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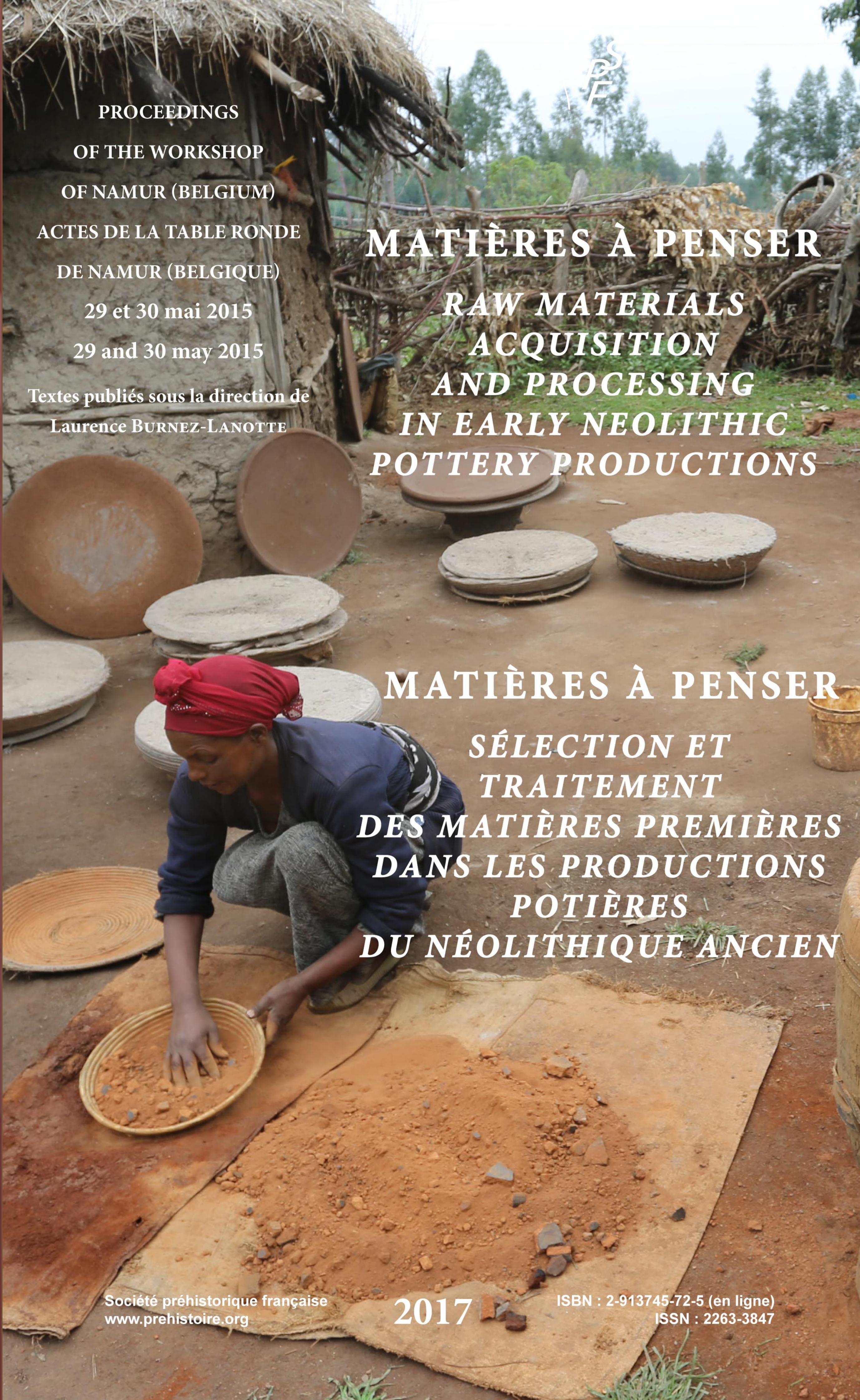

PROCEEDINGS
OF THE WORKSHOP
OF NAMUR (BELGIUM)

ACTES DE LA TABLE RONDE
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29 et 30 mai 2015

29 and 30 may 2015

Textes publiés sous la direction de
Laurence Burnez-Lanotte

MATIÈRES À PENSER

RAW MATERIALS ACQUISITION AND PROCESSING IN EARLY NEOLITHIC POTTERY PRODUCTIONS

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SÉLECTION ET TRAITEMENT DES MATIÈRES PREMIÈRES DANS LES PRODUCTIONS POTIÈRES DU NÉOLITHIQUE ANCIEN

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Raw Material Selection, Landscape, Engagement, and Paste Recipes: Insights from Ethnoarchaeology

Dean E. Arnold

Abstract: Ancient ceramics are not self interpreting and understanding their meaning is the most central issue facing the archaeologists that study them. Some assume that compositional analysis by various methods can provide this meaning, whereas others assume that the notion of choice explains potters' behavior. Both approaches, however, result in abstractions that need to be related to a variety of social, behavioral, technical, and environmental factors. Ancient ceramics, however, are usually interpreted with reference to archaeologists' inexplicit assumptions about the nature of pottery, and their relationship to society. Are ceramics simply the product of culture and tradition, or are they more complex showing interrelationships between indigenous knowledge, landscape, mineralogy and performance characteristics? After decades of publications showing the limitations and constraints of mineralogy, fabrication technique, and climate on pottery production, some archaeologists still believe that pottery, because it consists of fired plastic clay, reflects the mental template of the potter with no environmental or material constraints. Ethnoarchaeological research over the last 50 years in Latin America and elsewhere, however, reveals that potters use their indigenous knowledge to engage their landscape, the raw materials that came from it, and their performance characteristics. The resulting pastes change over time because of changing raw material sources, particular forming technologies, and different vessel sizes, uses, and shapes. Using ethnoarchaeological examples from Latin America, this paper enumerates some probabilistic generalizations that elucidate the relationship of raw materials to landscape, performance characteristics, paste recipes, and forming technologies. It examines some of the factors that influence potters' raw material selection and suggests that the choices potters make are not necessarily driven by tradition, a mental template, or non, technological criteria. Rather, all choices are multi-causal and linked to the potters' material engagement of their indigenous knowledge with a variety of different external factors.

Keywords: raw material selection, paste variability, engagement, landscape, resource distance, paste recipes.

