archaeometry

Archaeometry **54**, 1 (2012) 129–143 doi: 10.1111/j.1475-4754.2011.00609.x

DIATOMS AND CERAMIC PROVENANCE: A CAUTIONARY TALE*

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In order to answer the age-old question of whether a given pot was manufactured locally or elsewhere, some archaeologists have turned to geoarchaeological or bioarchaeological methods such as diatom analysis to establish potential clay sources. In this paper, we highlight the complexity of diatom analysis and illustrate how diatoms potentially coming from several sources may be introduced at different stages during the ceramic manufacturing process. Finally, we proceed to evaluate the reliability of diatom analysis as an archaeometric measurement for ceramic provenance, concluding that it may have a more limited usefulness within archaeology than its current frequency of use would indicate.

KEYWORDS: GEOARCHAEOLOGY, ARCHAEOMETRY, DIATOMS, CERAMIC PROVENANCE

INTRODUCTION

The presence of siliceous microfossils such as diatoms is frequent in archaeological contexts. Diatoms are used to discuss marine transmigration in coastal sites, examine the human impact on the environment, analyse site formation processes, reconstruct regional palaeoenvironments of excavated sites, and establish human transportation of water, sediments and vegetation (see, e.g., Linder 1942; Foged 1978; Shackley 1981; Mannion 1987; Battarbee 1988; Harris 1989; Nunez and Paabo 1990; Risberg 1990; Stabell 1993; Blinn *et al*. 1994; Winsborough 1995; Juggins and Cameron 1999; Kligmann 2009). In ceramics, diatoms are used to create pottery typologies as well as to establish ceramic provenance (see, e.g., Jansma 1981, 1984, 1990; Shackley 1981; Matiskainen and Alhonen 1984; Gibson 1986; Mannion 1987; Battarbee 1988; Håkansson and Hulthén 1988; Kriiska 1996; Quinn 1998; Juggins and Cameron 1999; de la Fuente 2002; Solá and Morales 2007). Archaeologists who have used diatom analysis to identify potential clay sources for the ceramic vessels/shards found at their sites hope that this method will answer the question of whether these ceramics are local or foreign. This is a deceptively simple question. The answer has more to do with the complexities of diatomological analysis coupled with multi-stage ceramic production using diverse raw materials than with the mere identification of diatom species under a microscope.

The following paper is an exercise in reasoning centred on a theoretical discussion about the interdisciplinary issues defining archaeometry and therefore does not present a case study. The discussion is about the use of biological and geological proxies to answer specific archaeological questions. Written from an archaeological perspective, the paper deals with the interaction

*Received 24 March 2010; accepted 22 March 2011
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between natural and social sciences, two worlds that are more often than not at odds. To showcase this inherent conflict, we have chosen the use of diatom analysis to determine ceramic provenance. Now that this method has been a common practice for a generation, it is timely to take a look at the logic behind it. The problem arises not necessarily from the natural sciences methods employed, but from the fact that archaeologists may be asking questions that diatoms cannot answer or may be misreading the information that diatoms provide.

We begin with a brief introduction to diatoms for the neophyte and establish the close relationship between clays and diatoms. A short overview of ceramic production and a discussion of the difficulties of establishing its provenance follow. Finally, we explain how diatoms find their way into ceramics, concluding that there are inherent pitfalls to be watched for in using diatom analysis to establish ceramic provenance.

A BRIEF OVERVIEW OF DIATOMS AS ENVIRONMENTAL INDICATORS

Diatoms are microscopic algae whose cells are encased in a wall (frustule) made of hydrated amorphous silica ($SiO_2.nH_2O$) comprised of two overlapping valves connected by intercalary bands. Current estimates indicate that there are between 20 000 and 500 000 extant and fossil taxa (Díaz and Maidana 2005). Diatoms can be found in oceans, fresh and brackish water, ice and damp surfaces, including some soils. They can be identified by their morphology and they are classified according to their lifeform as well as their salinity and pH tolerance and nutrient requirements, among other environmental variables (Battarbee 1986; Van Dam *et al*. 1994). Accordingly, diatoms are used to characterize bodies of water, both current and fossil (Battarbee 1988; Stoermer and Smol 1999).

From a morphological point of view (Fig. 1), diatoms have traditionally been divided into two groups: (1) centrics (*Coscinodiscophyceae*, most of them radially symmetric); and (2) pennates (often bilaterally symmetric). The latter can be further subdivided into raphids (*Bacillariophyceae*) and araphids (*Fragilariophyceae*). Raphids possess a longitudinal fissure called *raphe* that allows them to move. while araphids lack such a fissure (Round *et al*. 1990).

All categories of diatom life can exist within a single aquatic environment. There are diatoms living in open water (planktonic) and diatoms living in the bottom of aquatic systems (benthic). Within the benthos, diatoms can either move freely along the bottom or be attached to different substrata such as rocks (epilithic), sand grains (epipsammic), plants (epiphytic) or animals (epizoon). There are also ‘air loving’ diatoms that can survive desiccation (aerophilic) (Round *et al*. 1990; Stoermer and Smol 1999).

Although centric diatoms are abundant in plankton, both marine and non-marine, they can also live in the benthos. While benthic diatoms live associated with littoral substrata, both marine and non-marine, they can also be found re-suspended in the water column (Nora Maidana, pers. comm.). Therefore morphology, though indispensable for species identification, is not necessarily indicative of a specific type of environment.

