A STUDY IN THE USE OF SCRAP WOOD AS AN INEXPENSIVE FUEL TO BE USED IN A MULTIPLE-CHAMBERED KILN FOR FIRING CERAMICS

by

CLYDE LEE CANTRELL

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Major Professor

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Chapter 1

INTRODUCTION

Archaeological finds have inferred that the combustion of carbonaceous fuels had become a tool of man who lived six hundred thousand years ago.[1] Carbonaceous fuels that have been used include wood, animal dung, grasses, coal, peat, natural gas and other petroleum products. All of these fuels have had their influence on pottery. In the early days the combustible material used to fire the ware was the one most easily accessible. In the southwest part of the United States the American Indians of that region had access to animal dung rather than wood; thus animal dung was used to harden their ware.

However, in recent years fuel costs have risen due to production expenses and the diminishing supply of certain fuels. Coal production was cut back because the mining of coal by open pits ravaged the surface, and the land usually could not be used for any other purpose.

With the rising cost of fuels and the diminishing supply, the potters could easily be put at the bottom of the priority list for receiving fuel needed to fire their ware. Now and in the future potters will need to reevaluate the different fuels and should make better use of any existing fuel that is not being used effectively.

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[1]William Howells, Back of History: The Story of Our Own Origins (Garden City: Doubleday and Company, Inc., 1963), p. 81.

In these days when the nation is trying to utilize resources more fully, it is becoming more apparent that the potter might utilize wood resources to his advantage. The wood source that has not been tapped to its fullest extent is waste wood. This is the wood that most businesses needlessly throw away and ends up in the city refuse. To them the wood cannot be used further, but the potter can use it in his kiln. Usually this wood can be gathered free of cost except for the time and gas involved to drive and pick it up. Most of these wood outlets pay to have their scrap wood hauled off. The use of scrap wood by the potter could save the businessman as well as the potter money.

The use of waste wood could be a solution to the potter's problems of fuel cost and availability.

FOUNDATIONAL HYPOTHESIS

The study was founded on the hypothesis that waste wood could serve as an effective, low-cost fuel for firing ceramics.

LIMITATIONS OF STUDY

Certain limitations were imposed on this study: (1) time, (2) location, (3) wood kiln history, and (4) technical knowledge of the craftsman.

The work and experimentation for this study was located in the Ceramic Area, West Stadium, Kansas State University, Manhattan, Kansas, and spanned a two and a half year period.

Because a total peripheral study of fuel burning kilns from other nations was not necessarily beneficial to this thesis, the study of wood kilns was limited to a descriptive narration (history) of oriental multiple chamber, climbing kilns.

During the investigative part of the fuel chapter it was found that the resins in coniferous woods were very complex. The presentation was simplified so that other esoteric issues would not cloud the main emphasis of this paper. The most important thing for the potter to know without going into technical details is which coniferous woods are best for wood kilns and why the presence of resins in the fuel is advantageous for heat production. This chapter was written so it could be easily understood and used by the contemporary potter.

THE ORGANIZATION OF THE STUDY

The organization of the study is written so that the contemporary potter can use it as a foundation on which to design and build a multiple chambered wood kiln for firing pottery. The study first involves itself with a general background of the climbing kiln history. This understanding of the development of the chambered climbing kiln helps to develop the next phase which is to set up some basic rules to follow when building a wood kiln. In order for a potter to use wood, one should know what woods are best suited for use in a wood kiln. What makes a certain species of wood better than another and the pollution aspect of using wood as a fuel are also covered in this chapter. These chapters are followed by information on the collecting, cutting and stacking of the fuel. The final chpater is an objective summary on the use of waste wood for firing pottery.

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Chapter 2

A RETROSPECT OF THE DEVELOPMENT OF THE ORIENTAL CHAMBERED CLIMBING KILNS

Facts which led to the development of the climbing kilns in the Orient are needed to understand how the kilns came about. These facts will be presented in a logical order in this writing.

The first wood kiln used by man was the simple open pit or modified bonfire, Figure 1. This kiln was made by digging a hole in the ground at a predetermined depth and width. A layer of fuel such as wood or animal dung was then laid in the pit. The pots to be fired were laid on top of the first layer of fuel. Next, charred fragments of pots broken in previous firings were placed on top of the ware which protected the ware from the direct flame. A final layer of fuel was placed on top of the fragments and then lit. If needed, more fuel was added as the firing progressed. When the pottery reached red heat, the fire was allowed to burn itself out; and at the end, a hardened vessel was the result.[1]

As time passed, the kiln evolved into a more efficient tool. The early potters found that the more enclosed the kiln was, the hotter it got. In the Near East or Middle East the potters built the kiln above ground with high permanent walls and the firebox located at one side near the bottom, Figure 4, page 11. This design principle is called updraft because the flame path is in an upward movement around the pots and out the top of the kiln. However, the potters of the Orient

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[1]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 2.

proceeded in a different manner to build their kilns. They began making their kilns in a bank of earth, Figure 2, page 8. This style of kiln is considered to be a crossdraft kiln. A crossdraft kiln is one in which the flame path is from the firebox inlet flues, across and around the pots to exit flues on the opposite side. The exact location of the first crossdraft kiln is not known, but the development of the crossdraft kiln originated in the Orient.[2] The first type of crossdraft kiln was known as bank or hole kiln, or ana gama[3], as depicted in Figure 2.

The Japanese bank kiln was made by digging into a bank as shown in Figure 2. These kilns were not extremely large. The main chamber was about four or five feet across, three feet high, and ten or twelve feet long. The cave sloped at an angle of about 30°.[4] The entrance to the cave was just large enough for a man to crawl through. At the back of the chamber an upward hole was dug leading to the ground level above. This hole was the flue. The bank kiln was usually located in an area with sandy soil which contained a mixture of clay. Soil that contained large amounts of rocks was unsuitable because the rocks when heated were not stable. To load the kiln with pots the potter would crawl in through the firebox, stacking the ware at the rear of the kiln first, working his way forward to the firebox. These pots were set on the sloping floor on wedge-shaped pads of clay to make the pots stand upright, as shown in Figure 3. The pieces were stacked on top of one another without shelves or saggers.[5] (Saggers were fireclay boxes containing glazed ware which protect the ware from direct contact with the flame or atmospheric conditions in the kiln).

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[2]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 31.

[3]Ibid, p. 31. [4]Rhodes, op. cit., p. 19. [5]Ibid.

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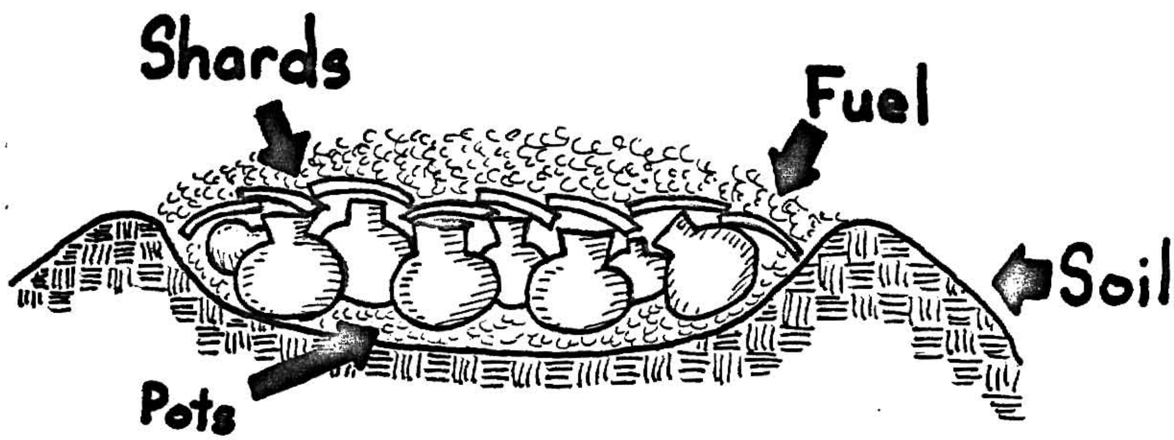

Figure 1

Open Pit Firing[6]

[6]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 3.

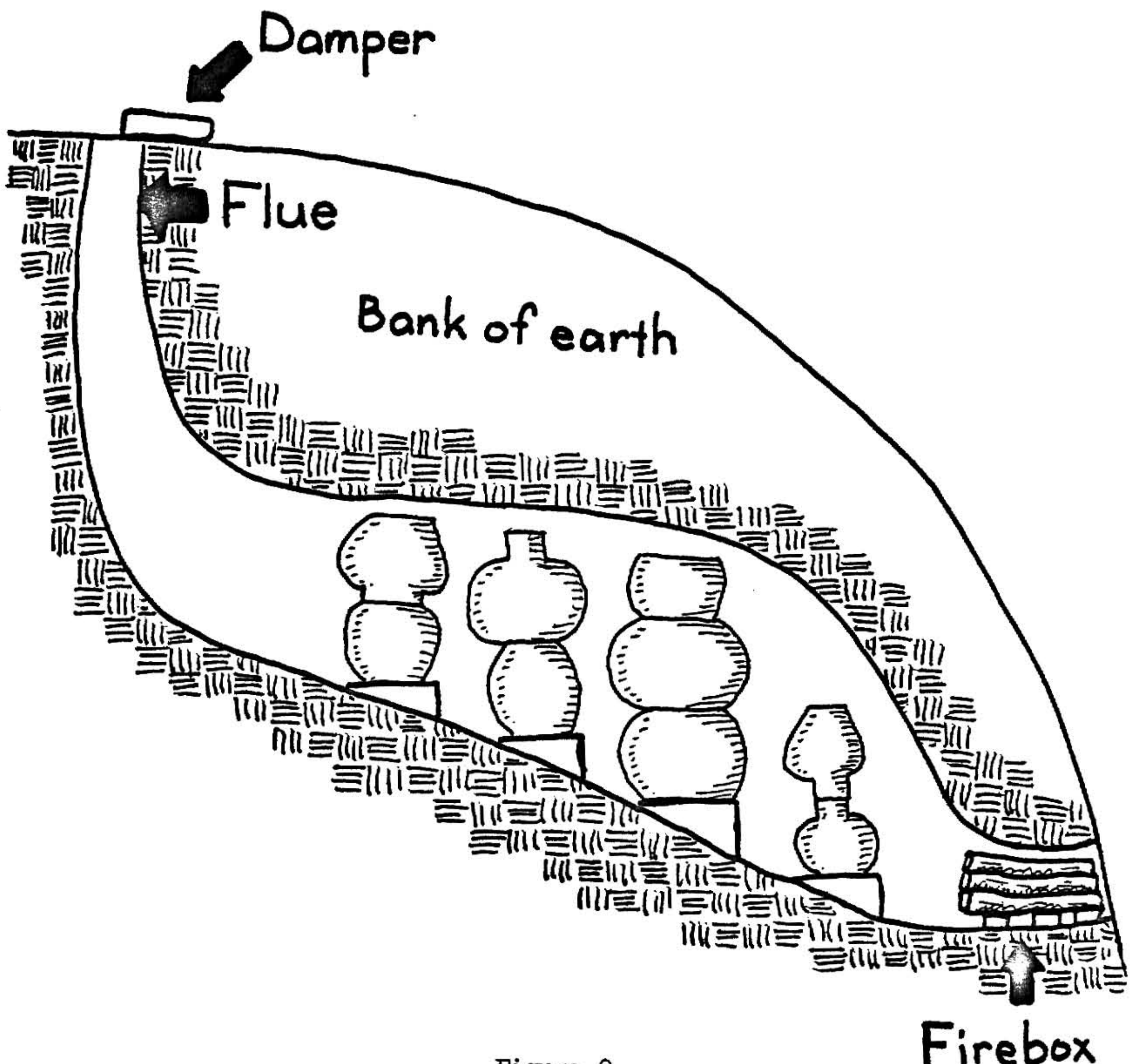

Figure 2

Japanese Bank Kiln[7]

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[7]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 19.

Figure 3

Clay Wedge to Level Pots[8]

[8]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 19.

The fire was started in the firebox at the lower end of the kiln, Figure 2, page 8. Flames traveled in an upward, crossdraft path around the pots and out the flue at the top. After considerable firings the clay soil on the inside became hard and a relatively permanent lining for the kiln.[9]

The first name associated with the cave or bank kiln was ana gama, and these kilns (ana gama) eventually were called old kiln, or ko gama. When the ko gama was built in a series up a sloping hill it was then called round kiln, or moru gama. If a large single chambered kiln was built, this was called oh gama.[10]

The bank kiln, ana gama, was much more advanced in design than the early updraft kiln, Figure 4, used by the potters of the Near East. An advantage of being built in a bank was the surrounding earth helped retain the heat longer than did the updraft.

The heat, being drawn through the pots in a crossdraft manner rather than the upward path the flame takes in an updraft kiln, helped disperse the heat more effectively. The flue hole was large enough to produce a draft that could be closed for draft adjustments.[11] A disadvantage of the bank kiln was the high fuel consumption.[12]

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[9]Daniel Rhodes, <u>Kilns: Design, Construction and Operation</u> (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 19.

[10]Hazel H. Gorham, <u>Japanese and Oriental Ceramics</u> (Rutland, Vermont: Charles E. Tuttle Company, Inc., 1971), p. 42.

[11]Rhodes, op. cit., p. 20.

[12]Gorham, op. cit., p. 48.

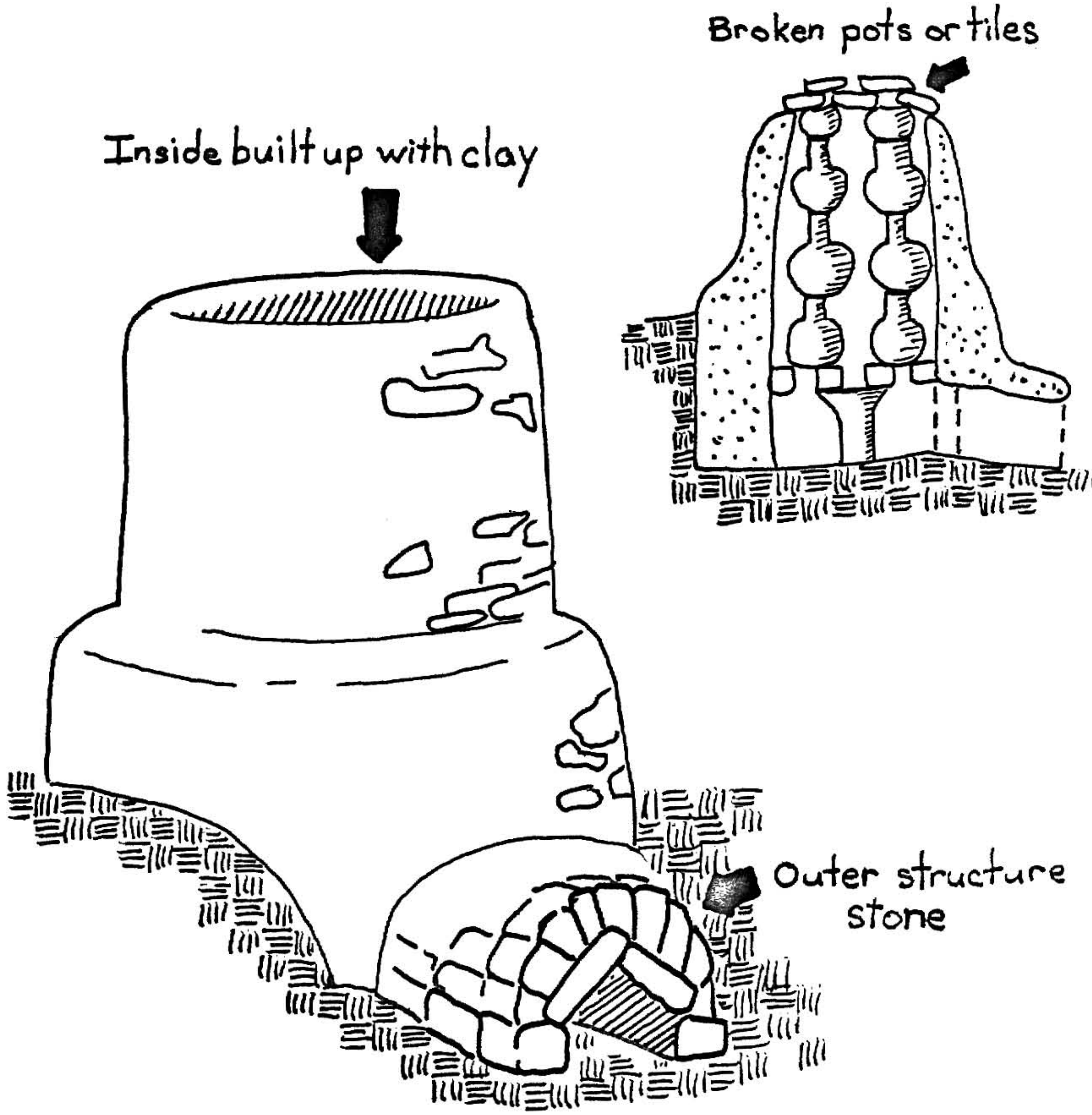

Figure 4

Open-top Updraft Kiln[13]

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[13]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 11.

As time passed, the bank kiln became too large for the chamber to be dug and formed into the bank of earth.[14] What followed was a more advanced type that had some characteristics of the bank kiln but was built largely above ground, Figure 5.

The new kiln which evolved from the bank was the tunnel kiln or climbing kiln (Nobori gama) which means kiln built on a hill[15], Figure 6.

One of the original earthenware kilns in Japan was the Tamba kiln,[16] which was a form of the tunnel kiln. In the early Kamakura Period (1185-1392 A.D.) migrant Korean potters built the Tamba style kilns and began to make pottery in Tachikui, Japan.[17] (See Figure 7, p. 15, for location of kilns in Japan.) The Tamba kiln, which was active during the Edo Period (1615-1868 A.D.) in Japan has flourished down to the present day. Ware produced was rather plain with dark brown or white glazing. The wares produced were for the use of ordinary people. The most popular pieces made during this time were the pepper jars and wine bottles with long, narrow necks.[18]

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[14]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 33.

[15]Hazel H. Gorham, Japanese and Oriental Ceramics (Rutland, Vermont: Charles E. Tuttle Company, Inc., 1971), p. 42.

[16] Olson, loc. cit. [17]Ibid.

[18]Hugo Muensterberg, The Ceramic Art of Japan (Rutland, Vermont: Charles E. Tuttle Company, 1964), p. 197.

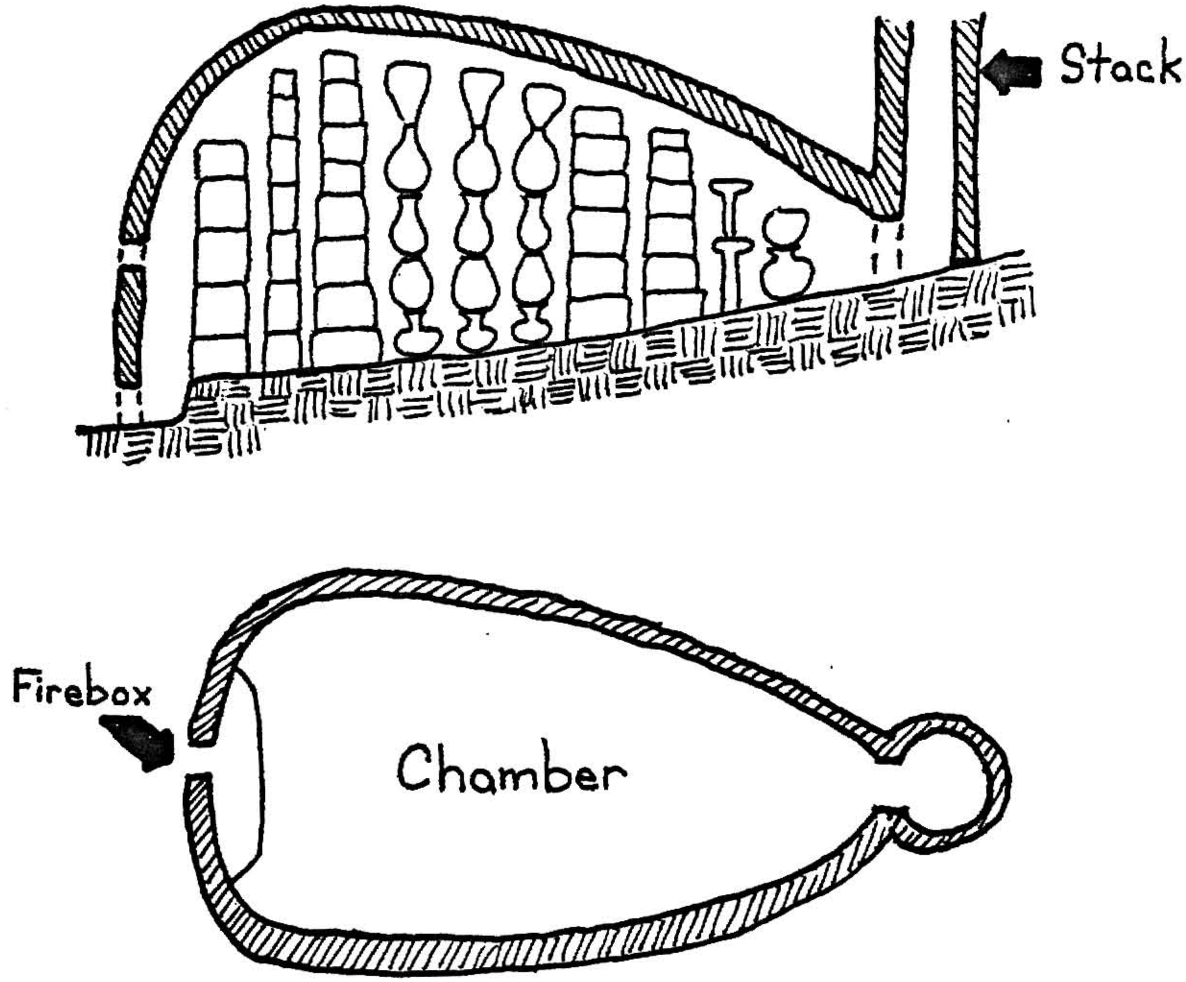

Figure 5

Chinese Ana Gama Used at Ching-tê-chên
for Firing Porcelain[19]

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[19]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 20.

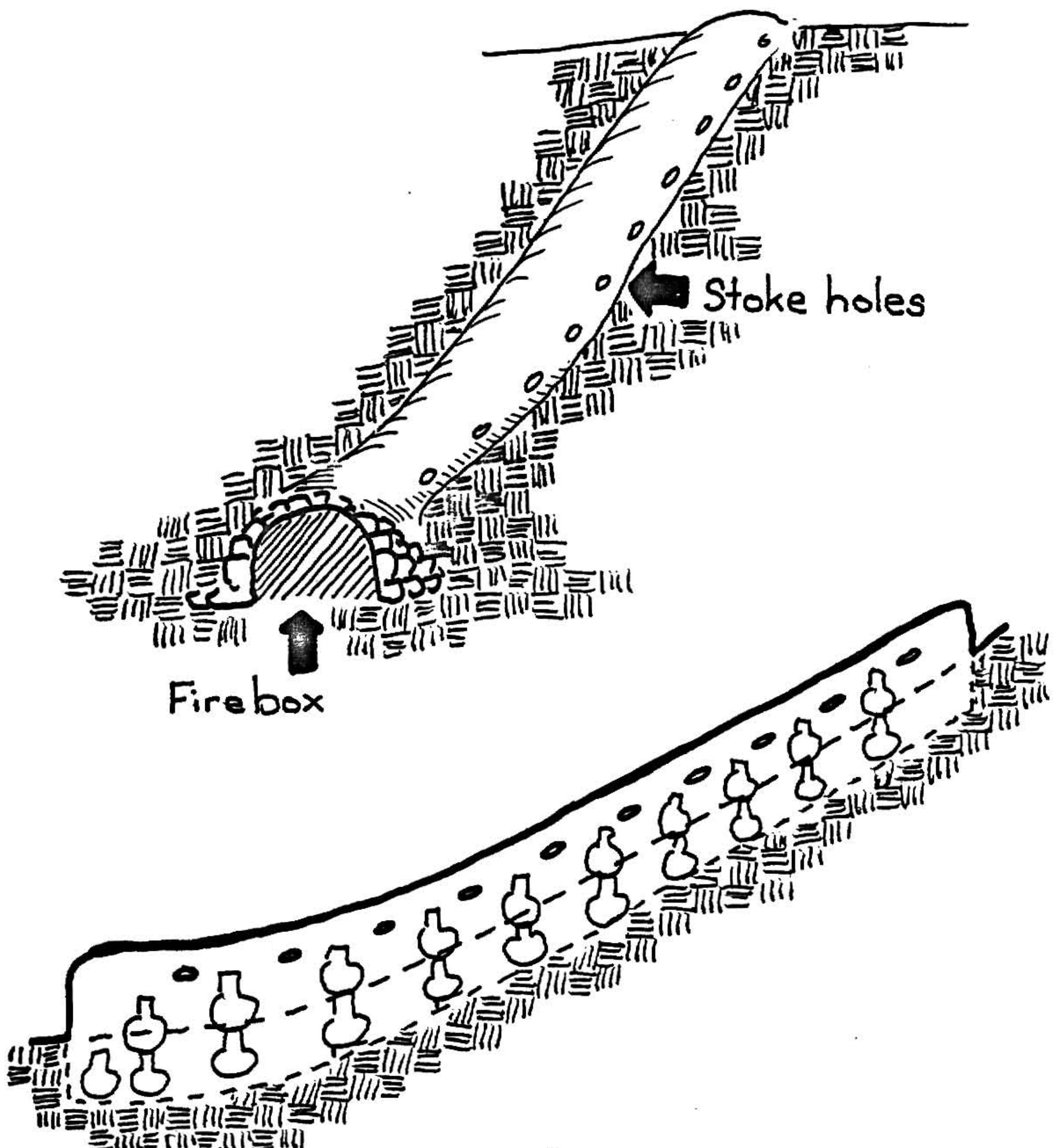

Figure 6

Early Tunnel Kiln[20]

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[20]G. St. G. M. Gompertz, Korean Pottery and Porcelain of the Yi Period (New York, New York: Frederick A. Praeger, Inc., 1968), p. 109.

