The Conservation and Restoration of Ceramics
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The Conservation and Restoration of Ceramics

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and

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Series editors’ preface

The conservation of artefacts and buildings has a long history, but the positive emergence of conservation as a profession can be said to date from the foundation of the International Institute for the Conservation of Museum Objects (IIC) in 1950 (the last two words of the title being later changed to Historic and Artistic Works) and the appearance soon after in 1952 of its journal Studies in Conservation. The role of the conservator as distinct from those of the restorer and the scientist had been emerging during the 1930s with a focal point in the Fogg Art Museum, Harvard University, which published the precursor to Studies in Conservation, Technical Studies in the Field of the Fine Arts (1932–42).

UNESCO, through its Cultural Heritage Division, had always taken a positive role in conservation and the foundation, under its auspices, of the International Centre for the Study of the Preservation and the Restoration of Cultural Property (ICCROM), in Rome, was a further advance. The Centre was established in 1959 with the aims of advising internationally on conservation problems, co-ordinating conservation activities and establishing standards of training courses.

A significant confirmation of professional progress was the transformation at New York in 1966 of the two committees of the International Council of Museums (ICOM), one curatorial on the Care of Paintings (founded in 1949) and the other mainly scientific (founded in the mid-1950s) into the ICOM Committee for Conservation. Following the Second International Congress of Architects in Venice in 1964 when the Venice Charter was promulgated, the International Council of Monuments and Sites (ICOMOS) was set up in 1965 to deal with archaeological, architectural and town planning questions, to schedule monuments and sites and to monitor relevant legislation.

From the early 1960s onwards, international congresses and the literature emerging from them held by IIC, ICOM, ICCROM and ICOMOS not only advanced the subject in its various technical specializations but also emphasized the cohesion of conservators and their subject as an interdisciplinary profession.

The use of the term Conservation in the title of this series refers to the whole subject of the care and treatment of valuable artefacts both movable and immovable, but within the discipline conservation has a meaning which is distinct from that of restoration. Conservation used in this specialized sense has two aspects: first, the control of the environment to minimize the decay of artefacts and materials, and, second, their treatment to arrest decay and to stabilize them where possible against further deterioration. Restoration is the continuation of the latter process, when conservation treatment is thought to be insufficient, to the extent of reinstating an object, without falsification, to a condition in which it can be exhibited.

One of the main objectives of conservation practice is that of conservation consists of values, aesthetic, historic, or technical grounds are often irreconcilable; decisions and methods need to be taken in a subject which is still developing and at the core of these differences there is often a deficiency of technical knowledge. The aim of all the contributions in this series is to provide conservationists with the state of know-how of the subject. In most of these matters ethical principles are the subject of much discussion and generalizations cannot cover (say) buildings, furniture, easel paintings and waterlogged wooden objects.

A rigid, universally agreed principle is that all treatment should be adequately documented. There is also general agreement that structural and decorative stabilization should be avoided. In addition there are three other principles which, unless there are
overriding objections, it is generally agreed should be followed.
The first is the principle of the reversibility of processes, which states that a treatment should normally be such that the altered case, if desired, be returned to its pretreatment condition even after a long lapse of time. This principle is impossible to apply in certain cases, for example, when the original material is destroyed in the process. The second, intrinsic to the whole subject, is that as far as possible desired parts of an altered case should be conserved and not replaced. The third is that the consequences of the ageing of the original material (for example 'patina') should not normally be disguised or removed. This includes a secondary proviso that later accretions should not be retained under the guise of natural patina.

The authors of the volumes in this series give their views on these matters, where relevant, with reference to the types of material within their scope. They stress that there is no universal or rigid approach to treatment (in a sense of essentially artistic significance and technique in which the interest is primarily historical, archaeological or scientific).

The volumes are unified by a systematic and balanced presentation of theoretical and practical material, with, where necessary, an objective comparison of different methods and approaches. A feature has also been maintained between the fine and decorative arts, archaeology and architecture in those cases where the respective benefits of the subject matter can best be achieved, for example in the treatment of stones and glass and in the control of the museum environment. Since the publication of the first volume it has been decided to include within the series related monographs and technical studies. To effect this enlargement of its scope the series has been renamed the Butterworth-Heinemann Series in Conservation and Museology.

Though necessarily different in details of organization and treatment (to fit the particular requirements of the subject), each volume has the same general standards which are that of such training courses as those of the University of London Institute of Archaeology, The Victoria and Albert Museum, the Conservation Center, New York University, the Institute of Advanced Architectural Studies, York, and ICOMOS. The authors have been chosen from among the acknowledged experts in each field and as a result of the wide areas of knowledge covered even by the specialized volumes in this series, in many instances multi-authorship has been necessary.

With the existence of IIC, ICOM, ICOMOS and ICCROM, the principles and practice of conservation have become as internationalized as the problems. The collaboration of Consultant Editors will help to ensure that the practices discussed in these volumes will be applicable throughout the world.
Preface

Ceramics conservators are required to possess an increasingly wide range of specialist knowledge, not only on everyday treatment of damaged objects, but also on subjects such as packing and handling of objects, display techniques, and procedures to limit damage in emergency situations. The aim of this book is to bring together this information. It is not intended to be a manual of techniques, nor can it pretend to be an exhaustive survey of the materials and methods used in past and present ceramics conservation. What it does aim to do is to present an approach to ceramics conservation that is based on an understanding and appreciation of the ceramic medium, of the materials used in its treatment, and of the ways in which the two interact. In doing so, an attempt has been made to draw together a very wide range of information on the subject, and where the amount of detail given has for reasons of practicality been small, references to further reading have been included.

