Edited by Jane Balme
and Alistair Paterson

Archaeology in Practice

A Student Guide to Archaeological Analyses

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Introduction

As much as we today take for granted porcelain teacups, glass food condiment jars, plastic storage bowls, stainless steel cookware, or aluminum beer cans, it is easy to forget that the uses to which these materials are put represent a constant struggle for survival throughout ancient times: How do you consume food beyond the very time and place of hunting/gathering? How do you manage to drink away from the actual source of water and make sure that fluids are available when you need them? How do you survive when there is no food/water readily available for weeks or months during winter or drought? The underlying issue in all of these questions is the need for a system of sanitary containerization. But containerization goes beyond the biological requirement to provide nutrition and the need is still with us. The present-day carrier industry is eager to declare (as did ancient Greek sea traders) how well they package, protect, and transport our food and nonperishable goods. Either a bank's safe deposit box or a purposely buried ceramic pot containing hundreds of Roman coins, respectively, can and did adequately protect valuables for future needs. And it takes little more than one news broadcast, or simple word of mouth, of forthcoming war to induce hoarding of food and other necessities. While we never really think about it, containerization has always been a major part of human existence, and this is why pottery on archaeological sites speaks volumes on social, religious, economic, and even political behavior.

Of course, other materials were used as containers in prehistory – leather, basketry, wood, stone, and metals – and ceramics never completely replaced, nor was replaced, by any of these technologies. But while these materials are still very useful, they have a number of inherent limitations. Leather, basketry, and wood are organic materials that may themselves become infested and are neither completely waterproof nor heat tolerant. Making stone bowls was

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common in prehistory, but this was arduous work, and the resulting product was also difficult to handle and transport and thus best reserved for heavy and specialized operations like grinding and milling. Before the manufacturing of iron, metals were rare and expensive, and most bronze containers were restricted to those in the sociopolitical or religious hierarchies who could afford such luxuries. Clay and its fired end product, ceramics, are another matter entirely. The raw material is ubiquitous across the Earth, easy to procure and handle, and pliable into any desired shape. Ceramics are heat tolerant beyond the cooking temperature range, unattractive to pests, waterproof, sanitary and easy to clean, nonbiodegradable yet recyclable, sufficiently sturdy and lightweight to transport goods overseas, and cheap enough to make at home or elegant enough to serve an emperor. As with other materials, there are drawbacks: Ceramic production does require fuel, and pottery can fracture easily. However, the fuel can be as cheap as cattle dung, and broken pots can be easily replaced and recycled.

In antiquity, besides containerization and food service, clay quickly became a building material to make hearths and ovens in the home, bricks to create architecture, pipes to supply hot and cold water, and tiles to make pavements. Ceramics took on artistic, playful, or religious roles to make statuary, models and toys, and ritual altars. Fired clay was and is still used as an industrial material in and of itself to service the manufacture of other ceramics and products of other pyrotechnologies: as casting molds and cores in the production of elaborate metallic castings; as recycled material for future ceramics; and for the construction of kilns to fire pottery, to fuse glass, or to liquefy metals. Once human beings discovered the properties of raw and fired clay, the uses to which this material was put were multifarious, and new uses are continuously being developed even today, from storage of nuclear waste to the manufacture of jet engine parts. Therefore, wherever humans have discovered the properties of fired clay, the products of this pyrotechnology are usually the most ubiquitous of archaeological finds encountered. Archaeologists have exploited this abundant material and focused considerable attention on the analysis of ceramics to further understand human cultural development.

This chapter can only suffice as an introduction to the study of archaeological ceramics. Anyone beginning ceramic studies should refer to the works by Shepard (1956), Rye (1981), Rice (1984, 1987), Arnold (1985), and Orton *et al.* (1993), which, taken together, will provide an excellent and comprehensive foundation. Before collecting and analyzing ceramic samples, the student of archaeology should become familiar with the specialized terminology (in italics in the following discussion), the geological history of clays, and the technology of ceramic production. This chapter encourages students to think long term about the excavation and handling of archaeological ceramics in the field, preserving the integrity of ceramics for prospective analyses, and ensuring longevity of ceramics as a future archaeological resource. This discussion has no geographic or chronological focus, but is intended to facilitate the research of any type of ceramic collection – from prehistory to the modern era – that has been excavated from any location, be it continental, island, or under water.

What Is a "Ceramic?"

Ceramic is best viewed as a transitional material, as a product of pyrotechnology lying on a solid–liquid continuum, between clay and glass. The term *ceramic* is usually applied to those objects or features made of clay and subsequently heat treated so that the final product is durable and retains its shape when exposed to water. *Pottery* is a more specialized term, under the rubric of ceramics, and refers to containers for the preparation, consumption, and storage of food and liquid or for the storage of other nonconsumable objects or materials. But in order to understand the manufacture and use of ceramics, one must first understand the raw, beginning product, "clay" (Ellis 2000a).

Geologically speaking, *clay* is a sedimentary rock formed from the products of erosion of other rocks, predominantly feldspars, but also granite, micas, other silicates, or volcanic formations. Clay is differentiated from other pedological materials (such as soils, silt, and sand) by extremely small particle sizes, less than 0.002 mm in diameter, which accounts for much of the observed behavior of clays when water is added (i.e., plasticity and colloidal suspension). Clays are classified either as *primary* (or *residual*) clays that formed at or near the parent rock, or *secondary* (*transported*) clays formed from products of erosion, which were transported to various distances by weather systems, water current, or glacial movement.

During the formation processes of primary and secondary deposits, the weathered sediments undergo both mechanical and chemical alterations that result in the formation of clay minerals. A *mineral* is defined as a naturally occurring substance, with a known chemical composition, whose atoms are arranged in a regular geometric array (*crystallinity*). The chemical composition and atomic arrangement of clay minerals can be quite complex, but essentially are based on a unit of SiO_4 – one silicon atom surrounded by four oxygen atoms arranged in a tetrahedral pattern (four triangular sides like a pyramid). Characteristic of most clay minerals is that many silica tetrahedra are joined together into a network, by sharing corner oxygen atoms, to form extensive sheets. These silicate sheets are then intercalated with layers of hydroxyl (OH) groups (i.e., chemically combined water) together with one or more additional elements (e.g., aluminum, magnesium, potassium, sodium, calcium, iron), which derive from and identify the weathered source rock. Two important issues derive from the chemistry of clays. (1) It is this variable composition, derived from the original parent rock, that has produced more than a dozen different clay minerals commonly found in nature. (2) Visible only under an electron microscope, these very delicate silicate sheets tend to form hexagonal-shaped platelets measuring half a micron or less. As will be described later, these platelets are the key to understanding all the unique aspects and behavior associated with clays and ceramics.

As part of the depositional process, clays also have natural inclusions (not to be confused with *temper*, defined later), which derive from the formation history of the clay deposit. Some of these inclusions (e.g., fragments of minerals and rocks, microfossils) can affect the thermal behavior of clay but also allow us to identify sources of clays. Pure, white clays are not common and therefore, most clays are naturally stained with iron oxides from the parent rock, and/or picked up during transport, and eventually determine the range of colors in fired clay.

