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Ceramic Micropalaeontology

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Abstract and Keywords

Microfossils found in archaeological ceramics include representatives of kingdoms Fungi, Protista, Plantae, and Animalia and are composed of calcite, silica, or resistant organic compounds capable of withstanding firing. Methods by which microfossils are isolated for study vary considerably, but the best results involve the disaggregation of potsherds into their individual grains or by cutting petrological thin sections. Microfossils can be related directly to the age and depositional environment of the source materials (clays, temper, and slip) used in the manufacturing process, although the introduction of contaminants at the time of construction must also be recognized. When incorporated into an integrated analysis, the microfossils may demonstrate provenance; contribute to a better understanding of the local environment and landscape; identify transportation routes; contribute to an understanding of the technology used, including construction methods and firing; and elucidate the use to which the vessels were put.

Keywords: microfossils, provenance, landscape, transportation, technology

Introduction

THE term “microfossil” includes a number of microscopic fossil groups. Although the non-mineralized tissues usually disappear shortly after death, the biomineralized shells and skeletons (composed of calcite, silica, apatite, or resistant organic compounds) may be preserved. Micropalaeontological groups include representatives of all kingdoms, including bacteria, fungae, single-celled aquatic eukaryotes (foraminifera, diatoms, radiolaria, silicoflagellates, calcareous nannofossils, dinoflagellates), the reproductive bodies and cell linings of plants (pollen, spores, phytoliths), and animals (such as ostracods and conodonts). They display morphological evolution over time and live in a variety of environmental conditions, making them invaluable in biostratigraphical studies and palaeoenvironmental reconstructions (cf. Armstrong and Brasier, 2005, and references therein).

Microfossils have a number of archaeological applications including environmental and habitat reconstructions (e.g. Whittaker, 1999; Boomer et al., 2007; Holmes et al., 2010; Smith, 2012), provenance of building materials (e.g. O'Rourke, 1983; Thomsen, 1983; Ayyad et al., 1991; Goren and Goldberg, 1991; Maritan et al., 2003; Wilkinson et al., 2008, 2010; Tasker et al., 2011, in press) and statues (Alaimo et al., 2007), provenance of artifacts (Shaw, 1995; Brooks and Dorning, 1997; Fiorentino, 1998; Vermylen and Hollister, 2006), enhancing the stratigraphy of excavations (Groenman-van Waateringe and Jansma, 1968), and understanding human behavior, cultural interactions, technology exchange, and trade routes (Vourela 1994; Quinn and Day, 2007; Quinn, 2008; Tasker et al., in press). As a result of processing, storage, and consumption of foodstuffs, pollen, spores, and phytoliths can also be found attached to the surfaces of ancient ceramic containers (Bryant and Morris, 1986; Bayman et al., 1996; Albert and Portillo, 2005), baskets (Bohrer, 1968) and tools (Hevly, 1964; Bohrer, 1968; Shafer and Holloway, 1983; Bryant and Morris, 1986; Albert and Portillo, 2005). Microfossils are occasionally used for the analysis of art (Svábenická, 1993, 1995; von Salis Perch-Nielsen and Plahter, 1995 (p. 267)) and are occasionally the subject of art; indeed the earliest illustration of a microfossil is found painted on an 850–1000-year-old Pueblo pot made by the Mogollon culture in the Mimbres Valley, New Mexico (Arnold, 1982). Ostracods painted on one such pot (Figure 16.1) appear to be *Chlamydotheca*, a genus that lives in freshwaters of Central America and grows up to 3 mm in length, therefore being visible to the naked eye.

The presence of microfossils in archaeological ceramics has been known for some time (e.g. Fouqué, 1879; Davis, 1951), although it is only more recently that their usefulness has been appreciated. The occurrence and nature of microfossil assemblages is related directly to the types of raw materials used in pottery manufacture, the environment of deposition of the raw materials, and to the methods and technologies employed in the construction of the artifact, notably firing. Although the presence of microfossils has often been recorded during the analyses of ceramics, detailed investigations are few, partly because of a misunderstanding of their worth, partly because specialist micropalaeontological knowledge is required to analyze them, but principally because methods required to extract microfossils from artifacts are destructive. A decision has to be made whether it is more important to keep a potsherd as entire as possible or surrender a part of it for analysis. Micropalaeontological investigations, when carried out at all, are generally confined to stratigraphically poorly constrained fragments or those of little stylistic value. For this reason, notable investigations into ceramic micropalaeontology are few (e.g. Alhonen and Matiskainen, 1980; Trojer et al., 1996; Quinn et al., 1998; Quinn and Day, 2007a, 2007b), although when carried out as part of an *integrated* analysis including ceramic style, petrology, and chemistry, the microfaunal and microfloral content greatly enhances archaeological investigations. Not only can the provenance of the raw materials be established and technology elucidated, but aspects of the local environment and landscape can be postulated and microfossils may also assist in identifying the use to which pots were put. *Integrated* analysis is emphasized because when considered in isolation, microfossils can lead to false conclusions unless their limitations are understood (Gibson, 1986; Battarbee, 1988; Juggins and Cameron, 1999; Kligmann and Calderari, 2012).

