Clay Materials–for the Self-Reliant Potter

Henrik Norsker

1990

Contents

Preface

This book is the second in a series of books for potters and ceramists working in developing countries. The term ”self-reliant potter” is the common name for the series and this reflects the condition of potters in many developing countries. Imported materials and equipment are seldom available, and the supply of raw materials within a country is often difficult. Self-reliance is therefore a practical approach to ensure profitable pottery production under such conditions.

The book is mainly directed to:

- Trainers, field workers involved with promotion and training.
- Technicians doing research in ceramics centres.
- Students of pottery in ceramics training institutes.
- Potters in established cottage and small scale industries.

Acknowledgments

This PDF Document

Typesetting

This document was typset by Erik Haugsby from the source material provided via the CD3WD:

`http://www.fastonline.org/CD3WD_40/CD3WD/APPRTECH/G41CLE/EN/B159_2.HTM`

This document attempts to replicate the source material and present it in a more accessible structure.

As the source material is freely available online and the cost of a print version of this text is prohibitively high, I believe this document is an important contribution to the collective knowledge of potters.

It improves upon the HTML version of the information by consolidating all sections into a single document, which is both viewable on the computer and can also be printed. Furthermore, it introduces clickable links/references between sections and tables.

Formatting: Changes, Errors, Omissions

I have attempted to preserve the original text and formatting.

Some changes to formatting, especially of tables, was unavoidable due to the LaTeX typesetting.

Some corrections were made to spelling and grammar.

Unfortunately, no images are available in the online version of this document. Inline references to images have been maintained, but will always appear as **??**.

The possibility of minor or unavoidable changes in layout and formatting, as well as unintentional errors in transcribing the original text, cannot be excluded.

Should you find any errors or omissions, I would greatly appreciate you either notifying me by email, or initiating a pull request via Git.

Link to GitHub project: https://github.com/erikhaugsby/materials/

Citation

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Potters and colleagues in Bangladesh, Burma, Denmark, India, Nepal, Tanzania and Thailand have helped me in collecting the material and experiences presented in this book. Shailendra Maharjan has produced most of the drawings. James Danisch has contributed valuable suggestions and has corrected my English.

The Author

Henrik Norsker

Henrik Norsker has been making pottery since 1970. He left his pottery workshop in Denmark in 1976 to help with establishing a pottery school in a village in Tanzania. Since then he has continued working with promotion of modern pottery in developing countries. Besides Tanzania, he has worked for ceramics projects in Bangladesh and Burma. He is presently working for a ceramics project in Nepal.

The Deutsches Zentrum für Entwicklungstechnologien

Deutsches Zentrum für Entwicklungstechnologien-GATE

Deutsches Zentrum für Entwicklungstechnologien–GATE–stands for German Appropriate Technology Exchange. It was founded in 1978 as a special division of the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH. GATE is a centre for the dissemination and promotion of appropriate technologies for developing countries. GATE defines "Appropriate technologies" as those which are suitable and acceptable in the light of economic, social and cultural criteria. They should contribute to socio-economic development whilst ensuring optimal utilization of resources and minimal detriment to the environment. Depending on the case at hand a traditional, intermediate or highly-developed can be the "appropriate" one. GATE focusses its work on the key areas:

- Dissemination of Appropriate Technologies:

  Collecting, processing and disseminating information on technologies appropriate to the needs of the developing countries: ascertaining the technological requirements of Third World countries: support in the form of personnel, material and equipment to promote the development and adaptation of technologies for developing countries.

- Environmental Protection:

  The growing importance of ecology and environmental protection require better coordination and harmonization of projects. In order to tackle these tasks more effectively, a coordination center was set up within GATE in 1985.

GATE has entered into cooperation agreements with a number of technology centres in Third World countries.

GATE offers a free information service on appropriate technologies for all public and private development institutions in developing countries, dealing with the development, adaptation, introduction and application of technologies.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

The government-owned GTZ operates in the field of Technical Cooperation. 2200 German experts are working together with partners from about 100 countries of Africa, Asia and Latin America in projects covering practically every sector of agriculture, forestry, economic development, social services and institutional and material infrastructure. The GTZ is commissioned to do this work both by the Government of the Federal Republic of Germany and by other government or semi-government authorities.

The GTZ activities encompass:

- appraisal, technical planning, control and supervision of technical cooperation projects commissioned by the Government of the Federal Republic or by other authorities
- providing an advisory service to other agencies also working on development projects
- the recruitment, selection, briefing, assignment, administration of expert personnel and their welfare and technical backstopping during their period of assignment
- provision of materials and equipment for projects, planning work, selection, purchasing and shipment to the developing countries
- management of all financial obligations to the partner-country.

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Chapter 1

Origin of Clay

Clay is a product of the continuous weathering of the Earth's surface. Our study of clay begins with how the planet Earth was formed.