Résumé : Les céramiques anciennes ne s'interprètent pas d'elles-mêmes et comprendre leur signification constitue le problème central auquel est confronté l'archéologue qui les étudie. Certains considèrent que l'analyse de leur composition à l'aide de différentes méthodes suffit pour accéder à cette signification, tandis que d'autres considèrent que c'est la notion de « choix » qui explique le comportement des potiers. Or, ces approches mènent toutes deux à des abstractions qu'il s'agit de relier à des facteurs sociaux, comportementaux, techniques et environnementaux variés. Et cependant, les céramiques anciennes sont habituellement interprétées par les archéologues sur la base de suppositions non-explicites concernant la nature de la poterie et ses liens avec la société. Les céramiques sont-elles simplement le produit de la culture et de la tradition, ou révèlent-elles des interdépendances plus complexes entre le savoir indigène, le paysage, la minéralogie et les performances ? Après des décennies de publications exposant les limitations et les contraintes imposées à la production de poterie par la minéralogie, les techniques de fabrication et le climat, certains archéologues pensent encore que la poterie, puisqu'il s'agit d'argile plastique cuite, ne reflète que la représentation mentale du potier sans influence aucune de l'environnement et des contraintes matérielles. Cependant, la recherche ethnoarchéologique de ces cinquante dernières années, en Amérique latine et ailleurs, a bien montré que les potiers utilisent leur savoir indigène pour aborder leur environnement et son matériau brut avec ses performances caractéristiques. La pâte qui en résulte change avec le temps parce qu'elle doit rester en harmonie avec des ressources en matériau brut fluctuantes et doit s'adapter à des techniques de fabrication particulières, ainsi qu'à des tailles, des usages et des formes de récipients différents. Sur la base d'exemples ethnoarchéologiques latino-américains, cet article énumère des généralisations probabilistes permettant d'élucider la relation existant entre le matériau brut et le paysage, les performances, les recettes de pâte et les technologies de façonnage. Il examine quelques-uns des facteurs qui influencent la manière dont le potier sélectionne le matériau brut et suggère que les choix faits par le potier ne sont pas nécessairement guidés par la tradition, une représentation mentale ou des critères non-technologiques. En fait, tous ces choix sont plutôt motivés par des causes multiples et sont liés à la manière dont le potier utilise son savoir indigène pour aborder une variété de facteurs extérieurs différents.

Mots-clés : sélection des matières premières, variabilité des pâtes céramiques, paysage, distance des sources, recettes de pâtes.

Pottery is probably the most alluring object of archeological analysis. Its widespread occurrence among cultures of the world, the plasticity of its parent material, and the seeming mystery of its transformation into a stone-like object make it a unique type of material culture left behind by ancient societies. Further, the variability of both the chemical elements and the minerals found in pottery, and the great diversity of its shapes provide opportunities for archaeologists to use a wide variety of approaches in analyzing it.

Since archaeologists deal with artifacts apart from the humans that make and use them, they must rely on interpretive tools to put those artifacts into some social and cultural context that goes beyond the material objects themselves. These interpretive tools take the form of generalizations that are often based upon tradition (e.g. typology), ethnographic analogies with living societies, or theoretical constructs based upon those analogies, and often inexplicit assumptions about the relationship between pottery and people. Such generalizations are often limited because the past is not the same as the present, and human behavior is (and has been) variable for a variety of reasons, but even so, all archaeological interpretations come from the present whether in the form of analogies, or inexplicit assumptions in the mind of the archaeologist. Even the most accepted generalizations, however, still must be contextualized in environmental and cultural circumstances that inevitably affect variability of pottery, and the behavior that produced it. Further, interpretations of the past are underlain by considerable social theory and assumptions about the relationship of objects and society, whether implicit or explicit. This paper seeks to provide some insights from ethnoarchaeology that hopefully will contribute to understanding the selection of raw materials used to produce pottery in the past. Some of the points made here are distilled from more elaborate explanations described elsewhere (Arnold, 1985, p. 1-60, 2000 and 2008), but updated and rethought using new concepts.

TECHNICAL BACKGROUND [1]

The process of making pottery involves recognizing the material agency (Malafouris, 2004 and 2013, p. 119-149) of both its constituent raw materials and the process of transforming those materials into a stone-like object through a process that L. Malafouris calls 'material engagement' (Malafouris, 2013, p. 148). Selecting raw materials involves a practical understanding of the technical constraints of various kinds of clays and those of other materials mixed with the clay (such as temper or another clay) in order to achieve the desired performance characteristics. Generally, a clay with insufficient non-clay minerals is unsuitable to make pottery because it is too plastic to form into a vessel, and it will slump, sag, and crack when drying. Non-plastics in the clay reduce this plasticity, increase its workability, and enhance other performance characteristics such as allowing the water in the fabric to escape during drying and firing, and reduce shrinkage. Consequently, clays used for making pottery must consist of both clay minerals and enough non-plastic material in order to make the resulting paste workable. In some contexts, this non-plastic material consists of natural minerals already present in the raw clay such as quartz, sandstone, feldspar, or limestone. In other contexts, the potter must add non-plastics to the raw clay in order to achieve the desired performance characteristics. Such added temper may consist of a wide variety of mineral inclusions such as volcanic ash, sand, marl, calcite, and/or non-mineral materials such as bone, shell, chaff, ash, grass, and ground potsherds (grog). Although the potter may have many choices in selecting additional non-plastic materials (temper), some of these choices may also include clay minerals that may complicate mixing clay and temper. Some tempering materials, for example, contain both non-plastic materials and plastic materials such as volcanic ash and marl (Arnold, 1971 and 1972). Adding a seemingly non-plastic material with clay minerals in it thus complicates the preparation of the paste mixture, and requires further modification. Some pottery making communities may select several different kinds of clays and tempers to mix together to make the pottery (e. g. Mama in Yucatán; Thompson, 1958, p. 72; Arnold, 2000, p. 356; Gosselain and Livingstone Smith, 2005).

HOW DO POTTERS SELECT RAW MATERIALS?

How do potters know which clay to choose for making pottery? How do they know which kind of temper to use for mixing with it? The answers to these questions are complex and involve several levels of explanation. Potters often have a sophisticated indigenous knowledge of their raw materials that involves understanding the landscape of the sources, the kinds of raw materials available, and their suitability for making pottery.

The first level of explanation involves understanding the landscape within which the potters make their choices. Landscape is not just the geological and topographic characteristics of an area, but the potter's own socially and culturally-defined meaning and perceptions of it (Ingold, 2000). This meaning involves many features, but it involves the portions that potters have used in the past as sources for their materials. In Yucatán, Mexico, for example, potters' meaningful landscape around Ticul is different from that surrounding other pottery making communities such as Mama or Tepakán even though the geology is very similar. Geology is not the only factor that defines the landscape of a community of practice.

Even without knowing how potters define and use their landscape around their community, it has practical boundaries, and serves as the potters' resource area from which they select and use clays and tempers. Each community of practice thus utilizes their own unique landscape as sources of their raw materials, and potters' knowledge of this landscape is circumscribed by a practical limit.

This limit can be ascertained from the distances that potters around the world travel to obtain clays and temper when use their own bodies for transport. Using a graph to plot the data points of these distances (on the X axis) against the number of communities that travel those distances (on the Y axis) reveals a decreasing frequency from one kilometer, the most frequent distance, to a maximum radius of tens of kilometers from their production location. Practically, however, this landscape-based resource area is seldom larger than a radius of 7 km from the production location, such that potters seldom travel more than 7 km to obtain their primary raw materials of clay and temper (Arnold, 1985, p. 32-60, 2005b and 2006). J. M. Heidke (Heidke et al., 2007) and I. Druc (2013) have refined the distances and the model relative to the Southwest and Peru, but generally reaffirmed, in principle, that distances to resources tend to follow this distribution although they are slightly different for each area.

When these cross-cultural data are correlated with a power law trend line (a log-log scale on the X and Y axes), they reveal a high correlation (R^2 = 0.80) between the data and the trend line (fig. 1). A power law distribution reflects a kind of scale-free, self-organizing system that is found in a wide range of phenomena (Bentley and Maschner, 2001; Bentley and Shennan, 2003; Bentley et al., 2004). An explanation for such a distribution is not always known, but a power law distribution does not have a meaningful average (mean) value, and change occurs at all scales (Bentley and Maschner, 2003, p. 14).