The audience for this book is intended primarily to be working conservators and students of conservation. The behaviour and treatment of ceramics of all types are based on the same fundamental principles, and it is therefore intended that the contents should be of interest to those working in all sectors of the field of ceramics conservation. There has been a past some divergence of opinion between conservators working in commercial practice and those working in museums and other cultural institutions. However, these differences are becoming less apparent owing to the possibilities presented by modern materials for more satisfactory repair and restoration, coupled with a more widespread respect for the integrity of the object. Information exchange, which has taken place in the past, is now becoming more intense in this area. Information on the use of modern materials and their effects on ceramics is now being given in Appendix I.

The book is divided into four parts. Part One covers material which should be given due consideration before contemplating active treatment. Treatment should always be discreet, in the light of the characteristics of the object in question, and for the reasons, chapters have been included on the technology and deterioration of ceramics. Following on from this, the implications of these characteristics for preventive conservation are discussed, and finally, methods of examination and recording are surveyed.

Part Two covers active conservation methods, and begins with a review of past materials and techniques. Then, chapter by chapter, the different stages in the treatment sequence are considered. An attempt has been made to draw attention to the questions of why treatment should be carried out at all, what it is that treatment is intended to achieve, and the criteria on which the choice of treatment should be based. In this way, the details of technique are modified and developed by individual conservators to suit the way in which they work and the particular job in hand, but a basic outline of techniques in general use has been given.

It is important that the practical chapters should be read in conjunction with Part Three, which covers some of the more technical details of the materials involved in treatment, and the equipment, including health and safety equipment, required for their use. Some understanding of the nature of treatment materials is also important in order to allow proper assessment of the suitability of materials for particular purposes. For this reason, care has been taken to explain some of the basic principles involved in the behaviour of these materials in terms which, it is hoped, those conservators without a scientific training will find easy to assimilate. At the same time, it is intended that the information will act as a useful aid to those conservators with more experience in the area. Finally, then are materials and techniques in case that we have failed to
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mention, or materials or reports of research that have become available since the time of writing. However, it is hoped that this book will give some guidance as to the questions that must be asked before adopting such materials and techniques for use. Manufacturers of materials and equipment are given in Appendix II.

The final two chapters of the book, in Part Four, are of particular relevance to conservators with responsibility for large collections. They give information on display treatments and on emergency procedures.

The authors would particularly like to acknowledge the contribution of Professor Henry Hodges to Chapters 1 and 2.

The authors would like to thank a number of colleagues for their support and encouragement, offers of information and comments on the manuscript, in particular Dr Jonathan Ashley-Smith, Glenn Benson, Sandra Davison, Ian Freestone, fi Jordan, Judith Lawrence, Caroline Martyn, Peter Record, Dr Phil Rogers, Wendy Walker and John Watt. They would also like to thank Charles Underhill and Paul Sullivan for their invaluable assistance with the illustrations.

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Part One
The technology of ceramics

1

It is widely quoted that pottery was one of the first synthetic materials made by man as a result of subjecting clay to fire in order to produce an artificial stone. The discovery that clay could be fired at essentially any temperature and subjected to pressure to produce an object that would last for thousands of years reflects the inventiveness and the societies that made them. Many of the earliest artifacts that have endured the test of time for thousands of years reflect the work of civilizations and the societies that made them. In many parts of the world the techniques for making utilitarian pottery have changed little from the first primitive wares, while elsewhere they have developed into a highly sophisticated industry.

An introduction to the complex subject of ceramics technology would seem incomplete without some reference to earth, water, air, and fire: the basic essentials from which ceramics are derived (Rado, 1969; Fraser, 1979; Casson, 1977). The earth is mixed with water to make it workable. The resulting form is then dried in air. Finally, in subjecting it to fire, the object becomes hard and durable. The four raw ingredients, earth, air, water, and fire, are the most important in the process of turning earth into clay. As a deceptively simple material (Rhodes, 1977), clay possesses an almost unlimited range of variations in its composition that lead to a complex series of alterations during heating. The huge legacy of ceramic art in museums and private collections testifies to the range of possibilities that the clay and heat in combination possess.

Although an appreciation of ceramic objects is enhanced by, but not necessarily dependent on, an awareness of the technology behind them (Charles-ton, 1981), to the ceramics conservator an understanding of the technical processes by which the immense range of aesthetic and physical qualities derived by ceramics is directly linked to the way in which they were made, so too is their susceptibility to different types of damage and deterioration. The conservator should be able to understand and anticipate any certain types of damage a ceramic object may suffer and should be able to base the selection of a treatment process on a sound knowledge of how the treatment may interact with the fabric of the object, and this can only be achieved through familiarization with the technology of the material.

