an excellent example of the continuum nature of firing structure types.

"Pit Kiln" from Harappa

It might seem curious that only a single example of a "pit kiln" has been published for the Indus, from the recent excavations at Harappa (Dales & Kenoyer 1991, 1992). (Figure 1) This is particularly odd given that "pit kilns" are among the most common type of firing structure used in South Asia today. But on the one hand, some of the "ovens" from Mehrgarh (below), might well be classified as "pit kilns". On the other hand, many of the modern "pit kilns" in India and Pakistan would in fact be closer to either the "open-air" firing structures described above, or the single-chamber ("oven") firing structures described below, as they do not employ a scooped-out pit, but are built onto a surface. It may also be a case of these structures being overlooked, or mistaken for cooking structures, as noted in the Introduction.

The Harappa pit structure was found on the northwest corner of Mound E, one of three firing structures found in an area of some 70 square meters (Dales & Kenoyer 1991, 1992; Wright 1991). It was in deposits dating to Harappa Period 3, and is radiocarbon dated to about 2300 B.C. (calibrated) (Dales & Kenoyer 1991:43,Fig. 4.9). It differs from the "open-air" firing structures at Mehrgarh and Nausharo in that it is shallowly dug into a flat surface rather than placed on a sloping surface, it is very much smaller (80 x 75 cm, 30 cm deep), and it "has a definite opening to the west for air and possibly fuel" (Dales & Kenoyer 1991: 235). The bottom of the "tear-drop shaped" (ovate) pit contained a thick layer of

ash, covered with a layer of potsherds. Dales and Kenoyer (1992:60) draw on modern potters' techniques to suggest that the sherds may have been used as "setters to hold and cover the objects being fired and also to protect them from direct contact with the fuel".

One of the most noteworthy aspects of this structure is the concentration of numerous low-fired triangular terracotta cakes and *mushtikas* ("potato shaped clay lumps with finger impressions") in the western opening ("mouth") of the pit (Dales & Kenoyer 1991:235, 1992:60). Dales and Kenoyer note that modern Pakistani potters place old vessels or stones at the mouth of similar firing structures to allow air into the structure while sealing in the heat. As there is no stone for hundreds of kilometers, Harappan potters (and cooks) seem to have substituted terracotta cakes and lumps of various shapes in their firing structures and hearths, although terracotta cakes are also found in hearths in stone-rich areas, such as Nausharo (e.g., C. Jarrige 1994). The cakes, lumps, and stones would also function to reduce fuel consumption and even out the supply of heat over the course of the firing, by absorbing heat early in the firing sequence, then radiating heat as the fuel was consumed. (Many thanks to my anonymous reviewer for pointing this out.) Ethnographically, the objects to be fired would be placed in the main part of the pit, behind the cakes and lumps, together with the fuel. And based on modern ethnographic analogies, Dales and Kenoyer (1991:235, 1992:60) suggest that the filled pit was then covered with mud to form a domed covering with vent holes, which was broken open and rebuilt after each firing. (No discovered fragments of such roofing are mentioned.) Finally, they note that "no complete objects were found in this kiln", but suggest that the size of the structure indicates the firing of only small vessels or figurines (Dales & Kenoyer 1992:60).

Single-Chamber Structures ("Ovens") from Mehrgarh

The vast majority of single-chamber firing structures are reported from the site of Mehrgarh, particularly from the southern half of the mound of Area MR.1. This region of Mehrgarh is incredibly rich in pottery manufacturing evidence, and includes numerous areas with unbaked pottery, small terracotta objects, potters' tools, storage rooms containing hundreds of vessels representing a wide variety of types, and numerous firing structures. Trash from the potters' areas contained huge quantities of overfired ceramics mixed with other debris, including pebbles used in the firing process. (C. Jarrige *et al.* 1995; Santoni 1989) I will focus here on firing structures from Sectors MR.F and K, in deposits dating to the early to mid-third millennium B.C. MR.F/K was both a craft and habitation area during Mehrgarh Period VII (very roughly *ca.* 2700 to 2500 B.C.). A trench through the

mound also showed the presence of "intensive potters' activity" during the preceding Period VI (roughly *ca.* ?3000 to 2700 B.C.), including firing structures. (Santoni 1989:176; C. Jarrige *et al.* 1995:217,Fig. 4.21,427, see also 136,183 for firing structures from other parts of MR.1) The firing structures in MR.F/K ("ovens") are carefully distinguished from the roughly contemporaneous "large open firing areas" discussed above. Santoni (1989:176) states that these "ovens were probably used to fire the more elaborated kinds of pottery and particularly the painted grayware as well as small terracotta objects. Large jars and common pottery were fired in large open firing areas".

