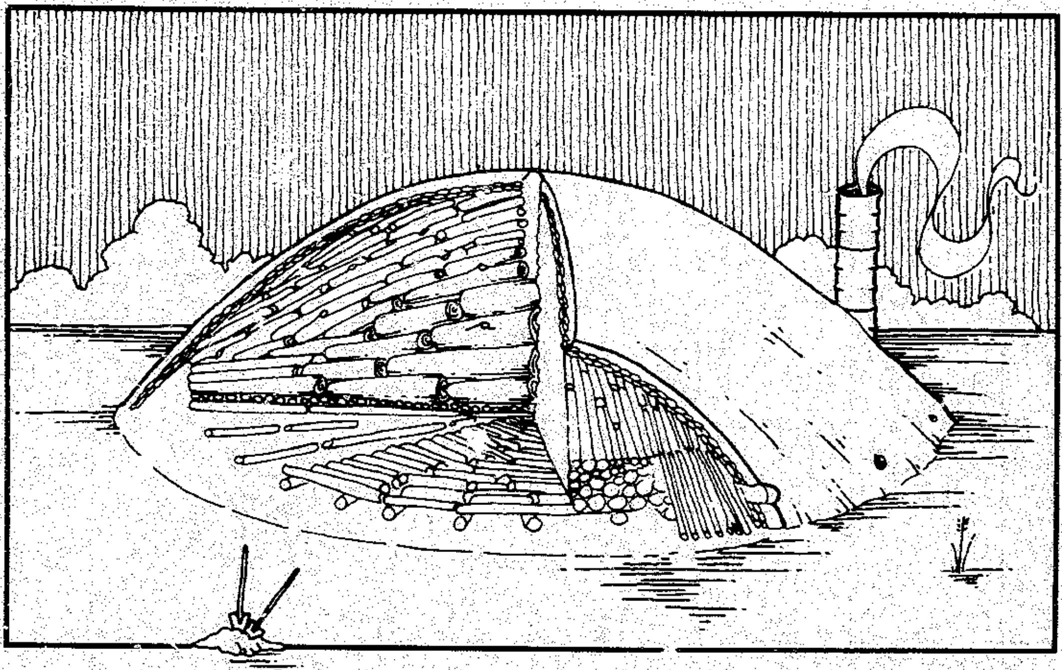
The Casamance Kiln



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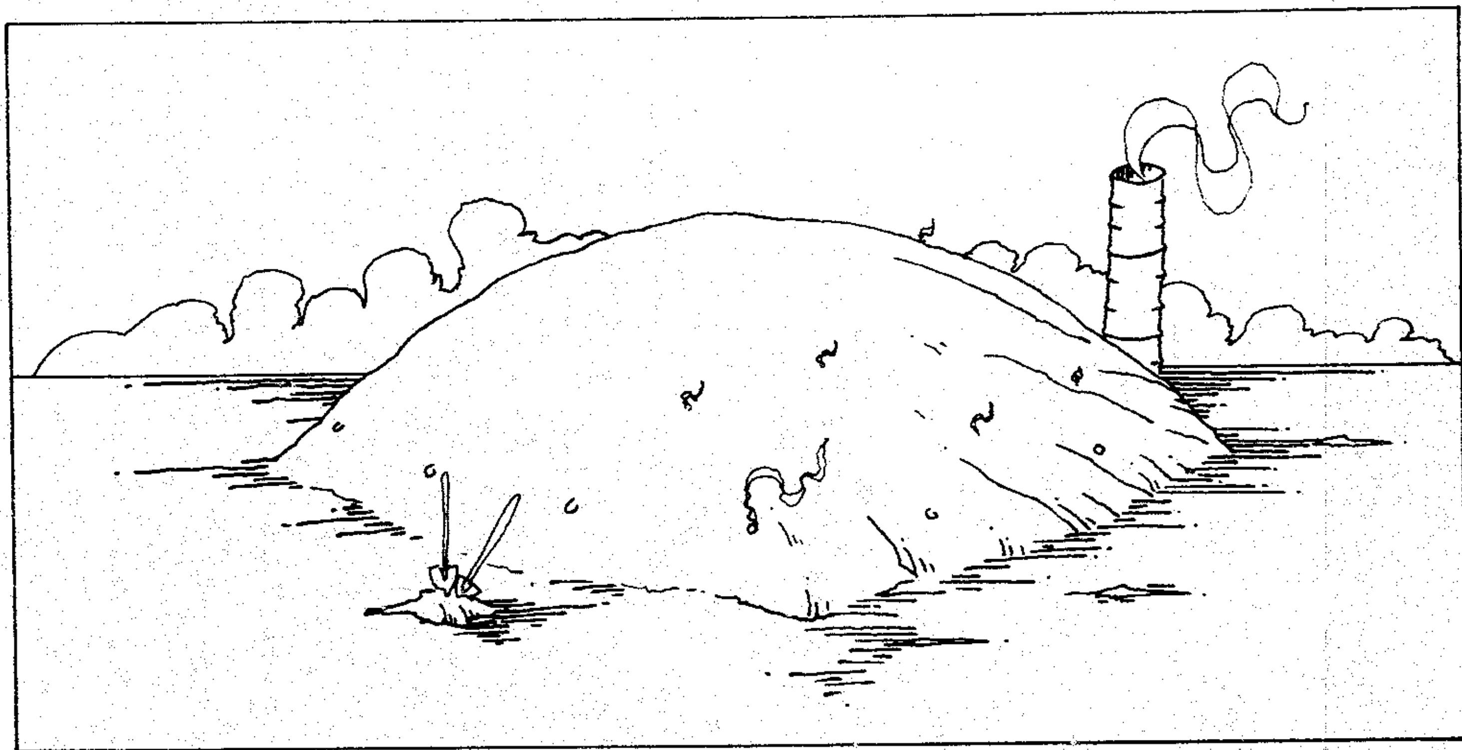
Contents

Introduction



The Casamance Kiln is based on the idea that an efficient, low cost kiln could be developed that would adapt well to local situations. The kiln was developed over several years of field research by agencies in the Casamance region of Senegal, West Africa. The resulting kiln showed a dramatic improvement in both production efficiency and economic returns over the traditional method and was well accepted by the local charcoal makers.

The preparation and dissemination of information on the Casamance Kiln has been minimal, not sufficiently detailed, and often erroneous. This publication is intended to show, step by step, how to build and operate the kiln. It is also offered as a case study of a technology that was developed from traditional methods and fits local needs. There is also included a description of the process of the kiln's development. We hope that this publication will clear up any previous misleading information about the Casamance Kiln.

Finally, it is important to emphasize that the authors are not promoting the Casamance Kiln as a most favored method of charcoal production. It is but one among several methods of production suitable for various sets of cultural, physical, environmental and economic site-specific conditions and constraints, and it is certainly not recommended for all conditions and situations.

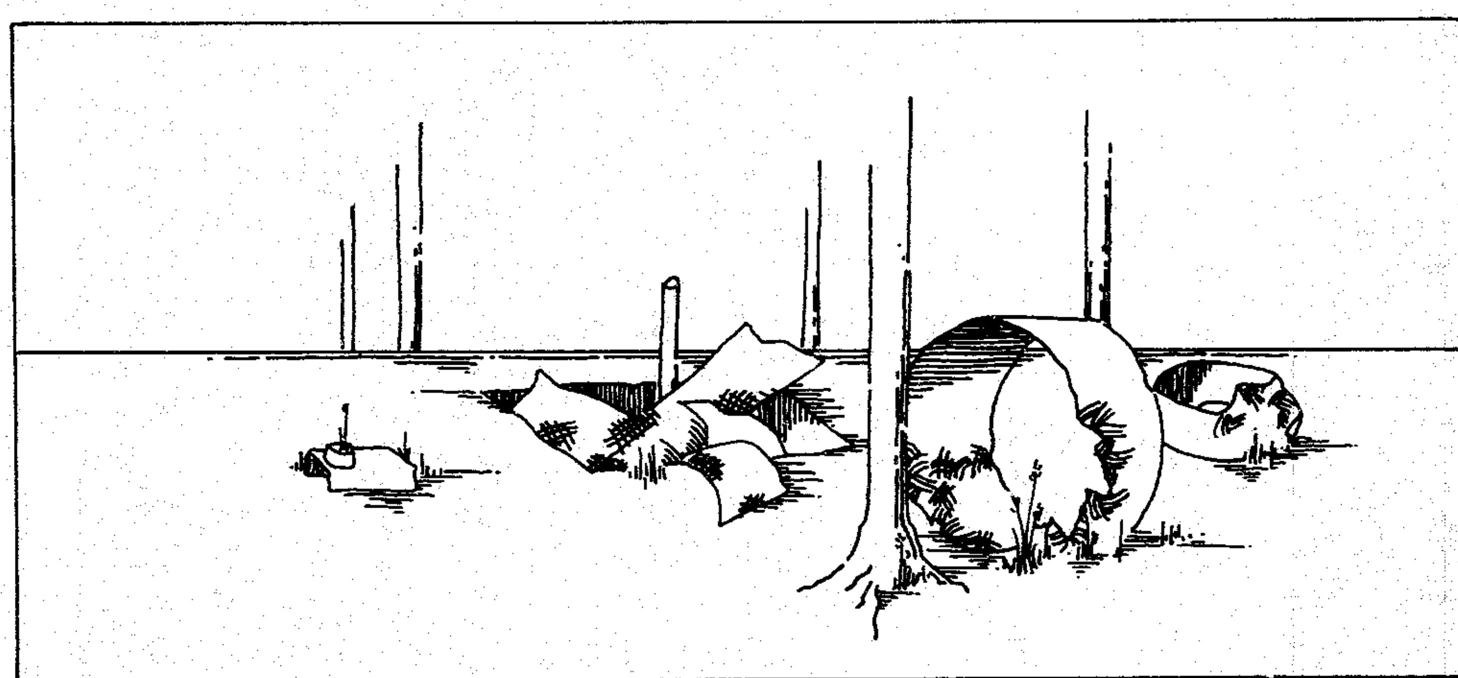
The authors wish to thank Gerald Foley for his review of an early draft of this document and William Sweet for his editorial work.

Chapter 1

Development of the Casamance Kiln

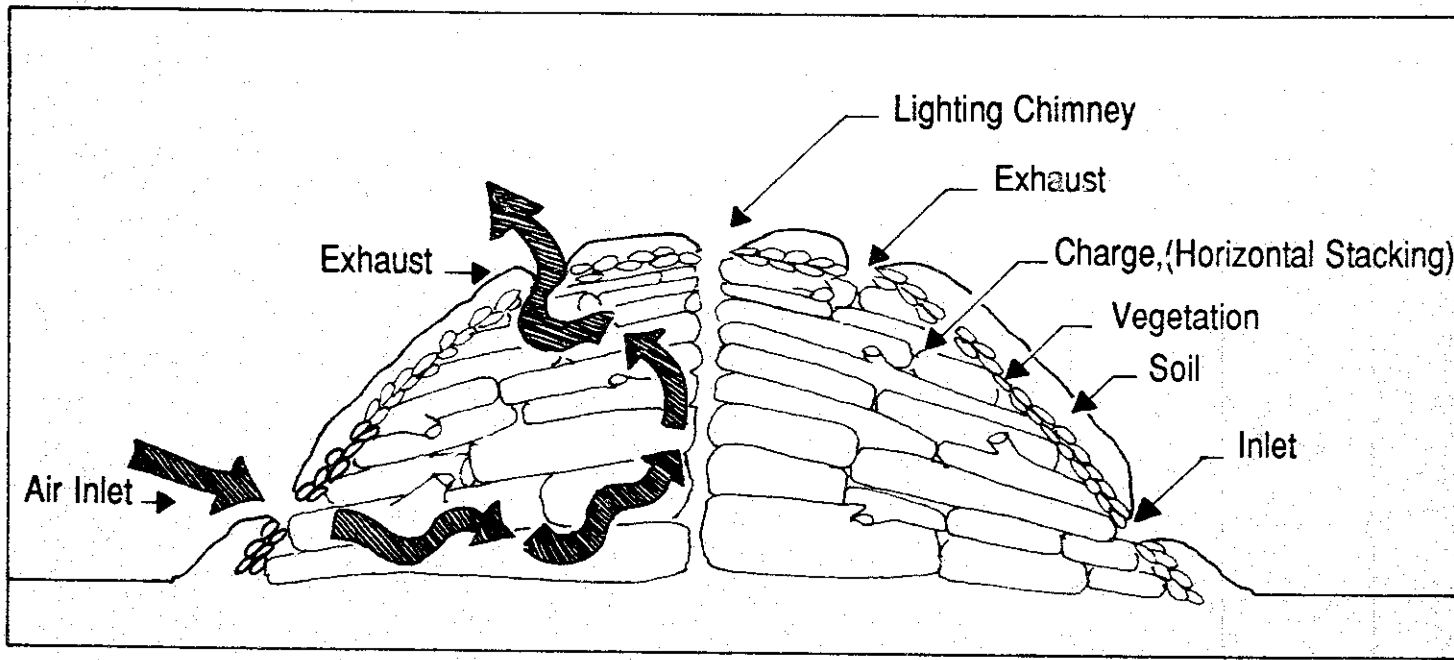
The Casamance Kiln was developed between 1977 and 1980 to meet the specific requirements of the UNDP/FAO project "Mise en Valeur des Forets de Basse et Moyenne Casamance & Assistance au Service Forestier SEN/71/522". This project was located in the Casamance region of southern Senegal. The overall objective of the project was to place the Casamance forests under management and to provide income from the sale of forest products to finance timber stand improvement and planting costs.

The kiln was developed to fit the following criteria:
- inexpensive to build
- easy to operate
- easy to train operators
- capability to produce high yield
- quick carbonization



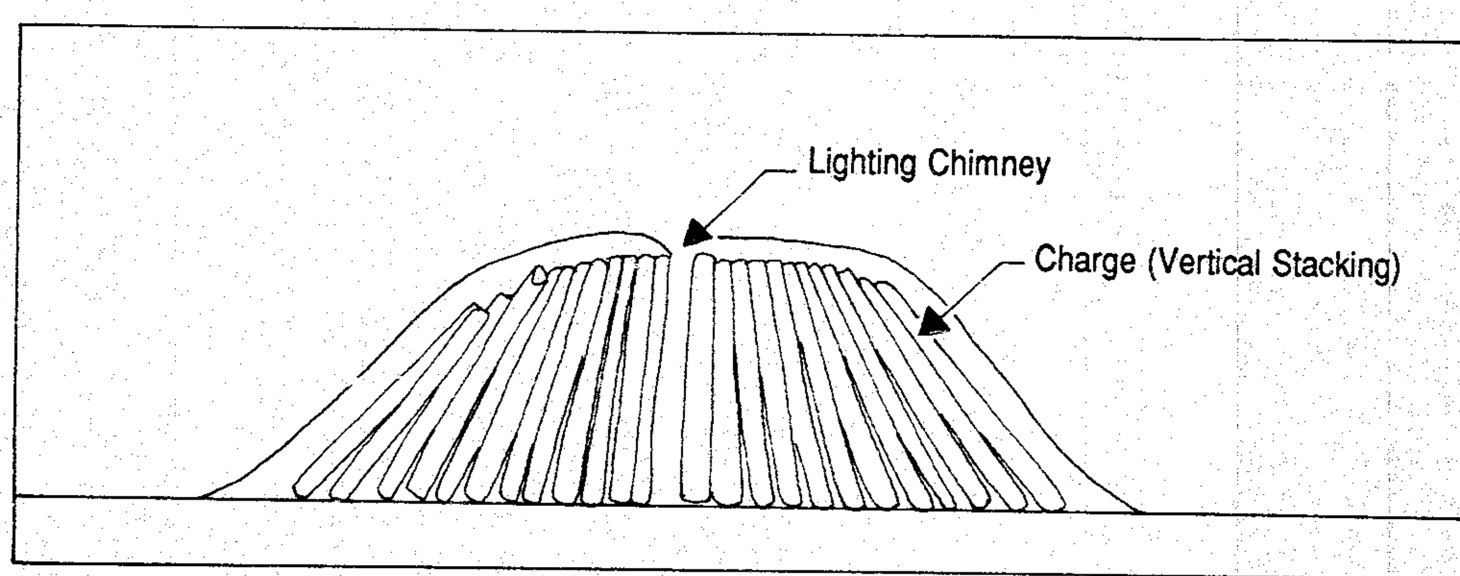
Evidence that the local charcoal makers had previously tried several "improved methods" was found in the remains of metal kilns and metal pit covers which were scattered throughout the forest and piled at the mill site. These gave a good indication of the way not to go.

The way to proceed was not so obvious. The first step was to study the local, traditional method to see if any obvious improvements could be made. The local kiln was a variation of the above-ground stack which had probably evolved from European origins. In the traditional kiln, the wood is stacked radially on the ground then gradually layers up to a parabolic shape. An open channel is left down the center to enable lighting. The classic European stack has approximately the same finished shape as did the local, traditional kiln but differs internally in that the lighting chimney is first defined and then the wood is stacked vertically outward from this chimney.



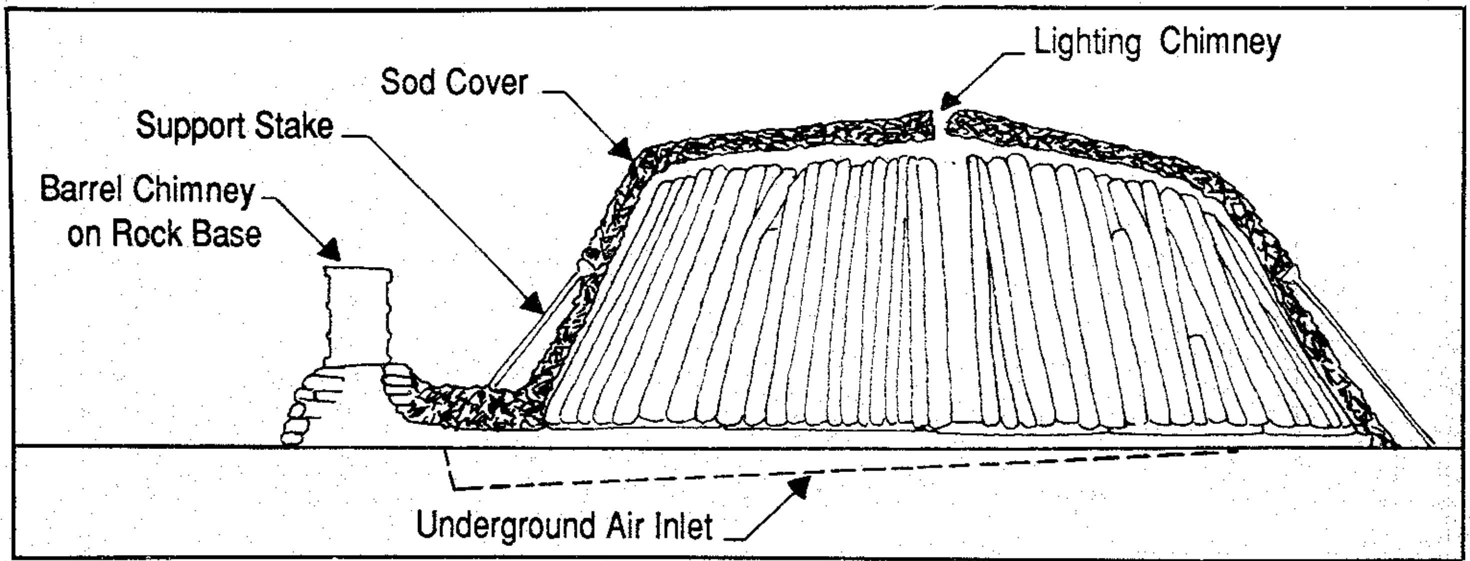
Cross Section Traditional Kiln

The local method was thought to be wasteful, and the yield was projected to be 10 percent on an oven dry basis. However, no one had actually measured it. During the following 3 months all wood going in and charcoal coming out of the kilns was measured. The resulting calculations gave an average yield of 18 percent. This provided the project with a fallback position. If no better method could be found to fill the project's needs, it would be possible to use the traditional kiln for industrial scale charcoal production.



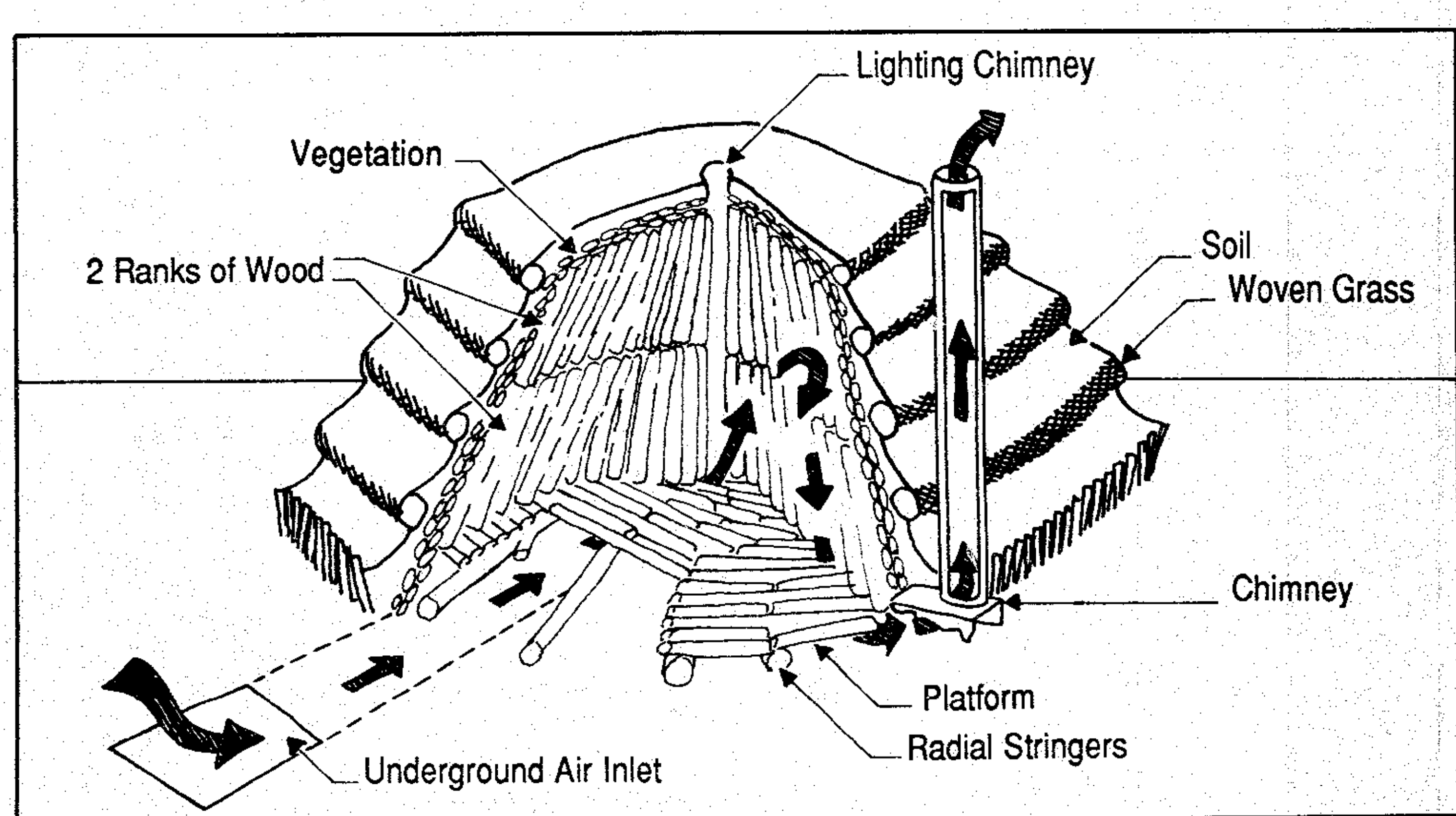
Cross Section Traditional European Kiln

Concurrent with studies of the local method, a literature search was undertaken. The Swedish Skorstensmila (stack with chimney) was rediscovered in an English translation of a French document which quoted from the original Swedish. As could be expected, much was lost in this chain of translation. After much pursuasion, the charcoal makers reluctantly agreed to try it.



Cross Section Swedish Skorstensmila Kiln

An external chimney which fitted onto a base which extended into the kiln was built at the local metal shop. The first run used teak about 10 cm. in diameter and of 1 meter in length. The stack was set up with a central lighting chimney filled with kindling. The entire charge rested on a platform of crosspieces resting on radial stringers which provided an air space of about 10 cm. under the entire kiln. Lighting was done from a central aeration tunnel dug underneath the platform. The wood was stacked against the lighting chimney just off the vertical. Since the wood was only 1 meter long and the kiln was to be more than twice that high, 2 ranks were used to get the correct height.



Africanized Traditional Swedish Kiln

When the sides were covered with brush, the first mistake was discovered. The earth cover would not hold on the steep sides. The European method had used sod, but there were no local sod forming grasses. The covering was completed by weaving earth holders from grass, which acted as terraces. The top edges were finally plastered with mud as a last resort.

The lighting was to be done with a torch on a long pole introduced into the tunnel to a position underneath the lighting chimney. However, not enough heat was generated and it went out. After 3 attempts, the last of which involved crawling part way down the tunnel, it finally caught. The burn proceeded well until during the night when another mistake became apparent.

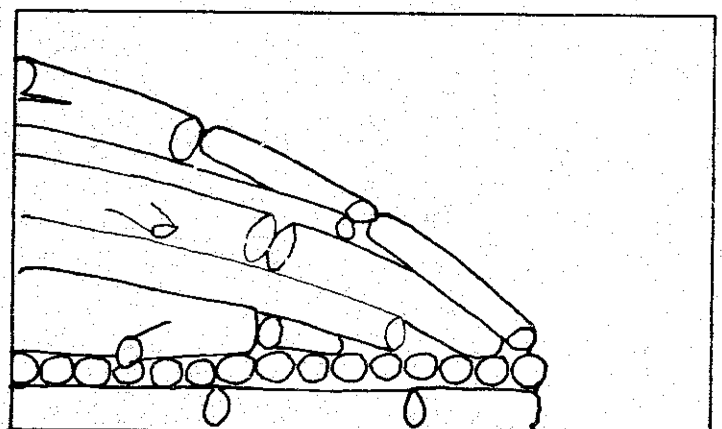
The natural shrinking process of the wood as it carbonized caused the top rank of wood to fall onto the bottom rank.This created huge holes in the top. The resulting fire taxed the abilities of the workers, but by substantial effort, they managed to keep it under control. The total time of carbonization was about 24 hours for a kiln of 38 steres. (A stere is 1 stacked cubic meter of wood)

Despite the problems encountered with the Swedish kiln, it was successful in terms of carbonization time and yield. The resulting charcoal was of high quality, and the yield was 22.6 percent. The normal time for a traditional kiln of comparable size would be at least 5 days.

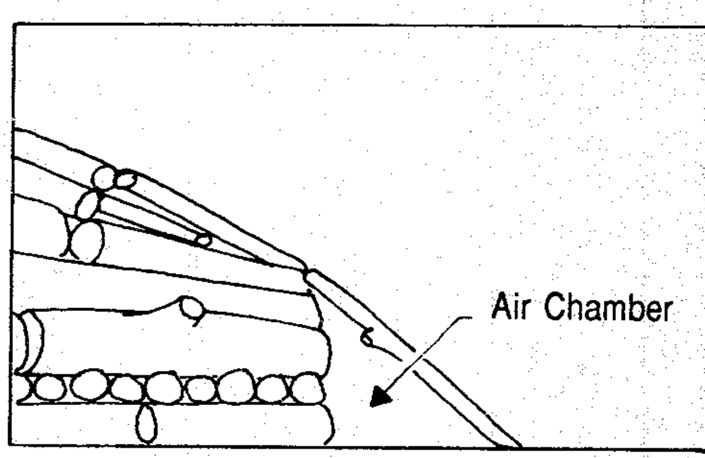
In consultation with the charcoal makers after this attempt at a Swedish kiln, it was decided that both the external chimney and the platform worked, but the stacking was all wrong. The charcoal makers recommended retaining the chimney and the platform but placing a traditional stack on top with no tunnel.

The workers also wanted to try a larger kiln in an attempt to boost earnings since they were paid by weight of charcoal produced. The available wood again was teak, this time mostly under 5 cm. in diameter. Each stere was weighed before being added to the stack. The final measure was 130 steres with an average weight of 301 kg. per stere. The kiln was about 3.5 meters tall and 6 meters in diameter.

A disagreement arose over how to place the final layer of wood. The charcoal specialist thought that the final layer should rest on the edge of the platform as the description of the Swedish kiln had inferred. The charcoal makers felt it should extend past the edge of the platform to reach the ground. The workers won the argument, and the result was the air chamber, which is the major difference between the Casamance and Swedish kilns.