Diatoms also live in different types of marine (*thalassic*) and continental (*athalassic*) water systems that can be classified, among other things, by their salinity. One of these classifications (Van Dam *et al*. 1994) separates continental waters into four categories: brackish (between 9 and 1.8‰), brackish-fresh (between 1.8 and 0.9‰), fresh-brackish (between 0.9 and 0.2‰) and fresh (less than 0.2‰). Thus, rivers, lakes and swamps may not always be made up of purely fresh water. An estuary, for example, has mixed waters, since salt water from the sea intermixes with fresh or brackish water from a river, following tide cycles.

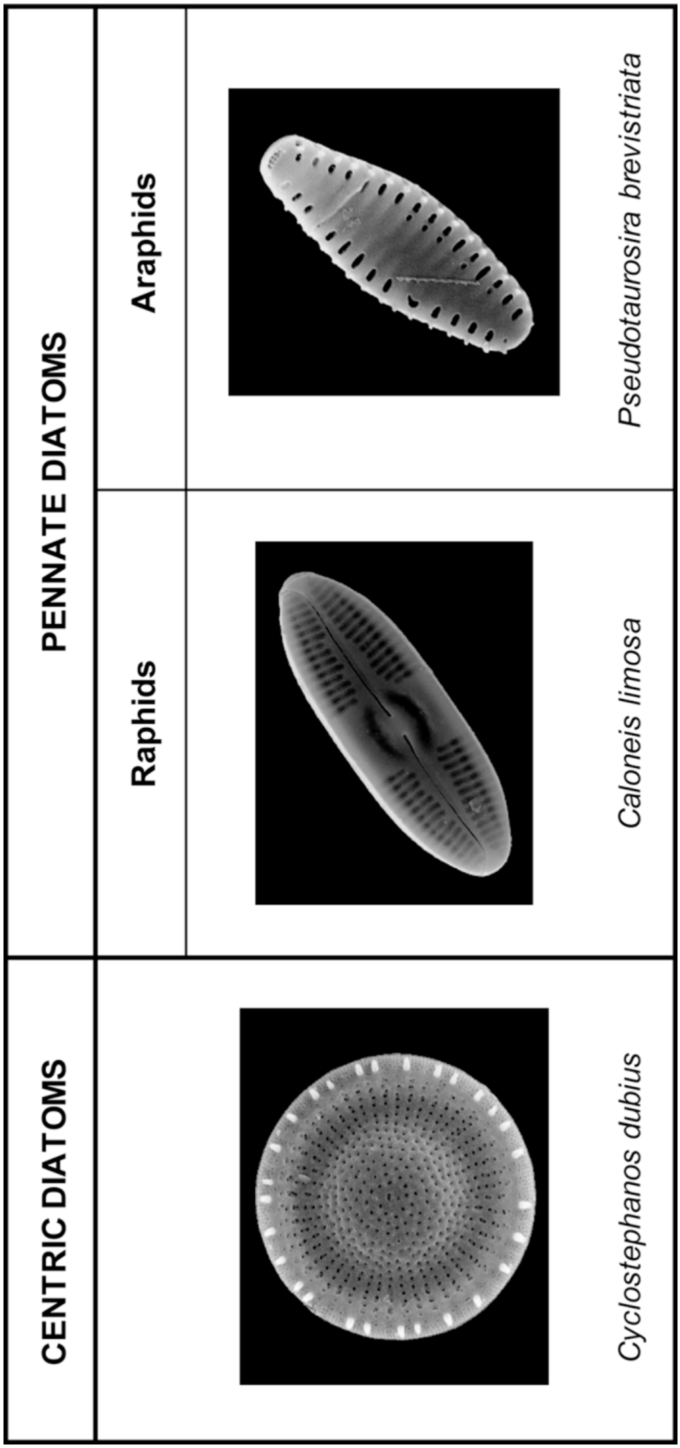

Figure 1 *Diatom morphology.*

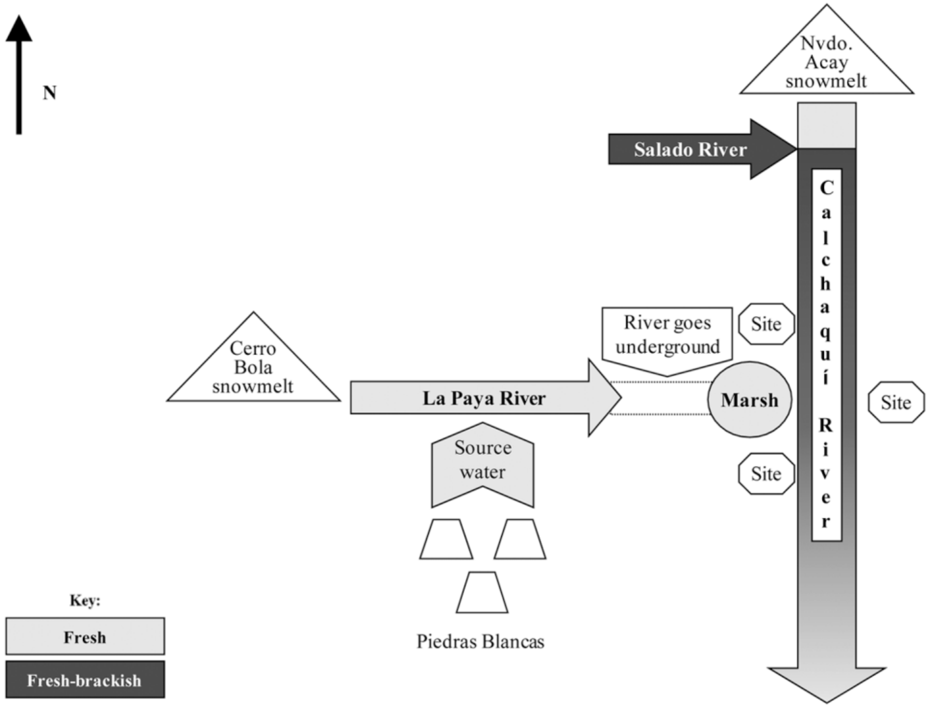

Figure 2 *A diagram of La Paya's water bodies.*

Many environmental factors can determine the diatom flora. Within the same inland body of water, we can find areas with different salt contents. For example, in northwestern Argentina, where we have conducted most of our research, the Calchaquí River runs north–south for about 200 km (Fig. 2). It begins with snowmelt from the Nevado del Acay (Na 0.014 g l^{-1}), but soon receives a fresh-brackish tributary on its west bank, called the Río Salado (Na 0.512 g l^{-1}) (Turner 1964). Water quality analyses performed by Vilela (1956) on the middle Calchaquí River indicate that although the water is good enough for irrigation, it is not appropriate for human consumption. Further south, in the lower course of the Calchaquí River, sodium levels decrease to acceptable values for human consumption (Na 0.08 g l^{-1}) (Vilela and García 1978). An in-depth discussion of the Calchaquí basin waters can be found in Vilela (1956), Ruiz Huidobro (1960), Turner (1964) and Vilela and García (1978).

Within one single archaeological locality, we can also find different types of bodies of water. At La Paya, for example, there are four identifiable bodies of water: the La Paya River, the Piedras Blancas sources, the Puerta de La Paya Marsh and the Calchaquí River (Fig. 2). The La Paya River runs west–east, and starts with snowmelt at the foot of the Cerro Bola. It receives more water from three underground sources inside very small caves marked by enormous white boulders (Piedras Blancas). Then it goes underground, resurfacing by the west bank of the Calchaquí River as a marsh.

One of us has conducted field research establishing that current water-quality issues determine the crops under cultivation at the La Paya archaeological locality (Calderari 1990). Due to the valley's arid conditions, agriculture can only be achieved through irrigation canals. On the east bank, right across the Puerta de La Paya archaeological site, the irrigation canal draws its waters from the Calchaquí River up north. The ruins of an ancient Inca canal are still visible today. The farmland in front of Puerta de La Paya allows the growing of bell peppers and tomatoes. According to the farmers interviewed there, these waters do not support the growing of beans, peas or fruit trees. Instead, on the west bank, the