The Period VI deposits (roughly *ca.* ?3000 to 2700 B.C.) contain one of the most convincing examples of a definite pottery firing structure. It was rebuilt 3 times in the same location (unfortunately, no plan of the Period VI finds is available). All three re-buildings are described as a "free-standing kiln" or "cupola kiln", built of clay on top of a layer of small stones or stones and sherds (C. Jarrige *et al.* 1995:427; Santoni 1989:176;Fig. 2). The second rebuilding was the best preserved, and was a round domed structure (1.6 m external diameter, 1.2 m internal diameter, preserved to a height of 35 cm) built on a layer of stones and sherds placed inside the base of the first structure. It had mud-brick walls and (like all of the re-buildings) was lined with clay that had been heavily burnt during firing, grading from "grey-white nearest the heat source to dark red to a lighter red" (C. Jarrige *et al.* 1995:427). This second rebuilding was filled with clay, earth, and a few stones and sherds, but no fragments of a possible roof or dome. Small stones were placed on top of the filling to form the base of the third re-building. The structure was surrounded by ashes, broken wall fragments from former firing structures, and wasters, including large fragments of Faiz Mohammed painted grayware (Santoni 1989:176; C. Jarrige *et al.* 1995:427). Fragments of unfired clay vessels were also found in the deposits around the structures (C. Jarrige *et al.* 1995:428). Note that in all cases the stones were found under the firing structure base, forming part of the structure, not inside the structure, unlike many of the other firing structures at Mehrgarh where the stones seemed to have been part of the "kiln furniture" (see above and below).

The Period VII (roughly *ca.* 2700 to 2500 B.C.) firing structures in MR.F/K are more difficult to interpret. They are found in "yards" between or in front of rooms (C. Jarrige *et al.* 1995:217). It is not clear from the published descriptions whether all of these single-chamber "oven" or "firepit" structures consist of excavated depressions/pits or are built above a flat surface; my impression is that all of the Period VII structures are pits. They are mostly circular to ovate and usually only their bases were preserved, with maximum diameters ranging from

1.0 to 2.50 meters, with one extremely large exception (below). Almost all are described as having "well-smoothed sidewalls" (C. Jarrige *et al.* 1995:217), but none of them appear to have a "mouth" of any kind, unlike the "pit kiln" at Harappa (above). The total number of firing structures in MR.F/K is not specified, but there are at least six separate groups of structures mentioned for the Period VII deposits. At least two of these structures in MR.F/K were destroyed and rebuilt three times, in the same location but at different orientations and sometimes different sizes. (C. Jarrige *et al.* 1995:217,Fig. 4.21; Santoni 1989: 176,Fig. 1). This phenomenon of re-building is also seen for the "cooking hearths" excavated recently at Harappa. (Meadow & Kenoyer in press) In contrast, the double-chamber pottery kilns at Lal Shah (below) were seldom re-oriented or re-sized during restorations of a particular structure, emphasizing the greater effort needed to construct a double-chamber updraft structure.

It is tempting to re-interpret some of these features as hearths or ovens for cooking rather than pottery firing. For example, the "firepit" at Locus CI/Square 10A sounds remarkably like the "fire alters"/"firepits"/"cooking hearths" described in the Introduction, except that it does not have a small central block/pillar: an oval structure about 15 cm deep with fire-baked walls, filled with ashes and charcoal mixed with burnt pebbles, with broken terracotta cake fragments nearby. Another structure at Locus CXIII/Square 1B (1.15 by 0.9 m) contained charged seeds of wheat, barley, and grapes, in addition to ash and charcoal, which would tend to lend weight to a cooking function. However, modern potters in the region frequently use as fuel both animal dung (containing seeds) and agricultural wastes, such as incompletely winnowed straw from cereals. (C. Jarrige *et al.* 1995:218; see also Rye 1981:104) And at least one of the other structures in this area was heated to the point of vitrification, far above cooking temperatures. The lowest base of a 1.8 by 1.5 m structure re-built 3 times (in square 1C) had a bottom almost vitrified with the heat, and was filled by a large number of heat-cracked pebbles and several overburnt terracotta cakes/lumps, "some almost vitrified" (C. Jarrige *et al.* 1995:217). (Note that the last re-building of this structure (1.7 by 1.4 m) is the only one of the Period VII structures said to have a wall made of bricks.) Once again, it is clear that it is very difficult to determine the function of "single-chamber" or "firepit" structures of the Indus region, especially on the basis of shape characteristics alone, and "[i]t is quite probable that these kilns and firepits were used for various different purposes" (C. Jarrige *et al.* 1995:217).