The value of integrated analyses of pottery was demonstrated by Tschegg et al. (2009) for Late Cypriot Bronze Age (1750–1050 BC) Plain White Ware ceramics centered on the ancient city of Enkomi, on the south-eastern coast of Cyprus. Here the integrated analytical program included major element, trace and rare earth compositions; loss on ignition; bulk mineralogy and clay mineralogy; textural, including microtextural, relationships; mineral chemistry; and micropalaeontology. These studies provide substantial evidence to determine affiliations, provenance, and technology, the characteristic composition of Plain White Ware ceramics being used to trace trade routes to ancient Mediterranean markets (e.g. Knapp and Cherry, 1994 and references therein; Maguire, 1995; Gomez et al., 2002 and references (p. 268) therein; Tschegg et al., 2008, 2009). Some of the pottery sherds contained numerous well-preserved calcareous microfossils of benthonic and planktonic foraminifera, holothurian sclerites, and scaphopod dentalia. The presumed Pleistocene source material in the immediate vicinity of the Enkomi excavation was found to contain an essentially similar microfaunal assemblage and can be suggested to be the source of the raw materials.

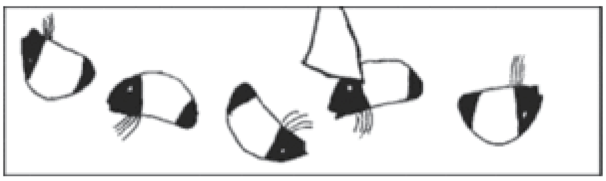

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Figure 16.1 The earliest known image of a microfossil, putative ostracods thought to be of the genus *Chlamydotheca* on a Pueblo pot made by the Mogollon culture in the Mimbres Valley, New Mexico, 850–1000 years ago.

(Redrawn from the photograph by Arnold, 1982.)

Microfossils in Archaeological Ceramics

There are many types of microfossils, and only those that have been recovered from ceramics are mentioned here. To help the non-specialist, they are arranged by the composition of their skeleton or shell (Figure 16.2). For a good general introduction to the major microfossil groups see Armstrong and Brasier (2005, and references therein).

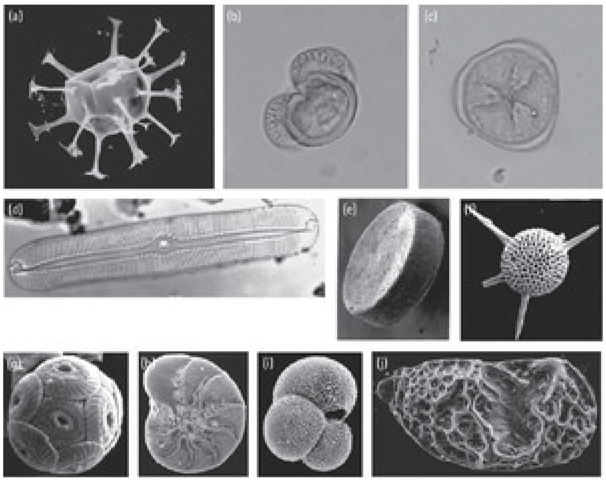

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Figure 16.2 Examples of the main microfossil groups that may be found in ceramics. For further discussion, see the text. a–c. organic-walled microfossils. (a) Eocene dinoflagellate cyst; (b) Holocene pollen grain of pine; (c) Holocene spore of sphagnum moss); (d–f) Siliceous microfossils; (d) Quaternary pennate diatom; (e) Eocene centric diatom; (f) Eocene radiolarian; (g–j) Calcareous microfossils; (g) Cretaceous coccosphere comprising numerous plates or coccoliths; (h) Holocene benthonic foraminifera; (i) Neogene planktonic foraminiferan; (j) Kimmeridgian ostracod.

(p. 269) Organic Walled Microfossils

Dinoflagellates are single celled protozoans (generally 20–150 μm in size) that propel themselves through fresh and marine waters by means of whip-like flagellae. During their life-cycle they go through a “resting stage,” or hypnozygote, where they produce organic-walled **dinoflagellate cysts** (Figure 16.2a); it is this structure that is fossilized. They are rarely found within ceramics as they are generally destroyed during firing; however, Hunt (1996) recorded them in Iron Age sherds from Milton Keynes, UK.

Pollen (Figure 16.2b) is the male reproductive stage of seed plants (angiosperms and gymnosperms), their resistant organic wall permitting preservation in the fossil record. "Lower plants" (cryptogams), including non-vascular bryophytes (mosses, liverworts, and hornworts) and pteridophyte vascular plants (such as horsetails and ferns), produce spores, which are similarly fossilized (Figure 16.2c). Spores and pollen are easily transported by wind and may be incorporated into the clay or slip of ceramics during construction. Pollen has been described from ceramics by, for example, Magid and Krzywinski (1988), Hunt (1996), and Ghosh et al. (2006).

Siliceous Microfossils

Diatoms are small (commonly between 20–200 μm), single celled, photosynthesizing algae with a siliceous skeleton (frustule) (Figure 16.2d–e). Some are colonial and form long chains that may reach lengths of up to 2 mm. They are found in almost every aquatic environment including fresh and marine waters and wet soils. Diatoms have been described in, and isolated from, ceramic material by Alhonen and Matiskainen (1980), Alhonen et al. (1980), Gibson (1983), Jansma (1977, 1981, 1982, 1984, 1990), Matiskainen and Alhonen (1984), Håkansson and Hulthén (1986, 1988), and Håkansson (1997).