better-quality waters of the La Paya river allow not only beans and peas but an array of fruit trees, such as apples, peaches, pears and figs, among other crops such as watercress and asparagus. Thus, the archaeological locality of La Paya enjoys an extraordinary diversity of agricultural environments due to contrasting topographical and water conditions, making it an ideal place for continuous human habitation for at least the past 2000 years (Calderari 1990). The example just described demonstrates the extreme diversity and complexity of water environments that an archaeologist has to take into account when undertaking diatomological research and sampling.

Good sampling techniques are necessary when trying to link diatoms in an archaeological context to their original body of water. Given that just one sample from the edge will not be a true mirror of the whole body of water, samples must be taken not only from every possible aquatic environment but also from several topographical locations. It is only after extensive sampling that one can determine whether a body of water is homogeneous or heterogeneous. Accordingly, the larger the body of water, the more diverse it is likely to be and therefore the greater the quantity of samples needed. Palaeoenvironmental studies point to the high diversity and site-specific distribution of diatoms (i.e., Kemp *et al*. 2009; Owen *et al*. 2009) that have a direct impact on their usefulness as proxies. In addition, the chemistry of the water sources may well have changed between the date when the pot was made and the present day when samples are taken by archaeologists.

UNDERSTANDING THE RELATIONSHIP BETWEEN CLAYS AND DIATOMS

Since many archaeologists have turned to geoarchaeological or bioarchaeological methods such as diatom analysis to establish ceramic provenance, we will now focus our attention on clays. They can be used for pottery-making as well as for construction elements such as bricks (both fired and unfired), mortar, plaster and roofing. Although all of these objects may contain diatoms, our focus is on pottery-making, since that is what most diatom analyses to pinpoint provenance deal with.

The chemical composition of clay is two molecules of water to every two molecules of silica and each molecule of alumina ($Al_2O_3.2SiO_2.2H_2O$), so clays are primarily composed of approximately 2/5 silica, 1/5 alumina and 2/5 water, also called composition water. Thus, water is inherently present in all clays. From a granulometric point of view, clay is the category with particles measuring less than 8 Ø or 0.0039 mm, while the particles of silt are between 4 Ø or 0.0625 mm and 8 Ø (Wentworth 1922). Suitable clays for ceramic production, also called silicate clays, are defined in the Ternary diagram of soil classification as the sample that contains about 60% of clay and 40% of silt (Rice 1987). Sediments with less than 60% of clay are not considered as potential clay sources for pottery manufacture due to their lack of plasticity and colloidal nature, invalidating the results of any clay provenance analysis.