Two of the remaining structures in MR.F/K Period VII are particularly interesting because they appear to incorporate transverse walls. Could these be a type of two-chamber kiln, with either the transverse wall supporting a suspended floor, or with the combustion and firing chambers separated horizontally rather than vertically? One of these structures (in Square 10B) is very oddly shaped, consisting of an almost L-shape divided into an oval and a semi-circle by a transverse, east-west wall. Only the semi-circular portion is floored with burnt pebbles, but no other information is given. (C. Jarrige *et al.* 1995:217,Fig. 4.21) There is more data for the other structure, which is the largest structure from MR.F/K, a 2.9 by 2.25 m oval with a hollow bottom and concave walls which "suggest the presence of a cupola" (C. Jarrige *et al.* 1995:217). This structure contained charcoal, charred seeds, and ashes, together with about thirty clay "sling balls", and "blocks" that may be fragments from the collapsed roof of the structure. Many of these fragments have mat or basket impressions (and in one case cloth), and Santoni suspected that mats or baskets were either used as a frame for a temporary roof, or for filling cracks or holes during firing. (C. Jarrige *et al.* 1995:217) No pottery wasters are reported from this structure, although a high level of heat is suggested due to the solidification of the ashes into whitish blocks (C. Jarrige *et al.* 1995: 217,Fig. 4.19A). About five courses of bricks are still preserved of a partition wall across the short axis of this structure, dividing off a third of the eastern end. It appears from the plan (Santoni 1989:Fig. 1) that the southeastern corner of the structure is missing, and that the wall does not completely stretch across the structure in the south, leaving both the western two-thirds and particularly the eastern third of the structure open from this point. However, it is not at all clear if this was the case in antiquity, or is due to post-use destruction. This transverse wall is only one brick thick, and does not seem substantial enough to support a suspended floor with a load of vessels. While the question of horizontally separated chambers remains, this wall may simply have supported the roof.

DOUBLE-CHAMBER UPDRAFT FIRING STRUCTURES (KILNS)

The last type of firing structure, the double-chamber updraft kiln, is the most common type of firing structure found (or at least recognized) at sites in the greater Indus region. (Figure 1) It is usually assumed to have been used for pottery firing. Most of the published examples come from Mohenjo-daro, but there are also well-described examples at Harappa, Lal Shah and Nausharo in the Kachi Plain. There are many more examples of firing structures in the literature, from excavations at Amri (Casal 1964), Balakot (Dales 1974), Kot Diji (Khan 1965), Lothal (Rao 1979), and several sites in present-day India (Sharma 1979-1989); and from surfaces surveys at Chanhu-daro (Sher & Vidale 1985; Vidale 1989) and sites in Cholistan (Mughal 1984, 1990). Many of these have a central pillar, and are thus presumably double-chambered. The structure from Balakot

was particularly well preserved, and may have been used for firing terracotta figurines (Dales 1974).

One of the great difficulties in analyzing firing structures from the Indus is discriminating between double-chamber and single-chamber structures on the basis of the archaeological remains. Most examples only have the combustion chamber preserved, and rarely a suspended floor, but are assumed to be double-chamber updraft firing structures because of the presence of a substantial central pillar. This assumes a certain type of double-chamber kiln structure—see the "Cylindrical Kiln" section below for suggestions about a possible double-chamber updraft kiln without a pillar. But the variations in double-chamber updraft kilns could form a paper in themselves, even with the scanty data available for most of the Indus firing structures. In this section I will only describe the remains of the double-chamber updraft firing structures found in recent excavations at Lal Shah, some of the most thoroughly studied of the recently excavated double-chamber structures, then briefly mention some of the similar firing structures at Harappa, Mohenjo-daro, and other sites.

Double-Chamber Updraft Kilns at Lal Shah, Mehrgarh

The remains of six double-chamber updraft firing structures, dating to two different phases of use, were found at Lal Shah, an 'industrial site' near Mehrgarh Area 1 of Mehrgarh Period VIIC (2700-2500 B.C.) (Pracchia 1985:460; Quivron 1994:629; C. Jarrige *et al.* 1995:85,462,506). These specialized production sites, with no evidence for associated habitation, are a phenomenon that is found most often during the "Mature Harappan" phase (*ca.* 2600 to 2000/1900 B.C.), according to survey work done in the desert regions between India and Pakistan where many such specialized firing sites were identified (Mughal 1984, 1990). The Lal Shah firing structures are all elongated "tear-drop" shaped structures with a central pillar. Based on measurements taken from Pracchia's drawing (1985: Fig 2), the Lal Shah structures have length to width ratios of roughly two to one (including the fire tunnel). Very roughly, the two earlier phase kilns, Kilns 1 and 2, are the largest at not quite 3 meters by 1-1/2 meters. Kilns 3 and 6 are about 2 meters by 1 meter and Kiln 4 just less than this in both directions, while Kiln 5, the roundest, measures roughly 2 meters by 1-1/4 meters.