The Earth was created some 5,000 million years ago, according to scientific theory. At first it was a gaseous molten mass, which slowly contracted. While the mass was still molten, the heavier materials like iron and nickel sunk to the centre of the Earth. As the hot Earth gradually cooled, a layer of solid materials formed the crust.The crust feels very secure to us, but it is only about 40 km thick, floating on a 3000 km deep layer of molten materials.

Slow currents in this molten sea cause whole continents to move at speeds of up to 2 cm per year. Where continents grind against each other, earthquakes and volcanoes occur. The map shows how all the big continent shave changed location during the last 200 million years. Africa was then so far to the South that it was covered by polar ice masses. The Indian plate moved North, and when it collided with the Asian continent the highest mountains on Earth- the Himalayas - were formed.In this way the crust of the Earth has changed continuously since it was formed. Where we see mountains today there may formerly have been wide oceans, and tropical forests may have been covered with arctic ice million of years ago. weathering: Weathering also causes major changes. Solid rocks are broken up by the alternate action of sun, rain and ice. The resulting small rock particles rocks are carried away by water, and even mountains wear away in a few million years. Clay and many other ceramic raw materials are produced by this process.

1.1 Minerals and Rocks

1.1.1 Minerals

A mineral is a substance which has a uniform chemical composition, in the form of one or many crystals. Quartz and feldspar are minerals, and so is salt. Salt crystals (sodium chloride) have a cubic shape which can easily be seen under a magnifying glass. When salt is dissolved in a glass of water and left for a while crystals will form slowly as the water evaporates.

1.1.2 Rocks

Most rocks are made up of several different minerals, though some rocks like gypsum only consist of one mineral. The rock named granite contains the minerals quartz, feldspar and mica, and the individual crystals can be seen clearly with a magnifying glass. Rocks can be arranged in three major groups; igneous rocks, sedimentary rocks and metamorphic rocks.

Igneous Rocks

When the young Earth slowly started to cool, different minerals formed crystals in the mass of molten rocks (also named magma). A variety of crystalline rocks were formed, according to the different conditions of their locality. Thus the igneous rock called basalt was created at a great depth, and contains little feldspar compared to granite, which formed near the surface.

If the rock cooled very slowly, the crystals had time to grow large, whereas rapid cooling produces small crystals. This process is still going on today where movement in the crust of the Earth causes deep layers of molten materials to rise to the surface. An erupting volcano lets out hot magma on the surface, where it cools quickly. The resulting volcanic rocks have microscopic size crystals, since the rapid cooling allows little time for the crystals to grow.

Sedimentary Rocks

Sedimentary rocks are made of materials produced by the crumbling of old rocks. All rocks eventually break up in the course of time when exposed to weather, and the broken up rock particles are carried away by water. These particles of clay and sand are transported to lower lying areas, or to the sea where they settle one layer upon the other. In the span of millions of years, the growing weight of sediments causes the deeper layers to compact and gradually turn into rocks, called sedimentary rocks. Much later, the movement of landmasses sometimes turns the whole area upside down, so that the old sea floor, with its sedimentary rocks, becomes a new range of mountains.

The upper part of new mountains consists of sedimentary rocks resting on deeply set igneous rocks. After some millions of years, the upper sedimentary rocks erodes away by weathering and the deeper igneous rocks are exposed.

Sedimentary rocks like sandstone and shale can often be recognized by their layered structure. Limestone is a sedimentary rock created by the left over skeletons of billions of small animals that lived in the ancient seas. Gypsum is formed by chemical sedimentation, in areas where seawater evaporated on a large scale. This produced a high concentration of gypsum which formed crystals in a fashion similar to the formation of salt crystals in a glass of salty water.

Metamorphic Rocks

Igneous and sedimentary rocks are sometimes changed into new forms by high temperatures and high pressure. Marble is an example of a metamorphic rock that is formed from a sedimentary rock named limestone.

1.1.3 Rock Cycle

Fig. **??** shows how one continental plate moves under another, causing some rocks to be exposed to high temperatures and pressure. Sedimentary or metamorphic rocks melt, and may later return to the surface as igneous rocks. These later will erode to become clay and sedimentary rocks. Fig. **??** shows this rock cycle graphically.

1.2 Formation of Clay

The formation of clay from rock is a most common event, taking place daily everywhere in the world. If a piece of granite is picked up and broken in two, the fresh faces of the stone will show a shiny surface and the crystals of the different minerals can be identified. The black shaded crystals are mica. The yellow, white or red colored crystals with a pearly shine are different types of feldspar. The clear colorless crystals are quartz. The weathered surface of the granite will most probably show a rough surface with many holes, where the soluble feldspar crystals have been washed away by rain, whereas the less soluble crystals of mica and quartz remain. This is the beginning of the process of changing feldspar into clay.