The power law distribution of world-wide distances to clays and tempers thus shows that the curve of distances to resources drops steeply after one kilometer and then much more slowly after five kilometers (fig. 1; Arnold, 2011, p. 87). These data suggest that most communities of potters travel no further than five kilometers to obtain their basic ceramic resources, and this distance probabilistically marks the practical limit of the culturally-defined resource landscape of most communities of potters.

Do potters travel greater distance to travel to their resources? Of course they do, but archaeological interpretations are based upon patterns, not on exceptions, and like all human patterns, the distances to raw materials in the model are probabilistic. As I have said before, however, it is important to understand the probabilistic nature of a Power Law curve, and thus the distances to resources in the model (Arnold, 2005b). The distances are not certainties, and not deterministic as some have claimed. High frequency patterns do not incorporate all cases, but the power law distribution can be seen as a graphic statement of crude probabilities that distances to clay and temper sources that are one kilometer away occur more frequently than a distance of say, ten kilometers. With 'energy extenders' such as beasts of burden, and water and motorized transport, however, the resource landscape of a community can be extended to unknown limits beyond the five kilometers. Without generalizations of how far potters go to obtain their resources, however, there is

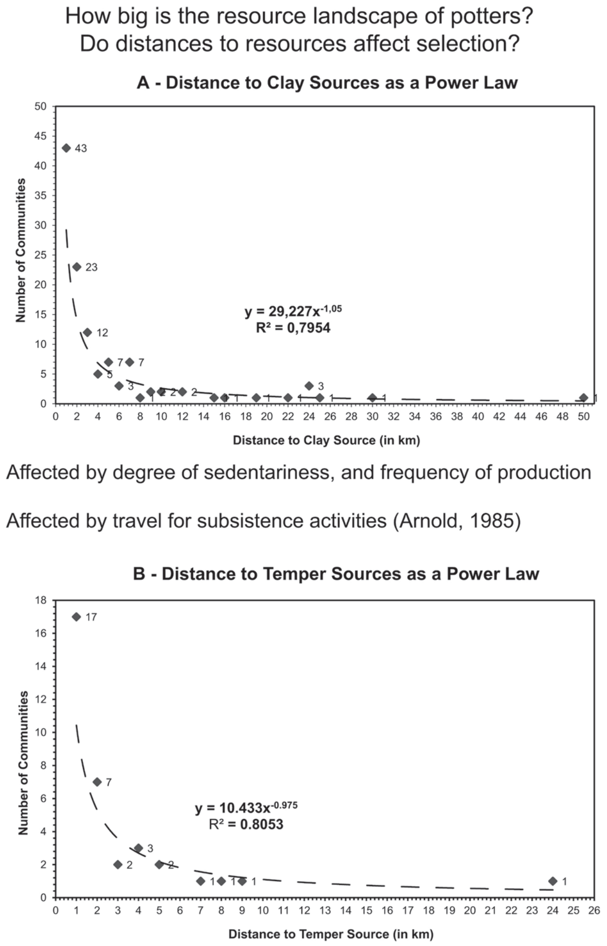

Fig. 1 – Two plots of frequency (Y axis) and distance (X axis) of a cross cultural sample of clays (top) and tempers (bottom). The trend line has been drawn as a power-law curve with the appropriate formula using the power law option from Excel (after Arnold, 1985).

***Fig. 1** – Deux graphes de fréquence (axe vertical) et distance (axe horizontal) d'un échantillon transculturel d'argiles (en haut) et de dégraissants (en bas). La ligne de tendance a* été *tracée par une loi de puissance à l'aide de la fonction loi de Puissance d'Excel (d'après Arnold, 1985).*

no empirically-based interpretation of ancient local and non-local production unless definite evidence of production debris in a site can be related to a precise geological, geochemical and mineralogical source of the constituents used in its pottery. Nevertheless, the power law curve does indicate that five kilometers is a place to start for ascertaining the limits of the resource landscape of a community.

This notion has been hard for some archaeologists to grasp. One way to think about it is to imagine a person carrying, say, twenty or thirty kilos of clay or temper from a source location to one's house. Frequent production means more frequent trips and greater effort simply to provide the raw materials to make pottery. Less frequent production (or its intensity) involves fewer trips, the likelihood that resources could be further away, or could be procured as a consequence of travel to fields, a hunting trip, or transhumant pattern of seasonal movement of herds. Extended distances beyond the probabilities in the model probably occurred with potters in non-sedentary or partially sedentary societies (Arnold, 1985, p. 109-126). All that was needed was weather that was dry and warm enough for at least a few days, and someone who occasionally procured adequate raw materials as a consequence of another activity such as men traveling past a source on the way back to the household from a trip to their fields, from an (probably unsuccessful) hunting expedition, or from tending their livestock [(2)].

Once pottery production intensified, however, potters needed raw materials more frequently, and those potters that lived closer to sources of raw materials were selected for and those production locations further away were selected against. With greatly intensive production, however, that required massive amounts clay such as brick making, production was located on top of clay deposits as it was in Guatemala City in 1970, on the southern limits of the city of Cuzco, Peru, and in the flood plain of the nearby Vilcanota River east of Cuzco in 1972-1973.

The radius of a resource area around a potter's community of practice thus provides a tentative boundary of a socially and culturally-defined landscape for the community and an initial guideline in discovering the sources of acceptable raw materials. Equally important, this area circumscribes the choices available to potters, but all of their potential choices are not equally viable for making pottery. Potters always have a choice in the materials that they use, but often the sources of clay and tempers are so obvious to both the potters and ethnoarchaeologists that it may appear that potters have no choice at all. In reality, potters' traditional knowledge has taught them to select raw materials from some locations and reject those from other locations, and the rejected options may be unclear, if not unknown, to potter and ethnoarchaeologists alike. Around Ticul, Yucatán, Mexico, for example, clay occurs in pockets in marl deposits and in beds at the base of those deposits that are exposed when the marl and the rock are quarried and used for construction purposes (Arnold, 1967a, 1967b and 1971) virtually anywhere such quarries exist around the community. In the late 1960s, long before the current focus on technological choices, surveys of clay deposits around Ticul by clay mineralogist Bruce F. Bohor and me revealed that almost all of these clays consisted of the clay mineral smectite (montmorillonite). Because of their great plasticity, however, these clays were unusable for making pottery because vessels made from them would sag and crack, and thus potters did not even consider choosing them. Potters may say, however, that if they did use them, they would only make the smallest food bowl. Yet, in almost fifty years of working in Ticul, I have never heard of, or seen, any potter using this ordinary clay for making pottery of any kind. Further, this rejected clay tends not to be mentioned in the literature on Yucatecan pottery making, and although it is technically a choice for potters in their local landscape, they seldom considered it to be so. Unfortunately, ceramic ethnoarchaeologists and archaeologists usually acknowledge and study those materials that potters use, not those that they do not use.

On the other hand, clays that are excellent for making pottery are rare in Yucatán and found in only a few places (Arnold, 2008, p. 154-155; Schultz et al., 1971). Up until early 1992, one of these places was Hacienda *Yo' K'at* located 5 km Northwest of Ticul along the highway to Muna. Unlike the common, more abundant clay found in marl mines around the community, this clay consists of a random mixed layering of kaolinite and smectite and a small amount of kaolinite (Schultz et al., 1971). Although not as plastic as the smectite found universally around Ticul, the *Yo' K'at* clay was still very plastic, so that the potter needed to add a tempering material to reduce its plasticity, and prevent sagging, cracking, and breaking during drying and firing.