Clay and its origins

Clay can be found in abundance on the earth’s surface. Clay is the product of thousands of years of intensive geological weathering of the igneous and metamorphic rocks such as granite that predominate in the composition of the earth’s crust. The action of hot gases focused on the hard igneous rock resulted in its decomposition to produce a softer rock, and eventually chemical and physical breakdown into a hydrated silicate of aluminium, a clay mineral (Rhodes, 1977).
Amongst the secondary clays, examples include: ball clays, red clays, earthenware clays, marls and fire clays. Another important group of clay minerals is the montmorillonites derived from basaltic rather than granitic rocks. Their composition differs from kaolinite in that the layer structures in montmorillonites are more disordered, contributing to the high plasticity of this group of clays. These clays are usually transported thousands of miles by water, are deposited in the lower reaches of rivers, lake beds or the sea. Many impurities, such as iron, organic matter, calccareous material and other mineral decomposition products of igneous rock including quartz (Hodges, 1964). Kaolinite has an ordered, novel structure, made up of composite layers (1:1 mineral). Hexagonal, plate-like crystals arranged in stacks. Another important group of clay minerals is the illites, derived from basaltic rather than granitic rocks. Their composition differs from kaolinite in that the layers in illite are less well defined. Illite is a clay mineral derived mainly from the breakdown of micas and is relatively rich in potassium. It is common in many older sedimentary clays, as they are known, are exposed to groundwater, steam and gases. Typically, deposits of clay tend to be mixed with small fragments of rock that have been weathered by the action of groundwaters, vatos and gales. Typically, deposits of clay will occur as irregular pockets amongst the unchanged parent rock (Rhodes, 1977; Casson, 1977). If the moisture is allowed to evaporate the mass of clay will no longer be modelled (Figure 1.1). At the same time, the whole mass of particles becomes progressively more rigid until it can provide a material that is plastic and capable of retaining its shape after being deformed by pressure. In this way, the whole mass of particles possesses a polarity, known as the water of plasticity, caused by the particles adhering, and at the same time, allowing them to move over one another in response to pressure. In this way, the whole mass of particles possesses a polarity, known as the water of plasticity, caused by the particles adhering, and at the same time, allowing them to move over one another in response to pressure. In this way, the whole mass of particles possesses a polarity, known as the water of plasticity, caused by the particles adhering, and at the same time, allowing them to move over one another in response to pressure. In this way, the whole mass of particles possesses a polarity, known as the water of plasticity, caused by the particles adhering, and at the same time, allowing them to move over one another in response to pressure. Clay bodies

Clay is the term generally used for the raw material of which the non-metallic raw materials are prepared. Clays are used to make ceramic products such as pottery, tiles, and bricks. They are also used to make non-ceramic products such as adobe (dried mud) and concrete. Clays are a subgroup of the group of silicate minerals. The primary clay will occur as irregular pockets amongst the unchanged parent rock. Secondary clays can be very pure. An example is a kaolinite clay bed.

Clay bodies

Clay bodies are the raw materials from which ceramic products are made. Clay bodies are made from a variety of clays, including primary clays, secondary clays, and mixed clays. Primary clays are clays that have been weathered by the action of groundwaters, vatos and gales. Secondary clays are clays that have been weathered by the action of groundwaters, vatos and gales. Mixed clays are clays that have been weathered by the action of groundwaters, vatos and gales.

Clays can be classified in various ways, though the simplest is based on origin and divides them up as primary, or residual clays, and secondary clays. Primary clays, or residual clays, are those which are found at the site of their formation. They are derived from rock that has been weathered by the action of groundwaters, vatos and gales. Typically, deposits of primary clay will occur as irregular pockets amongst the unchanged parent rock. Secondary clays are clays that have been weathered by the action of groundwaters, vatos and gales. Typically, deposits of secondary clay will occur as irregular pockets amongst the unchanged parent rock.

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Figure 1.1 (a) Water acts as a lubricant between clay particles, making the clay soft and pliable, (b) As the water evaporates the particles are drawn closer together, producing increased friction and the clay becomes leather-hard. (c) When most of the water has evaporated, the particles can no longer move, and the resulting effect is hard, dry clay.

strong negative charges. Consequently, if the clay is mixed into water containing an alkali, the negative hydroxyl ions in the solution prevent the particles from coagulating and they will remain in suspension. In an acidic solution, however, the hydroxides ions will serve to balance the negative surface of the particles, and they will coalesce and flocculate. Hence the clay can be made into a mass paste which can be hardened by setting, so that the particles can no longer move, and the resulting effect is hard, dry clay.

Figure 1.1 (a) Water acts as a lubricant between clay particles, making the clay soft and pliable, (b) As the water evaporates the particles are drawn closer together, producing increased friction and the clay becomes leather-hard. (c) When most of the water has evaporated, the particles can no longer move, and the resulting effect is hard, dry clay.