Weathering breaks up the granite rocks and enables the water to wash away the soluble soda, potash or lime parts of the feldspar. These soluble parts are carried away by water and the soda ends up adding to the salt of the oceans. The process is shown in fig. **??**. Most of the remaining alumina and silica of the feldspar combines with water and forms a new mineral: clay. Some of the silica from the feldspar does not take part in formation of clay and forms instead another mineral known as quartz.

1.3 Primary Clay

Clays which have not moved from the location of their parent rock are known as primary clays. Kaolin (also called China clay) is a primary clay.

1.3.1 Steam and Acid

In some cases the parent rock was exposed to steam from volcanic activity or to acid seeping down from above. The acid or hot steam slowly changed the rock into clay, quartz and mica in the same location. Such a deposit may only contain 25% clay, and in some cases where the granite rock is only partly changed the clay content may be 10% or less.

1.3.2 Kaolin

Kaolin clays are pure, without impurities like iron oxide and limestone. Therefore, they have a high melting point (about 1780°C) and they fire to a white colour. Kaolin has little plasticity due to its large particle size.

1.4 Secondary Clay

Clays which have been removed from their place of origin and have settled somewhere else are called secondary clays. Fig. ?? illustrates this process; rain washes the clay out from the site of its parent rock and the clay is carried downhill by rivers and streams.

1.4.1 Grading

A rapid river can even carry small stones, but as the flow of the river slows down, the heavy particles will start to settle, then the coarser sand, and finally the fine sand. The clay remains suspended in the water and will only settle where the river flows into a lake or a sea. At the mouth of the river, the silt and coarser clay will settle, whereas the fine clay will only settle further away. In this way, the original materials of the erosion process are graded according to their particle size (fig. ??).

1.4.2 Grinding

The clay may travel thousands of kilometers before it settles. During transport the clay particles are subjected to the grinding action of pebbles in the streams. This works very much like grinding in a ball mill and makes the clay particles still smaller, thereby adding plasticity to the final clay.

1.4.3 Impurities

The river or stream carrying the clay will also pick up all kinds of impurities on its way through the landscape. These impurities will later be deposited together with the clay. It is very rare to find a pure secondary clay, i.e. a white firing plastic clay.

The most common impurity is iron oxide (rust) which gives the fired clay a buff, red or brown colour. Iron oxide exists in slightly different forms which may be yellow, red, grey or brown in the raw clay. However, the different iron oxides all turn into red iron oxide (FE_2O_3) during an oxidizing firing. The clay may also contain organic matter which was added in the form of leaves and other vegetation from contemporary forests. This organic matter (carbon) gives the raw clay a grey or black colour, but as the carbon normally burns away during firing it does not affect the fired colour of the clay. Black clay is usually not black after firing. Other impurities like feldspar, mica and limestone lower the melting point of clay.

In general, secondary clays are plastic and have a lower melting point compared to primary clays, due to their impurities. The quality of secondary clays varies from one deposit to another, and even within the same deposit the quality of a clay can vary considerably.

Chapter 2

Prospecting and Mining Clay

2.1 Prospecting Clay

Pottery clay can be found in most countries. In areas where pottery or brick-making have a long history suitable clay deposits will already be well known. However, introduction of new techniques like glazing or high temperature firing may call for new types of clay. In some countries the land may still be virgin from a potter's point of view and before any production facilities are established a reliable source of good pottery clay must be found.

2.1.1 Practical People

It is worth talking to people who make water wells, and builders of dams and roads. They should have first-hand information about the soil of the region. Farmers in the area will know about the upper layers of soil on their fields. Sometimes clay is used for other purposes, like whitewashing houses or medicine. In Tanzania iron smelters use a highly refractory clay for their furnaces, and in Nepal the brass makers use a local fireclay for their casting moulds.

2.1.2 Prospecting

When setting out to explore the countryside one should bear in mind how nature created clay. Recent deposits of plastic clay are most likely found in the plains and valleys, or along rivers. They are often close to the surface. Older secondary deposits may be found in the hills where the land was raised and folded, millions of years after the clay was deposited. Such deposits may be covered with a thick layer of other materials.

River Banks

A good potter's clay will often be covered by several meters of overburden. Instead of digging test holes through the overburden at random, a general idea of the deeper soils in the area can be obtained by examining the soils exposed in river banks, escarpments and cut areas where a road or a railway was made through a hill. Quarries, wells and ditches should be examined as well. Termites bring soil up from below, and the material from termite hills indicates the quality of soil located 1–2 meters down.