This tempering material consists of a unique culturally-defined marl (Arnold, 1971 and 2008, p. 191-214). Marl deposits occur universally in Yucatán near the surface under the limestone cap rock, and it would seem that these ubiquitous deposits would likely be used for tempering pottery because they are relatively easy to mine, and contain abundant non-plastics in the form of calcite and/or dolomite. This material could, in fact, be considered to be a choice for the potters, but again, they do not consider it to be so. Most of these marl deposits, however, also contain varying amounts of the clay material smectite (montmorillonite) that increases the plasticity of the paste mixture, and can have significant negative effects on pottery requiring more modification when it is added to the paste.

Ticul potters thus reject this ubiquitous marl for temper, but rather use a material that consists of a cultural (rather than a natural) mixture of the marl and the clay mineral palygorskite that comes from a unique place in the landscape called *Yo' Sah Kab*, literally meaning 'over marl' (called *sah kab* in Yucatec Maya, see below). In a geological sense, any place in Yucatan is 'over' marl, but the deposit at *Yo' Sah Kab* is unique, and potters recognize it to be so because the marl there is mixed with a material potters call *sak lu'um* ('white earth' in Yucatec Maya) that, in fact, is the clay mineral palygorskite. Palygorskite has a plastic limit that is higher than that of the clay used for forming the body of vessels, a mixed layer kaolinite and smectite (White, 1949). Consequently, even though it is a clay mineral, palygorskite does not act as a plastic in the paste, but rather as a non-plastic (Arnold, 1971).

Similarly, in the pottery making communities in the Valley of Guatemala such as Sacojito, Chinautla, Durazno, Sacoj, clays can come from many sources (Arnold, 1978). In Chinautla, for example, there are many exposed clay beds along the river that runs through the community. Potters prefer, however, to use a white clay that fires to a cream color and comes from a single mine on a farm nearby called Finca Primavera. They have a choice of clay to use to make pottery, and choose the white clay, but again, the other clays that are available are not usually preferred to make pottery. If potters want to make large storage vessels, however, they use the clay occurring along the river.

The temper used in Sacojito, Chinautla, Durazno and Sacoj, on the other hand, is volcanic ash that blankets the entire Valley to a depth of about 500 meters. This ash is universally available, and potters obtain it from several locations (Arnold, 1978).

When ceramic resources are selected from unique places, and consist of a unique high quality material compared to other materials in the area, these places are not just a mine, hole, or a spot on a map, but also have important cultural meaning that makes them a special part of the potters' landscape. This meaning involves a sense of place for potters that sets such sources apart. The tradition behind this meaning is itself sufficient to guide potters to the best sources of their raw materials, and this pattern may make one believe that potters have no choice of raw materials at all because it appears that they have no alternatives.

Such locations with a sense of place may have unique place names. In Ticul, Yucatán, the sources of clay and temper have names derived from the resource in the ground below it. The place name for the source of potter's clay was Hacienda *Yo' K'at* ('over clay'); the name for the source of temper for non-cooking pottery was *Yo' Sah Kab* ('over marl'); and *Aktun Hi'* ('crystal cave') was the place name for the source of the crystalline calcite (*hi'*) used for the temper for cooking pottery that was found within it. All of these places were significant locations in the landscape and potters returned to them again and again to mine their raw materials. For generations since the Terminal Classic Period (800-1000 AD), potters obtained their raw materials from these places (Arnold and Bohor, 1977; Arnold, 2005a). In summary, these traditional sources of clay and temper do not just have a unique sense of place associated with them, but the raw materials obtained from them were mineralogically unique in comparison to other materials in their landscape and resource area (Arnold, 1971 and 2008, p. 155-193).

These places and the unique materials that came from them became so important to potters that they also took on a sacred meaning. The availability of clay at Hacienda *Yo' K'at*, for example, was associated with the patron saint of the Hacienda, San Pedro (Saint Peter). When the clay mine on the Hacienda yielded only inferior clay and rocks in the 1940s, potters paid the expenses for one of the nine nights of prayers (a *novena*) for the Saint so that he would restore the quality of the clay there. Subsequently, potters decided to move the location of the mine and again found high quality clay, answering their prayers for quality clay. To assure continued supply of such excellent clay, the potters reaffirmed their promise to the Saint in the early 1950s by bringing it to Ticul after the *novena* at *Yo' K'at* concluded, and then sponsored an additional *novena* at one of the potter's houses there, continuing that practice until about 1978. When the clay at *Yo' K'at* became exhausted in late 1991, however, one potter instituted a private *novena* to *San Pedro* in his own house to restore the clay at *Yo' K'at*, and also enlisted native Maya priests to perform rituals to thank the spirits of the forest for clay from his newly acquired private source in Campeche. Access to the clay from *Yo' K'at*, however, was not restored (Arnold, 2008, p. 154-183).

Potters in the Valley of Guatemala also had a sense of place associated with their principal clay source. A unique white clay was used to make pottery in Chinautla and Sacojito and was called *espirit ak'al* or 'spirit clay' that was found in single mine at Finca Primavera (Arnold, 1978). In Quinua, Peru, some sources of pottery materials were also associated with the Mountain God, and required offerings of propitiation (Arnold, 2000).

VARIABILITY OF RAW MATERIAL SELECTION

The composition of ceramic pastes can vary based upon the natural variation in the clays and tempers in the deposits (Hein et al., 2004), and social, cultural, and individual causes of selection and paste preparation (Gosselain and Livingstone Smith, 2005). One cause of variability occurs when the sources of raw material change.

One such cause is the seasonal weather. In Ticul, Yucatan, and in Chinautla and Sacojito, Guatemala, traditional sources of raw materials come from deep mines that involved tunneling underground and were subject to collapse during the rainy season. In Chinautla, Guatemala, the traditional white (cream-firing) clay came from an underground mine that collapsed during the rainy season making the clay from there unavailable (Arnold, 1978). If potters did not have enough white clay to sustain themselves, they would either cease production (if they could afford to do so), or use the red-firing clay exposed in beds along the river that flowed through the village. So, even though potters preferred to use the white clay, there were occasions when that clay was not available, and potters had to use the more common clay on the banks of the river.

As long as the clay is consistent in quality based upon its performance characteristics, potters continued to use it with the same paste recipe. When a source becomes exhausted or access to it is denied because of land tenure and/or political issues (Arnold, 2008, p. 153-189), then their sense of place for the sources of their raw materials no longer played a role in raw material selection. Potters thus needed to use their indigenous knowledge based upon their previous material engagement with clay and temper. This knowledge served as a means to evaluate and select materials from new locations with which they had no familiarity. As a result, they had to experiment with the new material and familiarize themselves with its properties and performance characteristics.

Potters engage the properties of the new materials by using their long-term and working memory (Baddeley, 1992; Fusi, 2008) gained from their experience in mining, selecting, mixing and drying those materials used previously for making pottery. Potters in Ticul, Yucatán, for example, recognize five different colors of clays, but color was not an important component of clay selection. Historically, useful clay for making pottery came from Hacienda *Yo' K'at*, and was white or yellow. It had a salty taste and did not open up and fall apart when it was dried in the sun (Arnold, 1971 and 2008, p. 222). When clay mining was not possible at *Yo' K'at* in the past (Arnold, 2008, p. 143-189) and was acquired from other locations, potters had to engage properties of the new clays and depend upon the feedback from their senses in order to evaluate its appropriateness for making pottery considering if changes in the amount of tempering were necessary to prepare the paste.