Primary or **residual clay groups** derive directly from the underlying bedrock by *in situ* decomposition. The non-plastic naturally occurring inclusions consist of unweathered or partially decomposed fragments of the underlying bedrock. These clays have low organic content (1%), are coarse and have low plasticity. **Secondary** or **sedimentary/transported clay groups**, preferred by potters, are carried to their resting place by different transport agents such as glaciers, the sea, rivers or wind. The non-plastic naturally occurring inclusions can come from a wide range of materials that are incorporated into the clay during the process of transportation (Rice 1987; Orton *et al*. 1993).

Following Ries (1927), secondary clays can be classified as glacial, marine, estuarine, alluvial, lacustrine and aeolian. Each one of these types of clay may contain diatoms incorporated at different stages of the sedimentary cycle, as shown by Gibson (1986). That author found great intra-clay variation in the diatom content, especially when sampled vertically. Spatial and temporal variability in sediments present in archaeological sites has been thoroughly discussed in diatom-pottery papers (e.g., Jansma 1981). When archaeologists decide to sample a clay source in order to find out what diatoms are present in it, they must take into account that the larger and/or the more diverse the source, the wider the sampling should be.

THE COMPLEXITIES OF ESTABLISHING CERAMIC PROVENANCE

Archaeological objects made of chemically unaltered materials (such as obsidian arrowheads, jade figurines and amber beads) are much more suitable for sourcing than ceramics, metals and glass, whose production may bring about significant changes in the composition of the finished artefact (Pollard *et al*. 2007). For these pyrosynthetic objects, provenance has inherent pitfalls, as discussed by Cherry and Knapp (1991), Tite (1991) and Wilson and Pollard (2001), among others. Unlike a lithic spear point, a ceramic vessel is the result of combining at least three staples—clay, water and fuel—to which temper must often be added.

Clay is required in great quantities and is very heavy and inconvenient to carry around. If needed, however, clay can be transported long distances to a place where the potter has water and fuel available (Van der Leeuw 1977; Nicklin 1979; Arnold 1980, 1985; Rice 1987). Ethnographic studies show great variety when it comes to clay acquisition (see examples cited by Rice 1987, 115–16). The distance travelled to obtain the clay is highly variable. Arnold (1980, 1985) found this distance to vary from 1 km to 50 km, with about 85% of the resources acquired within 7 km of the potters' living or work areas.

Means of transportation should also be considered. For example, in pre-Hispanic mountainous Andean cultures, due to the absence of the wheel, transportation of goods occurred on foot or by means of llama caravans known to travel only 20 km per day, carrying loads of about 30 kg (D'Altroy 2003). In Gallo-Roman France, by contrast, transportation included ox carts and river barges. Therefore, clay acquisition is constrained by topography and predetermined by the transportation means available to the potter. Based on the foregoing considerations, it may be argued that locality is a theoretical construct made by the archaeologist. For an in-depth review of the identification and mapping of clay sources, see the review on provenience studies by Rice (1987, ch. 14), where the assumptions, procedures, physicochemical methods and their limitations are thoroughly examined.

Temper, defined here as intentionally added non-clay inclusions (e.g., shards, dung, shell, straw, ash, carbonates, mica, quartz and rocks), is the easiest to transport, as potters do not need it in such great quantities as clay, water or fuel. It is useful to correct stickiness, increase porosity, reduce shrinkage, decrease drying time, lessen deformation at drying and improve firing (Shepard 1956; Rice 1987; Orton *et al*. 1993). Tempers need to be crushed and/or finely ground in order to incorporate them in the clay. They store well and most are non-perishable. However, tempers are not always necessary, since some very fine potteries appear to be untempered.

Water is the next easiest ingredient to transport. A few litres suffice to build several small-sized vessels. Water, however, tends to evaporate and potters need it to drink, cook and clean.

Therefore, although water for ceramic production is not needed in great quantities, it is necessary to sustain the potters and their families. Accordingly, ceramic production generally happens close to water sources, where people are apt to live (Rice 1987; Orton *et al*. 1993).

Fuel is not limited to wood; one must also consider agricultural by-products and animal dung. Anyone who has witnessed the cooking of ceramic vessels can attest to the great quantity and variety of fuel needed. Some fuels burn slowly; others burn quickly. Some fuels burn at low temperatures, others only at high temperatures. Moreover, some fuels make smoke (a desired effect by some potters) and others burn clean. Therefore, a good quantity and variety of fuel sources are necessary for any serious ceramic production to take place. Furthermore, just as potters need water to live, they also require fuel for cooking and heating. Accordingly, ceramic production generally happens close to fuel sources (Shepard 1956; Rice 1987; Orton *et al*. 1993). It follows that areas where fuel is extremely scarce are unlikely candidates for large-scale ceramic production.

In summary, if a clay source is close to abundant water and fuel, then this site is ideal for pottery manufacturing. However, if it has abundant water and fuel but no clay sources, the relevance of identifying the origin of the clay becomes readily apparent. The goal of most diatom-pottery analyses is to establish ceramic provenance by identifying the diatoms contained in the ceramic vessels and to compare them to the clay sources nearby. The reasoning behind this is that if the diatoms in the ceramic vessel and in the nearby clay sources are the same, then the vessel may be considered local. On the other hand, if the diatoms are different, then the ceramic vessel may be considered to have been manufactured elsewhere.