Radiolarians (Figure 16.2f) are holoplanktonic, generally non-motile, marine protozoans (super group Rhizaria). Those that have opaline silica skeletons (about 50–200 μm in size) are commonly preserved as fossils, but other forms with strontium sulfate skeletons are rarely preserved. Radiolaria have been recorded within chert inclusions in thin sections of ceramics by many authors, including Farnsworth (1964), Whitbread (1995), and Day et al. (2011).

Silicoflagellates are unicellular, planktonic algae that form a siliceous skeleton (about 20–50 μm across), composed of a network of bars, spines, and spicules (they resemble radiolaria, but are generally much less complex). Silicoflagellates, which are found in marine environments, are rarely recorded in ceramics, although one example was reported by Håkansson (1997).

Phytoliths (or "plant opal") are formed by certain plants that take up soluble silica (as monosilicic acid) from the soil and deposit it (as silicon dioxide) within intracellular and extracellular structures. After the death of the plant, the silica is released from the decayed plant and preserved as microscopic phytoliths of varying sizes and shapes. Phytoliths have several archaeological uses including interpreting agricultural practices, food sources, and food preparation and storage, having been found associated with garden areas, ritual offerings, grinders, scrapers, and cooking and storage vessels (e.g.

Pearsall and Piperno, 1990; Jones, 1993; Tubb et al., 1993; Pearsall, 2000; Hodson, 2002; Harvey and Fuller, 2005; Albert and Portillo, 2005; Piperno, 2006; Lustek, 2006).

(p. 270) Calcareous Microfossils

Calcareous nannofossils are formed by extremely small (0.25–30μm) single-celled, marine eukaryotic haptophyte algae called coccolithophores. Their calcareous skeleton forms a spherical body (coccosphere) composed of a number of individual disk-like plates (coccoliths) (Figure 16.2g). On death, the coccosphere usually breaks up into its individual coccoliths. Nannofossils have been recorded only occasionally in ceramic samples (Troja et al., 1996; Fiorentino, 1998; Quinn et al., 1998; Quinn and Day, 2007a, 2007b). This may be related to their small size, which is below the resolution of most petrographic microscopes, or by being detrimentally affected by the firing of ceramics (Quinn, 1999a).

Foraminifera (Figure 16.2h–i) are single-celled rhizarians bearing a shell (or test; they are sometimes called "armored amoeba") usually composed of calcite or sand and silt grains that have been cemented together by calcareous or siliceous cement. The test may be a single chamber or a group of chambers variously coiled and usually between 250 and 1000 μm in length (although some may be as small as a few tens of microns and others reach several centimeters in length). Each chamber is connected to the next by a series of holes called a foramen (hence the formal name of Foraminiferida, "hole-bearers"). Foraminifera are found in all marine environments, where they have either a planktonic or benthonic mode of life. This group of microfossils has been observed on numerous occasions in potsherds in thin section (e.g. Fouqué, 1879; Einfalt, 1978; Williams, 1978; Riley, 1981, 1982, 1983; MacGillivray et al., 1988; Vaughan, 1990; Day, 1995; Stilborg, 1997; Vaughan et al., 1995; Montana et al., 2003; Ajdanlijsky et al., 2008), and have been isolated for detailed analysis by Quinn (1999b).

Ostracods are arthropods belonging to class Crustacea. The animal is suspended from and enclosed by a dorsally hinged carapace composed of two low magnesium calcite valves (typically between 500–1000 μm in length) that are commonly found as fossils (Figure 16.2j). They are found in all aquatic environments from the deep sea to temporary freshwater ponds where they have a nektonic or benthonic mode of life, and a few species live in wet soils and damp leaf litter. In order to identify ostracods at the species level, details of their morphology such as muscle scars (preserved on the internal surface of the carapace), lobation, ornament, and hinge type are required. These characteristics may be seen when specimens are recovered after the disaggregation of a sherd into its constituent grains (Williams et al., 2015), but not in petrological slides where it is possible only to record their presence (Day et al., 1999a; Whitbread, 1995; Alaimo et al., 1997; Whitelaw et al., 1997).

Sample Preparation

There are numerous techniques available for the preparation of samples for micropalaeontological analysis of artifacts. These may require the preparation of thin sections or the disaggregation of a potsherd into its component grains. The method chosen must reflect the microfossil group being analyzed; for example, very small fossils (such as coccoliths) may be obscured by larger grains in a petrological thin section, and a technique involving acid will isolate certain microfossils, but damage or destroy others. Detailed preparation techniques are too complex to give in detail here, but techniques can be readily found elsewhere (p. 271) (e.g. Kummel and Raup, 1965; Battarbee 1986; Pearsall, 2000; Albert and Portillo, 2005; Armstrong and Brasier, 2005; Riding et al., 2007; Quinn, 2013).

WARNING:

All methods of preparation require the use of hazardous materials and equipment. Preparation should only be carried out in properly equipped laboratories, in a fume cupboard, wearing the correct safety clothing, and under the supervision of, or after training from, qualified laboratory technicians. For UK laboratories, remember to comply with the laboratory’s risk assessments and COSSH instructions (national and local regulations will apply to laboratories outside the UK).