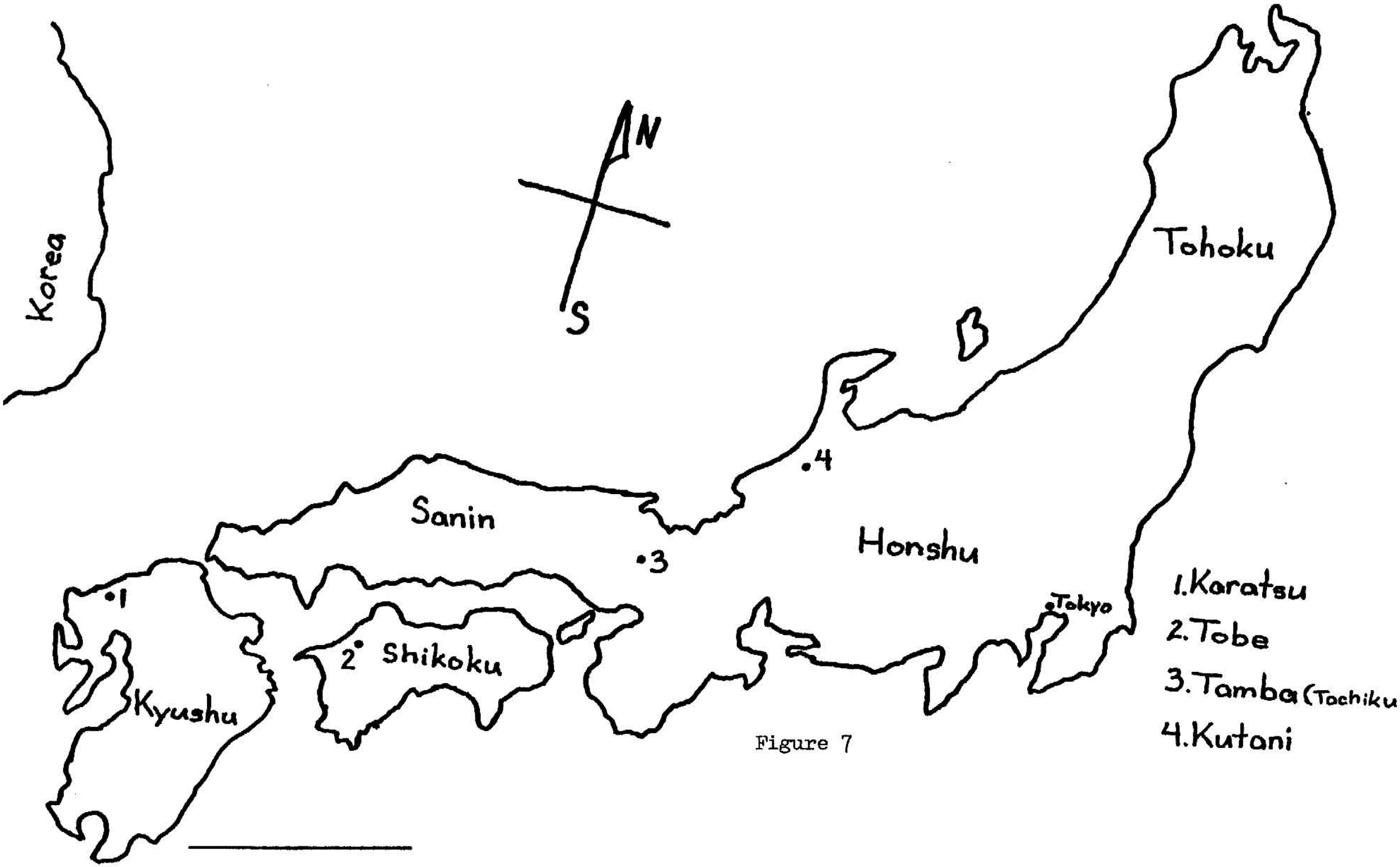

Figure 7

[21]Hugo Muensterberg, <u>The Ceramic Art of Japan</u> (Rutland, Vermont: Charles E. Tuttle Company, 1964), p.

The early Tamba potters were faced with several problems such as how to fire large containers averaging 13 to 24 inches in height. Another problem that confronted the potters was the need to fire large numbers of pots at a time, perhaps as many as 500. To resolve the problem, migrant Korean potters extended the bank kiln to over 100 feet and built the top half of the kiln above ground.[22] The average Tamba kiln (tunnel kiln) was approximately 150 feet long, 4½ feet wide and 3 feet high,[23] Figure 6, page 14.

The main drawback to the tube or tunnel kiln was the uneven heating. During the Japanese invasion of Korea, 1592 A.D., Korean potters were taken to Japan. These Korean potters started splitting the long chamber of the tunnel kiln into separate compartments such as the Chinese potters had done long before. Each chamber had inlet and outlet flues at the bottom of the dividing walls. This basically turned the tunnel kiln into a semi-continuous downdraft kiln,[24] Figure 8.

A revision of the tunnel kiln into the segmented climbing kiln enables a higher temperature to be achieved. Dividing the large chamber into individual compartments also enabled the potter to have greater control in firing.[25] Saggars were also used to help direct the flame path, coinciding with better temperature control.

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[22]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 33.

[23]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), pp. 34-35.

[24]Bernard Leach, A Potter's Book (New York: Transatlantic Arts Inc., 1951), pp. 185-186.

[25]Olson, op. cit., p. 37.

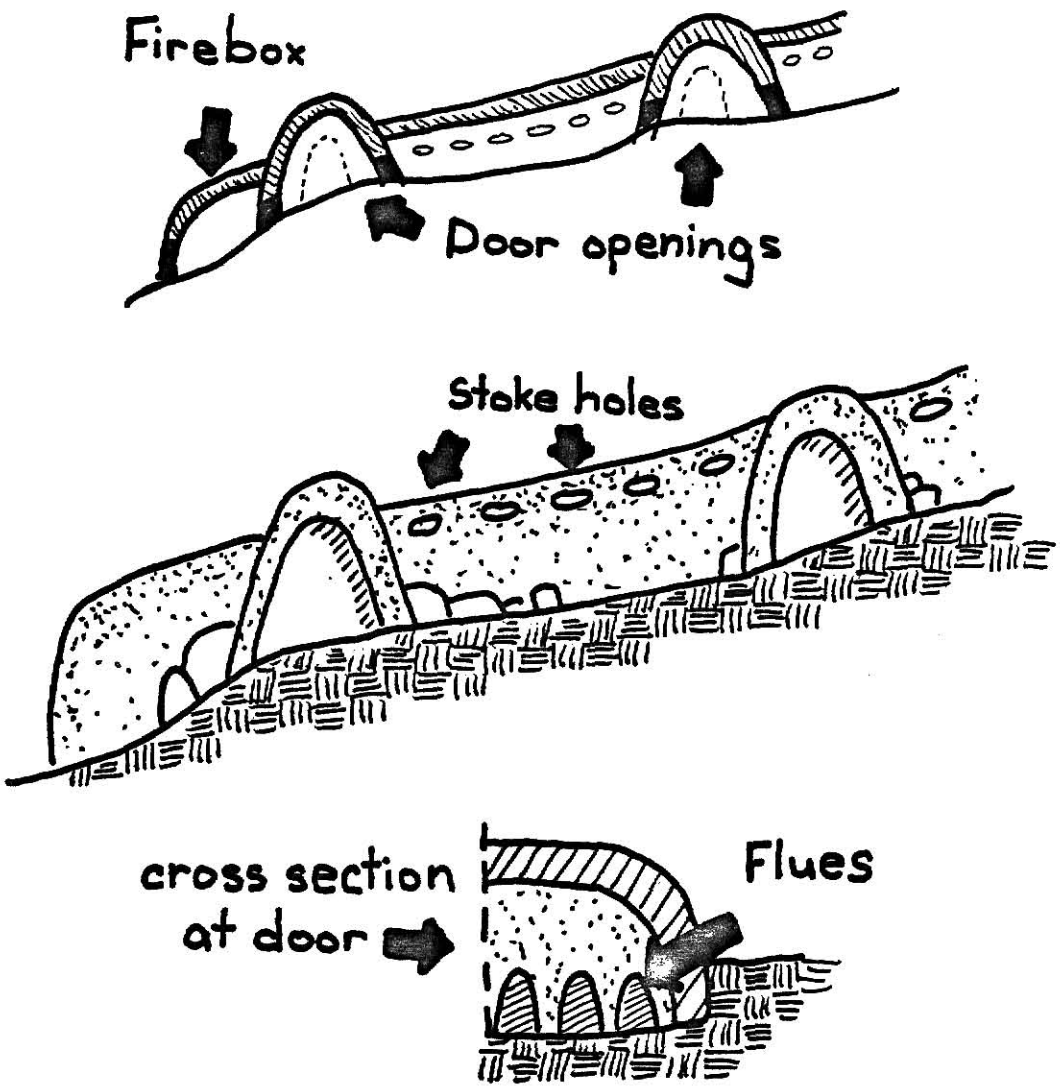

Figure 8

Semi-continuous Downdraft Tamba Kiln[26]

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[26]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 30.

Saggars were placed near the firebox in each chamber making a bag wall that directed the flame to cold spots in the kiln. They were set close together and piled up to within 18 inches of the crown or top of the kiln. Behind the saggars were placed the other pots to be fired.[27]

Another innovation from the design of the tunnel to the segmented climbing kiln was the use of stoking holes in each chamber. Once the kiln was brought up to red heat in the first chamber, two men located on either side of the kiln started stoking wood into stoke holes on each side of the kiln. The wood used was usually long poles put crosswise in the kiln between stacks of pots. When the temperature was reached in one section, the stoking began in the following chamber.[28]

There were various names given to the chamber kilns. In Korea the kilns that resemble a bamboo cane split from end to end containing fifteen or more chambers is called "split bamboo" or wari take gama,[29] Figure 9. Another view of the "split bamboo" kiln by Daniel Rhodes reputes the sentence above:

> The Korean kiln, Figure 28, is also built on a slope, but is not divided into separate chambers. It may be a surviving type which had been in use earlier in China, or it may be a local Korean development. The kiln is essentially a long tube, partially buried in the earth and set on a slope of about 25°. It has been called the 'split bamboo' kiln because of its half buried form.[30]

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[27]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), pp. 34-35.

[28]Ibid.

[29]G. St. G. M. Gompertz, Korean Pottery and Porcelain of the Yi Period (New York, New York: Frederick A. Praeger, Inc., 1968), p. 75.

[30]Rhodes, op. cit., p. 27.

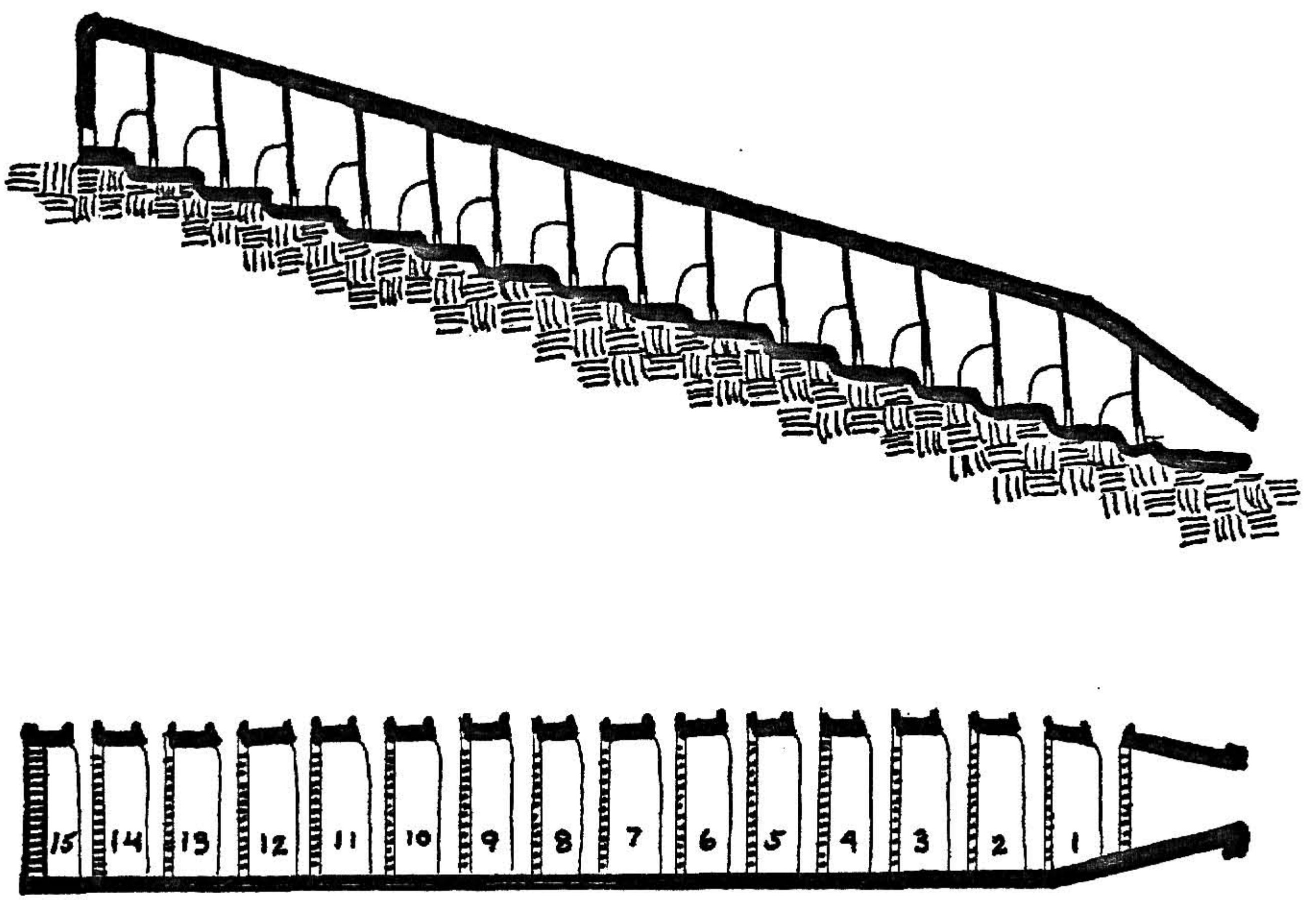

Figure 9

Plan and Elevation of Modern Korean Pottery Kiln: A Split-bamboo Type Upright Kiln with Fifteen Chambers Located at Hoeryang in Northeast Korea (Kiln Is Similar to Those Excavated at Keryong-san, So That They Are in the Traditional Form)[31]

[31] Gompertz, op. cit., p. 77.

In a personal interview in January 1977 with Professor Angelo C. Garzio, Kansas State University, he stated that during his studies in Korea in 1973 he talked with various people at length about the "split bamboo" kiln; and all of them gave reference to the kiln not being split into chambers.[32]

The "split bamboo" was first introduced in Japan at Karatsu,[33] see Figure 7, page 15, for map of Japan. Other names have also been applied to "split bamboo", such as maru gama, meaning kiln built connecting with another kiln. Two other names should also be included: nobori gama, meaning when built on a hill, and kani ko gama, meaning crab kilns because of the resemblance to baby crabs on a skewer.[34]

The final development of the climbing kiln in Japan was to arch each compartment on the upward slope,[35] as illustrated in Figure 10. Several chambers were linked together on the slope of the hill. At the base of each connecting chamber were flue inlets which allowed the heat to be transmitted from chamber to chamber. This makes use of the crossdraft circulation.[36]

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[32]Statement made by Angelo C. Garzio, personal interview, January, 1977.

[33]Hazel H. Gorham, Japanese and Oriental Ceramics (Rutland, Vermont: Charles E. Tuttle Company, Inc., 1971), p. 42.

[34]Ibid.

[35]Bernard Leach, A Potter's Book (New York: Transatlantic Arts Inc., 1951), p. 186.

[36]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 31.

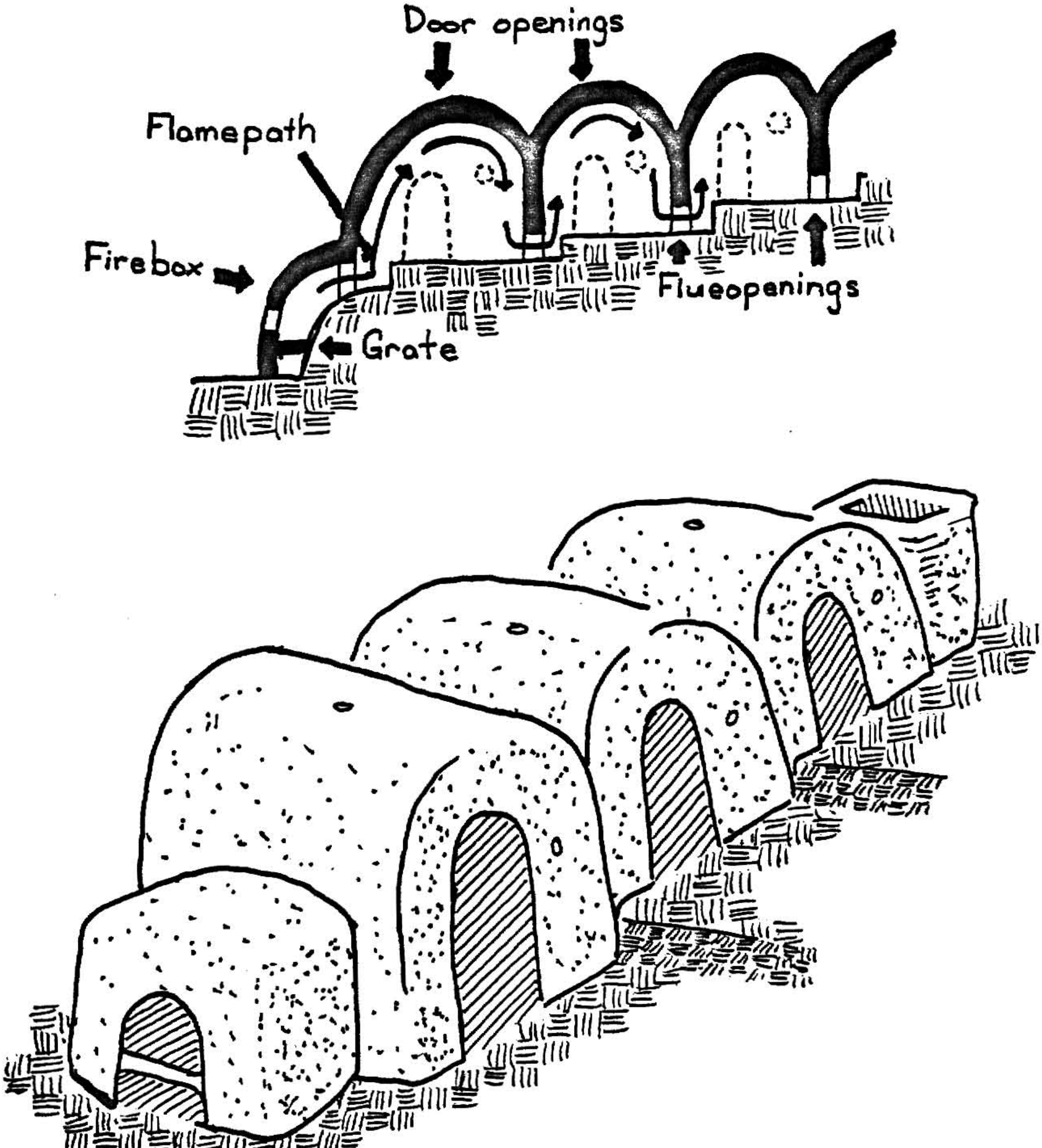

Figure 10

An Oriental Chambered, Climbing Kiln[34]

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[37]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 21.

The rough stoneware and kitchen ware made in Korea was fired in the "tunnel kiln", Figure 6, which had a single chamber, open all of the way through from top to bottom.[38] The kiln used in Korea to fire the better quality stoneware and porcelain was the kiln known as the "split bamboo",[39] Figure 11.

Along with the historical aspect,the size, design and firing of the chambered climbing kilns should also be examined. The first one to be dealt with is the chambered kiln of Tewah in the Province of Fukien in Southern China. The drawing in Figure 12 was made in 1935 and was based on information collected by Willard J. Sutton. The kiln consisted of six very large chambers.[40] Individual chambers measured 20 feet deep, 10 feet wide and 15 feet high. Each chamber floor was divided into five steps on which the saggars were set. The domes were somewhat pointed, and the bricks were laid in a herringbone pattern. The base of the kiln was reinforced with rock on the outside and was approximately two feet thick. Each chamber had two doors and were five feet high. All the bricks were made in the general area in which the kiln was built. This particular kiln was used to fire porcelain to approximately cone 14 (1366°C or 2491°F) with a neutral or reducing atmosphere. The individual chambers took approximately twenty-four hours to reach the desired temperature. The total time of firing took one week.[41]

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[38]G. St. G. M. Gompertz, Korean Pottery and Porcelain of the Yi Period (New York, New York: Frederick A. Praeger, Inc., 1968), p. 75.

[39]Ibid.

[40]It should be noted that Daniel Rhodes describes the kiln in Figure 12 as a six chambered kiln; however, the drawing merely depicts five chambers. The firebox is usually not considered a chamber.

[41]Rhodes, op. cit., p. 25.

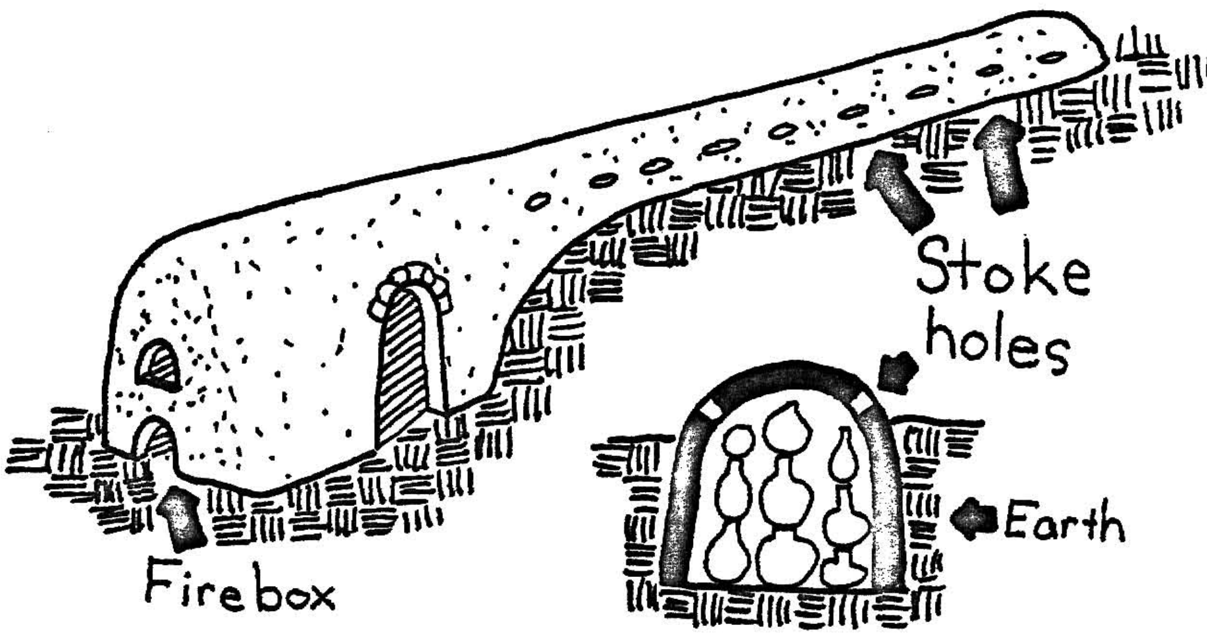

Figure 11

A "Split Bamboo" Kiln[42]

[42]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 26.

