The role of interdisciplinary science in the study of ancient pottery

DAFYDD GRIFFITHS
Institute of Archaeology, University College London, UK

In the context of the modern world, the term ceramics suggests a very versatile group of materials capable of being designed to have particular physical and chemical properties and to fulfil a wide range of functions, functions that traditionally have often been fulfilled by other types of material. While suitably designed ceramics may hold the key to overcoming many of humankind’s future technological problems, it is interesting to reflect on how much ceramics can also tell us about our past. Future technological innovations in ceramics will influence and be influenced by wider aspects of human culture; so too it may be expected that there was a similar relationship between ancient ceramics and the past societies that made them. In archaeology, ceramics hold an important and varied role as a key to understanding many aspects of the development of human civilisations. This paper aims to explore some of the ways in which ceramics have been studied by archaeologists, and to illustrate some of the many contributions interdisciplinary science has made to the study of ancient pottery.

Archaeology may be defined as the study of the human past based on the material remains of past human activity. Material remains most directly provide evidence of material culture but many archaeologists aim to do more than recreate the material culture that existed at particular times and places in the past. They seek also to understand something of how and why it changed over time, and to understand something of the interaction of material culture with the natural, social, economic, and political environment. The existence of a relationship between material culture and other aspects of human existence gives the opportunity to infer something of these other aspects from the study of the material remains. The relationship is not a simple one, and it may appear to vary with time and place, but there is still a relationship. To address these more challenging higher level inferences, however, it is usually necessary to look first at questions that can more directly be answered by the study of ancient remains. These more direct questions will occupy the bulk of this paper.

In the case of ceramics some of the major basic questions relate to their date of manufacture, the technology of their manufacture, their provenance (in terms of both the source of the raw materials and the place of manufacture), and their use. Although much of this paper will consider primarily pottery vessels, much of what is said will also apply to other clay based ceramics such as bricks, tiles, and refractory ceramics. The paper does not purport to be comprehensive in its coverage: for example considerations of the use of pottery could involve discussions of mechanical and thermal testing of different products, but this is not covered here. The aim rather is to give a sufficient overview to illustrate the importance of interdisciplinary science in the study of ancient pottery, and perhaps thereby to encourage further developments. It should also be noted that other archaeological ceramics such as plasters, cements, faience, glass, glazes, and enamels are also important in archaeology and have also benefited greatly from interdisciplinary input. In this paper, however, they will receive only brief mention in a later section sufficient to serve as a reminder of the wider context of pottery research.

Importance of pottery in archaeology

In considering the importance of interdisciplinary science in the study of archaeological pottery, it may be useful to start by considering what makes pottery important in archaeology. The reasons for the importance of pottery are several. The raw materials for making pottery (clay, water, and fuel) are widely distributed over the surface of the earth. Clay has the property that while it is wet it is plastic and can be deformed into the desired shape; but as it dries it becomes hard and when heated sufficiently its shape becomes permanent and cannot be made plastic again by the addition of water. These are the basic properties that have made clay useful to man. In sedentary (as opposed to nomadic) societies, pottery making is widespread, all the great civilisations having produced considerable quantities of pottery.

Several authors have sought to classify the history of the role of pottery in antiquarian studies. Orton for example identifies an art historical phase of interest in whole pots from 1500 to 1880, a typological interest in sherds from 1880 to 1960, and a subsequent contextual interest considering all aspects from microstructure to the constitution of assemblages. He notes
parallel themes of interest in each phase, with ethnography and quantification being added in the last phase to existing interests in the archaeometry (physical and chemical analysis) and the technology of pottery. Ethnography has provided ideas that may assist in the interpretation of archaeological evidence related to pottery production and use. The ideas and ‘cautionary tales’ it provides are food for thought rather than answers that apply directly to other cultures, although cross-cultural generalisations are sought. Quantification provides an objective means of characterising and comparing pottery assemblages, and works towards integrating ceramic studies with studies of whole assemblages of varied material artefacts. A more conceptual view of recent ceramic studies is provided by Arnold, who also examines relationships between potters, ceramic production, environment, and culture, while Renfrew and Bahn provide a more general introduction in the context of the whole of archaeology.3

Until absolute dating methods were available the prime importance of pottery in archaeology was to provide an indication of the date of the context in which it was found based on established sequences of changes in vessel form and decoration. Dating based on appearance is still an important aspect of the role of pottery in archaeology, but in recent decades other aspects such as identifying sources of raw materials, the technology of manufacture, modes of distribution, and the contents of vessels have also become important topics of research.

Further importance derives from the great variety of possible form and decoration coupled with the fact that potting is a fairly traditional craft. Pottery manufacture is a highly interactive process with a great range of possible actions available to the potter at each stage in the process, not least in shaping and decoration. Each action on the part of the potter leaves its mark on the object and in principle each action can be deduced from careful observation of the finished object. If however all pots were one off creations unrelated to the time or place of their creation, pottery would be far less useful as a tool for dating or identifying cultural contacts. Fortunately for archaeology, pottery styles remain relatively stable over considerable periods and can be fairly characteristic of a place and time in history. Nevertheless one cannot assume a simple correspondence between the style of the pottery and other aspects of human culture: social and political culture may change considerably without corresponding changes in pottery.

A further notable reason for the importance of clay based ceramics in archaeology is the survival of pottery and ceramic building materials in the archaeological record. Once fired, pottery is very durable. Pottery may be broken into sherds but it does not rot away and generally it is not recycled. In contrast, the organic material which may often have constituted the great bulk of the manmade objects in daily use is often lost almost entirely, except when preserved by unusual environmental conditions such as permanent waterlogging, desiccation, or freezing. Even objects made of non-organic materials such as metal or glass may be very underrepresented in the archaeological record by virtue of having been remelted and made into new objects.