Contaminants

Naturally occurring clays are usually contaminated, most commonly with compounds of iron, usually in the hydrated state. This can cause the clay to be red, yellow, or grey, depending on the amount of iron present. Contaminants such as carbonates or carbonates (calcium carbonate CaCO₃), the result of the clay acting as a lubricant in a body that is normally white, in the case with balls that fall a thousand or more. Some contaminants can be removed and may cause severe problems, such as calcite or calcite inclusions (calcium carbonate CaCO₃), the result of the clay acting as a lubricant in a body that is normally red or orange, in the case of clay that has experienced a heat treatment. If contaminants are present in very small amounts, they may act as catalysts for other reactions. However, if contaminants are present in large amounts, they may dominate the firing process and prevent the clay from achieving its full potential. For example, if the clay contains too much iron, it may result in a clays which is too dark and difficult to work with. If the clay contains too much carbon, it may result in a clays which is too soft and difficult to shape. For this reason, it is important to remove contaminants from the clay before firing, as they can have a significant impact on the final product.

Fluxes

In order to decrease the firing temperatures of the clay body, fluxes may be added. These form viscous liquids at high temperatures, combining with other materials such as quartz and then cool to give glasses or glassy materials. Examples include alkaline earth metal oxides and feldspathic minerals. Calcite or whiting (calcium carbonate CaCO₃) in a very finely divided form can also be used as a flux.

Forming processes

There are many techniques that may be employed in making ceramic objects. They range from the most primitive methods to highly mechanized industrial processes.

Sgraffito

Sgraffito is a technique used to create designs on a clay surface. It involves scratching away the top layer of clay to reveal the underlying layers. The resulting design is then left as is, or can be further decorated with slip or glaze. Sgraffito is a popular technique used by potters to create intricate designs on their work. It is also used in the creation of mosaics, where it is used to create patterns or images on a surface.

Slip trailing

Slip trailing is a technique used to create fine lines or patterns on a clay surface. It involves pouring a slip (a thin mud-like substance) onto the clay surface and then using a tool to draw lines or patterns in the slip. The resulting lines are then left as is, or can be further decorated with slip or glaze. Slip trailing is a popular technique used by potters to create intricate designs on their work. It is also used in the creation of mosaics, where it is used to create patterns or images on a surface.

Stenciling

Stenciling is a technique used to create designs on a clay surface. It involves using a stenciled (a thin metal or plastic shape) to create a design on the clay surface. The stencil is then removed, leaving a design that is then left as is, or can be further decorated with slip or glaze. Stenciling is a popular technique used by potters to create intricate designs on their work. It is also used in the creation of mosaics, where it is used to create patterns or images on a surface.

Tiling

Tiling is a technique used to create patterns on a clay surface. It involves pouring a slip (a thin mud-like substance) onto the clay surface and then using a tool to draw lines or patterns in the slip. The resulting lines are then left as is, or can be further decorated with slip or glaze. Tiling is a popular technique used by potters to create intricate designs on their work. It is also used in the creation of mosaics, where it is used to create patterns or images on a surface.

Turning

Turning is a technique used to create round or cylindrical objects. It involves shaping the clay using a lathe, which is a machine that rotates the clay at high speeds. The resulting objects are then left as is, or can be further decorated with slip or glaze. Turning is a popular technique used by potters to create intricate designs on their work. It is also used in the creation of mosaics, where it is used to create patterns or images on a surface.

Venting

Venting is a technique used to create holes in a clay body. It involves punching a hole in the clay body using a tool. The resulting holes are then left as is, or can be further decorated with slip or glaze. Venting is a popular technique used by potters to create intricate designs on their work. It is also used in the creation of mosaics, where it is used to create patterns or images on a surface.

Wirework

Wirework is a technique used to create intricate designs on a clay surface. It involves using wire or thin metal rods to create designs on the clay surface. The wire or metal rods are then left as is, or can be further decorated with slip or glaze. Wirework is a popular technique used by potters to create intricate designs on their work. It is also used in the creation of mosaics, where it is used to create patterns or images on a surface.
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Figure 1.2 Making a simple pinch pot.

Figure 1.3 Coiling a pot.

Both pinching and coiling techniques are used to make utilitarian wares and sculptural forms. If flat sheets of clay are rolled out, or sliced from a lump of clay, then built up to make a form, the technique is known as slab building (Figure 1.4). The success of the method relies on making the slabs when the clay is at the right state of plasticity. They must be allowed to dry slightly, to a leather-hard or cheese-hard consistency, before joining. In order to ensure the joints do not separate and crack during firing, the edges must be scored with a point, then scored with slips of clay mixed with water to cement the two parts, which are then luted together.

For thousands of years the technique of press moulding has been employed to mass produce a shape (Kingery and Vandiver, 1986). Clay is pressed into moulds made from an absorbent material such as low-fired unglazed (i.e. biscuit) clay, plaster of Paris, or wood. After trimming away any surplus, the clay is left to place until dried to leather-hard stage, after which shrinkage facilitates its removal. Complex forms can be assembled from a series of moulds by joining and adding pieces.

The development of press moulding techniques into a mechanized process is represented by jiggering and jollying (Figure 1.5). For making circular or cylindrical forms (such as flat ware or hollow ware respectively), a mould roughly lined with clay is rotated while a template is gradually brought towards the mould, squeezing away excess clay (Hodges, 1964).