Microfossil Analysis

All methods of analyzing microfossils in archaeological ceramics require the destruction of a part of the artifact and should therefore be mainly applied to sherds of lesser stylistic or contextual importance, but where numerous sherds are present; sacrificing one may result in a better understanding of the remainder. Microfossils are best studied with the use of a petrological or biological microscope depending on the type of microfossil, but electron microscopy will allow the finest details to be viewed.

Petrological Thin Sections

Analysis of petrological thin sections of ceramics is the most convenient means of detecting the presence of most microfossil groups. Foraminifera and ostracods have a distinctive appearance in thin section that makes them stand out from the inorganic mineral constituents of the paste (Quinn, 2013). However, there are limitations in this method of analysis. Whilst microfossil identification at the generic level is usually possible for foraminifera, recognition at the species level is often impossible when it depends on morphological details (e.g. ornamentation, aperture characteristics). In addition, because microfossil analyses are essentially destructive, sample sizes are kept to a minimum and microfossil abundance in each thin section rarely exceeds a few individuals of larger microfossils, such as foraminifera. For smaller microfossils (e.g. dinoflagellates, diatoms, and pollen), identification is hindered when specimens are obscured by larger inclusions and details of almost transparent diatoms are obscured by the clay matrix in ceramic thin sections (Håkansson and Hulthén, 1986; Håkansson, 1997). Calcareous nannofossils, being extremely small in dimension (less than 10 μm), can often be observed as complete specimens in thin sections (which are normally about 30 μm thick); however, as they are often obscured by other grains, it is better to prepare smear slides (Quinn et al., 1998; Quinn and Day, 2007).

Despite the problems associated with working with petrological thin sections, this technique provides the best way of assessing the relationship between microfossils and the ceramic. Microfossils occur in several different contexts within a ceramic sherd: in the raw clays used in pottery making, in particles added as a filler or temper, in slips and paints added as decorative coatings, or via unintentionally airborne contamination during manufacture. Thin sections therefore complement analyses of disaggregated or digested (p. 272) residues and smear slides by elucidating the context, occurrence, and distribution of the microfossils in relation to the artifact and add a further dimension to the interpretation of ceramics. They are also a good means of assessing the microfossil content of archaeological ceramics and determining whether it is worth submitting samples for further, destructive analysis.

Disaggregated Samples

Isolation of individual microfossil specimens by the disaggregation of ceramic sherds into their individual grains by mechanical and chemical treatment is the preferred method of analysis as it permits the three-dimensional analysis of specimens. Most foraminifera and ostracods need to be isolated from the surrounding clay matrix in order to identify them to species level at low magnifications (often less than x 100 through to about x 200)

(Davis, 1951; Quinn, 1999b; Quinn and Day, 2007). Disaggregation is the only viable means of studying smaller microfossils such as diatoms (Gibson, 1983; Håkansson and Hulthén, 1986; Jansma, 1990), silicoflagellates (Håkansson, 1997), and palynomorphs (Magid and Krzywinski, 1988, Hunt, 1996; Ghosh et al., 2006), when magnifications required are high (at least x 1000). Calcareous nannofossils can be studied by taking a minute scraping from a pot in order to make a smear slide for examination in polarizing light (Fiorentino, 1998; Quinn et al., 1998; Quinn and Day, 2007a, 2007b). Both organic walled microfossils and siliceous microfossils have to be isolated by dissolving the sediment that surrounds them with strong chemicals such as hydrogen peroxide, hydrochloric acid, or hydrofluoric acid (Gibson, 1983a; Håkansson and Hulthén, 1986; Magid and Krzywinski, 1988; Jansma, 1990; Håkansson, 1997; Ghosh et al., 2006, Riding, 2007). Some can then be studied in normal transmitted light at magnifications of x 100–400, but others require magnification in excess of x 1000 and oil immersion lenses. For magnifications in excess of x 1500, samples should be viewed in the scanning electron microscope (SEM) (Quinn, 1999a, 1999b; Quinn, 2008).

The Application of Microfossils in the Interpretation of Ceramic Technology

Microfossil analysis can be used to elucidate the technological processes used in the manufacture of archaeological ceramics, particularly in terms of methods of paste preparation and ancient firing technology in spatial, temporal, and cultural contexts.

Materials and Manufacturing

The process of preparing clays in readiness for pot manufacturing often involves the intentional combination of different materials, including the addition of temper or the mixture of two or more clay sources, and where these different materials contain (p. 273) microfossils, a record of their different origins may be preserved (Jansma, 1977, 1981, 1984; Matiskainen and Alhonen, 1984; Hunt, 1996) (Figure 16.3). A complex intermixing of microfossils may result when clays and tempers of different geological ages and/or of different environments of deposition have been used, rendering interpretation of the conflicting information a challenge. For example, calcareous marly inclusions within the clay matrix of Middle Bronze Age pyxides from Knossos, Crete, were observed to contain well-preserved Early Pliocene planktonic foraminifera and calcareous nannofossils (Quinn and Day, 2007). Fossil assemblages were essentially similar to those recovered from marls of the Early Pliocene Finikia Formation, although that deposit had poor workability and was considered unsuitable for the production of ceramics (Day, 1989). It can be concluded that the marl inclusions were added as a temper, and the presence of the same species of microfossils in the clay matrix, is indicative of the degree of mixing.