In addition to more utilitarian incarnations, some ceramics have clearly been items of great prestige: one may think here of painted Greek vases or fine Chinese porcelain. A further reflection of the prestige attained by some ceramics is given by the life of the inventor of European porcelain, the self-styled alchemist Böttger, who was held captive by the King of Saxony for many years at the beginning of the eighteenth century pending fulfilment of his promise of being able to make gold. No gold was made but porcelain was, and the King regarded that as the next best thing.4

Pottery is thus widespread in time and place, it gives clear indications of how it was made, it is fragile and fairly often broken in use, once broken it tends to be discarded, and once discarded it tends to survive in the archaeological record indefinitely. Nor are ceramics confined to one aspect of life: while many ceramic objects are simply functional others are decorative and indicative of more than function, and some are objects of prestige and ceremony. Coupling all this with the fact that pottery can often be dated, that it can sometimes be matched to its place of manufacture, and that occasionally its exact use can be determined makes it clear that ancient pottery is a vast repository of archaeological information on technological, cultural, and economic aspects of the human past.5 This paper aims to show how the application of a wide variety of approaches has caused unpromising heaps of muddy or dusty potsherds, cast out by their original owners as useless, to yield up their treasures.

Origins of ceramics

In some ways it is at first surprising to find how late in human history ceramics start to appear. The use of fire stretches back into the depths of human antiquity, with good evidence in South Africa dated to about 1·5 million years ago. It would presumably have been noticed that a fire would harden the earth around it but the first evidence for fired ceramic objects is provided by terracotta figurines dating to around 26 000 years ago found particularly in Czechoslovakia. Ceramic vessels however do not appear to have been produced before 9000 years ago in the Old World, at which time they appear more or less simultaneously (as far as we can tell with the limited resolution of radiocarbon dating) throughout the Near East. The introduction of pottery was preceded by widespread use of plaster for floors, figurines, and vessels. It would appear that the introduction of pottery coincided with the advent of a more sedentary lifestyle, possibly with the introduction of dairy produce.6 The introduction of pottery may thus have been delayed not by ignorance but
because it was not needed and was not appropriate to the more nomadic lifestyle of earlier cultures.

**Analysis of ceramic fabrics**

The traditional approach to the investigation of archaeological ceramics rests primarily on the study of the form, decoration, and distribution of the artefacts. Over the last four decades it has been increasingly recognised that much complementary information can be derived from the study of the material from which the ceramic is made, often referred to as the ‘fabric’ of the ceramic. Fabric analysis is a supplement to more traditional methods of investigation rather than a replacement, each type of analysis providing a different, though still blinkered, perspective on the totality of information carried by the ceramic.

The constitution of a ceramic fabric is the sum of all the processes that have contributed to its creation, from the formation of the clay deposit, through its excavation, the preparation of the raw materials, the formation of the artefact, its firing, use, and post-depositional changes, to its eventual archaeological excavation. The sherd has been affected by and potentially carries information about all these stages in its history, and it is the aim of fabric analysis to deduce the history of the sherd from its present constitution and thus to answer archaeological questions.

Of the many archaeological questions that might be asked it is perhaps those of how, where, and when that may most readily be approached with the aid of fabric analysis. In other words one may seek to answer questions about how fabrication and firing of the pot was effected, about the provenance of the raw materials and where the pot was made, and about the date of manufacture of the pot.

One might also seek to understand why a pot may have been made in a particular way. While it may be possible to suggest a rational explanation for a pot having been made in a particular way, caution must be exercised in answering questions about the motivation and mental processes of the potter. A pot is a material object and in itself carries some information about the material culture of the people that made it. Other larger questions of the significance and meaning of a pot are at least one step of inference further removed from the material evidence. These considerations are however general to archaeology as a whole and need not be considered further here.

In some ways an extension of ethnography and the observation of present day craft pottery, one particular approach to the study of ancient pottery that deserves mention here is the use of experimental reconstruction to test hypotheses of production and use, and to heighten awareness of particular aspects of production and use. This approach has been used in many areas of ancient technology but has been particularly actively pursued in ceramic studies for some time and has produced worthwhile results. The more successful examples of this approach have often had the benefit of significant interdisciplinary input. An ancient clay based ceramic fabric typically comprises a fine grained matrix of fired clay with fine silt sized particles. Within this matrix there may also be larger inclusions, which may have occurred naturally in the sediment from which the ceramic was made or which may have been added deliberately by the potter to manipulate the properties of the material before and/or after firing. The fabric may contain pores and may carry a surface paint, slip, or glaze. Each phase present may have one of three possible origins: it may be a relict phase (inherited more or less unchanged from the mixture used to form the pot), it may be the result of reactions during firing, or it may be the result of the environment of the pot during use or burial. Clay based archaeological ceramics are thus inherently inhomogeneous: this fact must of course be considered carefully when taking samples for analysis and in the interpretation of analytical results.\(^7\)

It is possible to extract an almost endless body of data from a collection of potsherds, even more so with the recent proliferation in the availability and variety of instrumental analytical techniques. This places a considerable burden of choice on the archaeological ceramicist as to how to proceed in order to obtain the desired answers most efficiently.