Field Testing

In the field a few simple tests can establish whether the clay is worth examining further. First, take a sample from about 30 cm inside the exposed surface, and mix it with water. If it turns into a plastic sticky mass it is clay. Then knead it well and form a rope the thickness of a pencil. If you can bend this rope around two fingers without seeing big cracks, the clay has plasticity (fig **??**).

If you bite the plastic clay gently with your front teeth you will get an idea of how finely grained the sand content is.

Then rub a sample of dry clay in the palm of your hand until the fine particles are rubbed away. What remains is the grit content, which may be particles of feldspar, quartz or mica.

Small pieces of limestone will cause trouble in pot-making, so the deposit and its vicinity should be examined for signs of white or grey limestone. Lime powder thoroughly mixed with the clay will lower its melting point and is often used for low-temperature pottery. But a piece of limestone the size of a pinhead will crack the pots or bricks when they are exposed to moisture after firing. Screening the clay through a fine sieve reduces this problem, but if possible, it is better to look for another clay. Lime content can be tested by putting a few drops of dilute hydrochloric acid on a sample. If there is lime, bubbles will form from the reaction.

Sample Collection

If the clay, after field testing, has proven to be of interest samples should be collected for further and more thorough testing. The quality of clay from different places in the same deposit will differ slightly, so in order to get a representative sample, clay from 4 different spots within a few meters' distance are dug out. The clay should not be taken from the exposed surface of the deposit but rather from 30–50 cm inside since the clay at the surface may be contaminated with other soils or washed out by rain.

The 4 samples are mixed well at the location and a sample of about 5 kg is then packed and labeled with its location .

Make a sketch of the location as accurately as possible, indicating features of the landscape like big trees or rocks. If a motor vehicle is used, note the exact distance on the odometer from the nearest town to the clay site. A photograph of the clay site will help in finding the right site again later.

Probe Digging

In areas where initial survey and testing indicates deposits of suitable clay, holes should be dug in a regular grid in order to ascertain the size of the deposit. Initially, holes should be dug with a grid distance of 50 m. and where the best quality clay is discovered, the distance can be reduced to 15 m. It is worthwhile to ensure that the deposit is large enough to supply the planned production for a long time. The holes can be dug with a spade, but if a hole is more than 2 m deep the sides of the hole should be supported by planks.

A bucket auger (fig **??**) is a very useful tool for taking samples. One or two people rotate the auger, which drills its way into the soil. The shaft can be extended so that samples can be taken from depth of 5 m or more. The bucket auger can be made at a local machine shop.

Map

A map should be made of the whole grid area, and on the map the probe holes are marked with a number, thickness of overburden and depth of clay layer.

The map is drawn with the help of a few fixed features, like trees and large stones (fig **??**). The distance between three fixed points is measured as accurately as possible. The map is made in a scale of 1:100 (1 cm on the map represents 100 cm (1 m) in reality) or 1:200 (1cm=2m). The three fixed features are then marked on the map like on fig **??**. The location of the test holes is measured and marked on the map according to its distance from the fixed points. Each test hole is given a number, which is marked by the hole itself, on the test sample label and on the map.

After testing of all the samples has pinpointed the best area, a more detailed plan (e.g. scale 1:50) of that area should be drawn, showing the depth of the various layers of top soil, clays and possibly other materials.

2.1.3 Economy

After having established the quality of the raw clay, the approximate size of the deposit and the thickness of the overburden the final decision of whether or not to start mining the clay remains to be done. Many factors control the economy of mining clay:

- The distance from the deposit to a suitable road, and the cost of transport to the workshop. It may be necessary to construct a small track from the deposit to the nearest road.
- The cost of removing the overburden com- pared to the amount of clay underneath.
- The cost of renting or buying land.
- The quality of the clay. If the raw clay contains large amounts of sand, it may be necessary to wash the clay at the mine in order to reduce the cost of transport.

The total cost of opening up the mine, and the cost of digging and transporting the clay as listed above should be calculated as cost per kilogram of clay. This cost per kilogram is then compared with the cost of possible alternative sources of clay.

2.2 Clay Mining

2.2.1 Before Mining

The clay you intend to mine may have been deposited in an ancient lake as shown in fig **??**. It may have taken hundreds of thousands of years to fill the lake with sediments, and during that period variations in climate, course of rivers, etc., caused the layers of sediments to vary. Each layer may contain its own type of clay or sand and the thickness of each layer may vary considerably.

Clay Layers

Before you start to dig the clay, expect it to be limited to certain layers. Today these layers will often be positioned horizontally in the same manner as they were laid down (fig **??**). But they may also have been turned upside down by later folding of the landmasses and could be positioned as suggested in fig **??** and fig **??**. The digging of probe holes as mentioned above should indicate how the clay layers are positioned.

Overburden

First the top soil or overburden has to be removed and piled away from the clay pit where no future clay digging is planned. Care should be taken to avoid mixing top soil with the clay. If the overburden is several meters thick, it may be worthwhile to hire a bulldozer to clear away enough top soil for several years' clay mining.