Another type of moulding technique involves pouring a homogeneous mixture of clay or slip into an absorbent mould. As the water is drawn from the slip into the plaster, or biscuit clay, a thick layer of clay builds up on the inner surface of the mould. When the desired thickness has been reached, the remaining liquid slip is poured away. Complex hollow forms such as figurines can be made using the technique which is known as slip casting. Moulds may be made up of several pieces in order to accommodate undercuts. Components may be slip cast individually, then luted together later.
The art of throwing clay is well documented (Leach, 1976; Cardew, 1969) (Figure 1.6). It involves centring a ball of clay on a rotating turntable or wheel and then, by applying firm pressure with both hands, pulling up the walls of the vessel aided by the centrifugal force. Individual potters develop distinct styles and variations in their technique. The basic vessel form may be manipulated to give a range of flat and hollow shapes to which additions such as handles and spouts may be added.

Drying and finishing

It is important that most of the water content of the clay has evaporated prior to firing, otherwise steam trapped in the pores of the body may blow the pot apart. Evaporation takes place at the surface, water being drawn by capillary action from the interior of the pot. Gradually the particles shrink closer together to fill most of the spaces formerly occupied by water, until a point is reached when no more water can escape. At this stage the clay consists of a dry open framework. Some water will remain trapped in the pores and also as a film of water molecules on the surface of the clay particles.

Drying may have to be interrupted in order to finish the pottery. In very coarse earthenware it may be necessary to wait for a period of several months before a reasonable hardness is achieved. Once the pot is pinched or rolled it will be harder to turn and move. The application of some types of decoration may also interrupt the drying process, utilizing the plastic condition of the clay. By incising, carving or impressing the surface, using whatever tools or objects are to hand, an enormous variety of effects can be achieved. Different coloured clays can be inlaid into grooves or impressions made in the surface (Figure 1.7). Slips or engobes can be applied after petals to coat the semi-dry pot and, depending on
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Figure 1.7 A detail of inlaid white slip on a Korean box cover, partly obscured by the overlying celadon glaze (Victoria and Albert Museum, London).

Figure 1.8 A detail of combed slip decoration on earthenware. Bands of a contrasting dark-coloured slip have been combed across the underlying slip (Victoria and Albert Museum, London).

Figure 1.9 A detail of sgraffito decoration where a pattern has been scratched into a layer of slip exposing the underlying body colour (Victoria and Albert Museum, London).

how they are applied, whether dipped, poured or painted, different surfaces can be produced. Slips of an appropriate consistency may be used rather like icing, in order to pipe and trail lines onto the surface. Contrasting colours can be combed (Figure 1.8), or partially mixed at random to give swirled or marbled effects. Sgraffito is where designs are scratched through a layer of slip into the underlying body (Figure 1.9).

Firing

Although the composition of the body is the main factor in deciding the nature of manufactured wares, the firing cycle is of equal importance. The term 'firing cycle' implies the sequence of events from the time the raw bodies are set in the kiln, to the moment the finished objects are withdrawn. The event also encompasses the time taken to cool the kiln, the rate of temperature change, the position of the wares and any atmospheric changes that occur within the kiln. Clearly, there may be many variations in the cycle between the production of one vessel and another, but in general a number of events and stages will follow one another in sequence (Figure 1.10). An object may undergo a number of separate firings in order to achieve a complex decorative effect. The first firing is often referred to as the biscuit firing, then a succession of glaze firings may be necessary in order to achieve different effects such as enamels, lustres and gilding (Hamer and Hamer, 1986). It should be remembered however that before the medieval period glazed pottery was rare outside China.

With modern studio and industrial ceramics the initial rate of temperature increase is kept below 60°C per hour, in order to allow the remaining water trapped in the pores to escape gradually. Too rapid an increase may result in the sudden production of steam which could burst the body. By the time the boiling point of water is reached, most of this moisture should have evaporated. Subsequently the water adsorbed on the surfaces of the particles is driven off, again slowly. On reaching 200°C all this water should have been eliminated. Any organic material derived from vegetation should also start to break down at this stage.

Between 400°C and 600°C the chemically combined water that forms part of the molecular structure of clay is given off. The temperature increase must be gradual (100°C per hour) to prevent rapid evolution of water at the surface of the wares, which makes it difficult for the gases to escape. Between 400°C and 800°C the object should be removed from the kiln and cooled slowly. If heated to a higher temperature, the object will be irreversibly altered, having undergone the ceramic change, and...
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<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>Maximum earthenware biscuit formation starts.</td>
</tr>
<tr>
<td>1000</td>
<td>Maximum stoneware biscuit formation complete.</td>
</tr>
<tr>
<td>1100</td>
<td>Mullite ceases to develop.</td>
</tr>
<tr>
<td>1250</td>
<td>Maximum firing limit for earthenware glazes.</td>
</tr>
<tr>
<td>1300</td>
<td>Maximum firing limit for stoneware glazes.</td>
</tr>
<tr>
<td>1400</td>
<td>Hard-paste porcelain glaze starts to form.</td>
</tr>
</tbody>
</table>

Figure 1.10: Example of possible sequences of changes that occur in kaolinitic stoneware or porcelain clay bodies during firing.