This happened many times in Ticul over the course of the last 150 years. Although clay was mined at *Yo' K'at* from at least the Terminal Classic Period, 800-1100 AD, (Arnold and Bohor, 1977), there were times when the clay from there was not available, and potters had to go elsewhere to obtain it. One such alternative source was in the Barrio of Mejorada within Ticul itself. Clay was reportedly procured there in the nineteenth century and in the 1930s when access to the clay at *Yo' K'at* was denied by its manager. Potters had to suspend their usual selection criteria in order to engage an unfamiliar clay in order to prepare it properly for making pottery.

When one potter bought the land with the Mejorada clay deposit in 1952 (Arnold, 2015, p. 183), he found that the clay there was better than the more common clays found throughout the area, but not as high in quality as the clay from *Yo' K'at*. So, he mixed the clay from *Yo' K'at* with that from his own private source.

Beginning in the late 1980s, the clay from *Yo' K'at* began to change, and included many more naturally-occurring rocks than previously. Potters adjusted to this change by changing their paste recipe and adding less temper (Arnold, 2000 and 2008, p. 222). These changes were reflected in the changing elemental composition of the pottery based upon INAA analysis (fig. 2).

In late 1991, the clay source Hacienda *Yo' K'at* became exhausted, clay was imported from the State of Campeche 55 km away (straight line distance) where mining marl and rock for building purposes had exposed large clay deposits at the base of several marl quarries. Clay was mined and delivered by truck owners from Dzitbalché (except those two potters who had their own sources), and not by potters or the mining specialists that had mined clay at *Yo' K'at*. As potters used some of this new clay, they came to realize differences in its quality from the *Yo' K'at* clay because large pots made from some of it would sag and crack.

This material engagement with the clay led potters to respond in several ways. The first and most obvious response was to refuse to buy clay from the Campeche supplier known to sell inferior clay, and purchase higher quality clays that came from other suppliers. A second response was to mix the inferior clay that they had already purchased with the higher quality of clay from elsewhere.

A third response that potters made to the new clay sources was to change their paste preparation. As the potters engaged the properties of the new clay, they discovered that it had many more rocks in it than the clay from *Yo' K'at*. So, they adapted in two ways. First, they changed their paste recipe by reducing the amount of temper in the paste. Another less common adaptation to using the new clay was to levigate it in a large pottery vessel. By adding water and stirring the mixture, most of the clay particles would go into suspension, and the rocks would fall to the bottom of the receptacle. The clay was poured out, allowed to dry partially and then mixed with the temper using the traditional paste recipe. The rocks were discarded. All of these changes in sources and paste preparation were also reflected in the changes in the composition of the pottery between 1964, 1988 and 1994 (fig. 2). When the pottery from these same years were plotted with that from Tepakán and Akil, the Ticul pottery showed great overlap with the pottery from Tepakán because it shared a clay source with Ticul potters after their own source near Ticul (*Yo' K'at*) was abandoned (fig. 3). The meaning of these plots of INAA analyses of clay composition means that change in clay sources, paste preparation, and paste recipes may not have a social meaning except the exhaustion of a previous source.

PASTE PREPARATION AND SOCIAL MEANING

It is not unusual for archaeologists to explain the variability of pastes, whether from minerals or chemical elements, as different paste recipes made by the same or different communities of practice. Such an explanation, in fact, is not an explanation at all, but rather is just a different level of description because differing paste recipes still have yet to be related to a social explanation in a meaningful and convincing way. Different paste recipes have no inherent social meaning, and, as described above, a given paste recipe in a community is not immutable. Rather, it may change because of factors unrelated to social explanations. It may result from natural variability within the sources used, changes in the composition of materials from the same source through time, different production units using different sources, the same production unit using different sources over time (fig. 2 and 3), or, as just described, changes in the clay source used by a community. These same explanations of changes in clay sources, paste preparation, and paste recipes have also been described by O. P. Gosselain and A. Livingstone Smith (2005) for Africa.

All of these explanations have occurred in Ticul during the last fifty years. In addition to the change in clay sources over time for most of the potters, two potters had their own sources. Before the clay was exhausted at *Yo' K'at*, some potters began to buy up quantities of the *Yo' K'at* clay, and sell it for a profit to other potters after they could no longer get clay from *Yo' K'at*. Other potters began prospecting for new sources in Campeche. One wealthy potter bought his own source, a large marl quarry that had a deposit

