CERAMIC SKILLBOOKS
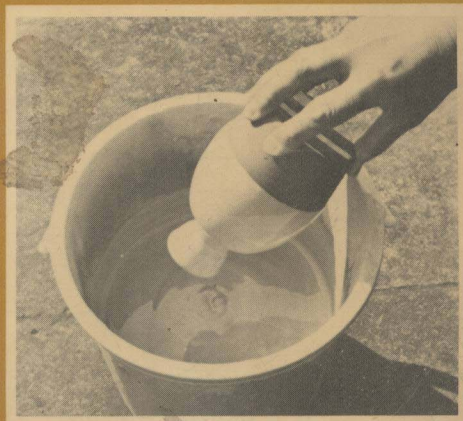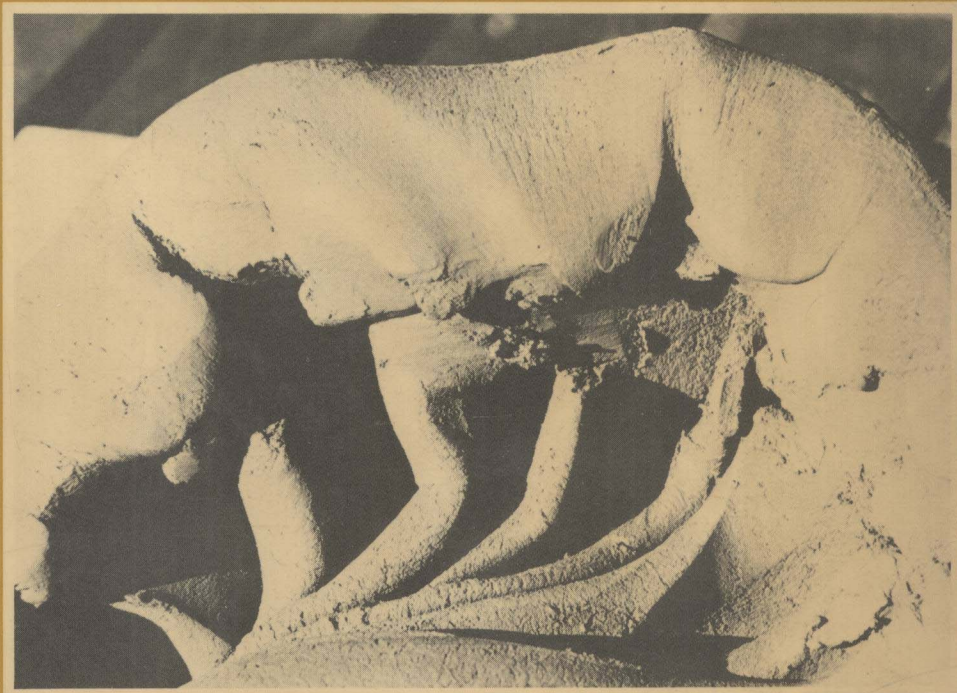
Clays

Frank and
Janet Hamer

CERAMIC SKILLBOOKS

Series Editor:
Murray Fieldhouse

Clays

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Introduction

Clay users are heterogeneous, from those who prospect from the ground up to those who buy convenience clays, wheel-ready or mould-ready, from those who work alone to those who constitute manpower, from those who seek artistic expression to those seeking economic viability. Nevertheless, their practical needs are surprisingly similar.

Clay is that marvellous creative substance upon which pottery, ceramic sculpture and architectural ceramics are based. Our lives are enriched by the direct expression held in these forms. We also depend upon clay for tableware, sanitary ware, electrical insulators, bricks, cosmetics and in paper and rubber.

Sometimes dry, powdery, shaley or sticky, sometimes smooth and fine or coarse-grained, in colours of blue, grey, white, yellow, pink, buff or terracotta, clay is common to most parts of the world.

Chemically it is composed of the commonest of elements: silicon, oxygen, aluminium and hydrogen; but it has two important and unique characteristics. Clay can be given a form which it retains, and it can be changed by heat from a mutable to a durable material.

This book describes the origin of clay, its chemical and physical make-up and its properties of workability and drying. It explains how to retain and improve these properties by knowledgeable preparation, how to make up clays for specific purposes and gain from their special characteristics, and gives advice on purchasing clays.