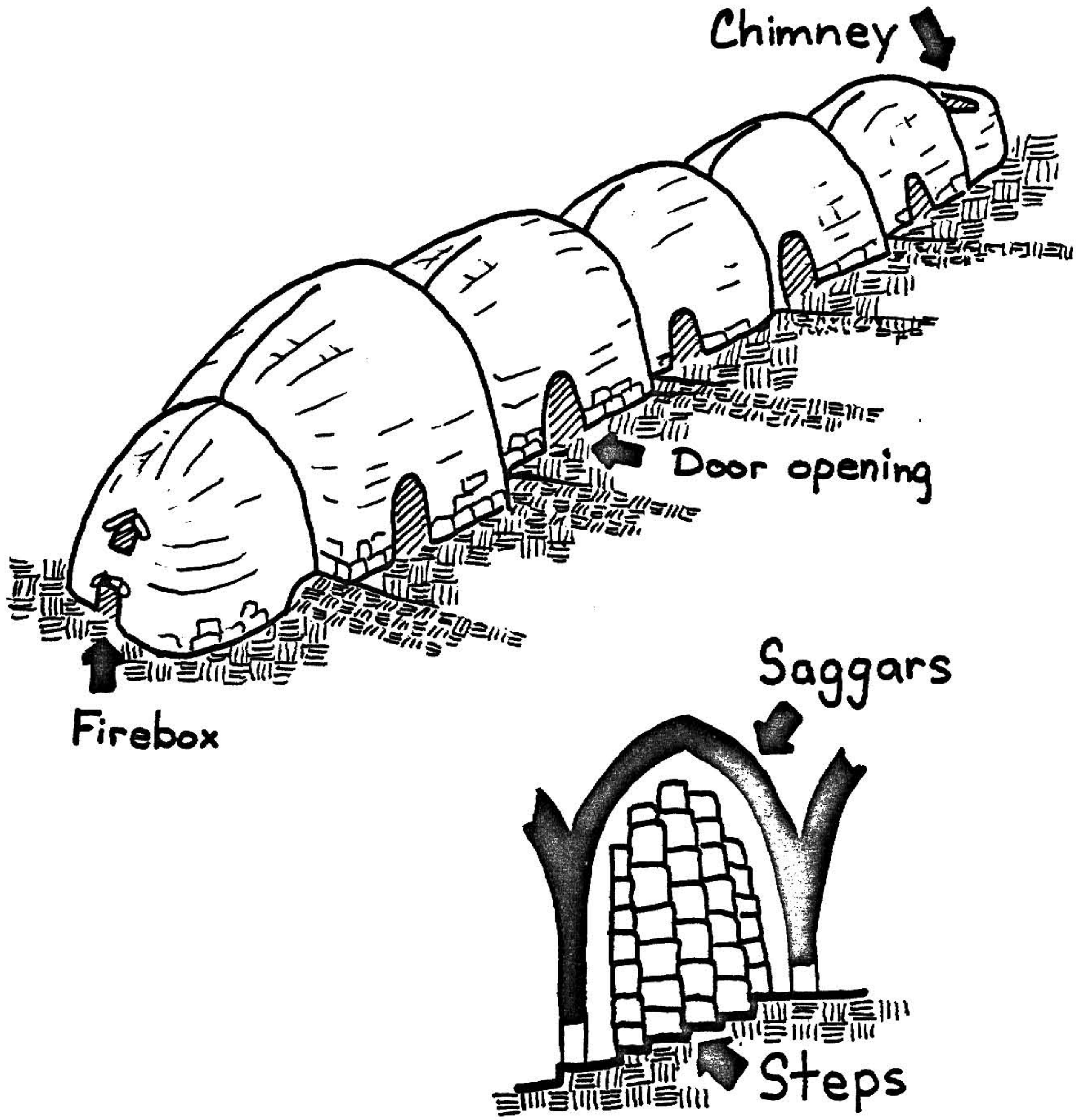

Figure 12

Large Chambered Kiln for Porcelain at Tewah, Fukien Province, China
Drawing Based on Data Supplied by Dr. W. J. Sutton[43]

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[43]Rhodes, op. cit., p. 27.

The largest chamber recorded in Japan was the Tobe Village kiln, see Figure 7, page 15, for location, which was destroyed in July 1963. The total chamber capacity was 15,000 cubic feet. The largest of the seven chambers was 25 feet long, 10 feet tall and 10 feet wide. The firing of this kiln took 40 tons of wood at an approximate cost of $800.00 a firing.[44]

The firing technique as well as the design of the chambered, climbing kiln is important in understanding why this type of kiln was better than the tunnel kiln in achieving higher temperatures. Each chamber was loaded with ware to be fired, and the doors were bricked up. When all doors were closed, a fire was built in the main firebox at the lower end of the kiln, Figure 10, page 21. The firebox was a domed structure with gratings to hold the fuel and passages to allow air to enter. At the early stages of firing the kiln a slow stoking was maintained to allow for a slow heat rise.[45] As the firebox got hotter, so did the first chamber. The heat produced in the main firebox heated not only the first chamber but the following chambers, making use of heat that would ordinarily be wasted in a single chambered kiln. The draft created by the heat flowing from chamber to chamber is known as downdraft,[46] Figure 10, page 21. Between each chamber at the foot of the walls

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[44]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 39.

[45]Daniel Rhodes, Kilns: Design, Construction and Operation (Radnor, Pennsylvania: Chilton Book Company, 1968), p. 21.

[46]Ibid.

there were several air openings allowing the heat to flow from one chamber to the next.[47] As the first chamber reached the correct temperature, fuel started to be fed into the second chamber.[48]

There was no grating or special firebox in the ascending chambers so the ware in the kiln was stacked in between the stoking holes in the arch of each chamber, Figure 10, page 21. When the preceding chamber reached the temperature desired, it was closed off by plugging any air holes in the chamber. The next chamber was then stoked with wood in the stoking holes. Each chamber was fired in the same way as stated until the whole kiln was fired.[49] The atmosphere during the firings was normally a neutral or reducing type, depending on how much wood was stoked.[50]

There are several advantages to chambered climbing kilns such as heat being transferred from one chamber to the next, unlike conventional one-chambered kilns which use the heat once, and then it is wasted. The climbing kilns of the Orient were also self-supporting, because the caternary arches butress each chamber, otherwise having no external bracing. Finally, the slope of the climbing kiln induces the heat to rise through the kiln. At the top end of the kiln, holes were made in the end allowing for the smoke to escape and at the same instance acting as a chimney;[51] however, some kilns had an external chimney but it was of no great height.

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[47]G. St. G. M. Gompertz, Korean Pottery and Porcelain of the Yi Period (New York, New York: Frederick A. Praeger, Inc., 1968), p. 74.

[48]Rhodes, loc. cit. [49]Ibid. [50]Gompertz, loc. cit.

[51]Rhodes, op. cit., p. 24.

Chapter 3

WOOD KILN CONSTRUCTION AND OPERATION

When building and designing a wood kiln there are several factors that must be taken into consideration.

The area in which the kiln will be built should be considered--whether or not to build the kiln in a rural, suburban, or urban area. Before building the kiln in an urban or suburban area, the potter should check with the city zoner and fire marshal to see what restrictions might be placed on the kiln and its operation. The individual rights of neighbors should also be respected because they will be affected by any smoke emitted by the kiln. If the kiln is to be built in a rural setting, the kiln would probably not be subject to such stringent regulations as one built in a city or residential area.

The design of the wood kiln is almost limitless. Severals books on the market give specific design specifications. Books that can be referred to are: (1) The Kiln Book, Frederick Olson; Kilns: Design, Construction and Operation, Daniel Rhodes; and (3) Pioneer Pottery, Michael Cardew. Besides the hardback books, numerous periodicals are also available. Some of these periodicals are Ceramics Monthly, September 1976, and Studio Potter, issues Volume 3, Numbers 1 and 2, and Volume 4, Numbers 1 and 2. These above listings about wood kilns are some of what was available at the time of this writing.

The shape and dimensions of the chamber are most important when building a kiln. This area will be dealt with later in this chapter.

Before a wood kiln design is selected, the availability and accessibility of wood as a fuel should be considered. This topic will be discussed at further lengths in Chapter 4.

The inside chamber dimensions should be based on what kiln shelves are available to the potter. Certain manufacturers of kiln shelves only make shelves in specified lengths, widths, and thicknesses. If the potter should want shelves cut to a different size, this would cost him extra, thus raising the cost of the kiln.

When the kiln is being designed and built, one should allow for minor adjustments that might have to be made in flue openings and any air sources into the kiln. It is better to have openings too large than too small. After the kiln has been fired once, and it is determined that there is too much draft, the flue openings could be made smaller by bricking them up according to the needs of the kiln.

Once the general design or shape of kiln has been chosen and a suitable location has been found, specific aspects of the apparatus must be examined. The three parts of kiln design to be examined are the firebox, the chamber, and the stack. All solid fuel kilns with a natural draft have a firebox but not necessarily a grate area. The grate area size is different when using solid fuels other than wood. The grate area for a wood kiln should be ten times greater than the horizontal section of the chimney. The grate is usually better if it is too big than too small. If the grate is too small, when the kiln is stoked the temperature will not rise because of a lack of combustion area.[1]

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[1]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), pp. 25-27.

The inlet flues into the first chamber should equal the exit flues. If the exit flues are too small, this will slow down the flow of air and retard the combustion efficiency which in turn retards the temperature rise. The combined size of the inlet flues should be slightly larger in volume than the horizontal chimney section.[2]

This paper will cover the two main types of fireboxes used in wood kilns, right side up and up side down. From these two main designs other variations are possible. The upside down will be covered first followed by a description of the right side up.[3]

The up side down firebox is usually called the "Bourry" firebox, Figure 13. The "Bourry" firebox is most efficient once the heat is built up and the draft starts, and the logs used are of the same length. The logs are placed in the upper opening of the firebox or "hob" and rest on brick projections from the inside wall of the hob.[4]

As the air is being drawn in between the logs, combustion occurs. The flame then follows the direction of the arrow as shown in Figure 13 into the first chamber. As the logs burn, embers start dropping into the ash pit. Heat is also used from the burning embers by the air entering through the ash pit door, moving the heated air into the first chamber. This type of firebox produces long flames, and the wood is consumed quickly unless the upper opening is closed with a damper.[5]

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[2]Emile Bourry, <u>A Treatise on Ceramic Industries</u> (London, England: Scott, Greenwood & Son, 1911), p. 195.

[3]Ibid. [4]Ibid. [5]Ibid.

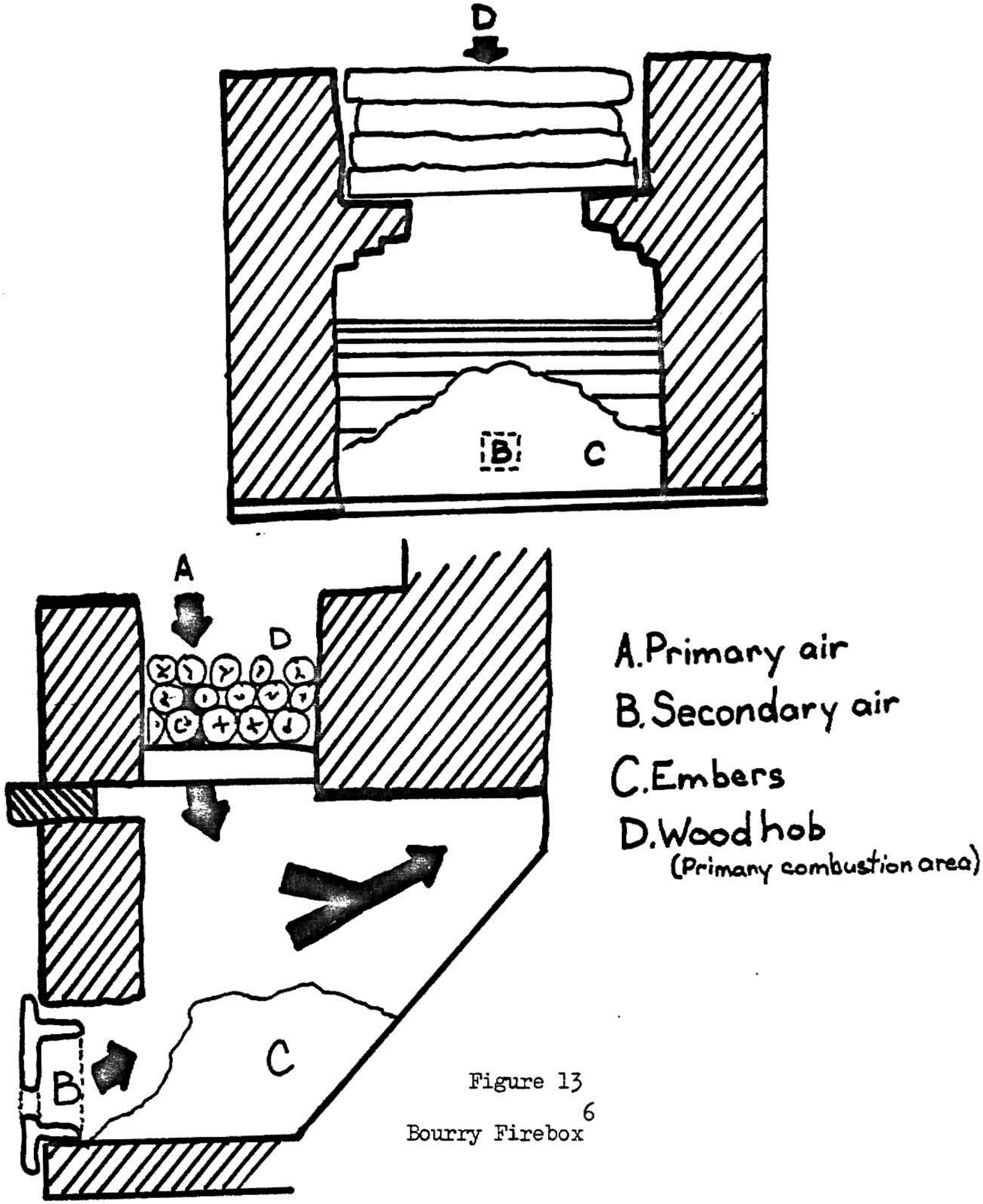

Figure 13

Bourry Firebox[6]

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[6] Emile Bourry, A Treatise on Ceramic Industries (London, England: Scott, Greenwood & Sons, 1911), p. 195.

A variation of the upside down firebox was designed by Michael Cardew, Figure 14. The grate area used is the same as the "Bourry" firebox where the logs of the same length can be placed at right angles to the direction of the draft with their ends resting on the brick projections or hobs. Again, the air enters at or near the top opening of the firebox; and the flames are drawn through the wood and enter the chamber. The embers fall into the ash pit, and from time to time the wood is stoked. Before stoking the firebox, the unburnt ends of the logs are pushed and allowed to drop burning into the ash pit. These burning ends quickly ignite the new wood stoked above. The hob is then covered.[7]

Air for primary combustion is admitted by two holes, about three by four inches, which are made approximately six inches down from the upper edge of the hob. The amount of air that is admitted is controlled by either a sliding clay or metal shutter, or a tapered brick, A. in Figure 14.[8]

Air for secondary air is needed to burn gases that are allowed to escape at the level of the hob just below the point of primary combustion, B in Figure 14. The secondary air hole is a three-inch square adjuster, D in Figure 14, with a grooved fireclay slab, Figure 15.[9]

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[7]Michael Cardew, Pioneer Pottery (New York, New York: St. Martin's Press, 1969), p. 178.

[8]Ibid. [9]Ibid., p. 179.

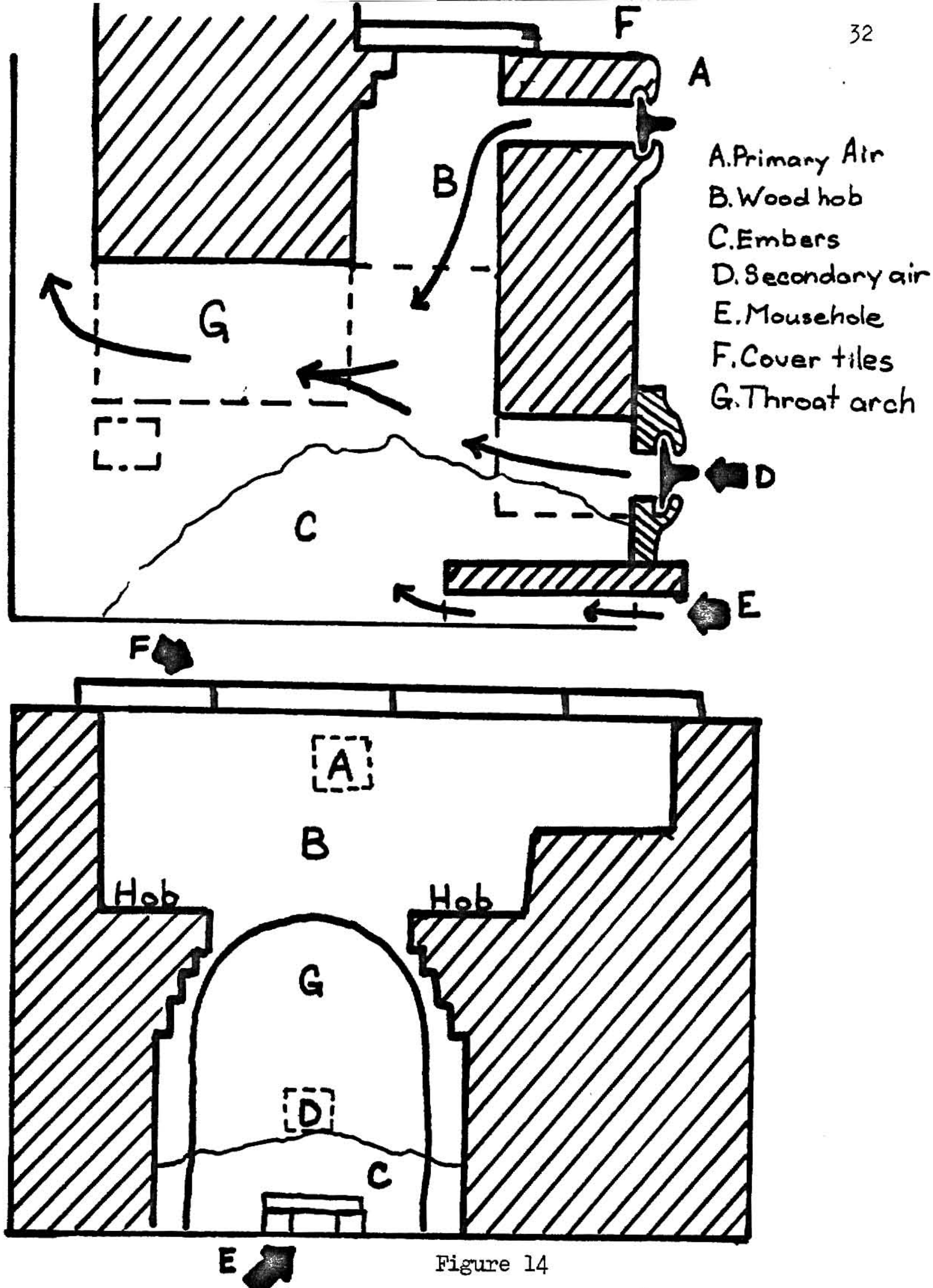

Figure 14

Cardew Downdraft Firebox[10]

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[10]Michael Cardew, Pioneer Pottery (New York, New York: St. Martin's Press, 1969), p. 167.

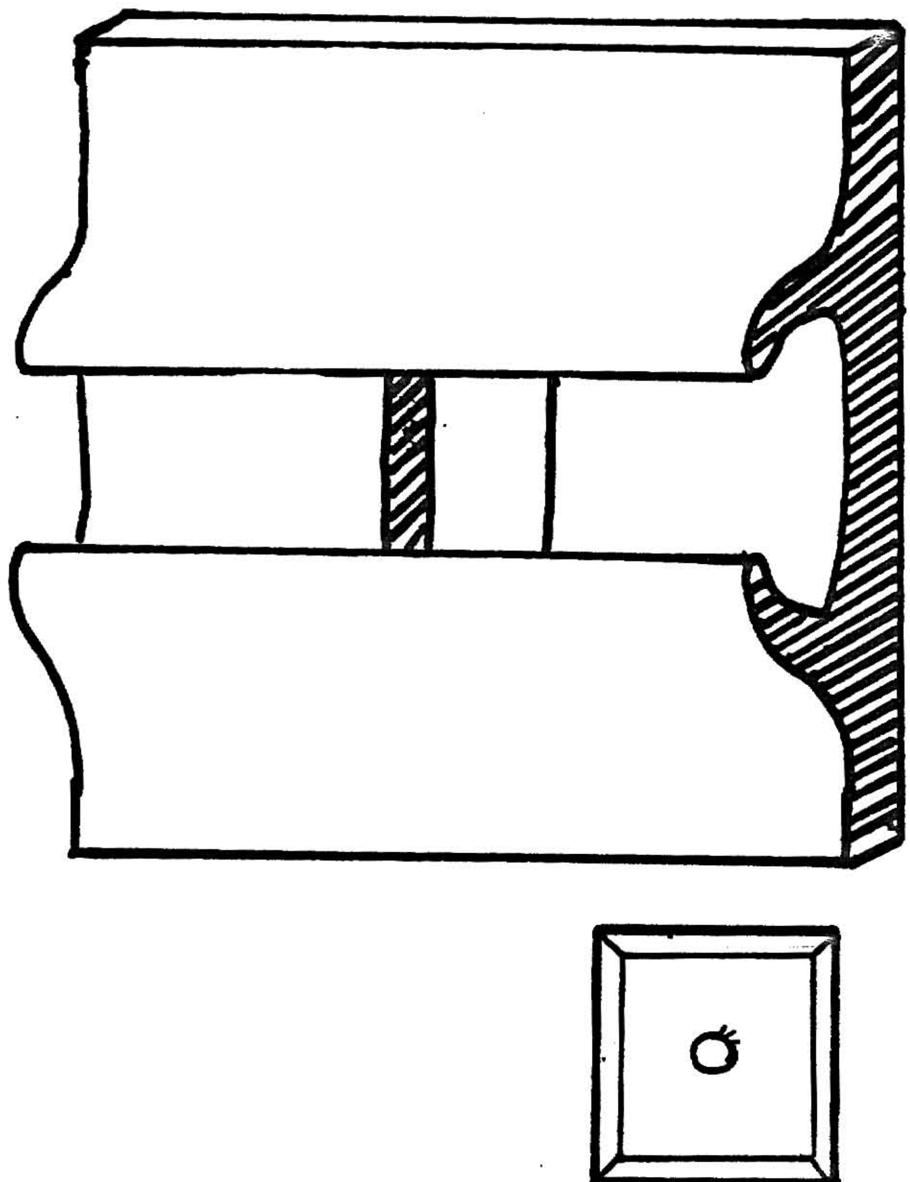

Figure 15

Clay Shutter for Secondary Air Control[11]

[11]Michael Cardew, Pioneer Pottery (New York, New York: St. Martin's Press, 1969), p. 192.

The pile of embers that accumulate in the ash pit ignite the new wood in the hob and also heats the secondary air. Efficient combustion in the ash pit depends on an adequate air supply. The embers are allowed to reach the level of the secondary air but are not allowed to cover it. If the secondary air port were covered, the proper combustion would not occur because of lack of oxygen. The height of the embers is controlled by a small opening at ground level which is called the "mousehole". The mousehole is a firebrick tunnel two by three inches, E in Figure 14, page 32. Periodically this tunnel should be poked and cleared as to prevent the end in the ash pit from clogging and cutting off the source of air to the embers.[12]

The design of the right side up firebox is different from the up side down firebox with the main difference being the path that the flame and air travel. The right side up does not necessarily need a grate area, but one is preferred. The grate holds the wood up off the floor of the firebox just as the hob did in the up side down. As the wood burns, new wood is placed on the grating periodically; and the embers fall into the ash pit. An air source should be made to allow the burning of the embers. If the embers are allowed to build up and clog the flow of air, the temperature will stop climbing and possibly drop rapidly. If the firebox works properly, the ash deposit will not be considerable. The firebox used for the compilation of this writing was a right side up. Figure 16 is a diagram of the firebox that was used. As the kiln was fired, it was found that by shutting the primary air, D in Figure 16, completely and using only the

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[12] Michael Cardew, Pioneer Pottery (New York, New York: St. Martin's Press, 1969), p. 178.

secondary air the kiln would still fire properly; and the bed of embers were kept to a minimum. It was also discovered that the ash pit would have to be cleared several times during the course of the firing.