In some cases, the overburden is too thick to be removed, and underground mining must be considered. This method is especially tempting if the clay is situated on a riverbank, on a slope or on an escarpment so that horizontal shafts can be dug. That will save the tedious task of removing the overburden, but this advantage may be offset by the extra cost of using lumber supports for keeping the walls of the underground shafts from collapsing. Underground mining of clay in vault shaped shafts without supports is often seen but is dangerous.

Digging Tools

Commercial mining of clay on a large scale in industrialized countries uses heavy machinery (fig **??**). In most other places manual methods are more economical.

Manual digging is done by spade or hoe. A shovel is no good for breaking up clay, but it is useful when loading the clay into a wheelbarrow or truck. A wheelbarrow is used for bringing clay from the pit to a vehicle.

Supervision of Clay Winning

While digging, the worker should sort out roots, limestone, rocks and other unwanted material. The digging should always be supervised by an experienced person who can judge the quality of the raw clay. As the working of the clay pit progresses it may reach layers of inferior clay. The supervisor should regularly test the quality of the clay using the simple methods described above. Production of first class pottery demands raw materials of consistent and uniform quality. A potter adjusts production methods to the clay, and if it suddenly changes its behavior, it may ruin the production. If, for example, the clay becomes more plastic it may cause pots to crack during drying.

Even within the same layer of clay the composition of the raw clay may differ. Therefore, it is prudent to dig clay from several levels or locations at the same time, and to mix the material before loading it for transport. A worker can dig 4 to 8 tons of raw clay per day, depending on conditions in the clay pit.

If the worker is paid according to quantity (piece work) the quality of the clay may suffer unless the supervision is thorough. In the long run, it may be less costly to pay by the hour (time work) in order to get better quality clay.

Safety

Clay is normally extracted from open pits, which are much safer compared to underground mining. However, safety should also be a concern in open pits. Clay should not be dug from a vertical clay face higher than 2 m because a large portion of the face could break loose and bury the worker. The digging of clay in deep pits should be done in benches as shown in fig **??**. The overburden is removed away from the clay face being worked on, so that no top soil will get mixed with the clay itself. The benches on the clay face are made in steps about 1 m high and 0.5–1 m wide. The material from different levels can be thrown to the bottom of the pit for mixing, in order to even out variations in clay quality.

Record

A record should be kept of where in the pit the different batches of clay are extracted, so that sudden changes in the quality of clay can be traced to specific locations in the pit, and these can be avoided in the future. The movement of the digging area is recorded on the original map and is compared with the location of the original test holes. In this way, the supervisor can decide in which direction and to which depth to direct the digging, and he will be able to avoid clay beds of inferior quality that are shown on the test hole map.

2.2.2 Stockpiling and Weathering

Planning

Clay mining is impractical or impossible during rainy seasons, and in some areas of the world the ground freezes hard during winter. Therefore, it is necessary to extract sufficient clay during the dry season or during the summer to cover a whole year's production. That means you will have to plan your clay digging and production 0.5–1 year ahead, or you will run out of clay.

Weathering

Storing the clay in the open, and exposing it to the action of rain, sun or frost is called weathering. The alternate wetting and drying, or freezing and thawing, improves the plasticity of the clay by breaking it into smaller particles.

Weathering will reduce the content of possible organic matter in the clay, and this may have a bleaching effect on the raw clay. Weathering also washes out soluble salts. The clay should not be piled higher than 0.5 m. Clay may be weathered from a few months up to one year.

Clay Storing

When clay is received at the pottery it should be piled as shown in fig **??**. Each truck or cart load is spread out in a thin layer covering the whole storage area. This makes horizontal layers.

The raw clay is collected from the clay bin by making vertical cuts in the pile, so that a little clay from each truck load is part of each batch of clay used in production. This procedure will ensure a more uniform clay quality.

Chapter 3

Clay Washing and Clay Body Preparation

3.1 Washing at the Pit

After extracting the clay from its pit, it is normally brought directly to the pottery for further treatment. However, some raw clays contain so much sand that it is more economical to dispose of the sand at the clay pit, thus avoiding the cost of transporting this unwanted material. The true clay content found in primary clay deposits may be only 15% or less. The whiteness or the refractoriness of such clays may still make it profitable to mine them.

3.1.1 Commercial Kaolin Mine

In some commercial kaolin mines, clay is extracted by washing the clay face in an open kaolin pit with a high-pressure water-jet. The fine clay is carried away with the water leaving behind most of the coarse materials. In older mines, the resulting clay slurry is run through troughs, where the non-clay materials settle, after which the clay slurry is pumped into settling tanks. After siphoning off the clear water, the clay slip is de-watered in filter presses and dried in ovens. In more modern works, the trough type settling tanks have been replaced by centrifuges.