Kiln 1 (Wright's Kiln A) was initially excavated by Wright (ms), then Pracchia (1985) conducted further excavations over 120 square meters in 1985. Kiln 1 was the only kiln still to have the base of the firing chamber (grate/suspended floor) preserved. It consisted of a combustion chamber about 1.5 m in diameter, cut into the side of the hill and lined with a single course of bricks laid edgewise (10 cm thick). A 50 cm diameter pillar built of baked bricks and clay filler supported a grate/suspended floor made of bricks stretched between the central pillar and the walls. The combustion chamber was finally completely plastered with vegetal (straw)-tempered clay, including the pillar and the domed underside of the grate/ suspended floor. There were three layers of this vegetal-tempered clay lining, indicating that the combustion chamber had been used and re-plastered on at least three occasions. At least the final use of the kiln reached temperatures high enough to result in the slagging of this lining (below). (Pracchia 1985:460, Fig. 3; Wright ms; Wright & Mishara ms; C. Jarrige *et al.* 1995:462,Fig. 10.30)

The remains of the grate/suspended floor contained 7 cone-shaped holes (narrower in diameter on the firing chamber end than the combustion chamber end) placed around the perimeter of the grate (Wright ms). The original structure probably had about 12 of these interior flues, allowing hot air circulation between the lower combustion chamber and the firing chamber above it. As is usual for updraft kilns (Rye 1981:100), the area of maximum heat during operation was in the combustion chamber around these interior flues, as shown by the formation of stalactites of molten clay (C. Jarrige *et al.* 1995:462). The wall of the firing chamber, which originally stood above ground level, was made of bricks and preserved to a height of 25-30 cm. The floor of this chamber (the upper side of the grate) was coated with 3 layers of a white coating (discussed below), again representing at least three occasions of use. The upper part of the firing chamber may have been impermanent, such as a covering of potsherds, earth, mud plaster, and/or the circular flat straw-tempered clay disks mentioned above, which would be replaced for each firing. This would make loading the kiln much easier. (Wright ms; Pracchia 1985:460; C. Jarrige *et al.* 1995:462,Fig. 10.30; Santoni 1989:176)

Unfortunately, the fire tunnel (Wright's "fire box") was cut by a later grave pit (Pracchia 1985:Fig. 3). Enough remained to show that while some ash and charcoal were found within the combustion chamber, most of it was found piled near or within the fire tunnel, in several layers to a depth of 25-30 cm (Wright ms). One of the most unusual features of the structure is a "large hole" near the junction of the fire tunnel with the combustion chamber. This "hole" connects the combustion chamber with the exterior of the kiln. Wright suggests that the circulation of heat within the kiln was controlled by manipulating both this "regulating hole" (which would also give the potter a view of conditions in the combustion chamber) and the stoking hole (i.e., the entrance to the fire tunnel). (Wright ms; Santoni 1989:176; C. Jarrige *et al.* 1995:462)

Subsequent analyses of the slagged clay lining from Kiln 1's combustion chamber using SEM and X-ray diffraction indicate that it was heated to above 800°C (Wright & Mishara ms). The white coating from the grate/suspended floor of the firing chamber was also analyzed by SEM and XRD, and found to be impure gypsum, not lime as was previously thought (Wright & Mishara ms; Jarrige *et al.* 1995:462; Pracchia 1985:460). Although traces of possible post-depositional gypsum salts were found throughout the structure, these abundant coating layers were probably deliberately applied rather than post-depositional (Wright & Mishara ms). Wright and Mishara (ms) suggests that the gypsum might be from secondary use of the kiln for gypsum plaster manufacture (normally fired at 100-200°C), as well as pottery firing at higher temperatures. It is also possible that the gypsum coatings were deliberately applied, and had some sort of refractory or pyrotechnic function, to protect the firing chamber or the vessels being fired from collapse or sticking during high temperatures. (Cp. the white coatings—in this case steatite/talc paste—on "dishes" from Harappa (Miller in press).) Either scenario would explain the regular re-coating of the grate.

While the remaining kilns were preserved to lesser degrees (down to Kiln 6, with only traces of the base of the combustion chamber left), all had both the vegetal-tempered clay linings of the combustion chamber walls and the white (gypsum) coating of the grate regularly replaced (Pracchia 1985:460). The regular restoration of "calcareous lime-like pavings" around the kilns allowed the chronological division of the use of the six kilns into two structural phases (Pracchia 1985:460,466-467). (Based on the description, the "calcareous lime-like pavings" are probably also gypsum.) Kilns 1 and 2, the most complete kilns, were operating simultaneously during the first phase, during which 7-8 restorations of the kilns were noted. The remaining four kilns were operating during the second phase, and there were signs of at least two restorations of each of these four kilns during this second phase. Pracchia (1985:466,ftnt. 1) notes that if these restorations corresponded to a yearly cycle of firing activity, the area could have been used for a period of 9 to 14 years, with or without a break between the two phases.