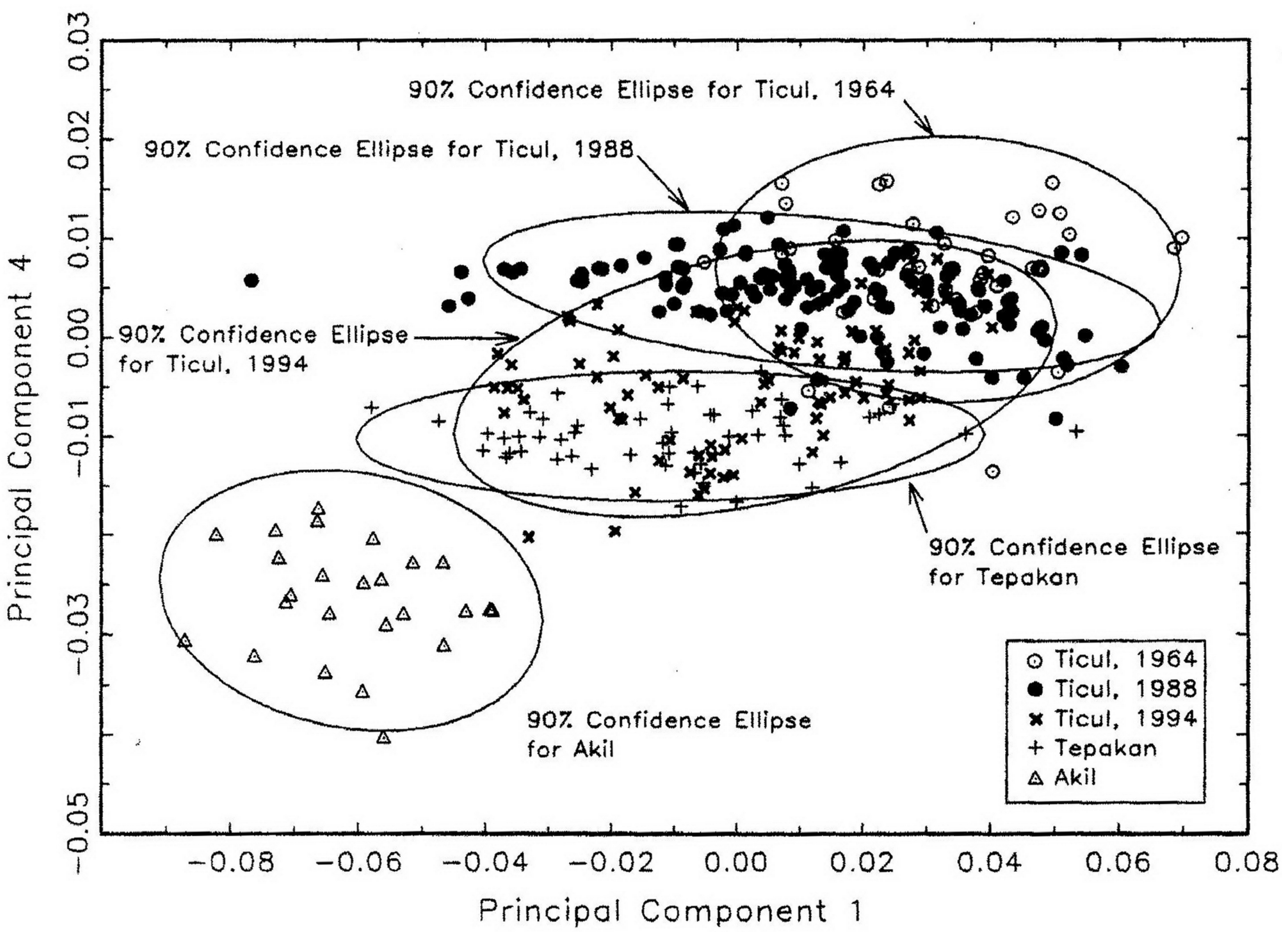

Fig. 2 – Biplot of Principal Components 4 and 1 of data from INAA of ethnographic kiln wasters collected from potters in Ticul Yucatan in 1964, 1988 and 1994, but plotted with the data from kiln wasters from the pottery making communities of Akil and Tepakán. In 1997, Ticul potters were making pottery from the clay used by Tepakán potters, and that shift is revealed by these data. Neutron Activation Analysis was done at the Missouri University Research Reactor (MURR) by Hector Neff and Michael Glascock. Ticul pottery is a combination of two parts temper and one-part clay, and the shift in the change in the composition reflects change in the clay sources and in paste recipes. Ticul and Tepakán analyses are shown in relationship to clay analyzed from Akil, another community with only a few potters that made food bowls for the Day of the Dead rituals, and located 28 km from Ticul and 74 km from Tepakán. All samples collected by the author (table from Arnold et al., 1999, p. 74).

***Fig. 2** – Diagramme de double projection des Composantes Principales 4 et 1 des données INAA concernant des déchets de cuisson ethnographiques collectés auprès des potiers de Ticul Yucatan en 1964, 1988 et 1994. L'échantillon de 1964 a été collecté par Duane Metzger dans le four d'Alfredo Tzum, l'échantillon de 1988 a été collecté par l'auteur auprès de six potiers différents, y compris Alfredo Tzum (déjà échantillonné en 1964), et l'échantillon de 1994 a été collecté auprès de cinq potiers différents (y compris Alfredo Tzum et ceux échantillonnés en 1988). L'analyse par activation neutronique a été réalisée sur le réacteur de recherche de l'université du Missouri (MURR) par Hector Neff et Michael Glascock. La poterie de Ticul est une combinaison de deux parts de dégraissant et d'une part d'argile, et les changements dans sa composition reflètent les changements dans les sources d'argile et dans les recettes de pâte. Les analyses pour Tikul et Tepakan sont représentées en relation avec les analyses d'argile d'Akil, une autre communauté avec seulement quelques potiers qui fabriquaient des bols pour la nourriture dans le cadre des rituels du Jour des Morts, et qui se situe à 28 km de Tikul et à 74 km de Tepakan. Tous les échantillons ont été collectés par l'auteur (d'après Arnold et al. 1999, p. 74).*

of clay at its base. Another potter purchased usufruct rights from the owner of another marl quarry where he mined clay at its base. Meanwhile, entrepreneurs from Campeche began mining and selling clay from both their own land, and from the public *ejido* land of Dzitbalché that had been used as a marl quarry.

Just as in Ticul, the potters in Mama, Yucatán, changed their paste recipes between 1951, when R. H. Thompson (1958, p. 72) visited the community, and my visits there in 1968 and 1992 (Arnold, 2000). The source of their raw materials throughout this period was a large sinkhole 3.75 km outside of town. In 1951, R. H. Thompson (1958, p. 72) noted that the paste mixture consisted of inexact ratios of raw materials, and I tried to quantify these roughly based upon his description (Arnold, 2000, p. 356). Potters classified them into four different culturally-defined types, but they could not easily be grouped into clay and non-plastics because the materials contained varying amounts of both. To adapt to the varying amounts of plastics and non-plastics in these materials over time,