**Ceramics and dating**

Before the advent of absolute dating methods (starting with Libby’s radiocarbon technique in 1949) the main importance of pottery in archaeology was as an indicator of date. This date was based on established sequences of changes in vessel form and decoration or changes in the constitution of vessel assemblages. One form of this seriation dating was developed by Sir Mortimer Wheeler (who had been entrusted with predynastic burials in upper Egypt at the end of the nineteenth century. He put the grave assemblages into chronological order by assuming that the best order would occur when the greatest number of types of vessel had the shortest spread possible across the different assemblages. The overwhelming importance of pottery as a dating tool, often to the exclusion of other interests, may be gauged from Petrie’s own view of his collection of Palestinian antiquities. In 1935 he wrote to Sir Mortimer Wheeler (who had been entrusted with the collection) from Jerusalem demanding the guarantee that once ‘weeding duplicates’ (especially in the pottery) had been effected, the series ‘shall be as inviolable as any Natural History type series, and inseparable’.\(^8\) A pottery artefact was here simply regarded as an example of its type in an established series. Duplicates could add nothing of value and therefore could be weeded out! (In fairness to Petrie it should be noted that his interests were far wider, but the extract serves to illustrate the historical point.)

Radiocarbon dating may serve to date an archaeological context containing organic remains but it can

---

**INTERDISCIPLINARY SCIENCE REVIEWS, 1999, VOL. 24, NO. 4 291**
seldom be applied directly to the dating of pottery. The first absolute dating technique to be applied to pottery was thermoluminescence dating, this being developed by physicists working in archaeology from about 1960 onwards. Thermoluminescence is the emission of light by a sample when it is heated, excluding that due to incandescence. When ionising radiation (alpha, beta, and gamma) passes through a non-conducting solid, many free electrons and holes (electron deficient centres) are created. The vast majority recombine, but a few electrons diffuse away from their point of formation and become stabilised by being trapped at some defect in the structure. When the solid is heated the trapped electrons escape from their traps and a proportion of these recombine with holes at luminescence centres emitting their excess energy in the form of light. (The thermoluminescence used in dating involves the emission of visible light at temperatures below those at which black body radiation becomes visible.)

When a crystal is formed, as for example during the precipitation of calcite in a cave, the structure generally contains no trapped electrons. This known starting point (zero trapped electrons and zero thermoluminescence) is also attained when a sample is heated sufficiently, for example when a pot is fired: all the natural thermoluminescence in the geological raw materials is released by heating during the firing process. After the ceramic fabric has cooled, the trapped electron population starts to build up again in the constituent minerals. The amount of thermoluminescence stored is a function of the total radiation dose the fabric has absorbed since firing and the sensitivity of the sample. The thermoluminescence in the fabric is measured by heating a sample in front of a light detector. It is then measured again in a series of similar samples that have been given known artificial radiation doses in addition to their natural dose. Plotting the intensity of the thermoluminescence as a function of the artificial dose allows the natural dose to be determined by extrapolation of the line to zero thermoluminescence intensity, the situation just after firing. To obtain the time since firing, the total natural radiation dose is divided by the annual radiation dose the sample has received from cosmic radiation and radioactive impurities in the ceramic and the surroundings. The annual dose has to be measured or calculated from analyses and is a significant source of uncertainty in dating.

Another physics based dating technique that has found considerable employment in the study of archaeological ceramics is archaeomagnetic dating. This relies on the fact that most clays contain particles of iron oxide. In an unfired clay artefact the magnetic domains of the iron oxide particles are fairly randomly distributed. During firing the particles lose their magnetic properties but as the iron oxide cools after firing the magnetic domains tend to align with the local magnetic field of the earth, so that the direction of the ‘thermoremanent’ magnetic field of the fired clay artefact is parallel to that of the earth at the time the clay cooled and the intensity of its magnetic field is proportional to the intensity of the earth’s field again at the time the clay cooled. This record of the earth’s magnetic field preserved in a fired clay artefact can potentially be used to date the last time it was fired because the direction and intensity of the earth’s magnetic field at a given location changes gradually over the course of hundreds of years (secular variation), probably as a result of changes in convection patterns within the liquid core of the earth. Dating is based on matching the magnetic orientation or direction recorded in the sample with a known chronology of past secular variation in the earth’s field at the location of firing.

Records of secular variation in the earth’s magnetic field have been kept in various places for the past 400 years or so. As the secular variation field does not follow a recognisable pattern and is different at different points on the earth’s surface, earlier secular variations must be determined by measuring the thermoremanent magnetism in samples whose last firing can be dated by other means. Fired clay such as a kiln floor that has remained in a fixed orientation since its last firing and can be well dated by other means (historical, archaeological, radiocarbon, or thermoluminescence) provides the best material for determining past secular variation. Portable items such as pots carry information on the ambient field intensity at their time and place of cooling but their orientation during cooling is generally unknown. Once a sufficient number of structures of various known ages have had their thermoremanent magnetisation measured a calibration curve of time against magnetic orientation and/or intensity may be drawn for that region. Other structures may then be dated by their thermoremanent magnetism alone by referring to the calibration curve. A given master sequence of secular variation may be valid within a radius of several hundred miles of the area in which it was established. Hitherto palaeointensity measurements have made by far the greatest impact in archaeology but in some areas and periods palaeointensity variations may have been sufficient to be useful for dating movable objects such as pots. The accuracy of magnetic dating is dependent upon the quality of the master sequence and the rate of change of magnetic field at the time in question. Uncertainties in the dating of structures by other methods are carried through to uncertainties in the calibration curve. Although not always very accurate in terms of absolute date, archaeomagnetic measurements can be quite precise and have proved very useful in developing local relative chronologies, for example by cross-correlating different stratigraphic successions of kiln rebuilds at different locations within an industrial area.

**Technology of manufacture**

Although dating was one of the major roles of pottery in archaeology particularly before the 1960s, there
has always been some parallel interest in ceramic technology. It has been noted above that each of the processes that have contributed to the final state of the excavated pot (selection of raw clay, preparation of clay, forming, drying, firing, use, and burial) have potentially left clues as to their nature within the pot. Processes up to and including firing are studied under the general heading of pottery technology, but it is clear that issues concerning access to raw materials and the organisation of production will also be closely involved, although not discussed here. The aim of this section is not to review the whole field but to highlight some of the areas in which interdisciplinary approaches have made a significant contribution.