We are indebted to researchers and clay suppliers, especially R. W. Ford, W. Ryan, F. Singer, S. S. Singer, W. E. Worrall, English China Clays & Co. Ltd, Watts Blake Bearne & Co. Ltd. We acknowledge the assistance from others mentioned in the text and are grateful to Pitman Publishing Ltd for use of material

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from *The Potter's Dictionary of Materials and Techniques* by
F. Hamer. The photographs and drawings are by the authors
except where otherwise credited.

We dedicate this book to all aspiring, inspired, determined and
successful potters.

Ponthir April 1976
Frank Hamer
Janet Hamer

1 The Origin and Geology of Clay

Rock into clay

All clays originate as deep-seated igneous or metamorphic rocks. Hot magma pushes upwards but does not reach the surface and therefore cools slowly in large masses. These are domes of rock created where the magma is prevented from making further upward movement. Such domes are the granite bosses which today form upland areas like Dartmoor in south-west England. While cooling and still in thermoplastic state, the future clays are subjected to infiltration by hot gases pushing their way upwards. These gases include boron, fluorine, carbon dioxide and water which in two stages of substitution decompose a potentially hard rock and create a soft one which includes clay. The clay content is unlikely to exceed twenty-five per cent of the overall bulk of rock involved.

Granite engenders a pure clay which is referred to as the mineral kaolinite. Its crystal structure is ordered (strictly regular) and strong. Natural clays as they are dug, are less than perfect, but the crystals of china clay approximate to the mineral kaolinite and are accorded this quality.

The less pure clays originate from rocks other than granite. Such rocks are both igneous and metamorphic, that is, both the hot molten rock pushing upwards from the earth's interior and the country rock which is changed by heat and pressure through its proximity to the igneous intrusion.

The parent rocks of the less pure clays look similar to granite but are darker in colour. Their difference is one of chemical composition. They contain many more chemical elements and their structures also are more complex. This is why they engender the less pure clay which in mineral terminology is called disordered kaolinite. The name refers to the crystal structure which is distorted in comparison with the strictly regular kaolinite one.
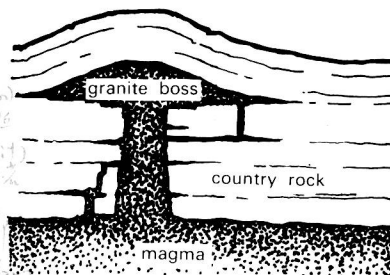

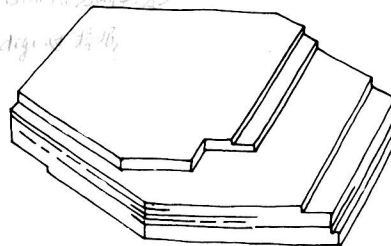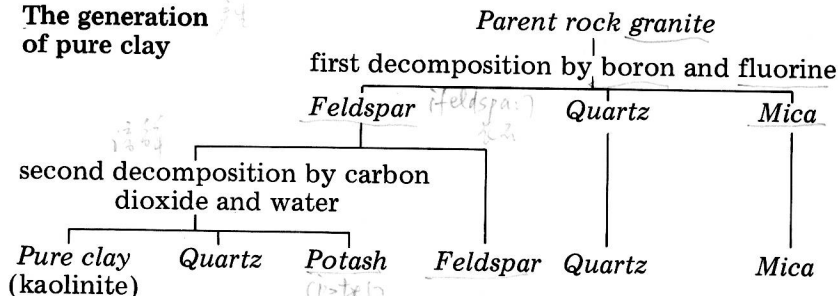Fig 1. The creation of a granite boss where the hot magma is limited in upward movement.

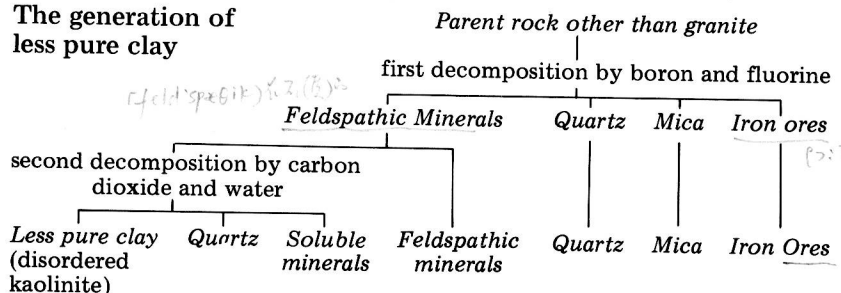Fig 2. Clay crystal magnified 150,000 times.