Some wood kiln designs do not include a grate area in the firebox, Figure 17, and yet other designs do, Figures 18 and 19. The firebox in Figure 19 was built and designed by William Alexander in 1962 at Uster, Switzerland. This design made use of frontal stoking with a small grate area. The size of the stoke holes and ash pit were designed so that, if necessary, the size could be easily adjusted. The grates would be covered with wood across the entire surface.[13]

The firebox in Figure 20 is that of a modern firebox found on the Kitade Tojilo Kiln in the Kutani area of Japan. This style of firebox is efficient in wood consumed because unlike the frontal stoking fireboxes of older Oriental kilns which have to be packed full of wood to control the air, this style has adjustable air openings. The stoking holes are located on the sides of the firebox instead of at the front of the firebox. The only major air source is what comes up through the ash pit, and these air inlets can be adjusted to let more air in.[14]

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[13]William C. Alexander, "The Uster Kiln" (unpublished notes compiled in Uster, Switzerland, 1962), p. 5.

[14]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), pp. 83-84.

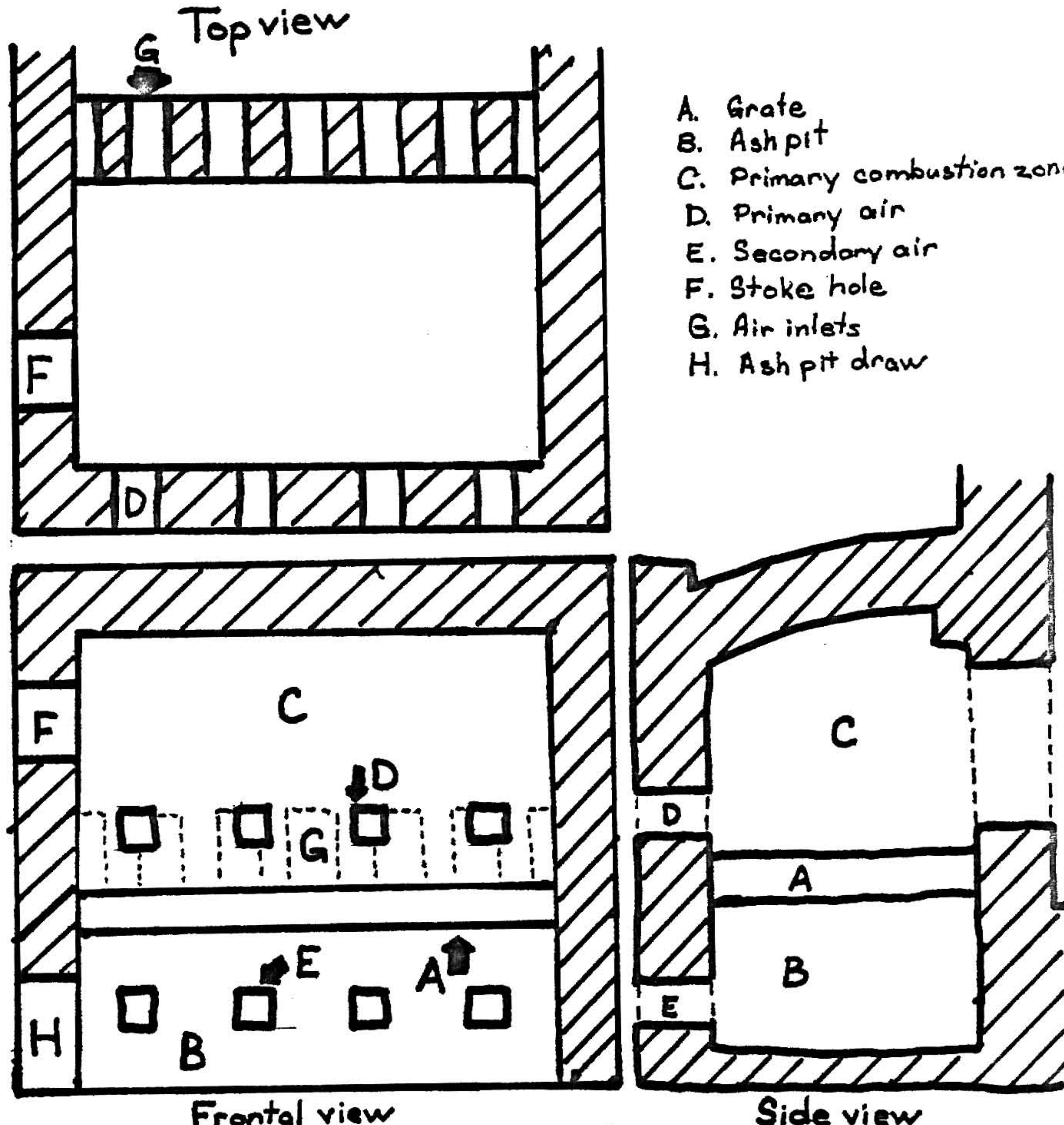

Figure 16

Firebox Used for Thesis Information

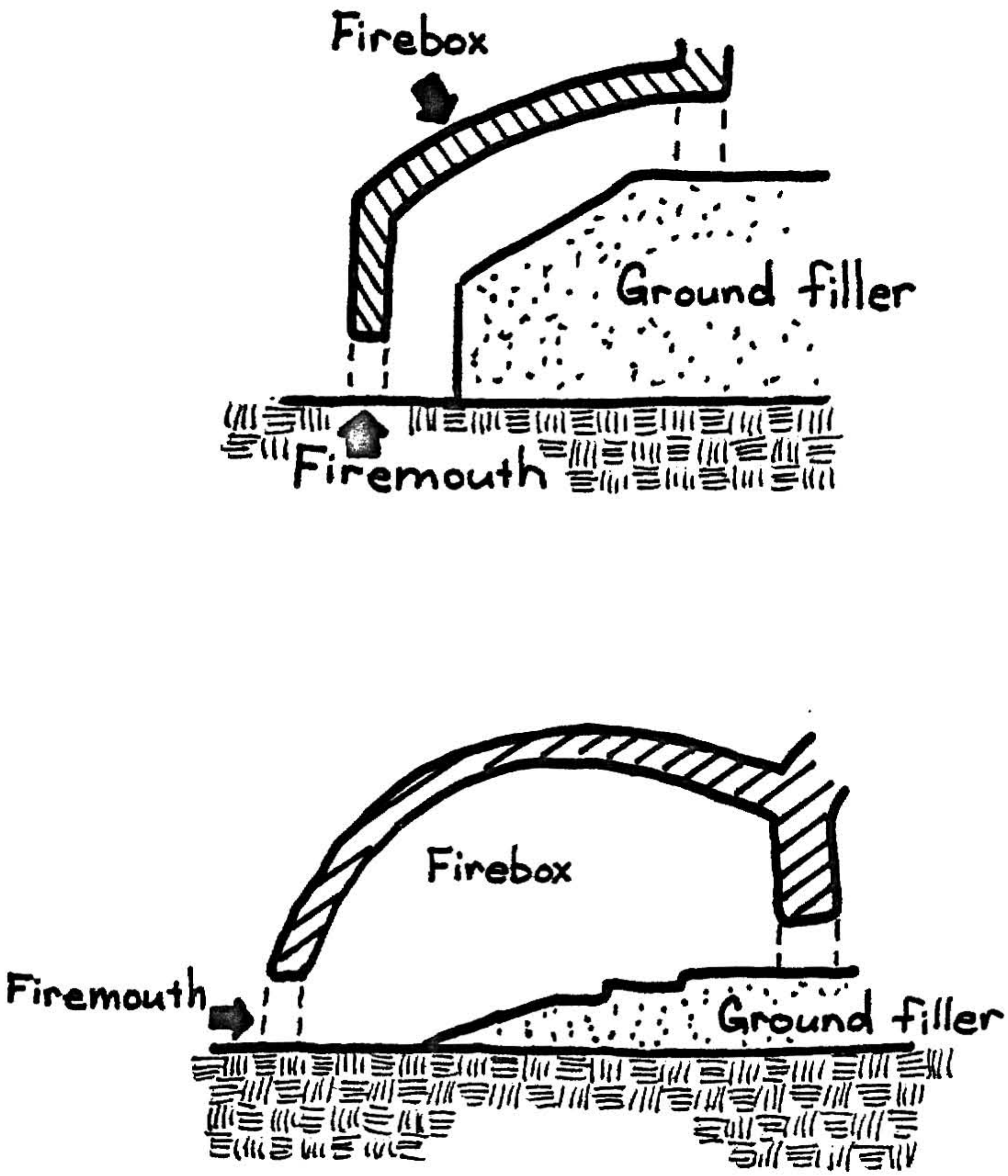

Figure 17

Two Fireboxes Without Grates[15]

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[15]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 47.

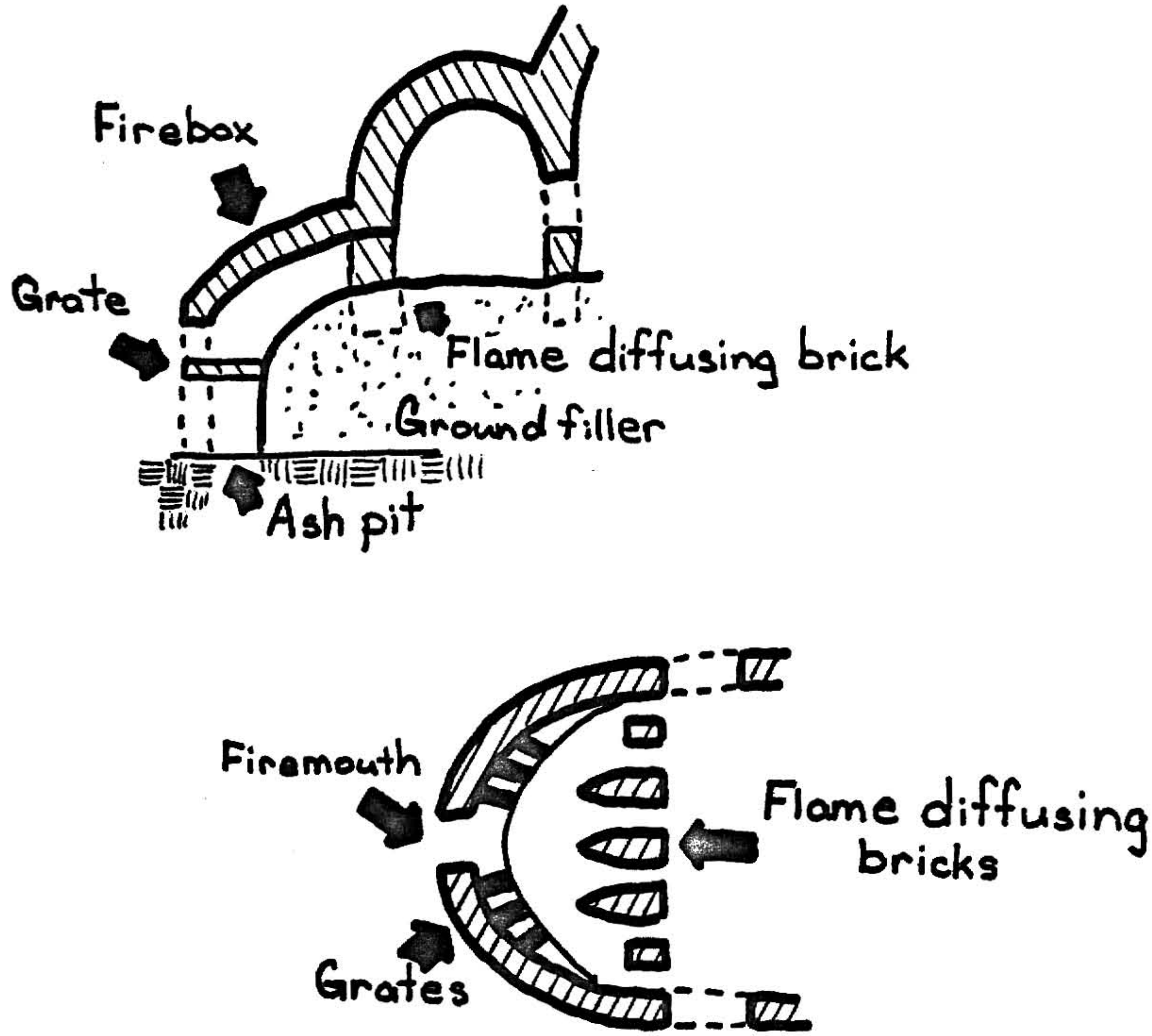
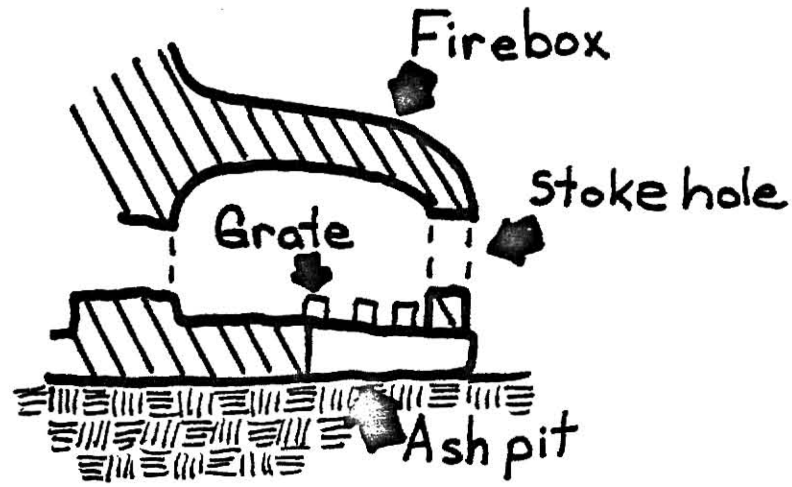


Figure 18

Firebox of the Kyoto Bidai Climbing Kiln[16]

[16]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 41.



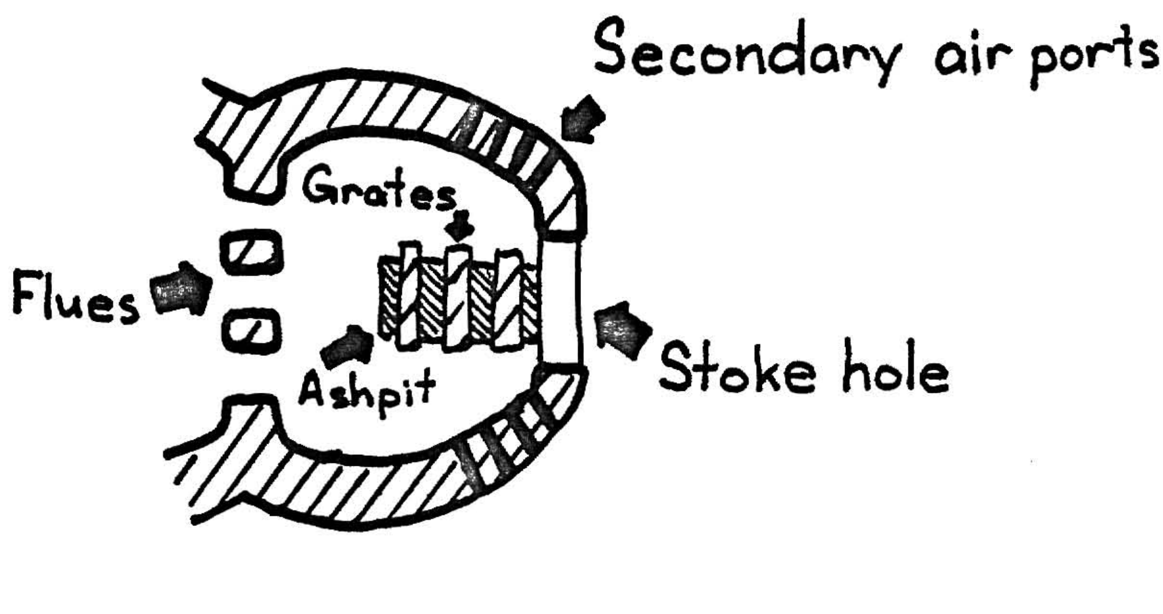


Figure 19

Wood-fired Climbing Chambered Kiln
Uster, Switzerland[17]

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[17]William C. Alexander, "The Uster Kiln" (unpublished notes compiled in Uster, Switzerland, 1962), p. 10.

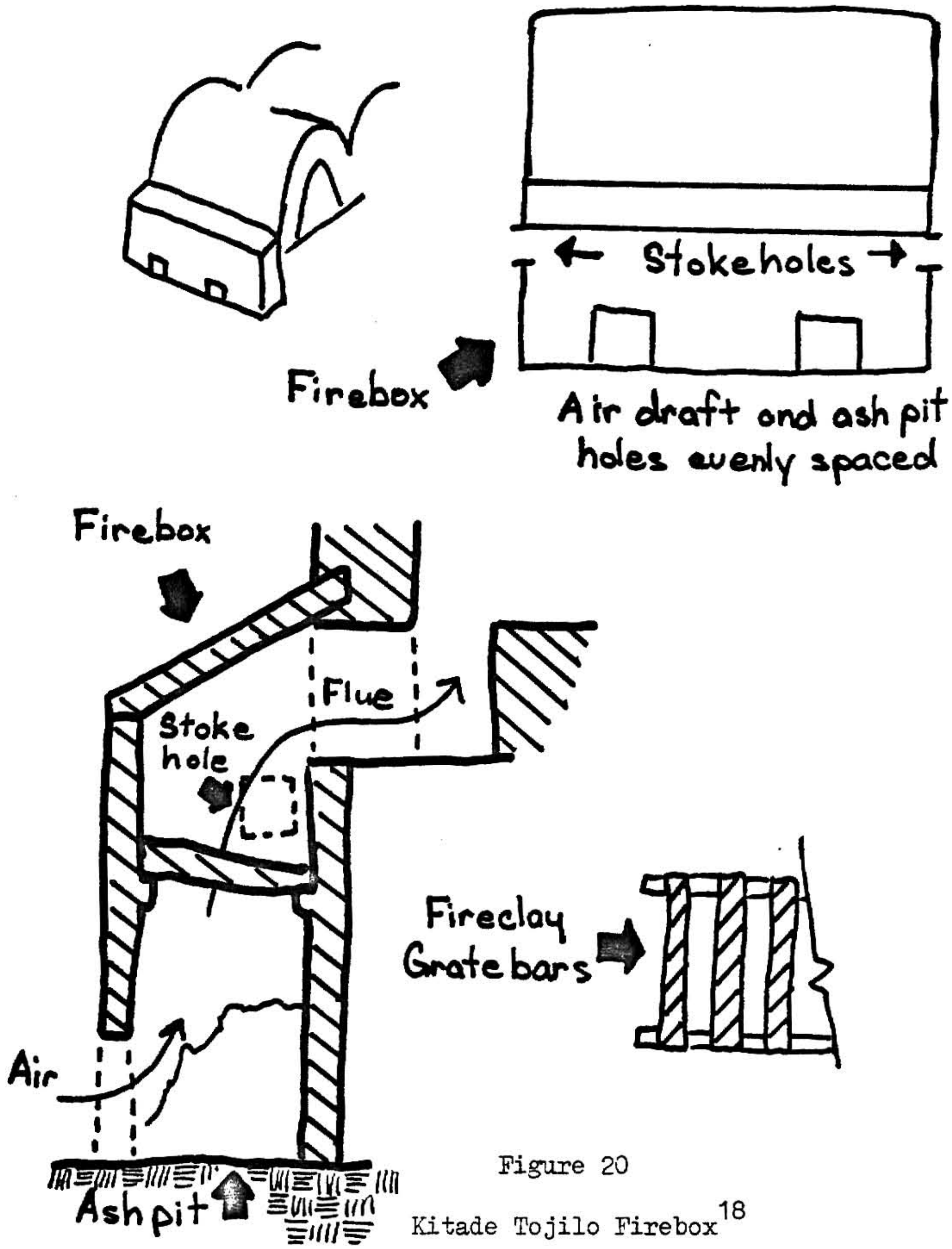

Figure 20

Kitade Tojilo Firebox[18]

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[18]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 85.

Another firebox that should be considered is the firebox located directly in each chamber following the first chamber, see Figure 21. This firebox is used to fire each consecutive chamber in a multiple chambered climbing kiln. Once the first chamber has reached its desired temperature, the first chamber firebox is closed off; and stoking is started in the second chamber firebox. The heat from the first chamber also heats each consecutive chamber. The second chamber of the kiln used for the experimentation phase of this study usually would reach a temperature of approximately 1814°F or 990°C by the time the first chamber had reached 2300°F or 1260°C. This firebox is usually smaller than the main firebox at the base of the kiln. The reason for this is that it takes a shorter time to reach temperature in each consecutive chamber and fewer pieces of wood are used for quicker heat release. The chambers as they are being fired still are drawing heat from the previous chambers. The chamber firebox should be located at the front of the chamber. The grate area should be above the inlet flues into the chamber allowing the air to come up through the wood. The ash pit should be large enough to allow for any embers that should fall, and the area can be the depth of the inlet flues. This should allow ample space for ash deposit. The bag wall is not totally necessary in this firebox. Saggars stacked in the area of the bag wall will take the place of a brick bag wall. A stoking hole is situated above the grate area in the side wall of the kiln.

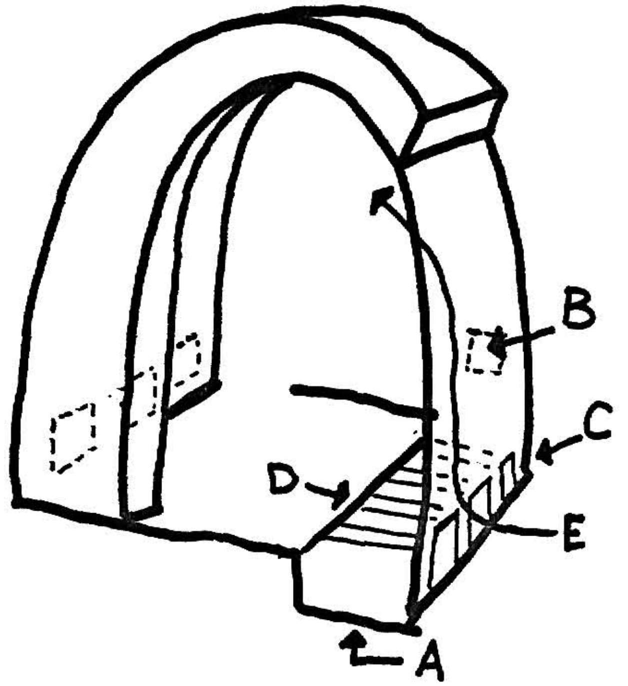

Figure 21

Chamber Firebox From Les Blakebrough's Chimney Kiln, Australia[19]

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[19]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 86.

This should be high enough so the wood can be dropped on the grate area for ease of stoking. During the firing of the following chambers, the ash pit might have to be cleared so the ember buildup does not choke the kiln and retard the temperature rise.[20]

It was noticed that the stoking of the chamber firebox was critical for temperature rise. The wood should first be tossed completely across the grating to the opposite side of the kiln. The wood is then allowed to drop across the grate to where the wood is being stoked, Figure 22. As the heat intensifies, the stoking speeds up; and the wood pile in the chamber grows higher and burns more quickly. The color of the firebox changes from bright orange to an almost bright white as the firing reaches its peak temperature. It is of the utmost importance that the grating in the chamber firebox be covered completely with wood for even temperature rise.

The next part of the design of the kiln to be dealt with is its chamber. There are two main types of chamber shapes, with variations, used in kilns—the cube shape and a catenary arch. When talking in terms of a cube design, Olson states the best design for an updraft kiln is one with the arch on top of the cube, A. in Figure 23, and not contained within, B. in Figure 23.[21] A chamber that is basically cube shaped tends to be better for oxidation firing to middle firing; whereas a chamber that is taller than wide facilitates a curving pattern to the flame and induces reduction.[22]

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[20] Frederick Olson, <u>The Kiln Book</u> (Bassett, California: Keramos Books, 1973), p. 85.