Natural clay deposits normally comprise a mixture of clay minerals with accessory non-clay minerals. Although some waterlogged clays may be suitable for pot forming in their raw state, the majority need some preparation to bring the material to a workable condition. The first stage in making pottery will be to select suitable clays from the great variety of natural deposits provided by natural processes. The factors controlling the particular properties of a natural clay and water mixture (and thus its suitability for making a particular object) include its clay mineral composition, the exchangeable ions present, its non-clay mineral composition, the organic content, the grain size distribution of the components, and the water content. Ancient potters could and did manipulate all these factors in order to achieve the desired working properties from a given raw material, thus accommodating imperfections in raw materials or developing the possibility of making new kinds of artefact from existing materials.

For example, if a raw clay is insufficiently plastic when wet, the workability may be improved by blending with a more plastic clay, by removing non-plastic inclusions, or by breaking up the clay mineral flocues or crystals into finer particles. Adding salts or acids to effect ion exchange of the positive ions on the surface of negatively charged clay crystals may change the electrostatic potential of some or all of the surfaces of the crystal and cause deflocculation. (Interparticle forces will also greatly affect the viscosity of a slip or the ability of a glaze suspension to keep colourant particles in suspension.) Reduction in particle size distribution of the clay body may also be achieved by intercalation, as in the use of urea to prise open and break apart the layers of clay crystals. Adding animal dung or leaving the clay to sour in a plastic condition for a long time may affect a combination of these two processes and others, the end result being an increase in workability. These and other preparative processes, such as settling a suspension of clay in water to yield a deposit of varying particle size distribution from a single raw clay, were practised by potters on the basis of empirical knowledge: they knew by experience of the material or by tradition that under given circumstances a particular preparative process would have a certain effect.

The processes of selection and modification of raw materials are also of great interest to archaeologists as evidence of technological continuity or change but the archaeologist has to infer the use of the processes from the end products after firing, use, and burial. This is quite a challenge and has required input from a wide range of other disciplines including clay mineralogy, soil science, sedimentology, colloid science, fluid dynamics, fire dynamics, industrial ceramic technology, craft pottery, materials science, and geochemistry. The archaeological ceramicist must draw together information from all these disciplines because of the need to be able to understand how all the different phases in the original clay–water system would have interacted and how the body would have behaved during forming, during drying, during firing, during use, and during burial. Only through this level of understanding of pottery technology in all its stages can the archaeologist develop the sensitivity to be able to suspect possible actions, notice subtle clues in the archaeological remains, and eventually infer what actions the potter might have taken to influence any one of the stages of production for the better. So, to give a simple example, if analysis reveals that the clay used to make a pot has a high proportion of smectite minerals, the archaeologist will know that the potter may have experienced problems owing to uneven shrinkage during drying and will be alert to signs of possible steps taken by the potter to mitigate the damage caused by such problems.

Much can be learned about how a pot has been formed from visual examination as the formation of the plastic clay body will result in characteristic marks on the surface topography of the vessel. These may be obscured by later processes such as finishing in many examples but a clue can usually be found if a sufficient number of sherds of a given type can be examined. Elongate inclusions, pores, and the plate-like clay mineral crystals themselves will tend to become aligned in the direction of viscous flow as the clay–water mixture is plastically deformed into the desired shape. This alignment can be seen by eye and under the microscope in suitable sections, and can indicate how a pot was formed. The use of X-radiography and xeroradiography for detecting internal alignments should also be noted. These techniques use differences in optical density with respect to X-rays to reveal the alignment of pores (and to a lesser extent inclusions) and thereby indicate the technique of manufacture of a ceramic object. The techniques were developed in medical radiology and have since been applied to the study of ancient ceramics with considerable success. Xeroradiography involves recording the X-radiographic image on electrostatically charged plates instead of on conventional X-ray film. This technique is particularly good at delineating edges even when the density differences are very small. Internal alignments in ceramic fabrics are thus seen clearly and non-destructively.

As in other branches of science the study of causes of failure can be most revealing. This is no less true...
in the study of ancient pottery ‘wasters’, ceramics which for some reason failed to achieve the desired final appearance (perhaps because of cracking or melting during firing) and were discarded as useless in the vicinity of the pottery workshop site. Studying the faults that arose, and in some cases the means by which they were in due course overcome, provides considerable insight into ancient ceramic technology. As clay dries from the plastic state, water evaporates from the surface and further water moves from the internal pores towards the surface to replace that lost by evaporation. As the interstitial water moves out towards the surface, the clay particles are drawn closer together and the object shrinks. In smectite clays the crystals themselves also shrink. Uneven evaporation rates lead to uneven drying rates, uneven shrinkage, distortion and/or internal stress, and, if the stresses exceed the tensile strength, cracks. Alignment of clay minerals during forming is also important as it gives rise to anisotropic shrinkage during drying. Soluble salts in the pore water may also cause problems by crystallising within the pore structure during drying. Many faults arise during drying and firing, the latter sometimes revealing incipient faults from the drying stage.14 Valuable insight in this area is gained from modern ceramic technology, but also from areas such as mechanical engineering and building conservation.