Kaolinite and disordered kaolinite are both clays but it is possible during decomposition for other mineral structures to be created which resemble clay, yet are not clay. Mica and montmorillonite are two. They are both group names. The micas are present in most clays when dug and are rarely described individually. Instead they are referred to collectively as mica or micaceous sand. They give a fine texture to the clay.

Montmorillonites are of exceedingly fine particle size and although present in clays in only small amounts they account for noticeable strength and plasticity. The natural material bentonite is nearly pure montmorillonite and is used to plasticize clay bodies. It so strongly resembles clay that it is often referred to as a clay although it is not of kaolinite structure. Beds of bentonite are found separately from clays as a product of the decomposition of volcanic ash.

The generation of pure clay

Parent rock granite
|
first decomposition by boron and fluorine

Feldspar   Quartz   Mica

second decomposition by carbon dioxide and water

Pure clay (kaolinite)   Quartz   Potash   Feldspar   Quartz   Mica

The generation of less pure clay

Parent rock other than granite
|
first decomposition by boron and fluorine

Feldspathic Minerals   Quartz   Mica   Iron ores

second decomposition by carbon dioxide and water

Less pure clay (disordered kaolinite)   Quartz   Soluble minerals   Feldspathic minerals   Quartz   Mica   Iron Ores

Primary clay

Clays which are found in their place of origin are called primary or residual clays. The china clay of south-west England is a primary clay and it is possible that a few of the most refractory

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fireclays are primary also, but it is no longer possible to identify the parent rock. Bentonite is primary montmorillonite.

Secondary clay

Clays which are transported from their place of origin and settled elsewhere are called secondary or sedimentary clays. All the highly plastic clays like ball clay and red marl are secondary, and so also are some low plasticity clays like fireclays and the china clays of south-eastern U.S.A. (called kaolins in the U.S.A.).

There are a few wind-blown secondary clays but most secondary clays are transported by water and ice. Rain enters the cracks of the decomposed parent rock and in freezing, expands to loosen a section. Little by little over thousands of years the bulk of rock disintegrates, collapses and is washed away in streams and rivers, is eroded by sea or lake, or is scraped away by glaciers.

During transportation by water, the clay is subjected to impact and the already tiny particles become smaller still. Some associated minerals like quartz sand and mica may be separated from the clay by the process of natural levigation. A fast-flowing river can carry large and small particles, even large pebbles, but as the river reaches flatter ground it slows down and loses the energy necessary to move the heavier objects. The finest particles, and these are the clay ones, are carried the furthest before being deposited in a lake or on the sea bed. Even here there is a sorting of size. A clay stratum has a progressive variation from coarse to fine with possible change of colour and composition. Sedimentary clays rarely show a uniformity over a wide area, which is why blending of different clays is necessary to maintain a constant product.

When clays are transported by glaciers they are subjected to physical grinding. This produces superfine clays which are plastic and sticky. They accumulate where the glacier melts and thus are not levigated like water-borne material but are mixed with sand, gravel and rock. They are called boulder clays, which is an apt name
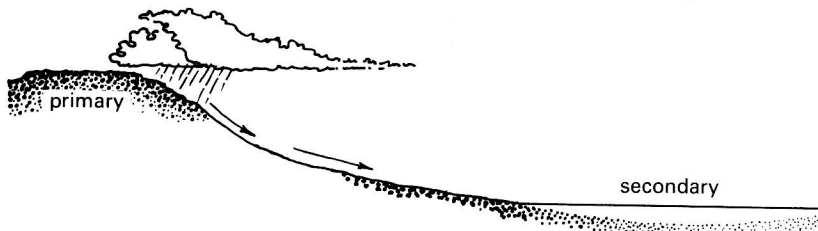

Fig 3. Natural levigation from primary to secondary clay.

since the boulders often considerably outweight the clay content.

High and low plasticity clays

Plasticity and strength are important to potters using traditional forming methods. They are properties which make clay different from chemically similar materials, and they enable the potter to make an infinite variety of shapes with speed and confidence. Clays which lack sufficient plasticity for the job in hand are called short or lean clays. Clays which have abundant plasticity are called long or fat clays.

Plasticity is directly related to particle size. The finest clays are the most plastic and since through transportation the clay is impacted, ground, and finally sorted by particle weight, it follows that secondary clays are superfine clays. This gives the general rule that secondary clays are highly plastic while primary clays are of low plasticity.

The rule is usually applicable but it is too neat to be universal so there are important exceptions. Some secondary clays resist the acquisition of plasticity even though transported considerable distances with ideal refining conditions. Clearly the reason for this must lie with the clay itself — we have already seen that there are two types of clay structured as kaolinite and disordered kaolinite and born of different parent rocks.