Firing waste products ("shards of cracked or over-fired pottery, setters and supports for earthenware jar manufacture") covered the entire excavated area in varying concentrations (Pracchia 1985:460). (Pracchia (1985:460-461) and C. Jarrige *et al.* (1995:85,462,506) discuss the pottery types found in association with the kilns.) The only kiln furniture found were fragments of setters, but these

were a bit different from the "rectangular-sectioned bangles" thought to have been used as setters from Mehrgarh Area 1, MR.K (Santoni 1989:181,184-185). Based on the photograph (Pracchia 1985:Fig. 7), the Lal Shah setters are short, thick, roughly-made, semi-circular coils of clay mixed with straw, most about 3-5 cm in cross-section. Finds of "conical stands used for jar forming" (molds or chucks), two smoothers made from pottery sherds, and a bull figurine in unbaked clay (Pracchia 1985:461,Fig. 6,8,9), indicate that this area may have been used for forming as well as firing of pottery and other terracotta objects.

It is also of note that three of the Lal Shah kilns (2, 5 and 6, the westernmost kilns) are oriented roughly north-south (with the fire tunnel opening to the south), while the remaining three kilns are all oriented in very different directions, both from north-south and from each other. (Pracchia 1985:Fig. 2; the implication in C. Jarrige *et al.* 1995:462 that Kiln 1's mouth opens southwards is incorrect—it opens northwest. Kiln 2's mouth opens southwards.) A south-facing orientation may have related to prevailing winds during the summer season (when modern firings normally take place). In any case, there was clearly no concern for at least Kilns 1, 3, and 4 with either the direction of prevailing winds or with conformation with culturally important directions. (Habitation structures and streets are usually oriented roughly north-south at the planned sites of the Indus civilization.) Since 1 and 2 are the earliest kilns, and 5 and 6 probably the latest, it may be that making structural use of the small mound into which Kilns 1, 2, 3 and 4 were dug was more important than other considerations of orientation. Orientation north-south then again became a primary concern for Kilns 5 and 6, when the space around the small mound was filled.

Double-Chamber Updraft Kiln at Harappa

The remains of a large double-chamber updraft structure, Kiln 100, was found on the northwest corner of Mound E at Harappa, one of three firing structures found in an area of some 70 square meters (Dales & Kenoyer 1991, 1992; Wright 1991). (See the "pit kiln" described above.) Its last use is radiocarbon dated to about 2300 B.C. (calibrated) (Dales & Kenoyer 1991:43,Fig. 4.9). Like the kilns at Lal Shah, Kiln 100 is "tear-drop" shaped, but it is larger and less elongated than any of the kilns at Lal Shah, measuring 3 m in length (including the fire tunnel) by 2 m in width. Only the bottom meter of the combustion chamber was preserved, including the large central pillar (about 1 m diameter) (Kenoyer 1994:Fig 29.3). All of the interior walls of the combustion chamber were heavily vitrified, including the pillar. Sherds (mostly unvitrified) from the surrounding deposits were analyzed by Wright, and seem to indicate that only the most complex types

of vessels in the assemblage of this period (Harappa Period 3) were being fired in this firing structure, including very large storage jars of a type traded as far as Oman. Wright also notes that "while some misfired pottery and firing structure wasters have been found, they are not present in large quantities, suggesting a well-developed knowledge" of firing (Wright 1991:83). Pottery production tools found near the kiln include a chuck/mold, hematite, bone and stone tools, and clean clay (Dales & Kenoyer 1991:235, 1992:62; Wright 1991:78-83).

The most unusual feature of Kiln 100 is a type of clay slab structural element, always heavily vitrified on its concave side, most of which were found in the fire tunnel or the entrance to the combustion chamber. Several functions have been suggested for these elements—as flues (either external or between the combustion chamber and the firing chamber), as bars to form the grate/ suspended floor, or as arch elements for the roof of the fire tunnel. Kenoyer (1994:352) has used the last suggestion in his reconstruction of Kiln 100 for experimental firings.

Double-Chamber Updraft Kilns at Mohenjo-daro

Other examples of similar firing structures come from the excavations at Mohenjo-daro in the 1920s & 1930s, particularly from Mackay's excavations in DK-G area. (Mackay 1938, Marshall 1931) Some seven possible double-chamber updraft kilns were found in deposits of the "Late II and I (b & a) Phases", one in the northern portion of DK-G, one in the middle of the street dividing DK-G, and five in the southern portion. Dating of these structures is a serious problem, as the great majority of the excavations at Mohenjo-daro were done prior to radiocarbon dating. (See Franke-Vogt 1994 for discussion.) The most helpful aid to dating these old excavations will be further development of a pottery chronology for Mohenjo-daro, but it is worth noting that two of the DK-G firing structures had associated wasters of numerous 'Pointed Base Goblets' (among other vessels). (Mackay 1938:54,103) This is a very distinctive pottery type which at Harappa is primarily restricted to Harappa Period 3C (*ca.* 2250 to 2000/1900 B.C.) (Jenkins 1994:325-326; Meadow & Kenoyer in press).