Every time a pot undergoes heating or cooling, a reversible alteration occurs at 573°C, at which point any unreacted portion of the clay body will undergo a quartz inversion (Figure 1.11). Although no shrinkage will have occurred, the clay body will now be extremely fragile and porous. Somewhere between 700°C and 900°C, carbon and sulphur contained in the body will hum out with the creation of dioxide and trioxide gases (CO, CO₂, SO, SO₂, SO₃). These are derived from carbonate and sulphate impurities, and also the organic carbon that does not burn off at lower temperatures. It is important that the burning out process is completed with no carbon or sulphur remaining, otherwise bloating may occur at a later stage in the firing as the trapped gases attempt to escape causing blister-like formations.
The Conservation and Restoration of Ceramics

Clay particles welded together at points of contact.

**Figure 1.11** Sintering: the clay particles are secured to each other at points of contact. Although the pot is extremely fragile at this stage, sintering provides enough support to hold the object together.

Red as all the iron compounds in the body allow and highly porous. Biscuit firings tend to be within the range 950°C to 1100°C, depending on the properties of the body and the strength required.

Vitrification starts to occur around 800°C as the fluxes and free silica in the clay body start to melt and fuse, if they have not already progressed substantially, the particles become fused together in a glass. At 950°C the formation of spinels starts; these are the double oxides of various metals, usually magnesium, iron and aluminium, derived from the clay matter. They are short-lived in the firing sequence, and by 1000°C they have been totally absorbed into the subsequently formed glass. They are of relevance in this context since their presence in a mineralogical section can sometimes indicate the firing temperature of the wares from which the sample was taken.

From here on as the temperature increases, the free iron compounds in the body convert to rust, filling the pores and disintegrating the particles that they formed. By 1300°C all the iron compounds have been oxidised to free iron compounds, and the quality of the body is determined by the melting of the siliceous matter. This is the temperature at which the body will begin to melt and fuse, and the body will no longer be able to withstand the weight of the pot. At this stage the body will have lost all its plasticity and will have become a hard, glassy mass.

Wares fired above 1250°C, the hard porcelains, are thus non-porous and their bodies may be seen largely as a mass of glass supported by crystals of mullite. Wares fired around 1100°C, are generally not very porous and vary in their texture, the iron compounds in the body allowing for a more open structure. The body may be very hard and strong, but the iron content will vary, and the body will have a more open structure, with smaller crystals of mullite and more free silica. At 1250°C the formation of spinels starts; these are the double oxides of various metals, usually magnesium, iron and aluminium, derived from the clay matter. They are short-lived in the firing sequence, and by 1000°C they have been totally absorbed into the subsequently formed glass. They are of relevance in this context since their presence in a mineralogical section can sometimes indicate the firing temperature of the wares from which the sample was taken.

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production of some interesting colour contrasts, as for example classical Greek red and black wares.

Glazes

A glaze is little more than a thin layer of glass that has been fired onto the surface of the ware. It has three main functions: to strengthen the pottery, to provide an impermeable hygienic coating, and to decorate the surface (Hamer and Hamer, 1986). Like glass, a glaze will contain glass-forming materials, fluxes and stabilizers. The most important glass-forming material is silica (SiO2), which is usually derived from flint, feldspar or china clay. The fluxes, such as oxides of sodium, potassium, calcium, magnesium and lead, are added to lower the melting point of the glass-forming oxides. The glaze stabilizer is most commonly alumina (Al2O3). Other metallic elements may be added to produce colours (Green, 1963; Shaw, 1971).

From a functional and practical point of view it is important that the glaze and body have comparable rates of thermal expansion. The glaze-fit, as it is known, is determined by its composition; each component has a direct effect on the expansion rate depending on the amount present. In general it is usual for there to be some stress between the glaze and body, and preferably for the glaze to be under compression. Where the relationship is not balanced, faults such as crazing, dunting and shivering may occur (see Chapter 2).

In practice, either glazes are made raw, where ingredients are ground together, suspended in water and applied to the surfaces of the wares; or they may be produced as frits, in which case the ingredients are heated until fused to form a glass and then cooled, ground to a powder and suspended in water prior to application. There are also exceptions to this general outline in which silica in the body provides the quartz of the glaze. For instance lead compounds, such as the red or yellow oxides, are sometimes applied directly to the surface of the dried unfired vessels. On firing, the lead forms a glaze with the silica in the body, and produces a deep red, brown, yellow or green glaze, depending on the conditions of firing.

Glaze colourants

The colour associated with glazes is achieved using a relatively small number of metallic compounds, the metallic ions generally being responsible for the colours. The behaviour of these metallic compounds depends on various concentrations, under different firing conditions and temperatures, in association with other materials - producing a surprising range of effects. Five such colourants, iron, copper, cobalt, manganese and antimony, were known from antiquity, and until the range of colourants was dramatically increased in the nineteenth century, some colours were difficult to achieve. A good red colour was one of these, and copper could be made to yield a semiglossed or matte under severe reducing conditions during the cycle for burning. Incandescent elements absorb considerable amounts of heat, and give yellow through orange appearance. The range of colour in a glaze, depending on the concentration used. A bright yellow, although somewhat opaque, could also be achieved using antimony, provided the oxide contained lead, the colourotient being in fact a very fine dispersion of lead stannate. Similarly, the green, around 5% of copper in a lead glaze would give a dead green, while at higher concentrations the lead, with the green, would be a bright turquoise blue. The common colourant for blue was cobalt, while manganese gave oxides and purples, depending upon the quantity present. Black glazes were made by using antimony and lead compounds, and the actual black would result from a very fine dispersion of the material in the glass.