For *clay* to become *ceramic*, heating has to be sufficient, in terms of both duration and intensity, to force the atoms in clay minerals to dissociate from their rigid crystalline arrangement. Once a certain temperature level (depending on the chemical composition of clay) has been reached during firing, the perimeters of the hexagonal clay platelets begin to melt into glass (liquid), which means that the atoms in this location are in an unpredictable (noncrystalline) arrangement. Meanwhile, the interior of the platelet remains crystalline (solid). In the course of firing pottery, there is an increased development of glass, as melting progresses inward toward the center of the platelet. As heating continues, the glass phase is extended further (*vitrification*) with the result being a densification and shrinkage of the clay into a permanent, irreversible shape (e.g., the fired pot). If fired correctly, this partial formation of glass cements the clay particles together (*sintering* in ceramic terminology) and is responsible for producing a solid and potentially water-tight object. If the heating process were to continue unabated at high temperatures, the clay platelets would completely melt into a glassy substance, too much liquid phase could not retain the potter's desired shape, and the end product would be a deformed and unusable mass (*slumping*). Hence, as stated earlier, a ceramic lies on the continuum between clay mineral (solid) and glass (liquid), retaining many of the visual and tactile characteristics of clay combined with the rigidity of glass.

Not all objects, features, structures, or materials made from clays should be classified as ceramics, however. Usually, clay products that have been *sun baked* (e.g., adobe, sun-dried brick) are insufficiently heated to cause a change in crystallinity and thus are technically dried clay and not ceramic. While the dense and compacted mass of sun-baked clay is still exceptionally durable for architecture in an arid environment, this building material will eventually be dissolved by rainfall if not protected by a plaster facing or otherwise maintained.

How Is Pottery Made?

There are three required steps in the manufacture of pottery or other ceramics (i.e., clay preparation, object formation, firing), with additional steps if the object is to be decorated either before or after firing.

Clay preparation

After raw clay is quarried and transported to the work site, it will usually need to be sorted and cleaned to remove vegetal and animal matter or other unwanted geological debris. Normally, raw clay has to be pulverized to provide a more even consistency and to allow rapid and even absorption of water. If the finished product requires a certain fineness (small particle-size range), then the clay may have to be refined by mixing into a water suspension in a settling tank, or even a series of settling basins, in order to separate the finer fractions of clay.

After cleaning and refining, then the clay is prepared for working. Different clays have vastly different mechanical behaviors (e.g., workability, absorption capability, shrinkage, firing characteristics) based on the chemistry of each clay mineral. For this reason, potters often mix clays based on their properties and availability. It is very important for both archaeologists and students to keep in

mind that clays may have been mixed, and this can affect chemical analyses used to determine the provenance of the pottery.

When water is added to clay, it lubricates and interlocks the clay platelets, and the resulting plasticity allows the potter to form the object and for clay to retain that shape. However, added water will evaporate and the object will shrink during the drying and firing phases. To prevent excessive shrinkage and stress cracks, potters add *temper* to the cleaned clay. Temper may consist of any particulate or pulverized material that (ideally) is noncombustible, nonplastic, and nonhygroscopic; yet, in point of fact, potters will try anything at least once (e.g., sand, shell, rock, recycled ceramics, bone, gravel, volcanic glass, and even vegetal material). However, the natural inclusions in the clay, which may or may not be visible, can also serve the same purposes as temper, if they are present in sufficient quantities.

Object formation

Ancient ceramics were produced completely by hand, with the assistance of rotary motion, and/or with molds. Clay pots may be made by the *pinch-pot* method (pinching and sculpting the clay into the desired form), the *coil method* (alignment of successive coils of clay, with each coil smoothed and joined to the one above and below), the *paddle-and-anvil method* (beating the exterior clay surface with a paddle while holding an anvil on the interior surface, both usually made of wood), or any combination thereof. Pottery was also produced with the assistance of rotary motion from a simple platen on a pivot, which is turned by hand or with a stick, to the more complicated fast-wheel (or *kick-wheel*). The fast-wheel consists of a circular turntable for the working of the clay, at waist level of a seated potter who is able to use the feet to kick (i.e., spin) a lower, horizontal wheel – both turntable and wheel joined by a rod of wood or iron. Ceramic objects, especially bricks, can also be made with the use of molds, into which wet clay can be pressed, then allowed to dry and shrink away from the mold to allow easy removal.

Prefire decoration

The potter has a choice as to whether to decorate the finished object either before or after firing. Decorative surface treatment before firing takes advantage of the plasticity and absorptive properties of clay while still "leather hard." A tremendous variety of decorative techniques were used in ancient times, including modifying the clay surface by incising, excising (gouging of clay to produce a design in sculptural relief), impressing (e.g., using shells, cord-wrapped stick, fingernails), clay appliqué, or inlay work (for instance, filling incisions/excisions with powdered mineral colorants.

The surface of the unfired object may also be decorated by using a *slip*, which is a suspension of clay in water, plus an optional colorant (such as finely powdered iron-, manganese-, or calcium-based minerals). A slip is not a *glaze* (see the following discussion), and occasionally, these two terms are used incorrectly in the archaeological literature. After a slip is applied, then it is usual practice to rub the surface of the slip (*burnishing*) with a smooth tool (e.g., polished bone or stone) or with a piece of leather. Burnishing has the effect of aligning

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the clay platelets in the slip, which increases its durability and also enhances surface reflectivity. Any of the above decorative techniques can and have been used in combination.

Firing

When the clay objects have been allowed to dry thoroughly, they can be fired. Firing of clay not only irreversibly changes the fundamental chemistry and crystallinity of clay, but may also change the color of the final product. Pottery may be fired in simple pits dug into the ground; on the ground surface under a mound of fuel; or in single-, double- or multichambered kilns, which themselves may be constructed out of compacted clay or brick. If firing a simple pit, at the ground surface, or in a single-chamber kiln, the fuel and the objects to be fired (the *charge*) are placed together for the combustion process. In double- or multichambered kilns, the fuel can be kept separate in its own chamber (*fire box*); the heat then either travels up or down, depending on the design of the kiln, to fire the objects in another chamber.

The success of a firing and the quality of the ceramic products are ascertained by how effectively the potter achieved and controlled the temperature of the fire and the surrounding gases (*atmosphere*). Combustion produces a mixture of gases including oxygen, carbon monoxide, carbon dioxide, sulfur compounds, and water vapor. However, depending on how the charge and fuel are arranged in the pit or in the kiln, a potter tries to control both the composition and flow of the gases to ensure an even firing. Unless the raw clay was originally white, natural iron oxides in the clay will render a permanent color depending on the firing atmosphere. If the potter desires a ceramic in the orange/pink/red range, then the surrounding gases will have to be oxygen rich (*oxidizing atmosphere*), that is, with a good input and circulation of air during firing. If the potter wants a brown/black/gray ceramic body, then the input airflow must be controlled to produce a *reducing atmosphere* rich in carbon monoxide. Any miscalculations in the firing process can result in serious surface imperfections.