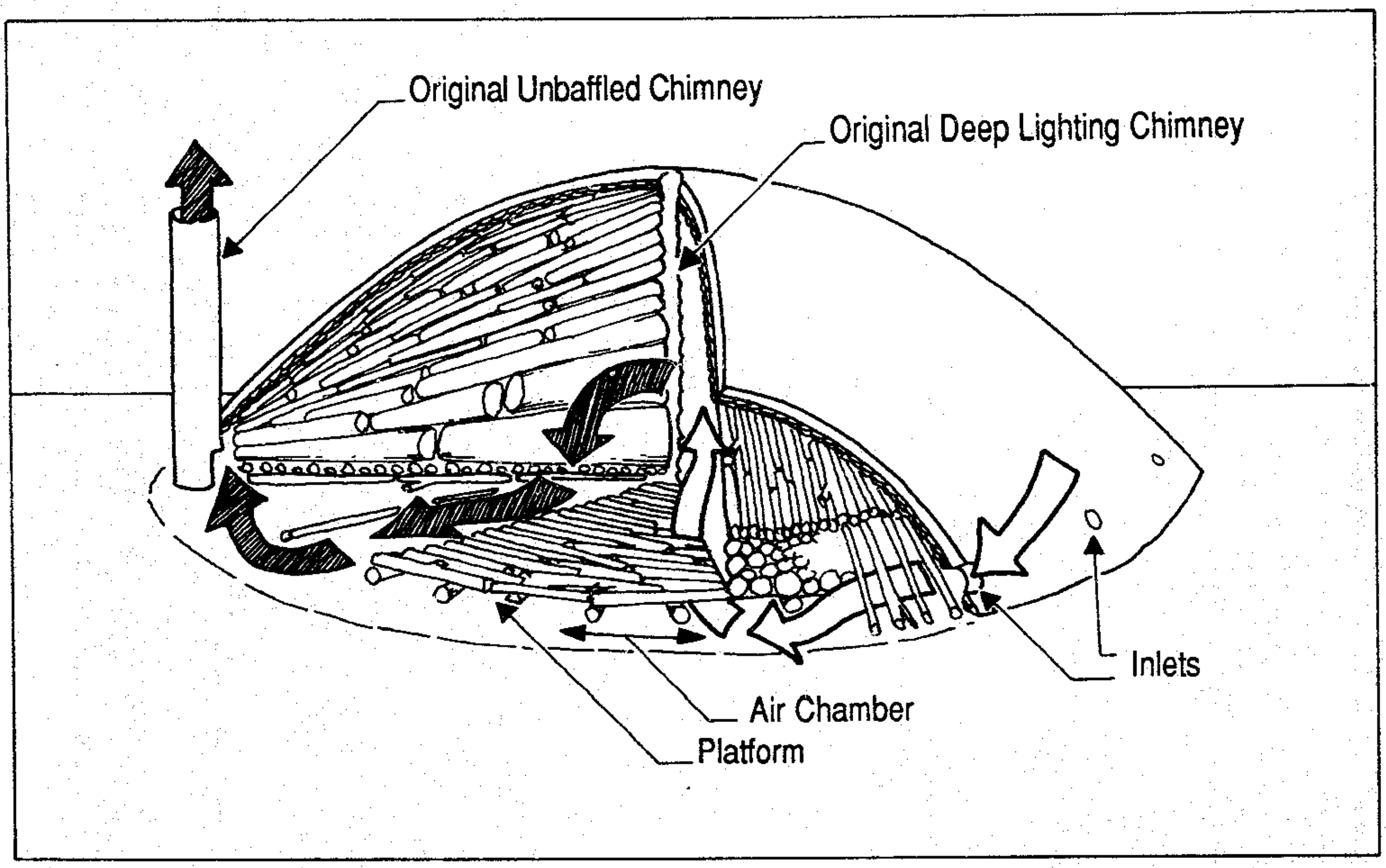


Stacking envisioned by the charcoal "expert"



Stacking as done by the local charcoal makers. Note the creation of an air chamber.

This kiln was lit down the lighting chimney and ran for 77 hours giving a yield of 27.7 percent, and was, in fact, the first Casamance Kiln. From this point on, research was directed towards learning what the kiln could do and how it might be refined.



First Casamance Prototype

The air chamber in the first Casamance Kiln accomplished several functions:

1. The cool, incoming air is heated by the hot exhaust gas thus reducing the amount of additional heat needed for combustion.

2. The cooling of the exhaust gas reduced the amount of heat transfer necessary for the chimney to condense the volatiles.

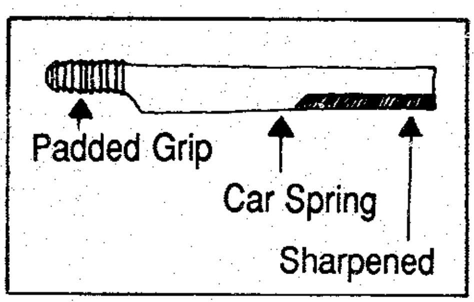
3. The incoming air is diluted by the outgoing gas which is poor in oxygen. This regulates the speed of carbonization. If combustion speeds up, this mixing action also speeds up and slows combustion.

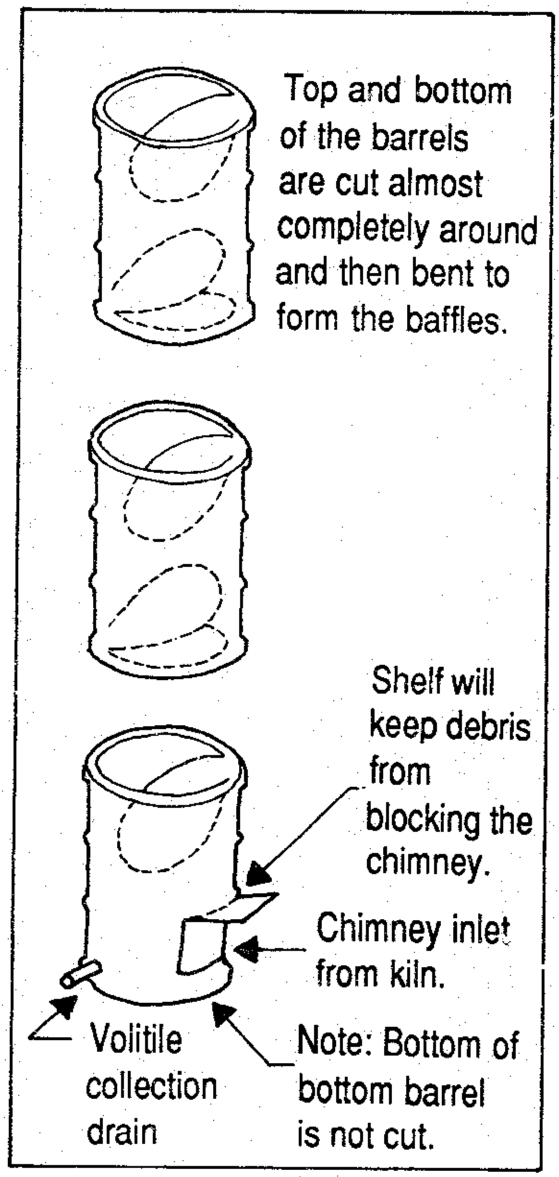
The combination of the platform, external chimney, and the air chamber gives the Casamance an excellent air distribution system. No part of the kiln is more than 2 1/2 meters from an air passage. Although the amount of air is restricted, the mobility of that air is not. The draft of the chimney powers the whole system, drawing from all parts of the kiln. This results in a rapid and complete carbonization of the charge. As a result of this circulation system, the kiln is virtualy self-regulating, and very easy to control.

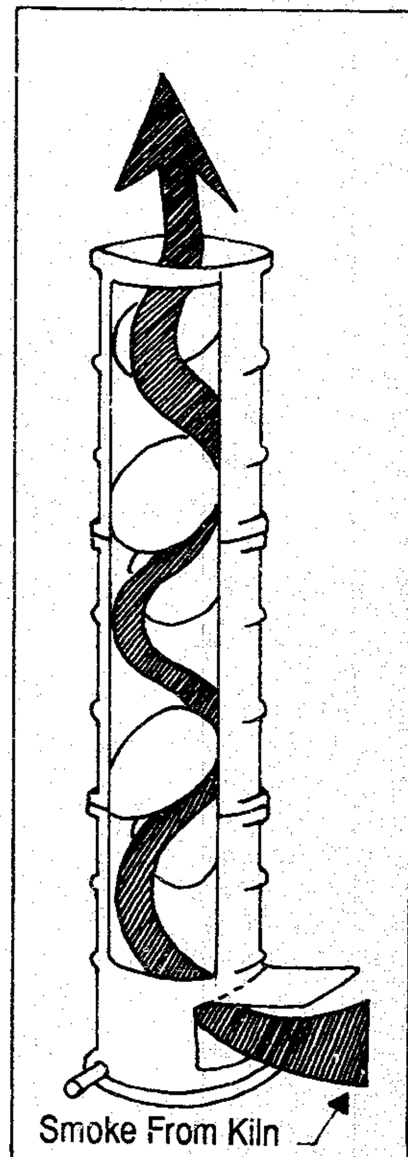
Further kiln runs experimented with carbonizing large diameter pieces of wood mixed with small pieces. It was found that anything that could be rolled onto the platform by 3 strong workers would carbonize along side of a small chunk. The small chunk would carbonize first,but the limited air supply prevented overkilning. For the same reason, woods of different species and moisture content could be managed in the same charge.

During a demonstration of the kiln in Mali, there wasn't time or money to build a "normal" chimney at a metal shop so 3 empty oil drums were pressed into service. They were opened with a cold chisel and wired together. This was the forerunner of the present chimney which is much simpler, and cheaper, than the original chimney. Later chimneys would be welded to reduce a leakage problem. This chimney recovers much of the condensable volatiles and doesn't collapse under heat as did the base in the original. In addition it could be moved around to a different side of the kiln during the carbonization process, if necessary.

Building a Casamance Chimney



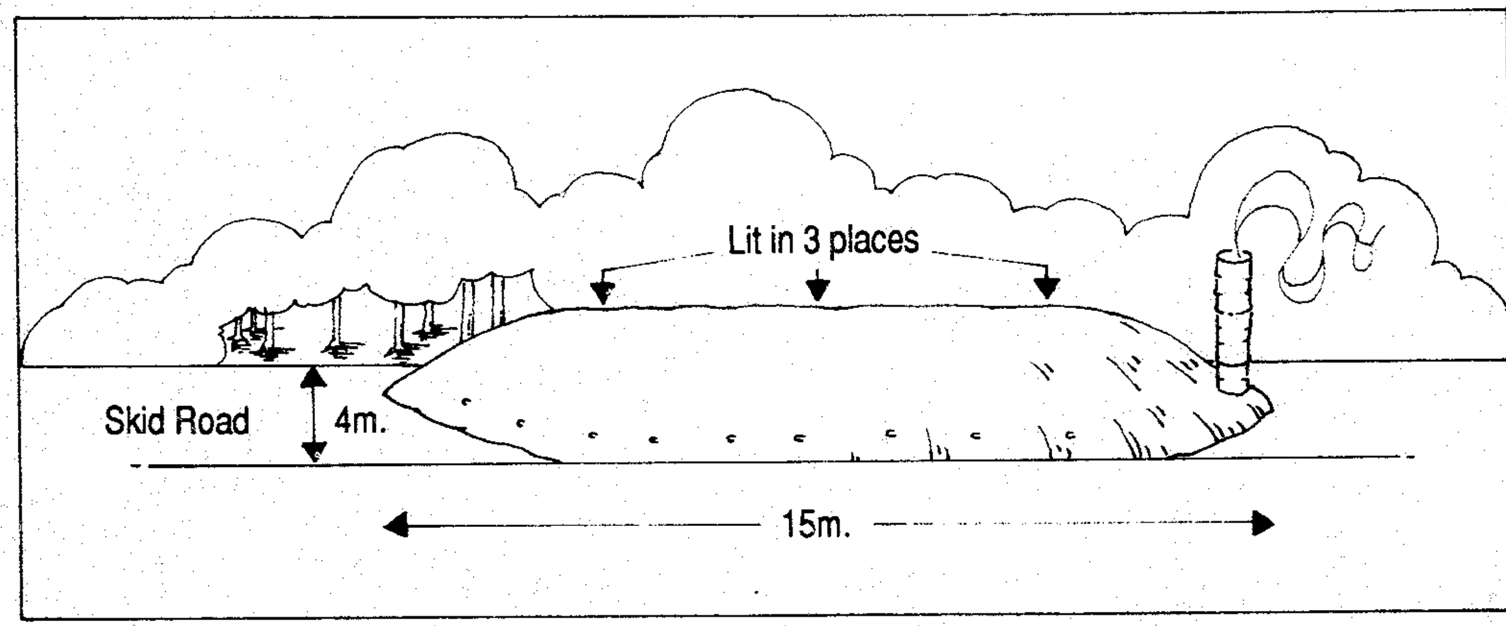




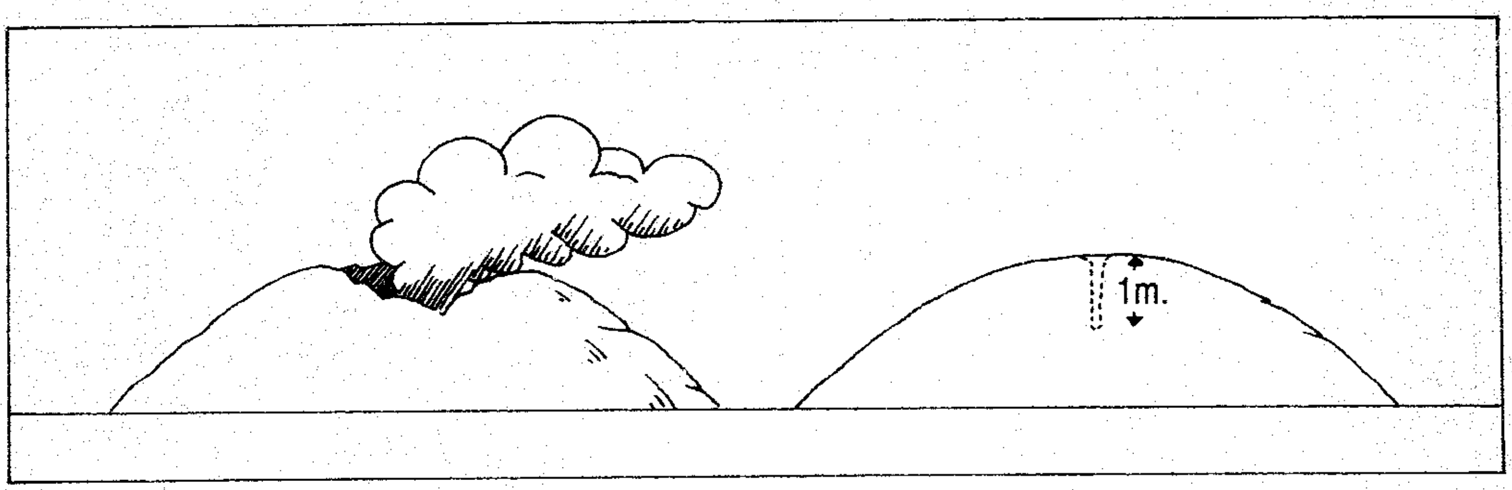
Chimney with Baffles

Experience with the kiln showed that optimum crew size was 3 persons for a kiln of 60 to 130 steres. Kilns smaller than 60 steres have a much lower heat mass and yields start to drop. Kilns larger than 130 steres tend to become inefficient because they become too hard to operate.

In other experiments in an effort to limit the damage to the forest soil, there was an attempt to produce a Casamance Kiln that would fit on tractor roads. The dimensions were stretched to fit the road. It worked, but not as well as the parabolic shape. One of these kilns got away and burned up 100 steres of wood. It was first judged to be from negligence in the surveillance, but about a month later, another one escaped. The long Casamance was just too hard to handle and was abandoned.



A recurring problem was the collapse from shrinkage of the charge which occurred in the center of the kiln along the lighting chimney. On 100 stere kilns, this would occur about 4 a.m. during the first night when the crew was at their lowest energy level. Patching a large hole in the dark is dangerous. It was suggested that lighting about 1 meter down from the top instead of near the bottom might cure this problem, and it did. The shrinkage still occurs, but over a longer period of time which usually will not cause a severe collapse.



The 4 a.m. volcano. New lighting chimney extends only 1 meter into the kiln.

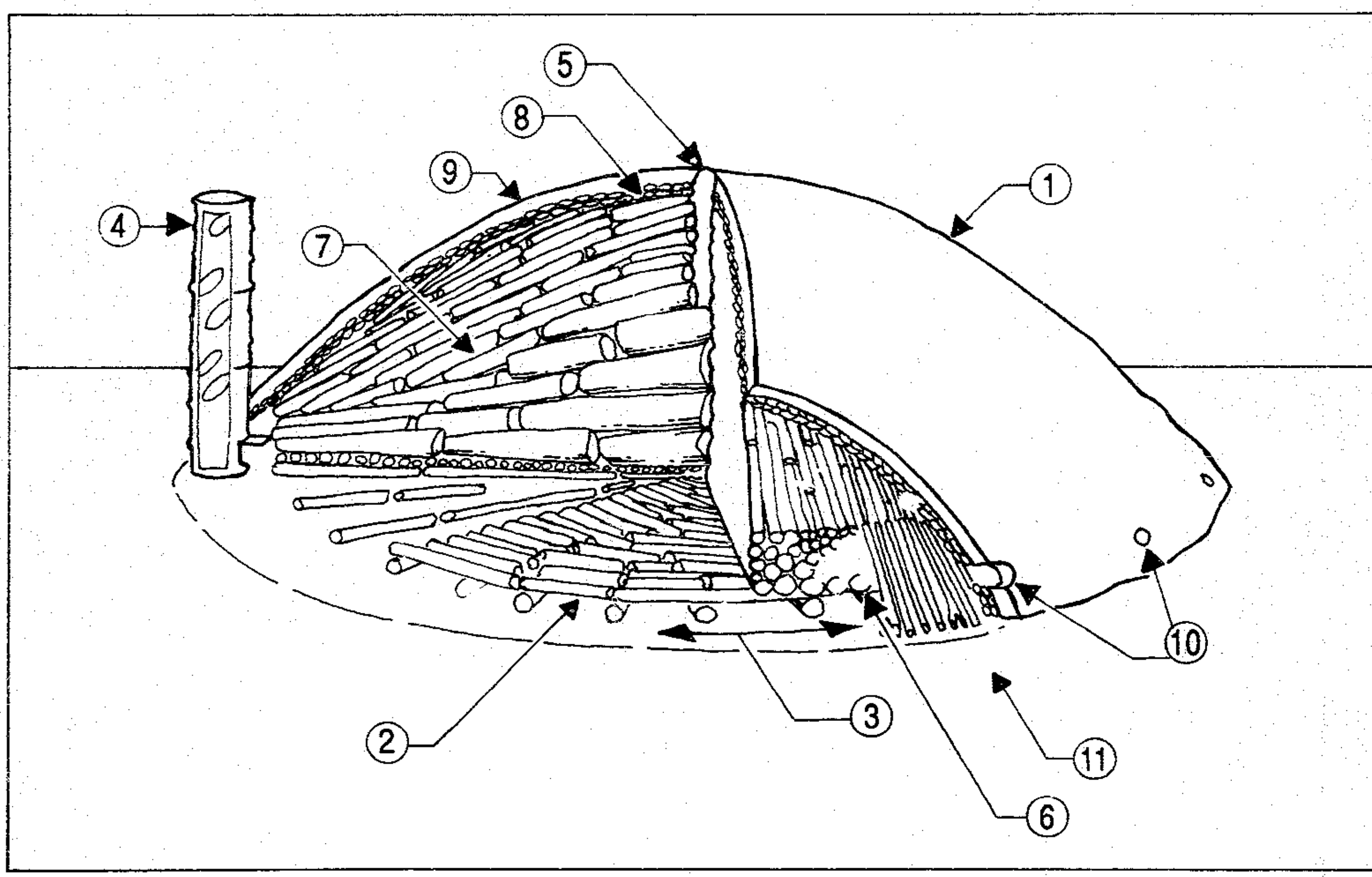
A recent change has been to finish the kiln without the final layer of small wood on the outside. The labor involved in handling this small wood was not warranted by the minor increase in production. This layer served to smooth out the final contours of the finished kiln and made it look better. But the kiln works just as well without it, and since there are only a few who can really appreciate the aesthetics of a kiln, the small wood layer was no longer added. The small wood now goes to supply fuel to the surrounding villages and probably gives a better return in good will with the local villagers.

Each of these changes has improved the efficiency, speed or ease of operations, or just felt like the thing to do. This design works for the operators, and they use it. A good design is no good if it is not used.

As a footnote to this chapter it should be mentioned that in Senegal, the Casamance Kiln has seen only limited success outside the project largely because there are few incentives for the workers within the organizational structure of a typical Senegalese charcoal production operation (See Kiln Analysis, page 34).

It has been more successful in other countries as a substitute for local traditional methods. It is currently used in Mali, Burkina Faso, Cameroun, Mozambique, Kenya, Uganda, Rwanda, Burundi, Belize, and has probably crossed a few other borders in one form or another.

The Characteristics of a Casamance Kiln



Casamance Kiln

1. **Low Domed Shape**
   * Places thick pieces of wood at the center of the kiln for complete carbonization
   * Gentle slope of kiln sides allows easy sealing with earth

2. **Platform**
   * Allows air to get in and out of any part of the kiln

3. **Air Chamber**
   * Mixing of exhaust and intake air preheats input air and cools exhaust air, dilutes oxygen and increases carbon dioxide content. This makes the kiln easy to control.

4. **Baffled Chimney**
   * Provides draft to promote quick carbonization
   * Allows the collection of condensable volatiles

5. **Top Central Lighting**
   * Promotes even carbonization by allowing no favored air path
   * Minimizes collapsing during the run

6. **Radial Layering**
   * Promotes even carbonization by allowing no favored air path

7. **Tight Packing of the Charge**
   * Minimizes collapsing
   * Lengthens gas path

8. **Vegetation**
   * Keeps earth out of charge

9. **Earth**
   * Serves as a barrier to air

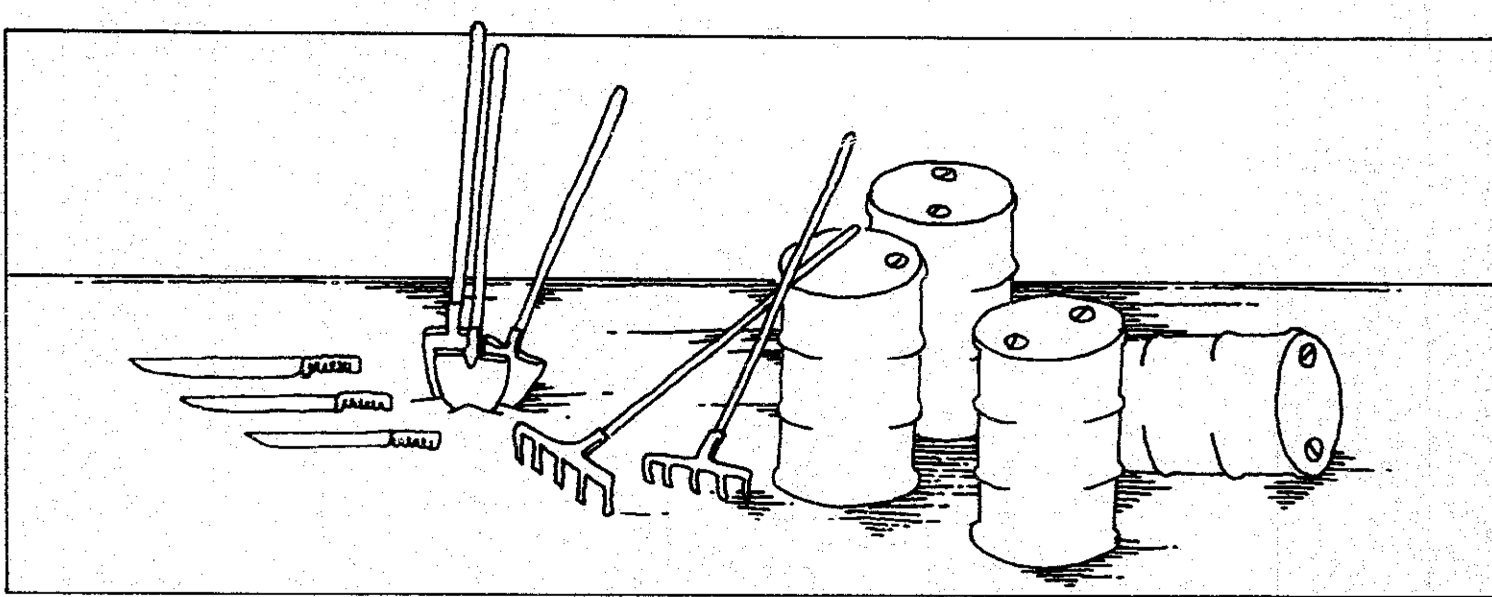
10. **Inlets**
    * Allows air into the air chamber

11. **Size**
    * Between 90 and 130 steres for maximum efficiency

Chapter 2

Construction

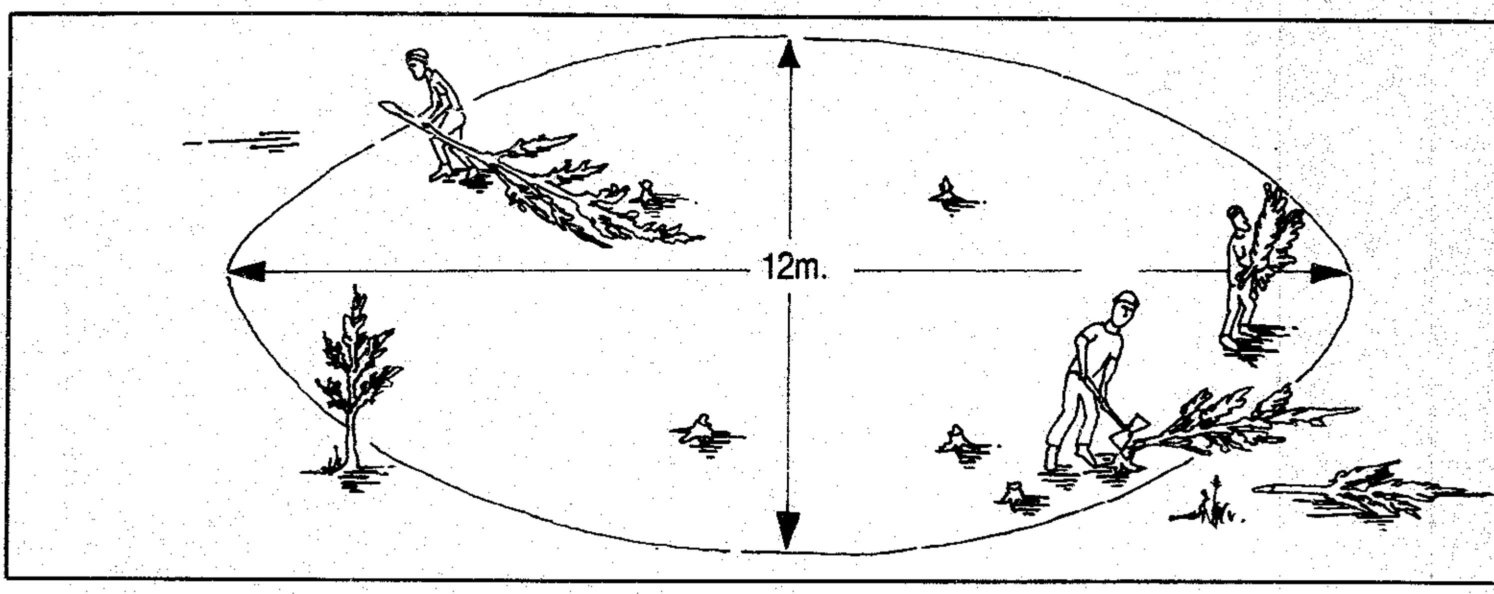
To construct a Casamance Kiln, you will need shovels, machetes, rakes and four 200 litre drums, three for the chimney and a half drum to collect the condensables. In addition, to fabricate the chimney, you will need access to welding equipment.