The purest clay mineral referred to as kaolinite comes from the feldspar in granite. It has a laminar structure of alternate gibbsite and silica layers which is well ordered and thus strong. The result is a relatively large crystal, and when many crystals aggregate they tend to do so in an orderly way, producing a clay particle which is virtually one large crystal. This large crystal resists weathering and therefore the purest clays are never highly plastic. China clays and fireclays are examples of this, whether from primary site or secondary deposit.

On occasions, nature fortuitously creates superfine kaolinites giving freak clays in isolated pockets. Such plastic china clay enabled the Chinese to produce their superb thrown porcelain. Similar pockets are reported in the U.S.A. and Australia.

When rocks other than granite decompose, the resulting clay crystal cannot be the regular kaolinite. Some of the sites in the crystal structure are occupied by substitute atoms which disorder the crystal. Disordered kaolinite crystals aggregate in very random fashion to form clay particles and thus, even if pressured into shales, they have little compact strength. Such particles are readily broken down to extreme fineness. Even the crystal itself succumbs to weathering.

Disordered kaolinite clays are therefore the more plastic and their plasticity is a direct result of the substitute atoms within the crystal. These substitutes also give a dark colour and act as fluxes during firing. Some soluble minerals are washed away during transportation but others are attracted to the crystals. Secondary clays can be expected to contain a number of minerals extra to the clay mineral, and these are known collectively as 'impurities'.

Thus three very general rules of thumb emerge about clays: (i) that primary clays are low-plasticity clays while secondary clays are high-plasticity clays; (ii) that the lighter the colour of the clay, the more refractory it is, while the darker the clay, the more likelihood there is of its being a fusible clay; and (iii) that primary clays are more refractory than secondary clays.

Prospecting

Prospecting has romantic associations. For the potter it involves understanding something about geology, thus being aware of the likely places for clay deposits and looking with an enquiring eye. Large companies have already thoroughly investigated most countries for remunerative deposits so there is little likelihood of the individual discovering a miracle clay in large supply. But prospecting is based upon hope and in more than one case has resulted in a reasonable short-term supply. Many potters prospect only for small amounts which can be used as coloured slips and in glazes.

Prospecting is not confined to open country but is applicable everywhere. One rural potter realised that the best clay in the area was probably some five miles away in the valley and under the town centre. His opportunity to get the clay came with major alterations to the town centre when the excavations for foundations produced over a year's supply of excellent clay.

But for most potters a large supply is more likely to be discovered at existing quarries. Many brick quarries contain a seam of better clay which is mixed with the poor quality for brick-making. Quarry owners know their clays and generally are keen to discuss them with like minds. Hand-picking the raw lumps provides the best opportunity. Sometimes dust from the grinding pans and shredded or milled clay can be bought.