Postfire treatment

It can be more difficult or complicated to decorate a ceramic after firing, because clay particles have now lost their original properties. At this point, the surface cannot be sculpted, and any colorant has to be bonded in some way to the surface using organic-based adhesives (e.g., tars, resins, gums, or proteins), the fresco process, or glass technology (i.e., glazes). *Glazes* are commonly formulations of finely powdered glass, quartz sand, or quartz-bearing rock, with or without added metal oxides as colorants or opacifiers, mixed with water and painted on the ceramic surface. The object is then fired a second time in order to melt the quartz-bearing base material or to remelt the powdered glass. The potter may apply several types of glazes simultaneously (or even sequentially with multiple firings, provided that each overglaze melts at a temperature lower than the previous application, sometimes referred to as *enamels*). Glazes may be made from other, nonsiliceous materials, such as throwing salt onto the pot during the firing.

Handling of Ceramics during and after Excavation

In the past 25 years, I have yet to visit an archaeological excavation or storage facility where mistakes in the handling and processing of ceramic materials have not been made. My observations are based on being involved in, and teaching about, locally and internationally, all three facets of the archaeological process: conducting archaeological excavations, doing laboratory analytical studies of both my own and others' excavated ceramics, and working in the museum field. Therefore, what follows are a few easily implemented suggestions for the handling and treatment of finds at archaeological sites to help students (or scientists with whom they may collaborate in the future) avoid problems when conducting laboratory analyses of ceramics.

The combined effects of object handling at the site (excavating, cleaning, marking, and repairing) and long-term storage cause perhaps the greatest damage to ceramics and the potential to provide incorrect results of laboratory-based analyses. Unfortunately, a number of practices in field archaeology are propagated from one generation of archaeologists to the next, partly because we teach what we ourselves learned and partly because there is rarely enough time to include preventative conservation methods in typical, one-semester field method courses (see Sease 1994 for more details). Moreover, two more serious problems are (1) the failure to think long term on future research needs and (2) the tendency for archaeologists to neglect ceramic collections once the fieldwork and report writing are over. The languishing of archaeological materials in (usually) poor packaging and storage conditions has been termed in the United States as the *curation crisis*, especially prevalent in repositories designated for the collections of salvage and rescue archaeology (*cultural resources management* in North America). We do not know what future methods of analysis will be developed or refined for archaeological applications, nor do we know the future directions of archaeology as a discipline, or even if we will be able to continue the practice of archaeology in certain areas of the world as a result of repatriation legislation. Existing collections in storage may prove to be invaluable to future generations of archaeologists for testing new hypotheses and research strategies (cf. Cantwell *et al*. 1981; Hardin & Mills 2000). Therefore, simple preventative conservation methods used at the time of excavation will ensure that (1) the integrity of samples will be maintained for future laboratory work, (2) samples will survive for new areas of archaeological research, and (3) samples will be available if archaeological excavations are limited or precluded.

Careful excavating

In the process of excavation, a lot of valuable information can be inadvertently damaged or discarded with the back fill. Both seasoned archaeologists and their students should resist the temptation to "see" the surface of decorated pottery or sherds by scraping off soil or encrustations with the trowel or other abrasive tools. Tool marks and scratches are particularly damaging to fragile decorative slips, and since slips can be highly diluted by the potter, laboratory techniques may require as much slip as is on the entire surface of the sherd for analysis of the colorant. If a whole vessel, or a significant part of the base of a pot, is excavated, one should seriously consider *not* emptying out the soil contents. Retaining

the soil inside the pot can allow one to analyze the residues for information about the original contents of the vessel. Retaining soil immediately surrounding the exterior of the vessel will also allow more precise dating of the ceramic using the thermoluminescence (TL) method. Attentiveness during the excavation of pottery manufacturing sites might also yield some of the raw materials used to decorate pottery – for example, lumps of hematite, limonite, or manganese-based minerals – which would otherwise be easily thrown out by a shovel.

Cleaning ceramics

On-site cleaning of sherds destined for laboratory analysis should be minimal and the least invasive. If time allows, soaking sherds in water to remove loose soil is the least damaging for any future physicochemical and petrographic studies. After washing, pottery should be dried in the shade and packed only when thoroughly dried to avoid mold growth. Hard brushes can be quite abrasive to fragile slips and should be avoided on painted pottery. At many sites, however, ceramics are encrusted with hard, calcareous deposits (phosphates, sulfates, carbonates), which are impossible to remove without chemicals. Many archaeologists clean such encrusted pottery at the site using baths of hydrochloric acid (HCl) diluted in water. Personally, I never use HCl on my excavations, first and foremost for the safety of students in the field. Second, HCl destroys certain information and negatively affects subsequent laboratory analysis by chemically altering white slips (with possibly calcium-based minerals added by the potter) and dissolving calcium-based tempering materials and natural inclusions important for identifying the clay source (e.g., crushed shell, calcite, microfossils). Third, such strong acid baths have more harmful, long-term effects on the ceramic fabric once in museum storage. HCl can produce a powdery surface, even on well-fired pottery (900–1000°C range), which can be gently rubbed to remove the slip and other usable information. The dilemma for the archaeologist is that so much pottery is found, with usually no one else to take care of it, that some kind of bulk and rapid cleaning has to be done in the field. Therefore, if no local museum can assist with cleaning the pottery, citric acid is a milder alternative to HCl. The field team should first decide whether the pottery needs cleaning right away and, if so, experiment with a few heavily encrusted sherds, documenting different concentrations of citric acid and logging the time needed for the desired results, before subjecting all ceramics to the same treatment. But, *most importantly*, always reserve a representative sample collection of sherds, which have *not* been cleaned at all, for subsequent laboratory analysis. (I have a policy of not accepting sherds cleaned with HCl for analysis, unless the archaeologist can supply uncleaned sherds as controls.) Even if no ceramic studies have been planned by the site director and even if one is unsure if analysis will ever be done, someone in the future may need this unclean pottery for analytical study – the dirt has been attached to the sherds for hundreds or thousands of years, a little longer will not do any more harm.

Marking ceramics

Marking artifacts with location and inventory information, while absolutely necessary, is a cause célèbre in archaeology primarily because of the persistence

of many archaeologists who continue to use inappropriate materials – for example, nail varnish and white correction fluid. These highly improper products, which are still used as base coatings upon which to write information onto the object, are neither chemically stable nor permanent, and, when (not if) they peel off, both the critical provenience information and the topmost surface of a prehistoric ceramic will disappear. A conservation-safe varnish (such as Acryloid B-72) as a sealant and nonwaterproof black India ink or Pelikan white ink should be used for writing information on pottery. Moreover, thinking first about the placement of the written information on the object is also important if one anticipates removing a sample for laboratory analysis – I myself have had to saw through inventory numbers to make a viable thin section from ceramics excavated by other archaeologists.

