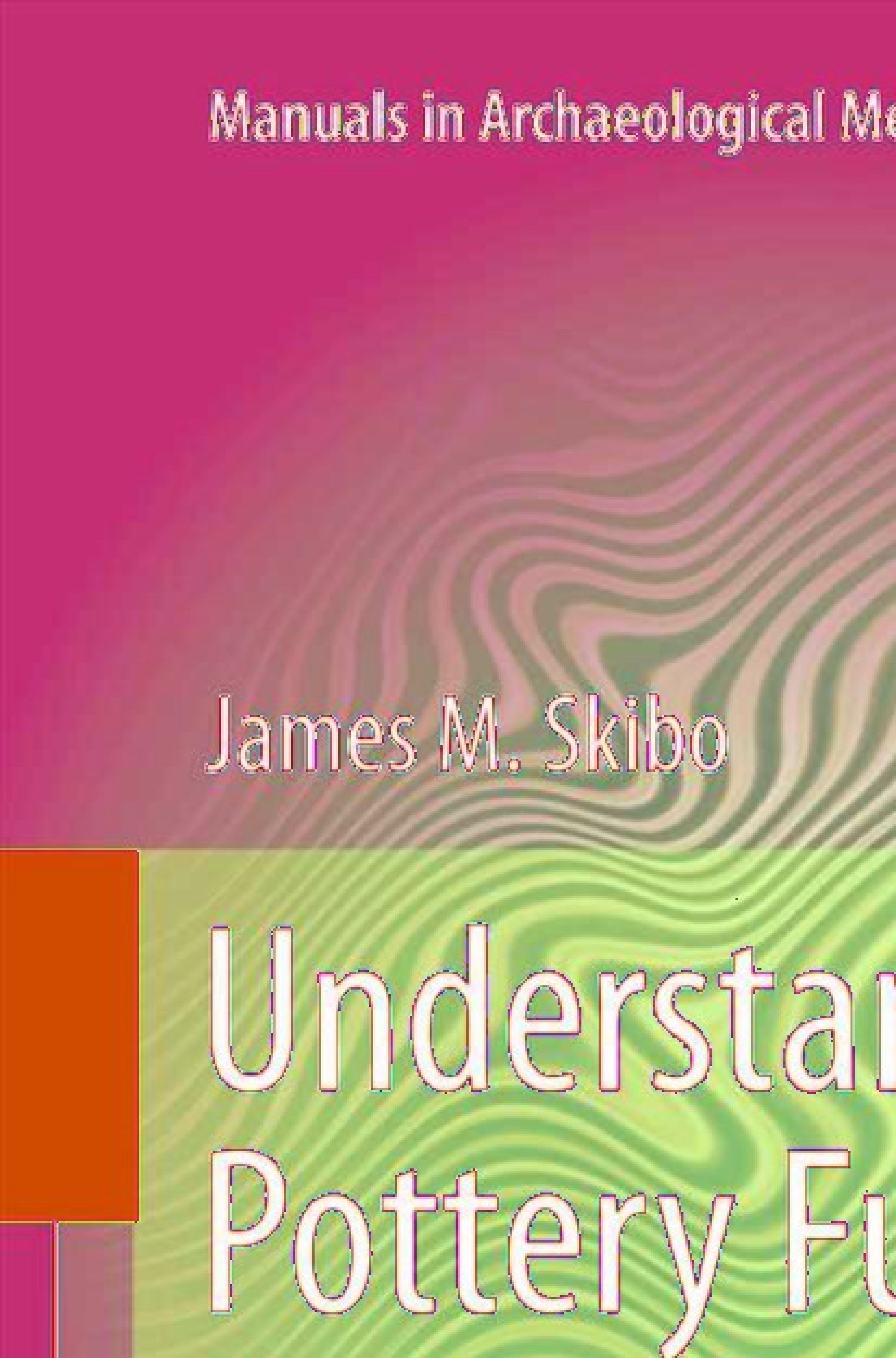

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Understanding Pottery Function

Springer

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Preface

My first exposure to prehistoric pottery came at the Scott Point Site, located on a Lake Michigan sand dune in the Upper Peninsula of Michigan. A field school, directed by Marla Buckmaster, provided my first experience excavating a site. Most archaeologists fondly recall their first field school and this was certainly my experience as we sifted through the sand and uncovered living surfaces, numerous features, and, of course, thousands of pieces of pottery. Even though I grew up in the Upper Peninsula of Michigan, I was unaware that beneath our small towns, roads, and beaches there was an abundant amount of information about the people who once roamed these lands. I was given the opportunity to analyze the pottery from that year's excavation as part of a senior project and I was hooked. With my friend Tom Carle, I sorted the pottery into these exotic sounding types like Juntunen Drag-and-Jab, Black Duck Banded, and Bois Blanc Beaded. With Marla's prodding, I wrote a paper on the ceramics and presented it at the 1981 meetings of the Michigan Academy of Science. Just as I was about to start my presentation, a little bald-headed man walked in and ceremoniously made his way to the front row and sat down just feet away from the podium. This was, of course, James Griffin, who along with his students from the University of Michigan had excavated many of the most important sites that defined Great Lakes archaeology. Griffin had a notorious reputation for verbally torturing students and professionals alike at professional meetings, but I had no idea who he was so I proceeded with my presentation without concern. At the conclusion of the paper he did indeed ask several questions but in hindsight he went easy on me either because he realized that I was just an undergraduate learning my way or perhaps he understood that I would long outlive him and have plenty of opportunities to recount this story. Whatever the reason, his uncharacteristically gentle treatment encouraged me to continue this line of research and I have since been interested in prehistoric pottery and the people who made and used them.

I had thought about writing this book for a long time, as Teresa Krauss, Senior Editor at Springer, often prodded me about writing a revised edition to *Pottery Function*, which had come out in 1992. A good portion of that book, however, involved a discussion of ethnoarchaeology and the methods used to collect my data as part of the Kalinga Ethnoarchaeological Project. Much of that information would simply not be necessary in an updated book. So instead of trying to make a revised edition I have written a completely new book that serves as a practical guide for understanding intended and actual pottery function. But I appreciate Teresa along with Morgan Ryan, at Springer, for their long-time support. Springer's series, *Manuals in Archaeological Method, Theory, and Technique* seemed like a perfect place for such a book. By happy coincidence, my long-time friend, collaborator, and mentor, Mike Schiffer is coeditor of the series and he too was enthusiastic about this book project.

There are many people to thank along the way. Bill Longacre and Mike Schiffer deserve special credit as they not only encouraged my interest in pottery and served as the co-chairs of my dissertation committee, but they are lifelong friends. The only thing that eclipses their esteemed stature in our field is being two of the greatest people I have ever met. It is an honor and privilege to know them. They also commented on a draft of this book, and Mike Schiffer took on the herculean task of untangling my sometimes tortured prose.

And it was fun once again to write about the Kalinga and pottery use-alteration, like visiting old friends after a long absence. The assistants in Guina-ang made the original ethnoarchaeological project possible. They include Amboy Lingbawan, Joseph Abacan, Nancy Lugao, Edita Lugao, Judith Sagaya, Iya Lubuagon, and our landlords, Solono and Pascuala Latawan.

Many students played a large role in this book, first in forcing me to explain things in a clearer fashion and in some cases helping directly with the book. Let me single out Susan Kooiman and Jess Haglund who helped me with some of the final tasks in preparing this manuscript. Other students also commented on drafts or made suggestions along the way and they include Emma Meyer, Carol Richards, Tom Collins, Jessica Miller, Sean Stretton, Montana Martin, Fernanda Neubauer, Michael Schaefer, Nathan Hardwick, Jessica Griffin, and Lindsey Helms. My university and especially my current chair, Fred Smith, have always been very supportive of my work. Fireside chats with Eric Drake, my long-time codirector and friend, have had a big influence on this book and my work in general. And as always, Becky, my beautiful bride of many years, has been part of my archaeology journey from the very beginning and I am forever indebted to her. Becky's constant support and encouragement have been instrumental throughout my career.

Normal, IL, USA James M. Skibo

Contents

Chapter 1
Understanding Pottery Function

> *The problem of function is perhaps one of the most difficult faced by those studying archaeological ceramics (Orton et al. 1993, p. 217)*

My ethnoarchaeological experience among the Kalinga changed forever the way I look at pottery. When I pick up a vessel and see the patterns of soot, I can also smell the smoky wood fire as it curls around the pot and then rises slowly to the roof. The charred residue over the lip makes me envision a boil-over and a doused fire because a cook was distracted by a fussy baby. As I run my fingers over the surface of a vessel I can see the clay-stained fingers of the potter, skillfully shaping the wall with a paddle and anvil as she jokes with the other potters.

Ethnoarchaeology gives us both sides of the important correlation—the pots and the people. Ethnoarchaeologists have the finished product and we can observe and collect information about the decisions that go into designing and then using the vessels. But we prehistorians are left with just the pile of sherds and it is sometimes easy to forget that each vessel has a story to tell—its life history. Our job is to reconstruct that life history. Luckily for us, pottery accumulates traces—during manufacture, use, and deposition—which permit us to piece together much of the life history from when the potter first dug up the clay through manufacture, use, breakage, perhaps recycling, deposition, and then recovery by the archaeologist. In terms of function, a pot's life history can be divided into two broad segments, intended and actual function.