Great care must be paid to distinguish microfossils from temper, contamination during the preparation of the clays for pot production, and microfossils from the clay matrix. For example, pottery from a Neolithic site at Mahagara in North Central India contains rice husks and phytoliths that were apparently used as temper, rather than being accidentally added during production (Harvey and Fuller, 2005).

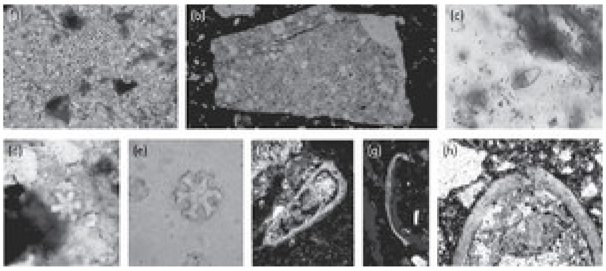

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Figure 16.3 Examples of microfossils in ceramic matrices that can be applied in provenance studies: (a–c) Siliceous microfossils in thin sections of Bronze Age archaeological ceramics from Crete: (a) fragment of radiolarian skeleton within a calcareous inclusion (width of view 50 μm); (b) spherical radiolarians within a chert inclusion (width of view 1.5 mm); (c) a pennate diatom within the calcareous slip (width of view = 0.8 mm); (d–h) Calcareous microfossils in thin sections of Bronze Age archaeological ceramics from Crete: (d) calcareous nannofossil (discoaster) in the groundmass of the ceramic and e. isolated in a smear slide (width of view = 25 μm); (f) foraminifer (*Dentalina terquemi*) from a thin section of an Iron Age shelly potsherd at Burrough Hill, Leicestershire (width 300 μm); (g) Ostracod in a thin section of a Garamantean potsherd from North Africa (width of view 0.5 mm); (h) ostracod in a thin section of Bronze Age archaeological ceramics from the Mediterranean demonstrating the preservation of an articulated hinge (width of view 0.5 mm).

(p. 274) Firing Temperatures

Perhaps the most important process in the manufacture of ceramics is firing, when it is given its stability, strength, and impermeability (Quinn, 2013). Early investigations (e.g. Davis, 1951; Linné, 1957; Brissaud and Houdayer, 1986) appeared to indicate that ceramics fired at low temperatures contained well-preserved microfossils whereas ceramics subjected to higher temperatures contained poorly preserved microfossil assemblages. This is an oversimplification. Although the occurrence and preservation of microfossils in ceramics is dependent on both firing temperature and atmosphere (Quinn, 1999a, 1999b, 2013; Quinn and Day, 2007) (Figure 16.4), the type and composition of the microfossils must also to be taken into account in order to interpret firing technology.

Organic walled microfossils are sensitive to the firing of ceramics. Above 400°C, in the presence of oxygen, most organic matter, including pollen and spores are destroyed (Ghosh et al., 2006), but, in oxygen-poor or reducing conditions, it has been discovered that palynomorphs can withstand very high temperatures (>1000°C). Hunt (1996) used the thermal alteration index of palynomorph coloration (Staplin, 1969) to determine reduction-fired temperatures for Iron Age ceramics from North Furzton, England, concluding that they had been fired to a temperature of around 400°C. However, laboratory experiments into the behavior of palynomorphs during firing (Quinn, 1999b) suggest that this may be an underestimation, as the thermal alteration of pollen, spores, and dinoflagellate cysts appears to proceed at a much slower rate in reduction-fired ceramics.

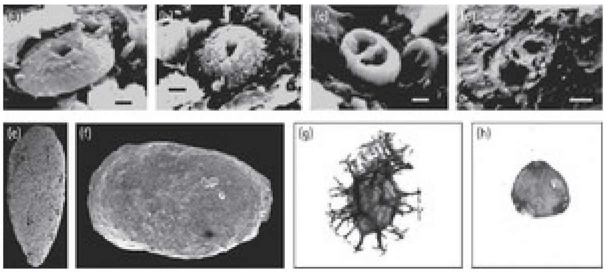

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Figure 16.4 Degradation during firing. (a–d) Preservation of nannoplankton (coccoliths) from Gault clay briquettes fired at 600 °C (a-c) and 800 °C (b–d) (viewed under the scanning electron microscope): (a-b) *Watznaueria barnesae*; (c-d) *Zeugrhabdotus erectus* (scale bars = 1 μm); (e) The remains of a foraminiferan recovered from an Iron Age ceramic from Burrough Hill, Leicestershire by freeze–thaw methods (specimen height 0.55 mm); (f) *Kinkelinella* sp lacking much of the calcite carapace recovered from Iron Age potsherds from the hill fort by freeze–thaw methods (specimen length 0.55 mm); (g–h) Organic walled microfossils: although rarely recorded in ceramics, their potential for preservation is indicated by the recovery of (g) dinoflagellate cyst of *Spiniferites* (width of view 0.15 mm) and (h) angiosperm pollen (width of view 0.8 mm) in reduction-fired London clay briquettes.