Repairing ceramics

Ceramic materials should be repaired by a museum professional or a trained graduate student with museum experience, because a number of unstable adhesives and plasters have been used throughout the history of archaeology. Typical adhesives, still in use, are cellulose nitrate (clear "cement") and polyvinyl acetate (PVA) emulsions ("white glue"). Cellulose nitrate-based adhesive is easy to apply and effective; however, over the years, it becomes brittle and yellow, and the repaired object falls apart. There are numerous "white glues" on the market, which may or may not be PVA emulsions. The manufacturing formulae for white glues are often changed without notice to the consumer. Unless it is certain that a 100% PVA emulsion is being used, this adhesive should be avoided as well. The most reliable and thoroughly tested adhesive used by museums is Acryloid B-72 (also known as Paraloid B-72). A thermoplastic acrylic resin, Acryloid B-72 is an excellent, all-purpose adhesive that is resistant to discoloration, heat, and water. Museums who have ceramics repaired with cellulose nitrate – and now falling apart in vast numbers – are replacing the old adhesive with Acryloid B-72 (Neiro 2003).

Initiating an Analytical Program for Ceramics

The study of any archaeological material usually begins with a question from which hypotheses are formulated, research designs developed, and samples selected together with analytical methods appropriate to the problem. While the focus of this volume is laboratory analysis, it should be emphasized here that the behavioral component of ceramic production must always be first and foremost the aims of ceramic studies. The research program and objectives are always grounded firmly within the context of archaeological and anthropological theory, a subject beyond the scope of this volume (see Arnold 1985). Chemical analysis for the sake of chemical analysis – as an appendix of scientific graphs not integrated into or referenced by the site report, so prevalent in archaeological publishing up to 20 years ago and still occasionally seen – should no longer be considered in archaeological research. The objective in any analytical program is to reveal and better understand human behavior in the past, by whichever means that may be achieved. In this section of the chapter, issues concerning laboratory analysis of ceramics are outlined.

Prefatory issues before undertaking an analytical program

If the research design necessitates the use of microscopy and/or physicochemical methods of analysis to answer questions or verify hypotheses about the ceramics under study, then the student should first evaluate if she or he, the research program, and the artifact samples are adequately prepared. Furthermore, decisions need to be made on available resources, expendability of samples, and kinds of results desired.

First, is the proposed analysis of ceramics hypothesis driven? If not, then not only may valuable time and resources be wasted, but unique archaeological material may be destroyed as an unavoidable part of the laboratory technique. It is not uncommon for both novice and seasoned archaeologist to ask a specialist to analyze a collection hoping that the data will reveal inner secrets that can be used in thesis or dissertation research, a future publication, or a conference paper. (I once received a package of ceramics from a prominent archaeologist with a handwritten note, "Please analyze.") It is true that, oftentimes in the process of analyzing a collection, new ideas, unanticipated results, or different approaches can and do change the direction of research. Rarely is research purely deductive, and inductive reasoning is nearly always part of the intellectual process. Furthermore, specialists from other disciplines such as chemistry, biology, physics, or geology may not be able to make cogent decisions about approaching an archaeological problem (i.e., selection of best analytical method, sample types, and sample size) if no well-thought-out basis for analysis has been formulated by the archaeologist.

Second, the archaeologist needs to evaluate which specialists from other disciplines should be consulted and the depth of expertise the archaeologist can develop within a reasonable time frame. In the case of ceramic studies, and depending on the nature and needs of the research, the student may have to decide whether she or he should undertake some coursework – for example, in petrography, sedimentary geology, materials science, physicochemical methods of analysis, or dating methods – or to establish a collaboration with colleagues in these scientific fields. In order to make the future collaboration more meaningful (i.e., to be able to ask the right questions of specialists and understand the significance of the results), students entering archaeology as a profession should try to strengthen their knowledge base in a relevant specialized field (e.g., geology and/or materials science for ceramic studies).

Quantitative analysis of ceramics

Much archaeological literature abounds on proper sampling strategies and quantitative analysis of archaeological finds (see Orton *et al.* 1993: 166ff., with cited publications by Orton who has written extensively on this topic, especially for ceramics). However, the ability to subject ceramic objects and their laboratory analysis to quantitative treatment needs to be approached with great caution. The long-standing controversy over quantification of pottery (and, in fact, of all archaeological materials) begins at the excavation and field collection phase. Statistical treatment of a group of objects or data implies that the total population is known – an impossible task in archaeology because we only see a residual component of what formerly existed in the past. Other basic issues

are as follows: How much of the site was excavated? How were the excavated areas chosen and sampled? How was the site excavated (which can be anywhere on a continuum from salvage or "bulldozer" archaeology, at one extreme, to fine screening of all soil excavated, at the other)? Furthermore, how do you interpret fragments from a single object that end up in different archaeological contexts at the site? Just as importantly, these biases in quantification will, unavoidably, be transmitted throughout the "chain of research" to all subsequent laboratory analyses – a point often ignored. One should not be nihilistic about quantitative studies of ceramics, quite the contrary, but the results cannot conform to the rigorous standards of scientific *accuracy* and *precision*, that is, respectively, the veracity of the information and the ability to reproduce the same results if the analysis is conducted by someone else. Therefore, results of quantitative analysis should not be solely relied on, as a final data set, but rather be considered useful guidelines whose conclusions should be corroborated by other kinds of studies.

For archaeologists, though, there are serious questions that can only be answered by employing some quantification method: How much pottery is there? How much pottery is local versus nonlocal (foreign)? Do some sites in the region have more pottery than others and why? How long was the site occupied and how does it relate chronologically with other sites in the region? Therefore, quantification methods are necessary for (1) seriation (to ascertain temporal distribution of categories of ceramics), (2) intrasite analysis (to identify spatial distributions of ceramic types to determine the utilitarian functions of ceramics or social aspects of ceramic production such as kinship patterns and social stratification), and (3) intersite analysis (to identify regional distribution patterns and economic relations among sites).

Quantification of ceramics has taken four basic approaches:

Sherd count involves simply counting all individual sherds from each excavation unit and calculating the percentage of sherds according to local typologies. The obvious flaws here are that (1) individual fragments do not necessarily represent a unique vessel and (2) different ceramic types will have different degrees of *brokenness* (i.e., the more fragile the fabric, the greater the number of fragments). Therefore, attempts are usually made to match sherds together to reflect more accurately the total vessel count. One can even provide two calculations – counting sherds before and after repair attempts – to provide a maximum and minimum number of vessels, but one can never be sure and inevitably the total vessel estimation will be too high. Ceramic fragmentation patterns are a major issue and are different for each object based on its manufacture, size, shape, density, and mass, together with taphonomic processes such as the manner of disposal, human behavior around refuse areas, and exposure to weather.

Sherd weight again is concerned with calculating percentages of sherds according to their classified types but based on their weight. This method may correct for one of the problems of sherd counting by taking into consideration the differential breakage patterns as a result of mass and density. Sherd weight counts may also be corrected by measuring wall thickness and

dividing sherds accordingly into groups, weighing each of those groups separately, and treating the results mathematically to estimate the number of whole vessels (Hulthén 1974; but see Rice 1987: 290ff. for other possible manipulations of sherd weight data). But, ultimately, heavier pots will always be overrepresented.

Calculating *number of vessels represented* (i.e., identifying and counting actual vessels) also has significant difficulties, because of both *brokenness* and *completeness*. Orton (1985) introduced the idea of completeness – the proportion of the original vessel that is present in the archaeological assemblage. The problem here is that ceramics with low completeness and high degree of brokenness will, again, be overrepresented (same problem as in the sherd count method). But more importantly, the same vessel can have different degrees of brokenness and completeness depending on the nature of its use, discard, and depositional history. Assemblage calculations therefore will be biased, but worse, assemblages from different contexts at the same or different sites cannot be compared, even when analyzing a single pottery type. Furthermore, when dealing with ceramics produced on an industrial scale (e.g., Roman period), mass production techniques may thwart efforts to determine the uniqueness of individual ceramics.