[21] Ibid, p. 21.

[22] Based on personal correspondence between Frederick Olson, Pinyon Crest Pottery, Santa Rosa Mountains, California, April 25, 1976.

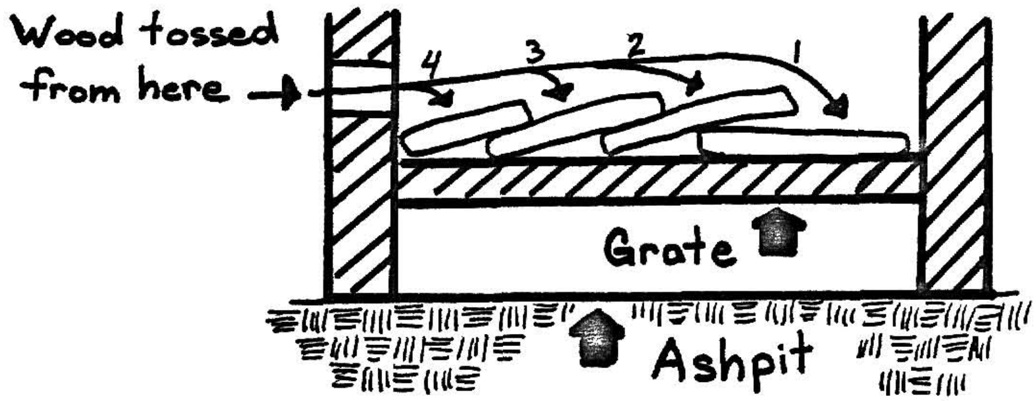

Figure 22

Stoking of Chamber Firebox

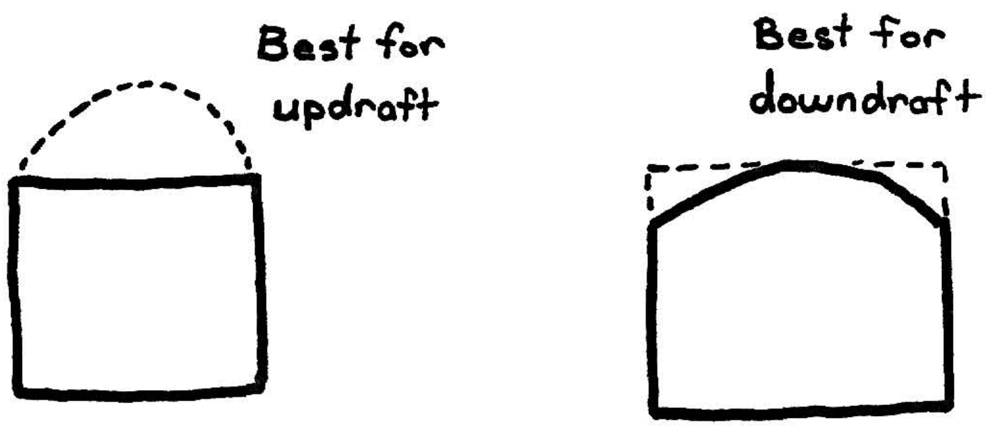

Figure 23

Desired Shape of Chamber for Either Updraft or Downdraft[23]

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[23]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 26.

There are two important rules one should follow when determining what shape of chamber is desired. First, the flame and heat path should follow the arch of the chamber, Figure 24, and should not be at right angles to the arch. Secondly, the flame and heat path should have only one right angle to negotiate within the chamber. This right angle usually is at the firebox inlet flue and bag wall. If there are too many right angles, problems of irregular heating or hot spots could lead to refractory failures and bad firings.[24]

The catenary arch chamber is similar in design to the cube chamber. To build a chamber for reduction, use a double radii arch with the acute radius off center towards the back. This chamber is usually taller and narrower than the conventional arch. This position of the offset key in the arch causes a slight backup in the draft flow by rolling the flame over,[25] Figure 25.

The middle fire and oxidation chambers are closer to a single radius arch. This type of arch does not cause the backup of smoke and so facilitates oxidizing conditions,[26] Figure 26.

Figure 27 gives three examples of chambers with the correct path of the heat and flame.[27]

When trying to determine the size of inlet and outlet flues along with the cross section size of the chimney, make them all equal. If in doubt about inlet and outlet sizes, make them larger because they can be plugged up if needed.[28]

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[24]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 27.

[25]Ibid., p. 40. [26]Ibid. [27]Ibid., p. 27.

[28]Ibid., p. 28.

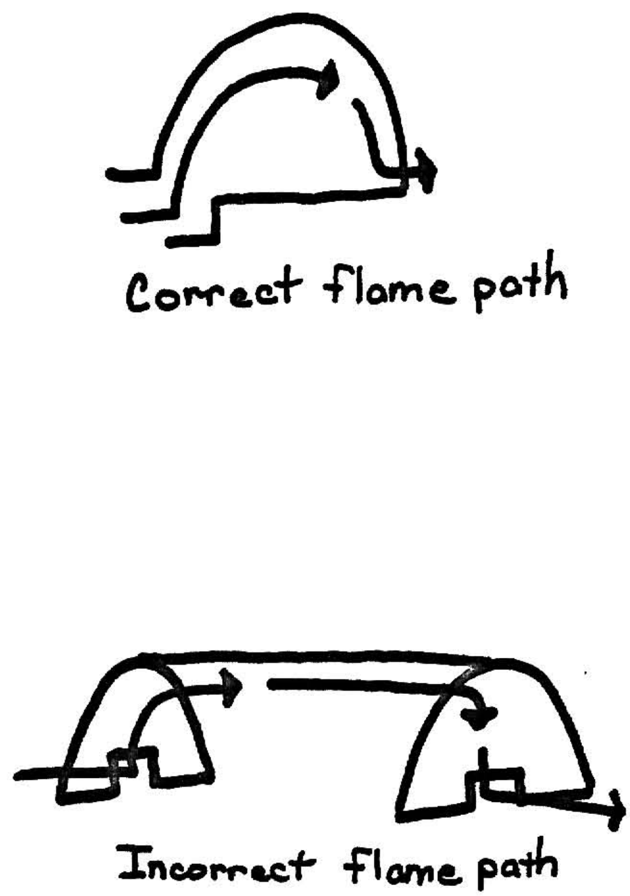

Figure 24

Path of Flame[29]

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[29]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 27.

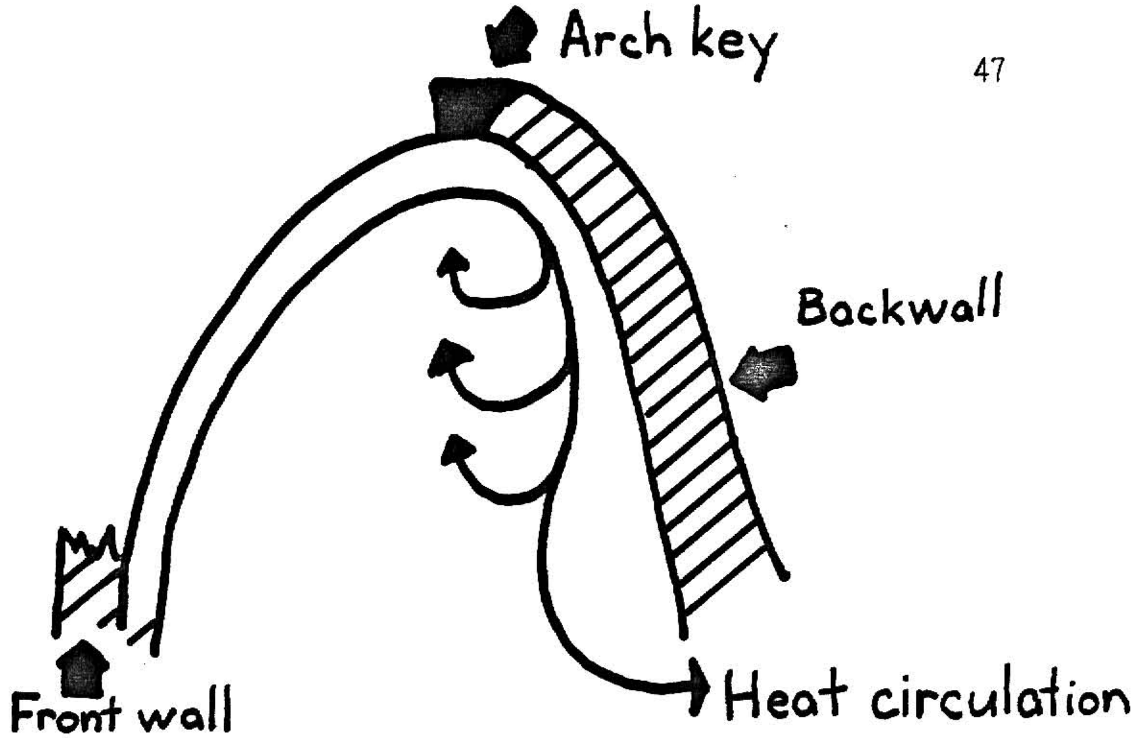

Figure 25

Offset Arch for Reduction Firing

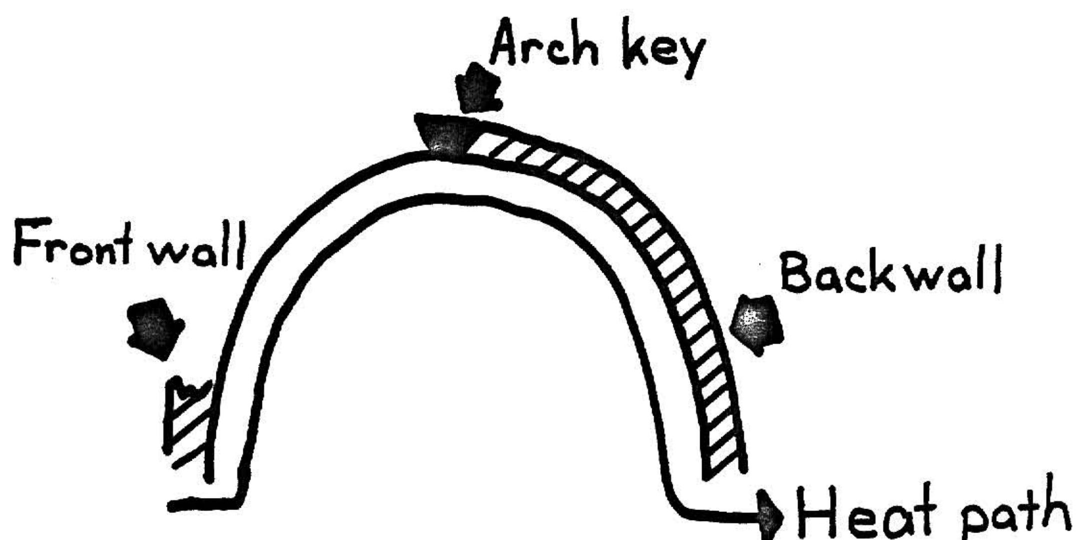

Figure 26

Arch for Oxidizing Firing

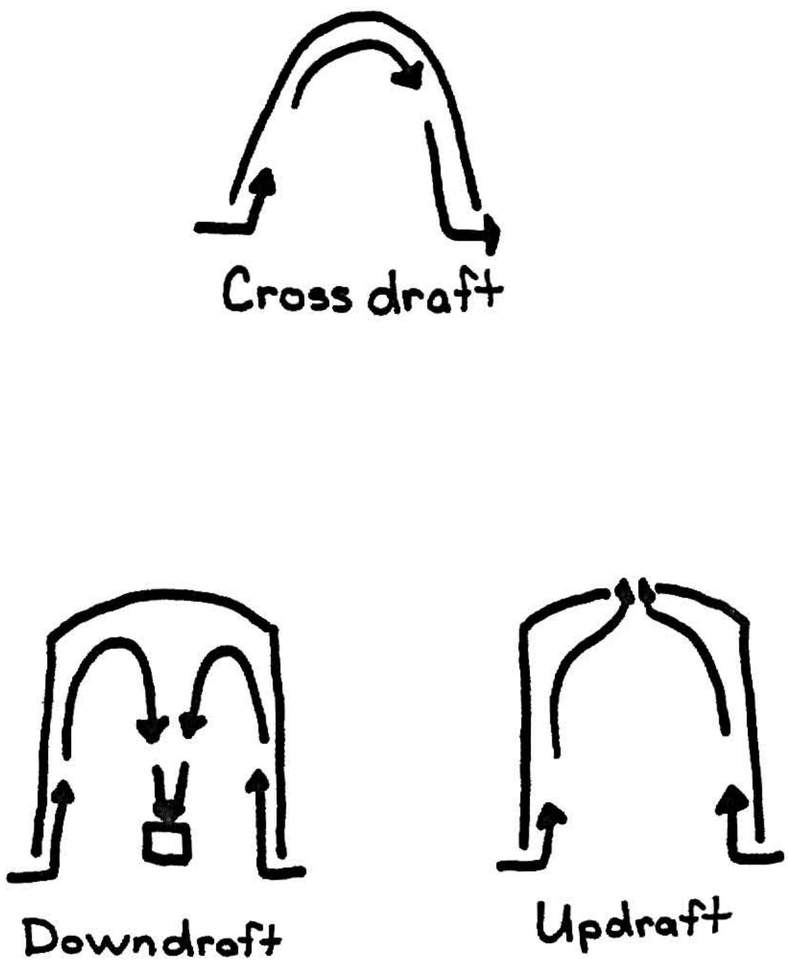

Figure 27

Proper Heat and Flame Path[30]

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[30] Frederick Olson, <u>The Kiln Book</u> (Bassett, California: Keramos Books, 1973), p. 28.

Make all areas of the kiln so they can be easily changed or repaired. Also, the design of the kiln should be based on the size of brick to be used. The standard size of bricks are 9 inches by $4\frac{1}{2}$ inches by $2\frac{1}{2}$ inches; the large standard is 9 inches by $4\frac{1}{2}$ inches by 3 inches.[31]

Fred Olson states that 80% of the time the normal flue dimensions will be one brick in size standing on end 9 inches by $4\frac{1}{2}$ inches and spaced 9 inches apart.[32]

The final part of the kiln design to be examined is the chimney. When designing a multiple chambered, climbing kiln the height of the chimney should be equal to the slope of the kiln itself,[33] Figure 28.

To determine the chimney height, place a line along the chamber tops, provided each chamber is the same size, and have the chimney line up on the same line as the chambers. A long chimney increases draft, but one too excessive in height will cause irregular heating by pulling the heat too fast out the chimney. If too short a chimney is used, this in turn can slow down the firing by decreasing the draft, therefore decreasing the amount of oxygen pulled into the kiln and not allowing proper combustion.[34] Without proper combustion there is a waste of fuel in the form of excessive smoking or soot.

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[31]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), pp. 29-30.

[32]Ibid., p. 30. [33]Ibid., p. 29. [34]Ibid.

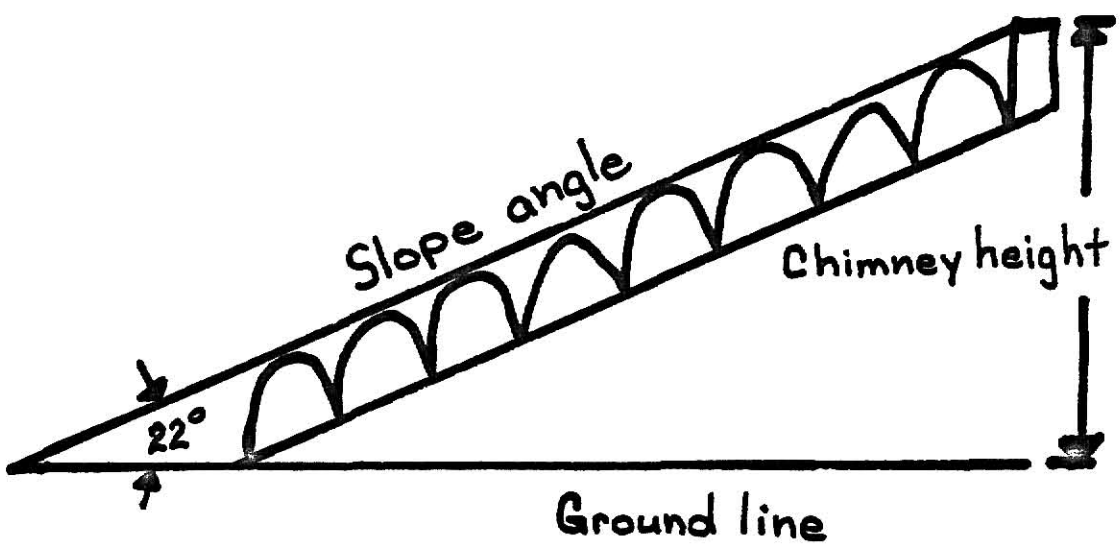

Figure 28

Height of Chimney Equals Slope of Kiln[35]

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[35]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), 29.

There should also be three feet of vertical chimney to every one foot of downward pull (chamber height), plus one foot of vertical chimney to every three feet of horizontal pull. If the height of the chamber is five feet, there is five feet of downward pull; and for every foot of downward pull, there will be three feet of chimney height. The height of the chimney will be as follows: five feet of chamber height x three feet of downward pull = fifteen feet of chimney plus the width of the chamber, four feet, and the width of the collection box, one foot, and the chimney, one foot, (4 + 1 + 1 = 6 + 3 feet of horizontal pull = 2 feet). The downward pull and the horizontal pull (15 feet + 2 feet = 17 feet) are then added, arriving at 17 feet for the total length of the chimney,[36] Figure 29.

A properly built kiln should have a draft rate of four to five feet per second, from x to y in Figure 30. To determine the draft, measure the inside circumference of the chamber up the front wall, over the arch, down the back wall, out the flues, and up the chimney,[37] Figure 30.

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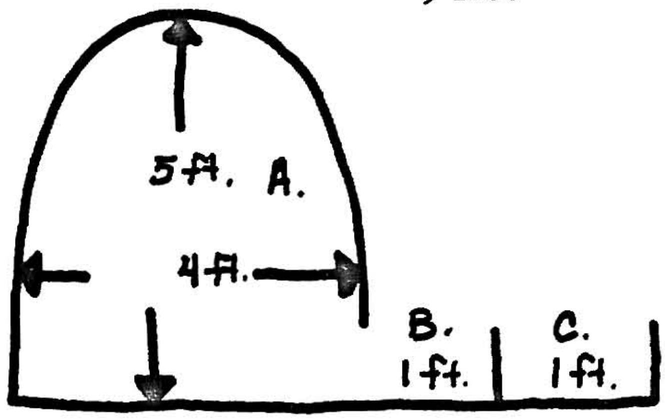
[36]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 29.

[37]Ibid., p. 28.

$$3\text{ feet} \times \text{downward pull} + \frac{\text{horizontal pull}}{3\text{ feet}} = \text{total chimney height}$$



A. Chamber
B. Collection box
C. Chimney

Figure 29

Method of Determining Chimney Height[38]

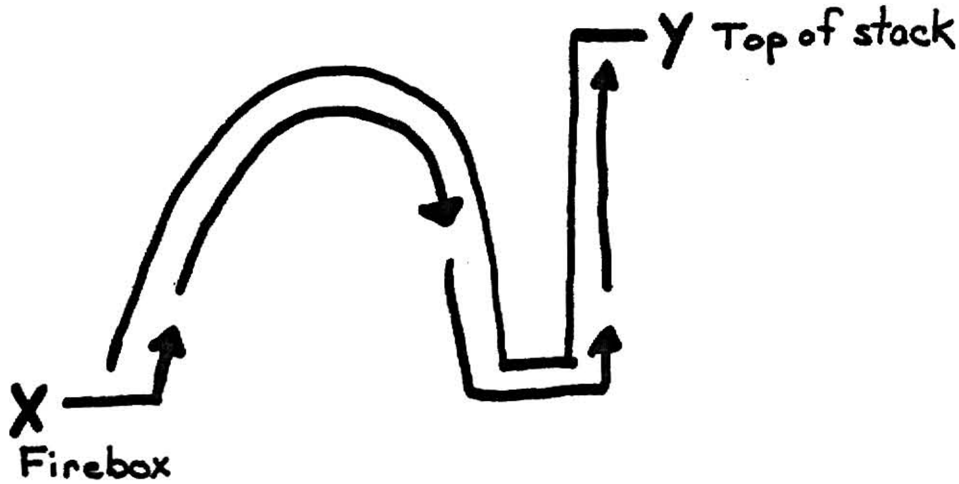


Figure 30

Method of Determining Draft Rate[39]

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[38]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 28.

[39]Ibid.

Once the measurements have been determined, while firing the kiln, take an oily rag and throw it into the firebox, point x in Figure 30, page 52. Count the number of seconds it takes for the smoke to exit out of the chimney. Divide the number of seconds it takes the smoke to reach the top of the chimney from the firebox (point y from x in Figure 30, page 52) into the total number of feet. This should give the speed of the draw in the kiln. To speed up the draft, the potter could taper the chimney. A normal taper for a kiln chimney that is between sixteen and twenty feet tall with a base cross section of twelve by twelve inches would be nine by nine inches. The tapering of the chimney reduces atmospheric pressure which in turn increases the draft. The base of a natural draft chimney should not be any less than nine by nine inches base cross section.[40]

The width of the chimney is determined by it being 1/4 to 1/5 the size of the chamber. If the chamber is 6 feet wide, then the diameter of the chimney will be at least 1½ feet.[41]

According to Michael Cardew,

> Draft in the chimneys is caused by the difference in weight between the column of expanded gas inside the hot chimney and an equal volume of cool air outside. This difference will increase (within limit) with the increase of the temperature in the chimney and with the quantity of hot gas in it. The greater the height (and to a small extent the area) of the chimney, the stronger the draft will be.[42]

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[40]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 28.

[41]Ibid., p. 29.

[42]Michael Cardew, Pioneer Pottery (New York, New York: St. Martin's Press, 1969), p. 163.

The draft in any chimney reaches its maximum when the expanding gases in the chimney have reached 150°C (302°F). At this point the volume of air given out becomes almost constant but the draft keeps increasing. If the draft needs decreasing, it is often necessary to use a damper; however, dampering at the wrong time will cause reduction or incomplete combustion of gases. If reduction is not wanted, a special opening at the base of the stack should be used. This opening diminishes the weight of gases given out or otherwise the cold air rushing into the chamber cools the chimney, reducing the draft.[43]

In conclusion, three rules should be kept in mind when designing and building kiln flues and chimneys: (1) Make all flues adjustable by either plugging or knocking out; (2) Make the chimney inlet adjustable; and (3) Be able to control the chimney height easily.[44]

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[43]Emile Bourry, A Treatiste on Ceramic Industries (London, England: Scott, Greenwood & Son, 1911), p. 209.

[44]Frederick Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 30.

Chapter 4

Through the ages man has been using wood as a fuel. Our earliest ancestors used fire for cooking and as protection from wild animals. As man evolved, so did his use of fire. Maybe through chance he discovered that fire with wood as its fuel could turn his soft clay pots into an object that was hard and less breakable.

Man has always had an abundance of wood, but the gradual utilization of the virgin forests has reduced the availability of wood. Steps have been taken to replant the barren land stripped of its trees so the supply of wood can be replenished. Wood is of importance not only for building and industrial purposes but to the potter as well.

The main emphasis of this chapter will be a discussion of various woods, their calorific value and B.t.u. values, results of combustion, and why some woods give off more heat than others.

Fuels are considered to be those substances that contain carbon, or carbon and hydrogen. When carbon and hydrogen are united with oxygen, heat is produced. This union is called combustion, and the products of this unionization are called carbon dioxide or carbon dioxide and water.[1] These gases given off are not considered to be air pollutants since they are harmless.[2]

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[1]Herman Poole, The Calorific Power of Fuels (New York: John Wiley & Sons, Inc., 1918), p. 1.

[2]W. G. Lawrence, Ceramic Science for the Potter (Philadelphia: Chilton Book Company, 1972), p. 128.

Air pollution is a factor when there is incomplete combustion of the fuel. Incomplete combustion occurs when there is not enough air to oxidize the fuel. Incomplete combustion in a kiln usually happens during the reduction stage of the firing cycle. The air pollutant is carbon monoxide (CO); and in extreme cases, soot particles are formed producing smoke.[3] Webster's New Collegiate Dictionary defines carbon monoxide as "a colorless very toxic gas CO that burns to carbon dioxide with a blue flame and is formed as a product of the incomplete combustion of carbon."[4]

Under most circumstances it is an easy matter to introduce enough oxygen into the kiln to turn the carbon monoxide (CO) into carbon dioxide (CO_2). This can be accomplished in two ways. The first would be to have enough secondary air ports in the chamber which could be adjusted to let the right amount of air in to burn the gases properly. Second, there should be an adjustable opening at the base of the stack, Figure 31. This opening should furnish enough oxygen to complete the combustion of any unburned carbon particles before they are able to exit the stack in the form of soot or carbon laden smoke.[5] However, for the burning of gases in the stack, the gas temperature must be in the range of 1000°F to 1500°F. These gases must also contain enough combustible material to develop a flame when the air is introduced.[6]

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[3]W. G. Lawrence, Ceramic Science for the Potter (Phildadelphia: Chilton Book Company, 1972), p. 128.