Smaller clay works cannot afford such machinery. Instead the raw clay is mixed with water, and stirred either manually in ponds or in a washmill.

3.1.2 Washing Ponds

Next to the clay pit and close to a source of water two or more shallow ponds are dug, measuring about 4 m by 2 m and 0.5 m deep. The sides of the ponds can be lined with bricks or simple wickerwork plastered with clay.

The pond is half filled with water and the raw clay is added until the pond is nearly full. The raw clay is then stirred with a shovel, until all the clay is separated from the sand. With dry sandy clays this may take less than 20 minutes. Finer clays need longer stirring and for very fine ones it may be necessary to let the clay soak for a day. However, clay that fine is in no need of having its sand removed.

When all the clay is suspended in water and the material at the bottom of the pond is only sand (without a clayey feeling), the clay slurry can be transferred to a settling pond. If possible the settling pond should be located at a slightly lower level so that the clay slurry can run in by itself. Otherwise, the clay slurry is transferred by bucket, which is filled in a small pit connected to the stirring pond with a pipe. In this way the bucket will not disturb the settled sand in the stirring pond.

When a very pure clay is desired, the clay slip is led through several settling pits before filling the final settling pond. During the slow flow through the intermediate pits, the fine sand particles will settle and only the much finer clay particles will flow on.

After the clay has settled in the settling pond, the clear water on top can be transferred by pump or by bucket, back to the stirring pond, which first has been emptied of its sand. The bucket or pump intake should not be dipped into the settling pond since that would stir the settled clay. Instead the surplus water is led to a small pit next to the settling pond, and water is taken from here. For each stirring pond several settling ponds are needed. The clay is then left in the settling pond until it is stiff enough to be removed for further drying.

3.1.3 Washmill

For large quantities of clay an animal powered washmill is useful (fig **??**). The circular tank is half filled with water and raw clay, preferably dry and without large lumps, is added while stirring, until the tank is almost full. After stirring for 1–2 hours (depending on the properties of the clay), the clay will be suspended in the water, while stones and coarse sand settle at the bottom. The clay slurry is then run into settling ponds.

The washmill can also be operated continuously; first it is filled as described above and when the clay and sand have been separated, more raw clay is added gradually. The added raw clay will sink to the bottom, where it is worked by the harrows, and an equal amount of clay slurry will run off at the upper outlet. Fresh water is added from a pit with an inlet at the bottom of the tank. After operating the washmill continuously for some days, sand and stones accumulated at the bottom of the tank has to be cleaned out.

Sand Separator

If the fine sand content of the clay is not desired, the slurry is run (on its way to the settling tanks) either through a fine mesh sieve, a grooved tray (fig **??**), a series of settling tanks (fig **??**) or a sand separator (fig **??** and fig **??**).

Washmill Construction

The washmill is built of bricks laid with cement mortar. The centre section supports the beam that turns the harrows. The beam turns in simple bearings, that can be made of hardwood which is kept well greased. A sluice system with adjustable outlet levels can be fitted with a grate to catch roots and other organic material. The harrows should be made of iron or of wood reinforced with iron. Fig **??** shows how an extra set of harrows hinged onto the main harrows improves the disintegrating action. The tank should not be more than 1 m deep, and increased capacity is achieved by widening the diameter of the circular tank. A tank with a diameter of 4.5 m can wash at least 6 ton of raw clay at a time.

The washmill can be powered by one or two persons or by a draught animal. A motor could also power the washmill, but since a rather high gear ratio is needed, the washmill becomes much more costly. Alternatively, the raw clay can be washed in a high speed blunger.

3.2 Clay Body Preparation

Two different methods are used for preparing the clay for production: dry and slop. Each method has many variations, and the right choice of techniques and machinery depends very much on the nature of the clay and on the type of ware to be produced. Therefore, before deciding on any method, the clay should first be tried out thoroughly–from preparation of clay to forming, glazing and firing.

3.2.1 Dry Method

After weathering, the clay is dried completely. If the clay can be used as it is, without having sand or stones removed, the dried clay is wetted directly and left until it has a plastic consistency. Then it is kneaded manually or in a pugmill. fig **??** shows such a system with dry clay stored in the back, a slaking pit in front, plastic clay covered under wet cloth ready to be pugged.

In must cases, however, sand and other impurities have to be removed. The dried clay is then first pulverized either manually by a lever hammer, or with the help of a hammer mill or pin mill.

Lever hammer

The lever hammer is operated by two persons. One steps on the short lever, thereby lifting the long lever onto which a heavy iron or wooden hammer is fixed. This falls on the clay, which is fed to the hammer by the second person, who may also screen the powdered clay.