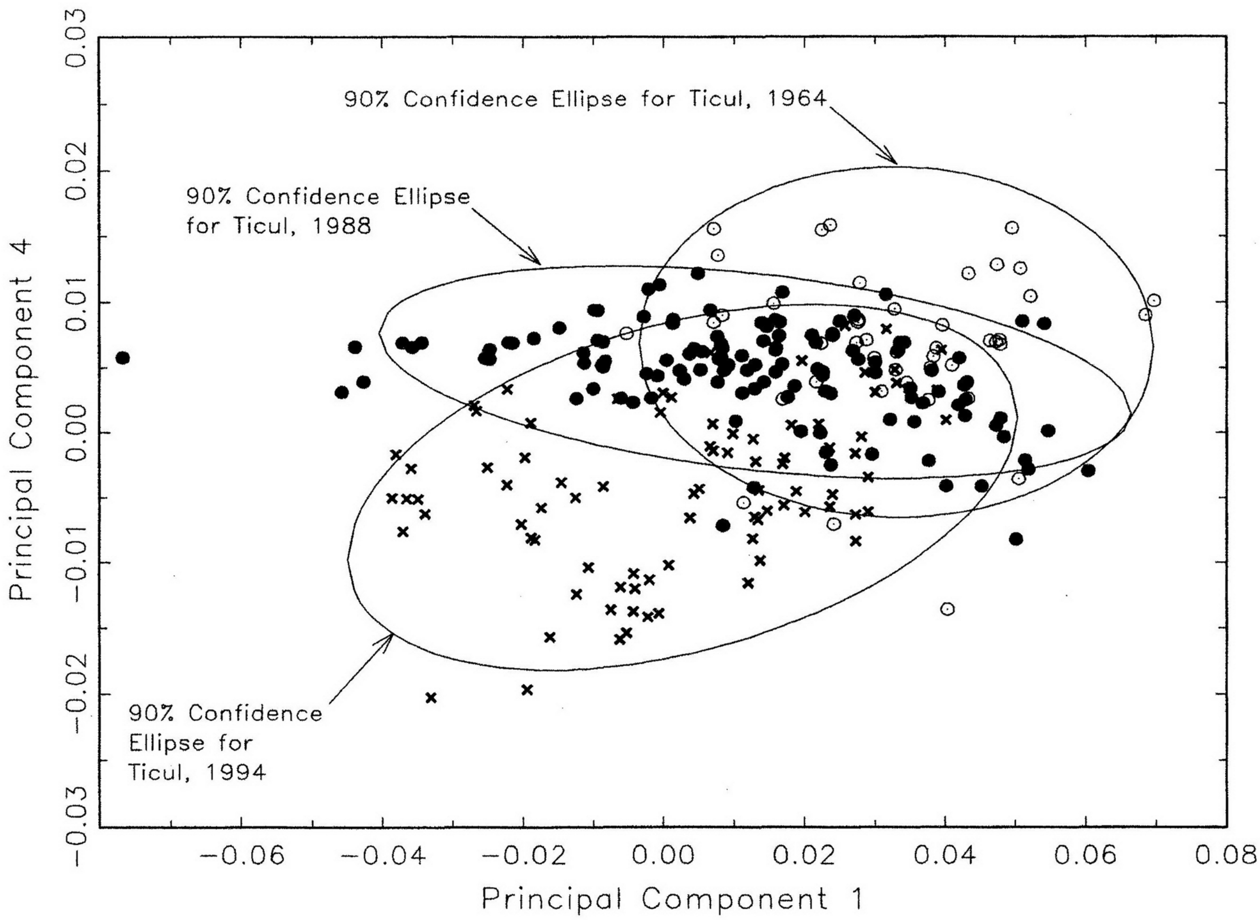

Fig. 3 – Biplot of Principal Components 4 and 1 of data from INAA of ethnographic kiln wasters collected from potters in Ticul Yucatan in 1964, 1988, and 1994. The plots show the changes in the composition of clay based upon changing clay sources. The sample from 1964 was collected by Duane Metzger from the kiln of Alfredo Tzum, the sample from 1988 was collected by the author from six different potters including Alfredo Tzum (also sampled in 1964), and the 1994 sample was collected by the author from five different potters (including Alfredo Tzum and those sampled in 1988). Neutron Activation Analysis was done at the Missouri University Research Reactor (MURR) by Hector Neff and Michael Glascock (Arnold, 2000). Ticul pottery is a combination of two parts temper and one-part clay, and the shift in the change in the composition reflects change in the clay sources and in paste recipes.

***Fig. 3** – Diagramme de double projection des composantes principales 4 et 1 des données INAA concernant des déchets de cuisson ethnographiques collectés auprès des potiers de Ticul Yucatan en 1964, 1988 et 1994, mais figurant cette fois en compagnie des données de déchêts de cuisson provenant des communautés de potiers d'Akil et de Tepakan. En 1997, les potiers de Tikul fabriquaient des récipients à partir de l'argile utilisée par les potiers de Tepakan, et ce changement est mis en évidence par ces données. L'analyse par activation neutronique a été réalisée sur le réacteur de recherche de l'université du Missouri (MURR) par Hector Neff (Arnold, 2000). La poterie de Ticul est une combinaison de deux parts de dégraissant et d'une part d'argile, et les changements dans sa composition reflètent les changements dans les sources d'argile et dans les recettes de pâte.*

potters changed their paste recipes (Arnold, 2000). Consequently, through the forty years after R. H. Thompson visited the community, the paste recipe changed with each of my visits presumably because of variability of plastics and non-plastics in each category of raw material. Even so, firing resulted in breakage rates of 20 - 40%, a rate that could not be sustained if potters wanted reliable returns from their craft. So, by 1992, pottery making was seasonal, and potters only made small food bowls for the annual Day of the Dead rituals.

What do paste recipes tell us? Adding temper to clay has the effect of reducing the plasticity of the clay, and improving its performance characteristics in forming, drying and firing. Clays and tempers in the resource area of a community do not always have a uniform composition. So, if the mineral composition of the clays and non-plastics change, potters may have to alter the proportions of each to achieve desirable results. Paste recipes are not the result of a mental template that the potter materializes when he makes pottery, but rather are the potter's adaptation to the performance characteristics of the paste necessary to make the desired vessel. Because the need to adapt clay recipes to the realities of changing raw materials, using social explanations for the variation (or lack thereof) in paste recipes should be invoked with caution, and then only after the natural variability of the raw materials is taken into account.

RAW MATERIALS AND VESSEL FORMING TECHNIQUES

The quality of clay and the characteristics of the paste also are linked to vessel forming techniques. All clays are not equally useful for every kind of pottery, nor for every kind of fabrication technique. In Ticul, for example, the potter's clay exerts material agency on the fabrication technique and the types of vessel made. The traditional technique used is slab coiling (also called modified coiling) in which large coils of clay are added to a base, then drawn up with a gourd scraper, and then scraped and shaped to make a vessel. Because the clay used before 1992 was a mixed-layered combination of smectite and kaolinite with a small amount of kaolinite, potters could not make a large vessel in one sitting, and could only form about 20 - 25 cm of it at a time allowing that portion to dry before adding another coil, and scraping and shaping it. Otherwise, previous portions of the vessel would sag and/or collapse. So, the forming technique was an adaptation to the performance characteristics of the clay.

In the 1940s, vertical-half molds were introduced into Ticul and their use continued up to the present. The size of vessels that could be made with molds, however, was limited to about 25 cm because they would sag when removed from the mold (Arnold, 2008, p. 254-256). Larger objects were made, but they were coin banks that were totally enclosed with the vessel walls providing mutual support to inhibit sagging. Further, in order to make other larger vessels with molds, or a vessel with a horizontal shoulder upon which a restricted neck rests, potters used two techniques to form the vessel in order to compensate for the limitations of the paste that would make the clay below the shoulder to sag: they used a mold to make the body, and then joined the halves of the molds together, smoothed the mold marks, and after a drying period, used slab coiling to make upper portion of the vessel (Arnold, 1999 and 2008, p. 253).

In the late 1990s, one potter tried to make pottery using a slip casting technique that he had learned in a local ceramics factory (Arnold, 2008, p. 262-265). Slip casting requires a liquid paste, and rather than buying powered clay especially prepared for slip casting, he tried to use the traditional paste. After much experimentation, he managed to come up with a rather complicated paste recipe that was totally different than the traditional recipe. Even though he was ultimately successful, the combination of slip casting, local raw materials, and local firing techniques resulted in many losses during his period of experimentation.

Besides introducing vertical half molds in the 1940s, a government development program also tried to introduce the wheel into Ticul presumably to make pottery production more efficient. There were many problems with the attempt (Arnold, 2008, p. 237-245), but the local paste was too coarse to use on the wheel and it abraded the potter's hands (Arnold et al., 2008, p. 237-245).

In summary, all clay-like material, or any paste, cannot be used to make any vessel, nor can any fabrication technique use any clay to make any vessel (Arnold, 2008, p. 229-279). Rather, the kind of clay minerals in the clay, the paste composition, the particle-size of the paste, the fabrication technique, and the kinds of vessel produced are all inter-dependent variables in pottery production.

ARCHAEOLOGICAL IMPLICATIONS

What does all this mean for archaeology? First, pottery materials are a product of a culturally-defined landscape, and discovering this landscape can be accomplished by surveying for ceramic raw materials around an archaeological site. Since the distances to resources that potters travel to obtain their resources on foot have a cross-cultural pattern, using a radius of 1 km for the survey area and then increasing that area to five kilometers will probably reveal pottery raw materials if pottery was made at the site. By analyzing the raw materials in this resource area, and then evaluating them experimentally to discover their value for making pottery, the archaeologist can then relate them to the analyses of the pottery from the site, the choices made by the ancient potter, link the pottery to the landscape, and assess whether the pottery was locally or non-locally made.

K. Michelaki et al. (2012) did this for the area around a Neolithic site in Calabria in Italy. By analyzing the raw materials found within the different geological provinces within 5 km of the site, testing and experimenting with these raw materials, and comparing the results with the analysis of the archaeological pottery from the site, she and her colleagues showed that the pottery was related to raw material sources from particular geological provinces. They found that the choices that potters made indicated that they had selected some clays and rejected others because some were simply unsuitable to make pottery. In a related paper, K. Michelaki and her colleagues also argued that the pottery from this same site was a congealed landscape (Michelaki et al., 2014). It certainly was, but it represented only that portion of the landscape that existed within the 4-5 km radius around the site that was used to obtain raw materials for making pottery. Using this same kind of methodology in other locations has enabled archaeologists to relate pottery from a site to the local landscape around it and to the choices that the potters made because they surveyed the area for potential pottery raw materials (Hein et al., 2004). Pottery, however, does not encapsulate or distill all aspects of the landscape, but only those from that portion that provides materials for making pottery.