An aspect of ceramic technology on which a great amount of interdisciplinary work has been conducted is the investigation of firing conditions. Control over firing conditions is clearly important in achieving reproducible high quality ceramic products. Control over firing conditions, including the ability reliably to attain high temperatures, may thus be taken as a yardstick of technological achievement. Before over-estimating the archaeological importance of exact determination of firing conditions, however, it is well to reflect upon the context within which such work is undertaken and to consider the potential archaeological significance of the results. Some of the techniques used are extremely sophisticated, but even the most precise account of the maximum firing temperature to which a sherd was subjected may in itself be of limited significance. This is because ancient firing technology was often rather crude and temperature control not very exact. Different parts of the same vessel may be fired to notably different extents depending on the stacking arrangements in a fire or kiln. This is not to imply that precise investigations of firing conditions are useless but rather to emphasise the need for interpreting the experimental results in the appropriate technological and archaeological context. This need for maintaining a clear perspective and awareness of the potential significance of results is common to all aspects of archaeological science.

Determination of the conditions under which an archaeological potsherd has been fired depends on measuring the extent to which irreversible changes that occur during firing have proceeded. These changes include mineral transformations and decomposition, the formation of glass phases, and the consequent changes in texture and physical properties. Factors affecting the extent of a given change generally include the initial composition of the unfired body, the temperature and duration of firing, and the nature of the kiln atmosphere. The fact that three or more independent variables may influence the extent of changes resulting from firing often limits the precision of the results that can be obtained. For example, a given extent of change may be achieved by firing at a low temperature for a long time or at a higher temperature for a shorter time. The result of an investigation into firing conditions might then be a set of possible pairs of temperatures and durations, although where rates change very steeply with temperature the range of temperatures corresponding to plausible durations may be fairly narrow.

Visual examination of the cross-section of a vessel wall may allow one to deduce something of the succession of firing atmospheres to which it has been exposed.15 In pottery fired below 1000 °C colouring and core effects are often due to interaction between carbon and the combustion gases. If any organic material (microorganisms and the like) is present in the clay – as it generally is in secondary clay deposits – this will char during firing and the fabric will become gray or black throughout. Above about 500 °C, if the atmosphere contains free oxygen the carbon will react with the oxygen and be removed as carbon monoxide or dioxide gas, starting on the surface and working in towards the centre of the vessel walls at a rate dependent on the permeability of the fabric to the hot firing gases. As the carbon is burnt out the colour of the clay body is revealed. Different areas on the surface may be treated to give different gaseous permeabilities for decorative effect: a short burst of oxidation at the end of a reduced firing will burn carbon out of the permeable areas but leave the impermeable areas black. In a situation where there are no organics in the clay or where they have been burnt out at an earlier stage in the firing, limitation of air supply may lead to the deposition of soot and blackening of the pottery. Where a black product is desired the potter may block the air inlet while fuel is still burning and keep it blocked while the furnace cools. Above about 900 °C oxidising or reducing atmospheres may react with iron oxides to change the colour of the ceramic fabric. Reduction and oxidation of colourants will also affect the colours developed in many glazes, glasses, and enamels. Processes occurring after firing may also change the colour of pottery especially at the surface, and it is important to distinguish these changes from those used to deduce firing conditions. For example a cooking pot may be blackened during use owing to deposition of carbon. Colour changes may also occur owing to surface layers being worn off and material being leached out or deposited in the surface pore structure during use or burial.

The influence of initial composition on the extent of a change resulting from firing can be very marked.
For example, a given state of sintering can be achieved in different compositions at very different temperatures, depending amongst other things on the amounts and types of fluxes present. Because the precise constitution of the pottery is often unknown and might be difficult to reproduce, a frequently employed technique is to refine the archaeological sherd itself for a given time at each of a series of increasing temperatures. The chosen parameter is measured after each heating episode, and it is generally assumed that no significant change will occur as a result of reheating below the original maximum firing temperature because at lower temperature reactions will generally be much slower than they were at the maximum firing temperature. When the measured parameter changes it is usually considered that the maximum firing temperature has been exceeded. There is, of course, a complication in that extending the time of heating at or near the maximum archaeological firing temperature may further the change being measured.

A wide range of scientific techniques has been applied to the problem of assessing the maximum temperature to which a ceramic was fired. Rice tabulates a dozen approaches and Heimann reports some others. An assessment of the degree of vitrification can with experience be made using the scanning electron microscope. Vitrification brings about associated changes in other properties. For example, porosity has been used in attempts to determine ancient firing temperatures, but as porosity depends on many factors further research is needed to allow proper interpretation. As with other measurements of physical and textural properties, it must be remembered that the value of a property measured on an archaeological sherd may differ from the value it had when new because of use and post-depositional processes. The velocity of ultrasound waves in potsherds provides a measure of the degree of sintering, and in combination with successive laboratory refiring can provide a good indication of firing temperature. On reheating a sherd, contraction also indicates the onset of further sintering or melting and gives a first approximation to the maximum archaeological firing temperature. Sophisticated corrections may improve the accuracy of the technique.

The decomposition and formation of new minerals during firing can provide an indication of firing conditions, but the mineralogical temperature scale is complicated by the dependence of the stability range of a mineral on the furnace atmosphere and by slow kinetics resulting in minerals surviving well above their equilibrium stability ranges and new minerals failing to form well into their equilibrium stability ranges. Impurities can affect stability ranges and exert a strong influence on kinetics. Post-depositional reactions must also be taken into account. Laboratory refiring may assist in the deduction of firing temperature from the mineral suite present in a potsherd. Mineralogical analysis may be performed by thin section microscopy, X-ray diffraction, differential thermal analysis, or electron microprobe analysis.

Recording the electron spin resonance (ESR) spectrum of a potsherd after each of a succession of reheating episodes may indicate the maximum temperature of previous heating by a sudden change in the spectrum on heating. Mössbauer spectroscopy allows the oxidation state and bonding of some atoms, particularly iron, to be measured. Changes in spectra on laboratory reheating can again be used to indicate the maximum firing temperature and combustion atmosphere. Radial electron density functions can be used in a similar way.