In many countries, the same traditional machine is used for rice hulling.

Hammer mill

A hammer mill or plate mill of the type used for grinding grain may be cheaper to operate compared to the lever hammer. It can be powered either by an electric motor or small diesel engine. In the hammer mill, a number of small exchangeable hammers are mounted on a rotating disk. The hammers disintegrate the material by impact until the particles are small enough to pass through a curved screen. The screens can be changed, so that coarse material like grog can be produced as well.

The rotation of the hammers produces suction at the centre and pressure at the perimeter. Therefore, the inlet of material should be at the centre the point of suction. The pressure helps to blow the ground material through the screen. The outlet should lead into a big cotton bag that retains the clay but lets the air through. Some hammer mills have the inlet at the perimeter, and that produces a lot of dust, which is a health hazard to the operator. The dust nuisance can be reduced by fixing an outlet with a long tube on top of the mill casing to release air pressure.

Pin mill

This mill has a rotor fitted with beaters which rotate between stationary pins. The material is fed through a hopper to the centre of the mill. The rotating beaters hit the material and fling it outward where it hits stationary pins. When it is fine enough, it passes the sieve surrounding the rotor.

The pin mill is suitable for slightly moist clay materials, which otherwise tend to clog the hammer mill screen.

Screening

After the clay has been pulverized, it can be mixed with other dry materials like sand, limestone, feldspar, kaolin, talc or grog (see p. 47). The mixture should be screened again, or put through the hammer mill an extra time in order to ensure proper mixing of the different materials.

For larger potteries a vibrating screen as shown in fig **??** will be useful. The screen can be replaced so it can be used for different particle sizes.

Wetting

Water is then added to the clay, either by pouring water into a pit in the centre of the clay and leaving it to be absorbed, or by sprinkling an even amount of water onto about 5 cm thick layers of clay, which are then covered by subsequent layers. After soaking, the clay is kneaded either by foot or hand. The clay should then be left in a moist place for at least a week. This could be a clay cellar, or a clay pit covered with wet cloth and plastic sheets.

Prolonged storage will improve the plasticity of the clay and give it a stiffer consistency.

Kneading

After storage, the clay should be kneaded again, either manually or in a pugmill. A vertical pugmill can be constructed locally. An animal powered pugmill of a type often used in brickworks is shown at fig **??**. The barrel is made from metal or wood and a vertical shaft is fitted with blades set at a slight angle, which forces the clay downward.

Conclusion

The advantage of the dry method is that little equipment is needed. Its drawbacks are that the workers are exposed to unhealthy clay dust, and that the clay only develops its full potential plasticity after prolonged storage. In some cases, troublesome impurities can only be removed by the slop method.

3.2.2 Slop method

The clay is made into a slip, other materials are added, and after screening the slip is dewatered until the clay has the right consistency. There are numerous variations of the slop method and a few examples are described below.

3.2.3 Industrial slip house

In industrial production of white ware, clay bodies are made up of several different clays, with additions of feldspar, quartz and other materials. Feldspar and rock quartz are first crushed to the size of gravel (2–4 mm) before further grinding in a ball mill. For that, one of the following machines is used.

Jaw crusher

This machine is used for the initial crushing of rocks (fig **??**). Large lumps of rock are reduced to 15-25 mm pebbles. This initial reduction can also be done manually with a hammer. A jaw crusher is often used for producing grog.

Roller crusher

Crushing rollers are used for breaking down lumpy clay or shale. The rollers may be smooth or with grooves, and they rotate in opposite directions to each other. The space between the rollers can be adjusted.

Pan grinder

One or two heavy wheels made of granite or steel rotate on a pan of similar material and crush the pebble size material to sand (fig **??**). In some cases, the pan is perforated. The pan grinder can also be used for crushing grog and for preparing clay bodies, especially granulated bodies for dust pressing of tiles.

Hammer mill

The hammer mill is widely used because it is so versatile. It is mainly used for softer materials like clay, limestone, talc and gypsum, but can also be used in an emergency for grinding feldspar and quartz, provided these have first been shattered by calcining above 600°C. The hard materials will quickly wear out the hammers and the sieve of the mill. ball mill: the final grinding takes place in a ball mill, which can grind materials up to coarse sand size. A ball mill is a hollow mild steel cylinder, lined with special bricks made of hard rock (like granite), or porcelain, or a thick rubber sheet. The ball mill is filled about 50% with pebbles of flint or porcelain, 25% material for grinding and 20% water (measured by volume). The ball mill is rotated slowly, so that the pebbles constantly roll down the inner slope of the cylinder, and the material is ground by the rubbing action between the pebbles. (See appendix **??**).