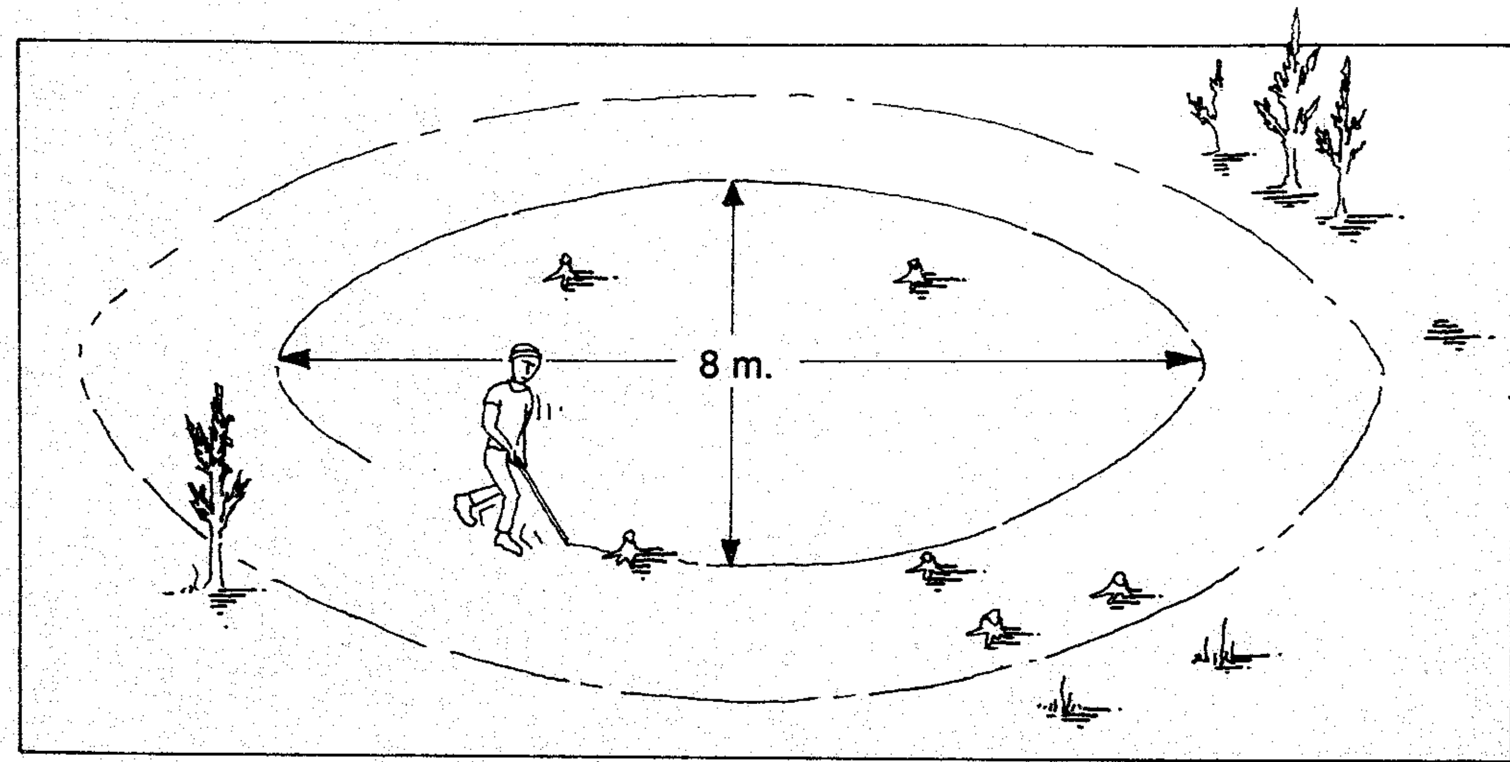
Once the wood has been cut, an experienced crew of 3 people should be able to assemble a 100 stere kiln in 3 days. Ideally, the wood should be allowed to dry at least a month before carbonization in order to save energy that would be wasted in boiling off water.

Charcoal is usually made in the dry season, and although light rains will not affect the operation of a Casamance Kiln, a heavy rain will reduce yields.

Layout

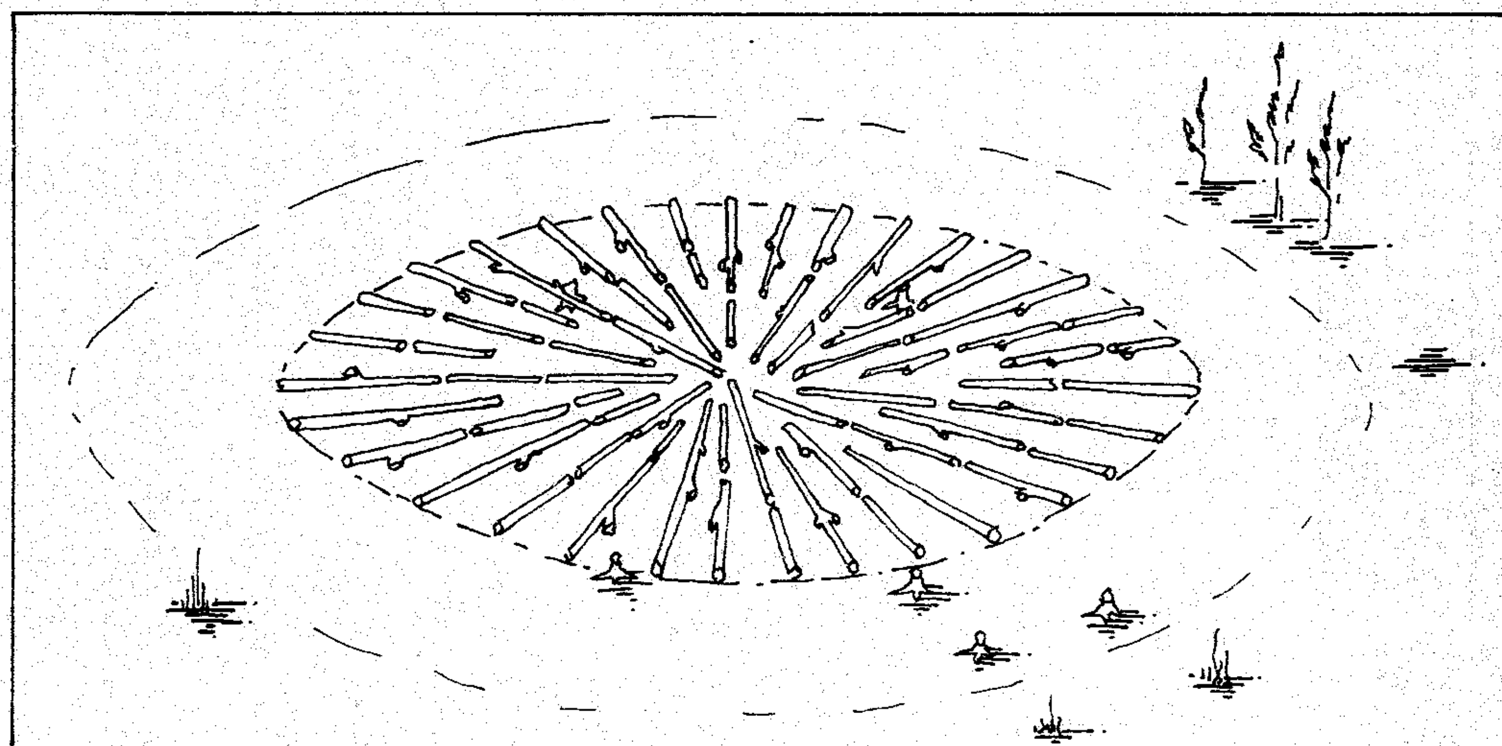


Clear the brush from the area where the kiln will be built. It is not necessary to move any earth.

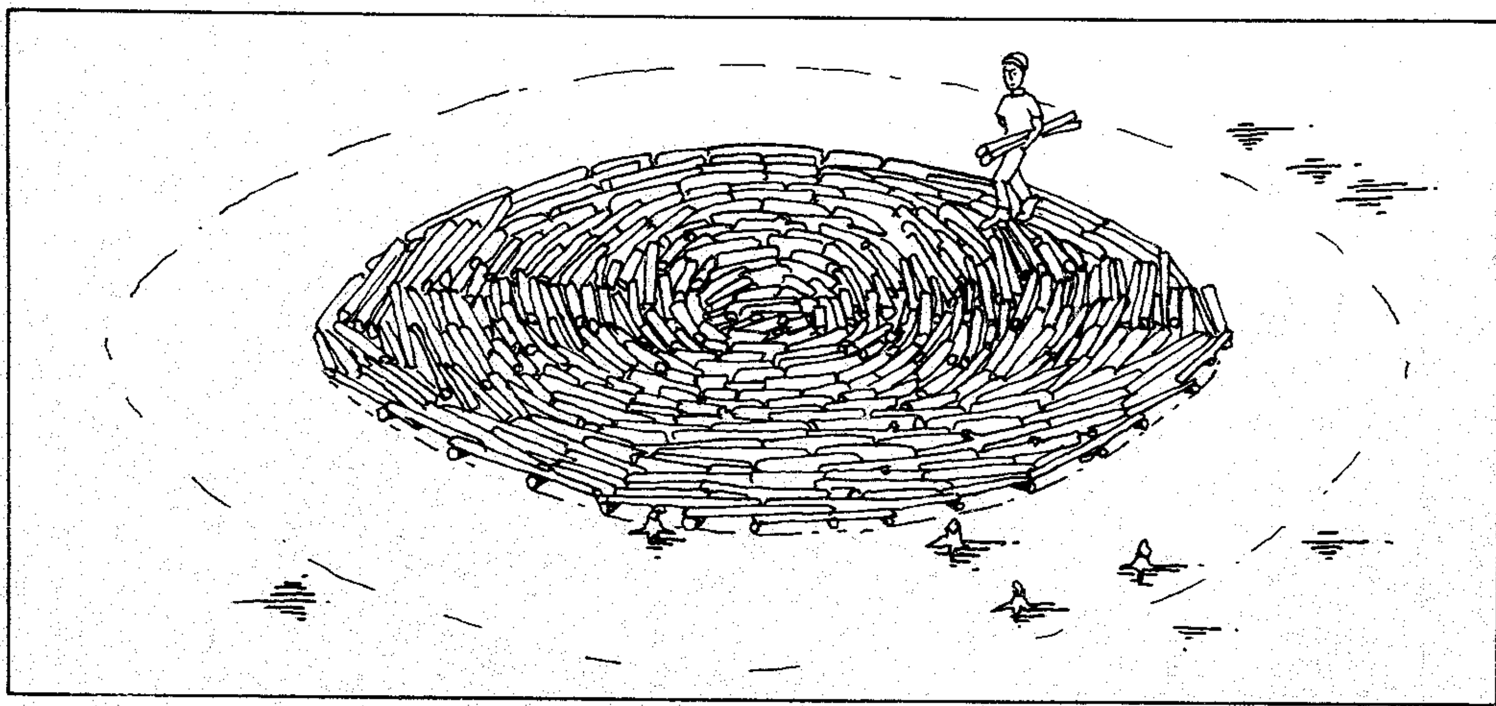


Use a stick to draw a circle 8 meters in diameter on the forest floor. This will be the size of the main part of the charge.

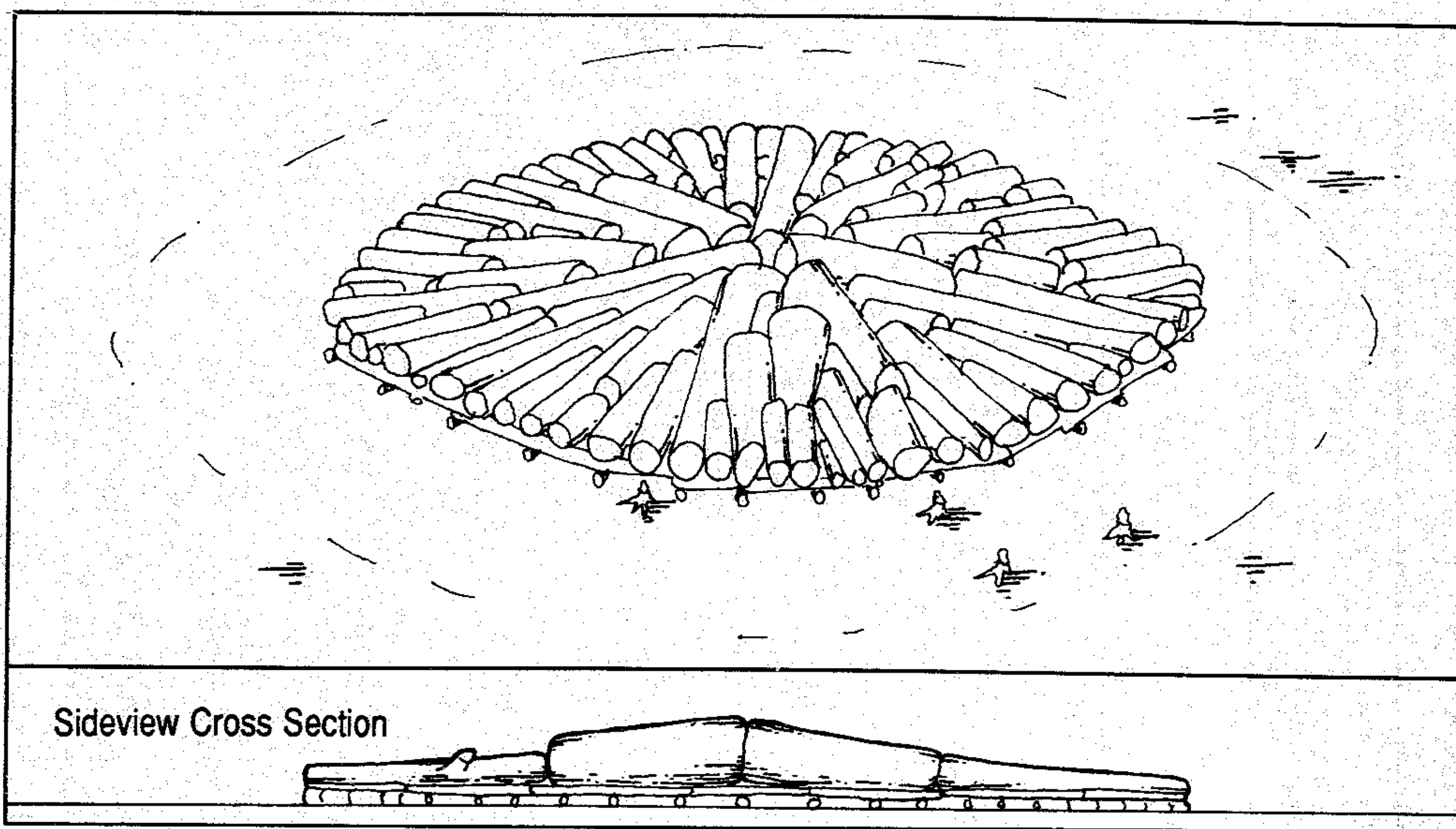
Stacking



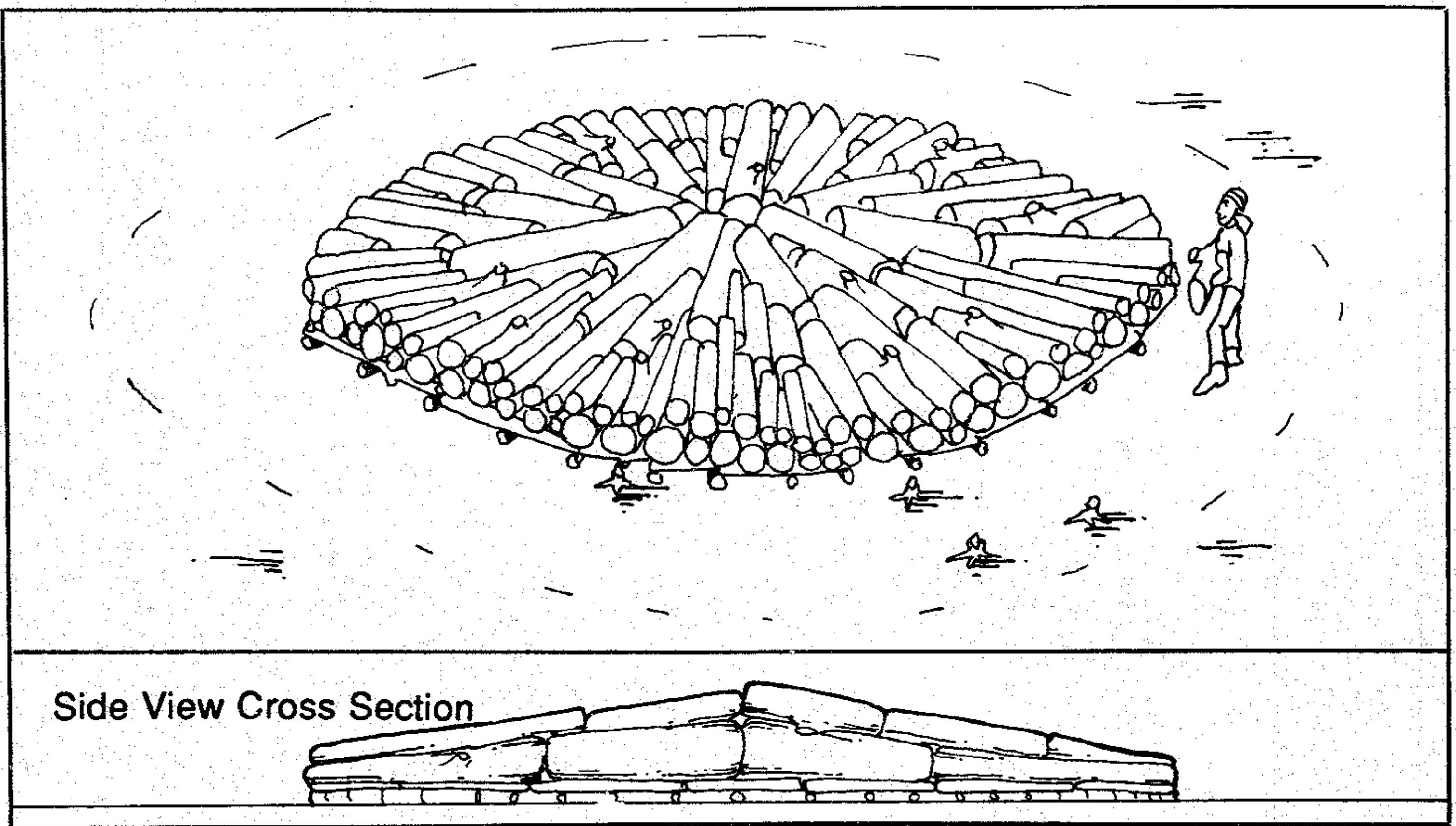
Place pieces of wood of at least 10 cm. diameter as stringers in a radial pattern. Allow enough space between the stringers to provide easy air passage. Be sure that the stringers lie flat to provide a stable base for the platform. The stringers do not have to be laid end to end.



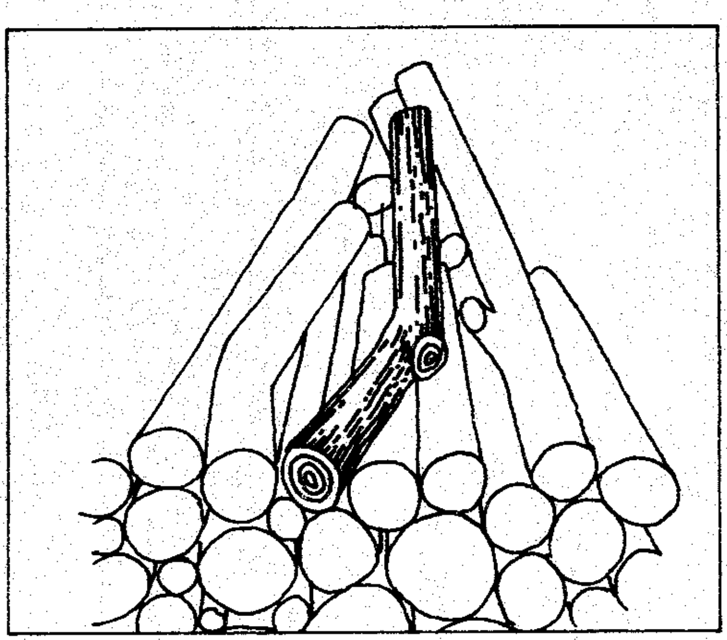
Use smaller diameter material to build a sturdy platform. The area under the platform will be for air distribution. Walk around on the platform to test its strength. A strong platform makes it easier to stack the charge and keeps large logs from blocking the air passage below.



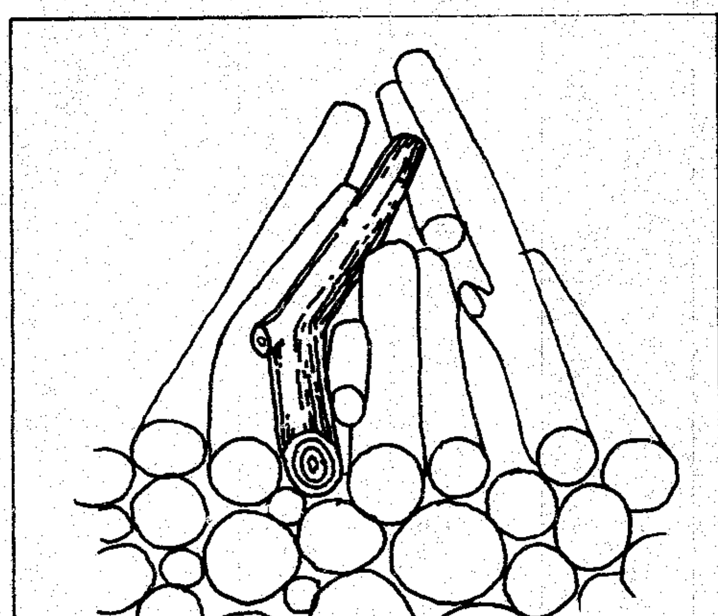
The thickest pieces should be the first placed in the stack. Place the larger end of the log toward the center of the kiln and fill in around it with smaller logs. Tight stacking of the charge is essential.



After placing the second layer of wood on the kiln, the stacking becomes random. Pick up a log and walk around the kiln until you find a place where it fits tightly. Fill in small spaces with chunks of wood and small sticks.

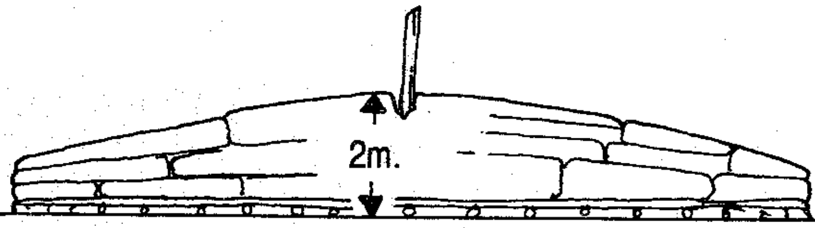


Loose packing



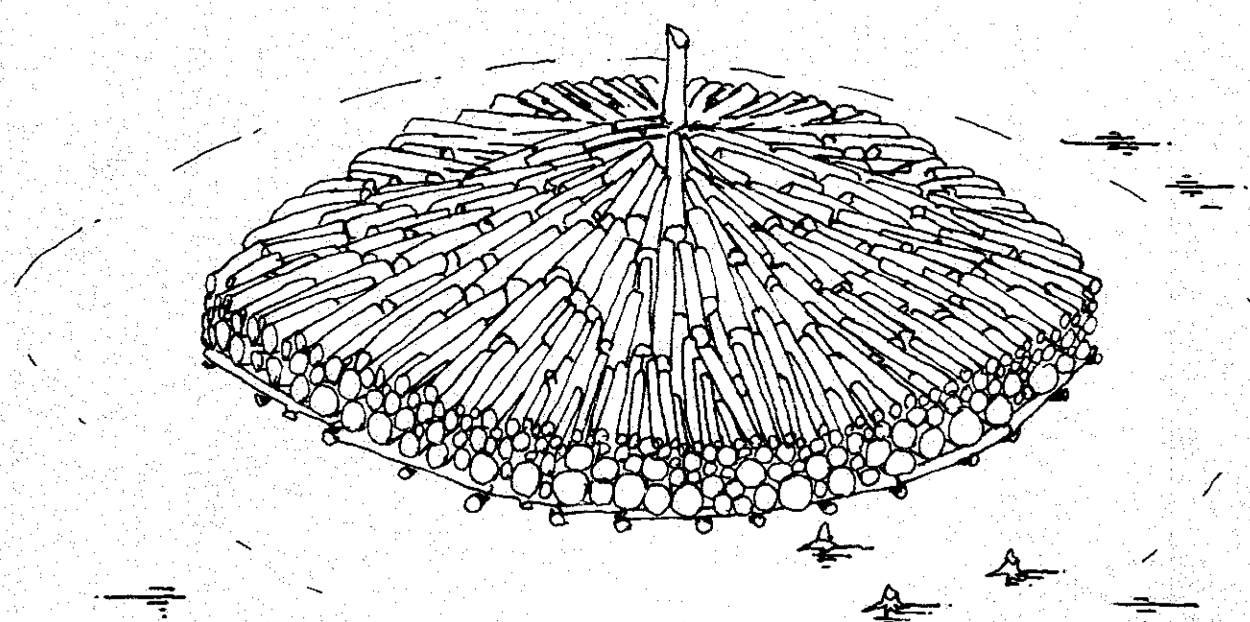
Tight packing

Tight packing gives better yields, prevents collapse, and provides a more even carbonization. The end result should be more like a large puzzle than a loose pile of wood. Each piece should fit the hole it goes into. Smaller holes are filled with smaller pieces.

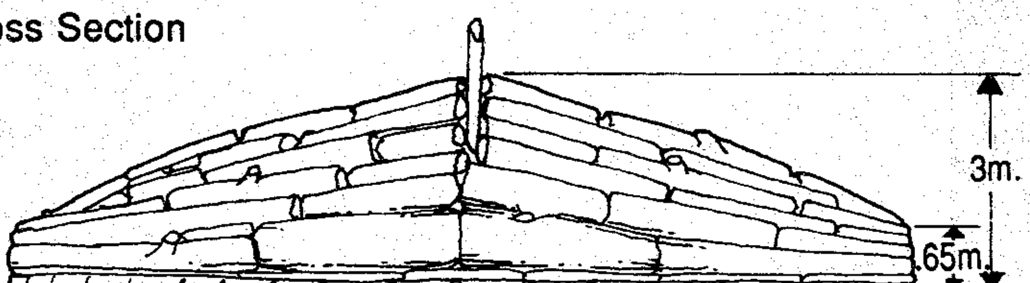


Side View Cross Section

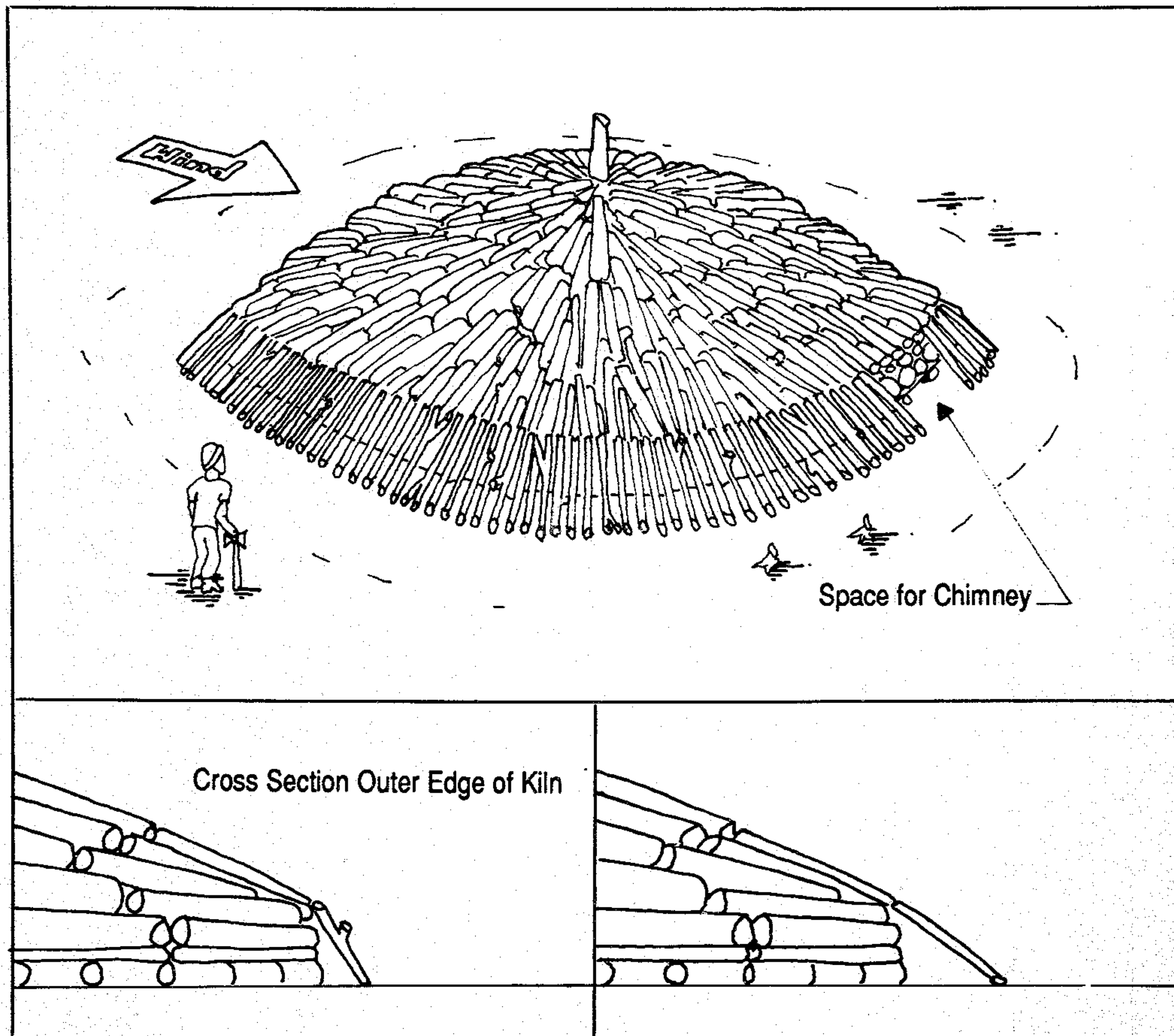
When the stack is 2 m. high, place a stick 15 cm. in diameter in the center. When the kiln is finished and the stick is removed, the void it created will form the lighting chimney.