[4]Webster's New Collegiate Dictionary (Springfield, Massachusetts: G. & C. Merriam Company, 1973).

[5]Ibid., p. 130. [6]Ibid., p. 131.

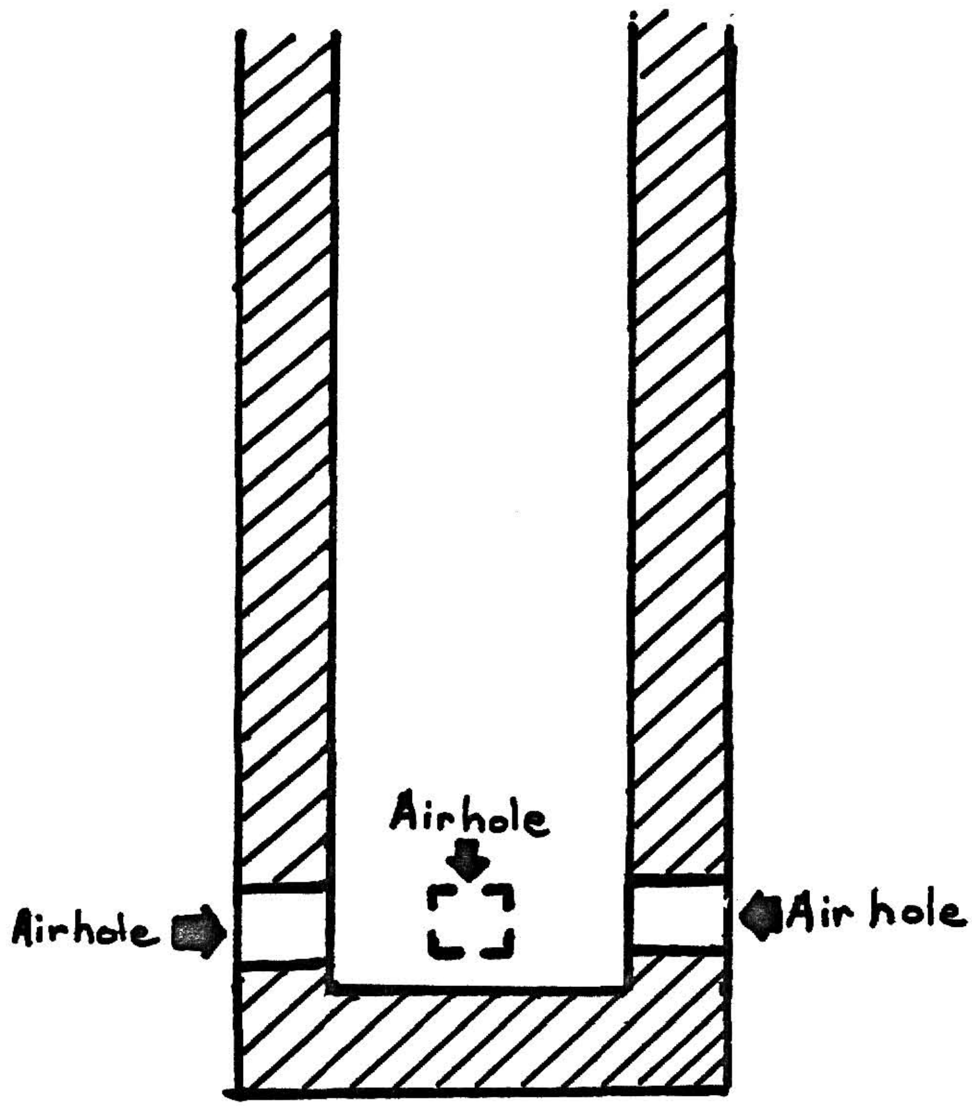

Figure 31

Secondary Air at Base of Stack

According to W. G. Lawrence, "If these two conditions cannot be satisified, simple secondary air injection cannot solve the problem."[7] The basis for most smoke problems is in the areas of operation, maintenance, and design.[8]

Certain principles for smoke-free combustion of all types of fuels are as follows: (1) Correct fuel to air ratio; (2) Sufficient mixing of air and fuel at the appropriate stage of the firing cycle; (3) Enough ignition temperatures for combustible gases; (4) Proper kiln space to allow for burning of gases; and (5) Correct design of firebox.[9]

If the potter is interested, commercial afterburners can be purchased. These afterburners are designed to burn the unburned gases in the stack.

An analysis of wood by Haslam and Russell is useful so the potter will know the composition of wood and exactly what is being emitted into the atmosphere, Table 1.

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[7]W. G. Lawrence, Ceramic Science for the Potter (Philadelphia: Chilton Book Company, 1972), p. 131.

[8]Walter H. Rupp, "Air Pollution Sources and Their Control", Air Pollution Handbook, ed. Charles Ackley (New York: McGraw-Hill Book Company, Inc., 1956), p. 11.

[9]Ibid., pp. 13-14.

Table 1

An Analysis of Woods[10]

Wood	lbs. per cu. ft.	lbs. per cord	Per cent Carbon	Hydrogen	Oxygen	Nitrogen	Ash	B.t.u. per lb.
Ash	46	3,520	49.18	6.27	43.91	0.07	0.57	5,420
Beech	43	3,250	49.36	6.01	42.69	0.91	1.06	5,400
Birch	45	2,880	50.20	6.20	41.62	1.15	0.81	5,580
Elm	35	2,350	48.99	6.20	44.25	0.06	0.50	5,400
Oak	52	3,850	49.64	5.92	41.16	1.29	1.97	5,460
Pine	30	2,000	50.31	6.20	43.08	0.04	0.37	6,200
Poplar	36	2,130	49.37	6.21	41.60	0.96	1.86	6,660
Willow	25	1,920	49.96	5.96	39.56	0.96	3.37	6,830

[10]Robert T. Haslam and Robert P. Russell, Fuels and Their Combustion (New York: McGraw-Hill Book Company, Inc., 1926), p. 133.

Oxides of nitrogen will be produced anytime combustion at high temperatures takes place when in the presence of atmospheric nitrogen and oxygen.[11] Several oxides of nitrogen may result— nitric oxide (NO) and nitrogen dioxide (NO_2). These two by-products are air pollutants. The amount of nitric oxide (NO) given off by a kiln is minimal and is affected by the maximum temperature attained, the rate of cooling of combustion gases, kiln design, and the fuel used.[12] However, data gathered and extrapolated by W. G. Lawrence indicate that hardly any nitrogen oxides are formed at or below approximately 1430°C or 2600°F.[13] The data indicate that even though small traces of nitrogen are present in wood large amounts of air pollutants will not be emitted at temperatures below approximately 2600°F or 1430°C.

Wood begins to decompose at about 275°C or approximately 527°F, and the decomposition is exothermic (formed with evolution of heat). When decomposition occurs, combustible and incombustible gases and vapors are formed. After this first breakdown of the fuel what is left is a combustible residue, charcoal, Figure 32. This decomposition of wood at 275°C, or approximately 527°F, is under ideal conditions.[14]

If the wood possibly had any water content, the actual final ignition temperature of wood would not be affected because the moisture would have been removed before the wood reached the ignition point.

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[11] W. G. Lawrence, <u>Ceramic Science for the Potter</u> (Philadelphia: Chilton Book Company, 1972), p. 134.

[12] Ibid., p. 135. [13] Ibid.

[14] L. F. Hawley and Louis E. Wise, <u>The Chemistry of Wood</u> (New York: The Chemical Catalog Company, Inc., 1926), p. 187.

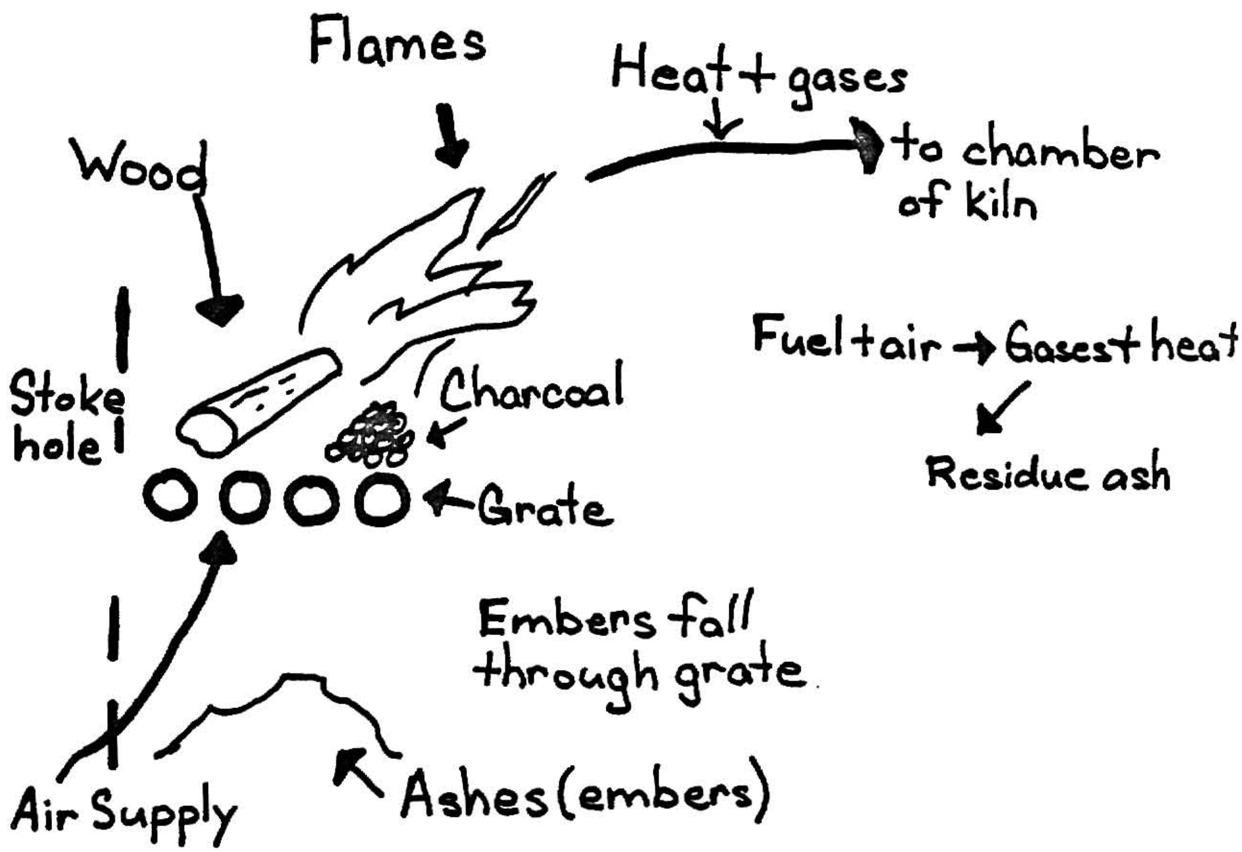

Figure 32

Combustion of Wood[15]

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[15]Frederick L. Olson, The Kiln Book (Bassett, California: Keramos Books, 1973), p. 80.

The presence of moisture will affect the speed at which the wood is heated to the ignition point.[16] A temperature of 100°C (212°F) is required for moisture evaporation.[17]

The combustion of wood is considered as taking place in two stages: the first is the combustion and vapors given off by the initial exothermic process and, secondly, the combustion of the solid residues of charcoal,[18] Figure 32, page 61. The charcoal left by the combustion of wood contains quantities of hydrocarbons which are organic compounds containing only carbon and hydrogen and are often found in petroleum, natural gas, coal and bitumens.[19] Further heating of the charcoal gives only gases with traces of tar and methanol,[20] which are volatile at temperatures above combustion of the solid residue of charcoal. Because the gases are volatile, they will aid in the heating of the kiln. Due to the complexity of the tars and methanol when broken down into their chemical structures, further explorations of them would be esoteric and not pertinent to this writing.

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[16] L. F. Hawley and Louis E. Wise, The Chemistry of Wood (New York: The Chemical Catalog Company, Inc., 1926), p. 188.

[17] Ibid., p. 191. [18] Ibid., p. 188.

[19] Herman Poole, The Calorific Power of Fuels (New York: John Wiley & Sons, Inc., 1918), p. 120.

[20] Hawley, op. cit., p. 197.

The heat of combustion is measured in calories or British thermal units (B.t.u.). The amount of heat that is generated by the combustion of a definite quantity of fuel in oxygen is called the calorific power, heat value, or heat of combustion.[21] The British thermal unit is the quantity of heat required to raise the temperature of one pound of pure water one degree Fahrenheit at or near 39.2° Fahrenheit, or 9° Centigrade.[22]

Table 2 gives the B.t.u. output of various fuels, the relationship of B.t.u. of other fuels to wood and how much fuel is needed to equal one cord of wood.

The presence of resins or oils in soft woods (conifers) tends to raise the heating value of wood. Pound for pound, resin gives twice as much heat as wood and produces more smoke.[23] Resin has a high fuel value of 17,400 B.t.u. per pound which is computed from 20% terpenes and 80% abietic acids.[24]

Due to the complex structure of those resins in various soft woods (conifers), a discussion of the break down of these terpenes and acids will not be included in this writing. The most important thing for the potter to know is that the resin content in soft woods (conifers) is what makes these the best fuel for wood kilns.

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[21] Herman Poole, The Calorific Power of Fuels (New York: John Wiley & Sons, Inc., 1918), p. 2.

[22] Webster's New Collegiate Dictionary (Springfield, Massachusetts: G. & C. Merriam Company, 1973).

[23] Allen J. Johnson and George H. Auth, Fuels and Combustion Handbook (New York: The McGraw-Hill Book Company, Inc., 1951), p. 111.

[24] L. F. Hawley and Louis E. Wise, The Chemistry of Wood (New York: The Chemical Catalog Company, Inc., 1926), p. 190.

Table 2

Direct Heat-Value Ratios of Various Fuels[25]

Fuel*	B.t.u.	Equivalency of fuels**
Wood	21,000,000/cord	1.0
Coal	26,000,000/ton	.81
Fuel Oil #1	137,300/gal	152.4
Fuel Oil #2	141,800/gal	148.1
Fuel Oil #6	148,000/gal	141.9
Natural Gas	1,000/cu. ft.	21,000.00
LPG	97,000/gal.	216.5
Electricity	3,413/kw. hr.	6,153.0

*Chart based on comparison of 1 cord of wood to other fuels. All comparisons made on a direct B.t.u. basis without corrections for possible difference in efficiency.

**Based on ratio of B.t.u.'s of other fuels compared to a cord of wood.. (Example: 152.4 gals. of fuel oil #1 is the direct fuel equivalent of a cord of wood.

[25]Allen J. Johnson and George H. Auth, Fuels and Combustion Handbook (New York: The McGraw-Hill Book Company, Inc., 1951), p. 494.

If the potter wants to read more about the resins in wood, one can refer to the following: The Chemistry of Wood by B. L. Browning and The Chemistry of Wood by Hawley and Wise. These are just two of the many available books on this subject.

The calorie is the quantity of heat required to raise the temperature of 1 kilogram of water 1 degree Centigrade.[26] Poole states that the calorie is the quantity of heat required to raise 1 kilogram of water from 15 to 16 degrees Centrigrade, or from 59°F to 61°F. One calorie equals 3,968 B.t.u. whereas 1 B.t.u. equals 0.252 calories.[27]

Besides the resin content in the conifers, it is not known what effect the differences in composition between conifers and hard woods have upon the calorific value.[28] Therefore, the heat value of coniferous woods is greater than hard woods because of the resins, but the calorific value does not vary extensively between the various species of wood. Dry wood usually has 8,500 to 9,000 B.t.u. per lb.[29] Table 3 shows Gottlieb's findings on the calorific power of various woods. Gottlieb obtained these figures by using a calorimeter of constant pressure. He used a 2 gram piece of various woods which were burned within a span of 2 or 3 minutes, resulting in the findings in Table 3. These findings show that soft woods do give off more heat than hard woods.

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[26] Webster's New Collegiate Dictionary (Springfield, Massachusetts: G. & C. Merriam Company, 1973).

[27] Herman Poole, The Calorific Power of Fuels (New York: John Wiley & Sons., Inc., 1918), p. 120.

[28] L. F. Hawley and Louis E. Wise, The Chemistry of Wood (New York: The Chemical Catalog Company, Inc., 1926), p. 188.

[29] B. L. Browning, The Chemistry of Wood (New York: Interscience Publishers, 1963), p. 85.

Table 3

B.t.u. & Calorific Value of Various Woods*[30]

Type of Wood	Calories	B.t.u.
Pine (Soft)	5,085	9,153
Fir (Soft)	5,035	9,063
Beech (Hard)	4,774	8,591
Birch (Hard)	4,771	8,586
Elm (Hard)	4,728	8,510
Ash (Hard)	4,711	8,480
Oak (Hard)	4,620	8,316

*Authority on the above Gottlieb.

[30]Herman Poole, The Calorific Power of Fuels (New York: John Wiley & Sons, Inc., 1918), p. 123.

The weight factor, as indicated in Table 4, between the hard woods and soft woods is another reason why soft woods (conifers) would be best to use as fuel for a kiln.

Table 4

Amount of Lbs Per Cord of Wood[31]

Wood	Lbs. per Cord
Hickory	4469
Oak chestnut	3955
Oak white	3821
Ash white	3450
Dogwood	3643
Oak, Black	3254
Oak, Red	3254
Beech	3236
Walnut	3044
Maple, hard	2878
Cedar, red	2525
Magnolia	2704
Maple, soft	2668
Pine, yellow	2463
Sycamore	2391
Butternut	2534
Pine, New Jersey	2137
Pine, Pitch	1904
Pine, white	1868
Poplar, Lombardy	1774
Chestnut	2333
Poplar, yellow	2516

[31]Herman Poole, The Calorific Power of Fuels (New York: John Wiley & Sons., Inc., 1918), p. 120.

Chapter 5

COLLECTING, CUTTING, AND STACKING WOOD

Before the potter is able to make use of wood as a fuel for firing a kiln, he faces the problem of where to obtain the wood, the splitting and finding a dry location in which to stack it.

These tasks are not difficult but can be time consuming and strenuous. The advantage wood has over other fuels is that it is a clean fuel to gather. The potter won't have the mess that accompanies gathering oil or coal for a kiln. The potter should first consider the space for storing the fuel before the wood is gathered. Being orderly is important to the potter when the wood is stored and split for usage.

It has been found there are many wood outlets, but five potential sources used in this study will be covered: (1) individuals, (2) lumber yards, (3) construction sites, (4) prefabricated builders, and (5) wooded areas.

The equipment needed for gathering of the wood depends on the wood source. First on the priority list would have to be a vehicle of some type in which to haul the wood. A truck would be the ideal vehicle, but a car would suffice if a trailer could also be used.

INDIVIDUAL CONTRIBUTION

The smallest amount of wood gathered would be from individuals. In the course of a year's time most people do not make enough wooden objects from which to have scrap wood available to the potter. In order to gather enough wood to fire a wood kiln, the potter would have to spend too much time going from house to house gathering this wood. This outlet could be used for the source of wood but should be used as a last resort when all other outlets have failed to produce wood.

LUMBERYARD

A lumberyard may be one of the best sources in an urban community. The individual should contact the manager of the lumberyard to see if and when the scrap wood could be picked up. There are certain days of the week when enough considerable scrap wood would make the trip profitable. Usually the lumberyard will save the scrap wood if they know someone can use it. Otherwise, it will be discarded.

CONSTRUCTION SITES

This outlet also is an excellent source. The individual might call the construction firms in the area to see if there are any building sites where waste wood may be available. The potter could also stop at various construction sites and talk with the foreman about collecting the scrap wood. One drawback to this type of wood is that it usually has nails in it, or it has been sitting in the weather and is damp. If this were true, the wood should be allowed to dry before using.

PREFABRICATED BUILDERS

The majority of wood used for this study was gathered from this source. The source was a company which was making prefabricated trusses for buildings. The wood was either pine or fir and of varying sizes: 2"x4"x24", 2"x4"x8', 2"x12"x24". Having the wood in these sizes made it easier to split. All the wood was waste wood with knot holes, warped, split, or just ends that could not be used. Usually the wood was placed in 55 gallon containers which could be picked up and emptied, then the containers were returned. This saved handling the individual pieces and thus saved time. The owner was more than happy to let us have the wood; otherwise, he would have had to pay someone to haul it off.

WOODY AREAS

This outlet was not used at all for this study. Enough scrap wood was found within the city limits. If the potter did not have access to any of the aforementioned outlets, this could possibly be the best. The drawback is the time consumed in chopping down a tree and then cutting it up into sections to be split and allowed to dry. A chain saw is a great convenience to fell a tree, and this would be an added expense. Unless the potter is the owner of wooded land, he would have to find such land and seek permission from its owner to cut down any trees. Once the tree is cut, the wood would then have to air dry for at least six months before it could be used. The area in which the wood is stored would have to be covered, protecting the wood from moisture. It could be pointed out to the landowner that thinning the trees would be beneficial to the growth of the other trees, thus providing the potter with a source of wood and aiding the landowner.[1]

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[1]Allen J. Johnson and George H. Auth, Fuel and Combustion Handbook (New York: The McGraw-Hill Book Company, Inc., 1951), p. 110.

SPLITTING THE WOOD

This portion of the wood operation seemed to consume the most time. For informational purposes to this study the wood was usually split and stacked into cords (128 cu. ft., pile 4x4x8 ft).

Certain tools are needed in order to split the wood with ease. These tools are: (1) Hatchet for short pieces, (2) Axe for larger pieces, and (3) Sledge hammer and at least two different size wedges for splitting initially the large tree trunks. A person splitting wood should have at his disposal a heavy cutting block on which to split the wood. The cutting block used in the latter part of this study was procurred from the Kansas State University Grounds Department. The grounds department had been cutting down trees during the summer of 1976, and the stump was given to the Ceramic Department at no cost.

For firing purposes, the wood was split into pieces 2"x2', 1"x2', ½"x2' or even thinner and of varying lengths. The reason for splitting the wood into such thin pieces was the thinner the wood, the greater and quicker the resulting heat release.

The wood was usually split up before each firing; but if this is not possible, the wood can be split during the course of the firing if more than one person is going to fire the kiln. Varying amounts of time was taken each week prior to the firing to split wood. Approximately 1 to 2 cords of wood were split before each firing. Splitting the wood ahead of time saved on fatigue of the potter during the firing process.

STACKING THE WOOD

The potter should decide ahead of time where the wood is to be stored. An area 4 feet wide, 4 feet high and 12 feet long was used to store the collected wood for this study. The bin was a wooden frame built of scrap 2x4's and plywood. The wood was held off the ground by wooden pallets. This was done so the wood would not get damp when it rained. This bin was a collection box where the wood was stored until the potter was ready to split it.

After the wood was split it was then stored in cords at the front and rear of the kiln, Figure 33. This placement of the wood made it easy for the stoker to reach when the kiln was being fired. The front stack was used to fire the first chamber, and the rear stack was used to fire the second chamber.

This area used for stacking the wood was far enough from the kiln so it would not be ignited from the intense heat of the firebox or popping embers. Also, the distance the wood was stacked from the kiln gave the potter easy access to all parts of the kiln when it was being fired.