Little information is given for most of the DK-G firing structures other than their measurements; the presence of a pillar is not always mentioned even in kilns with portions of a grate/suspended floor or pillar clearly visible in the photographs. Four of the seven definitely had pillars and/or suspended floors preserved. But since some of the structures have neither published photographs nor drawings, I can only guess that all but one were probably double-chamber updraft kilns, based on their grouping together by Mackay. The exception is an enormous, "not perfectly circular" structure some 4.8 m by 4.7 m, with a 46 cm thick, "very roughly built" wall of broken and unbroken bricks of various sizes

(preserved to a height of 1.5 m), which was found in an open space between Blocks 7 & 9. Described as "unfinished", it may be the remains of a single chamber/open air type of firing structure, although Mackay (1938:84-85) notes that two short parallel walls to the south of the structure may be the remains of a fire tunnel, which is characteristic of either double-chamber updraft structures, or the "pear-shaped/sub-triangular" single-chamber structures.

The remaining six structures from DK-G are described as irregular ovals or ellipticals or "practically circular", with length to width ratios, where given, of 2.0 m to 1.0 m, 1.8 m to 1.4 m, 2.2 m (diameter), and 1.4 m by ? m. (It is not clear whether the fire tunnel is included in these measurements.) They seem to have mostly been built of broken (baked?) bricks and plastered with clay/mud on their interiors, including the pillars built also of (baked?) bricks. (Mackay 1938:33,62, Pl. Lb, 102-103,Pl. XXIII2,Pl. Ld,154,Pl. Xd,Pl. XX) At least two of these structures had portions of their clay grates/suspended floors preserved, perforated by holes (interior flues) averaging 10 cm and 12 cm in diameter arranged around the edge of the grate (Mackay 1938:62,102). The best preserved kiln had almost a complete grate/suspended floor some 12-13 cm thick, with the holes in a ring around the edge of the grate plus a singe hole in the center, offset from the supporting pillar below (Mackay 1938:102,Pl. XXIII2,Pl. Ld).

Three other double-chamber updraft kilns found in earlier excavations in other areas of Mohenjo-daro (Marshall 1931:193,Pl. LIa,226,Pl. LVIIIb) and by the IsMEO surveys (Pracchia 1987:153; Pracchia *et al.* 1985:219) are slightly different in shape, with a much more abrupt join between the body of the firing structure and the fire-tunnel. At least two of the three had "tongue-support" type of pillars, projecting out from the rear wall of the kiln (Marshall 1931:Pl. LIa; Pracchia 1987:153), rather than the more common free-standing central pillars. Whether this reflects differences in use of the kilns or chronological changes in kiln construction cannot be determined on the basis of these examples. But obviously, there were probably a variety of types of double-chamber updraft firing structures in use, and we are only beginning to distinguish between them. Two more types of structures which may have been variants of double-chamber updraft kilns for pottery firing will be briefly discussed below.

"Pear-Shaped" (Brick-Lined) Firing Structures

Vats' (1940) excavations at Harappa uncovered 16 firing structures of various types in an area of less than 60 x 60 m (Trench IV on the southwest corner of Mound F). These 16 structures were found in four different major phases, and it

is not at all clear how many were actually in operation at once. (At the moment, these four phases can only be vaguely dated as "Mature Harappan", *ca.* 2600 to 2000/1900 B.C.) However, the majority of these structures were of a very unusual type. 13 pear-shaped firing structures were found, eight of which were lined with baked brick, and 5 of which were "mere pits dug in the ground". Vats (1940:472) only gives general size measurements, indicating that the structures ranged from 1.9 m to 2.5 m in length, and from 1.0 m to 1.7 m in width, and were preserved to no greater height than about 75 cm. (Figure 2)

All of the structures resemble each other in shape (Vats 1940:472-473), and are similar in outline to the "tear-drop" shaped double-chamber updraft kilns found at so many Indus sites. However, only three of Vats' structures (Fk, Fn, and Fc) had central pillars, one of which projects out from the rear wall; the remaining 10 firing structures did not have pillars at all. Vats did not believe that the two free-standing pillars were used to support the floor of another chamber. However, Vats (1940:473-474) mentions a brick-lined firing structure found by Mackay at Mohenjo-daro that is an "almost exact parallel of the pear-shaped furnaces from Harappa", which clearly has a free-standing central pillar (Mackay 1938:103,Pl. Ld). Mackay notes that this structure was exposed to high temperatures, so that the pillar is partly vitrified. Another very similar "pear-shaped", brick-lined, mud-plastered structure from Mohenjo-daro (Mackay 1938:62,Pl. Lb) even has the suspended floor preserved, with holes around its perimeter.