Side View Cross Section



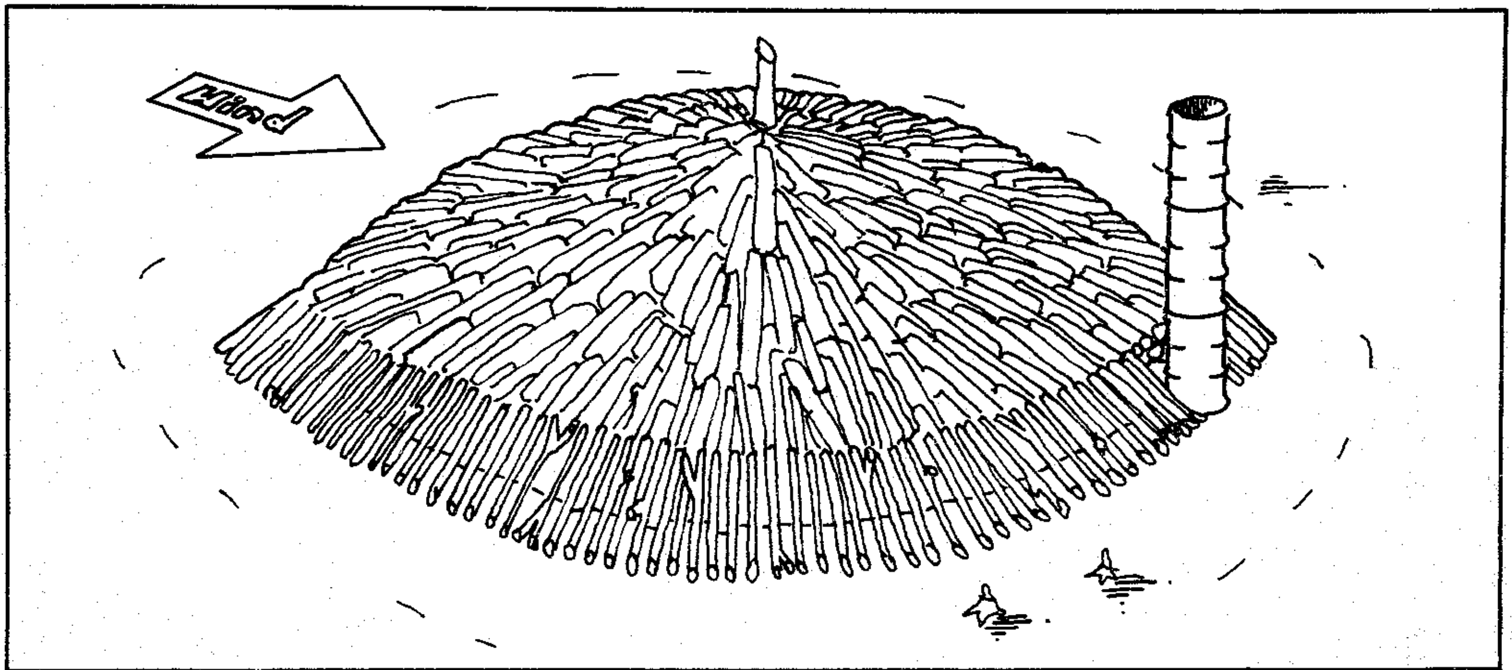
The wood is stacked to approximately 3 meters in height. As you stack, try to create the shape of the characteristic Casamance charge, straight sides and a top which slants up to the center.



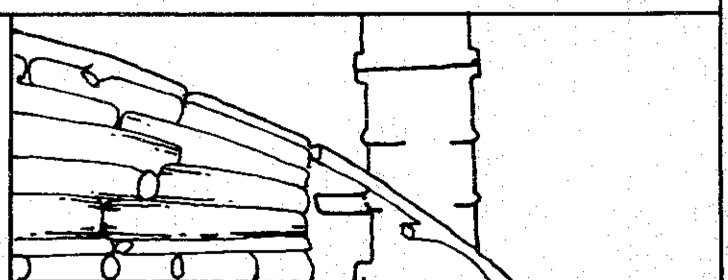
Air chamber too restricted　　　　Correct air chamber

Construct the air chamber surrounding the kiln with small diameter sticks. These should be sticks long enough so that the sides of the chamber will not be too steep. The gentler slope makes covering the kiln with earth much easier and creates a larger clean air passage. Leave a space open for the chimney on the lee side.

Chimney placement

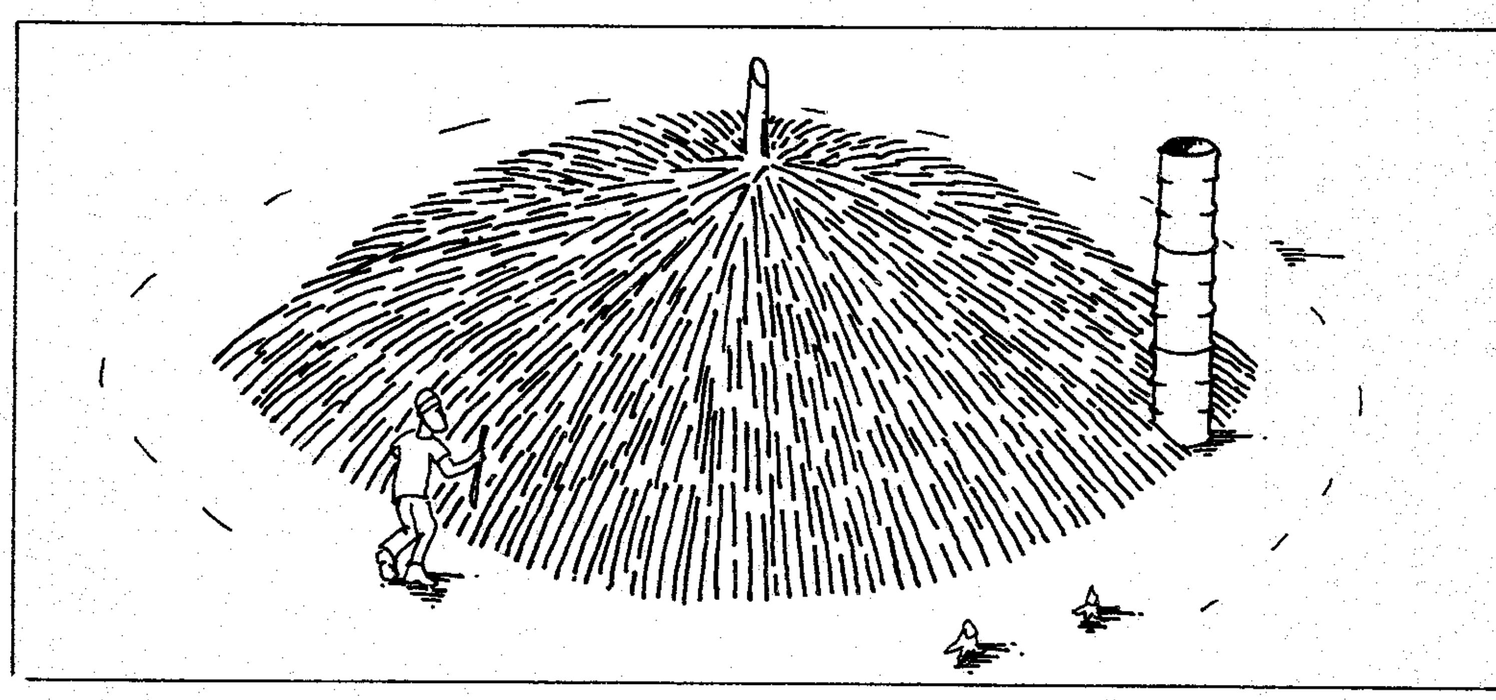


Place the chimney on the kiln making sure that the passage from the air chamber to the chimney inlet is clear.

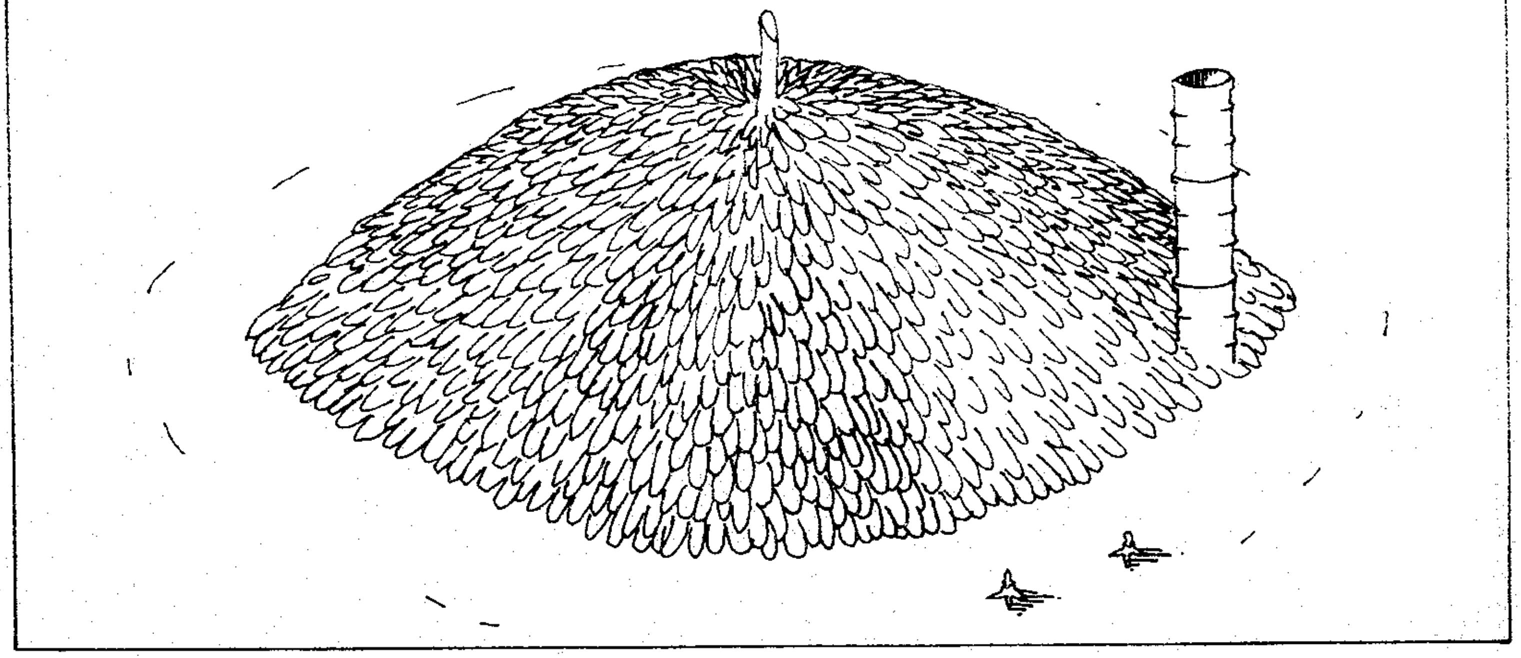


Cross Section Outer Edge of Kiln

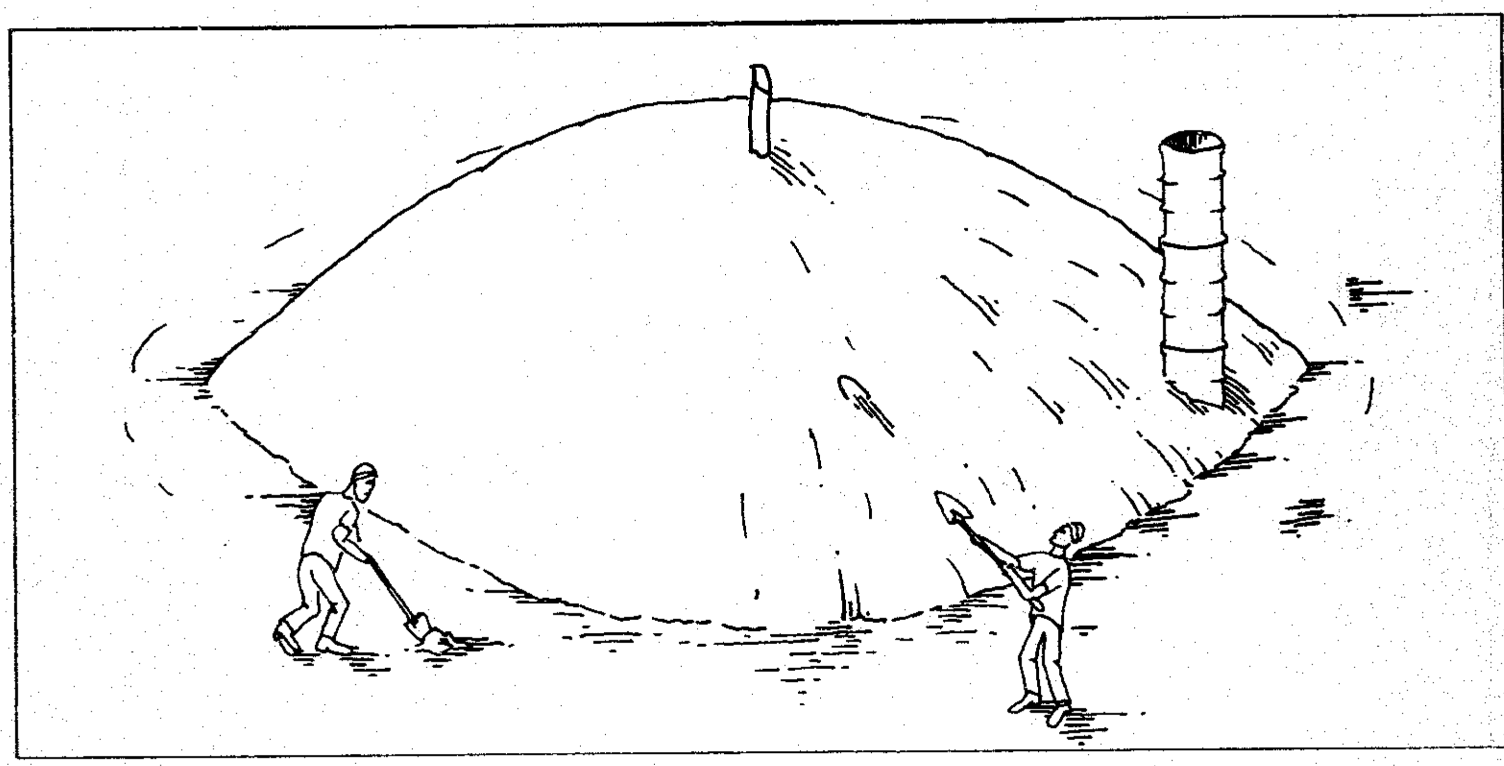
Covering



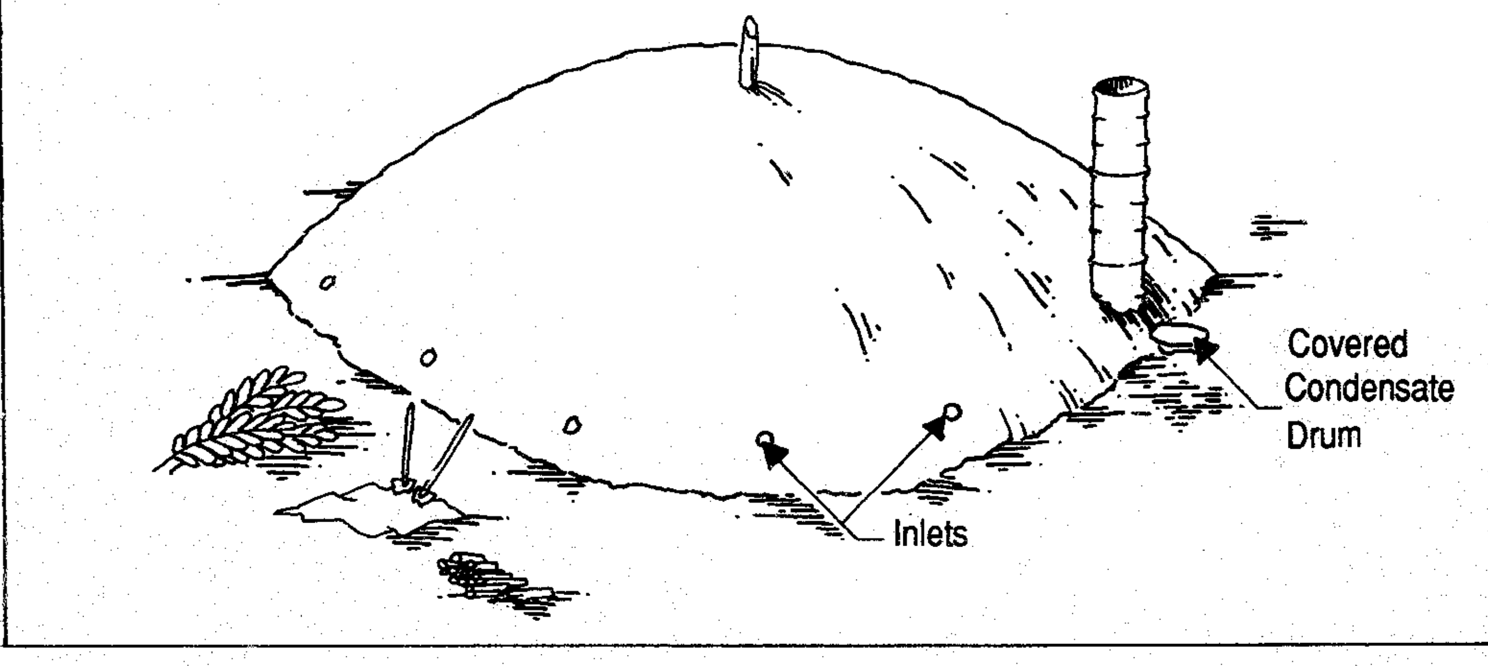
On the final layer of wood, use small sticks to fill in any remaining holes and to give better support to the vegetation. This is optional, but should be done with the first several kilns as it easier to cover with earth.



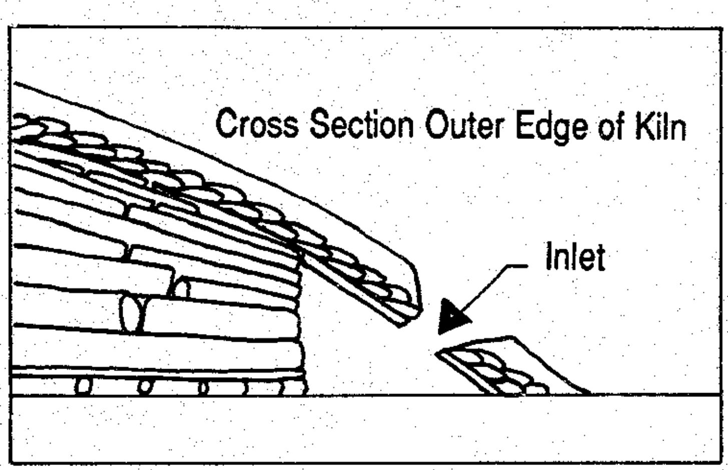
Cover the entire kiln with vegetation. Most any vegetation will work, but given a choice, use vegetation that will easily lie flat, such as palm fronds. Start at the bottom and layer the vegetation over the previous piece as you go up. Lay the material as flat as possible in order to avoid creating air channels through the earth layer. Apply 2 to 3 layers to ensure no earth will touch the charge.

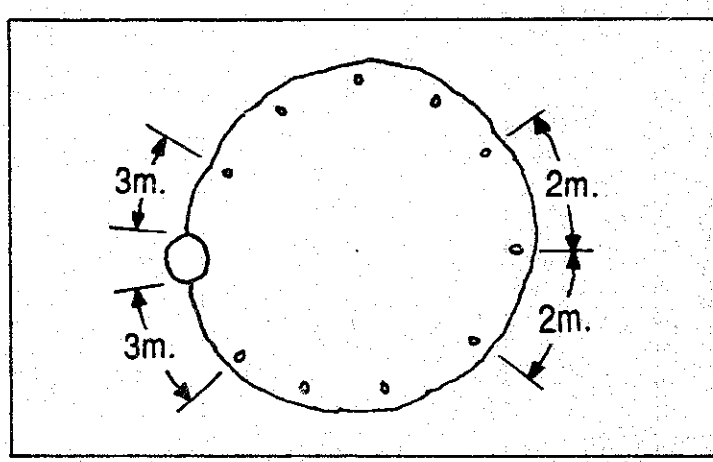


Cover the kiln with earth by working your way around the kiln. Start piling earth up at the bottom so that it stacks on itself to a degree. Put on just enough to seal the kiln, usually about 10 to 15 cm. in depth. Sticks or vegetation mixed in the earth cover can poke through it to act as unwanted chimneys.



Dig a hole next to the chimney for the condensate drum. Position it in such a way that it can be easily emptied during the run without upsetting the chimney.





Vent Placement (Top View)

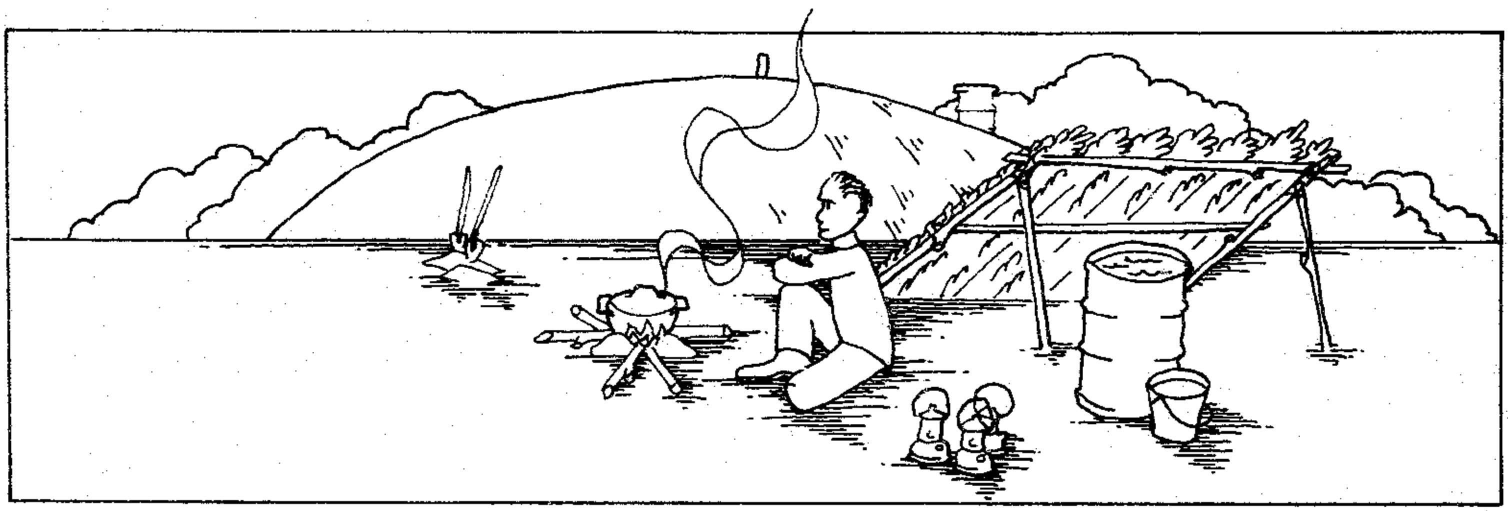
Make air inlets through the cover into the air chamber. They should be 10 cm. in diameter and placed about 2 meters apart and about 20 cm. above ground level. No intakes should be placed within 3 meters of the chimney. Keep loose earth, vegetation and small wood chunks available for patches if needed.

The kiln is now ready to light.

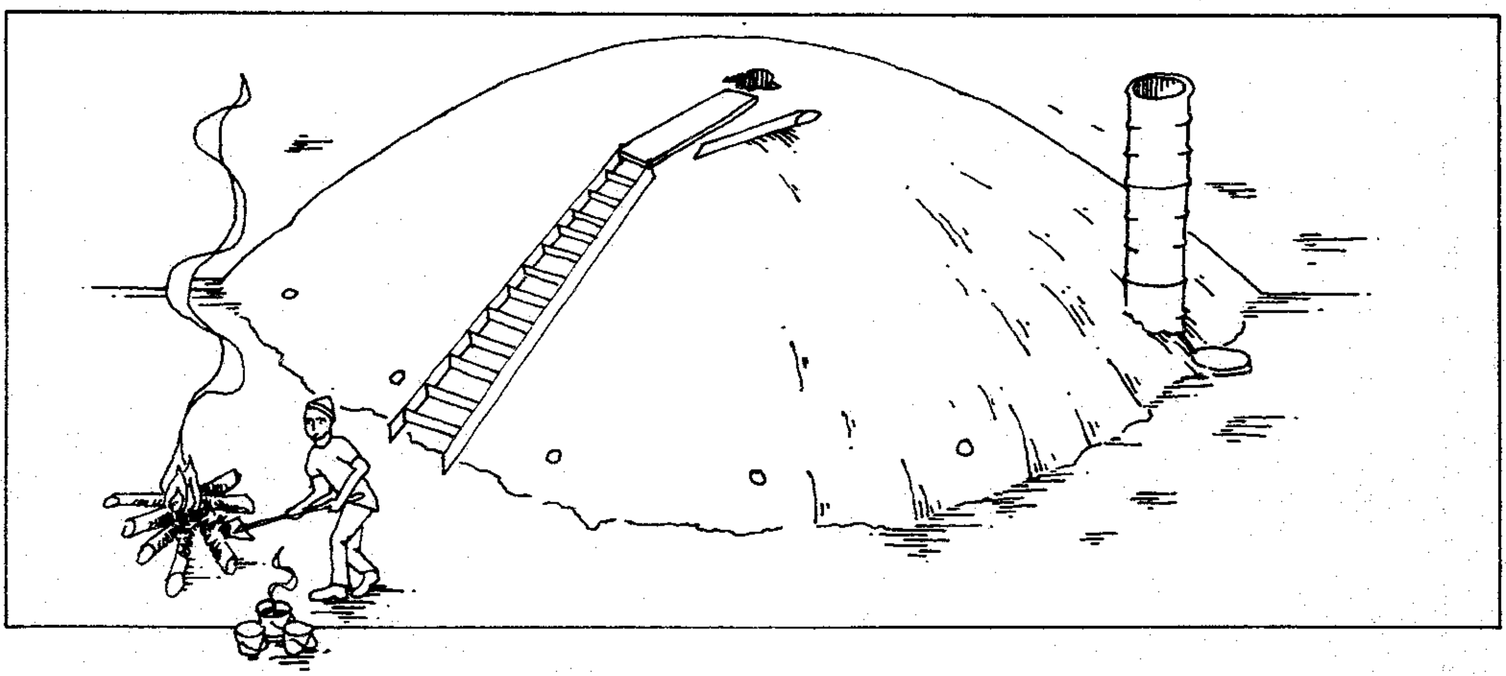
Chapter 3

Operation

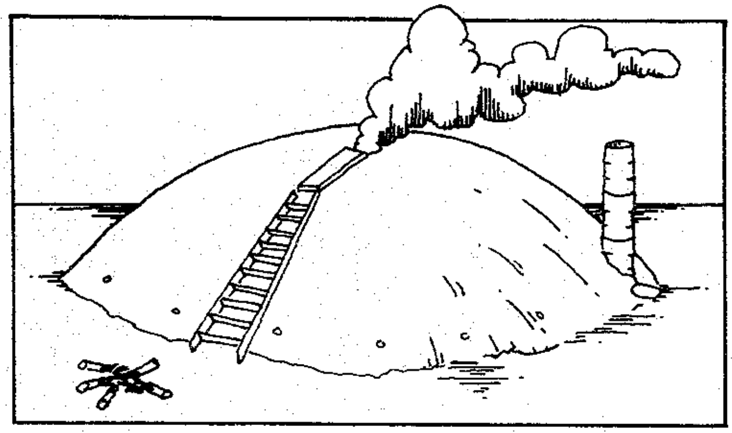
To operate the kiln you have just built, you need additional supplies. A nearby water source is needed for drinking, fire fighting and possibly extinguishing the charcoal. Lanterns will be needed to observe the kiln at night. The kiln will run for up to 5 days and will require constant attention. The comfort of the workers should be provided for on site.

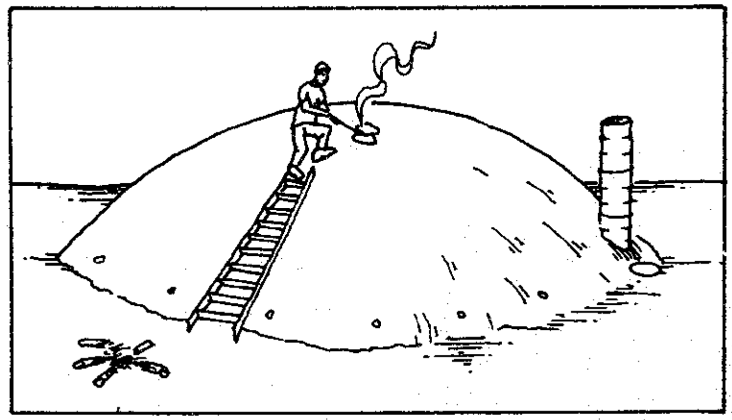


Lighting



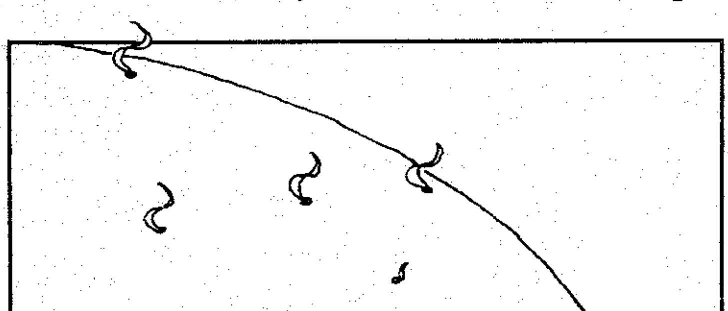
The Casamance is lit at the firing chimney with hot coals.The first step in lighting is to make sure that all vents are wide open to encourage combustion. A fire is lit to one side of the kiln and when coals are red hot the stick in the ignition chimney is pulled out and the coals are dumped in. The entire channel is packed full of coals. Since the coals have already shrunk, there should be much less chance of collapse with top lighting. The entire kiln will gradually descend with only minor holes.