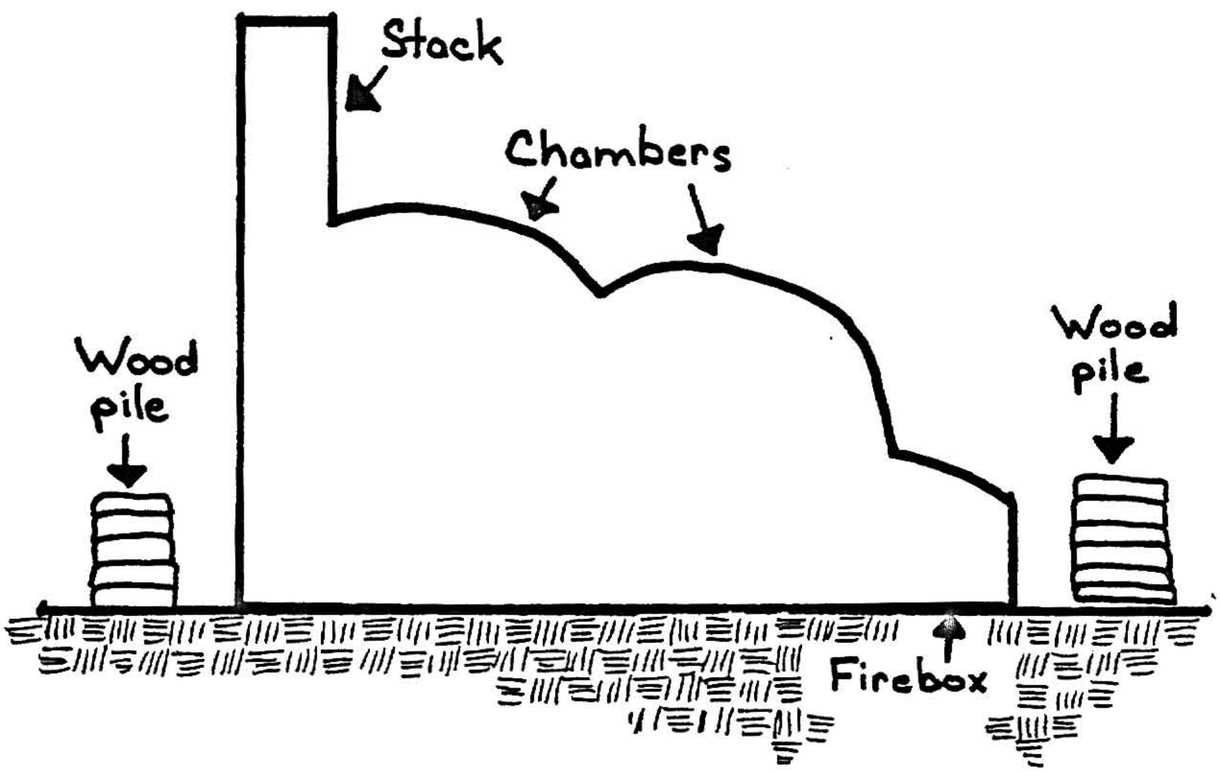


Figure 33

Placement of Split Wood

Chapter 6

CONCLUSIONS

One important problem confronting the contemporary American potter is the need for an alternate and low cost fuel as a result of dwindling fossil fuel deposits. There are various alternatives that the potter can use as heat sources besides electricity and natural gas. These alternatives have recently been experimented with but not in great depth. The alternatives are solar energy, methane gas derived from animal and human feces, waste oil, and scrap wood. The need for a low cost fuel prompted the research and experimentation of this study. The foundational hypothesis that waste wood could serve as an effective, low cost fuel for firing ceramics was found to be true in cost terms of scrap wood.

The cost of the wood used in the two year study was free of charge to the experimenter. As stated in Chapter 5, various firms gave wood freely; however, other costs did arise when collecting, splitting, and firing the kiln. If scrap wood were to be used by the contemporary potter, these cost factors should be high on his list for figuring the budget. The first cost to arise was the use of a vehicle, gasoline, and wear and tear on the vehicle when collecting wood for use. Secondly, the time spent splitting and stacking the wood for usage should also be considered. The last expense would be the period taken to fire the kiln. All of the above are time consuming and will take time away from the potter doing his own creative work.

It is a fair assumption to make that a potter is a potter because he or she wants to be involved in the total process of potting. If one process such as collecting, splitting wood and firing the kiln takes too much time, then a wood kiln would not be feasible. The potter should allocate time for each process to make potting profitable.

There are advantages to a wood kiln that are not available in other fuel burning kilns. Basically, the only major investment in building this type of kiln would be the bricks. The potter would not have to spend extra money for gas lines, burners, blowers, rheostats, and so forth that are needed in other types of kilns. These extra expenditures could be quite costly for the beginning potter.

Another factor to be considered is the aesthetic value of a pot fired in a wood kiln. The ash deposits and licking of the flames on the pots give the pots a distinctive character. The same glaze on a pot will be matt on one side and glossy on the other. The clay body will also be different where the direct flame and flying ash deposits itself on the pot. The ash deposit and flashing is not detracting but very pleasing to see.

There is also something very exciting and romantic about firing a wood kiln. The steady, rhythmic stoking of the firebox and the crackle of the flames is a satisfying experience; and the knowledge that the kiln is dependent entirely upon its stoker for a successful firing is a challenge.

To make the use of wood feasible to the studio potter as a fuel, there are various things that should be done. First the design of the kiln should be a multiple chambered climbing kiln. What is meant by a multiple chambered kiln is one containing two or more chambers of at least fifty cubic feet each. The large dimensions of the chambers take into consideration the long flame that wood has and makes use of the heat potential in each chamber instead of letting the heat escape up the chimney. By using a multiple chambered kiln the potter is conserving time and energy by using the heat in each chamber that would otherwise be used once and wasted in a single chambered kiln.

Secondly, the potter should have an assistant to help gather, split and fire the kiln. The time spent firing a multiple chambered kiln is quite lengthy and tiring. To fire a kiln by oneself is difficult, and an assistant would be beneficial for relief periods. The time spent firing the kiln could be divided between the potter and the assistant, giving each a time of rest.

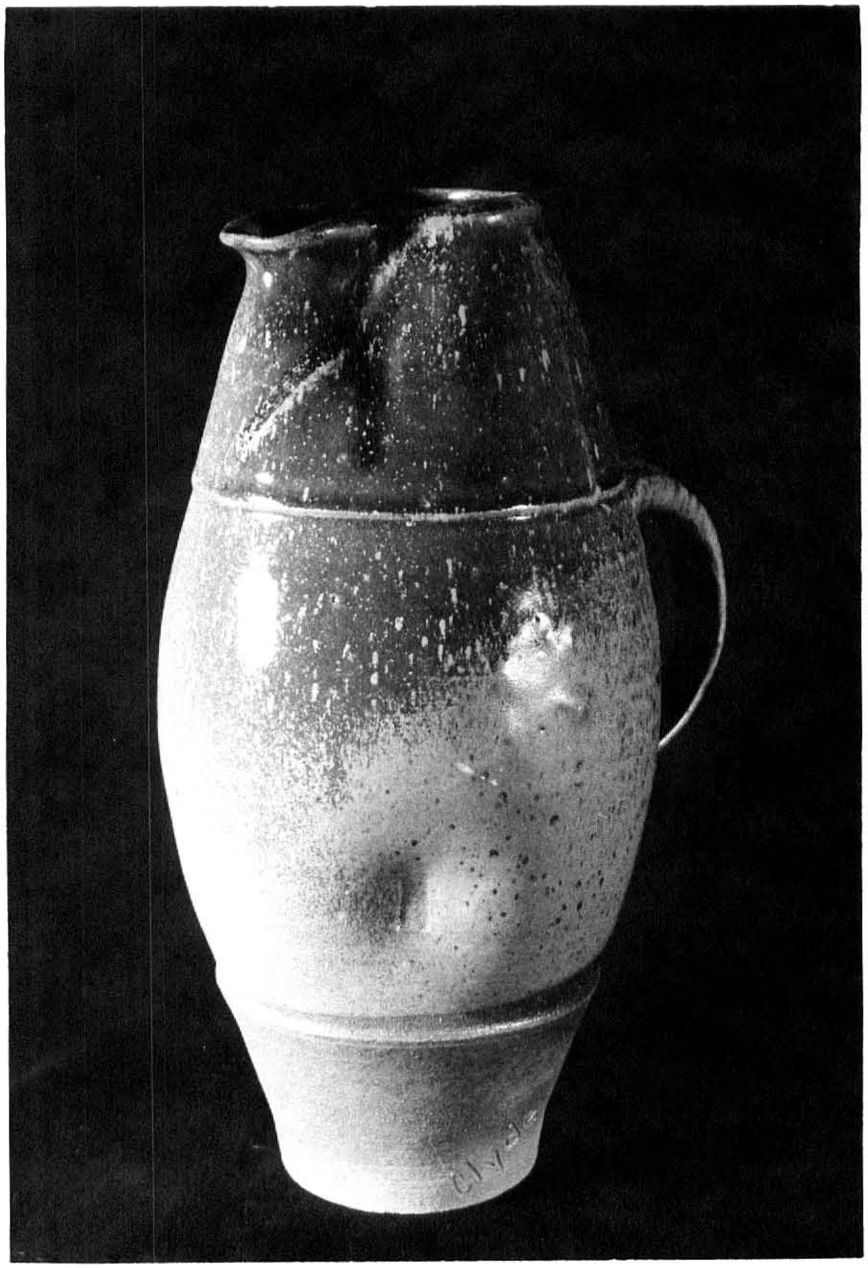
The use of wood as a fuel can be practical for only the hardier and more energetic potters who could devote time for the total process of using a wood kiln. The potter who wishes to use this source of fuel will have to justify to himself the advantages and disadvantages. This study should give him some insight into the problems discussed in the preceding pages.

There are still new horizons for combining the use of wood with other fuels which could make the use of wood more advantageous to the potter. The interest by potters wanting to conserve energy and be more efficient with its usage can improve the design and efficiency of wood kilns.

A PORTFOLIO OF WOOD FIRED

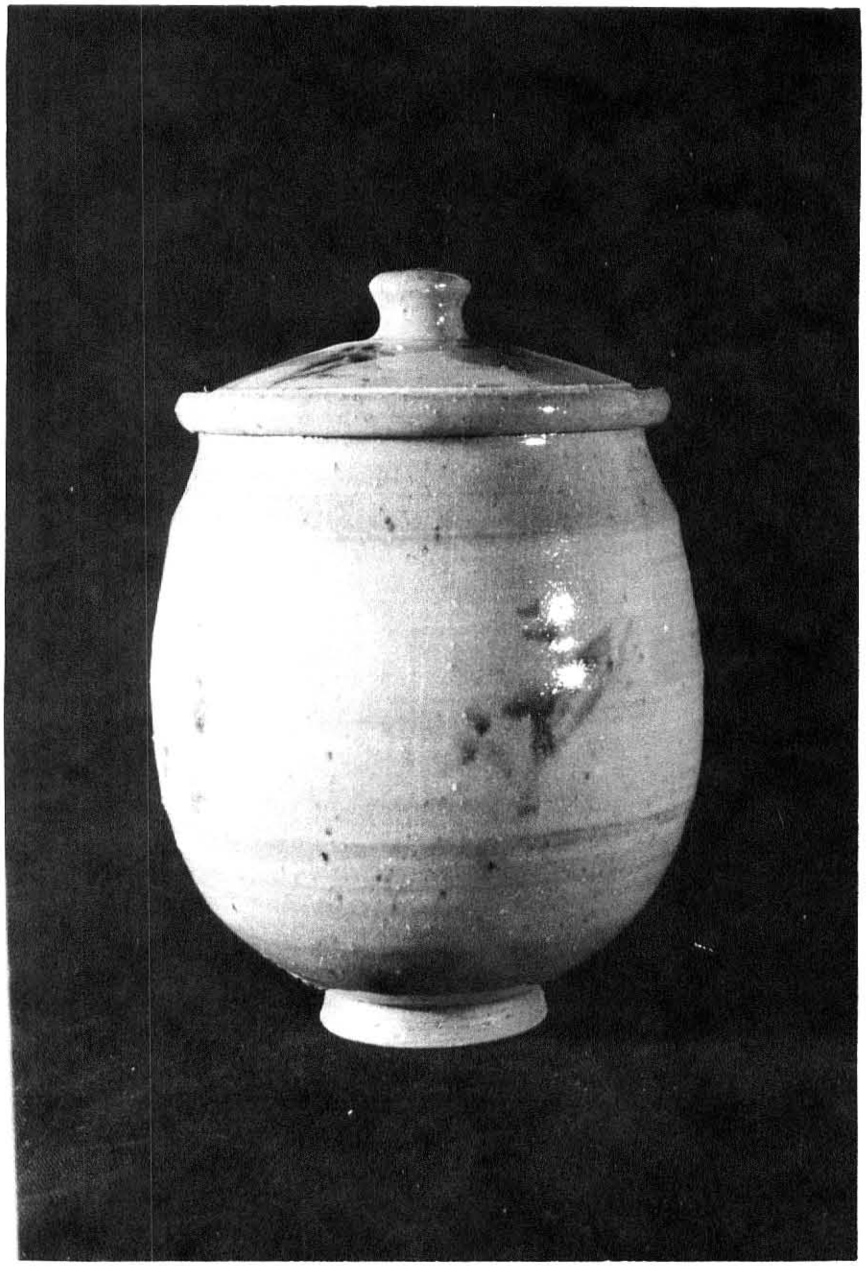
POTTERY

PORTFOLIO PLATE I



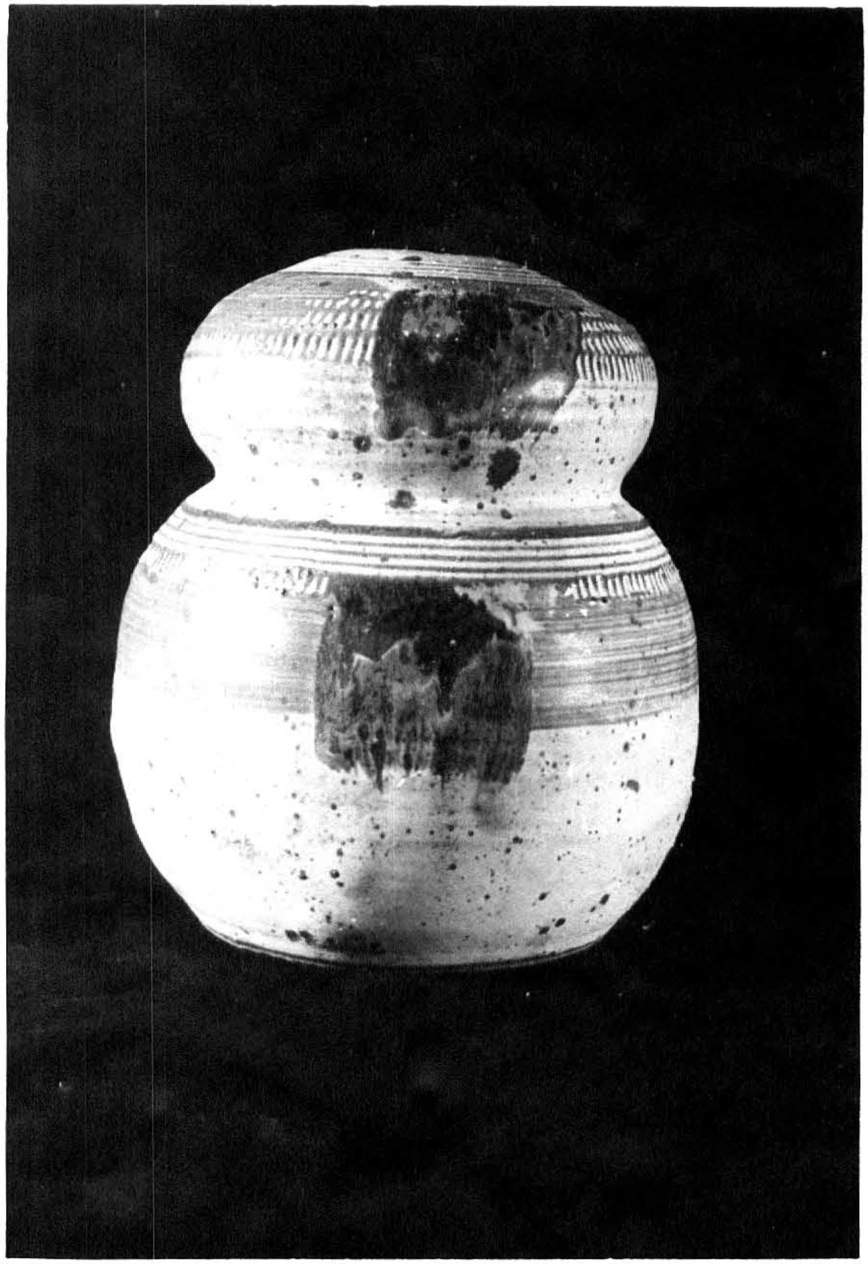
BLUE PITCHER
Width 4½", Height 11"

PORTFOLIO PLATE II



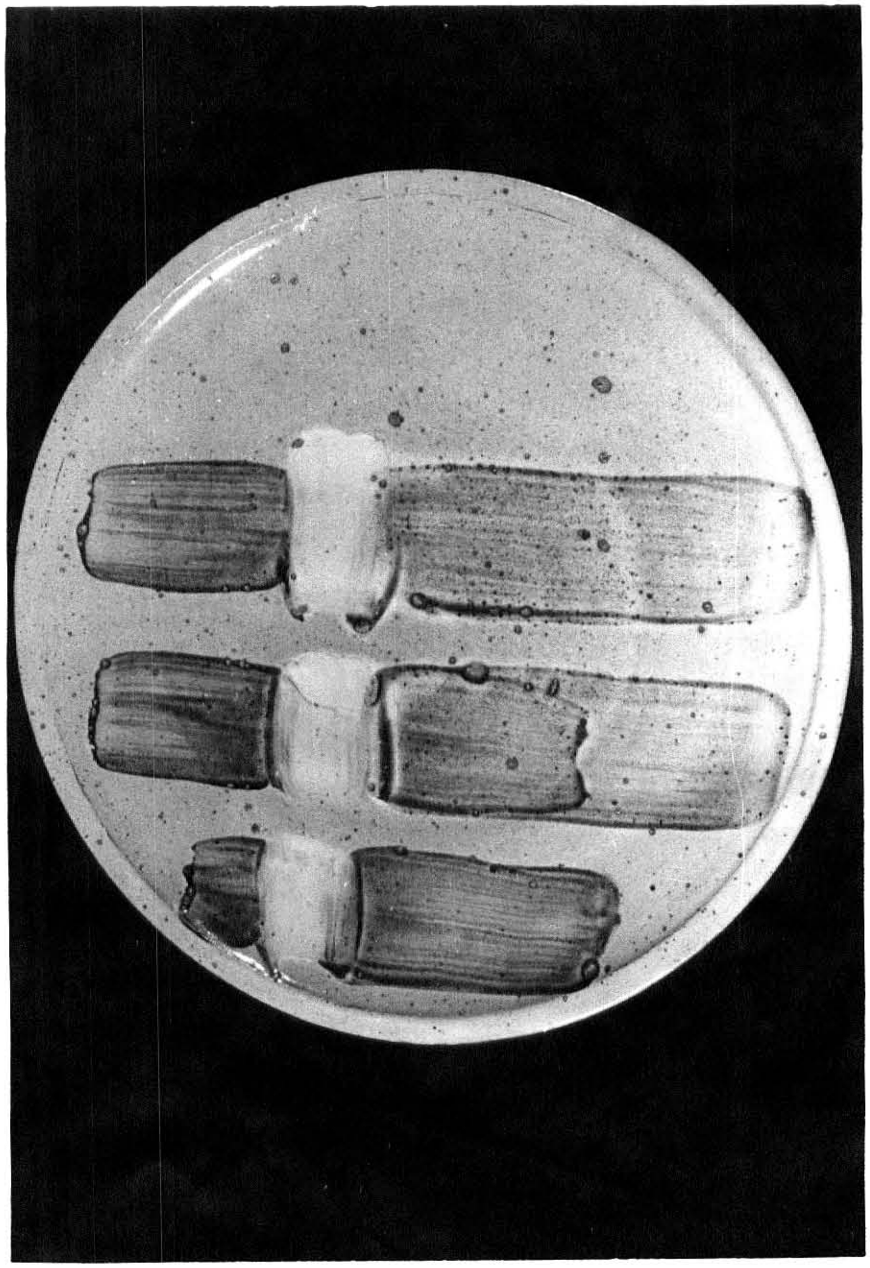
CELADON JAR WITH IRON STAIN DECORATION
Width $5\frac{1}{2}$", Height 8"

PORTFOLIO PLATE III



WHITE VASE WITH COLORED ENGOBES
Width 6", Height 8"

PORTFOLIO PLATE IV

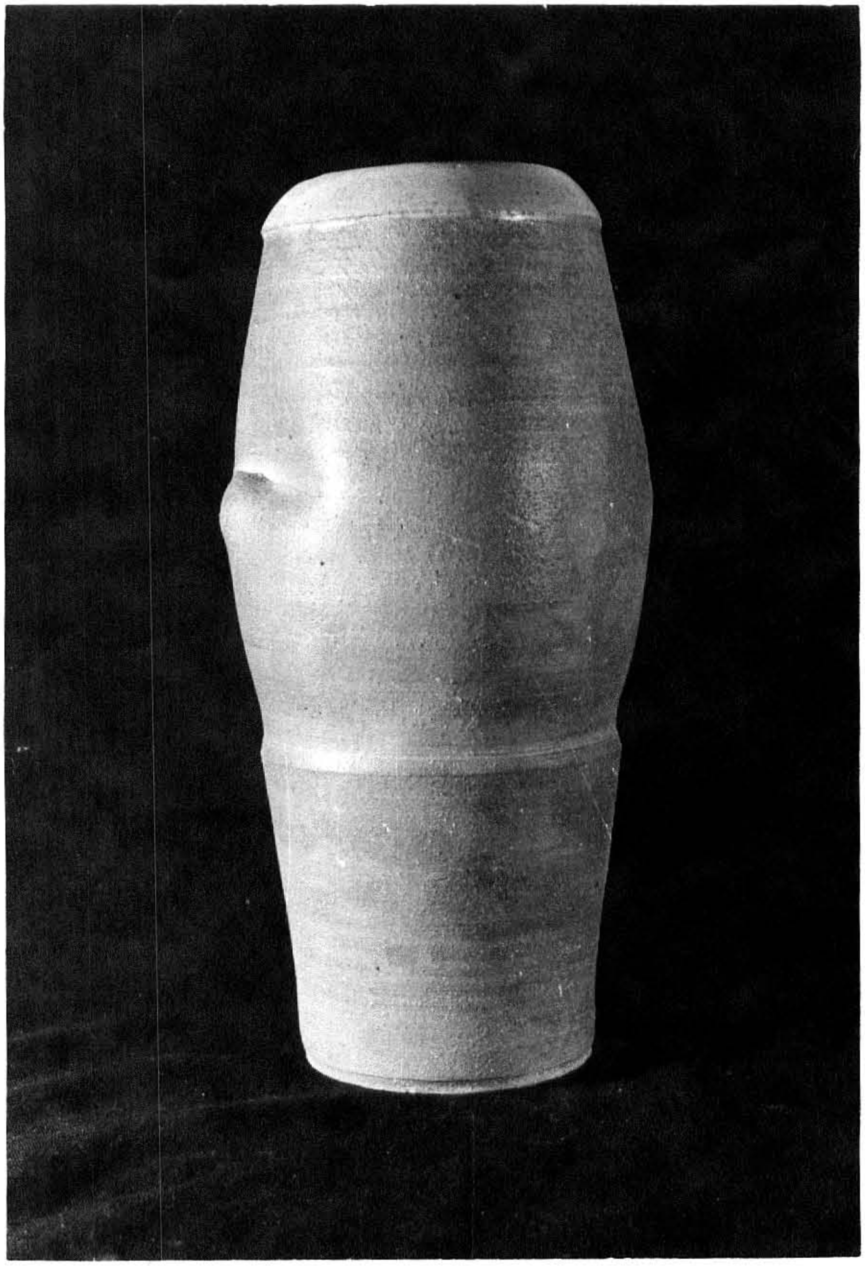


CREAM PLATE WITH THREE STRIPES OF BLUE
AND WHITE ENGOBES
Width 14", Height 2"