The eighteenth century saw the introduction of several important new colouring materials, principally oxides of chromium and nickel. Undoubtedly the most important of these is chromium oxide (Cr2O3), since it can be made to yield red, yellow, pink, brown or green glazes, depending on the composition and firing temperatures. Nickel oxide (NiO), while less versatile, is mainly used to make bright colours more sober. Other red and yellow colourants such as vanadium, selenium, tin and manganese are used.

Figure 1.13 Detail of salt-glazed stoneware, showing the typical orange peel textured surface (Victoria and Albert Museum, London).
most recent introduction, as is the use of uranium which provides a vivid yellow.

There are a number of ways in which these colourants may be applied. They may be painted directly to the surface of the wares before glazing as underglaze colours (Figure 1.14), or they may be incorporated in the glaze composition to produce a glaze stain or in-glaze colour (Figure 1.15). Alternatively, the colourant may be prepared with a frit or low-firing glaze, and applied on the already glazed surface of the ware as an enamels (Figure 1.16). Such on-glaze or overglaze colours are fired to relatively low temperatures around 750°C.

Colours that are applied under the glaze are less vulnerable to deterioration, since the overlying glaze must be destroyed before they are attacked. In contrast, enamels may have very poor adhesion to the glass if the frit is too fluid and the decoration may spall away easily. Some enamels may prove to be too soft for practical purposes, making them prone to abrasion while others may be chemically too reactive and easily attacked, for example, by alkaline cleaning materials. The low temperatures to which enamels are fired allows a wider range of colours. Originally enamels were applied with a brush, as the suspended in oil. The labour intensive nature of the technique led to the development, from the mid eighteenth century, of transfer printing, a process that lent itself to cheap mass production. A transfer would be made by etching an intaglio copper plate with the finely ground frit in oil, printing the image from the plate onto specially prepared paper, and then transferring this to the surface of the object. At first only a single colour was used (Figure 1.17), but by the middle of the nineteenth century full colour printing, using as many as five different intaglio plates, came into use.

lustres are another type of on-glaze decoration, resulting from a low-temperature reduction firing of compounds containing copper, tin, silver, bismuth, and other metal oxides. The effect is produced by heating the ware to around 600°C, in a reducing atmosphere, and then quickly cooling it to about 300°C, allowing the metallic copper to oxidize and redden to produce a metallic, reflective surface.
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The end product is a very thin colored film of semi-covering and calming to the glass. The Persian lustre wares are the result of the application of preparations containing metallic salts fired in a very strong reducing atmosphere. Copper will produce red, salmon or gold colors; gold produces bright yellow or greenish-brown shades, and itself gives the well-known iridescent quality of certain Chinese wares, in which the colloidal metal or metallic salts are present as a suspension in a viscous oil. Carbon from the wood and oil includes the metal which is then deposited as a thin layer.

Lustres may also be fired in an oxidation kiln, in which the colloidal metal or metallic salts are present as a suspension in a resin or oil. Carbon from the resin and oil reduces the metal which is then deposited as a thin layer.

One of the more confusing aspects of the study of pottery can be the wide range of ways in which various wares may be described. Thus the same vessel might be variously termed as earthenware, slipped ware, Mediterranean ware, or lead-glazed ware, all of which terms may be technically correct. Tableware described as earthenware is not necessarily the same as earthenware described as tableware.

Wares described by shape

The essential difference between hollow and flat wares as defined by Rado (1969) is that hollow wares have some volumetric capacity (cups, bowls and most jars), whereas flat wares are essentially flat (plates and saucers). Hollow wares may be further subdivided into open and closed wares: open wares being those in which the aperture is the widest part of the vessel, and closed wares being those in which the widest part of the vessel is below the aperture (flasks, bottles and most jars).

Wares described by clay body

For example, Caron ware, or by naming the makers, such as Pennsylvania Dutch ware. However, in this instance only the technical aspects of such terminology will be considered.

Earthenware

Generally earthenware bodies are distinguished from those of stoneware by possessing a porosity of more than 5%. This is usually the result of a biscuit firing at temperatures up to 1150°C, followed by a glost firing at temperatures generally between 1200°C and 1300°C, during which the glaze is applied and fused to form a vitreous surface. This type of firing is known as a two-stage process and is used extensively in the production of earthenware tableware.
Table 1.1 General categories of earthenware (porosity >5%)