My book, *Pottery Function: A Use-Alteration Perspective*, came out in 1992 and was based on an ethnoarchaeological study among the Kalinga, a group of pottery makers and users living in the remote mountains of the Philippines (Longacre 1974, 1981, 1985, 1991; Longacre and Skibo 1994; Stark and Skibo 2007). The central focus of the book was that of developing method and theory for understanding how pottery was actually used. At the time of the original study archaeologists had been making advances in understanding pottery technology and linking technical choices by potters to function, that is, understanding intended use. But there was little emphasis on trying to determine how pottery was actually used. *Pottery Function*

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was designed to fill that lacuna. Archaeologists for generations had noticed, and sometimes recorded, evidence of pottery use in the form of sooting/carbonization, scratches and wear, and various residues, but there was little understanding of how these accretional or attritional processes occurred. Thus, ethnoarchaeological and experimental data were called upon to help build models for explaining these processes so that the prehistorian might infer use behavior from the surviving traces. Since that book was published there have been many advances in understanding how pottery was actually used, particularly through residue analysis. Less frequently investigated but equally important, abrasion and sooting/carbonization traces also have been used to infer actual function. At the 20th anniversary of that study it is time to assess what has been done and what has been learned. One of the most common queries I receive is that people are still unsure how to "do" use-alteration analysis on their collection. This book is designed to fill that void, to serve as a manual for applying use-alteration analysis to infer actual pottery function. To illustrate how to actually do use-alteration analysis, the emphasis is on case studies either taken from my work or the work of others who have successfully incorporated use-alteration analysis into their study of ceramics.

A second track of my work on pottery is trying to understanding intended function—that is, the connections between technical choices and function. Through a series of experiments and analyses of prehistoric assemblages, linkages were established between technical properties and functional performance. The term "functional performance" is used in the most general way to include not just utilitarian performance but also various types of visual and tactile performance characteristics. Because this book is intended as a manual for understanding pottery function to the fullest extent, I also spend some time treating intended function. This area of research, however, is far more advanced than actual function, so the book's focus is on the later side of the functional equation.

The Joys of Pottery

Pottery, in many ways, is the ideal artifact, both in its flexibility and in its willingness to give up its life's story (Abbott 2000; Arthur 2006; Buko 2008; Claudi-Hansen 2011; Crown 1994; Falconer 1995; Gibson and Woods 1990; Hally 1986; Mills and Crown 1995; Habicht-Mauche et al. 2006; Jordan and Zvelebil 2009; Nelson 1985; Nelson 2010; Orton et al. 1993; Rice 1987, 1996a; Scarcella 2011; Shepard 1956; Sillar and Tite 2000; Sinopoli 1991; Skibo and Feinman 1999; Stilborg 1997; Tite 1999, 2008; Velde and Druc 1998). Pottery's flexibility refers to the fact that it can be made into an endless variety of shapes and sizes to suit various intended functions, be they techno-, socio-, ideo- or emotive functions. What is more, the clay, including clay mineralogy, working properties, and color, can be altered to influence how the clay performs in manufacture and use. There is also a variety of manufacturing techniques, from slab building to coil and scrap, paddle and anvil to mold and wheel thrown, that can be employed to create vessels that have important performance characteristics in manufacture and use. Surface treatments such as slips, resins, and texturing can also be employed to alter manufacturing and use-related performance characteristics. Finally, potters can control the firing temperature and atmosphere to attain desired ends. These steps create an endless variety of choices for potters so that they can create a vessel suited for particular utilitarian, social or ideological functions. These technical choices all leave physical and chemical traces on the vessel itself so that the analyst can infer how the vessel was made. Together these technical choices can be grouped by the various performance characteristics they affect so that the overall intended functions of the vessel can be determined. Chapter 2 focuses exclusively on intended function, illustrating how technical choices can be inferred.

Another important joy of pottery is that it is a vital part of everyday life, from the sacred to the profane. Although pottery often does play important roles in communication, ritual, and religious behaviors, its major function is in food processing. One important goal of understanding pottery function is to explore ancient food consumption, which has both nutritional and social components (Gumerman 1997). The primary reason why pottery is so ubiquitous archaeologically is that it plays such an important role in food collection, processing, and consumption.

The final joy of pottery, now from the perspective of the archaeologist, is that it breaks so frequently and is constantly entering the archaeological record, which enables us to make a variety of inferences related to population, occupation spans, and other aspects of a village's life history (Beck 2006; Beck and Hill 2004; Falconer 1995; Pauketat 1989; Varien and Ortman 2005). Ethnoarchaeological research demonstrates that cooking pots last, on average, from just several months to a little over a year (Arthur 2003; Longacre 1985; Tani 1994; Tani and Longacre 1999; Varien and Mills 1997), so there is a constant stream of vessels entering and exiting a household. The added benefit is that once broken, these sherds, literally fragments of human-made stone, are very stable and resistant to chemical and mechanical breakdown. Low-fired pottery is a bit more susceptible to various processes in the depositional environment (Reid 1984; Schiffer 1987; Skibo et al. 1989a), but on the whole ceramic vessels, once broken into sherds, can and do last millennia with little deterioration.

It is ironic, perhaps, that the elevated status of pottery in archaeological analysis is not shared by the makers of this technology. The Kalinga seemed mystified by our focus on pottery (see Longacre and Skibo 1994; Skibo 1999a, p. 1), which for them was a relatively insignificant aspect of their lives (Trostel 1994). The men, in particular, seemed dismayed by this odd fixation, although the women who made and used the pots seemed to enjoy the attention. On more than one occasion (see Skibo 1999b), men tried to tell us what they knew about pottery (usually incorrect), which was met with scorn from their wives and mothers (Skibo and Schiffer 2008, pp. 1–2). The technology of most importance to them was their rice fields or carabao. Crossculturally, potters often have low status and frequently turn to this craft when other opportunities are not available (Foster 1965; Kramer 1985, p. 80; Longacre 1999; Rice 1987, p. 172; Sinopoli 1999). But it is to the archaeologist's advantage that pottery is so common and is so closely linked to the lives of people—the focus of much archaeological research. Nonetheless, the low status of pottery and potters should be a sober reminder that for reasons mentioned above it is we—ceramic archaeologists—who accord this technology an extremely high status.

Actual Versus Intended Pottery Function

Inferring intended function is an important first step, but it is not enough because pottery functional studies now put a "heavy inferential burden on ceramics" (Rice 1996a, p. 138). For a number of reasons it is important to also engage actual pottery function (Feathers 2006, p. 111; Henrickson 1990, pp. 87–88; Rice 1990; Sillar 2003, p. 176; Tite 2008, p. 228). First, an analysis of actual pottery function permits more precise inferences. No artifact has been used to make such a wide variety of inferences, from diet and demography, to social organization and ritual (Crown 1994; Gibson and Woods 1990; Habicht-Mauche et al. 2006; Hurcombe 2007; Kingery 1990; Mills and Crown 1995; Pauketat and Emerson 1991; Rice 1987; Sinopoli 1991). As we seek to make more refined inferences, it is imperative that we start with the most specific information possible for how the container was used throughout its life history. Understanding intended function is simply not enough in many cases (Rice 1996a, p. 140; Tite 1999, p. 182). For example, Arthur (2002) demonstrates that the relationship between socio-economic status and pottery use is invisible if one looks just at intended function. Among the Gamo, contemporary potters of Southwest Ethiopia, the same types of vessels are in use in wealthy, middle class, and poor households. But only the wealthy and middle class brew beer, and the fermentation process leaves a distinctive attritional trace (see Chap. 4).

Second, actual function does not always correspond to intended function. Pots may be designed for cooking stew but the household may need a storage jar, so the cooking pot is called into service for a role that the potter never intended. The Kalinga made two types of cooking pots, one used to cook rice and the other to cook vegetables and meat. The vessel types could be easily discriminated, in most cases, by the orifice diameter, height to width ratios, and rim angle. But Kalinga vessels are hand-made without the use of molds, so sometimes a vessel had intermediate metrical properties. The potter's intent may have been to make a rice cooking pot but the user could decide when it was first obtained whether it was to be used for cooking rice or vegetables and meat. Even though the intended function was ambiguous, the use-alteration traces for rice and vegetable meat cooking distinctive and provide unambiguous evidence for use (Skibo 1992). Knowing actual function, therefore, provides a more accurate guide to vessel use when inferences drawn from the potter's technical choices may be unclear.

The third reason that inferring actual pottery function is important is that pots can be designed to be multi-functional. A good example of multi-functionality is the earliest pottery on the Colorado Plateau (Skibo and Schiffer 2008, pp. 37–52). Although this example is discussed in more detail in Chap. 3, the important point here is that the technical choices made by these early potters (globular shape, thin-walled, polished or smoothed exterior, heavily tempered) created what we called the "Swiss Army Knife" of pots—one that could be used for a variety of functions (see also Garraty 2011). In this case, the analysis of use-alteration traces confirmed the vessel multi-functionality as the vessels had been used for boiling, stewing, and in the fermentation of alcohol. An analysis of intended function, in this case, could only suggest that it may perform many functions adequately; it is only through an examination of use-alteration traces that we can infer what some of these functions might have been.