In large factories, each raw material is ground separately and then mixed in a blunger according to its slop weight. In smaller factories kaolin, feldspar and quartz are measured by dry weight and milled together. In that way the total ball milling time can be reduced by adding kaolin after the harder materials (quartz and feldspar) have been milled for some time.

A coarse screen fitted to the ball mill holds back the pebbles while the clay slip is poured out and led to a blunger through wooden troughs.

Blunger

In the blunger (mixing ark) plastic sedimentary clay (often ball clay) is added to the milled materials. The blunger shown at fig **??** stirs the clay slip by rotating two sets of blades at 17 rpm (rotations per minute), and blunging time for ball clay is more than 10 hours. A high speed blunger with a single shaft propeller (fig **??**) cuts blunging time to 1–2 hours and is now replacing the slower type.

Screening and de-magnetizating

After blunging, the clay slip is screened through a fine mesh screen (80–150 mesh per sq. inch). The screen is vibrated to prevent it from getting clogged. By fitting a coarser sieve mesh above the fine mesh screen the clogging problem can be reduced. 2– and 3–deck screens are commonly used.

In production of white ware, the clay slip is passed through magnets that catch iron compounds, which would otherwise produce brown specks in the fired product. The magnets are either permanent magnets or electromagnets. Old loudspeaker magnets suspended in the blunger are adequate.

Filter press

The clay slip contains about 50% water when being screened, and half of that must be removed before the clay has the right consistency for forming. In modern industries, dewatering is done in a filterpress. This consists of a series of frames which form chambers when fitted together. Each chamber is lined with a filter cloth, and the slip enters the chambers through holes in the frames. The filter cloth is hung over both sides of the frame and the two halves of the cloth are sewn together around the inlet hole. The frames are fitted together in one long row, and sealed by tightening a heavy screw.

The clay slip is then pumped into the filterpress under pressure ($7--10kg/cm^2$) and the water is forced out through the filter cloth. The water drains away through grooves in the frames.

Filtering time varies according to the particle size of the clay and the pumping pressure. Filtering of a coarse grained kaolin clay may take only two hours, whereas a highly plastic clay may take 8 hours. After the water has stopped dripping from the frames, the tightening screw is opened and stiff clay cakes are removed from between the frames and transferred to the clay storage.

Compressed air pump

A durable and simple filterpress pumping system can be made with the help of an air-compressor and a tank capable of handling pressures up to $10kg/cm^2$. At the bottom of the tank a pipe connects to the filterpress inlet. After filling the tank with clay slip, compressed air is pumped into the tank. An adjustable pressure valve maintains the desired pumping pressure. When the clay in the filterpress is dewatered, the compressed air is shot off, the pressure in the tank is released and another batch of clay slip is loaded.

This system has several advantages over a conventional piston pump system:

- The clay slip is forced through the filterpress under a constant pressure, thus reducing filtering time and lamination problems.
- Maintenance cost is very low, since no moving parts come in contact with the abrasive clay slip.
- The pump system is much cheaper and it can be made from locally available parts.
- It uses very little energy.

The pressure tank is the most expensive part, but this cost can be reduced by using a smaller tank, which is then charged twice during one filterpress operation.

Pugging

The clay is then left to mature in the storage area for at least two weeks in order to improve its plasticity. However, the clay still requires hand or machine kneading to remove entrapped air and make the clay uniform.

Kneading table

A kneading table works the clay with horizontal and vertical rollers (fig **??**). The upper horizontal rollers press the clay down, and afterwards the vertical rollers press the clay up. This alternate movement up and down squeezes entrapped air out of the clay and gives it a uniform consistency. The clay is laid in a circular wad on top of the kneading table, and each operation takes about 50 minutes.

The kneading table is mainly for bodies with low plasticity, like porcelain bodies, but is little used today.

Pugmill

The pugmill has replaced the kneading table in modern ceramics plants. It is a more costly machine, but it produces a better quality clay, especially if the clay is de-aired during pugging. The pug mill consists of a large cylinder with an axle running through its centre.

Sets of iron blades are attached to the axle and these both cut the clay and move it forward. Clay is fed from one end and pressed out through a mouth piece at the other end in a continuous column, that is cut up in convenient pieces ready for forming.

The flow of clay through the cylinder is not even. The clay at the centre moves at a different speed compared to the clay next to the cylinder wall, and this produces different densities in the clay body. That causes stress in the finished ware, which may warp during drying or crack during firing (these special cracks are called lamination cracks). Hand kneading after pugging is often required.

A de-airing pug mill takes the clay through a chamber where a strong vacuum is maintained by a vacuum pump. In this vacuum all entrapped air is sucked out of the clay, which greatly improves its plasticity. At the same time, de-airing reduces the problems of lamination stresses in the finished products.

Chapter 4

Nature of Clay

Chapter 5

Clay Bodies

Chapter 6

Testing of Clay