<table>
<thead>
<tr>
<th>General type</th>
<th>Characteristics</th>
<th>Average firing temperatures (°C)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscuit</td>
<td>Porous body due to low firing temperature. Body contains calcium carbonate and</td>
<td>950-1100</td>
<td>Japanese tea bowls, some studio pottery, and other utilitarian ceramics</td>
</tr>
<tr>
<td></td>
<td>without the thermal shock of the liquid source glass firing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common pottery</td>
<td>Usually made from mineral clays which produce a porous, light ware,</td>
<td>650-950</td>
<td>Includes engobe coats and glazes, redware, some salt-glazed pottery,</td>
</tr>
<tr>
<td></td>
<td>which fuses evenly to form a dense body and fire clay in order to withstand</td>
<td>600-1100</td>
<td>slipware, some nutmeg and mace.</td>
</tr>
<tr>
<td></td>
<td>the thermal shock of the rapid uneven glaze firing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terracotta</td>
<td>Technically a type of common pottery. The raw material is derived from the</td>
<td>750-850</td>
<td>Includes unglazed ancient and primitive wares, medieval wares,</td>
</tr>
<tr>
<td></td>
<td>Italian for fired earth. Loosely includes unglazed low-fired bodies made from</td>
<td></td>
<td>some Staffordshire slipware, and also some studio ceramics,</td>
</tr>
<tr>
<td></td>
<td>grey- or buff-coloured clay firing to red, though also includes red clay and</td>
<td></td>
<td>amongst others.</td>
</tr>
<tr>
<td></td>
<td>cream-firing clays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tin-glazed pottery</td>
<td>Low-fired, porous, soft body, coated with a lead glaze specified with its</td>
<td>850-1000</td>
<td>Generally associated with sculpture and modelled clay as well as</td>
</tr>
<tr>
<td></td>
<td>body. The tin glaze surface is then painted with different metal oxides which</td>
<td></td>
<td>modern Greek and Etruscan pottery</td>
</tr>
<tr>
<td></td>
<td>fuse and blend into the glaze during firing. The body is usually of a lead</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or white (calcium stearate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine earthenware</td>
<td>Usually white or off-white earthenware coated with a lead glaze specified</td>
<td>1050-1150</td>
<td>Creamware: Earthenware body with Mattanewcome red glaze, developed in</td>
</tr>
<tr>
<td></td>
<td>with its body. The advent of transfer printing in the mid eighteenth century led</td>
<td></td>
<td>the early eighteenth century centres in England. The Suite typically</td>
</tr>
<tr>
<td></td>
<td>to the German potteries, making them available to the early eighteenth century</td>
<td>900-1050</td>
<td>consists of off-white (c 2%), half dull (c 4%), flat (c 20%), and</td>
</tr>
<tr>
<td></td>
<td>body to the age of the early eighteenth century. It is self to this type of</td>
<td></td>
<td>black (c 5%).</td>
</tr>
<tr>
<td></td>
<td>popular ware.</td>
<td></td>
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</tbody>
</table>

*Note: The table contains information on the different types of earthenware, their characteristics, firing temperatures, and examples.*
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Table 1.2 General categories of stoneware and porcelain (porosity <5%)

<table>
<thead>
<tr>
<th>General type</th>
<th>Characteristics</th>
<th>Average firing temperatures (°C)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stoneware</td>
<td>Hard, durable, well-fired body with low porosity, head and glisten smooth surface that is produced when body is fired at a high temperature producing a well-developed glaze. Body fired at 950-1200°C. Can be made from naturally occurring clays that are rich in fluxes, or from other clays modified by the addition of fluxes.</td>
<td>1200-1400</td>
<td>Salt-glazed stoneware: two single firings at about 1300°C. The glaze is applied at about 1200°C, followed by a second firing at the same temperature. This is fired in the kiln, combining with the clay body at the surface of the joint. Other examples include: ironstone china, flintware and white granite.</td>
</tr>
<tr>
<td>Semi-vitreous and vitreous china</td>
<td>Basically a fine earthenware-type body with increased amounts of flux. Dense, though slightly translucent, off-white colour, with a slightly granular fracture. The relatively low-fired glaze is soft and liable to scratching. The body typically contains 90% bone ash; the remaining ingredients added in equal proportions include china clay and Cornish stone. The bone can act as a flux or a refractory depending on the amount added and the other ingredients present. The body is denser than hard-paste porcelain, and more durable than soft-paste porcelain.</td>
<td>1100-1200</td>
<td>Examples include: ironstone china, flintware and white granite.</td>
</tr>
<tr>
<td>Bone china</td>
<td>The body typically contains 90% bone ash; the remaining ingredients added in equal proportions include china clay and Cornish stone. The body is denser than hard-paste porcelain, and more durable than soft-paste porcelain.</td>
<td>1200-1300</td>
<td>In England during the middle of the eighteenth century, Thomas Frye patented the method for a body that included the addition of a small amount of calcined bone as a flux. Bow was the first factory to produce it. It is produced by two factories: Bow, Derby and Chelsea, Bow being the first to develop a bone china body. The typical recipe, where half the body consists of bone ash, was developed subsequently by Josiah Spode II in the late eighteenth century. Other examples include: Minton, Crown Derby and Doulton.</td>
</tr>
<tr>
<td>Soft-paste porcelain</td>
<td>Consists of a brittle body with a high flux content, which melts during firing. The body is more porous than the foot, and with cracks filling from the foot to the mouth. It fractures with a granular sugary texture.</td>
<td>900-1000</td>
<td>Towards the end of the sixteenth century, the Medici factory in Florence developed a porcelainous body with a high silica and alkali content. A similar recipe was adopted in Rouen, France (1673), and spread to St Cloud and Sevres, and finally to England. Bow, Derby and Chelsea then explored its use. Examples include: Meissen, New Hall, Coalport and Spode.</td>
</tr>
</tbody>
</table>