Second, sources that have excellent raw materials for making pottery may have a sacred meaning associated with them, and this association may be one factor in their long term use in antiquity. The persistence of Neolithic steatite-tempered pottery in Silesia through time and its presumable single source suggests that a religious association may have reinforced the value of the temper for improving the thermal properties of cooking pots as well as its use for other pottery (Borowski et al., 2015). Further, just as in Ticul, high quality raw materials in Silesia are not widespread, but have a restricted distribution.

Third, do potters materialize a mental template when they make pottery? The changes in raw materials through time even in the most promising of production locations suggest that potters' indigenous knowledge does consist of some a priori knowledge, but rather potters' long-term and working memory, and their engagement of the raw materials using feedback from them enables the potter to choose appropriate raw materials for their forming technology and vessel shapes, cope with changes in those materials across space and through time, and adjust their paste recipes accordingly. Similarly, just as the raw materials, forming technique, the vessels that potters make change, so the paste recipe may also change.

Finally, there is a strong tendency to over-interpret paste composition, paste homogeneity (or lack thereof), and its change through time as having some social cause. It may or may not, but priority should be given to doing raw material survey, linking those raw materials in the paste to the local landscapes, and using experimental approaches to discover *first* if the choices made by the potter have a technological basis or not. Only then can raw material selection be related to some social or cultural explanation. By evaluating the technological foundations of raw material selection, raw material variability, its changes through time, and the technological foundations of paste recipes and their variability can one begin to understand social and cultural dimensions of ancient pottery that involve the selection of raw materials.

OTHER IMPLICATIONS FOR THE NEOLITHIC: SOME CAVEATS

Although the application of the probabilistic distance model presented above appears to be consistent with the Neolithic data from Calabria in Italy (Michelaki et al., 2012), the general application of these issues to the Neolithic period elsewhere may be rather complicated.

First, the geomorphology of the terrain, especially in alluvial contexts, may have varied significantly from the remote past such that Neolithic clay sources may be deeply buried by alluvial deposits. When mineral materials have been used for temper, however, a search of nearby exposed rocks may be more productive than a search for clay sources.

Perhaps even more important is a more fundamental question: did each localized population in an archaeological site make its own pottery, or was production specialized in communities that possessed superior raw materials and whose products were selected for over time, and then traded or exchanged? Whether or not one agrees with the probabilistic distance to resources model, the cross-cultural data suggest that long distance importation of ceramic resources was improbable, and pots rather than raw materials were imported.

Third, were all Neolithic populations fully sedentary, or did they occupy different niches over the yearly cycle that resulted in migration? Some populations might have been transhumant, living in the low lands during the summer and then moving their herds to higher elevations during the winter. Since making pottery is more difficult, and precarious during periods of low temperatures and precipitation, little if any pottery was probably made in the winter. In any event, S. B. McClure (2015) has argued that Neolithic peoples may have occupied several different niches with varying degrees of non-sedentism.

Further, except for the production of a few vessels, pottery production was probably restricted seasonally in Europe during the Neolithic because of the constraints of temperate and moisture on the drying and firing of clay and pottery. How might seasonality and degree of sedentariness affect raw material selection, and the variability of ceramic pastes?

Finally, such non-sedentary populations could easily collect raw materials from anywhere along their route and use domestic animals to carry it to the production location. Since cross-cultural data on pottery making reveal that women in most cultures were probably potters (Arnold, 1985, p. 99-108), how might sexual division of labor affect raw material selection? At least some evidence indicates that although women are potters, men may select and obtain the raw materials. So, it is possible that even though potters may have been sedentary, men may have brought raw materials from some distance away when the returned from a hunting trip, or returned to the settlement with their cattle, perhaps having the cattle carry some clay. This possibility is heightened when the raw materials used for making pottery possessed a sacred meaning or came from a sacred location.

CONCLUSION

The material presented here closely parallel the data and conclusions presented by O. P. Gosselain and A. Livingstone Smith (2005) in Africa. Their data was synchronic across potters in various communities whereas the data presented here is cross-cultural drawn largely from one community of practice in Yucatan, Mexico, and to a lesser extent from several communities in Guatemala. Further, the Yucatan data is diachronic covering a period of more than thirty-two years.

Potter's selection of raw materials is multi-layered and has multiple explanations. Many potential raw materials may occur across the landscape, but their quality for making pottery may vary; all clays and other potential raw materials may not be equally suitable for making pottery. Nevertheless, potters have extensive indigenous knowledge about them, and select appropriate raw materials by using several criteria: 1) the source's sense of place and its sacred meaning, 2) the obvious physical properties of the raw materials, and 3) their performance characteristics in making pottery. There also may be considerable individual variation.

Raw materials and their sources change across time and space. Access to sources may be denied for political reasons because of issues of land tenure and micro-politics. Sources may also become exhausted for the same reasons. In such situations, potters need to use their indigenous knowledge to find new sources and use their problem solving ability to engage, assess, evaluate raw materials from new sources. These changes may involve paste preparation with multiple raw materials, and result in new paste recipes that adapt to the making pottery using their forming technology. All this is to say that changes in raw materials, pastes, and paste recipes do not necessarily indicate changes in society, cultural complexity, organization of production, or migration, but rather may mean something as simple as a change in sources, or within-source variability. Pastes are not immutable. Rather they are adaptations to local materials to make a viable pot. Changes in raw materials and paste recipes across space and time do not necessarily have social meaning.

Potters' selection of raw materials and paste recipes are usually local, close to communities that are fully sedentary, and have resulted from selecting materials from a landscape with a limited radius. Potters' choices are circumscribed by a highly probable 5 km distance from a production location. Since archaeological budgets are limited, surveying for raw materials around an archaeological site thought to be a production location (or along a hypothetical migration route) at a distance of up to 5 km provides a cost-effect way that is likely to encounter sources of raw materials used in pottery production. Another way of saying this is that based on the distance model, the import of raw materials is possible, and does occur, but it is improbable; the trade and exchange of vessels are more probable. Pottery thus is a distilled landscape of raw materials that are local to a community of practice.

Further, some communities of practice may emerge through time as unique sources of pottery because of more durable viable vessels (e.g. cooking pots, the Silesia example). The development of specialized communities in the Neolithic producing a unique product thus is quite possible, although such community specialization is usually associated with more complex societies that are fully sedentary.

SOME QUESTIONS

In light of what has just been said, the selection of appropriate raw materials in the European Neolithic raises two questions. First, since cross-cultural data on pottery making reveal that women in most cultures were probably potters (Arnold, 1985, p. 99-108), how might sexual division of labor affect raw material selection? At least some evidence indicates that although women are potters, men select and obtain the raw materials. Second, except for the production of a few vessels, pottery production was probably restricted seasonally in Europe during the Neolithic because of the constraints of temperature and moisture on the drying and firing of clay and pottery, how might seasonality and degree of sedentariness affect raw material selection, and the variability of ceramic pastes?

NOTES

(1) This paragraph is a summary of Shepard (1965), Rice (1987), and Rye (1982).

(2) A successful hunting expedition would likely obviate the transport of additional weight back to camp.

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