Fourth, vessels can be reused and recycled. Pots are designed for their primary function (unless designed for multi-functionality as discussed above) and so an analysis of technical choices can only enable an inference about this primary function. But ethnoarchaeological studies have demonstrated that once the pot is no longer used for its designed function, because it breaks or otherwise wears out, it can be reused in a variety of secondary functions (Arthur 2006, pp. 102–120; Deal 1985, 1998; Longacre 1985). Once the pine pitch that was applied to the interior of Kalinga cooking pots had worn away, allowing water to more easily permeate the vessel walls and interfere with the heating process (water would no longer boil), they would be reused in a variety of ways, usually for storage. In fact, because cooking pots have such a relatively short use-life, they would often spend the vast majority of their life history serving a secondary function before eventually breaking and entering archaeological context. These secondary functions are also important and it is only through an analysis of use-alteration traces that they can be inferred.

Fifth and finally, utilitarian pots can be used in a ritual contexts (Walker 1995, 2001). Pots used to boil stew during the day may perform a secondary function at night to hold foods important in a ceremony. Ceramic vessels are commonly employed in various rituals, especially burial, so that everyday cooking pots can be elevated to perform important ideo-functions. Although the context of recovery of the vessel may be most important for inferring this segment of life history, use-alteration traces could possibly inform on how the vessel might have been used as part of the internment ritual.

In a complete ceramic analysis, both intended and actual pottery function should be determined as together they can fill out the story that vessels, individually and collectively, have to tell about the people who made and used them (Tite 1999, p. 181). There are three types of use-alteration traces, residue, sooting/carbonization, and attrition. I refer to these traces as "use-alteration" instead of "use-wear" as is done in lithic studies, because as David Hally (1983, 1986) correctly pointed out, use-wear or the attritional process is just one class of traces of interest here. Chapters 3, 4, and 5 provide instructions for linking these three classes of traces to actual pottery function.

Pottery, therefore, is the ideal artifact for the archaeologist because it can be fashioned into a seemingly endless variety of shapes and sizes, using a variety of techniques, all of which leave physical and chemical traces that can be used to infer intended vessel function. It is also an ideal artifact because post-manufacture activities also leave traces that can be used to infer actual pottery function as well as other reuse and recycling activity.

An Approach to Pottery Function

Rice (1996a, p. 141; see also Rice 1987, 1990) correctly identifies a three-pronged attack to the question of pottery function: experimentation, ethnoarchaeology, and materials science. This approach has been coupled with an orientation to ceramic analysis that began with Shepard (1956) and Matson (1965) and is best described by Braun's phrase, "pots as tools" (1983; see also Kolb 2011, and Tite 2008). In the history of archaeology, pottery has played many roles, first as a chronological marker and a means to define cultures (e.g., Gladwin and Gladwin 1934; McKern 1939; Kidder 1924). It was the ceramic sociologists (Deetz 1965; Hill 1970; Longacre 1970) who are often given credit for suggesting initially that perhaps pottery style could also be used to infer much more about a past society including social organization and post-marital residence rules. One of the problems that these innovators had was that they lacked knowledge about how pottery was made, used, and deposited (Schiffer 1987; Skibo et al. 1989b), which led to what I have called elsewhere as the "modern era of ethnoarchaeology" (Skibo 2009). Longacre (1974) and others soon realized that in order to establish these complex correlations between pottery and people we must first develop the method and theory using ethnoarchaeology before such inferences can be attempted with prehistoric pottery. What emerged was a series of important ethnoarchaeological studies (e.g., Arnold 1978; David and Hennig 1972; DeBoer 1974; Kramer 1985) that continue today (e.g., Arthur 2003; Beck and Hill 2004, 2007; Frink and Harry 2008; Harry et al. 2009). The focus of this research is not in providing analogies to be used by archaeologists but rather to create models of pottery manufacture, use, and deposition that then can be used by prehistorians who are interested in the relationships between pottery and its makers and users.

Bronitsky (1986) was one of the first to suggest a materials science perspective in archaeological pottery studies, which was inspired by Shepard (1956), Matson (1965) and more recently Kingery (2001), Tite (1999, 2008), and of course Braun (1983) all calling for a greater understanding of ceramic technology. It was never questioned that chipped stone was part of a tool making technology, but archaeologists seldom explored ceramics in the same way, instead looking at pottery stylistically and concerning themselves with how the vessels might inform on cultural groups (Henrickson 1990; Tite 2008, p. 216). As Tite (1999, pp. 181–182) notes, physical sciences are especially important for understanding intended function but can also inform on ceramic use behavior throughout a vessel's life cycle.

In a series of experiments beginning in the mid-1980s, members of the Laboratory of Traditional Technology at the University of Arizona focused on how individual technical choices, like temper and surface treatments, influence vessel performance in use (Schiffer 1995, 2010, pp. 102–105). In one of the first experiments we examined how organic temper, like that used by the first potters in the Southeastern United States, influences vessel performance in manufacture and use in comparison to sand temper (Skibo et al. 1989). On the basis of these tests we suggested that the organic temper was used in the first pottery as the absorbent matter that dried out the clay and permitted a vessel to be made in one sitting. The addition of sand temper, in contrast, would not necessarily make overly wet and plastic clay workable.

These temper studies were followed by a series of experiments on the performance advantages of various surface treatments (Schiffer 1988, 1990, 2010; Schiffer and Skibo 1994) related especially to the cooking vessel (see also Pierce 2005). These experiments helped to reshape attitudes toward cooking pots, which for generations were considered "crudware," made without much concern for their design. In contrast, knowing the important performance requirements of cooking pots, especially thermal shock resistance, we argued that these vessels were in fact sophisticated technological achievements made by women (Skibo and Schiffer 1995).

I should note that this approach shares some important features with approaches to ceramics employed by others across the globe such as the "Leiden School" (Annis 1985; Franken 1975; van As 1984; van As and Jacobs 1995), various French ceramicists (e.g., Gosselain 1992, 2000; Roux 2003, 2010) and a field of study referred to in Scandinavia and elsewhere as "ceramology" (Hulthén and Vincenzini 1995; Lindahl and Stilborg 1995; Stilborg 1997). According to Stilborg (1997, p. 89), "ceramology is the study of ceramic artefacts, raw materials, the technology and organization of the craft and the use of the products." Where our approach differs from the above occurs when the archaeologist needs to explain ceramic variability and change. Whether it is studied experimentally (including a materials science perspective), ethnoarchaeologically or prehistorically, the explanation of pottery variability requires a theoretical perspective that I refer to as the "performance-based life history approach" (Skibo and Schiffer 2008).

Performance-Based Life History Approach

Although this approach, whose centerpiece is a theory of artifact design, is employed here to study pottery, it has been successfully applied to variety of technologies, both ancient and modern (e.g., Cooper 2012; Schiffer et al. 1994; Walker 2001; Zedeño 1997). Here I am going to briefly review the theory, but interested readers have a number of sources to consult should they require fuller elaboration (Schiffer 2010, 2011; Schiffer and Skibo 1987, 1997; Schiffer and Miller 1999; Schiffer et al. 2001, 2003; Skibo and Schiffer 1995, 2001, 2008; Skibo et al. 1989b). The theory for artifact design can be broken down into four components: life-history/behavioral chain, activities and interactions, technical choices, and performance characteristics and compromises. The discussion of these components is followed by a case study employing experimental writing that involves alternating between a hypothetical case study, where we all travel back into time to the first potters on Grand Island, and a theoretical discussion of concepts like performance characteristics and technical choices.

Life-History/Behavioral Chain

All artifacts, including pottery, have a life history, in which an item's role in activities is being constantly being contextualized and recontextualized. Although there are similarities among the concepts of "life history," "*chaîne opératoire*," and "behavioral chain," there are some notable differences as well. Life history and *chaîne opératoire* focus on the gross process and can be useful for generating course-grained explanations for artifact variability and change (Lemonnier 1992; Schiffer 1972). But to understand a technology fully one must focus on individual activities in the entire life history, which is referred to as the "behavioral chain" (Schiffer 1975, 2004; Skibo and Schiffer 2008, pp. 17–34). Equally important, *chaîne opératoire* focuses on manufacturing processes alone (Lemonnier 1986, 1992) whereas behavioral chain follows artifacts, activities and interactions past manufacture to use, reuse, recycling, etc. to disposal and then archaeological recovery. Thus behavioral chain, because it is more fine-grained and a more complete biography of an artifact, is highly appropriate for pottery use-alteration analysis. Some prefer the concept of *chaîne opératoire* because it emphasizes the social instead of the utilitarian side of technology and find it a better marriage with agency and practice theory approaches to technology (Dobres 2000; Dobres and Robb 2000, 2005; Lemonnier 1992; Pauketat and Alt 2005; Scarcella 2011). Although there is a good deal of overlap in these approaches and the one advocated here, I prefer to keep an open mind as to the reasons (e.g., social, utilitarian) for a technical choice along the behavioral chain. As discussed below, performance characteristics can be utilitarian and thus affect mechanical, thermal, and chemical interactions of a vessel, but they can be sensory as well and relate to "symbolic and other cognitively based phenomena" (Schiffer 2004, p. 579; Schiffer and Miller 1999).