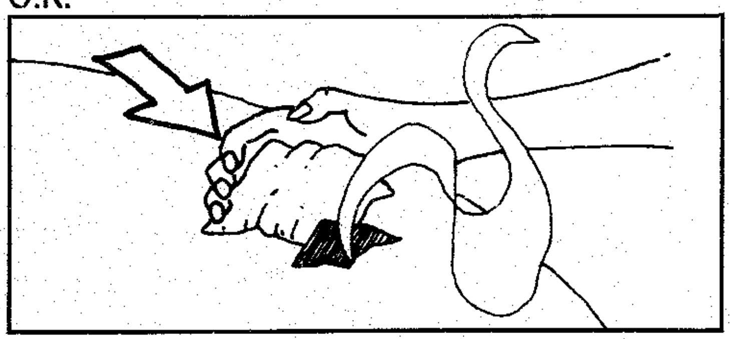


After the coals are in place, thick smoke will begin to pour out of the lighting hole in the top. The lighting chimney can now be sealed. All the necessary heat for ignition is already in place. Seal the lighting chimney with vegetation followed by earth. If the wood is wet, it is advisable to delay sealing for 10 minutes to insure ignition.

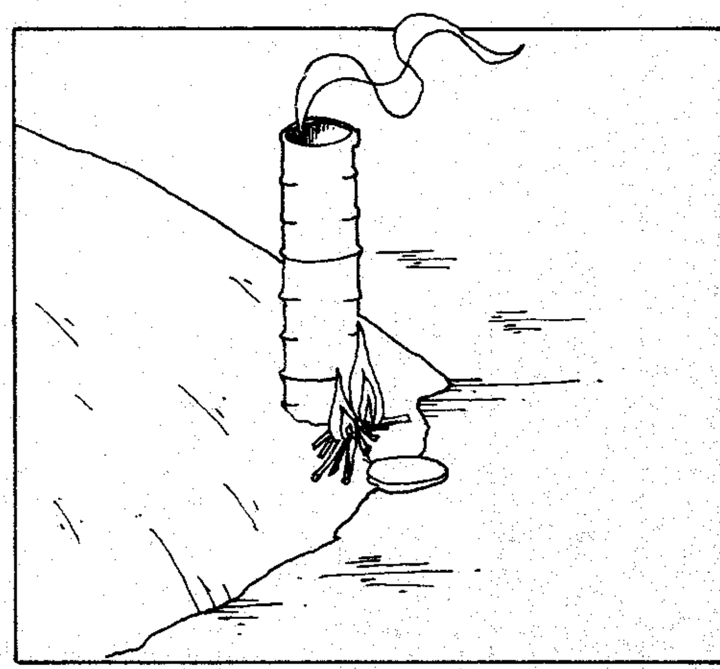
When the lighting chimney is sealed, the kiln has a slight positive pressure inside caused by expanding gas. The small smoke leaks caused by this pressure can be ignored, but any large cracks or holes revealed by the smoke should be repaired.



O.K.



Fix larger holes.

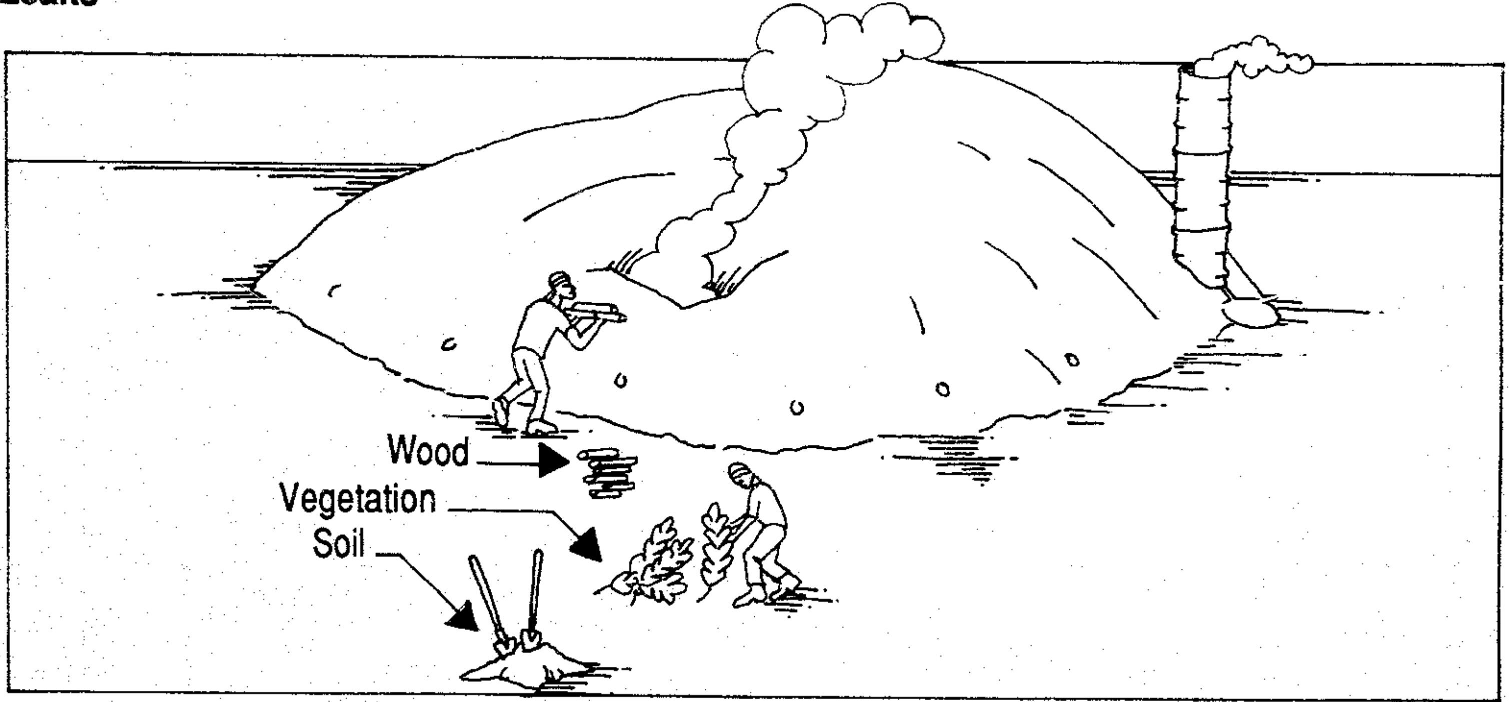


Heating chimney to create draft

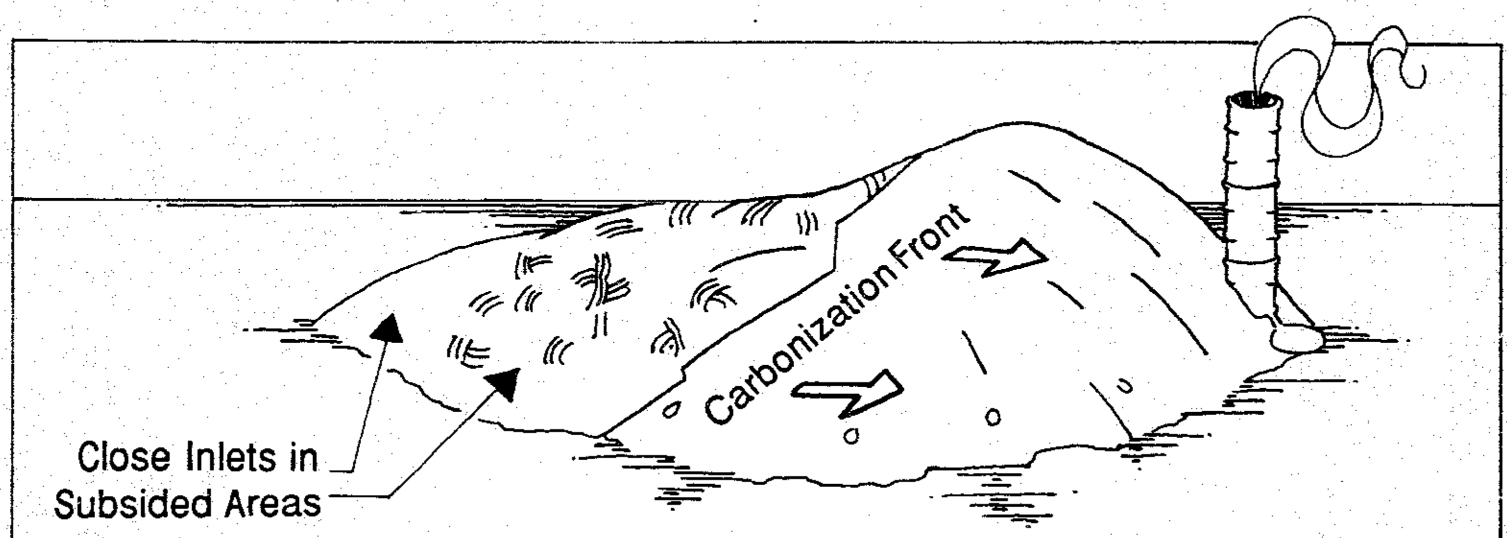
After sealing, if smoke is not seen coming from the chimney, a fire should be lit next to the chimney to heat the metal and start the draft. All air holes should be open during the firing phase to allow maximum combustion.

The smoke coming from the chimney will appear to die down soon after lighting. This reduction is caused by the volatiles condensing on the charge and giving up heat to the charge. If this condition continues for more than 2 hours, the lighting hole should be opened and examined to see if it needs relighting. Just opening the top is usually sufficient for the heat to pick up again, but if it is dead out it must be relit.

Leaks



It is normal for a kiln to have small smoke leaks all over the cover. If none are present, the kiln needs more air. Depending on the seriousness of the leak, larger holes can be repaired in several ways. Small holes can sometimes be repaired by merely raking earth from one part of the kiln to the other. If there are major leaks, these should be sealed with additional earth. Collapses where the earth cover drops into the charge must be sealed with vegetation before covering with new earth. If there are large holes, small pieces of wood may be needed to support the vegetation.



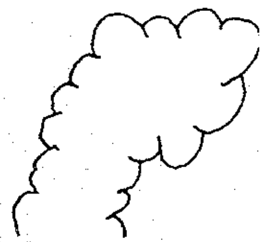
As carbonization proceeds, there will be a slow collapsing in certain areas of the kiln. These should be watched for holes, especially along the edges of the subsidence. This is where there is an active carbonization front.

Safety

If repairing the kiln requires you to walk on it, always walk on boards so that your weight is distributed over a large area. Falling into a kiln is deadly.

Following the Carbonization Process

IGNITION ——————————→ CARBONIZATION COMPLETE → COOLING

Appearence of Smoke					No Smoke
Type of Smoke	Thick, dark	Thick, white, billowy as moisture is driven off	Thin, yellow as the wood starts to break down	Thicker, blue smoke as the charcoal starts to burn	None
Smell of smoke	Like burning wood		Slight sweet smell	Burning charcoal	None
Feel of smoke	Hot	Cool, moist	Hotter, oily	Hot	None

Temp. of the kiln surface By touching the kiln and feeling where the heat is, you can find where the front is within the kiln.

Sound of the kiln As the wood carbonizes, you will hear snaps and crackles in different parts of the kiln resulting from the shrinking of the charge as it becomes charcoal.

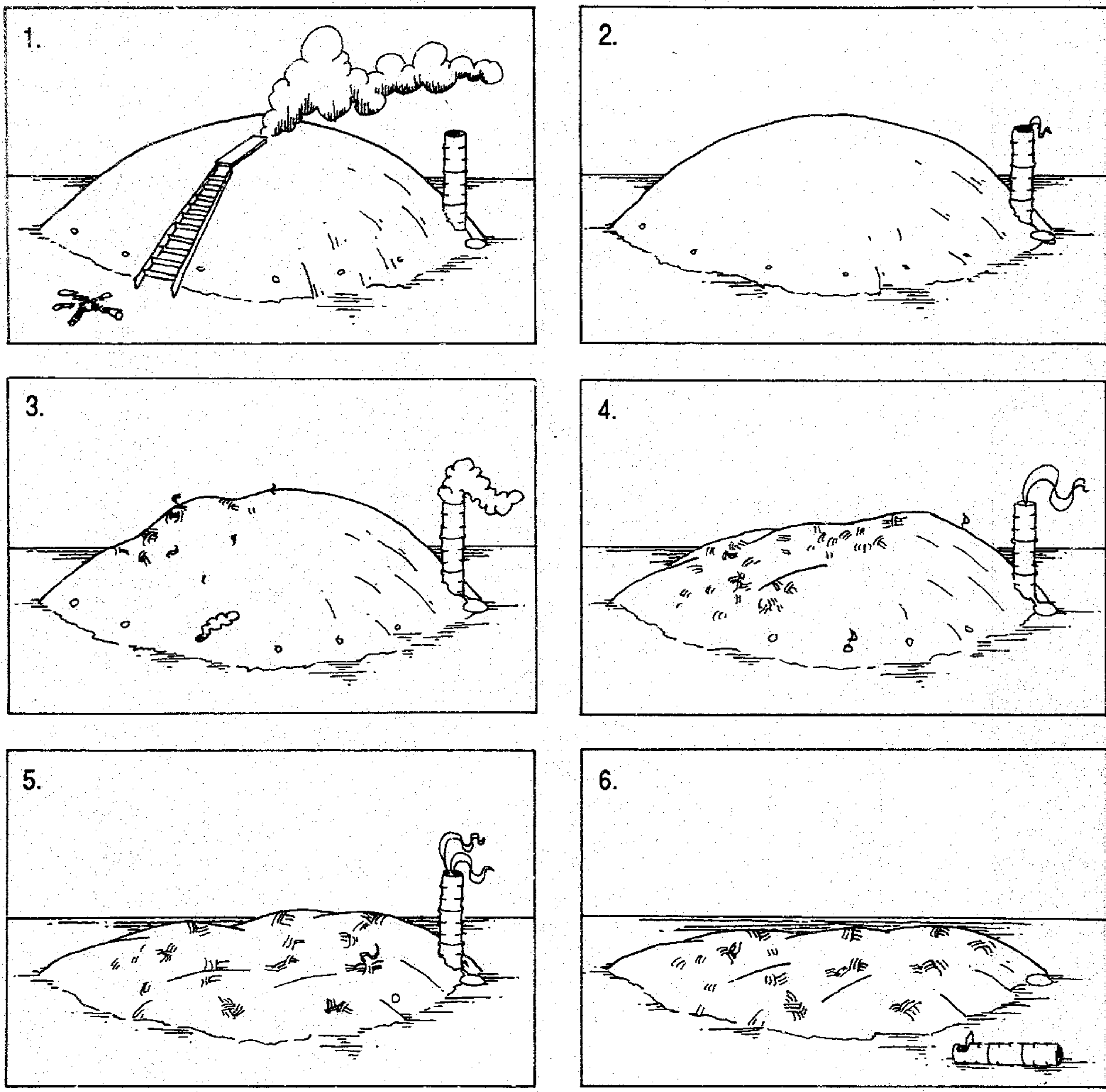
Time After running a particular kiln a number of times, you can make a reasonable guess how it is progressing just by knowing how long it's been since you lit it.

Inspection If you are uncertain what a particular part of the kiln is up to, open that section and find out.

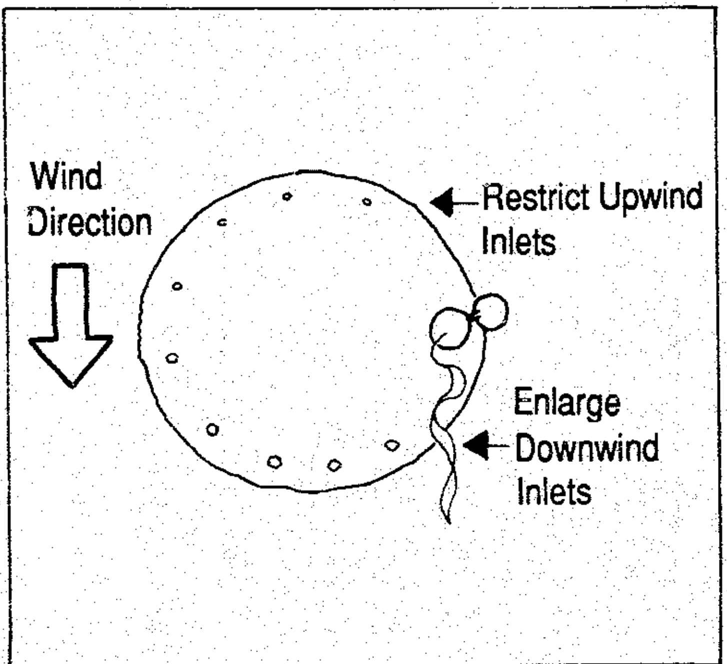
Shape As the charge carbonizes, it will shrink causing the kiln to change its shape.

Color of the earth cover The tars driven off the wood will darken the earth covering.

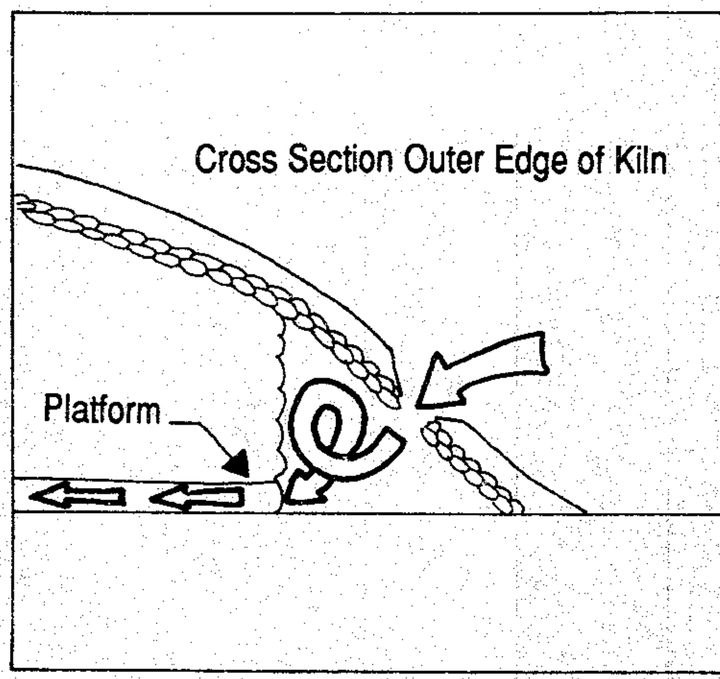
Kiln appearence during a carbonization cycle



Air Adjustments



Top View Casamance Kiln



Function of Air Inlets

Aeration is accomplished through a hole into the air chamber. As carbonization progresses, it may become necessary to adjust the amount of air intake. This is usually not necessary, but a strong wind on one side might require shutting holes on the windward side and opening additional holes on the lee side. It is normal for smoke to occasionally exit through an air vent and this may occur often with shifting winds. If a vent persists in acting like a chimney for several hours, close it.

A rare condition can occur near the end of the carbonization cycle where all the air holes start rhythmic puffing in and out. If this occurs, shut down the kiln and let it rest a bit, then try opening some vents. If it still persists, then seal the kiln. Air channels have been created inside the kiln that cannot be adjusted. This occurrence has been observed only twice in several hundred runs.

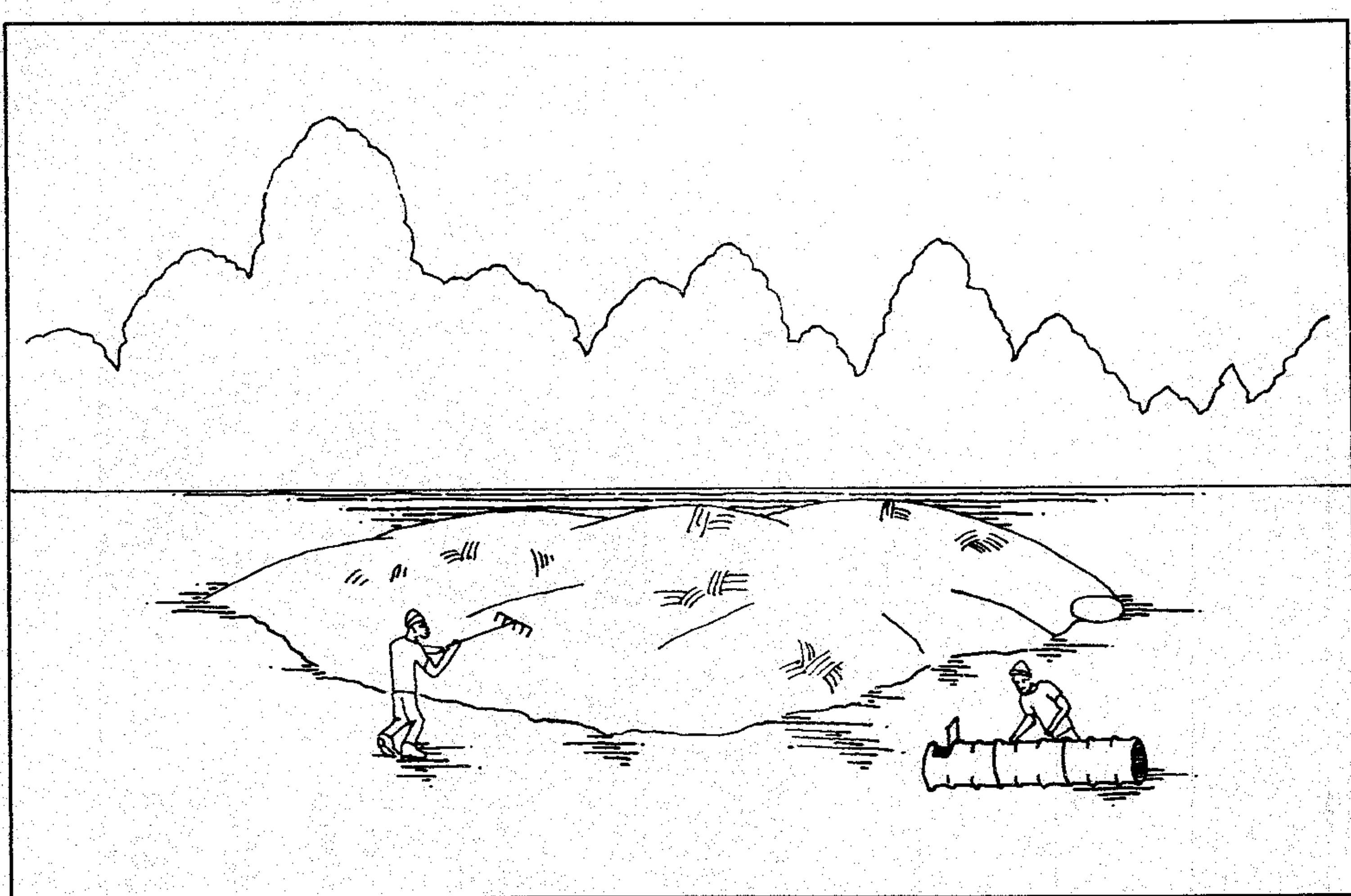
Moving the Chimney

If one of these carbonization fronts moves into the chimney area, it then becomes necessary to move the chimney. This is not difficult to do, but it may become very smoky. First, open a hole big enough to fit the chimney into a side that has not subsided. Pick up the chimney and place it into its new location. It is easier to carry the chimney when it is lowered to the horizontal than when it is upright. When the chimney is in place, seal around it with vegetation and earth. Seal the old hole once the chimney is relocated.

Shutting down the Kiln

You can tell a kiln is done by several factors:

- The collapse of the kiln is complete
- The smoke takes on a blueish tint
- The kiln is hotter and smells of burning charcoal



When the kiln has finished carbonizing, remove the chimney and seal all air inlets. Use a rake to smooth the cover and remove small stones, leaves, clods, etc. This raking loosens the earth cover so that any cracks are sealed as well as removing material that might be hard to separate from the charcoal. After the debris has been raked from the cover of the kiln, continue raking the area around the kiln.

Cooling

The kiln needs to cool as much as possible before extracting the charcoal to avoid the necessity of extinguishing burning charcoal with water. The amount of cooling time necessary depends on the climate, earth moisture, etc. Three days is the usual minimum for a 100 stere kiln. If the air and earth are dry, it may be necessary to extinguish the charcoal with water even after 3 days.

The cooling process can be accelerated by opening a small hole in the cover and pouring in 2 or 3 litres of water. The water will immediately be turned into steam, lowering the kiln temperature without dampening the charge.

Extraction

Charcoal is raked out while leaving the cover as intact as possible. Do only a small section at a time working from top to bottom. Work the charcoal out to the previously cleared area and spread it evenly. The section worked should be resealed immediately with earth after the charcoal is removed. The next area to be extracted will be to either side of the first. Continue to work around the kiln until the storage area is filled.(This process will usually require filling the storage area 4 times.)

Do not walk on the charcoal. Rake paths through the charcoal for walking. These paths also serve as fire breaks between cooling areas. Watch the piles for burning charcoal. The only time that there is not likely to be fire in freshly pulled charcoal is when it is raining. The charcoal can be extinguished by covering with loose earth. Do not bury the charcoal, lightly cover it.

If there was much rotten or insect infested wood in the charge, this charcoal will be hard to extinguish due to the air channels into the charcoal. Some charcoal made from insect eaten wood may actually burn from the inside out. Under dry conditions, this can be extinguished only by dunking the wood in water. Water extinguishing should be held to a minimum, as it lowers the quality of the charcoal.

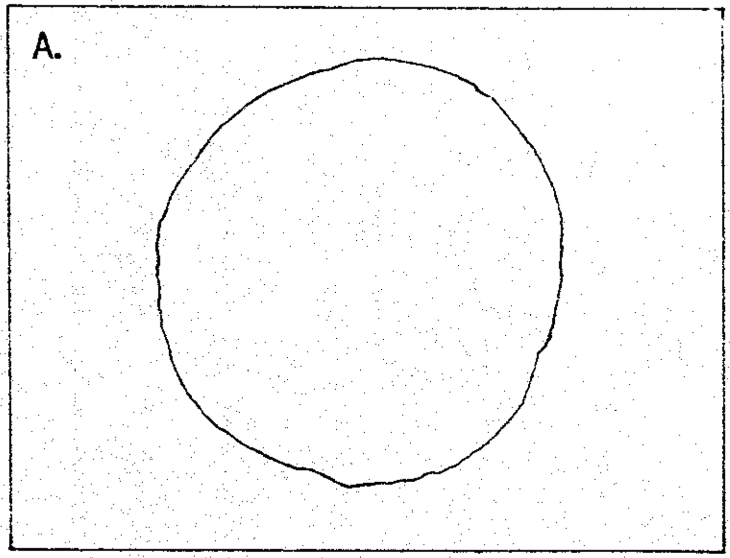
After the charcoal has cooled and no fire remains in the extracted charcoal, it can be raked into a pile on the outer edge of the cooling area. With hot charcoal, it is best to leave this step until the next day. Always move charcoal gently; it is fragile, especially when hot.

Sacking

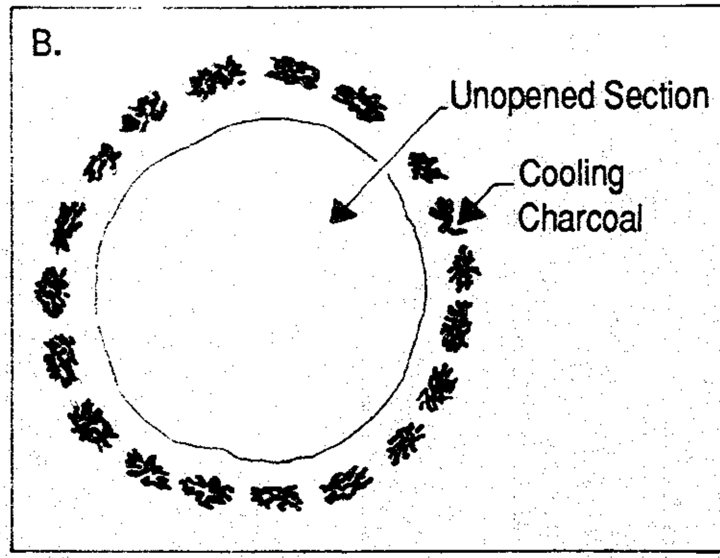
Larger operations may be able to skip this step if bulk handling is possible.

When the charcoal is cool and stable, it is ready to sack. The charcoal should be lifted into the sack with a pitchfork. There are several types of frames which hold the bag open for loading.