Calculating the *estimated vessel equivalents* (*EVEs*) avoids the problem of having to sort and match sherds from the same vessel in order to reproduce actual numbers of vessels but, furthermore, acknowledges that our calculations can only be *estimates*. For this method, one distinctive part of the pot must be selected – for example, a rim or handle but usually the former depending on the type of pottery and what survives – to represent that part of the whole pot. This procedure is analogous to the quantification of archaeofaunal assemblages in which a distinctive bone, with a good survival rate and unique to the anatomy of the species, is used to count the minimum number of individual (MNI) animals. Yet again, potential problems include underestimating the number of vessels because sherds from the body of the pot – as opposed to the rim, base, or handle – are usually an overwhelming majority in an assemblage.

Ceramics have highly variable fragmentation patterns based on their shape, density, size, and use–discard–depositional histories. Therefore, quantification methods for ceramics cannot mimic successfully those designed for other, especially biologically derived, materials like faunal remains (e.g., the MNI concept). While every archaeologist has an opinion, the fact of the matter is that no one has really come up with a reliable system for quantifying ceramic assemblages, which can yield reproducible results across different types of sites, cultures, time periods, technologies, and taphonomic processes (though Orton is an intrepid and clear exponent on the theoretical and mathematical issues). Among existing quantification methods, sherd weight and EVE, or permutations thereof, are the more reliable and should still be done, but with careful documentation of the procedures. The quantification of archaeological ceramics is a field definitely in need of continuing refinement.

Ceramic manufacturing processes introduce further complications to quantitative analysis unknown to other types of archaeological remains. The transferance of inherent errors in statistical results from the field through to the laboratory stage of research is unavoidable when examining products of *pyrotechnology*. The manufacture of ceramics, glass, and metals changes the original composition of the raw material, as opposed to the manufacture of objects by *subtractive technology* (rocks, flint, obsidian, bone), which does not modify chemistry. When we examine the definition of ceramics, the nature of the raw clay, and the production techniques of potters, as purposefully detailed earlier, it is immediately apparent that many assumptions and presumptions have to be made, and a lot of uncomfortable issues ignored, for statistical studies and sampling strategies to work: Clay deposits are an open system in nature, and geochemistry within a single clay bed is subject to the vagaries of the lithosphere–atmosphere interface. Furthermore, all potters mix, match, and change their clay sources as well as tempering and painting materials, and may deviate, unnoticed and undetected, from other aspects of ceramic production technology.

Sampling strategies and subsequent quantitative studies can also be affected by the more pragmatic issue of availability of ceramics for laboratory analysis – the process of negotiation can be an interesting education in and of itself. Obtaining ceramic samples should be relatively easy but can be complicated by a number of factors: whether they are coming directly from the field or are housed and already inventoried by a museum, whether the analyst and the prospective samples reside in the same country or in different countries, whether permission to take samples can be given by the archaeologist on-site or by a government bureaucrat. Laboratory studies requiring whole vessels are rarely undertaken except for special purposes such as TL dating or to determine their authenticity if they have circulated on the art market. Whole vessels deriving from current excavations have value as objects for public exhibition and are thus typically sent to museums for immediate conservation treatment and inventorying. However and fortunately, fragmentary archaeological ceramics are plentiful and have little display value. Therefore, for most ceramic studies, sherds should be sufficient – and this should be emphasized with whomever one is negotiating.

Given all of the foregoing, selecting ceramic samples for laboratory work (e.g., microscopy or physicochemical analysis) will depend on the nature of the research problem and the analytical methods chosen. The student, however, should take into consideration the following basic guidelines for any *intrasite* study: For diachronic ceramic studies, representative samples should be taken from each chronological period so that production variations through time can be documented. If the pottery has surface decoration (slip, glaze, incisions, excisions, inlay), samples from each "type" or "ware" should be selected. Undecorated ceramics should also not be ignored – as happens quite often. If there are ceramics with different uses (fine ware, cooking ware, storage vessels, etc.), samples from each category should be analyzed for technological variation in connection with intended use. If ceramic variation is to be studied

vis-à-vis location within the site (i.e., variations in ceramic inventories from different types of burials or from different residences), then samples need to be carefully analyzed from each context. For *intersite* study, in addition, representative samples need to be selected from each site, provided there is chronological control. For identifying the origin of "foreign" or otherwise intrusive ceramics, raw clay samples will have to be taken in addition to all of the preceding suggestions (more in the following discussion). Another level of sampling will be needed on the sherds themselves if point-by-point elemental composition (e.g., electron microprobe analysis of glazes) or TL dating of individual grains is to be conducted. Depending on the complexity of the research program, this may add up to a lot of samples, and the student, together with museum personnel, the site director and/or the analyst, will need to discuss available resources and costs (e.g., funding, equipment time, and sample prep time) – hence, an additional constraint and factor for quantitative studies.

How to begin analysis and select an appropriate analytical method

Before any work is done on ceramics, the student, supervising archaeologist, and any specialists should consult with each other as to the need for any specialized analytical investigations – such as dating methods, physicochemical methods of compositional analysis, or other kinds of testing – which are appropriate to answer the specific research questions. When analytical methods are under consideration, one should proceed from the most simple (e.g., optical microscopy) to the most complex avenues of investigation (e.g., nuclear methods of chemical analysis). It is imperative to plan laboratory analyses at the outset to determine financial requirements, to ascertain the student's role in such work, and most importantly to discuss all the implications for irreplaceable ceramic samples. Resources need to be identified and evaluated: What are the available laboratories, equipment, and expertise available at one's own university, at other universities, at major museums in the region? Are the samples expendable for destructive analysis (e.g., petrography) or must the analysis be less invasive or even nondestructive? If expendable, or if only a small amount of powder can be removed, are the sherds or whole objects sufficiently durable to undergo sample extraction (e.g., sawing, grinding, drilling)? For compositional studies, will quantitative results be necessary, or will semiquantitative or qualitative results be sufficient to answer the research questions?

Once a laboratory plan for analytical work has been agreed on, and before work begins on ceramics, all safety and legal issues must be observed. First, the object is photographed showing different angles or interior/exterior, front/back surfaces, with both color and measuring scales (cf. Dorrell 1989). Second, ceramic objects should always be studied on a clean, safe, padded table; carried in a sturdy and padded tray or box from/to storage; and stored in secure and padded trays or boxes on nonslip shelves or (preferably) in cabinets. Third, the student or analyst should remove all jewelry on hands and wrists when working with ceramics, remove other damaging materials (inks, pens), use only fabric (never metallic!) tape measures, use metallic profile gauges only if absolutely necessary (with a protective plastic sheet interface), and refrain from eating and drinking near archaeological objects to prevent infestation. Fourth, for legal and

practical reasons, anyone handling ceramics, especially those inventoried by museums, must document any surface defects, fragile or damaged decoration, broken or missing appendages, or structural damage already present on the object. A condensed template for an "Object Condition and Examination Report," which can be simplified for sherds, is included (Figure 7.1) to help the student develop a systematic pattern of observation and basic documentation.