A simplistic approach is as follows:

$$\text{diatoms in pot} = \text{diatoms in clay sources} \rightarrow \text{local pot;}$$
$$\text{diatoms in pot} \neq \text{diatoms in clay sources} \rightarrow \text{imported pot.}$$

Unfortunately, in archaeology things are seldom that straightforward. This approach does not consider the possibility that the acquisition of the clay and the manufacture of the vessel can occur in different places. Nor does it contemplate added water or temper. Though diatoms are sometimes contained in fuel, it literally goes up in flames and therefore fuel is not relevant for establishing ceramic provenance. For an in-depth review of the many factors that complicate the deceptively simple task of determining whether a pot is local or foreign, see Shepard (1956), Wilson (1978), Nicklin (1979) and Bishop *et al*. (1982), among many others. Physicochemical issues not withstanding, the behaviour involved in ceramic production is an important factor that confounds provenance. To better understand of the complexities of ceramic provenance muddled by human behaviour, we have devised a categorization system that revolves around two variables: sourcing and manufacturing. In this way, we have defined four degrees of provenance: local source and manufacture, foreign source/local manufacture, foreign source and manufacture and, finally, local source/foreign manufacture (Fig. 3).

INTRODUCTION OF DIATOMS THROUGHOUT THE CERAMIC MANUFACTURING PROCESS

In order to better understand what diatom analysis can tell us about ceramic production, let us first analyse the operational sequence, or *chaîne opératoire* (*sensu* Leroi-Gourhan 1964), of pottery-making (Fig. 4). Under this theoretical framework, technical acts are also understood as social acts. In an ideal world, potters would always obtain their clay from the same source. Potters, however, are opportunistic, using a single clay source or different sources at once. A favourite clay may not always be readily available, so they switch from one source to another. Clay

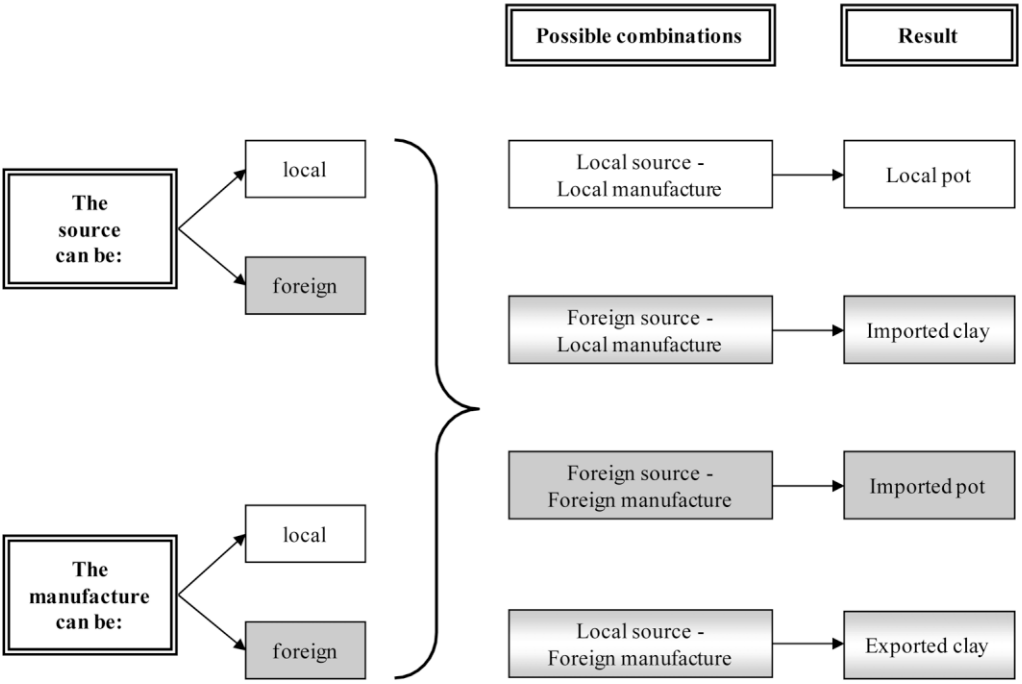

Figure 3 *The four degrees of provenance.*

availability may be seasonal. Perhaps potters cannot cross a particular river in summer due to strong currents, preventing access to their favourite clay. Different-sized vessels may require different clays: large vessels need coarse and structurally stronger clays than small-sized vessels, where coarseness is a hindrance. Since surface colour is generally achieved by a combination of type of clay and firing atmosphere, different ceramic styles may need different clay sources. Therefore, at best, should one be able to identify a clay source for a particular vessel, this does not mean that all vessels of that ceramic style or made by the same potter will share the same clay source. In addition, many potters mix more than one type of clay to obtain the elastic properties that they desire (Orton *et al*. 1993; Pollard *et al*. 2007). Diatoms contained in the clay are considered here to be of 'High impact' (Fig. 4), because they are forever intermixed in the paste and cannot be pulled apart.

During preparation, potters must knead the clay in order for it to become more malleable. For this purpose, they add water—which generally contains diatoms—to obtain the desired effect. This is referred to as mechanically added water. Forming almost always involves the use of some mechanically added water that evaporates during drying. Salt water is sometimes added to calcareous clays and clays tempered with calcareous materials (calcite or shell) in order to quell spalling (Rice 1987). Diatoms contained in the mechanically added water used for preparation and forming can also be classified as 'High impact' diatoms (Fig. 4).