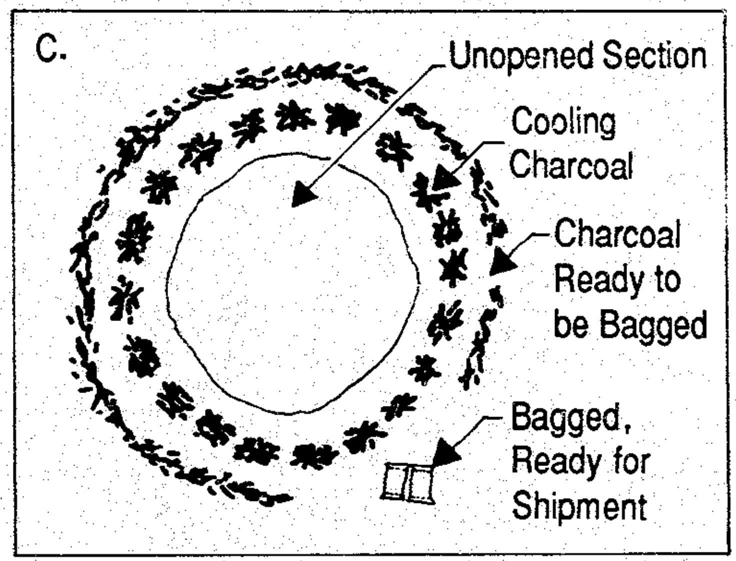
Extraction Sequence



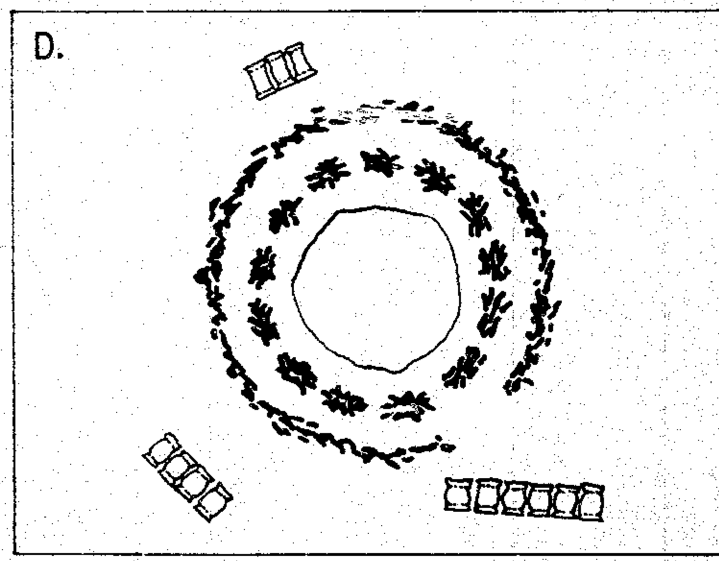
Top View Casamance Kiln after Carbonization



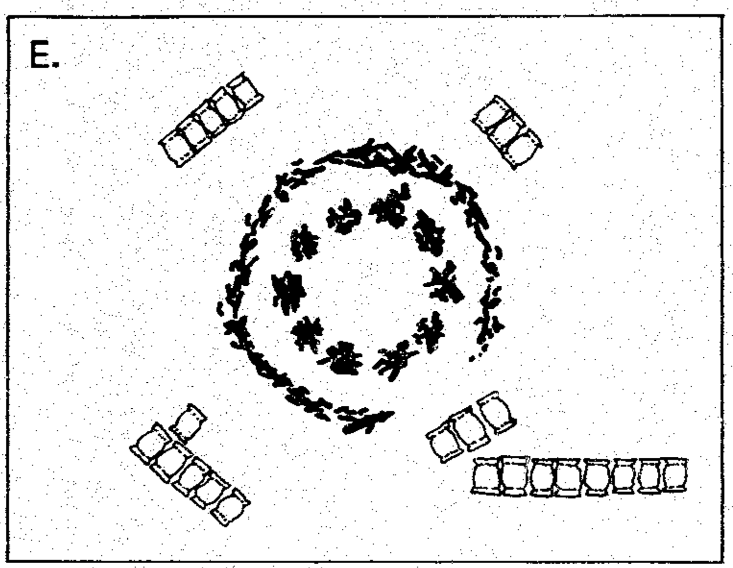
1st Extraction



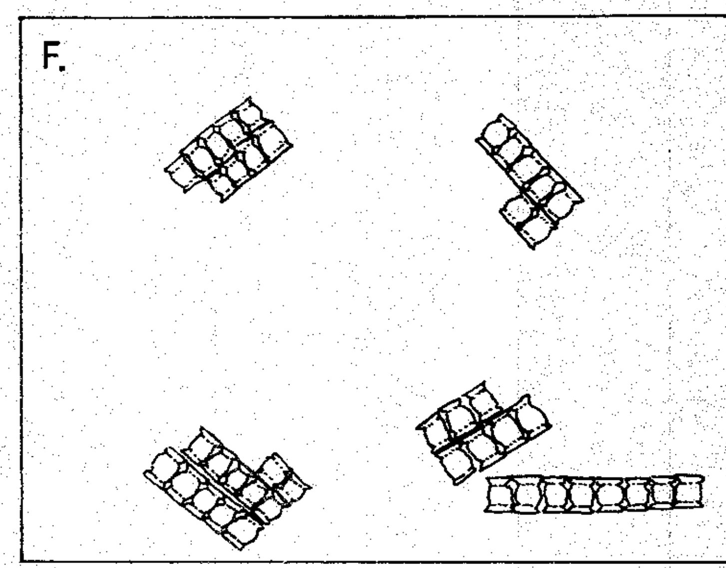
2nd Extraction



3rd Extraction



4th Extraction



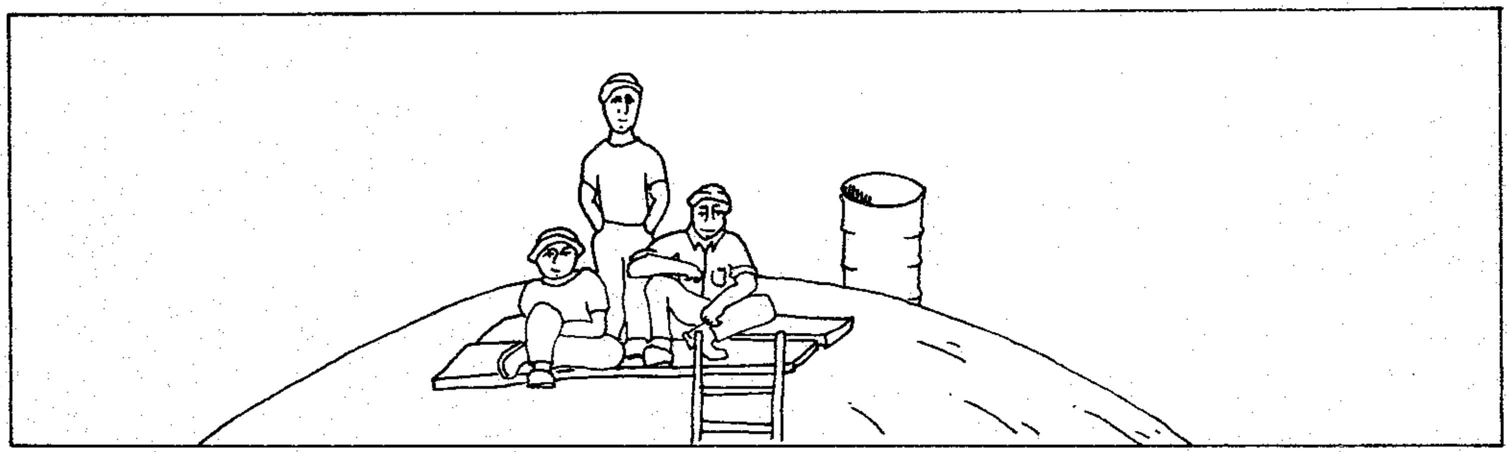
Extraction complete, all charcoal is bagged and ready for shipment.

Chapter 4

Analysis of the Casamance Kiln

Economic analysis of charcoal production with the Casamance Kiln shows that returns are most affected by the type of labor and the size of kiln employed.

Labor Considerations



Untrained labor will result in a poorly built and operated kiln. Such a kiln will produce lower yields of charcoal. The construction and operation of a Casamance Kiln is simple, but proper training is essential for high yields.

If labor is salaried, there is no individual incentive to produce charcoal. Laborers are paid for their time and not for charcoal produced. In this case, labor must be closely managed to maintain normal production levels that are produced when individual incentive does exist. Charcoal is a low value product and cannot support high labor management costs.

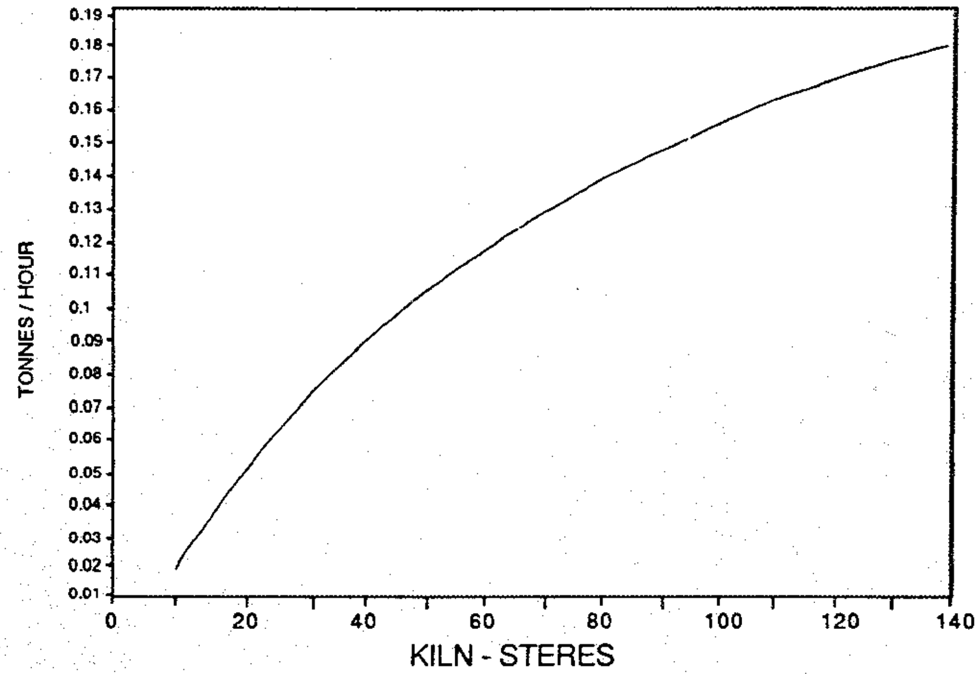
The Casamance Kiln is an improved traditional kiln and as such is a labor intensive technology. It will work best for independent producers who don't have high labor administration and management costs.

Kiln Size

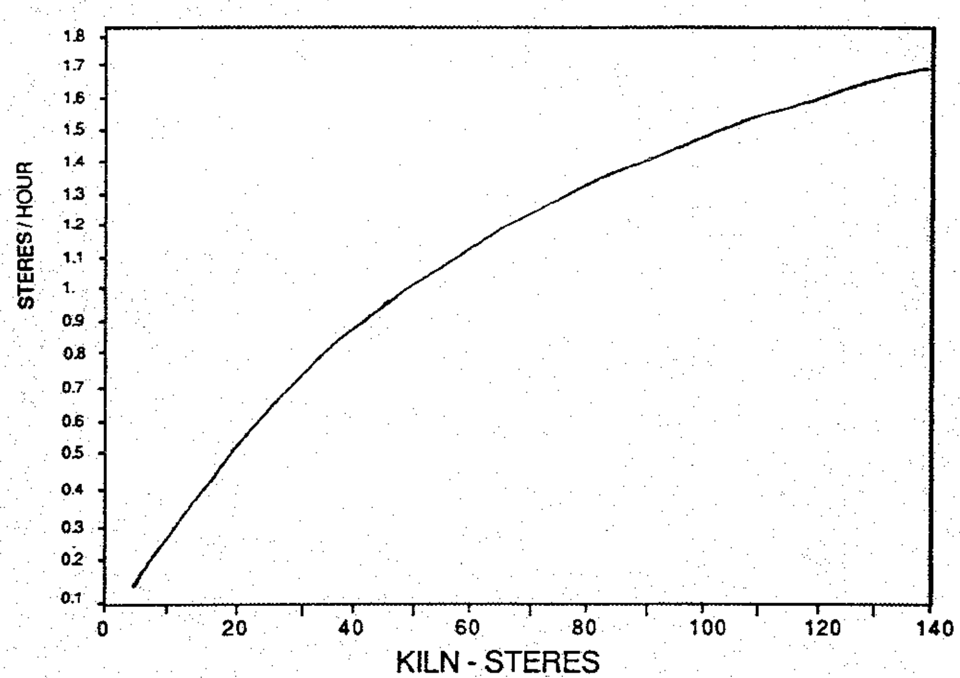
Through many years of research, Casamance Kilns of varying sizes have been built and operated. It has been found that the size of the kiln has a definite effect on the speed of carbonization, yield efficiency, and labor efficiency.

Size vs. Time

The choice of technology by small-scale independent producers is probably based on which kiln gives the most charcoal in the least amount of time invested. (Foley 1986)

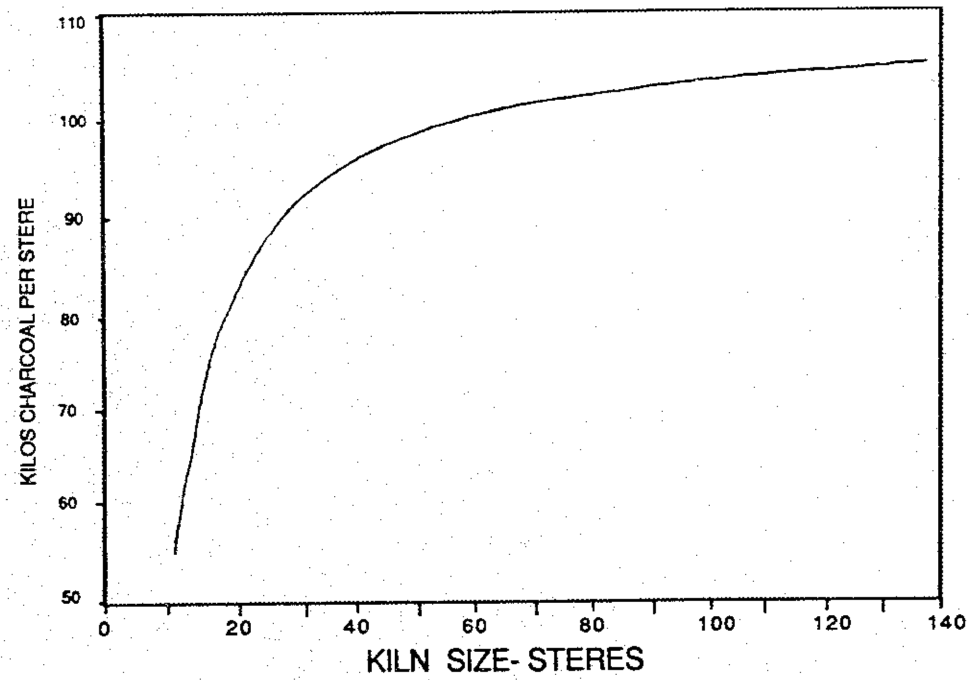


As kiln size increases more charcoal is produced in the same amount of time.



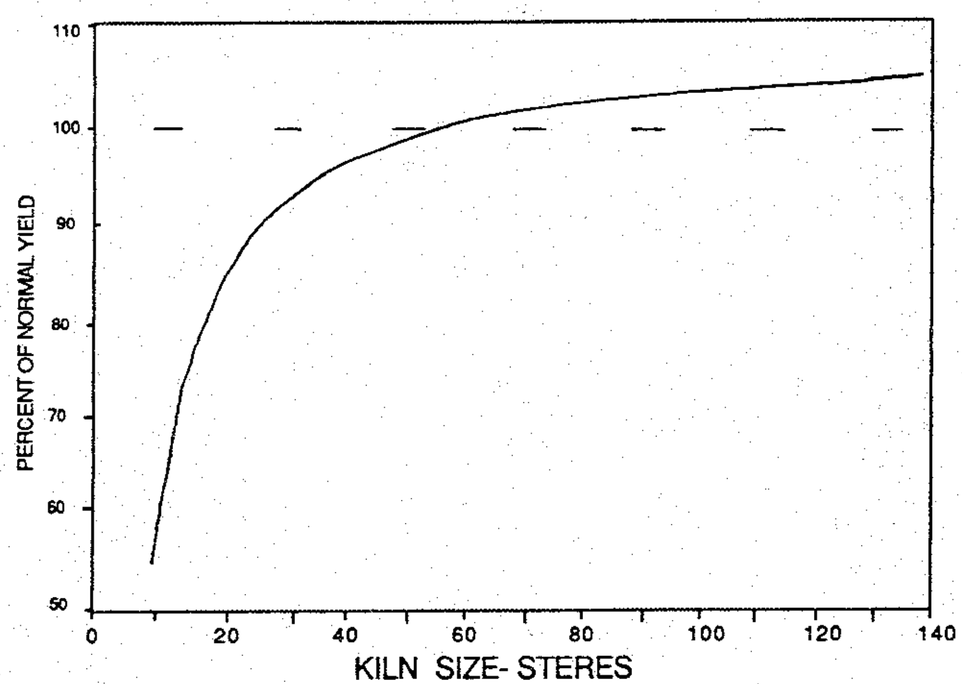
The number of steres per hour that are carbonized shows a steady increase as kiln size increases.

Size vs. Efficiency



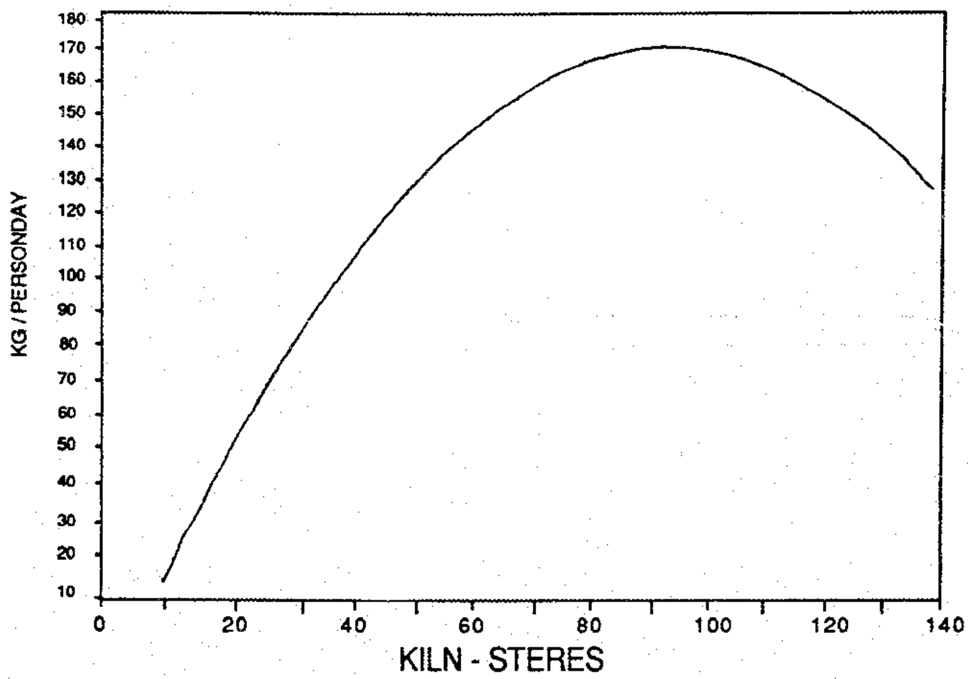
More charcoal is also produced per stere of wood as kiln size increases.

The rate of increase slows after about 60 steres. This gives a good point for stating that minimum kiln size should not be less than 60 steres. This is not, however, the optimum size.

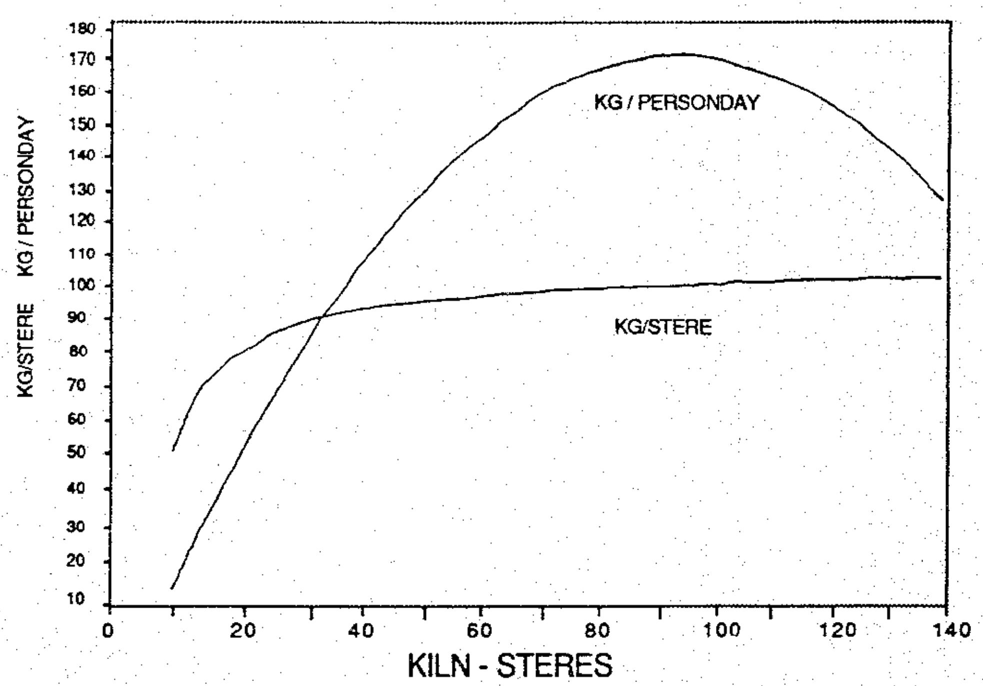


The expected yield of a Casamance Kiln, that is the amount of charcoal that can be produced per stere in a well-built and operated kiln, has been established at 100kg per stere. This level is not reached in kilns under 60 steres.

Size vs.Labor Efficiency



Output per unit of labor input is higher until it reaches a maximum of 90 to 100 steres. After this, labor efficiency starts dropping due to the scale of the kiln. A Casamance of over 120 steres is too large to be operated effectively.



This graph is a composite of thermal efficiency and labor efficiency. At 40 steres, the major gains in thermal efficiency have been made and the curve slowly increases from here on. Significant gains remain for labor efficiency between 40 and 90 steres.

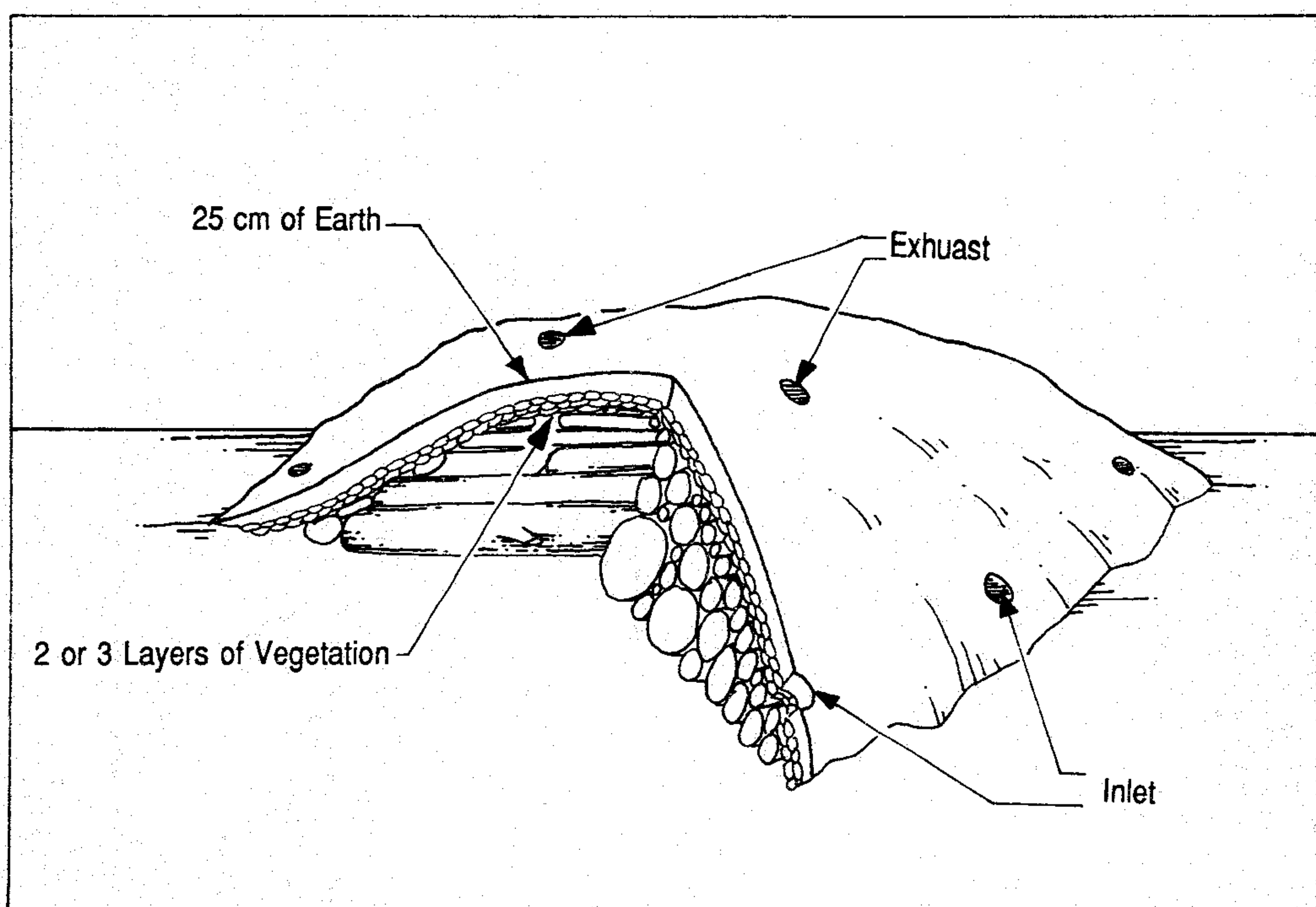
From the above analysis, it is seen that size is one of the most important criteria in the Casamance Kiln design. Optimum size is between 60 and 120 steres. Below 60 steres, the kiln is not thermally efficient. Above 120 steres, the kiln is not labor efficient.

Chapter 5
Other Kiln Types

The common assumption that an improved kiln can be used universally is not true. The social/economic/ technical requirements are usually so different that a "one size fits all" approach seldom works.

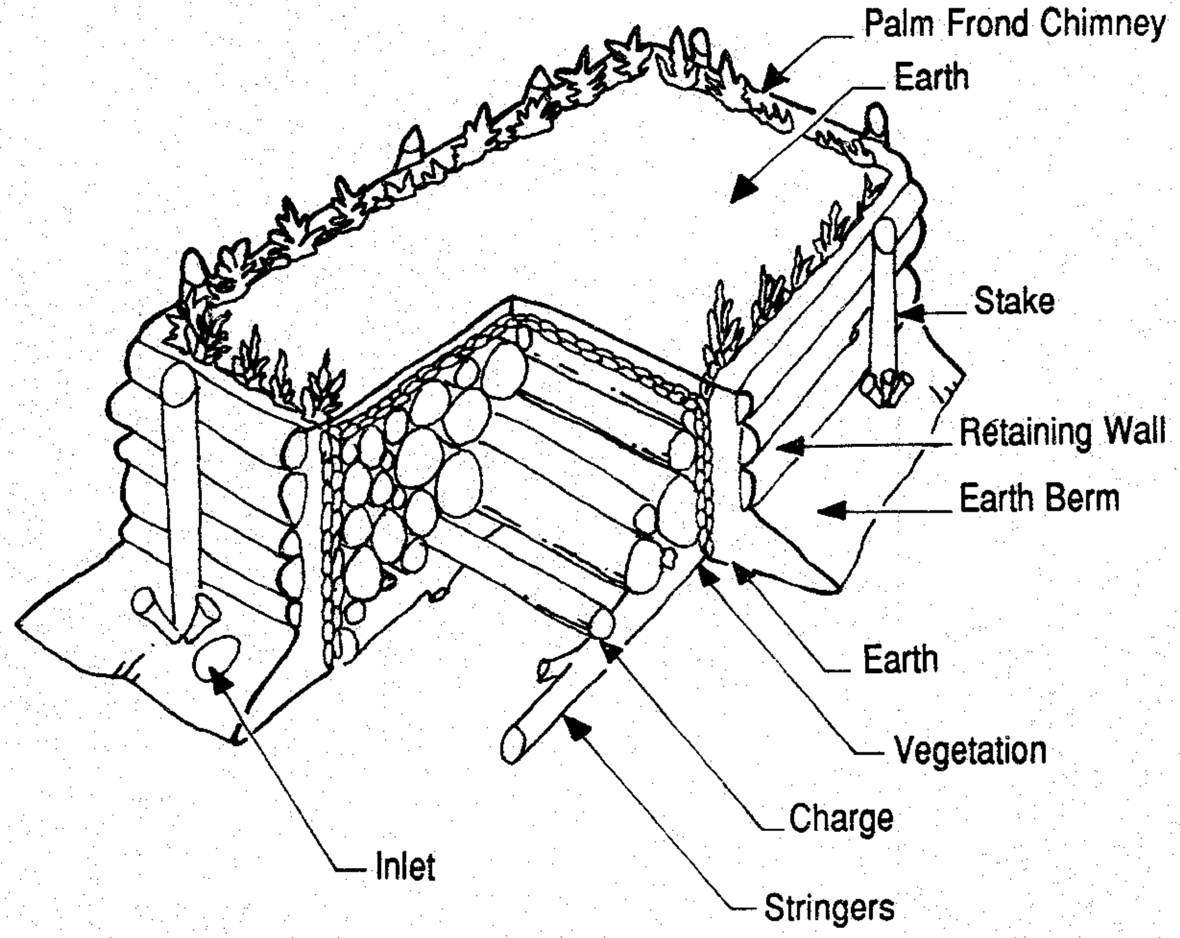
This chapter will provide the reader with a basic idea of other kiln designs. Each kiln embodies certain characteristics which may make it useful in particular circumstances. Some of these characteristics can be combined to produce a custom kiln for specific application.