PORTFOLIO PLATE V

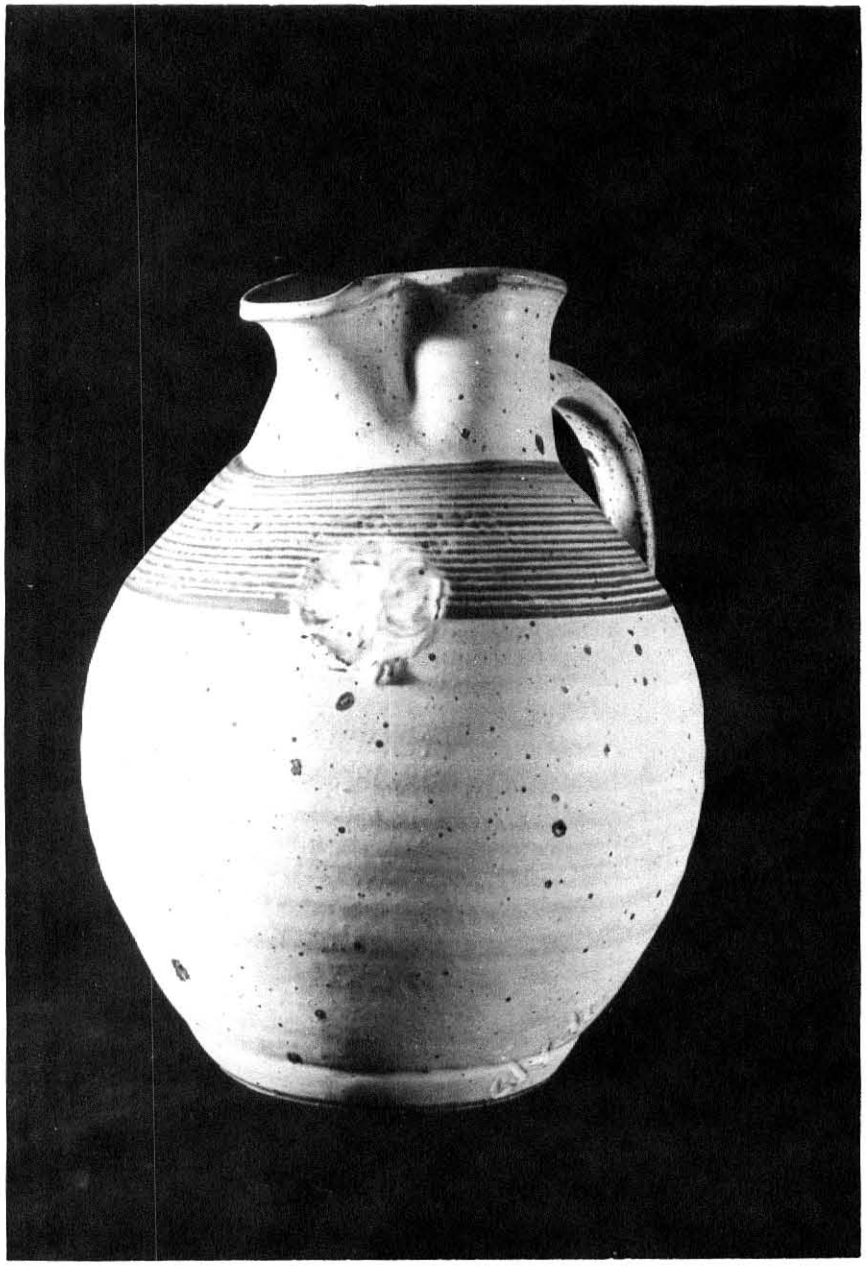
WHITE CASSEROLE WITH ASH DEPOSIT
Width $7\frac{1}{2}$", Height 5"

PORTFOLIO PLATE VI



VASE WITH FLASHING
Width $5\frac{1}{2}$", Height 12"

PORTFOLIO PLATE VII

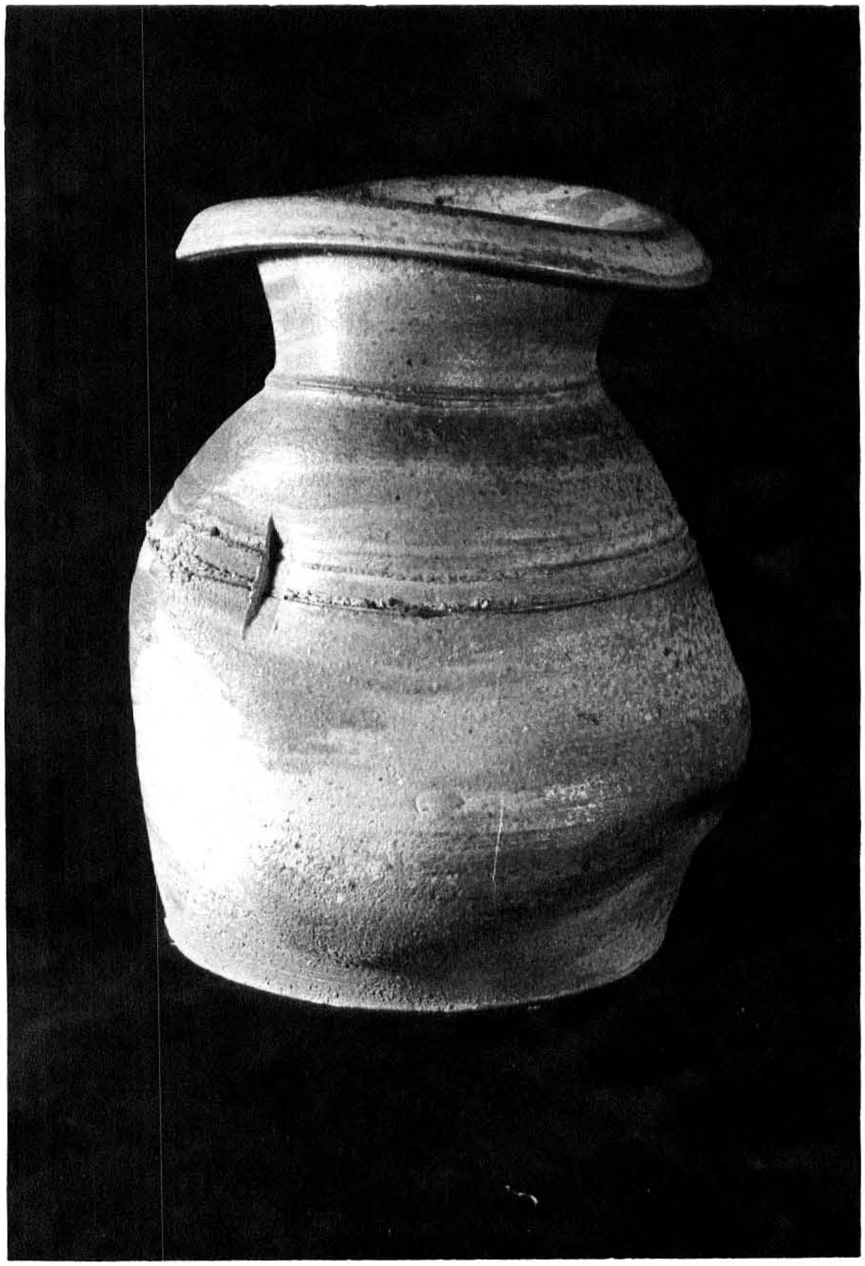


WHITE PITCHER WITH BLACK AND
WHITE ENGOBE DECORATION
Width $7\frac{1}{2}$", Height 10"

PORTFOLIO PLATE VIII

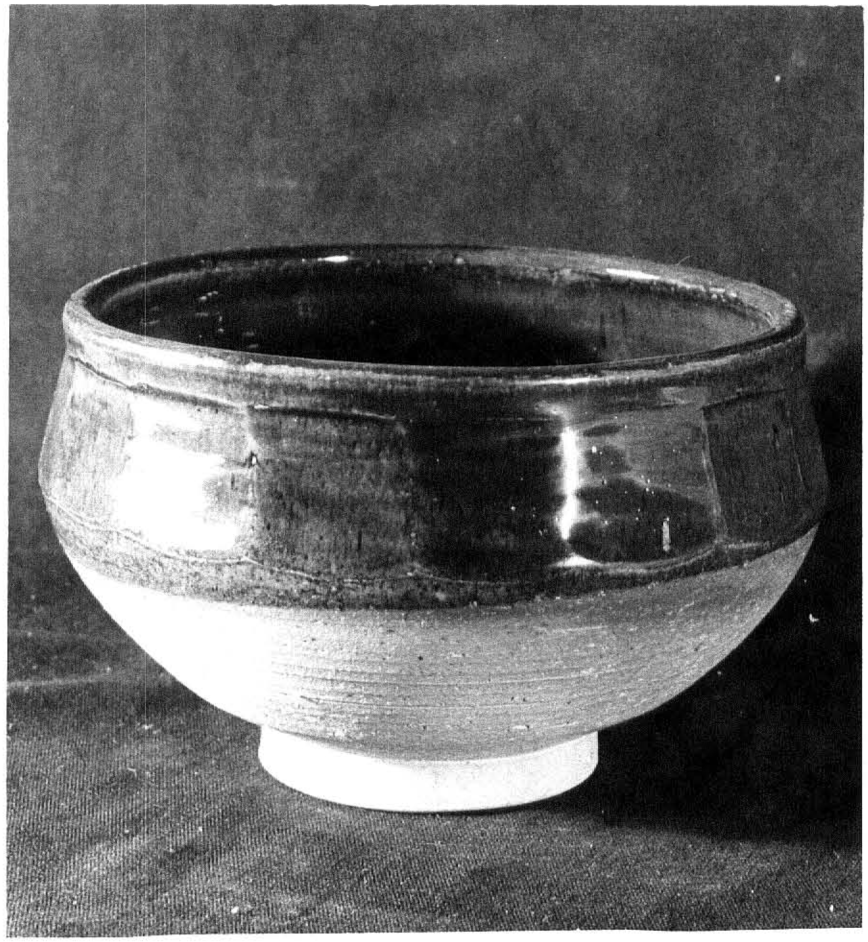
WHITE CASSEROLE WITH STAMP DECORATION
Width 7½", Height 7½"

PORTFOLIO PLATE IX



RUST RED VASE WITH BLUE ENGOBE
AND SLIT DECORATION
Width 6", Height 8"

PORTFOLIO PLATE X

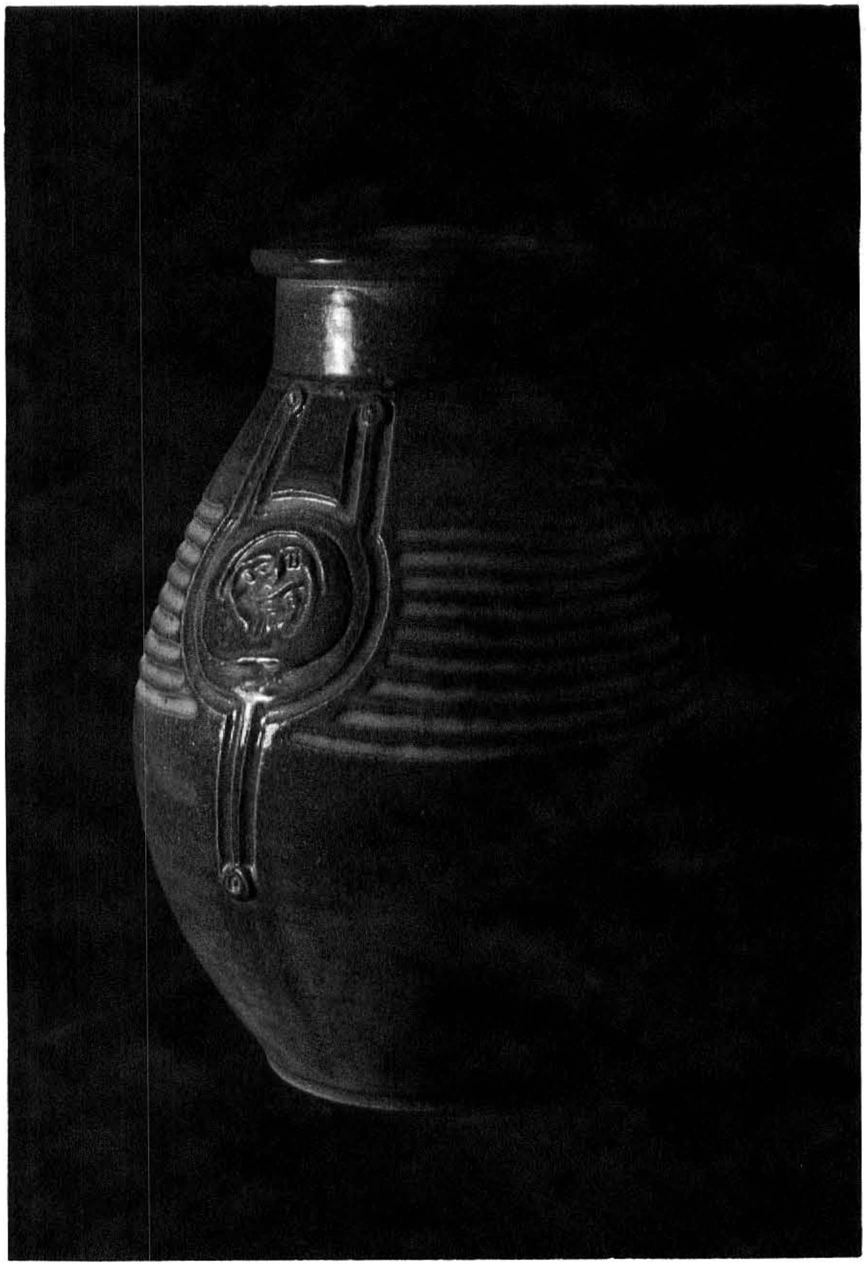


OXBLOOD BOWL WITH FACETED
SIDES AND FLASHING
Width 7", Height 4½"

PORTFOLIO PLATE XI

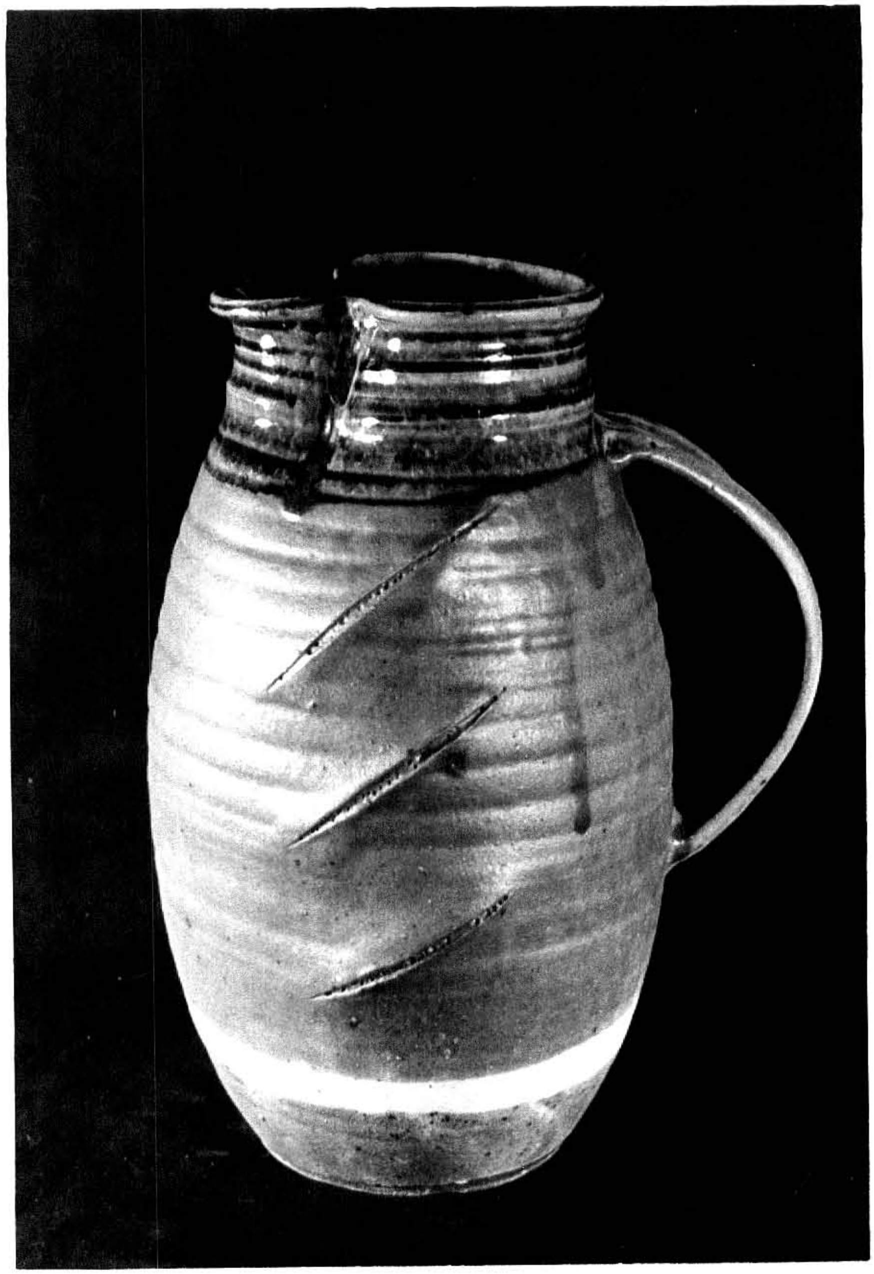
CASSEROLE WITH BLUE GLAZE AND
INCISED DECORATION
Width 11", Height 7"

PORTFOLIO PLATE XII



JAR WITH BLUE GLAZE AND INCISED
AND STAMP DECORATION
Width 8", Height 12"

PORTFOLIO PLATE XIII

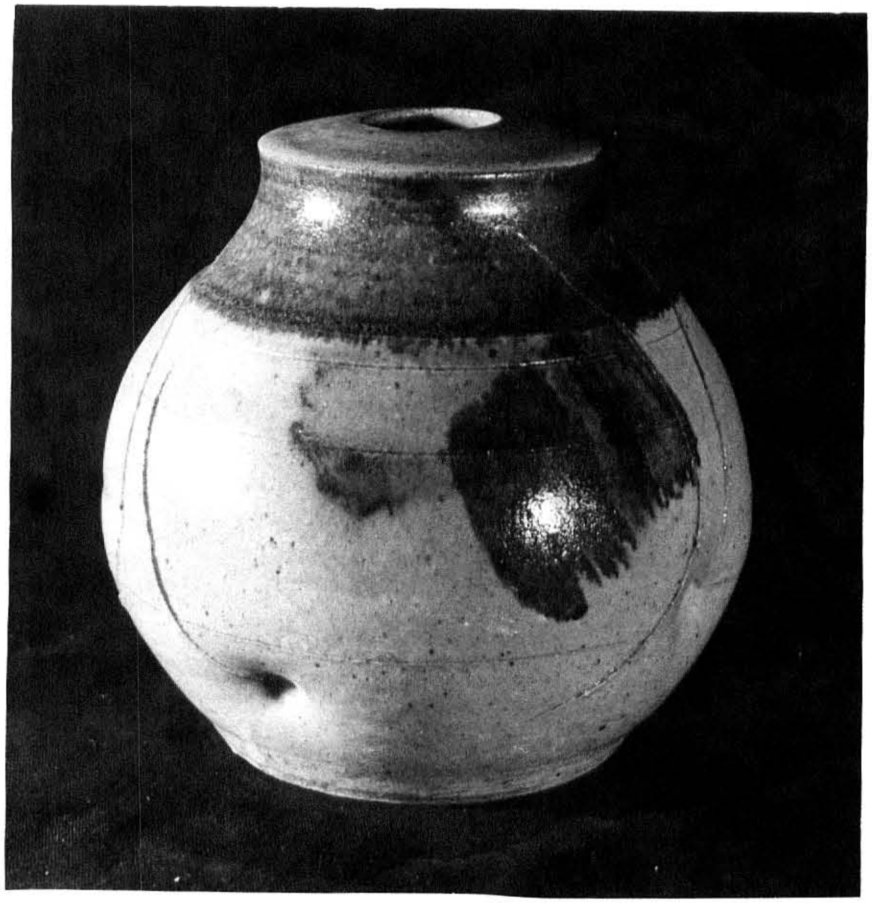


BROWN, GREEN, WHITE PITCHER
Width 6", Height 10½"

PORTFOLIO PLATE XIV

TRANSPARENT BEAN POT WITH
MISHIMA DEOCRATION
Width $5\frac{1}{2}$", Height 5"

PORTFOLIO PLATE XV

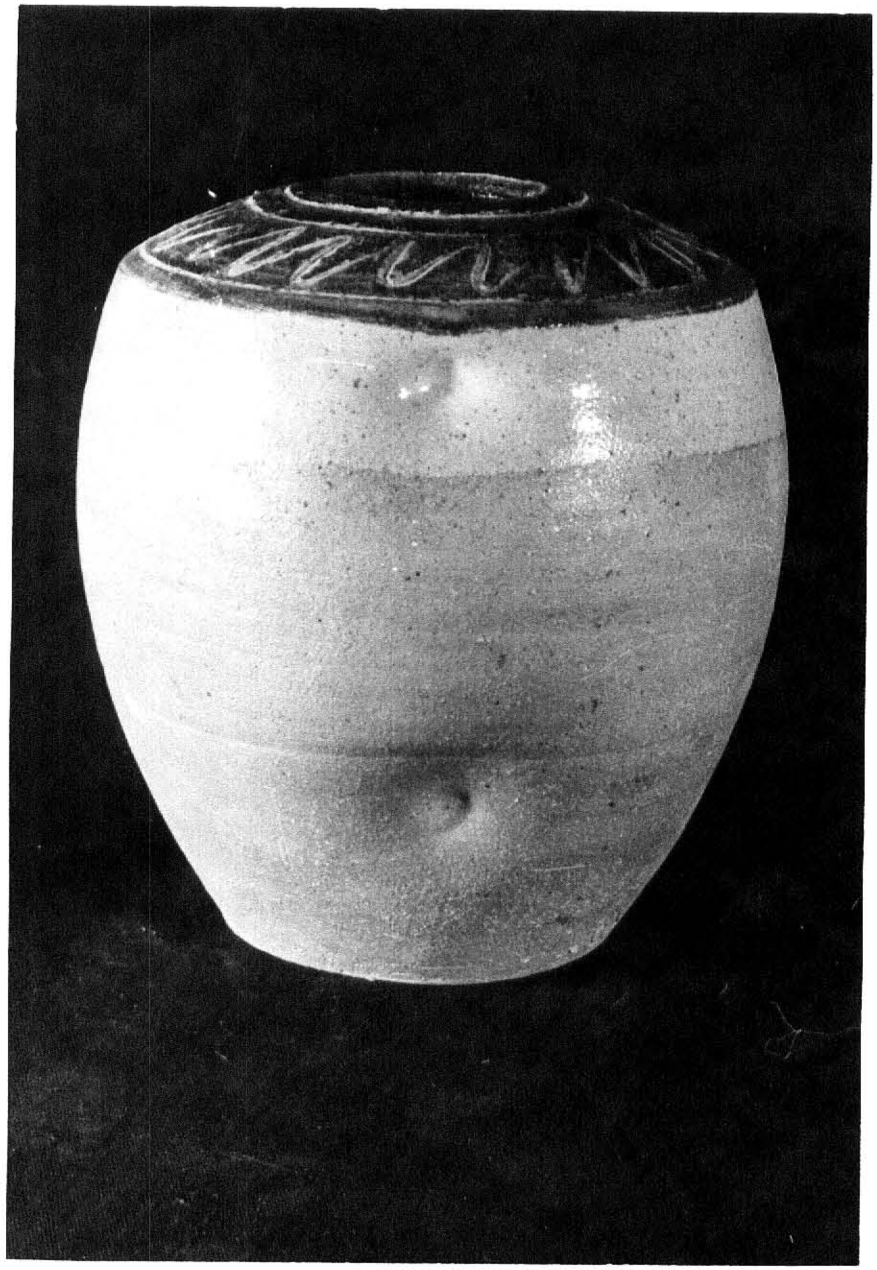


CREAM VASE WITH COBALT, COPPER,
IRON DECORATION
Width 7", Height 7"

PORTFOLIO PLATE XVI

RUST RED PUNCH BOWL WITH STAND
Width 15", Total Height 13"

PORTFOLIO PLATE XVII



BLACK, CREAM VASE
Width 7", Height 8"

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A STUDY IN THE USE OF SCRAP WOOD AS AN INEXPENSIVE FUEL TO BE USED IN A MULTIPLE-CHAMBERED KILN FOR FIRING CERAMICS

by

CLYDE LEE CANTRELL

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Over the past ten years people have become quite ecology minded, and developments concerning the cost of refining and drilling for fossil fuels have made the availability of fuel low and cost high. This study was founded on the hypothesis that waste wood could serve as an ecological and low-cost fuel for the potter.

As the study began, it was found necessary to gather historical data concerning wood burning kilns in general. As the study progressed, the history was narrowed to the development of the multiple-chambered climbing kiln of the Orient because the multiple chambers used the heat more than once.

To further understand what wood could be best used in a wood kiln, a thorough research of various hard woods and soft woods was done. Matters of B.t.u. and calorie output of various woods were studied and why the coniferous softwoods were most suitable.

Still other factors should also be examined and that was the dimensions of the flue areas, stack, grate, firebox and chamber sizes of a natural draft cross-draft system. This information was compiled from various sources and put in an orderly manner in this study.

The pollutant factor of emitting black smoke into the atmosphere was also dealt with as well as what effect the smoke had on the ware in the chamber and the vapor that was created by the free floating ash deposited in the kiln.

Matters of gathering wood, storing and splitting the wood were stated.

The conclusion of this study states the advantages and disadvantages of the use of waste wood by the potter. This study will provide a point of departure for the potter who wants to take advantage of the waste wood available.