The Ordnance Survey geological maps are the obvious starting points for prospecting in the U.K. 'Drift' rather than 'Solid' maps are required because these show what is at the surface including the alluvial and glacial deposits, both of which could contain clay.
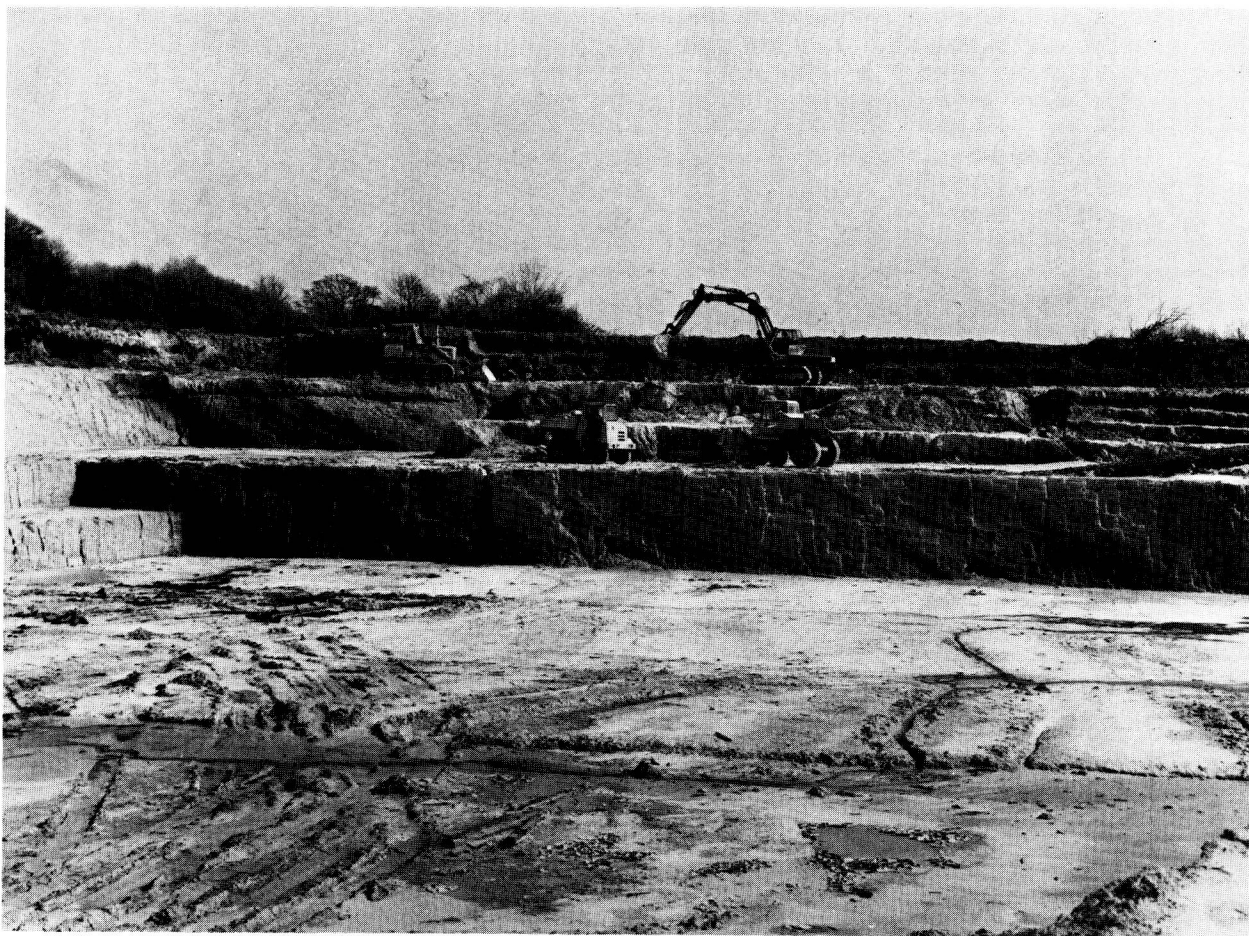
Fig 4. Opencast ball clay mine showing stratification and digging in progress. (*Photo supplied by Watts Blake Bearne & Co. Ltd.*)

Rocks are divided into those of igneous origin like granite and basalt, and those of sedimentary origin like limestone, coal and clay. Generally speaking, the mountainous areas are composed of igneous rocks while the lower land is sedimentary. For the most part prospecting will be in the sedimentary areas while remembering that the igneous areas contain small pockets of sediment often of glacial origin.

While geology maps are extremely accurate, their information is restricted to the evidence available at the time of the survey. Small local deviations therefore occur in areas which could not be surveyed in detail. There is always the chance of a lucky find.

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It may be small but two thousand pots can be made from a cubic metre of clay! The prospector should investigate stream and river banks and new cuttings for pipe-laying, roadworks and building foundations. In this way a detailed knowledge is built up. Of course, digging must only be pursued with permission. The upper twenty to fifty centimetres of most stable land is weathered to soil and is called the overburden. This is why it is necessary to look where sections are exposed. Even so there are tell-tale signs like pools of standing water after heavy rain.

Clay provides a waterproof layer. Rain runs off hills composed of clay and shale, cutting deep channels in the surface, washing

Fig 6. Clay banks erode into rounded spurs with deep fissures. Shrinkage cracks are noticeable in dry weather.

away and resettling elsewhere. Follow the streams and find where the clay has collected. Hills composed of porous rock and rocks with fissures allow the rain water to seep to the interior. The water eventually emerges at springs which can be located by a change of vegetation and are usually along a contour where the porous rock rests upon clay. Springs are marked on some maps. Look also for local names like 'clay hill', 'clay pit', 'brown hill' and interesting prospects like 'old levels' or 'disused quarry'. Thirty years of weathering in a disused quarry might have produced some excellent clay.