Traditional Earth Covered Kiln



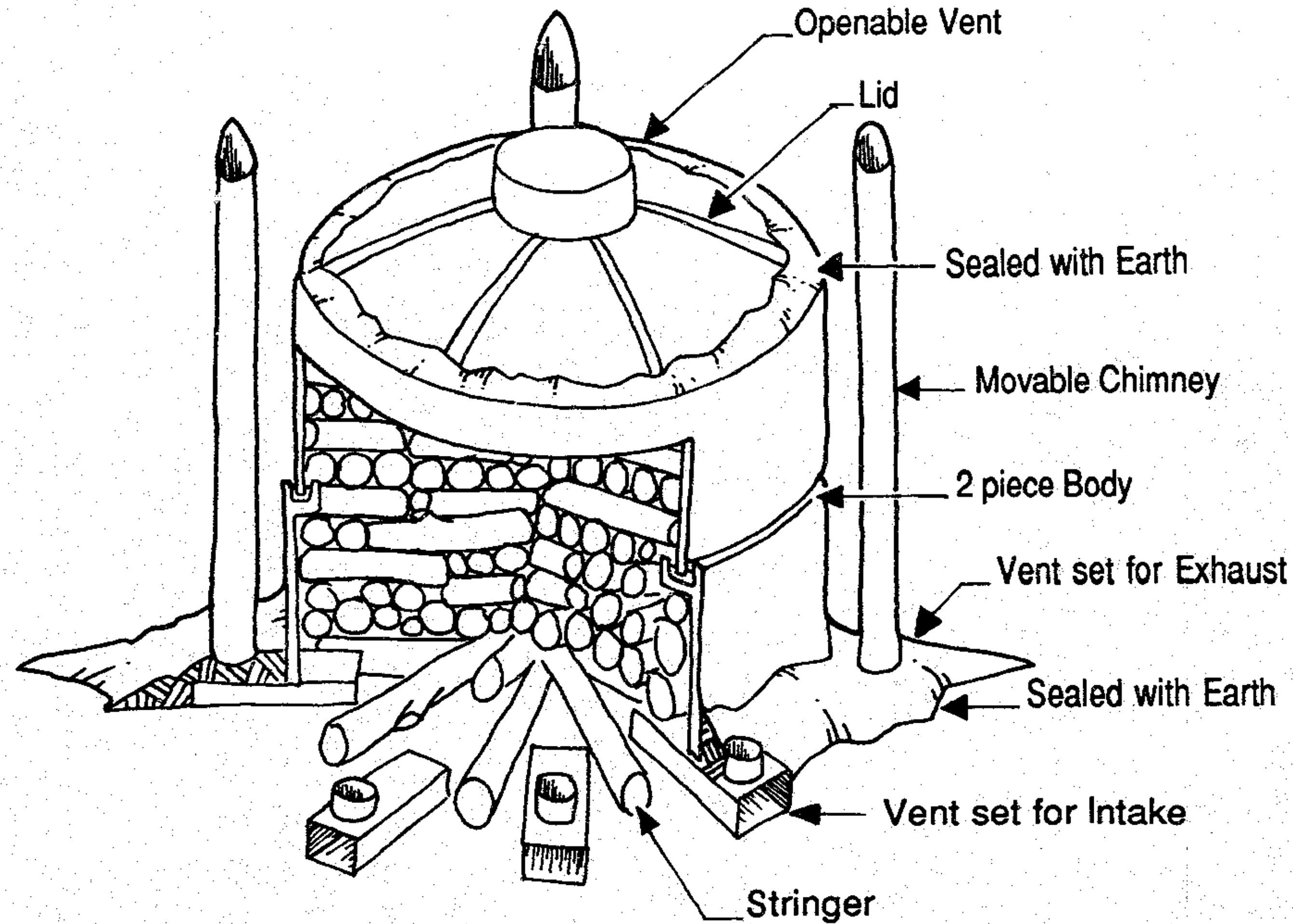
This mound shaped kiln is used all over the world. The wood is stacked in various configurations, but basically, the kilns are quite similar. The simplicity of construction and low capital requirement must be balanced against low yield, earth mixed with the charcoal and a long carbonization time due to poor air circulation within the kiln. Its capacity can reach 200 steres, but kilns of 10 to 15 steres are more common.

Woodwall Kiln



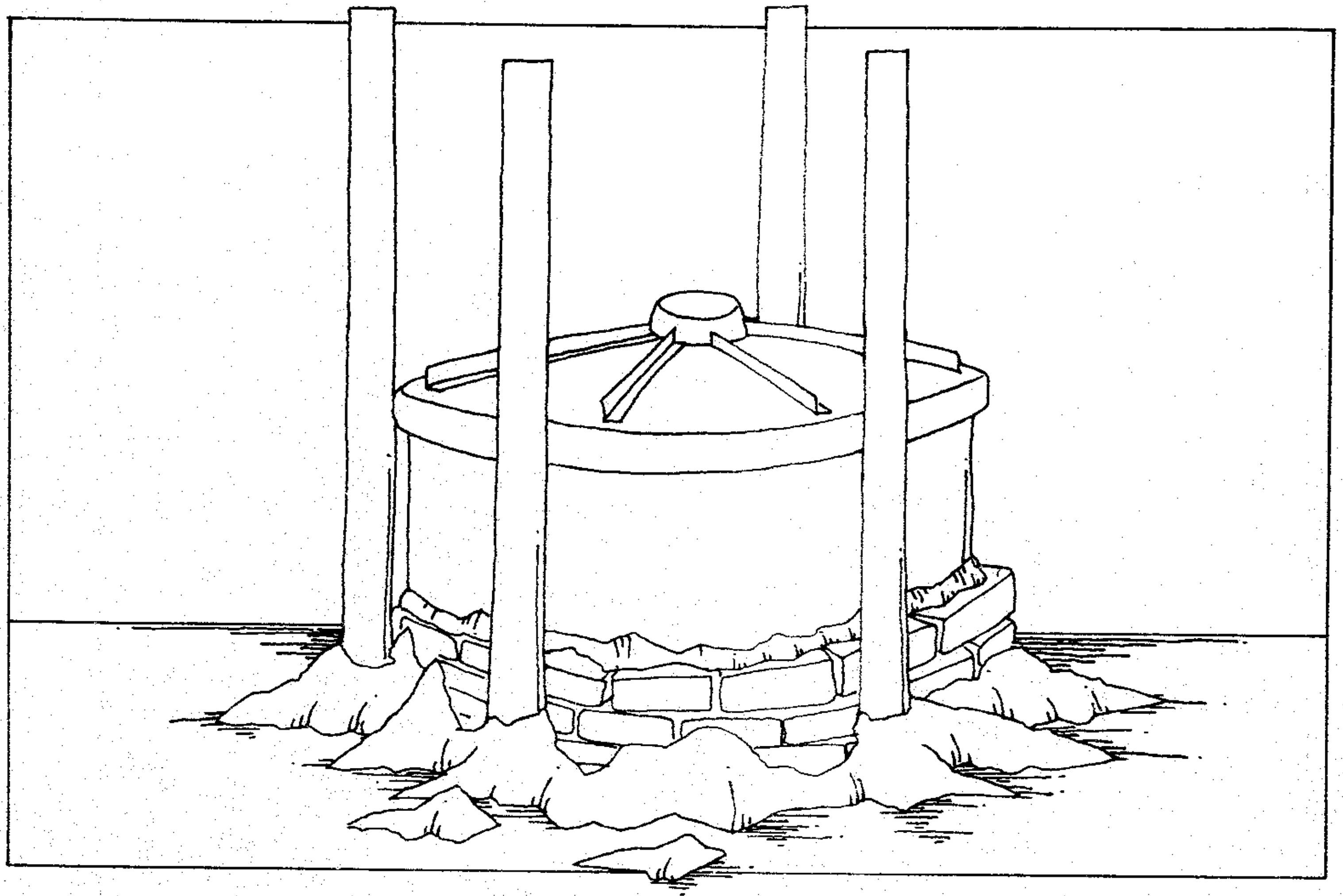
This is an efficient traditional kiln that has been in use for many years. The palm fronds create an air channel through the earth covering which, together with the platform, provide an excellent air distribution pattern. No part of the kiln is farther than 1 meter from these fronds, which act as both inlet and exhaust. The reuseable wood retaining wall greatly reduces the amount of earth needed to cover the kiln. The wood for this kiln must be cut to specific lengths to avoid puncturing the thin earth cover. As with any earth covered kiln, dust mixing with the charcoal can be a disadvantage. It requires a large labor input, is relatively slow, and has a small capacity. The Woodwall kiln is usually limited to under 5 steres.

Portable Metal Kiln

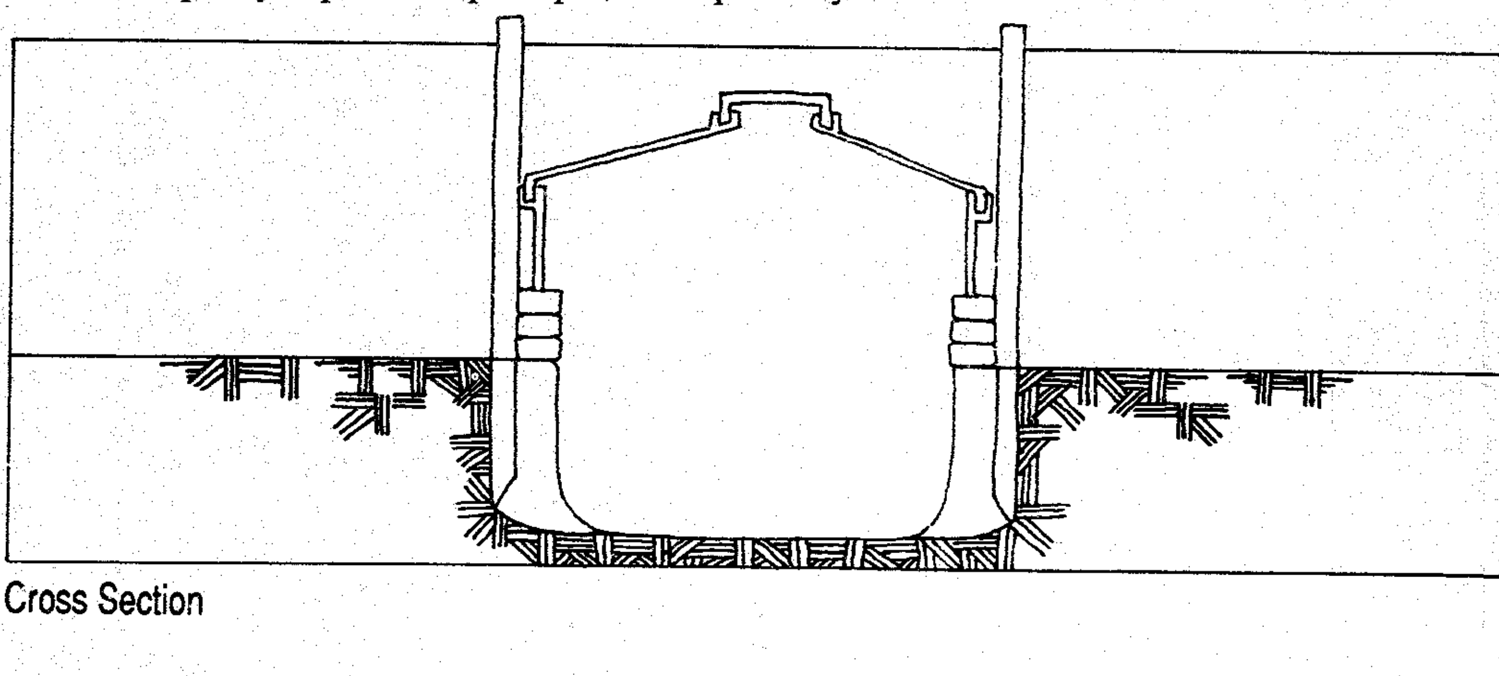


The metal kiln's eight reversible vents create a good air circulation pattern. The use of a metal cover prevents earth from mixing with the charcoal and saves the labor normally spent covering the kiln, but it requires more labor to load and unload as well as to cut the wood into smaller pieces. Top lighting and bottom exhaust make for a long gas path which increases efficiency. The metal kiln requires a high capital investment and uses about as much labor as earth covered kilns. Additionally, metal kilns have limited capacity, are prone to rusting and warping, and require constant attention to run properly. Its capacity is usually 6 steres; some larger models run up to 15.

Ghana Mixed Kiln



The chimneys used in the Ghana Mixed Kiln help solve one of the problems with pit kilns by providing air circulation deep in the kiln. The simple metal cover is cheaper than a full metal kiln, keeps earth out of the charge and simplifies covering. Since the kiln is lit at the bottom, the intense heat of carbonization is kept away from the metal. This feature, unfortunately, shortens the gas path which in turn should theoretically lower the efficiency. Pit kilns in general are also hard to unload. Capacity depends on pit depth, but is probably around 5 to 7 steres.

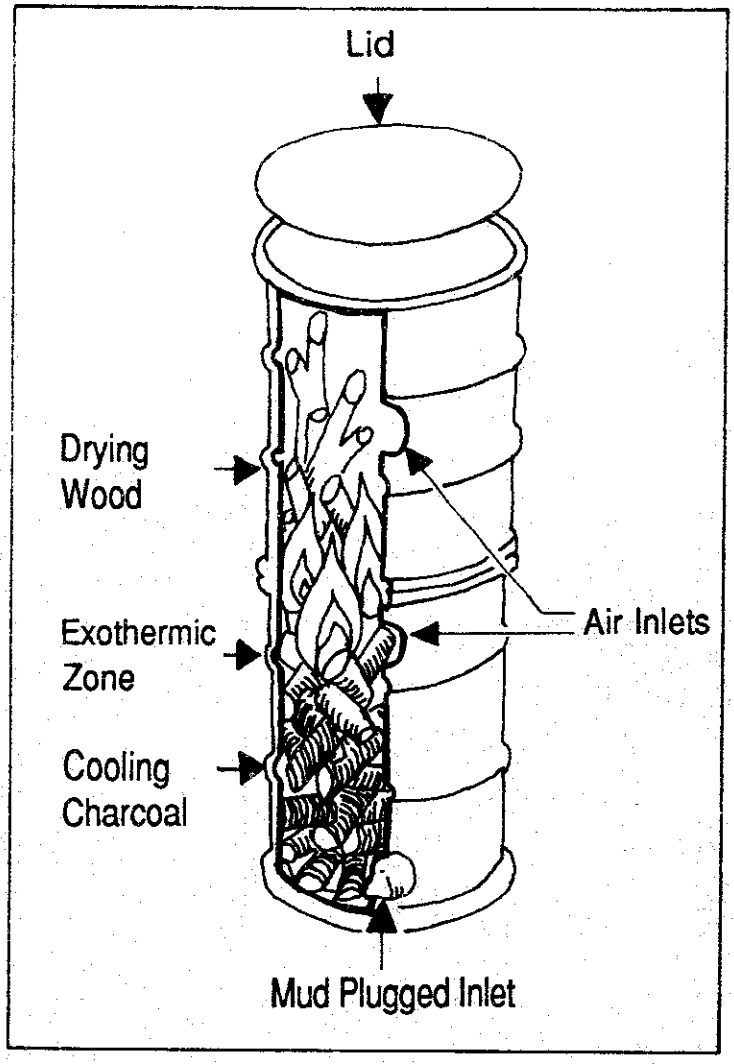


Cross Section

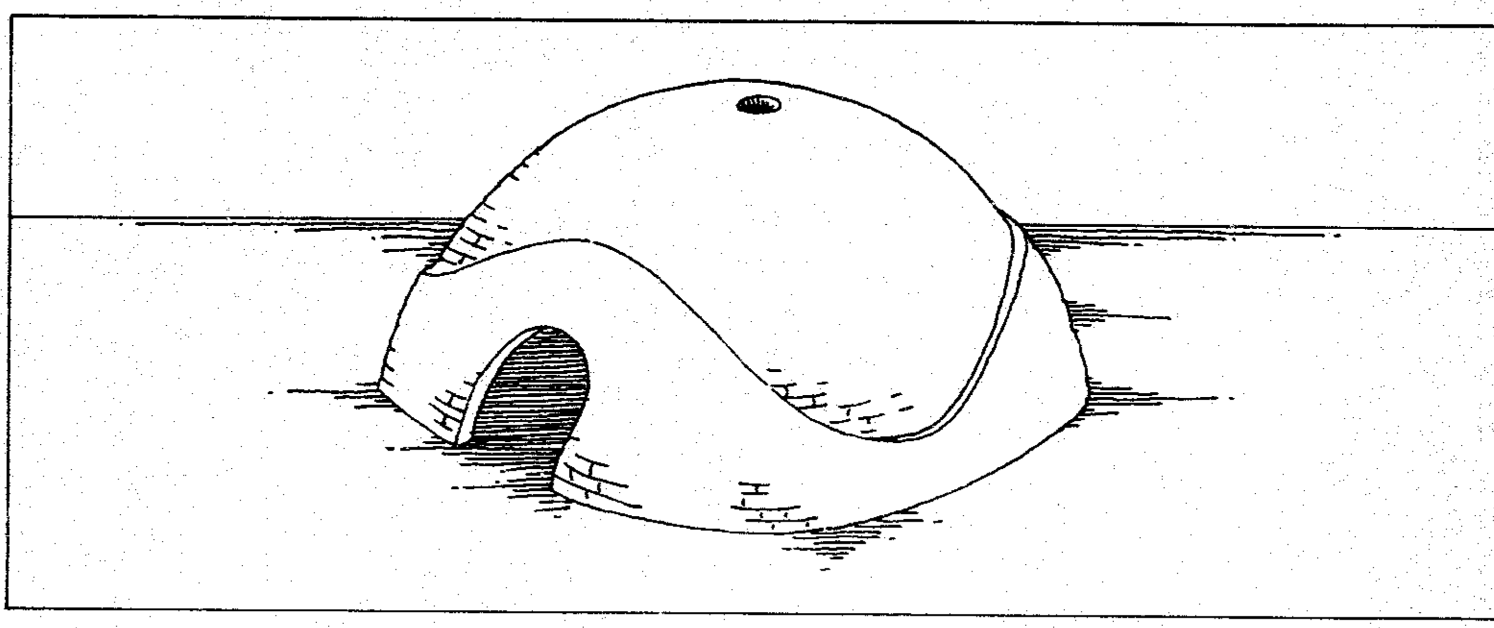
Barrel Kiln

The Barrel kiln has a totally different concept of design and operation. It operates as a continuous kiln until it is filled with charcoal. Two units can be welded together to double the capacity. To run the kiln, a fire is started at the bottom of the barrel with the top and all of the vents open. Sticks are added until smoke appears. After this wood ignites, more wood is added. As the wood carbonizes, it drops to the bottom of the kiln and the lowest vent is shut to keep the charcoal from burning. Since there is no oxygen at the bottom of the kiln, the charcoal starts cooling.

This process of adding wood and closing vents continues until the barrel is filled with charcoal at which time the cover is placed on top and sealed, or the entire kiln is turned over and earth is banked around what is now the bottom. The kiln runs quite fast, producing a load of charcoal ready for cooling in 3 to 4 hours. Though it seems unlikely, this kiln is surprisingly efficient. Several tests averaged 19 percent yield. However it is limited to small pieces of wood, and the charcoal produced is small and, therefore, difficult to market.

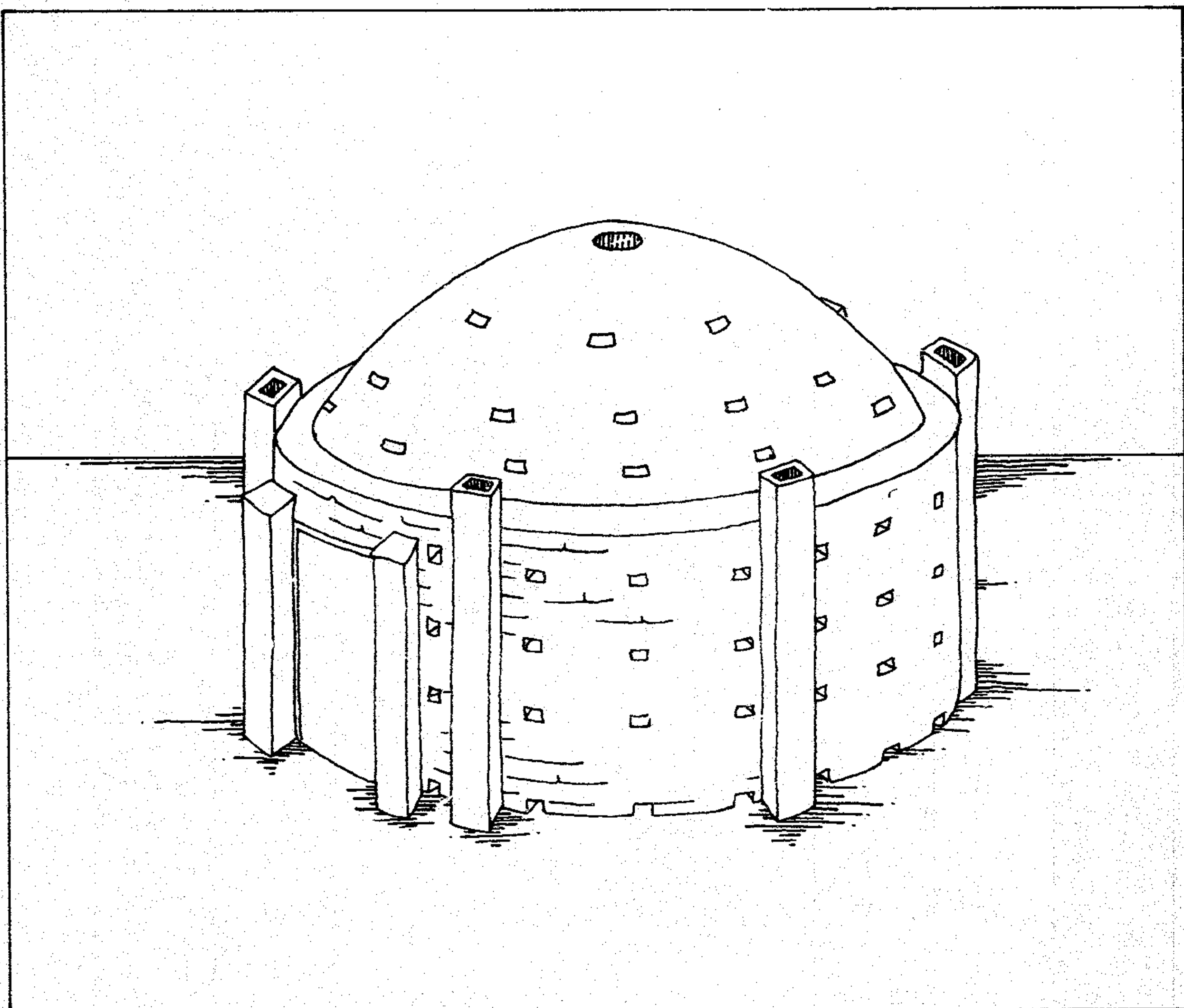


The Argentine Half Orange Kiln



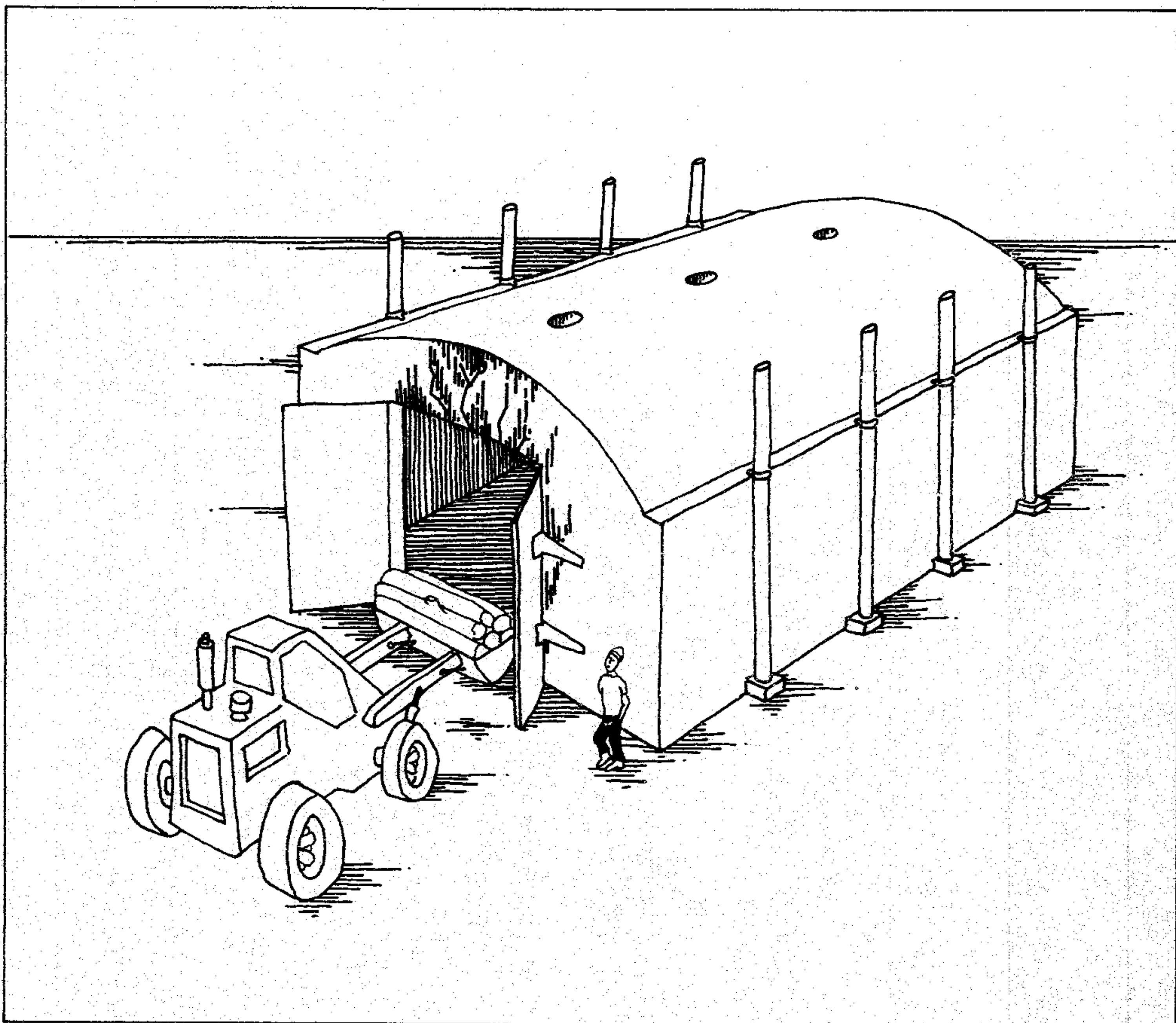
The Argentine Half Orange is made of brick and has an inefficient direct draft design with short gas paths.