Activities and Interactions

The links in a behavioral chain consist of one or more activities, which are composed of specific interactions of many kinds between people, people and artifacts, and between the artifacts themselves. Also important in any activity is the social unit and associated artifacts (Schiffer 1975); the entirety of social units in an artifact's life history is referred to as the *cadena* (Schiffer 2007; Walker and Schiffer 2006). Pottery is a technology that can be very gender specific. In household, hand-made manufacture, women are usually the potters and primary pottery users (Skibo and Schiffer 1995). Men may be involved in some activities, such as clay collection and transport or pottery firing, but in these contexts pottery is dominated by women both in manufacture and in use. This is a strong correlation that permits one to infer that virtually all of the pottery in North American prehistory was hand-made at the household level and thus made by women.

Technical Choices and Compromises

Decisions made by the potter during manufacture are "technical choices," which determine the formal properties (size, shape, characteristics of the paste, etc.) of the vessel.

Every potter has at their disposal a series of options or choices that result from available resources and knowledge. But no design is perfect—they all require compromises because any technical choice can affect a pot in a number of ways throughout its life history. If a potter adds lots of sand temper to increase a cooking pot's thermal shock resistance (a primary performance characteristic for cooking pots), it increases the vessel's porosity and water permeability, thus the completed vessel may not be water tight. The potter may then need to make a derivative choice to reduce permeability, such as adding a surface treatment. Such choices can have down-the-line ramifications if, for example, a tree resin needs to be collected, which is a time-consuming activity that can involve travel.

Performances Characteristics

Artifacts of all types are governed by a set of performance characteristics throughout its life history as different performance characteristics come into play with different activities. Use-related performance characteristics are the capabilities that a vessel must have to adequately perform its functions, be they utilitarian or symbolic. Materials science and engineering is familiar with the set of utilitarian performance characteristics associated pottery, such as thermal shock resistance, heating effectiveness, and impact resistance. But there is also an entire suite of sensory performance characteristics related to sight, sound, or touch that are important all along a vessel's behavioral chain. These are often subsumed under the concept of "style" or "technological style," which are too general to be useful if the goal is to understand how vessels perform, whether it be symbolically or in a more utilitarian way.

The Approach to the Writing in This Book

Like many archaeologists I often interact with the public especially during field work, where my excavation on Grand Island, Michigan is open to the public. There are many benefits to this, of course, but the one message I usually take away from our daily tours of the site is how interested people are in what we do. For many visitors this is their first opportunity to see an archaeological excavation in person instead of on the *Discovery Channel*, in their *National Geographic Magazine* or, more likely, at the movie theater. Most days at my excavation or at any archaeological project there really is not a lot of excitement, nonetheless, people seem captivated by the process. If you are a practicing archaeologist or even a student in the field, you know what is like almost every time you are on an airplane or in the dentist chair and someone asks what you do. People are usually quite fascinated when you tell them you are an archaeologist. This is why I have long advocated that archaeologists occasionally write for the public. Luckily we have some, like Bill Rathje, Brian Fagan and Steve Lekson, who are very skilled at the craft and should be encouraged to communicate with the public more often. But all archaeologists should make this effort.

One could argue, I suppose, that some archaeology is too technical, theoretical or so esoteric that it really cannot be put into a form that would captivate the public. I have done my share of that type of writing and publishing. And this book, one would think, is just this type of writing—understanding how pots were used from the traces left on them. But I maintain that even this type of writing can be done in a way that is much more interesting. Owing perhaps to my two decades teaching undergraduates or my short attention span when trying to read technical archaeology, the writing in this book is a bit different. I intersperse stories of various kinds with the dry science of use-alteration. This approach has three goals. First, storytelling is a form of communication that predates the written word and, as anthropologists, we know that it is a very effective means of learning. I do not think the serious ceramic analysts will mind if they occasionally run into a story like this in the book, and if they do they can simply skip it if they choose.

Second, a primary audience for this book is students of archaeology, graduate students and advanced undergraduates in a ceramic analysis course or struggling to make sense of a pottery collection they are analyzing. After spending more than two decades as an instructor, I am confident that students at all levels enjoy a good story interspersed with the science.

Third and finally, some would argue that background stories, of the type I tell in the coming pages, are an important part of our craft and should be incorporated into everything we write (see Tomášková 2007). My ethnoarchaeological experience made me realize that there are people behind those pots and we should not forget that even when immersed in a sometimes dry discussion about the fatty acids extracted from a cooking pot. As Tomášková (2007) argues, there are important reasons to make more explicit the story behind a particular research project in archaeological writing.

In that spirit, I end this chapter with a story that bounces between archaeological details and theoretical mastication, and the people who lived on Grand Island and made real choices about the adoption of pottery.

A Story of Pottery and People: Origins of Pottery Making on Grand Island

One of my archaeological fantasies is to have a time machine, so that as I puzzle over a pile of sherds and try to infer how the pots were manufactured and used, I could fly back in time, hover above the potters and witness, first hand, activities and interactions in a vessel's behavioral chain. Absent a real time machine, the narrative that follows tries to capture the essential elements of both a realistic case of pottery use and how archaeologists go about making inferences that can reproduce the choices the potter's made in the complexities of their real life. What follows is a story from an actual archaeological case study taken from our work on Grand Island, on the south shore of Lake Superior (Drake et al. 2009;

Skibo et al. 2004, 2009). The story is interrupted a number of times to illustrate the concepts in the performance-based life history approach: technical choices, performance characteristics and compromises, and activities and interactions. Here I show how the three-prong approach—ethnoarchaeology (including ethnography and modern material culture), experimentation, and materials science—all contribute to the understanding of pottery manufacture, use, deposition, recovery and analysis.

It is Fall on Grand Island. A couple of dozen people assemble on the south shore to take advantage of the Fall spawn of Lake Trout in the shallows and to harvest acorns from the grove of oak trees. Acorn meat is eaten, but they are most interested in rendering the acorn fat, which they can store or mix with dried meat and other items to help them get through the long winter ahead.

To understand the activities and interactions on Grand Island at this time, we turn to the ethnographic and archaeological record. Ethnographically (see Densmore 1979; Hilger 1992), we know that the Anishnabeg (which includes the Odawa, Ojibwe, and Potawatomi dialects) came together in large groups occasionally to fish and harvest various resources. We also have archaeological evidence for the harvesting of both Lake Trout and acorn on Grand Island (Dunham 2009; Skibo et al. 2007, 2009). The Native American adaptation (prehistoric and historic) in the northern Great Lakes can be characterized by the word “flexibility” (Martin 1989). The people in this region were hunter-gatherers up until and well beyond contact, and the plant and animal resources varied from year to year as did their response to them. Early visitors to Grand Island sometimes found a Native American settlement occupied and other times empty despite the fact that they might have been at this location 12 months earlier. Archaeology on Grand Island confirms this observation, as locations were used for up to 2,000 years on a seasonal yet intermittent basis (Skibo et al. 2004). The *cadena* (Schiffer 2007; Walker and Schiffer 2006) involved in the harvesting and processing of acorns is a kin-related group of females. In terms of gender, the ethnographic record is unambiguous about the collection, harvesting, and processing of acorns: these activities were done primarily by women. Residue analysis on both early ceramics and fire-cracked rock (presumably used in stone boiling) taken from a shoreline site on Grand Island’s Murray Bay, yielded a lipid profile characteristic of acorn fat (Skibo et al. 2009).

For generations they have been rendering the fat with stone boiling in a water-tight birch bark container, which has been working fine for processing the relatively small amount of acorn meat. The women on the south shore of Lake Superior have resisted pottery making despite the fact that their relatives, just 40 miles to the south, have been using pottery for as long as anyone can remember. The nearby potters use ceramic vessels to cook corn, which is not grown on the banks of Lake Superior. Recently, a young woman who had married into the Grand Island band rendered fat the way she was taught by her mothers, by simmering an acorn mush in a ceramic pot. In this way she was able to collect a lot more fat. After all, a good deal of fat was lost boiling the acorn mush with hot rocks in birch bark containers.

Not only was fat lost on the rocks as they were removed, but the splatter caused by the immersion of hot rocks also resulted in the loss of the oily liquid that floats to the top of the water. While the hot rock boilers struggled with the process, the young woman easily skimmed off the acorn fat that rose to the surface of the simmering acorn mush.