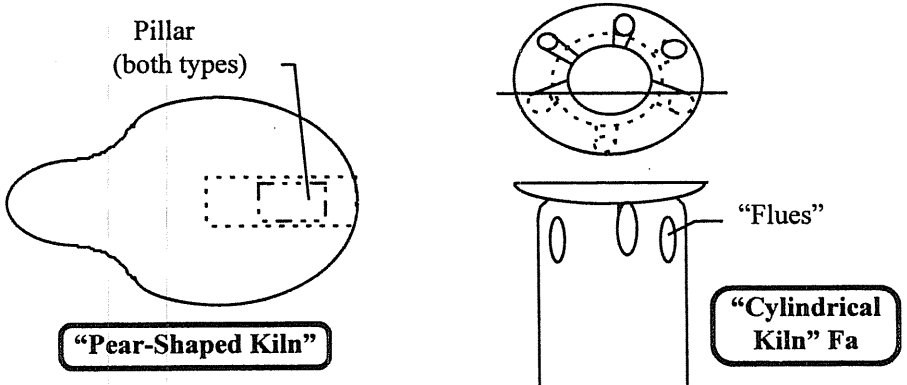


FIGURE 2 (after Vats 1940)

Perhaps the most intriguing aspect of these firing structures from Harappa is that all of the brick-lined firing structures, and probably at least some of those not brick-lined, are plastered with "mud mixed with a quantity of sand" ("to resist fusibility") (Vats 1940:472). "In several instances the original mud-and-sand plaster, which was generally turned into slag" was re-plastered, indicating that at least some of the firing structures were maintained and re-used. All of the other firing structures which I've seen or for which I have information, other than cylindrical "Kiln Fa" below, are plastered with straw-tempered clay—sand tempering is apparently unique to the structures on Mound F at Harappa. (Mackay makes no mention of any temper in the plaster on the similar structures from Mohenjo-daro.)

Vats briefly lists the possible products fired in these firing structures, based solely on the size of the structures and the high temperatures reached; there are no 'wasters' of any kind of product mentioned from this area of Mound F. He (1940:473) particularly dismisses pottery firing, as the structures would be "inconveniently small" and as "pottery does not require such intense heat as is evidenced by the vitrification in some of these furnaces". But the size of these firing structures is quite similar to known pottery firing structures from other excavations (above), and many of these structures are heavily vitrified. In fact, Mackay (1938:103) is quite insistent that the small kiln from Mohenjo-daro was for pottery firing. Without any discussion of mis-fired products, it is extremely difficult to assign a function to these structures, but the firing of pottery and/or other terracotta objects certainly cannot be ruled out. (NOTE: As is discussed in detail in Kenoyer and Miller (in press) the widespread notion found in the secondary literature that the 16 firing structures found on Mound F were associated with copper/bronze working is incorrect.)

"Cylindrical" Firing Structure

In his excavations on Mound F, Vats (1940:470-472,53,54) also found a "cylindrical kiln", Fa (in Stratum II, see above re dating). (Figure 2) Portions of Fa are still in place on Mound F at Harappa and I examined this structure in detail during recent conservation work (Miller in Kenoyer & Meadow 1992). When first excavated, half of the original structure was preserved (split vertically), revealing a surface so heavily vitrified that "its mud walls have actually run down in pencil-like formations of slag" (Vats 1940:471). Vats describes the structure as a pit 1.0 m in diameter and 1.1 m deep (although excavated to a depth of 1.6 m, there was no trace of fire below the 1.1 m depth). It was at least partially constructed with mud-brick, and its interior was covered with a sand-tempered

mud plaster (unpublished field notes, Miller in Kenoyer & Meadow 1992). Based on structural considerations and my examinations of the remaining walls of Fa, the existing structure was probably at least semi-subterranean. Vats (1940:470-471,Fig. d,Pl. XVIIa,b) notes that it had a vaulted roof, part of which was broken and lying inside the kiln, with four "flues" remaining at the springing of the vault and two more conjectured. Vats (1940:472) suggests that these "flues" were outlets for smoke and/or inlets for fuel that could be closed during the operation of the kiln. In addition, a fifth, slanting "flue" (barely visible in the photographs and not shown in the schematic) entered the kiln at "an obtuse angle" lower down, apparently just above the lowest vitrified levels of the kiln. Vats (1940:471-472) proposes that this lower "flue" was "used as an air channel worked by bellows from above."