When considering the number of diatoms that may be introduced through temper ('High impact' diatoms as well; Fig. 4), the first choice would be vegetation, followed by crushed shells and finally grounded shards ('*chamotte*') of a diatom-rich vessel. Therefore, we expect a

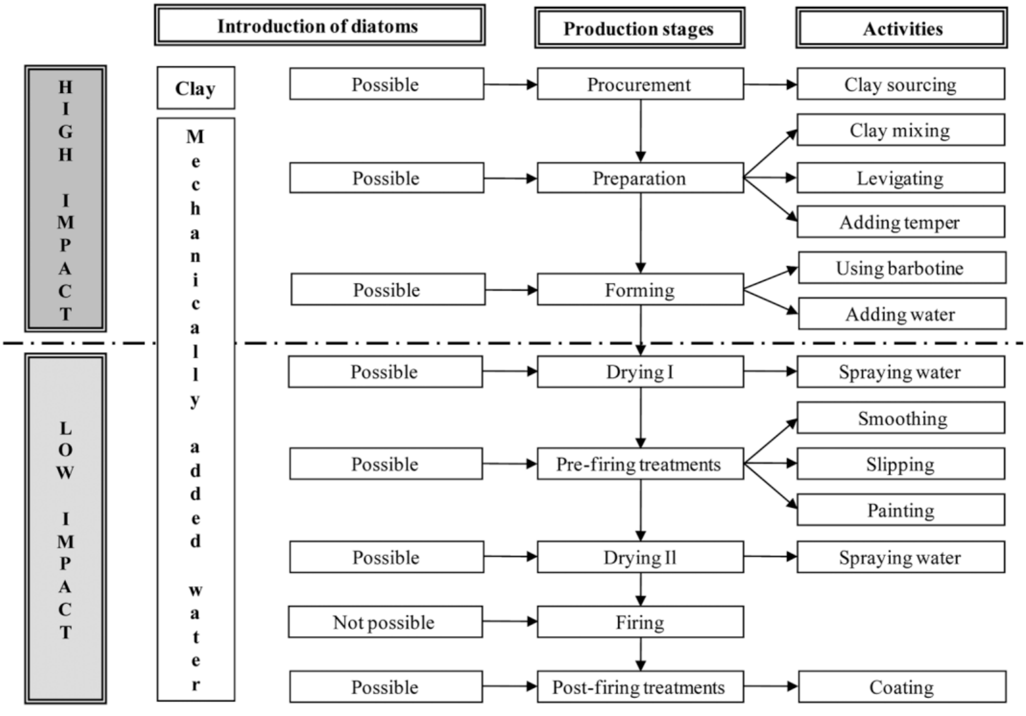

Figure 4 *The* chaîne operatoire *of ceramic production, showing the introduction of diatoms at different stages.*

significant amount of the temper diatoms to be highly fragmented, making species recognition more challenging, though not impossible.

During drying, potters sometimes spray water on the vessels to prevent cracking by drying too fast. Many surface treatments, such as smoothing, slips, barbotine and paint, can introduce their own diatoms. Also, some post-firing treatments, such as coating, can add some more diatoms to the vessel's walls. Given that paints and slips are needed in lesser quantities, they are frequently acquired by trade and may contain foreign diatoms. These diatoms are considered to be of 'Low impact' (Fig. 4), since they tend to remain on the surface of the pots. Accordingly, before preparing the samples to be analysed, archaeologists should scrape both the internal and the external surfaces in order to eliminate 'Low impact' diatoms. This practice would also eliminate those diatoms that had got stuck on the surface during usage.

PITFALLS OF DIATOM ANALYSIS FOR ESTABLISHING CERAMIC PROVENANCE

The provenance of archaeological ceramics is extremely complex (see Shepard 1956, table 11) and some authors have already cautioned archaeologists about the inherent difficulties in using diatom analysis to establish it (Gibson 1986; Battarbee 1988; Juggins and Cameron 1999). The assumption that scientific provenance is possible depends upon stringent requirements that are often not fully met in practice, as defined by Pollard *et al*. (2007, 15): '**characterizability** (the object contains a characteristic chemical or isotopic signal that is unique to a particular source), **uniqueness** (this source is sufficiently geographically unique to be archaeologically meaningful),

predictability (the signal to be detected should either be accidental and unaffected by human processing), **measurability** (the analytical procedures employed have sufficient accuracy and precision to distinguish between the different sources), and **stability** (any post-depositional alteration to the material should be negligible, or at least predictable)'.

We present here two explanatory trees for archaeologists dealing with diatoms in their shards (Figs 5 and 6). The advantages of a decision-making tree approach are that: (1) it helps to structure an explanation in an objective way; (2) it forces an explicit identification of alternatives; (3) it helps to distinguish between controllable (in square boxes) and uncontrollable (in oval boxes) variables; and (4) it allows one to incorporate uncertainty in a systematic way (Monks 1982, 163).

When the shard contains no diatoms, before assuming that the ceramic vessel was made using glacial clays (Kriiska 1996), we must first eliminate all other alternatives (Fig. 5). Perhaps the body of water where the clays rested and/or the mechanically added water did not contain diatoms because the water's high turbidity was not adequate for diatom development. Perhaps the water salinity, its temperature and/or its pH were too high for diatoms to thrive. Then again, perhaps there was insufficient light or nutrients for the diatoms to exist. One should also consider possible taphonomic changes occurring in both water and clay diatom assemblages (Flower 1993).