To understand the performance characteristics and choices relating to the origins of pottery, inspiration can be drawn from other cases of pottery adoption around the world, experiments, and the ethnographic and archaeological record. Pottery is a technology that requires a significant investment. There are many reasons that people may adopt pottery (Barnett and Hoopes 1995; Jordan and Zvelebil 2009), but the most common one is that it can be used to directly heat its contents (Skibo and Schiffer 2008, pp. 37–51). The people on the south shore of Grand Island clearly had knowledge of the technology as pottery makers and users were very nearby and it is likely that they even intermarried with groups using this technology. They chose, however, not to make pottery for hundreds of years—they made a choice based upon an evaluation of the performance characteristics of pottery and the fact that the technology currently in use, in this case hot rock boiling, performed adequately. Perhaps because of an increased reliance on acorns (Dunham 2009), they chose a container to render acorn fat based on performance characteristics related to this specific activity. Pots can be placed directly over a fire and retain a simmering temperature with little fuel and less attention than hot rock boiling. Moreover, simmering temperatures are ideal for rendering as roiling associated with boiling water does not permit the fats to rise to the surface where they can be skimmed off (Reid 1990).

After watching the success that the young woman had rendering acorn fat in a pot, the women decided that they would make some vessels during the late summer of the following year. At least half the women in the band were born and raised in pottery making communities to the south so they had learned pottery making as young girls. They knew of two clay sources on the mainland, which they thought would be appropriate for making vessels. On trips inland before winter and during the spring and early summer of the following year they stopped at the clay sources and tested samples for workability. They moistened it, made coils, and wrapped it around their finger to assess how the clay performed. They preferred one of the clay sources because it had just the right mix of large and small pieces of sand and required very little cleaning and no additional temper. The preferred clay source, however, was farther away and also near a main trail used by a rival band which recently had been at odds with the Grand Island band members. They chose to use the less ideal clay even though it also took a little more work to clean and make ready.

Many performance characteristics and other factors may be important in deciding whether to begin making pottery, and many areas of study, including materials science, ethnoarchaeology, the archaeological record, and the study of contemporary potters, are relevant for understanding the adoption of pottery on Grand Island. This is not a case of pottery invention, but rather pottery adoption, which is the most common way this technology first appeared in a region. There is strong evidence that Grand Island women had the knowledge and ability to make pottery long before it was adopted. They were so late in pottery adoption that there is no “Early Woodland” on the south shore of Lake Superior. In the Midwest, Early Woodland is defined by the appearance of pottery, but it happens so late in this region that archaeologists employ “Initial and Terminal Woodland” instead of the standard, Early, Middle and Late Woodland. Arnold’s (1993) extensive and cross cultural study of potters and clay acquisition, finds that potters typically obtain clay within a few miles of their village. Potters speak in terms of workability, which is really a whole suite of manufacturing performance characteristics (Bronitsky 1986; Rye 1976) based on clay minerals, water content, and composition and quantity of nonplastic interaction (Rice 1987). They choose clay that performs at an acceptable level in manufacture. But clay selection does not operate in a sterile lab where potters can test the performance of different clays under controlled conditions, choosing the one that performs best. Potters also have to consider factors, such as accessibility of materials governed by social boundaries (Longacre and Stark 1992; Stark 1998), unrelated to techno-functional performance that can also affect clay selection. In the expanded conception of function, these too are performance characteristics that play a significant role. Sometimes these social factors lead potters to select clay that is less than ideal in terms of manufacturing performance. For example, the clay may be too plastic, have too much or not enough temper, or shrink too much when dried. But the potters can compensate for poor manufacturing performance by making a series of derivative choices, such as letting the clay “cure” for several days, drying and sifting the clay to vary the amount of temper, or perhaps adding a surface treatment to deal with vessels with excessive permeability after it is fired. Choices build upon choices, but archaeologists have at their disposal a whole suite of materials science techniques that can assist in ferreting out these decisions that leave distinctive traces (see Tite 2008).

As noted, it is interesting that pottery adoption on Grand Island occurred quite late. Perhaps their technology for boiling, indirect heating with hot rocks, was performing adequately because of the small amount of acorns being processed. But there could have also been important social considerations that could have served as an impediment to change to pottery. In an examination of the earliest pottery in the Southeastern United States, (Sassaman 1995; Sassaman and Rudolphi 2001; see also Chap. 3) argues that the social performance characteristics (in my terms) of soapstone objects in indirect heating of water in fiber tempered vessels kept pottery users from putting these vessels directly over a fire. He suggests that soapstone manufacture and use performed a number of social functions related to gender, post-marital residence rules and inter-group relationships. Men, in this case, manufactured and obtained through exchange these soapstone objects and thus there was a resistance to adoption of pottery, made by women, for use over a fire. These types of similar arguments need to be examined for the slow adoption of pottery on Grand Island. Perhaps men made the containers used in indirect heating of water and a transition to a new ceramic technology, made by women, had a number of social ramifications.

On the trip to Grand Island for the Fall Lake Trout spawn and acorn collection, each family stops by the clay source and fills a large bag with clay, which is easily transported to the Grand Island village via their canoe. They grind up the clay on a rock, pick out the twigs and pebbles, but note that the clay still contains lots of sand. Although it is actually easier to make vessels with less sand in the clay, the women who learned pottery making before moving to the Grand Island band know that clay without lots of sand will produce pots that will break when put over a fire. Water is added to the clay and it is wedged to mix constituents evenly and to remove air pockets, which they also know from experience must be done or vessels can break during firing. About half the women learned pottery making while growing up in the south, and their experienced hands assess the clay's workability, which performs in a slightly different manner than the clay they used previously. Accordingly, they make subtle changes in the recipe as needed by adding more water, clay or sand. Once the desired mixture has been attained, the experienced potters begin to fashion coils and build the walls of the vessel. They move quickly, thinning and scraping the walls as the vessel quickly takes shape. Once the basic form has been created with a slightly out-curving lip, they set the vessel aside and start on another. They also spend some time correcting the novice potters by moving their hands and fixing their mistakes. Each potter makes several vessels, which they set in the shade to dry overnight. The next day, the clay has hardened enough so that the vessels can be handled. They each take a cord wrapped paddle, and a hand-sized beach-worn stone and begin to shape and thin the lower half of the vessel by gently tapping the exterior of the pot while holding the stone on the interior for support. The cord-wrapped paddle imparts a texture to the exterior surface that is not easily smoothed because of the excessive temper that has been added. The pots are then set aside to dry.

To understand the learning frameworks and the primary performance characteristics of cooking pots requires accessing information from a variety of sources but especially ethnoarchaeology and experimental archaeology. Cooking-pot sherds are often the most common artifact found at archaeological sites. Because cooking pots last, on average, from just a few months to around a year if used every day (Longacre 1985; Varien and Mills 1997), they break and must be replaced constantly. The thought once was that cooking vessels were "ugly" because they are the expendable everyday dishes and their overall appearance, in contrast especially with beautifully painted wares found in some regions, reflects ambivalence by the potters. But a series of experiments (e.g., Bronitsky 1986; Bronitsky and Hamer 1986; Feathers 1989; Frink and Harry 2008; Harry et al. 2009; Pierce 2005; Schiffer 1988; Schiffer and Skibo 1987, 1997; Skibo and Schiffer 1995; Skibo et al. 1989; see also Chap. 2) coupled with principles developed in materials science (Feathers 2006; Tite et al. 2001) demonstrated that these attributes, heavily tempered, low-fired, and textured, are actually related to a primary performance characteristic of cooking vessels—thermal shock resistance. The temperature difference between the inside and outside surfaces of a pot can be up 500 °C. This creates the potential for micro-cracks that can easily join with other cracks and result in catastrophic failure of the vessel—the pot breaks over the fire, the contents are lost, and the fire is doused. If a potter, however, adds excessive amounts of temper these micro-cracks are interrupted and such failure is postponed. Similarly, pores created by the low firing temperature or the uneven surface created by the texturing keep these micro-cracks from growing and breaking the vessel. It has been my long-term goal (Skibo and Schiffer 1995; see also Frink and Harry 2008) to change attitudes about cooking pots. Far from being crudware made without much concern, they are actually sophisticated technological achievements. The choices these women made created vessels—judged "ugly" by some moderns—that performed quite well as cooking pots when placed over a fire, furnishing the sustenance that kept their communities alive.

After the vessel is formed using the paddle and stone, the potters add some impressed designs to the lip. The designs are similar to those on the pots of their relatives living 40 miles to the south but they also choose to make some subtle design alternations to denote that these pots are made by women from the Grand Island band. Similar stylistic variations are seen in the bead work, clothing designs, hair styles and even language dialect. The older women also note that their daughters are making their designs with some small but noticeable changes.