(p. 275) ***Calcareous microfossils*** are known to be detrimentally affected during the firing of ceramics (e.g. Cau et al. *et al.*, 2002) by the alteration of calcite (Rice, 1987), although the temperature at which calcite transforms depends on several variables, as demonstrated experimentally by Quinn (1999a). The latter author fired briquettes of the Gault clay (used for millennia for pottery and roofing tiles) at various temperatures in an oxidizing and a reducing atmosphere in order to determine changes in the calcareous nannofossil assemblage (Figure 16.4a–d). The rich calcareous nannofossil assemblages began to change at temperatures as low as 600°C by deterioration in preservation, a reduction in abundance, and preferential taxonomic change as they were fired to increasing temperatures. Similar processes have been observed in two archaeological potsherds from the island of Mozia, Sicily (Quinn et al., 1998), the firing temperatures of which were calculated by X-ray diffraction (XRD) to be *c*.600–700°C (Alaimo et al., 1997). The sample fired to *c*.600°C revealed an abundant, diverse nannoplankton, whereas the higher-fired artifact contained only very rare, poorly preserved specimens. This demonstrates that preservation of calcareous nannofossil assemblages is a potential proxy for ancient firing temperatures.

Siliceous microfossils may also be destroyed during the firing of archaeological ceramics, although no experiments into this phenomenon have been carried out and the temperature at which it occurs may vary. Jansma (1981) considered that firing at temperatures above 800°C destroys diatom frustules, although Håkansson and Hulthén (1986) considered that diatoms can still be preserved at temperatures of 925°C, based on the melting point of amorphous silica at 1650°C. However, certain substances within the clay paste may act as fluxes, lowering the temperature at which siliceous microfossils melt (Rice, 1987). Based on the conclusions of Davis (1951) and Linné (1957), Jansma (1990) suggested that two technological phases of ceramic production could be demonstrated at a Neolithic site at Schokland, The Netherlands. Jansma (1990) identified an earlier phase of low temperature firing, characterized by ceramics containing abundant well-preserved diatoms, and a later phase of firing at higher temperatures, resulting in diatoms being less common and poorly preserved.

The Application of Microfossils in Determining Ceramic Provenance

Clay is a high-bulk, low-value commodity and, except in exceptional instances (such as the absence of suitable water and energy source), is unlikely to have been transported far from its source (Van der Leeuw, 1977; Nicklin, 1979; Rice, 1987). Arnold (1980, 1985) concluded that about 85% was sourced within 7 km of the point of manufacture, although this clearly depends on the historical context, availability of transport routes, and the technology available. There are two principal methods of determining ceramic provenance using microfossils, a biostratigraphical and a palaeoenvironmental approach, and the combination of both approaches may result in more rigorous conclusions. Taphonomic processes may affect both approaches and have to be taken into account during analyses, and fossil identification is made difficult when degradation removes morphological characteristics (Figure 16.4).

(p. 276) Biostratigraphical Analysis

Biostratigraphy is the method by which rock successions can be dated using their fossil content (Rawson et al., 2002; Armstrong and Brasier, 2005). It depends on the morphological evolution of fossils and their relationship to geochronology and stratigraphy. Key index species (which should be easily identifiable, commonly present, have a broad spatial distribution, and have a short chronological range) can be used to recognize biozones and subzones within a rock succession that allows regional and global correlation of rocks of similar age. Microfossils in archaeological artifacts can be correlated with known biozonal schemes and the geology of the region in which they were found, in order to determine the geological age of the raw material used for pottery production. This in turn can be used, in favorable circumstances, in combination with petrographic and geochemical data to locate the actual deposits used in the past (Quinn and Day, 2007a, 2007b).

Contamination and alteration of microfossil assemblages in archaeological ceramics can hinder accurate biostratigraphic interpretation and thus obscure provenance. Contaminants introduced during manufacture or usage of a ceramic artifact must be distinguished from the fossil microfaunal and microfloral content of the clay and temper used in provenance studies. During preparation, clay is kneaded, temper is mixed with it, and water is added to achieve the necessary malleability. The material is susceptible to contaminants at every stage from windblown pollen and spores on the surface of the wet clay to the presence of diatoms in freshwater sources. Further contamination may be added to the surface and into cracks after use and during burial.

In some cases the general microfossil group may be sufficient to postulate a provenance, particularly where the source rock is not far from the archaeological excavation, but often recognition of genera and species are required for detailed provenance studies. For example, radiolaria in chert temper in first-millennium Greek amphorae from Corinth could be correlated to a nearby outcrop of radiolarite (Whitbread, 1995), indicating local manufacture. In another instance the microfossils prove that a local provenance can be ruled out; a good example being Bronze Age sherds excavated at Tel Haror in the Negev Desert, Israel (Day et al., 1999a; Quinn and Day, 2007), where microfossils in combination with compositional and typological data prove a more distant provenance. The Tel Haror sherd is characterized by the presence of rounded coarse grains of basic igneous rocks and ostracods, contrasting with the local geology of the western Negev and the geochemical composition of other Israeli ceramics (Oren et al., 1996), but resembles a few sites east of Ierapetra on the south coast of Crete (Whitelaw et al., 1997; Day et al., 1999b). The sherd provides strong evidence for maritime connections between Crete and the Levant during the second millennium Middle Bronze Age.