In order to establish a foundation of knowledge, it is important to examine, with consistency, all phases in the production process as outlined earlier: clay preparation, vessel formation, firing process, and pre- or postfire decorative techniques (if any). Visual inspection of cleaned objects should cover, in a consistent manner, all surfaces: top to bottom, front to rear, exterior to interior, appendages, and associated parts (handles, legs, supports, lids). Examination should begin with the naked eye and progress to increasing levels of magnification using a stereomicroscope in the ×10–×60 range. Basic information on surface treatment, control over firing conditions (atmosphere), and kind and quantity of temper can be usually obtained at this level. On expendable sherds, a small chip can be snapped off with a pair of pliers, making a clean break, to examine the sherd in cross section: The presence of a *core* (a darker/reduced interior sandwiched between lighter or oxidized exterior and interior surfaces), for instance, indicates the extent and duration of firing.

Once microscopic examination has been accomplished, the next phase of ceramic analysis will depend on the nature of the research program and must be tailored to the needs of the hypotheses or issues under investigation. A multitude of methods of physical examination from chemistry, physics, and materials science engineering exist and have been applied to the study of ceramics and other archaeological materials. The general avenue of inquiry – for example, dating, provenance, firing temperature determination, use/wear – will dictate which methods will be appropriate. The final selection of the most appropriate method(s) is made in consultation with specialists and in relation to the quality of the samples and available resources. The basic details of the most commonly used analytical methods are outlined in Table 7.1. The limitations of this chapter cannot permit extensive discussion, and the reader is referred to the available literature for the underlying principles and applications of each individual method (cf. Ellis 2000c for descriptions by specialists in each field). What follows are some guidelines for how to approach more detailed laboratory analysis.

Areas of Ceramics Research and Their Analytical Approaches

The following discussion describes some areas of research for archaeological ceramics: How are ceramics made? Who made them? When was an object made? Where was it made? And, why was it made? Whether the archaeologist is working with major ceramic-producing traditions on a vast regional scale, or local ceramic production, or site-specific finds, eventually all of these questions will have to be addressed – as available time, funding, technology, and expertise allow. The examples of published research cited in the text are neither representative nor comprehensive of the discipline, but were selected from different areas of the world and applicable to research in various time

Object Condition and Examination Report for Ceramics

Institutional location of object: _____
Museum accession no.: _____ Field inventory no.: _____
Site and geographic location: _____
Archaeological context: _____
Cultural affiliation: _____
Chronological period/date: _____
Dimensions: _____|_____|_____|_____|_____|_____|_____|
[Metric unit _____ Length Width/depth Height Max/min circumference Rim diameter Base diameter]

Description and condition of ceramic

Type of object: ( ) Vessel: _____ ( ) Sculpture: _____
( ) Architectural element: _____ ( ) Other: _____
Auxiliary parts : ( ) Handle(s): ____ ( ) Leg(s): ____ ( ) Lid/other cover: _____
( ) Stand(s): ____ ( ) Other: _____

Manufacture: ( ) Hand built: _____ ( ) Wheelmade _____ ( ) Molded
Other production details: _____
Temper: _____
Firing: ( ) Oxidized ( ) Reduced ( ) Mixed/uneven ( ) Core: _____
Other firing details: _____
Color(s) of fired clay: _____
[Indicate location, extent, and Munsell values]

Condition of ceramic body {note size/extent and location of problem}:
( ) Cracks _____
( ) Chipping _____
( ) Abrasion/spalling _____
( ) Scratches _____
( ) Weathering/erosion _____
( ) Exterior accretions/stains: _____
( ) Calcareous deposits ( ) Crystallized salts ( ) Organic materials/residues
( ) Soil retained for analysis
( ) Interior accretions/stains: _____
( ) Calcareous deposits ( ) Crystallized salts ( ) Organic materials/residues
( ) Contents retained for analysis
( ) Fire damage _____
( ) Fire clouds ( ) Slumping ( ) Cooking ( ) Secondary firing ( ) Other _____
( ) Missing/damaged parts: _____
( ) Previous repairs: _____
( ) Cleaned, materials used: _____

Description and condition of surface finish or decoration

Description: ( ) Impressed ( ) Stamped ( ) Incised ( ) Excised ( ) Molded relief
( ) Appliqué ( ) Faience
( ) Slip(s) ( ) Glaze(s) ( ) Inlay _____ ( ) Other _____
Color(s) of slip/glaze: _____
Location of decoration: _____
Other details: _____

Condition of decoration {note size/extent and location of problem}:
( ) Scratches _____
( ) Abrasions _____
( ) Erosion/weathering _____
( ) Spalling _____
( ) Crazing _____
( ) Missing surface area _____
( ) Previous restorations: _____
Examined by {print}: _____ Date: _____

Figure 7.1. An object condition and examination report for ceramics. © Linda Ellis 2012.

Table 7.1. Laboratory methods of analysis for ceramic studies (© Linda Ellis 2012).

Analytical method	Acronym	Type/focus of analysis	Materials analyzed	Research applications
Petrography		Microscopy of ceramic thin sections; magnification range: ×50–×400	Ceramic body, temper, slip, glaze	Manufacturing methods, temper characterization, geological sourcing of clay inclusions or temper
Electron microscopy: *Scanning electron microscopy* *Transmission electron microscopy*	SEM TEM	High-magnification (50–300K) microscopy of microstructure of fired clay, temper, inclusions, applied decoration	Ceramic body, temper, slip, glaze	Manufacturing methods, temper characterization, firing temperature determinations, structural and chemical characterization studies when used with electron microprobe
X-ray fluorescence	XRF	Elemental composition (chemical "fingerprinting")	Source clays, ceramic body, slip, glaze	Provenance of pottery by matching to clay sources, manufacturing methods, compositional analysis of slips and glazes
Nuclear activation methods: *Neutron activation analysis* *Fast neutron activation analysis* *Proton activation analysis* *Proton-induced X-ray emission*	NAA FNAA PAA PIXE	Elemental composition (chemical "fingerprinting")	Source clays, ceramic body	Provenance of pottery by matching to clay sources
X-ray diffraction	XRD	Determination of crystallographic structure of minerals	Raw clay, fired clay, slip	Identification of high-temperature clay minerals and slip colorants
Mössbauer spectroscopy		Crystallographic environment of ^{57}Fe isotope	Fired clay	Firing temperature and atmosphere of iron-rich clays; provenance
Thermoluminescence	TL	Ionizing radiation dosimetry since last firing	Fired clay, mineral grains	Dating of ceramics
Archaeomagnetic dating		Thermoremanent magnetism of iron grains since last firing	Fired clay	Dating of *in situ* fired clay structures (e.g., kilns)
Thermal analysis: *Differential thermal analysis* *Thermogravimetric analysis* *Thermal expansion analysis*	DTA TGA	Observation of thermal behavior of clay during controlled reheating experiments	Fired clay	Determination of original firing temperatures
Xeroradiography		X-ray photography of object	Whole object or any part thereof	Manufacturing and construction methods; identification of forgeries and restorations; analysis of particulate inclusions

periods – from prehistory to the modern era – to provide the reader a starting point in visualizing the variety of possible avenues of investigation.