What a style "means" has intrigued archaeologists for generations (Graves 1994; Sackett 1977; Wobst 1977). From ethnoarchaeology and the study of contemporary people, different interpretations have emerged about a style's meaning such as group affiliation or generational differences. In many cases designs are purposeful choices by potters or groups of potters to communicate messages to anyone who would see the vessel. We have long advocated that the "style" and "function" dichotomy should be abandoned (Schiffer and Skibo 1987, 1997). Instead, it is more fruitful to think of style in much the same way that we think of function—by applying the performance approach. Style, in this case, is simply one or more performance characteristics that the vessel must have to adequately perform its roles in a social group- socio-, ideo, and emotive functions. Vessels not only have utilitarian performance characteristics (technical choices that impact the thermal, chemical, or mechanical interactions) but sensory performance characteristics as well (Schiffer 2004; Schiffer and Miller 1999). The vessels are a critical part of the social setting that involves social identity, gender, class conflict, or political power. We know from the ethnographic record that designs perform a variety of functions from simply looking nice to symbolizing group affiliation that can have life or death consequences. The later is illustrated by the Kalinga, where the shape of a pot in profile is a distinct and visible sign of group affiliation. A woman, for example, walking to her rice fields carrying her pots could be easily identified by the design, captured and perhaps killed if she encountered people from a rival tribe. Pottery, like all material culture, plays a distinct and essential role in human communication (see Schiffer and Miller 1999).

Once the pots had completely dried, they are set beside the cooking fire to remove the last of the moisture. They know from experience that a damp pot will not survive the firing process. To fire the pots, they simply stack them in a small pile and then cover it with wood. The fire is ignited but it burns quickly and within 20 min the pots can be removed from the fire. They know that if the fire is too big or if the vessels are *kept too long in the fire, they will get too hard and then will not work as cooking pots. They will break when put over a cooking fire.*

Pottery firing and the performance characteristics involved are informed by materials science, ethnoarchaeology and modern potters. Pottery firing is often the most stressful part of the manufacturing process because despite all the precautions taken by potters, vessels often break because the pots or perhaps the ground was too wet. It is with trepidation that even modern professional potters peer for the first time into a kiln for fear that their handiwork may have been ruined. If the goal was to make cooking pots, as it was with the Grand Island potters, then it is important to keep firing temperature relatively low. Firing temperature is one of the critical technical choices that affects thermal shock resistance. As firing temperature increases, to a point, thermal shock resistance decreases (Skibo and Schiffer 1995; Tite 1995, 1999). This is a well known correlation in ceramic engineering that is also confirmed archaeologically and ethnographically with cooking pots, the crudware, around the world.

Once the pots are fired they are ready for use. The pots are so low fired, porous, and permeable that water is visible on the exterior within seconds of being poured into the vessel. The women know that a leaky pot like this will not heat up to a simmering temperature and a surface treatment must be applied to reduce permeability. This could be done by smearing on bear grease or simply by using the pot to let the acorn fat seal the pores. To conserve bear grease they choose the latter option. Acorns are removed from their shells and put directly into the water-filled pot. For the first use, which "seasons" the pot, it takes twice as long to get to a simmering temperature, but after the first use, the pot reaches a simmering temperature relatively quickly. As the fat rises to the surface, it is skimmed off and placed into a birch bark container.

Experiments have been critical in understanding how cooking pots perform and the way that water influences heating effectiveness, which is an important performance characteristic in pots used to heat water. Low fired, heavily tempered pottery is very permeable. A number of experiments explored the relationship between surface treatments, water permeability, and heating effectiveness (Schiffer 1988, 1990). Water that passes through the vessel wall and is exposed to the fire's heat will evaporate and cool the exterior of the vessel (the same principle is seen on water storage vessels that leak just enough water to cool their contents). In fact, it is difficult if not impossible to boil water in a low-fired ceramic pot that has high water permeability. The Kalinga would retire a cooking vessel once the pine resin on the exterior wore away because the water in these pots would no longer boil because the permeating water was interfering with the vessel's heating effectiveness. The objective for the acorn processors, however, was only to reach and hold a simmering temperature, not boil the water. So the ideal vessel for this activity is one that has a mid-range heating effectiveness because if the pot were to reach boiling, the roiling of the water would stir the contents and keep the acorn fat from rising to the surface. The potters in this case sealed the vessel walls in the first use, which is a common method ethnographically (see Skibo and Schiffer 1995).

The pots perform much better than hot rock boiling and the women are able to collect far more acorn fat than they had in previous years with the same amount of acorns. Two of the ten pots in use break during the acorn processing time on the island. One evening the pots were set near the fire and a dog came into an empty wigwam to try and steal a quick meal. When someone came into the house and caught the dog in the act the guilty creature darted out the door but kicked one of the pots over and it broke into several pieces. The other pot broke as two 10-year-old cousins wrestled in the wigwam during a rainy cool autumn day and they crashed on top of a vessel, which broke into dozens of pieces. In both cases, the women gathered up the larger fragments and tossed them into the shallow ditch behind their house. When it was time to break camp for the season, a small hole was dug near the wigwam and some of the camp's tools were cached. This included a fishing net, acorn grinding stones, and, for the first time, several pots.

Ethnoarchaeological research has shown that dogs and children account for many broken pots and also how these vessels are disposed of (Beck and Hill 2004; Deal 1985; Longacre 1985; Schiffer 1987). When pots are broken in a house, larger pieces are usually removed and perhaps recycled or deposited as secondary refuse, while small sherds often get embedded in the floor or swept into dark corners where they become primary refuse. Caching is a common activity at seasonal sites in this region (Dunham 2000), and caches have been found on the island. Ceramic vessels are bulky and breakable, so they are routinely left behind on seasonal moves. The majority of the sherds found at archaeological sites are small sherds deposited as primary refuse. In this climate, these sherds can also be broken down by freeze-thaw processes that can make the sherds very friable or even reduce them to difficult-to-recover crumbs. Analysis of the vessels themselves also reveals that their design (heavily tempered and textured exterior surface) is related most closely to cooking vessels, and thus the intended function can be inferred. To determine what was cooked in the vessels required an analysis of use-alteration traces, in this case organic residue. The lipids were extracted from the sherds and identified with gas chromatography and mass spectroscopy (Skibo et al. 2009), which has become a routine form of residue analysis (Evershed 2008).

Review of the Book's Contents

The core of the book is Chaps. 3, 4, and 5, which discusses the three types of use-alteration traces associated with actual pottery function: sooting/carbonization, attrition, and residue. But because this book strives to be a holistic treatment of pottery function, Chap. 2 first examines intended function, which is the relationship between the potter's technical choices and the vessel's intended primary use. All of the elements that go into vessel production are examined, including morphology, paste characteristics, surface treatments, firing temperature and atmosphere. Any ceramic analysis needs to assess these technical choices and infer how they relate to function.

Chapter 3 discusses the processes for the deposition of external soot and internal carbonization. The chapter begins, however, with an introduction to the Kalinga and the ethnoarchaeaological project that initiated the original research. The principles of soot and carbonization deposition are outlined and a strategy for recording and analyzing these traces is presented. Besides the Kalinga case study, I present a number of archaeological examples of researchers inferring use behavior from the external and internal carbonization patterns. The case studies include Ken Sassaman's (1993) examination of external sooting patterns on Late Archaic pottery from the Southeastern United States. The study of internal carbonization patterns is illustrated with my own study on the earliest pottery on the Colorado Plateau in the Southwestern United States. In this study I also examine the intended function of the vessels by linking the technical choices (morphology, paste characteristics, surface treatments) to various performance characteristics. I conclude this chapter with a discussion of the strategy for recording carbonization patterns on whole vessels and sherds and how to move from the archaeological samples to inferences about actual pottery function.

Attrition is the topic of Chap. 4. After outlining the principles of ceramic attrition I review a number of case studies that illustrate clearly how these types of traces can be used to infer use activity all along the vessel's behavioral chain. After reviewing the Kalinga case study, I discuss several projects that linked various attritional traces to use. This includes Griffith's (1978) study of cutlery marks on lead glazed historic ceramics and Bray's (1982) examination of attrition on the interiors of Classic Period Mimbres bowls from the Southwestern United States. Hardin and Mills (2000) provide a more recent study of a ceramic collection by recording use attritional traces on ceramics to aid them in understanding the rate of stylistic change. I also illustrate in two case studies how attritional traces can be used to infer that sherds were being used as tools (López Varela et al. 2002; Sullivan et al. 1991; Van Buren et al. 1992). Finally, I discuss two case studies that link alcohol fermentation in ceramic vessels with a specific type of interior attritional trace (Arthur 2003; Skibo and Blinman 1999). As with Chap. 3, this chapter is concluded with a discussion of how researchers should go about recording attritional traces and linking them to specific use-activities.

Chapter 5, the final chapter, focuses on organic residue analysis. I spend some time discussing my attempt at residue analysis with Kalinga sherds, which was one of the early applications of this technique on pottery, and review the burgeoning literature on the topic. This chapter is co-authored with Mary Malainey, an expert in this technique, to give the reader the most up-to-date discussion of not only how to do residue analysis but also the issues of preservation and identification that have affected these studies for the past two decades. The various techniques are reviewed as well as the problems with diagenesis (post-burial deterioration). The case studies focus on successful applications of lipid analysis that range from the Upper Great Lakes and Western Canada, to the Southeastern and then Southwestern United States. Garraty (2011) investigated the earliest pottery in southeastern Arizona, which are globular neckless, jars, and explored the function of these vessels with an analysis of absorbed lipids. He found that the vessels were used to process a variety of different plants and animals, which countered the notion that these vessel forms are only used for storage. Finally, I review a long-term study by Reber and her colleagues (Reber and Evershed 2004a, b; Reber et al. 2004) who are exploring lipid biomarkers for maize. The introduction and spread of maize in North America is of enormous interest and they utilized a multi-faceted approach that not only included study of the absorbed lipids but also a paleoethnobotanical and stable carbon isotope analysis.