However, in the photographs and in the schematic drawing (Vats 1940:470,Fig. d, Pl. XVIIa,b), there is a shallow depression around these flues, with a diameter of perhaps 1-1/4 to 1-1/2 meters, which is not mentioned in the text. It is possible that Fa was a double-chamber updraft kiln, and these "flues" were air ducts leading into an upper firing chamber which was larger than the combustion chamber below. The "vaulted roof" would be the remains of the grate/suspended floor of the kiln, which was <u>not</u> supported by a central pillar due to the smaller size of the combustion chamber. The lower "flue" might be the remnants of a "regulation hole" similar to one described for Kiln 1 at Lal Shah (above). If the preserved part of Fa were indeed only the combustion chamber, it would explain the extreme heat indicated by the vitrification of the walls, as the combustion chamber and fire tunnel are usually the most vitrified portion of a double-chamber updraft kiln (Rye 1981:100). However, it would be necessary to do experimental recreations to see if this proposed reconstruction is structurally possible.

CONCLUSION

I have emphasized that there is a continuum in the "types" of firing structures in use in the Indus. Shallow "pit" kilns with built-up sides grade into single-chamber structures with impermanent upper portions and roofs. Repeatedly used "open-air" structures with plastered clay coverings grade into rapidly built single-chamber structures using loose mud bricks or clay lumps, both employing slopes and simple construction techniques to encourage a draft. The Mohenjo-daro single-chamber structure shows how these same principles can be employed in increasingly more permanent structures. We do not seem to see a gradation in double-chamber structures in the Indus (yet); the only structures with the separation of fuel and objects fired are well-developed double-chamber updraft kilns, unless the single-chamber "ovens" with a dividing wall indeed functioned as "horizontal" double-chamber kilns. With the current data set, double-chamber updraft kilns appear to be a phenomenon of the urban phase of the Indus civilization, first used around 2600/2500 B.C. at the beginning of this urban or "Mature Harappan" period. However, both the analysis of firing structures and the general Indus chronologies need to be considerably refined before we can discuss the origins and development of double-chamber updraft kilns for the Indus region.

The other point stressed is that there is not an evolutionary progression of firing structure types. We do see the development of new, increasingly complex firing structures over time, but variants of the older structures apparently continue to be used along with the new "types". (For example, the contemporaneous use of single-chamber and open-air structures at Mehrgarh, and of double-chamber updraft and open-air structures at Nausharo.) Why this is occurring is one of the more interesting questions about Indus pottery firing technology. How did the Indus craftspeople choose which type of firing structure to use? Were their decisions dependent on the quality of the objects being produced? Or the size of the objects? Or the fuel costs? To contrast the costs of a double-chamber updraft kiln with an "open-air" firing structure, the updraft kiln requires more labor to build and maintain, requires the permanent dedication of space to firing (an important issue in urban contexts), and uses more expensive fuel, as most updraft kilns do not use agricultural waste or dung, but primarily wood. The advantages of an updraft kiln are that the firing can be more easily controlled, is less affected by weather conditions, higher temperatures can be reached, and the products are protected from the smoke and dirt of the fuel. Which of these issues were important for Indus potters? High firing temperatures do not seem to have been a problem, but the separation of products from fuel and the maintenance of an oxidizing atmosphere may have been important. For example, Jenkins (1994:324-325) notes that the "Early Harappan" (Harappa Period 2, roughly *ca.* 3000/2800 to 2600 B.C.) pottery assemblages at Harappa are often unevenly fired and fire-clouded, while the "Mature Harappan" (Harappa Period 3, *ca.* 2600 to 2000/1900 B.C.) vessels are more evenly fired. Also, the earlier sherds have a "mottled, gray to brown color, indicating that they were probably fired in a slightly reducing atmosphere," while the Period 3 pottery is generally a light red and fired in an oxidizing atmosphere. The ability to fire in a wider range of weather conditions may also have been important. With the increase of vessel mass-production during the urban or "Mature Harappan" phase, it may have been necessary to fire pottery more often, almost year-round rather than only during the dry season. Again, to answer these questions we need better chronological control; we are still

working at the +/- 100 year level in the Indus, so that it is difficult to truly discuss "contemporaneity" and "development".

Finally, one of the reasons why we find so many double-chamber updraft kilns is because they are hard to miss, having been subjected to such high temperatures that the combustion chambers have vitrified. Why are there so many vitrified structures, especially the double-chamber updraft kilns? Occasional environmental problems, like windstorms, seems unlikely for such a large number of structures. Indus pottery is not particularly high fired (roughly 800°C, on average). And while there are many overfired pottery wasters at Mohenjo-daro (Pracchia *et al.* 1985), there are surprising low amounts of overfired and vitrified pottery wasters at Harappa (Miller, dissertation in progress; Wright 1991:83). How do we resolve this enigma of vitrified kilns and few wasters? Part of the answer may be the high illite content of Indus region clays, causing them to vitrify at relatively low temperatures (around 1000°C). To fire a large load of objects to 800°C in the upper chamber of a large kiln (itself a major heat sink), it would probably have been necessary to generate temperatures of over 1000°C in the combustion chamber. The Indus potters, like Indus craftspeople working with other materials, must have continuously pushed the limits of what they could achieve.

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