First tests

On-the-spot tests can tell us quite a lot about clay samples. Pinching a small pot is useful, as is doing a simple deformation test and a tie-a-knot test. In deformation testing, a piece of clay is pushed with the thumb or finger and we note how much initial resistance there is. Also we note whether the clay went in the way intended and whether it held the intended form. Some poor clays have too much initial resistance and feel hard and bouncy. Some have no resistance and stick to the fingers, spoiling the intended form. Others tear instead of sliding in the shear.

In the tie-a-knot test, a piece of clay is rolled between the palms to give a strip about the thickness of a pencil. This strip is tied in a knot. A good clay will accept this exercise without rupture. The poor clay will rupture if it does not actually break. These tests tell us about the clay's workability.

A rough idea of the throwing texture can be obtained from the bite and the palm tests. In the bite test, a fine section of the clay pressed between finger and thumb is gently bitten with the front teeth. What appears to be a fine clay reveals its sandy content in this way. In the palm test a dry piece of the clay is rubbed vigorously in the palm with the other hand. The fine clay is dispersed and the grit content remains. The feel of this action tells us

Fig 7. Plastic and short clays are assessed quickly by the tie-a-knot test.

Fig 8. The palm test gives an indication of the sharpness of the grit content.

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whether it is a sharp or a rounded content. It may be quartz sand, feldspar or mica. A comparatively large grain is tolerable in throwing if it is rounded. Sand, feldspar and mica affect the glaze fit and thermal properties of the finished product. These minerals can often be separately identified by the use of a magnifying glass.

A clay's composition is also indicated by its colour: yellow, brown, green and grey clays contain iron. Clays in chalk and limestone districts are likely to contain calcium carbonate. Remember the general rules about clays. The light-coloured clays are the more refractory. For high-temperature work over $1250°C$ ($2282°F$) it is necessary to use these, but we cannot expect them to be as plastic as the dark-coloured clays. The darkest clays will fire to a range of progressively darker browns from $900°$ to $1100°C$ ($1652°$ to $2012°F$). Above this temperature they quickly distort and break down. Clays containing calcium carbonate even if light in colour will have a ceiling temperature of $1100°C$ ($2012°F$). The cream-coloured clays, the grey clays and buff clays are middle range clays useful in the $1150°$ to $1250°C$ range ($2102°$ to $2282°F$). Note the exception to the general rule: blue and black ball clays appear very dark but their colour is not that of iron; it comes from a high carbon content which burns away. Many ball clays are at their strongest when fired to around $1200°C$ ($2192°F$) and are blended with the more refractory clays to produce stoneware bodies.
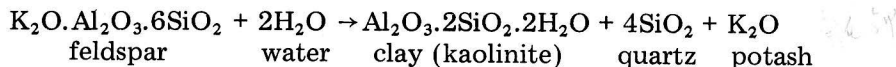
A lot can be estimated about the probable firing properties of local clays but do not overlook the evidence which can be seen in the bricks transported from brickyards and in the bricks of old buildings in disused quarries, since these bricks are likely to be of the local material.

2 The Chemistry and Structure of Clay

Physics and chemistry are man's attempt to understand and classify nature. They are of help to the potter who is trying to assess the potential of a particular clay. Will it withstand stoneware temperatures? Is it sufficiently plastic for throwing? We rely upon our own experience of previous clays that we have handled, but we can also use the experience of others through scientific analyses when we understand something of the chemistry and structure of clay.

The chemistry of clay

We saw in the first chapter how granite decomposes into feldspar, quartz and mica, and then how some of this feldspar further decomposes into clay, quartz and potash. The second stage can be represented in chemical symbols as:

$$K_2O.Al_2O_3.6SiO_2 + 2H_2O \rightarrow Al_2O_3.2SiO_2.2H_2O + 4SiO_2 + K_2O$$

    feldspar   water   clay (kaolinite)   quartz   potash

It is possible to use chemical symbols because the substances involved are all minerals and a mineral is a chemical compound, that is, two or more chemical elements combined in a predictable proportion.

In the equation clay is represented by $Al_2O_3.2SiO_2.2H_2O$. This is the pure clay mineral kaolinite. The symbols tell us that clay is a complex chemical compound involving three compounds in the proportion of one molecule of alumina (Al_2O_3), two molecules of silica (SiO_2) and two molecules of water (H_2O). This is a potter's approach. A chemist or a mineralogist would combine the symbols thus: $Al_2Si_2O_5(OH)_4$ and by this imply that the clay crystal is an integrated structure involving aluminium (Al), silicon (Si), oxygen (O) and hydroxyl groups (OH). The chemist

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