Using Chap. 2 as a guide, the researcher can offer inferences about the intended functions of ceramics. Chapters 3, 4, and 5 present an integrated approach to the various lines of evidence that can be used, singly and in combination, to infer actual uses of pottery. As the study of pottery function is still in its infancy, I hope that the pioneering studies discussed in this volume will stimulate researchers to elaborate the principles and techniques so that the study of pottery function will continue to advance.

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Chapter 2
Intended Function: Inferring Manufacturing Performance

> *Early studies of ceramic function tended to dwell in this realm (intended function), and were based on fast and loose reasoning drawn from intuitive expectations …. (Rice 1996a, p. 140)*

In the last two decades "fast and loose" reasoning, as Rice notes above, have given way to stronger inferences based on principles derived from materials science, ethnoarchaeology and experimentation. This chapter reviews this growing body of research, which has gradually transformed pottery analysis in archaeology from poorly supported reasoning to much stronger inferences regarding intended vessel functions. Although the focus of this book is actual pottery function, a complete pottery analysis should consider both sides of the functional equation.

An analysis of intended function starts with this simple premise—all pots are designed to be used. That is, the potter made technical choices related to performance in manufacture and use in accord with the vessel's intended function(s), whether techno-, socio-, ideo- or emotive-functions. Although all aspects of function can be important in the design of a vessel, the overwhelming primary function of ceramic vessels, both prehistorically and ethnographically, is in processing, storing, and transporting food and liquids (Rice 1987, pp. 207–208). When Braun (1983) famously stated that we should consider "pots as tools" he was referring to the fact that ceramic vessels, like their chipped stone counterparts, have uses. We now take this perspective for granted, but it is worth noting that the focus for ceramic analysis was once primarily on stylistic factors through time and across space. Although chipped stone analysis also focused on stylistic variability, no one questioned that lithics were tools used to cut, scrape, drill, pierce, etc. Below I review the relationship between technical choices at the disposal of the potter and the relevant performance characteristics keyed to the vessel's intended function.

Potters can control the formal dimension of ceramic variability, which includes the metric properties of form (morphology), paste characteristics, firing conditions, and surface treatments (Bronitsky 1986; DeBoer 1984; Reid 1990; Steponaitis 1983, 1984; Tite 2008; van As 1984). Inferring intended function of vessels is a two step

J.M. Skibo, *Understanding Pottery Function*, Manuals in Archaeological Method, Theory and Technique, DOI 10.1007/978-1-4614-4199-1_2,

process. The first step is to understand technological variability. For example, one must first determine the temper type, size, and surface treatments, etc. as these are the technical choices made by the potter. An entire suite of analytical procedures that range from simple observation to molecular chemistry are at the disposal of archaeologists wanting to understand the technological variability of their sherds and vessels. The second step is to link the potter's technical choices, like a resin interior coating or large orifice diameter, to intended performance. These two steps are discussed below for each of the major technical choices related to pottery manufacture and use: shape, size, and form (morphology); temper type, size, quantity, clay chemistry and mineralogy (paste composition); firing temperature, atmosphere, and conditions (firing); and interior and exterior surface additions such as slips or resins, or modifications, as in texturing or corrugation (surface treatments). This review is followed by a discussion of how these technical choices and performance characteristics can be used to infer intended vessel function. Several types of pots in three of the major techno-functional categories, cooking, storage, and transport, are used as examples to demonstrate these points. Finally, using examples from around the globe, this chapter closes with a discussion of how archaeologists can use sherd collections to make inferences of intended function.

Understanding Technical Choices and Performance

As Rice (1987, pp. 208–210) notes, the techno-function of domestic pottery takes place in three realms: storage, processing (or transformation), and transfer (or transport) (see also Buko 2003; Smith 1988). Potters make design choices in form, temper type, surface treatments, etc., to create vessels to perform these roles. Thus, a liquid storage pot might be large with a restricted orifice on which a cover can be affixed, and a cooking (processing) pot might have a round base, for strength, and an open orifice to permit easy access. Because of its fragility, pottery is often not the first choice for transfer of goods, but sometimes a vessel's other performance characteristics outweigh its tendency to suffer breakage. This is especially true in the transfer of liquids like wine or olive oil, which moved about in pottery vessels for millennia with the help of ships or wheeled transport. But within each basic category, vessels can be designed specifically to store, transport, or process specific foods or liquids—thus, the shape, temper type, surface treatments, etc. could reflect whether a vessel's contents were hot or cold, wet or dry, transferred a short or long distance, among other features of specific activities (see Rice 1987, p. 208). There are myriad activities or characteristics of an activity along the behavioral chain of a vessel that can affect its form.

Morphology

Anna Shepard was one of the first to note the importance of recording shape-related metrical properties. She states that the "study of vessel shape can be approached from the standpoint of function" and that "the purposes of the vessels tell something of the activities and customs of the people who used them" (Shepard 1956, p. 224). Although Shepard notes the importance of linking form to function, her emphasis was really on documenting shape for classification and taxonomy, which dominated all artifact analysis at the time. It is in this context that Linton published the important article "North American Cooking Pots." He states that "there is a tendency to underrate the importance of simple utilitarian artifacts [like cooking pots] of types which are widely distributed in time and space" (Linton 1944, p. 369). Although most ceramic archaeologists were concerned with time-space systematics and not vessel use, he clearly points the way for more sophisticated functional inferences (Reid 1990). Linton goes on to note that an "effective cooking pot must have a mouth large enough to prevent explosive boiling over and to permit of stirring its contents, but at the same time small enough, relative to the pot's capacity and heating surface, to prevent it from boiling dry every few minutes" (Linton 1944, p. 370). He clearly was on the right track in linking what I would call technical choices to performance characteristics important for cooking vessels. Despite this effort by Linton to draw pottery analysts to a more functional approach, his article seems to have had little impact at the time. Even Shepard (1956, p. 224), who was sympathetic to functional analysis, noted that linking form to function was complicated and there were still too many unknowns in this line of research. Nonetheless, it was these early attempts at documenting shape and form for the purposes of classification that set the stage for stronger functional inferences about pottery (Ericson et al. 1972).

Rice (1987, p. 207) notes that "morphological characteristics—their attributes of shape and technology—are closely related to their suitability for a particular activity." There are plenty of good resources at the disposal of the ceramic analyst for linking form and function (e.g., Buko 2008; Orton et al. 1993; Rice 1987; Riemer 1997; Smith 1985, 1988; van As 1984). Sometimes these correlations are regionally specific, but there are also many cross-cultural correlations that are important (Roux 2007). The methods to illustrate, record, quantify, and classify vessel form are well illustrated by Rice (1987), whose examples are primarily from the American continent, and Orton et al. (1993) whose focus is mainly European. Their work is quite thorough and I cannot do more than summarize their findings.

Recording Morphological Variability

Orton et al. (1993, pp. 152–165) divide classification systems for vessel shapes into three categories: type series, measurement-based systems, and manufacturing stages. The type series is the system of classifications found in every part of the world and was devised primarily in the late nineteenth and early twentieth centuries. In North America, each regional sequence of types has a long history, usually tied to a few influential archaeologists who were first to work in an area and were most responsible for defining the culture history, which was based, in many cases, on pottery types that they too defined (e.g., Colton 1939; Ford 1938; Gladwin and Gladwin 1930; Kidder 1924; McKern 1939; for a review of this period see Lyman and O'Brien 2003; Lyman et al. 1997; O'Brien and Lyman 1998, 2003; O'Brien et al. 2005). Most pottery classification in North America can be traced to these early scholars who created the types, for the most part, to recognize prehistoric cultures that they could trace through time and across space.

Although, most archaeologists today do not believe that a collection of traits, including pottery types, equals a prehistoric culture, we are still left with the legacy of these types. An archaeologist must be able to identify Snowflake Black-on-White in the American Southwest, Laurel Incised in the Upper Great Lakes, Deptford Stamped in the Southeast, Plumbate from the Maya Lowlands, and Beaker Ware in England. What these types "mean" is open to debate, but that does not keep us from training each new generation of archaeologists to have at least a passing knowledge of these types. This is helpful because the types are not only minimally tied to specific times and places but anyone attempting to learn the archaeology of a region must be able to master the local jargon including the major pottery types. However, when I teach ceramic analysis or the archaeology of the Midwest, the classes are not devoted to memorizing pottery types and sequences, as might have been the case in James Griffin's classes at the University of Michigan in the 1960s. Today's archaeologist, nonetheless, still must have a familiarity with the major ceramic types, particularly those that have been linked to well-dated contexts. At a local professional archaeology meeting such as the Midwest Archaeological Conference, pottery types like Heinz Creek, Black Duck Banded, or Ramey Incised roll off the tongues of the speakers and all in attendance can visualize the design, shape, and other formal properties of these vessels. Speakers at the Pecos Conference in the American Southwest would hear pottery types like Tanque Verde Red-on-Brown or Salado Polychrome and those in attendance would know exactly what they are referring to. In modern archaeology, such classifications are not an end in themselves as these categories have little relevance in a performance-based investigation that seeks to infer the range of vessel functions. These "blunderbuss categories," as we have referred to "style" and "function" previously (Schiffer and Skibo 1997, p. 43), even when given new names like "technological style," can get in the way of understanding the performance of the vessels. Nonetheless, students still need to have a working familiarity with the pottery types and sequences in their areas of interest as long as there is an awareness of the limitations that these categories bring.