Brick Kiln



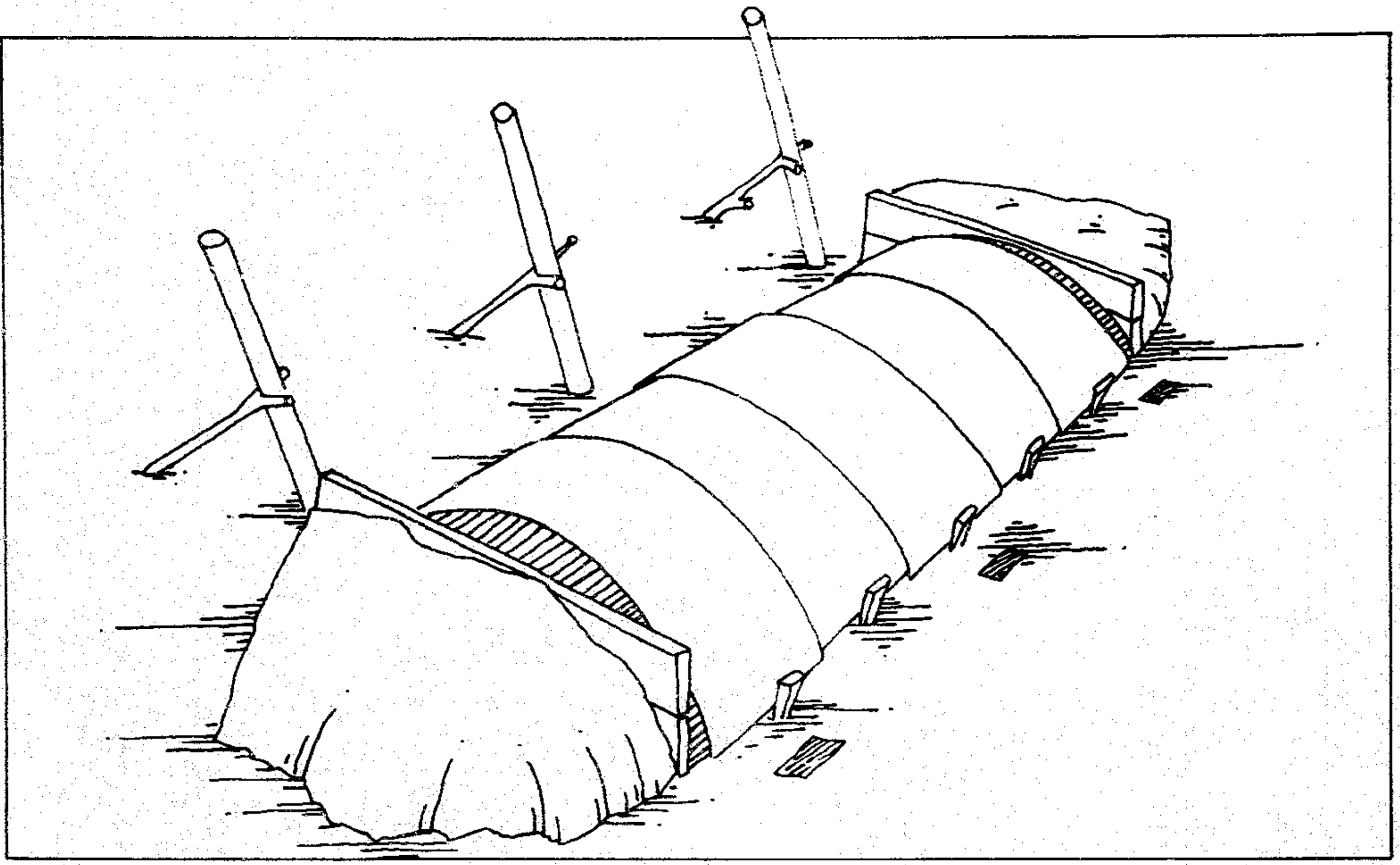
The brick kiln has been in use for many years in Brazil. The bricks allow a fixed kiln to be made inexpensively. Though considered to be fixed, the kiln can be disassembled and moved. The kiln is lit on the top with all the vents open. As the carbonization front moves down, the kiln vents are shut until the whole kiln is completely closed. This system of operation is reasonably efficient.

Missouri Kiln

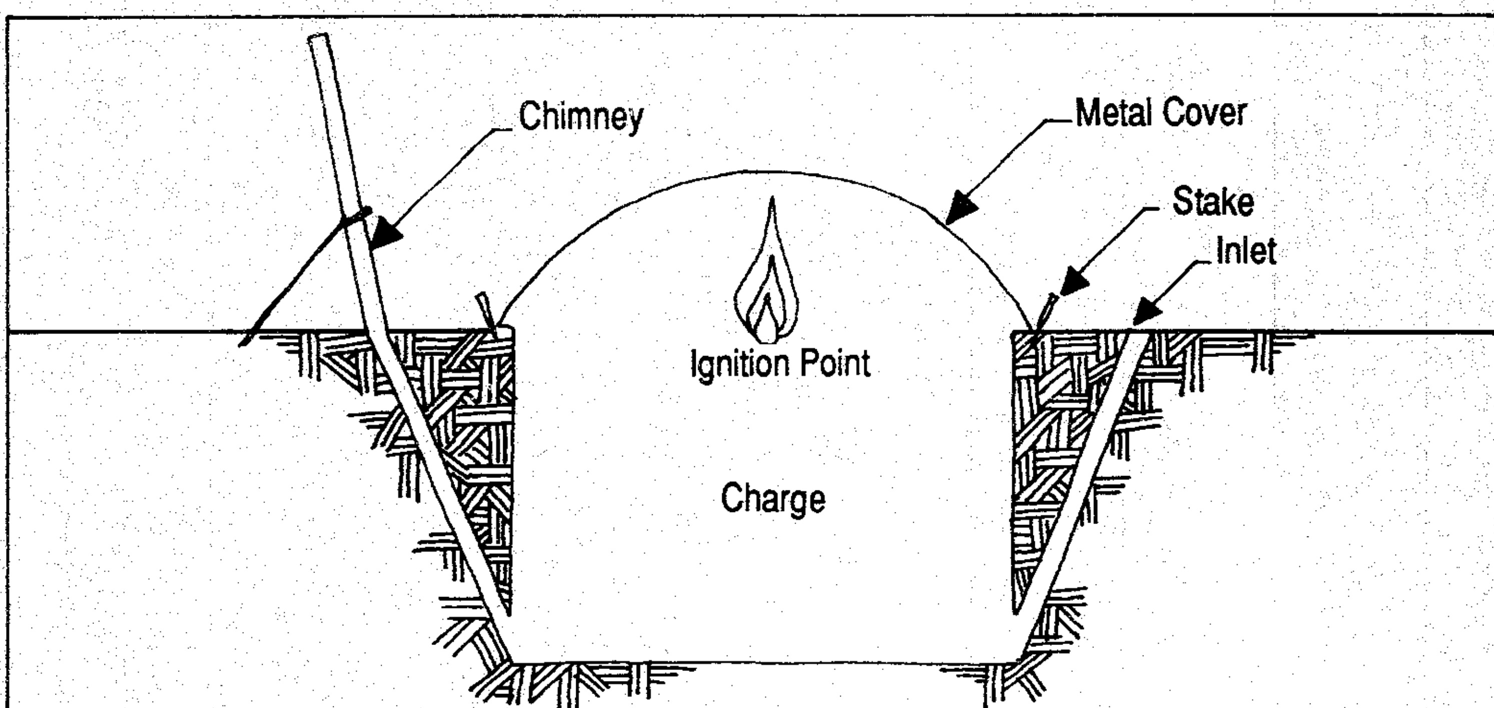


The Missouri kiln, developed in the United States, is huge. The kiln was designed to be loaded and emptied using a front end loader. The design requires cement and expanded shale aggregate which can stand the stress of high heat. A good understanding of cement construction and the necessary aggregate is required. A careful economic analysis is necessary for a successful Missouri kiln. Its large capacity and permanence means that wood must be transported long distances. The large investment requires a long amortization period.

Subri Fosse



The Subri Fosse appears to be another kiln with good social/economic/technological "fit." It is a kiln that combines techniques from pit, brick, and metal kilns to achieve ease of operation, low investment and high yield.



Cross Section

Appendix A

Literature Review

In recent years, a good deal of erroneous material concerning the Casamance Kiln has been published. By notating these discrepancies, we hope to promote a clearer picture of what a Casamance Kiln is and what it can do.

<u>Carbonization</u>
Rupert, M., 1980.

At one point in the evolution of the Casamance Kiln, it was thought that delivery of air to the charge without mixing with exhaust in the air chamber might be preferred. This separation of exhaust and input was accomplished by use of some old metal kiln chimneys inserted through the air chamber to reach under the platform. The results were localized overkilning at the air pipe outlets and more control was needed to regulate the speed of the kiln. The use of these air pipes was abandoned. Unfortunately, that design was frozen in a publication used for training forest agents at that time. This variation showed up later in Mali and most recently in Burundi, Lejeune and Bizimana (1985).

<u>Resultats, Conclusions et Recommandations du Project</u>
Lejeune, J. M., and M. Bizimana. 1984.

In a FAO project in Burundi, 3 kilns were used in a side-by-side comparison to see which gave the best yield. These were a metal kiln, a Subri Fosse, and a kiln which was built from the previously referenced Rupert publication listed above, but it was small (15 steres), had no air chamber, and, not surprisingly, gave poor yields (17 to 20 percent). Unfortunately, in the resulting publication, this kiln was inaccurately called a Casamance Kiln.

The report also brought out that this kiln took a longer period to cool than the other kilns tested and that the charcoal was mixed with the earth cover when it was extracted.

These two criticisms are equally valid for the Casamance Kiln. Earth is a much better insulator than metal, and heat is retained longer than in any non-insulated metal kiln. During certain periods of the carbonization process this is an advantage, but it is a disadvantage during the cooling phase. The mixing of the earth cover and the charcoal during the extraction process leaves dust on the pieces of charcoal. If the charcoal is to be used for an industrial process which has minimum ash requirements then this is a disadvantage, but for domestic use, it is not.

<u>Simple Technologies for Charcoal Making, Forestry Paper 41</u>
Food and Agriculture Organization (FAO), 1983.

The description of the Casamance Kiln in FAO paper 41 "Simple Methods of Charcoal Making" contains some major errors. It states that the Casamance is a mound kiln which is modified by inserting a central chimney made of old oil drums. This should be, of course, an external chimney, but the results would not be a Casamance; it is a mound with an external chimney. It also states that roots and stumps must be pulled out for site preparation. This is not necessary since roots or stumps will be carbonized in place. Additionally, it mentions that the chimney should be removed if the side on which it is situated is completely carbonized. This, of course, should read moved and not removed. At no place in the description is an air chamber mentioned nor is it shown in the illustration which does, however, show the charge piled vertically rather than horizontally on top of the base.

A major amount of space is taken up discussing a rather minor point in the operation of the Casamance, that is the condensation of volatiles by the chimney. The figures of 21 tonnes of condensate for a 100 stere kiln is given followed by 2 tonnes of tars. The actual average collection of both for 100 steres is under 50 liters or about .05 tonne. In reality, the chimney is an inefficient condenser. A solution is recommended for this non existent problem, which is to keep the chimney hot by insulating it with brick or else to build a brick chimney. It is stated that this will keep the chimney hot (i.e. about 100° C).

In actual experience when the chimney is at its hottest during the run, one can hold a bare hand against it. The chimney never reaches 100° C. The recommendation to build brick chimneys for portable kilns is obviously incorrect.

Charcoal Making in Developing Countries, Technical Report No. 5
Foley, G. 1986.

Unfortunately, in regard to the misinformation on the Casamance Kiln, FAO publications have a wide distribution and are regarded as standards regardless of quality. There have been two other recent publications which use this source. Foley (1986) quotes the FAO figures on condensate tonnage and goes on to state that even at 100° C chimney temperature the chimney will collect 25-30kg.of tar per tonne of wood. The source of this statement is not given. This would give between 750 and 900kg. of tar per 100 stere kiln. There is no known Casamance Kiln result which gives over 10kg of tar per 100 stere kiln, and it is usually less.

Foley also states that the Casamance Kiln is covered with clay. This would be the worst possible covering material as it would shrink and crack, leave air passages, and it would be difficult to separate baked clay lumps from the charcoal produced.

It states, again without the source, that the main disadvantage of the Casamance Kiln is that it requires a greater amount of labor than traditional kilns for cutting and stacking the wood. Labor for cutting and stacking will be about the same as with a traditional kiln as there is no special size requirement for wood used in the Casamance kiln, but due to increased production and faster carbonization, total labor will be much less, and return per labor unit will be much higher.

Guide Technique de la Carbonisation
Briane, D., and J. Doat. 1985.

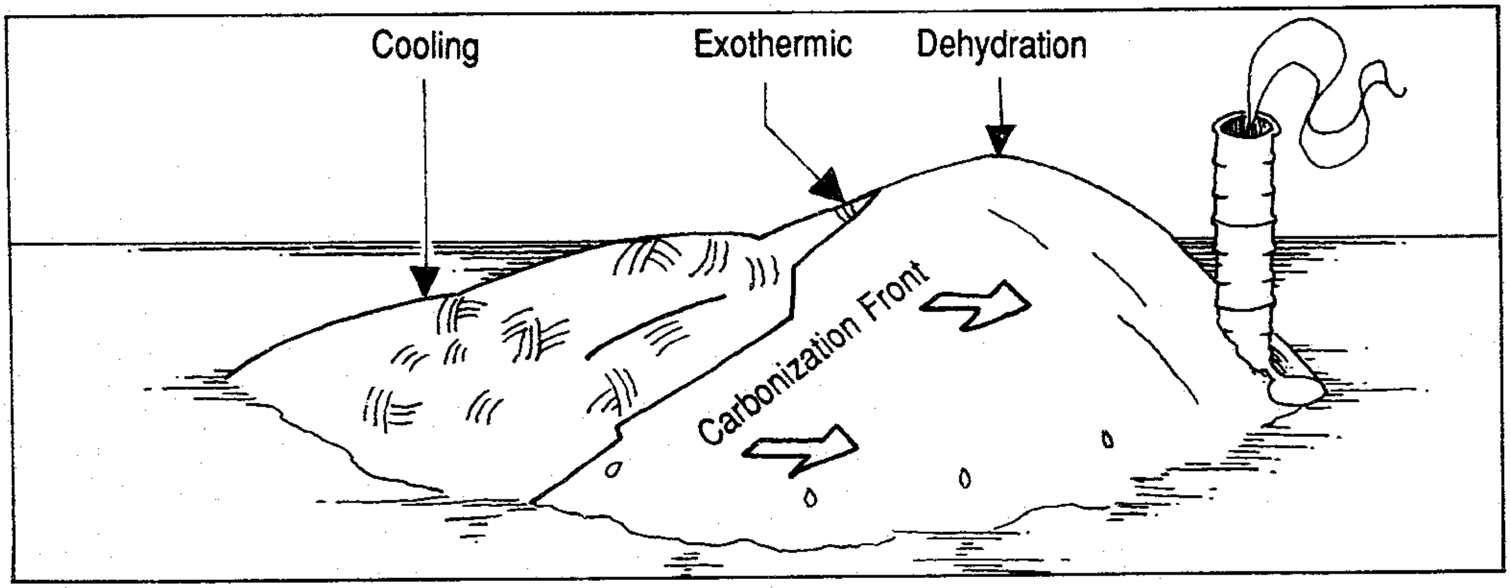
This publication uses the incorrect illustration from the FAO report showing vertical stacking of wood and no air chamber. The statement that 12 steres is the minimum size is also advanced.

Consultants Report
Rochon, P. A., and I. Ndiaye. 1986.

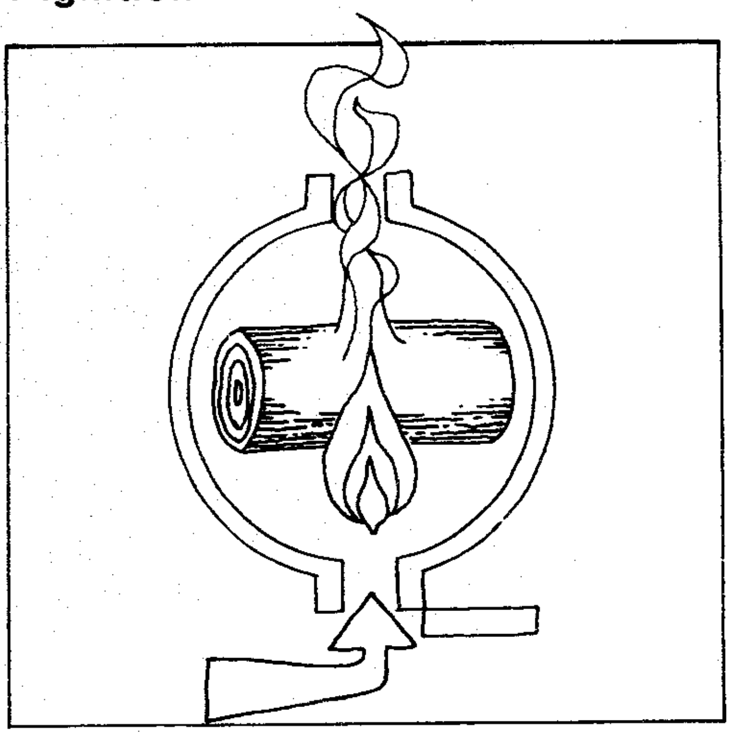
The Casamance produced fair yields in another side-by-side comparison of carbonization techniques, this time in Rwanda. Here again the size is limited to 15 steres so high efficiency could not be expected.

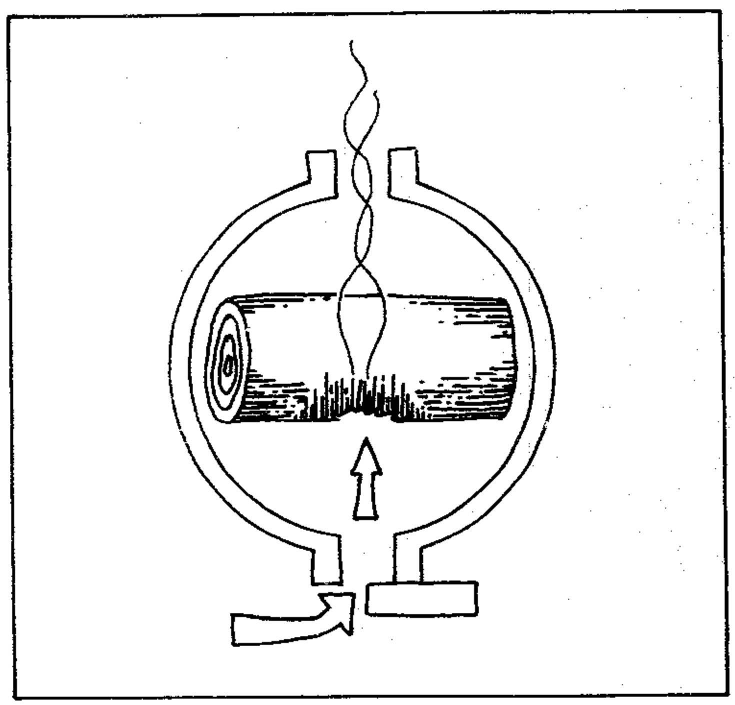
Appendix B
Principles of Carbonization

There are 4 processes involved in the conversion of wood to charcoal: Ignition, dehydration, exothermic and cooling. The duration of each phase varies with kiln size, the moisture content of the wood, type of wood and weather conditions. All of these steps may be present in the same kiln at the same time.



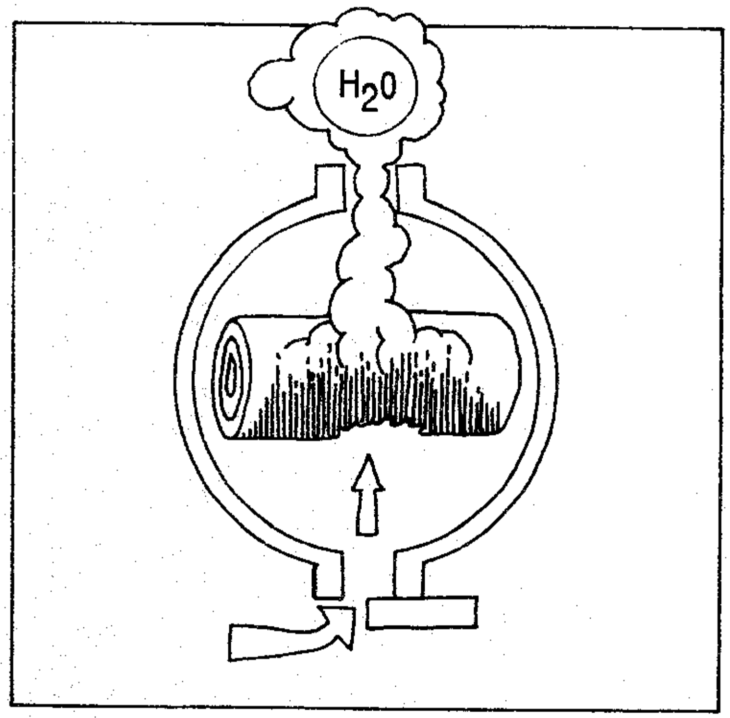
1. Ignition





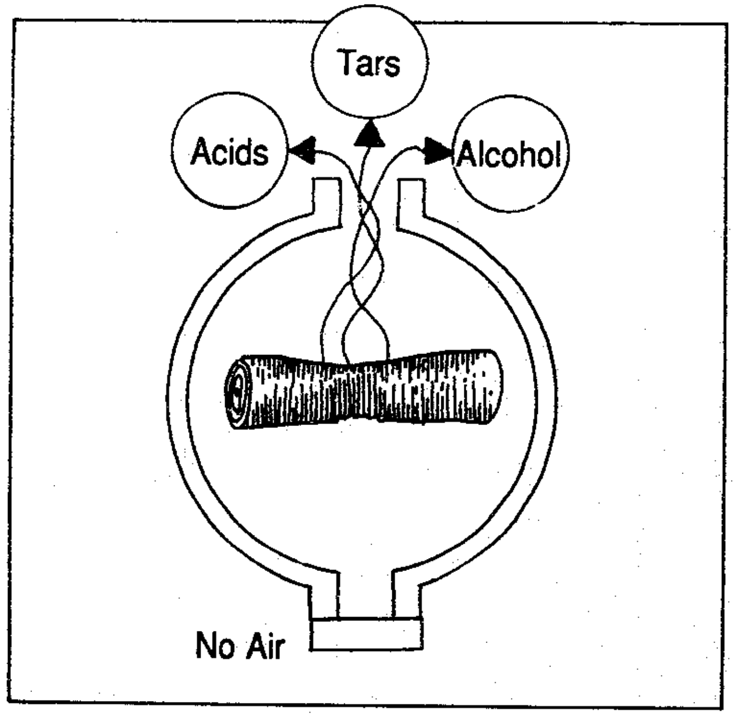
The kiln is lit, and the temperature rapidly rises. Once combustion has started, the air supply is restricted slowing the kiln and lowering the temperature.

2. Dehydration



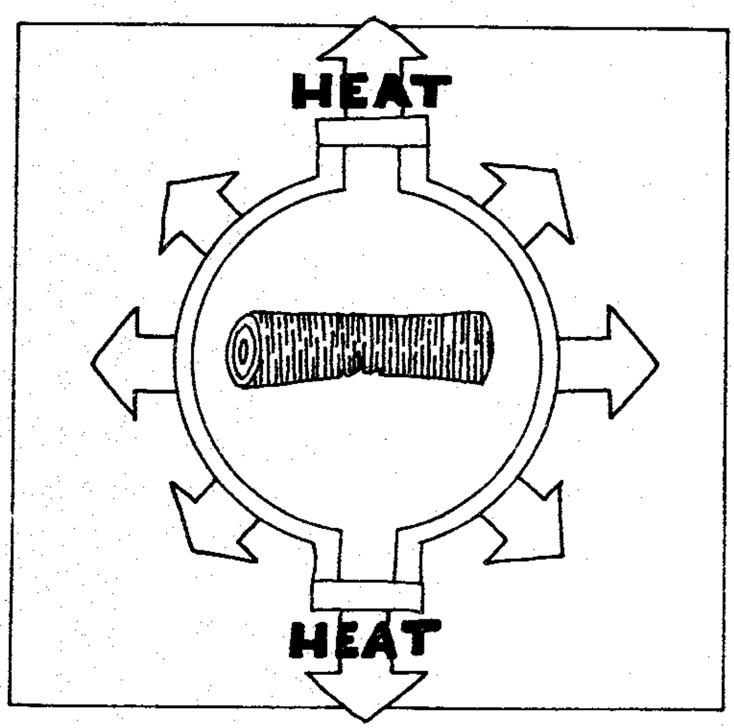
The heat of ignition starts the drying of the charge. As the process continues, the temperature rises.

3. Exothermic



When all the water is driven out, the wood begins to break down thus giving off heat.The process no longer requires external heat.

4. Cooling



Once the wood is carbonized, it must be cooled. This process stabilizes the charcoal and allows for easy handling.

Appendix C
Recovery of Volatiles

The chimney of the Casamance Kiln is designed to recover some of the volatiles. Depending on the moisture content of the charge and the ambient air temperature, up to 40 liters of pyroligneous liquids and tars can be recovered from 100 steres of wood.

These liquids can be used as a wood preservitive as described in "Charcoal: Small Scale Production and Use," GATE, 1983. These liquids can be used by pouring them into fence post holes, around telephone poles or any place where wood has to come into direct contact with the soil.

If there is no market for the liquids, just leave the baffles out of the chimney. Tar will accumulate in the chimney and will occasionally burn out.

Glossary

Above ground stack -
An earth covered kiln built above ground as opposed to a pit kiln. Also: clamp, mound.

Active carbonization front -
A wide area slowly moving through the kiln where carbonization is taking place. In front is wood, in back is charcoal starting to cool.

Air chamber -
A chamber surrounding the base of the kiln that provides mixing of exhaust and intake air, preheats input air, cools exhaust air, dilutes oxygen and increases carbon dioxide content.The chamber acts as a governor and makes the kiln easy to control.

Air hole -
Hole in the kiln cover to allow air to enter. Also: vent, intake.

Ambient air temperature -
The temperature of the air surrounding an object.

Baffles -
Obstructions placed to slow the flow of the gases and to increase contact with the metal walls for a longer period of time. This increases heat loss to the metal and promotes condensation.

Baffled chimney -
Chimney that contains baffles.

Batch fired -
A process where a kiln is loaded in a batch, fired, then unloaded.

Capital cost -
The amount of cash required to build something, sometimes translated into annual cost by use of an interest rate.

Carbonization time -
The time from lighting the kiln until it is sealed for cooling.

Central lighting chimney -
A space left in the center of the charge where the initial fire is placed. The term chimney is misleading as it never acts as a chimney, but this is the traditional terminology.

Charcoal permits -
A permit to make charcoal, usually issued by the government forest service.

Charge -
The wood which is placed in the kiln.

Condensable volatiles -
Those by-products of carbonization which will change from gasses to liquids or solids upon cooling.

Continuous kiln -
A kiln that is continuously fed and discharged.

Earth cover -
A covering of earth that is supported by vegetation and serves as an air seal.

Efficiency -
See yield.

Exhaust -
A mixture of gasses produced in the carbonization process.

External chimney -
A chimney placed adjacent to and connected to the kiln for the purpose of providing a draft.

FAO -
The Food and Agriculture Organization of the United Nations

Favored air path -
The least obstructed path.

Fire hole -
The place where fire is introduced to start carbonization.

Forest products -
Products produced from the forest, including wood and all other products.

Gas path -
Route followed by moving gasses.

Governor -
A device which controls speed.

Heat mass -
The steady state amount of heat retained by a body when heat input equals heat loss.

Human scale -
A size that can be constructed, operated, and controlled, using hand tools.

Ignition temperature -
The temperature at which combustion becomes self-sustaining.

Industrial scale -
Large-scale operation usually using a technology that is capital intensive.

Intake -
Place where air enters the kiln, an air hole.

Lee -
The side facing away from the wind.

Lighting chimney -
See central lighting chimney.

Lighting hole -
Hole in the kiln cover where fire is introduced.

Metal pit covers -
Metal sheets used as air seals for pits.

Oven dry basis -
See yield.

Overkilning -
Allowing the charcoal to be consumed inside the kiln.

Platform -
A crude floor which supports the kiln and allows air to pass below.

Preheat -
Raising the temperature to the ignition point.

Pyroligneous liqueurs -
Chemically complex liquids condensed from volatiles produced from pyrolysis of wood.

Pyrolysis -
Decomposition by heat. Also: carbonization, destructive distillation.

Radial stringers -
Stringers arranged radially.

Radially -
Going outward from a point like spokes in a wheel.

Ranks -
Wood placed vertically where the second row is stacked (again on the vertical) on top of the first, etc. As in the Skorstensmila Kiln.

Skorstensmila -
Swedish kiln with external chimney.

Sod -
Earth tightly bound by grass roots that is used as a construction material.

Stere -
A stack of wood measuring 1 meter by 1 meter by 1 meter.

Stringers -
Logs that serve to support the platform.

Subsidence -
A settling of the charge as it shrinks during the carbonization process.

Tars -
The semi-solid portion of the condensates resulting from destructive distillation of wood.

Teak -
A tropical hardwood scientifically known as *Tectona grandis*.

Timber stand improvement -
Silvicultural practices designed to improve the health or final product of a timber stand.

Top central lighting -
Lighting a kiln about 1 meter down from the top in a firing hole.

UNDP -
United Nations Development Program

Vents -
Holes in the kiln cover for gas exchange. May be either intake or exhaust.

Volatiles-
Substances which change to gas upon heating.

Windward -
On the side facing the wind.

Wood preservative -
A chemical substance, induced into wood by pressure or soaking, which poisons or repels insects or fungi that feed on dead wood.

Yield -

Measure of kiln efficiency usually expressed as a percentage. The weight of oven dry charcoal produced divided by the weight of oven dry wood that went into the kiln. It is sometimes calculated on a wet wood basis, but this is not accurate since the moisture content variable remains. Volume of wood per weight of charcoal as well as volume per volume are also used but again do not account for moisture content. Caloric value of wood per caloric value of charcoal is also used, but unless measured in a bomb calorimeter, it is pure guesswork.

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