There are numerous examples of calcareous, fossiliferous, shallow-marine clays, marls, and limestones being utilized for ceramic manufacture on the southern coast of Crete, which appears to have been a major center for ceramic manufacturing (Hein et al., 2004). The ceramics recovered from excavations at Fournou Korifi and Pyrgos, near Myrtos, may be taken as an illustration. The fabrics of almost half the ceramic artifacts excavated from the final occupation level of this Early Bronze Age site are characteristic of the south coast, and there is some suggestion that production may have been concentrated in the Myrtos area (Quinn and Day, 2007a, 2007b). The ceramic fabric is characterized by the use of Neogene clays and water-worn sand derived from basic igneous rocks. The presence of planktonic (p. 277) foraminifera such as *Globorotalia subscitula*, “dwarf” *Globigerina acostaensis*, and abundant *Sphaeroidinellopsis* together with calcareous nannofossils indicate that south coast ceramics were manufactured using Early Pliocene raw materials (Zachariasse, 1975; Spaak, 1983; Quinn and Day, 2007a). Quinn and Day (2007a, 2007b) concluded that the homogeneous and laminated Early Pliocene marls of the Myrtos formation were combined with river or beach sand and were probably used by the potters who formed the pottery by hand and finished it on a wheel.

Work on sites in Sicily by Troja et al. (1996), Alaimo et al. (1997), and Quinn et al. (1998) also illustrate the usefulness in a biostratigraphical approach to provenance studies. Quinn et al. (1998), recovered calcareous nannofossils from fifth–century BC ceramics and unused raw materials in a Punic workshop on the island of Mozia. Individual pots and the deposit of raw material were found to contain mixed calcareous nannofossil assemblages with species of Cretaceous, late Palaeocene, late Eocene–early Miocene, Early Pliocene, and possibly Pleistocene age. Ostensibly it would appear that materials had been collected from a number of sources; however, samples of clay from a nearby stream, which was a suitable local source of clay for the workshop, produced a comparable range of species, indicating that the clay had a single provenance. The river had eroded sedimentary outcrops of different ages further upstream and transported them close to the site of ceramic manufacture.

A preliminary investigation into the foraminifera in pottery sherds from the Thracian archaeological site of Ada Tepe, near Kroumovgrad, southern Bulgaria, was carried out by Ajdanlijsky et al. (2008). Archaeological data places the majority of the pottery sherds to the Late Bronze Age and Late Iron Age, but only pottery of the latter was fossiliferous. Most microfossils occurred as indeterminate molds and fragments, but common *Globobulimina* sp. and rare *Globigerina eocaena* were identified in the sherds. As these were also present in late Eocene sediments of the area it was concluded that local materials were being utilized.

Palaeoenvironmental Analysis

Palaeoenvironmental analysis is used to model past changes in, for example, climate, aquatic conditions (salinity, water depth, temperature, etc.), and vegetation coverand, in an archaeological and anthropological context, and can be used to identify human subsistence patterns, trade, industry, agriculture, and cultural change. Reconstructing palaeoenvironmental conditions is derived from chemical, isotopic, sedimentological, geological, and palaeontological evidence. For example, microfossils of extant plants can be used to interpret past climatic conditions as their modern requirements in terms of humidity/aridity, temperature, elevation, and soil conditions are well known. Similarly extant aquatic microfossils preserve information about water temperature, depth, and salinity, as well as changing environmental conditions through time.

The palaeoenvironmental interpretation of microfossil assemblages occurring in ceramics may also demonstrate relationships with the geology and have a potential in provenance studies, although usually with less precision compared to the biostratigraphical analysis. As a crude indicator, the proportion of freshwater to brackish to marine diatom species has been used as an indicator of provenance within northwestern Europe (e.g. Foged, 1968; Edgren, 1970; Jansma, 1977, 1981, 1984, 1990; Alhonen and Matiskainen, 1980; Alhonen et al., 1980; Alhonen and Väkeväinen, 1981; Gibson, 1983; Matiskainen and Alhonen, 1984; (p. 278) Stilborg, 1997). This distinction has been used to distinguish inland and coastal sources of clays. Jansma (1984) and Stilborg (1997) attempted to differentiate local and distal provenance of ceramics at coastal sites in the Netherlands and Denmark; sherds containing marine diatoms were assumed to have been produced locally whereas those with freshwater diatom floras were thought to have been manufactured inland and transported to the coastal site.

Phytoliths and pollen recovered from incompletely and fully fired sherds (*c*. 2,700 years BP) from the Yanghai Tombs, Turpan, Xinjiang, northwest China, were used by Yao et al. (2012) to reconstruct vegetation and climatic conditions. Bulliform phytoliths were considered to have been from *Phragmites*, which inhabit wetlands, and these authors went on to suggest that highly weathered bulliform morphotypes are indicative of warm and wet conditions. They also noted that a permanent change in phytolith color took place during firing, which has potential as a thermal indicator.

Another illustration of palaeoenvironmental analysis in a provenance study is that by Alhonen and Matiskainen (1980). Neolithic early comb ware ceramics from sites on the

Finnish archipelago of Åland were found to contain dominantly freshwater diatom species, including *Melosira arenaria* and *M. islandica*, and were essentially similar to the assemblage in the freshwater Ancylus Formation of the Baltic Sea. Clays of the Ancylus Formation do not occur on the Åland Islands, but are common on the Finnish mainland. Alhonen and Matiskainen (1980) postulated that during the Neolithic period, inhabitants of the Åland archipelago appear to have transported comb ware ceramics from the mainland. Maritime trade is also a possibility as the clays of the Ancylus Formation were used as a raw material for Neolithic ceramics at other archaeological sites (Alhonen and Väkeväinen, 1981).