In some cases, diatoms may be damaged by the firing process (Fig. 5). Jansma (1981) believes that firing temperatures above 800°C destroy diatom frustules, but gives no further details. Instead, others authors mention that at 925°C diatoms can still be preserved (Håkansson and Hulthén 1986). This is in accordance with the fact that the melting point of the frustules'

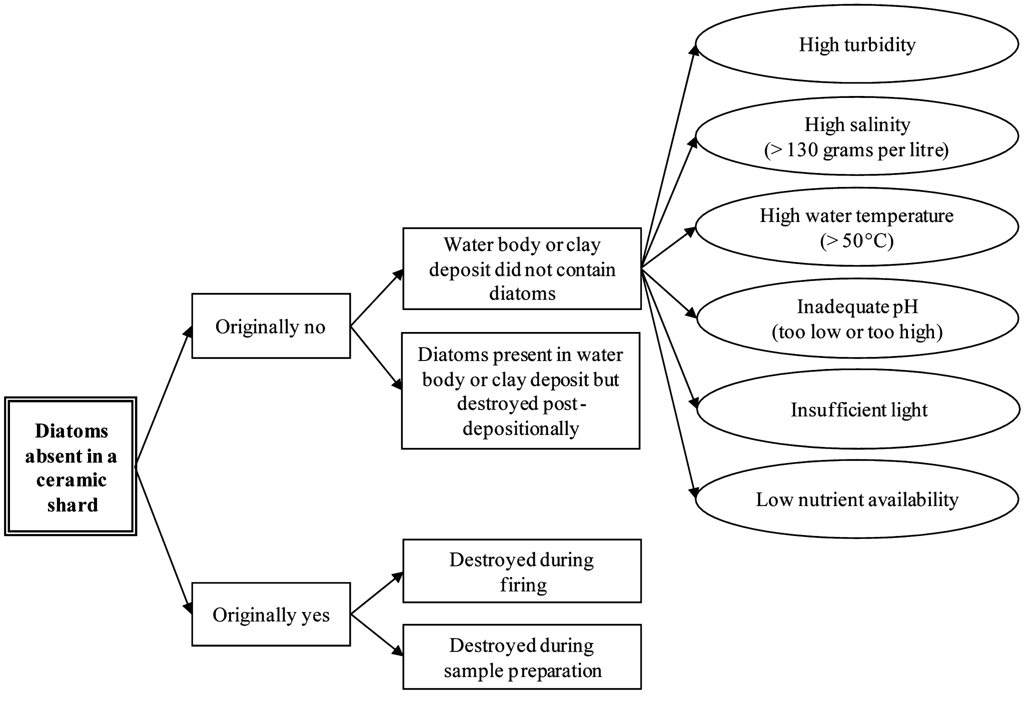

Figure 5 *An explanatory tree for diatoms and clay sourcing, 1.*

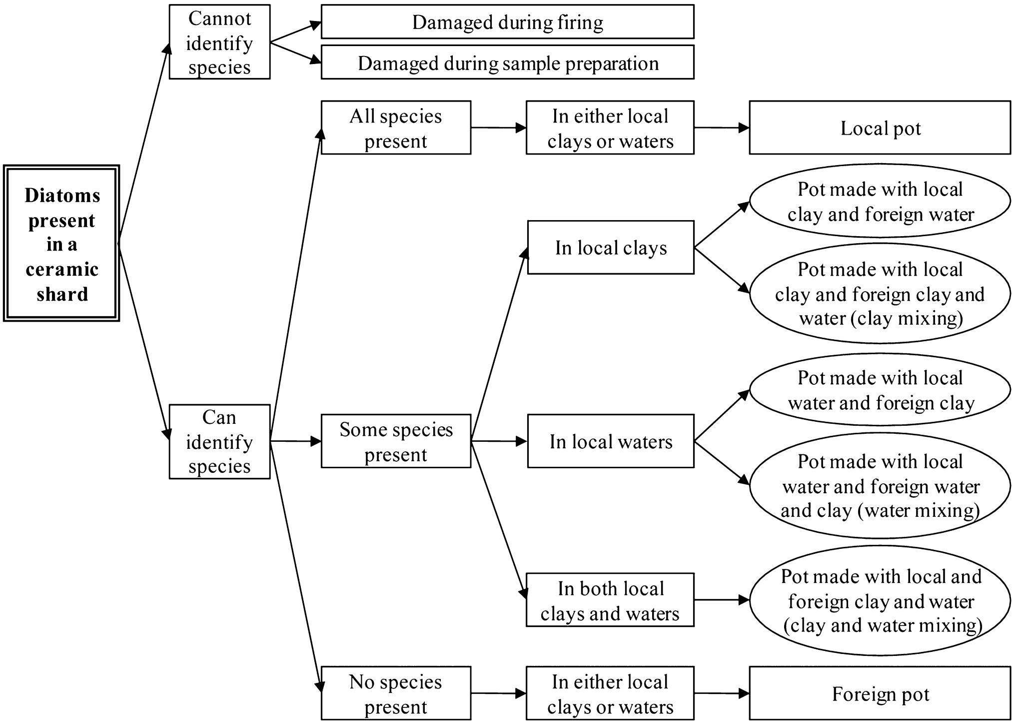

Figure 6 *An explanatory tree for diatoms and clay sourcing, 2.*

amorphous silica is at 1650°C. However, when silica is combined with other organic and/or inorganic materials, melting point fluctuations can occur. For example, some clay inclusions such as feldspars, quartz, mica, iron, boron and lead can lower the temperature at which vitrification occurs (Rice 1987). While earthenware, stoneware, china and porcelain have firing temperatures ranging from 900 to 1450°C (Rice 1987, table 1.2), pyrometric studies indicate that virtually all prehistoric archaeological unglazed non-kiln fired pottery objects are terracottas fired at temperatures well below 1000°C (Shepard 1956; Rice 1987; Bertolino and Fabra 2003). Due to the wide range of firing temperatures recorded for prehistoric pottery, one of us is currently supervising some experiments designed to verify whether the destruction of diatoms is a gradual or abrupt process, what kind of modifications they undergo and at what temperature they are completely obliterated (Kligmann *et al*. 2010).