Provenance studies

Provenance studies probably account for more interdisciplinary effort than any of the other areas considered in this paper. Information about source(s) of raw materials or production centres can be very significant archaeologically as it may indicate strategies for the procurement of raw materials, technological advancement, mechanisms of distribution, exchange and trade, and contacts between different archaeological cultures. Although in the past provenance studies have used traditional wet chemistry and gravimetric analyses, the field is now dominated by instrumental analysis. This is partly because of the large numbers of samples that need to be processed in order to account for the inhomogeneity and variability of much archaeological material. Optical microscopy still has an important role but automated image analysis of microscopic images is waiting in the wings, again spurred on by the need for rapid analyses of many samples.

Instrumental analysis helps to satisfy the need for large numbers of analyses but it does not deal with the correspondingly large multivariate data sets that it generates. This has been a weak link in some analytical projects and, while progress has been made in data handling in archaeology, there may still be room for further improvement. It should be noted that groups derived from numerical analyses of multivariate data are merely those that are statistically significant. This does not of itself imply that the groups necessarily have clear archaeological significance, so the results must be interpreted with care.

Provenance studies generally consist of matching the properties of artefacts of unknown origin to those of reference material of known origin. (Occasionally provenance studies may need to be attempted without the use of known reference material, as when trying to determine whether several groups of ceramics might be derived from the same raw materials, but the principles of comparison are similar.) The reference material for provenance studies might be geological material collected for the purpose, material of known place of manufacture (such as ceramic wasters excavated at a kiln site), or material whose origin can be presumed from its distribution density decreasing with distance from a production or distribution...
centre. When comparing artefacts with finished objects of known origin, instrumental analysis (including optical microscopy) is used in conjunction with more traditional approaches involving vessel form and style of decoration. In matching archaeological artefacts to the geological reference material (for instance matching a pot to samples of raw clay) instrumental analysis has to stand largely alone.

Data on the physical properties, texture, mineralogical constitution, and elemental and isotopic composition of ceramic fabrics may fairly readily be obtained given the availability of appropriate analytical facilities. Any and all of these classes of data may be of use in comparing the unknown to the reference material provided it can be shown that the value of the parameter is characteristic of origin rather than being the result of some other factor which may affect the value of the parameter, such as conditions of use or burial. In essence, one is trying to find within the vast body of potential data some feature that is common to the materials from a given source and serves to distinguish them from similar materials from other sources. Determining how to proceed through this seeming maze of possible routes will depend on the particular questions to be answered, the availability of the various techniques in terms of their cost in time and money, and on what is possible in terms of sampling: there is thus no substitute for common sense, clear thought, and a balanced knowledge of the factors affecting the composition of ceramics.

While the idea of provenance determination by comparison of unknown material with reference material of known origin is simple enough in principle, it is worth stressing that there may be many complications in practice. Although success has occasionally been achieved fairly straightforwardly, it is more common for results to be less clear cut. Provenance studies should not be undertaken lightly and it is important to conceive a research plan carefully to avoid great amounts of analysis yielding little information. Mineralogical, textural, and elemental compositions may vary between different parts of a single vessel, between different vessels of a common origin, or within a source of raw material. Thorough sampling, sufficient to give not only the average values of parameters but also a good idea of any range of variation, is important for both ceramics and raw clay deposits. The implications of the physical techniques of taking samples also require careful consideration. For example, the composition of a small sample drilled from a sherd for elemental analysis can be very different from the average composition of the object, particularly if the sample includes an unrepresentative proportion of inclusions or if it comes from near the surface where contamination or depletion is more likely.

While comparison of unknown ceramics with ceramic reference material of known origin has often been quite successful, identification of raw material sources for ceramics is much complicated by the possibility of mixing different raw materials and by the variety of techniques that might be used in preparing the clay, not to mention the more general variations in use and burial conditions. As with other materials, a detailed understanding of the technology of manufacture is important in making reliable deductions as to provenance. Even with the best work results may have to be described using phrases such as ‘not inconsistent with’. The use of several independent parameters clearly increases the security of the provenance determination and mineralogical analyses may help the interpretation of elemental data. Despite these potential and real problems, and despite the fact that certainty is still elusive in provenance studies, sufficient success has been achieved to make provenance studies an increasingly important field of interdisciplinary research.

Specific analytical strategies depend on circumstances but will often involve examining a range of fabrics by reflected light using a hand lens or low power microscope. A fresh break provides selective information on the fabric and should be supported by examination of a plane section wherever possible. This much is quick and requires only simple equipment. The identification of inclusions, be they native to the clay source or added by the potter, may be achieved by transmitted polarised light microscopy of thin sections, essentially using the techniques of optical petrology borrowed fairly directly from sedimentology. (Clay based ceramics are sediments that have been subjected to heat, rather as they might have been in contact metamorphism.) Examination of at least a few thin sections is worthwhile even when dealing with fine grained ceramics as it may reveal microfossils, fine silt inclusions, or argillaceous inclusions as well as indicating the nature of surface colourings. Provenance studies of fine grained ceramics will often require chemical analysis or X-ray diffraction analysis to identify small crystalline phases. Where larger inclusions are present they may or may not be diagnostic. In some river systems the suite of inclusions in the alluvium varies markedly as the river cuts different geological deposits and receives different contributions from tributaries. Ceramics made from such deposits may contain inclusions that are highly characteristic of their origin. On the other hand the inclusions in pottery containing quartz grains as the predominant inclusion are often not diagnostic. In this case one may crush pottery to extract a suite of rarer heavy minerals which are usually present in quartz sand and which may prove more diagnostic of source or one may attempt to match pots to source using textural analysis of the grain size and shape distributions of the quartz inclusions. This is time consuming and would lend itself (not without some difficulty) to automated image analysis. Quartz grains do have other features such as inclusions or extinction which may prove characteristic. More recently the possibility of using the cathodoluminescence properties of quartz as a characterising feature has been suggested.18
If these approaches fail, one may move to a range of techniques for elemental and isotopic analysis. These techniques are the standard geochemical analytical techniques although a few such instruments are used primarily for archaeological research. Commonly applied techniques include neutron activation, X-ray fluorescence, electron probe microanalysis, inductively coupled plasma emission spectrometry, inductively coupled plasma and thermal ionisation mass spectrometries, and atomic absorption spectrometry. Minor and trace elements have been given the most attention for the reason that the major elements are common to all clays. This approach is not always necessary, however, and some highly significant distinctions between groups have been made on the basis of major elements.