Technology studies

One of the first questions usually asked of pottery is "How was it made?" Oftentimes, this issue is addressed right at the beginning of archaeological work in a region as part of the process of creating ceramic typologies, since the archaeologist uses technology as well as ceramic form and decoration to differentiate pottery in time and space. However, the study of ceramic manufacturing methods can provide information on a far wider range of subjects beyond temporal and spatial distribution patterns, as was exemplified through the work of Frederick Matson (1965) – and his coining of the term *ceramic ecology* is still respected today. Furthermore, over the past 20 years, the field of *ceramic ethnoarchaeology* has demonstrated to archaeologists that the immeasurable variety of human behavior from living pottery traditions can inform the interpretation of analytical data from the laboratory (Longacre 1992; Nicholas & Kramer 2001).

A new area for ceramic studies is the close examination of how technological skills are taught and learned, how information is distributed, and how knowledge is preserved or changed over time (Minar & Crown 2001, but the entire issue has five articles devoted to this topic). This research draws from the fields of developmental psychology, neurophysiology, and cognitive theory, and thus is beyond the scope of this chapter, but is nevertheless important for archaeological attention because behavioral studies can test long-standing assumptions based on archaeological and laboratory data.

Pottery making can be evaluated as part of a larger "learning curve" about materials and their processing technology: Ascertaining firing temperatures attained and control over firing atmosphere will indicate how well the craftsperson understood empirically the chemical and physical changes that would take place during each phase of ceramic production. Furthermore, how ancient potters developed expertise to discover and evaluate the quality of available natural resources (e.g., different types of clays and tempers, selection of appropriate fuels) can reveal a remarkable "ethnoscientific" understanding about geological resources, pyrotechnology, and the landscape. Research on the characterization of the clay through its natural inclusions (identification of rocks, minerals, fossils) and a more precise analysis of temper can only be made from examining thin sections (0.03 mm) of ceramics using a *transmitted light* (or *petrographic*) microscope with magnifications in the range of ×50–×400. Making and analyzing thin sections is a method of examination developed within geology, which can, and should, be learned well by archaeology students interested in ceramic studies and is described in detail elsewhere (Ellis 2000b). This is a destructive laboratory technique, requiring a clean section of the ceramic to be sawn off, and should only be done on expendable sherds after they are photographed and drawn. The section can reveal much information about ceramic manufacturing methods, the interface between ceramic and applied decoration, as well as the most important details of temper and natural inclusions.

For technological investigations, petrographic analysis will yield most information required by archaeologists. More specific avenues of investigation include determinations of ceramic firing temperatures and compositional analysis of the slips, glazes, and fabrics. Scanning electron microscopy and Mössbauer spectroscopy can be used to determine firing temperature of ceramics. X-ray diffraction, which identifies specific minerals, can be used to identify pigments in slips as well as high-temperature phases of minerals as a result of firing. Electron probe microanalysis, X-ray fluorescence analysis, and inductively coupled plasma–atomic emission spectrometry (ICP-AES) each analyze elemental composition of pigments and fabrics, depending on the needs of the research program (see Ellis 2000c for descriptions of these methods).

Identifying the people producing and using ceramics

Students should be aware of two professional practices for identification of cultural affiliation of archaeological remains: using ceramics to designate "archaeological cultures" versus identifying ethnolinguistic groups through pottery production. The naming of "cultures" based on ceramic typologies is a shorthand, mnemonic strategy to assist the archaeologist in establishing relative chronologies and geographic boundaries of archaeological materials from periods with no historical documentation. Thus, "archaeological cultures" do not reflect any emic or etic ethnic reality. However, ethnoarchaeological field research (Hegmon 2000) has provided significant revelations on the uses of ceramic styles and production methods as indicators of social, ethnolinguistic, and political boundaries in extant societies. We are thus cautioned about the interpretation of ceramic distributions and boundaries in prehistory, which may not be ethnically derived at all. Furthermore, archaeologists are always mindful that "identity" is mutable, rather than fixed, and can even change during an individual's lifetime.

Archaeologists, however, have remained undaunted, and research to identify potters has been undertaken with significantly diverse strategies. The most extensive research on identifying potters, as individuals or lineages, has been conducted in the southwestern United States where Native Americans have produced numerous ceramic art traditions in prehistory. The painted pottery in Arizona has allowed archaeologists to identify individual potters by their techniques (Van Keuren 1999). At the next social level, the reflection of kinship structure and residence patterns, through analysis of pottery production, has been studied successfully over the past four decades, from the "ceramic sociology" of the 1960s to the behavioral archaeology of today (see Longacre 2000 for an excellent history and thorough bibliography of this research; also Brumbach 1984–85 for the northeastern United States). In order to identify individual potters, it is usually necessary to document very carefully the brushstroke patterns in painting, the development and spread of all artistic motifs, and patterns in the types and quantities of temper, as well as techniques of vessel formation and firing. These kinds of studies, however, can reveal who learns and makes pottery, how the information is transmitted from one generation to the next, and how pottery reflects both kinship systems and residence patterns.

"Who made the ceramics?" has been an alluring question for research in prehistory and the first millennium CE because written evidence identifying craft producers is either entirely lacking or erratic prior to consistent record keeping. The identification of ceramics with historically known cultural groups is more successful where written evidence can provide corroboration. Yet even in the modern era, written records are biased in favor of the economically dominant classes, relegating disenfranchised groups (identified by gender, religion, geographic origin, or class) as "people without a history." Moreover, ethnic identity can easily become politically exploited in the contemporary world, especially in areas with historical conflicts over primacy in land occupation, which makes understanding of archaeological ceramics that much more challenging in areas such as the Balkans (Ellis 1998) and the Middle East (Dever 1995).

For historical archaeology, "identity" is fraught with intercalated issues of racial and economic dominance arising from the transoceanic voyages of the seventeenth and eighteenth centuries, subsequent European colonization of Western and Southern Hemispheres, the involuntary relocation and servitude of populations, and the rise of capitalism (Meskell 2002). The retrieval of archaeological evidence of the forced resettlement or voluntary migration of transplanted populations worldwide has become the domain of diaspora archaeology. Retrieval of historical material culture, including ceramics, from overseas Chinese communities (Voss 2005) as well as African American settlements (Ferguson 1992) and African sites archaeology (Armstrong 1999) in the Western Hemisphere will continue to provide invaluable data for analyzing identity and sociocultural relations vis-à-vis the dominant economic class.