Diatoms originally present in the clay may also be destroyed during sample preparation (Fig. 5). Preparation techniques vary according to the matrix containing these microfossils. Crushing of the shards can break diatoms, making their identification difficult or even impossible (Håkansson and Hulthén 1986). According to these authors, placing small pottery pieces (less than 1 cm^2) in a solution of 10% H_3PO_4 (phosphoric acid) for several days to dissolve the ceramic and recover the diatoms seems to be a better alternative than grinding them. While using H_2O_2 (hydrogen peroxide) is a proven method for diatoms contained in sediments (e.g., Kligmann 2009), for those contained in shards it poses some problems, since it disintegrates the diatoms. The main difference between both methods is the exposure time. Diatoms contained in sediments only need to be submerged for a very short period, while those in shards need several days. Some authors caution us that high temperatures cause vitrification of the clay, which makes it almost impossible to dissolve the shard for diatoms analysis (e.g., Håkansson and Hulthén 1986).

In summary, establishing at what temperature the clay was fired and using the appropriate chemical solutions and techniques for sample preparation is crucial to determine whether the diatoms could have originally been present but have now been destroyed.

Having followed all the precautions and being able to identify species, it is still necessary to determine what to infer from the presence of diatoms in the shard (Fig. 6). Sometimes, the species are too cosmopolitan to pinpoint either clay sources or bodies of water. However, when **all of the species present** in the shard match those found in local waters or local clay sources, following Occam's razor, the simplest explanation is that the pot was manufactured locally. And yet taking the simplest explanation as the best one does not always lead to accurate results, even in this best-case scenario just described. Perhaps all of the species present in the shard can only be found in the local clays because the foreign mechanically added waters did not contain diatoms. Or perhaps all of the species can only be found in the local waters because the foreign clays did not contain diatoms. Either way, the previously safe assumption that 'the pot was manufactured locally' begins to bear more of a resemblance to a leap of faith.

Now, when only **some of the species present** in the shard are also found *in local clay sources* but not in local waters, we can assume that the pot was indeed made with at least some local clays, but with waters from an unknown, perhaps foreign, source. This could also be the result of mixing local and foreign clays with foreign waters. Either way, there is something foreign about such a pot (Fig. 6). Alternative explanations are unavoidable, because it is impossible to determine which one is correct.

Conversely, when some of the species are present *in local waters* but not in local clay sources, we can then assume that the pot was made using at least some local waters, but with unknown or imported clays. This could also be the result of mixing local waters with foreign waters and foreign clays. Yet again, there is something foreign about such a pot (Fig. 6).

When some of the diatom species present in the shard are found *in both local clays and waters*, we can safely assume that the pot is the result of mixing local and foreign clays with local and foreign waters. Once again, it is very likely that at least one component is foreign (Fig. 6).

Now it can happen that **none of the species present** in the shard are found in either local clays or waters. In that case, we can safely infer that the pot was imported (Fig. 6).

In summary, the possibility of mixing clays that comes from different sources, coupled with the mixing of waters that also come from different sources, contributes more layers of complexity to diatom analysis.

CONCLUSIONS

While a solid knowledge of diatoms and of the ceramic manufacturing process would seem to be essential, this knowledge alone cannot guarantee that our conclusions are sound. In archaeology, using a method from the so-called 'hard sciences' does not guarantee a scientifically reliable outcome. The use of diatom analysis to determine ceramic provenance is a great reminder that it is not only the methodology employed but also the reasoning behind it that makes empirical research scientific. It is always easier to zero in on data that support the hypothesis rather than to look for data that might discredit it. Any archaeological research must include an explicit recognition of all competing hypotheses that are not excluded or falsified by the available evidence.

Drawing reliable conclusions on ceramic provenance based on a comparison of diatoms present in shards, local clay sources and local waters presupposes that having previously defined the area to be considered as local, we have sampled all of the clay sources that are locally available, and that the sampling is representative of all stratigraphic layers. This also means that we have found all water sources, collected samples representative of all diatom microenvironments and confirmed that the body of water has not changed significantly over time. This is a great deal to assume.

We are of the opinion that the use of diatoms to establish ceramic provenance has great limitations, which may have been overlooked. After consideration of the above, it seems that diatoms are more reliable in refuting local ceramic provenance than in confirming it. To the seasoned archaeologist though, foreignness is sometimes obvious just by glancing at the shard. This first impression can be scientifically confirmed by diatom analysis (e.g., Solá and Morales 2007). Diatoms, however, are most useful when they can tell us something we did not already know (e.g., Kligmann 2009). In this way, diatom analysis can take its rightful—albeit humble, but more reliable—place in ceramic provenance determination.

ACKNOWLEDGEMENTS

For this paper, we have consulted extensively with a renowned diatomologist, Dr Nora Maidana, who provided invaluable critiques and furnished the photographs included in Figure 1. We also thank published author Lorane West for her help in editing the text and her insightful stylistic comments, Elena Díaz País for her input in some of the graphics and Dr Ramiro March for his very constructive critique.

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