The Application of Microfossils in Determining Ceramic Function

The function of a ceramic as suggested by its gross morphology may have been different from its actual use in the past. The use to which a ceramic container was put, such as food processing, storage, or consumption, can sometimes be ascertained by examining the pollen, spores, and phytoliths adhering to its surfaces (e.g. Bryant and Morris, 1986; Thompson, 1989, 1995; Bayman et al., 1996; Jones, Bryant, and Weinstein, 1998).

Pollen was used to interpret the function and use of a group of sealed jars of the Proto-Historic Period (*c*. AD 1500) from the Colorado Desert, USA by Bayman et al. (1996). The contents of the sealed containers had fifty-six pollen types, some from plant species known to have been used by native people of the area, but the dominant pollen type suggests that the final use of the sealed jars may have been to store flowering plants such as fruits and preserve them for future consumption. These data have implications with respect to the interpretation of diet and agriculture (Thompson, 1989). There are, however, limitations in such analyses because pollen may be unintentionally incorporated within ceramics during their production in the form of “pollen rain” (Magid and Krzywinski, 1988; García and Bernal, 1999; Ghosh et al., 2006), and distinguishing the contaminating pollen from that grown for food may be difficult (Ayyad et al., 1991).

(p. 279) Phytoliths may be preserved, even after the decay of the original plants and after having been heated to temperatures sufficient to cause charring. For example, scrapings from the interior of cooking vessels from the Valdivia period at the sites of Real Alto and La Emerenciana, Ecuador, released a number of maize phytoliths, proving its use as a food source and providing an insight into agricultural practices (Pearsall and Piperno, 1990; Pearsall, 2000; Piperno, 2003 and references therein).

Valdivia ceramics dating to the early occupation of Loma Alta, Ecuador (*c*. 6,450 years BP), are believed to have been used to process, cook, ferment, and serve plant foods. Zarrillo et al. (2008) demonstrated that charred residues adhering to the interior of cooking-pot sherds at Loma Alta yielded maize starch and phytoliths consistent with known maize cob residues. Other phytoliths in the cooking-pot residues include Aracaceae (palm family) and nodular spheres consistent with Marantaceae/Zingiberales/Bombacaceae and phytoliths of arrowroot (*Maranta* spp.) seed epidermis. Maize was cultivated and consumed here at least 5,300–4,950 years BP supporting the notion that, once domesticated about 9,000 years ago, maize spread rapidly from southwestern Mexico to northwestern South America.

Concluding Remarks

Detailed micropalaeontological analyses of archaeological ceramics have taken place in an ad hoc manner. This is likely to be because of a number of factors, including the destructive preparation methods needed to study microfossil assemblages and the specialist micropalaeontological knowledge required to identify and interpret them. Some microfossil groups may also have been overlooked owing to their small size and/or poor visibility in thin section. Lastly, there remains a lack of awareness of the value of microfossils in archaeology and the study of ancient artifacts. Microfossils clearly possess the potential to address important issues in the analysis of archaeological artifacts including ancient ceramics, such as their composition, processes that have affected them, their provenance, and the technology involved in their manufacture. In integrated analyses, micropalaeontology complements other compositional, typological, and archaeological characteristics.

Of the different groups of microfossils occurring in archaeological potsherds, calcareous nannofossils, diatoms, and foraminifera are the most useful in provenance studies, although for other archaeological artifacts, such as mortar, building stones, mud bricks, daub, and pit linings, a wide range of microfossil signatures, including ostracods, foraminifera, dinoflagellate cysts, and pollen provide excellent markers. From the point of view of sampling rare or archaeologically valuable artifacts, calcareous nannofossils probably remain the most useful group as so much can be determined by scraping a minute quantity of powder from a sherd.

The provenance of ancient pottery is a subject in which micropalaeontology can be used to supplement conventional methods of analysis, such as ceramic petrology and geochemistry. It requires an understanding of the nature of the artifacts and the enclosed microfossil assemblages, and the geology and raw materials in the neighborhood of the excavation as well as on a more regional scale. In some regions geological maps and specialist reports provide detailed geological information, whereas in other areas, primary geological investigation is required to map the distribution of suitable raw materials and fossiliferous deposits before data can be used archaeologically.

(p. 280) The investigation of ceramic technology can also be enhanced by micropalaeontological data, although this area of research remains understudied and the nuances remain to be understood fully. Microfossils show potential in terms of the recognition of paste preparation methods and understanding firing technology. Firing conditions are an important aspect of ceramic technology, and experimentation into the preservation of calcareous nannofossils (Quinn, 1999a) and palynomorphs (Ghosh et al., 2006) during firing suggests that their degradation takes place in a predictable manner and is related to temperature/oxygen levels. Although further experimental work is required, it seems possible that these microfossils have the potential to provide an archaeothermometric index by which temperature and oxygen levels during firing can be estimated.

There is real potential in microfossil data for the investigation of archaeological ceramics, and although there are strengths and weaknesses in the approach, more detailed studies will prove micropalaeontology to be an important tool in the analysis of archaeological artifacts and human development.

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