Dating of ceramics

For dating of ceramic materials, the archaeologist will need to ascertain if *direct investigation* (analysis of the ceramic itself) is necessary or if *indirect investigation* (analysis of materials in association with the ceramics) will be sufficient. Where sufficient organic material has survived, carbon-14 dating is the preferred dating method. If ceramic vessels are found reasonably intact, and not cleaned out at the time of excavation, much organic material is potentially available for C-14 dating. For direct dating of the ceramic itself, TL dating can be used on movable objects such as pottery versus archaeomagnetic dating for *in situ* features consisting of fired clay (e.g., structures, hearths, kilns) (cf. Ellis 2000c for details of dating methods by specialists). For archaeomagnetic dating of buried, fired structures, a hand-sized specimen has to be cut out, with current magnetic north and sample orientation carefully indicated. However, TL dating can be expensive and is usually only undertaken on ceramic objects in museum collections with no archaeological context (see Fleming 1975 for interesting applications). Fortunately, the laboratory technique for TL dating has been considerably refined so that dating can be done on individual grains taken unobtrusively from a valuable museum object. However, in a field situation, it also helps to have a sample of the soil surrounding an object to ascertain environmental radiation dosage to obtain a more precise date.

Provenance investigation – to identify the cultural, geographic, or geological sources of ceramic materials and their clay constituents – has been a major field of inquiry throughout the history of archaeology because of the potentially wide distribution of ceramics or their contents (see review by Tite 2008).

To determine provenance, one must clarify issues of research interest – to understand exchange systems in local, down-the-line, or long-distance trade networks; to match local ceramics to geological sources of clays; to verify whether pottery was made locally or to trace ceramics to archaeological sites outside the region; to identify interactions among populations at various levels of organization (intervillage, intercity, interethnic); to identify distributional patterns of mass-produced ceramics from major manufacturing centers – to name a few avenues of such research.

On sites with obviously intrusive (nonlocal) pottery, the behavioral question becomes, was the pot traded or were the contents traded? The trade in luxury Greek pottery versus Greek (and later Roman) amphorae for commercial trade in wine and olive oil are obvious examples but most other situations are not so clear and may need chemical analysis to determine the motive for the exchange. A further complication is that pots may have been exchanged multiple times to trade contents. Such reuse and recycling of ceramic materials merit closer analysis in archaeology.

Successful studies of provenance have been conducted worldwide, from prehistoric to historical periods: Eerkens *et al.* (2002) undertook the tracing of (frequently neglected!) undecorated ceramics produced by mobile hunter–gatherers – a population not usually associated with ceramic production. Grave *et al.* (2000) traced industrially produced ceramics to specific kiln operations, and their laboratory analyses were also able to detect changes in chemistry and firing over many years as a response to fluctuations in international markets for Asian products. In addition to pottery, provenance studies have been conducted on other ceramic materials, such as bricks and mortar from an eighteenth-century Irish castle (Pavía 2006).

For some studies, overall ceramic style and petrographic analysis are adequate to determine the site of manufacture if sufficient research on ceramics exists for the region. In order to match pottery to geological clay sources, multiple samples will have to be taken from each known clay bed within walking distance of the potters' residences and chemically matched to examples of each type of ceramic ware. The farther away the ceramics are transported from their site of manufacture, the more difficult it is to trace their original clay sources because of the sheer quantity of clay beds in any region, unless there are unique aspects of technology and style which set them apart. When dealing with situations of long-distance trading, or to identify origins of ceramics with no archaeological context (e.g., pots which have circulated on the art market), the best that can be hoped for is to identify the most likely area of origin based on stylistic attributes, to examine ceramics from all contemporaneous sites in that region, and to determine if the geological sourcing of clays is practicable and affordable.

To match ceramics with clay sources, physicochemical "fingerprinting" methods of analysis are necessary to determine the chemical composition of

the ceramics and clays. At this point, the student needs to appreciate the differences between major elements, minor elements, and trace elements and the importance of quantitative, semiquantitative, and qualitative results. Clays have many elements in common – for example, silicon, aluminum, iron, potassium – and the relatively high percentages of these major and minor elements will not assist in distinguishing among the various clay sources. Therefore, the trace amounts of rare elements need to be quantified to distinguish one clay source from another, and therefore semiquantitative and qualitative results are not sufficient. Such analyses can be done by a wide array of methods based on the interaction of energy (e.g., radiation) with matter and further differentiated by what part of the atom is being targeted: X-ray fluorescence targets the inner shell of electrons; nuclear activation methods target the nucleus of the atom. In these examples, the radiation forces the atoms of the sample to produce secondary radiation, of an energy and wavelength unique to that element, which can then be detected and identified as belonging to that element (cf. Ellis 2000c for descriptions of available methods). However, a warning before using such physicochemical methods of analysis: If the pottery was tempered with crushed sherds ("grog"), the recycled sherds may come from completely different ceramic traditions (skewing chemical analyses if sherd temper is not carefully separated from the clay matrix); other types of temper may also have similar effects (Cogswell *et al.* 1998).

Usewear and use-life studies of ceramics

"What was it used for?" is a question that may have interesting implications for dietary and medical studies of ancient populations. The technological quality of ceramics provides information on the possible uses for which the objects were made: Different firing temperatures and type and quantity of temper can determine whether a ware is more appropriate for cooking food and liquids or for food consumption and storage. Determining the use(s) to which ceramics – primarily vessels for the cooking, consumption or transportation of food, oil, and wine – were put involves two separate avenues of investigation: indirect analysis of the contents of uncleaned pottery versus direct analysis of the ceramic surface. Analysis of the soil and residues of recently excavated pottery requires consultation with specialists in the field of organic chemistry to identify proteins, fats, oils, carbohydrates, and other complex organic molecules deriving from foods and beverages and the technical literature abounds on this topic (see any volume of the *Journal of Archaeological Science*). The direct analysis of the surface of artifacts for traces of the patterns of use or wear, while a major area of archaeological research on stone tools for over 40 years, is still an underrepresented avenue of research in ceramic studies (see study of abrasion patterns on pottery from Africa by Reid & Young 2000).

The "life cycle" of ceramic objects – from manufacture, acquisition, service life, damage, repair, any intervening reuse, to final discard – has been used in attempts to date the duration of occupation of archaeological settlements. Estimates for the "life span" or longevity of individual ceramic vessels vary from 15 to 30 years. However, caution is needed to take into consideration the "time lag" that may occur after manufacture – especially for transoceanic or

overland transportation of historical ceramics or "export wares" – to their final destination (Adams 2003). For this type of research to yield meaningful statistical results, significant collections from multiple seasons of excavations at an individual site need to be available – a particularly appropriate and rich area of research for the vast ceramic collections in museum storage (Hardin & Mills 2000).

Conclusion

It is clear that archaeological studies of ceramics provide insight into diverse societies from the earliest instances of fired clay containers and building materials, through to the recent past (see Chapter 13). The key activities of description, quantification, and conservation characterize the work of the ceramic specialist in archaeology today.

Resources

Besides the general texts recommended in the introduction, the reader will find the following journals useful for current research on archaeological ceramics: *Archaeometry* and *Journal of Archaeological Science* publish technical articles on applications of existing and newly developed methods of analysis. Journals focusing on archaeological method and theory (e.g., *Journal of Archaeological Method and Theory*, *Journal of Anthropological Archaeology*, *Journal of Field Archaeology*) as well as national archaeological journals – such as *American Antiquity* (New World archaeology), the *American Journal of Archaeology* (archaeology of the circum-Mediterranean and the Near East), and *Antiquity* in the United Kingdom (covering archaeology worldwide) – regularly publish research articles relating to ceramic studies.

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