The above approaches to identifying the origins of raw materials all involve techniques that were initially borrowed from other sciences, primarily the geological sciences. Although interdisciplinary and innovative at their inception, some of these approaches have become fairly standard over the past few decades. The fact that they do not always produce clear answers has however encouraged further attempts to find new approaches, mindful of the possibility that any parameter characteristic of the source of the raw material and surviving the intervening processing, production, use, and burial might in principle be useful.

One area of current research that is investigating a non-geological interdisciplinary approach is the use of ecological and taxonomic expertise for the study of diatoms, a class of microscopic algae often used as sensitive indicators of environmental conditions. This research might provide an independent and accessible new approach to determining the location of clay deposits used in making particular examples of ancient pottery. The assemblage of diatom species living in a particular aquatic environment closely reflects the nature of that environment and is especially sensitive to salinity, pH, nutrient content, and local aquatic habitat. Diatoms are a particularly diverse class of microscopic algae and many thousands of taxa can be distinguished under the optical microscope by the characteristic form and decoration of their silica frustules, which comprise two valves enclosing a cell. These silica valves survive after death and become incorporated in clay deposits and sediments in ditches, ponds, lakes, rivers, estuaries, and oceans, many of which contain characteristic assemblages of diatom valves reflecting the depositional environment and post-depositional diagenesis. If they survive firing, characteristic diatom assemblages may be identified in an archaeological ceramic which may thereby be associated with one or more possible sources for the raw clay from which it was made. A small number of published studies conducted in Scandinavia have demonstrated that under some conditions at least the siliceous valves of diatoms can be extracted from archaeological ceramics and identified but give little indication of how widely applicable the technique may be in practice. The published work does not discuss in detail the techniques used for extracting the diatoms from the ceramic, the firing conditions necessary for diatom survival, or the possible skewing of diatom assemblages by clay preparation techniques, by preferential loss of some species during firing or by preferential destruction during extraction of the diatoms from the fired pottery.

A final factor to be considered in provenance studies is that there may be great advantage in conducting as much preliminary analysis as possible while still in the field. (This may mean adapting laboratory techniques for use in the field or simply arranging rapid feedback from a conventional laboratory.) Increasing political and bureaucratic restrictions on access to and movement of archaeological material often have the practical consequence that more analysis has to be conducted in the field. While such restrictions may in many ways hinder research, obtaining of analytical results while still in the field is, in its own right, a valuable and important part of optimising research productivity. If analytical results can be obtained while still in the field, they can be of considerable assistance in guiding appropriate sampling and excavation strategies and maximising the potential for obtaining new knowledge: information gained on later analysis may be information gained too late, especially if the excavation/site cannot be revisited. There is thus now both an academic and a politically imposed challenge to make further effort towards developing analytical equipment suitable for use in the field. The meaning of the term ‘in the field’ may range from in the back of a van, in a museum, in a hotel room, in a tent, to in the rain, but some degree of increased portability consistent with adequate analytical performance is needed. Exciting prospects are emerging based on devices made by etching and layering glass and silicon, although problems of sampling and sample preparation will still have to be tackled on a larger scale.

Uses of pottery

The exact uses to which particular pottery objects may have been put is not always clear. Documentary evidence including engravings and paintings may provide clues in some cases and ethnographic evidence of the use of similar shapes provides some further ideas. An interdisciplinary approach that has generated much interest in recent years is the identification of residues of the ancient contents remaining attached to the surface or trapped within the pores of pottery. Here the skills of the organic analyst, biochemist, and food scientist come into play. In most cases however this is far from being a straightforward analytical or interpretative problem. Separation techniques are nearly always needed prior to analysis of residues. It is also a particular problem that most residues will have decayed considerably from their fresh state, so a direct comparison between
a recent sample as an ancient residue of the same material would not in general produce a good match. This is of course a general problem in all physico-chemical analysis of archaeological materials, but it is particularly acute in the case of many organic residues. Many pottery contents are highly complex mixtures of relatively unstable compounds and knowledge of the modes of decay of those mixtures over prolonged periods of time is very limited. It is very rare for there to be standards in the sense of samples of ancient material of known identity that have been kept under conditions comparable to the sample being investigated. It also needs to be considered that pottery may itself have an effect on the mode of deterioration of the contents, possibly catalysing particular decay reactions. Despite the difficulties, it is likely that this area of research will receive considerable attention in the coming years. In the wider agenda of modern archaeology it will not only indicate the contents of various vessels but will produce some insights into how past humans may have used some of the organic plant and animal resources at their disposal.

Refractory ceramics

Archaeological ceramics inform us of far more than ceramic technology, for they often constitute a major aspect of the remains of other technological processes. In few areas can this be more true than in archaeometallurgy. A large proportion of the evidence for archaeometallurgical processes comes to us in the form of refractory vessels and structures, the valuable metal products generally being removed from the site. A good example of this was reported recently in Materials World. In this instance all that survived was a scatter of broken crucibles on the surface and, just below the present surface, the remains of three furnaces in the midst of early Islamic ruins in the Merv oasis on the Silk Road trading route in what is now Turkmenistan. From the scant remains of these refractory ceramics it was possible to deduce that the crucibles had been used to make steel by cofusion of a high carbon ‘cast iron’ with a source of low carbon iron to make a liquid steel of intermediate carbon content. It was also possible to deduce the mode of operation of the furnaces and to observe a recycling scheme for the refractory ceramics that was fully integrated into the steelmaking process. The furnace design, which is reminiscent of modern gas producer furnaces, is otherwise unknown in the archaeometallurgical record. Ceramics here provided evidence of a sophisticated and previously unknown steelmaking process that could have made the steel for the famed Damascus swords and which was not to be discovered in the West until the Industrial Revolution nearly a thousand years later. Here the interdisciplinary contact is with process metallurgy and, in the case of the recycling of the refractories, with the very current topic of sustainable technologies. Deducing details of the technological process is only part of the process as far as modern archaeology is concerned: the technological knowledge now forms the basis for further questions on procurement of resources (none of the materials were to be found at Merv), the organisation of production, the distribution and prestige of the products, and many other questions. This further research may involve many other specialists including those dealing with Islamic texts, ore deposits, wood micromorphology (to identify fuel), environmental reconstruction (to identify possible sources of fuel), the history of arms (for later stages in sword production), physical metallurgy (to study the requirements for the development of the Damascus pattern), and experimental archaeologists (to test the feasibility of the hypothesised process as deduced from the ceramic remains).

Other ancient ceramic materials

These include gypsum and lime plasters, cements, faience, glass, glazes, and enamels. Plasters predate pottery and were used for flooring figurines and vessels. Hydraulic cements (which set under water and are waterproof) may have been made inadvertently when using marly limes for plasters but were deliberately made by the Romans. Faience has a fine quartz body held together by small amounts of interstitial glass and a surrounding alkali glaze. Compositional and technological studies have indicated local manufacture by various methods as well as some trade or exchange. Further work on this material is still needed. Glazes on pottery and enamels fused to metals are a further class of archaeological ceramic where interdisciplinary research has brought greatly improved understanding.

Glass is far rarer in the archaeological record than pottery but it is still very important. It is however considerably more difficult to study than pottery because whereas recycling of pottery is quite common, with glass there is a strong incentive to recycle much of it because of the very long duration of intensive heating required to make glass from raw materials alone. This is limited by gaseous and solid state diffusion. The addition of glass provides a surrounding liquid with rapid transport properties which relatively rapidly dissolves the new raw materials at lower temperatures resulting in a very considerable saving in time and fuel. Current research topics in glass studies include considering workshop processes and possible recycling processes as well as devising ways of quantifying glass assemblages to permit quantitative comparison of the constitution and nature. Comparisons with methods developed for pottery are being considered but differences in the material make the direct transfer of techniques problematic. Of a more obviously interdisciplinary
nature is the work being done in collaboration with the British Museum and Royal Holloway isotope geochemistry laboratory to look at the trace element and isotopic compositions of early Egyptian and Mesopotamian glasses. This may help to address the question of whether the Egyptians were making glass from their own raw materials or simply importing and remelting Mesopotamian glass. Significant archaeological advances have often closely followed advances in instrumental capabilities, and here again the limits of the latest instruments are being stretched in an attempt to answer archaeological questions.

Conclusions

Ceramics have always been important as a prime source of information in the archaeological study of sedentary human societies, including virtually all of the world’s great civilisations. The role of ceramics in archaeology has changed over time with the changing interests of the discipline but the importance of ceramics as archaeological evidence has remained unchallenged. Interdisciplinary science has played a very important role in the analysis of archaeological ceramics over the last forty years. With the increasing aspiration of archaeology to contribute to the understanding of the human past in a broader and less purely material way, the demands upon ceramic evidence have increased. Because so much may now be built upon deductions from the ceramic evidence, it is perhaps more important than ever to ensure that the basic conclusions are sound. It is also more important than ever to understand the strengths and limitations of the data that have been gathered in the context of the questions that are being asked. In the coming years, success in archaeological ceramic research will rest on coordinating and marrying appropriate evidence with appropriate questions and appropriate analytical approaches. The analytical approaches are very likely to be drawn from an ever widening interdisciplinary spectrum.

Archaeology often provides new challenges to collaborating disciplines and very often gives unsuspected rewards to those who venture into new interdisciplinary fields. It is hoped that this paper may give readers cause to reflect upon whether their own expertise might not, under the right circumstances, serve to illuminate some aspect of the human past and thereby enrich the human present.

Notes and literature cited

In this section many of the sources cited have been selected because they provide the reader with a range of information on studies of archaeological ceramics. The specific citations thus also serve as a bibliography.


INTERDISCIPLINARY SCIENCE REVIEWS, 1999, VOL. 24, NO. 4 299


Dafydd Griffiths was an undergraduate at Oxford University and University College Cardiff before reading for his doctorate at the University of London. He is now a lecturer at the Institute of Archaeology, University College London. He is interested in analytical studies of ancient ceramics, glass, stone, and metal artefacts which aim to provide an understanding of the technology of their manufacture and the mechanisms of their decay. He has recently been involved with the analysis of glass and metallurgical waste in the International Merv Project. Other interests include developing improved methods of conservation and new approaches to conducting analytical work in the field. ‘The archaeology of geological catastrophes’, of which he is a coeditor, will be published by the Geological Society in 2000.