Formal and measurement-based classification (Orton et al. 1993) came about as a means to create more universal systems to describe and classify pottery assemblages. Smith (1988), in a cross-cultural analysis of whole vessels, found three metrical properties that are particularly relevant when correlating form to function: (1) the relative openness of the vessels profile, which is the ratio of the circumference of the lip to the total external surface area; (2) diameter of the vessel rim; and (3) the total volume. Using a series of statistical measures he found these properties to be particularly useful for determining if a pot was used for processing, storage, or transfer. Using a Southwestern United States ethnographic and archaeological collection, Smith (1985, p. 305) also came up with five "morphological correlates of use." They include:

1. Orifice size is proportional to the amount the contents are changed.
2. Serving of liquids or solids correlates with rim forms that do not curve inward.

3. Orifice size is inversely proportional to the duration of storage time.
4. Vessels that require access to the contents during use will have an orifice big enough for hand access.
5. Vessels used to transport liquids have a small orifice diameter.

These types of correlates can serve as a baseline for making more specific inferences about function from form.

The final classification category noted by Orton et al. (1993, pp. 163–165) is that of manufacturing stages. By this they mean classifying pottery based on manufacturing methods, such as the fast wheel, mold making, or hand modeling (Balfet 1984). Using traces on the vessels themselves, they infer the manufacturing life history, or *chaîne opératoire*. The Laboratory for Ceramic Studies at the University of Leiden has been especially active in increasing our understanding, through experimentation, ethnoarchaeological research, and the analysis of archaeological materials, manufacturing processes and stages, and how they may be inferred from traces on the vessels themselves (van As et al. 2008; see also Stilborg 1997). The focus is "on the translation of the phenomena observed on a pot or fragments of a pot, into the reconstruction of aspects of the potter's craft" (van As 1984, p. 131). I do not see this as a classification system so much as a critical component of any pottery analysis. Such holistic ceramic research has been going on in Leiden, mostly focusing on pottery from the Near East, for several decades with great success (e.g., Annis 1985; Franken 1975; London 1991; van As and Jacobs 1995), and much of the relevant research is published in the *Leiden Journal of Pottery Studies*. Students of ceramic research would be well served to become acquainted with their holistic system of analysis.

Performance Characteristics and Morphology

Morphology can be described and classified in many ways, and so the analyst needs to choose a strategy appropriate for the assemblage under investigation. When one's goal is to infer intended techno-function, these technical choices related to vessel morphology are grouped in relation to the performance characteristics they affect. Rice (1987, pp. 224–226) identified four performance characteristics related to vessel morphology, but she referred to them as "use-related properties." They are capacity, stability, accessibility, and transportability. Although other technical choices may affect these performance characteristics, they are impacted most directly by morphological characteristics. When the discussion is moved to performance characteristics, or the attributes the vessels must have to perform its functions, the analyst is in a much better position to infer intended function. A profitable way to access these performance characteristics is through a performance matrix, as illustrated in Table 2.1.

Capacity is the one performance characteristic related to morphology that can be easily assessed quantitatively as in liters or gallons. One must be aware, however, that vessels will have a maximum capacity and an actual capacity. In many use-contexts a vessel is not filled to its maximum capacity (but see Kooiman 2012);

Table 2.1 Performance matrix for Kalinga pottery vessels

	Vessel type		
Performance Characteristics	*Rice*	*Vegetable/meat*	*Water*
Accessibility	Low/medium	High	Low
Stability	Medium	Medium	Low
Transportability	Medium	Medium	Low
Capacity	Variable	Variable	Variable
Heating effectiveness	High	Medium	N/A
Thermal shock	High	High	N/A

cooking pots are often just filled to half or three-quarters overall capacity. Differences between maximum capacity and actual capacity can be determined by other use-alteration traces such as internal carbonization (see Chap. 3).

Stability is the ability of the vessel to stand upright. Shepard (1956, p. 237) notes that stability is determined by a vessels "shape, the distribution of its weight, and the breath of its base." Some vessels are flat bottomed or have legs and thus have high stability. Some round bottom pots have moderate stability in that they will stay in the upright position while on a flat surface but they will rock easily when nudged. Kalinga cooking pots are in this category, as are many Southwestern and Midwestern United States cooking pots that have round bottoms. A curved base increases strength but decreases stability, which is mitigated by having a tripod-like hearth design so that vessels rest securely on three points, sometimes referred to as "firedogs." When not on the fire, unstable pots could be placed on pot rests or concavities in the hearth or floor, as is done by the Kalinga. Some vessels have zero stability and cannot stand upright on their own. The Gamo of Ethiopia create cooking vessels that need support to stand upright (Arthur 2006), and many of the pottery types from the Eastern United States have conical bases as do Middle Eastern amphorae. In cases when pots have zero stability they must depend on other technologies to hold them upright.

Accessibility is a performance characteristic that relates to how easily the contents of the vessel can be accessed. The orifice diameter and the attributes of the vessel's neck have the greatest impact on accessibility. Many storage jars have a restricted orifice diameter and limited accessibility, so that neither hand nor an implement ever enters the vessel. In these cases, as is in liquid or seed storage, the contents are designed to be removed by pouring. The other extreme is complete accessibility, which is seen in many cooking pots whose contents have to be stirred and then removed by hand or with a utensil. Kalinga cooking pots provide a clear example of slight differences in accessibility: vegetable/meat cooking requires frequent stirring and a higher overall accessibility, but rice cooking pots are only accessed once when the rice is removed. Rice cooking pots thus have a narrower orifice diameter to limit accessibility (and also increase heating effectiveness).

Transportability relates to how easily the vessels can be moved short or long distances. Ceramic vessels in general are not known for great transportability as vessels are fragile and heavy, relative to other containers. But ceramic vessels are

Fig. 2.1 Kalinga vessel types. From left to right, *immosso* (water vessel), *ittoyom* (rice cooking vessel) and *oppaya* (vegetable/meat cooking vessel) (From Skibo (1992), p. 60)

well suited to holding liquids, and if the fragility issue can be countered by other technical choices to increase strength and with other technologies to avoid impacts (supports, wheeled carts, etc.), then such vessels will have increased transportability. Most vessels, however, have relatively low transportability and are designed to move relatively short distances, if at all. Kalinga water vessels have very low transportability when full, as they are heavy and awkward to carry. Consequently, many pots spend their entire life history on a shelf where they are refilled with water transported in other vessels. Most cooking pots have some limited transportability as they must travel on and off the fire. Such movement puts a limit on capacity because it becomes very difficult for one person to move a large vessel on and off a fire. Short-distance transport can be aided by implements, which can be used to grasp pots, an especially important consideration if they are removed hot.

Let's examine an ethnoarchaeological example from the Kalinga to illustrate the relationship between morphology and performance. The Kalinga have a water vessel (*immosso*) and, as noted earlier, two basic cooking pot forms; one to cook rice (*ittoyom*) and the other to cook vegetables and meat (*oppaya*) (Fig. 2.1). Each of the cooking vessels is made the same way in terms of paste, surface treatment, and design. The only design difference relates to accessibility and heating effectiveness; the latter is the ability of the vessel to heat its contents. Heating effectiveness, like most performance characteristics, is influenced by a variety of technical choices like thickness, temper type, and especially surface treatment. In this case, heating effectiveness is a secondary performance characteristic related to morphology (a more complete discussion of cooking pot performance involving all relevant technical choices is presented below).

An archaeologist who discovered Kalinga pottery in archaeological context would be able to correctly discriminate these two types of cooking vessels based upon measurements of the orifice diameters and the height-to-width ratio (except in the cases of the intermediate forms discussed in Chap. 1). The vegetable meat pots have a more open orifice diameter and are more squat in profile while the rice cooking pots

Fig. 2.2 Kalinga vessels in use. Rice cooking pots (L) is in the simmer position while the vegetable/meat pot is on the fire (From Skibo (1992), p. 137)

have a narrower mouth and are taller in profile. The metrics speak clearly to accessibility. Rice cooking pots are accessed only when the rice is added to the pot and then again when it is removed with a spatula-like wooden tool. Rice pots are put on the fire until the water boils, then the vessel is removed and placed next to the fire. Rice cooking pots stay on the fire for 20 min or so and are not accessed during this time (Fig. 2.2). Vegetable meat pots, on the other hand, can stay on the fire for over an hour (in the case of boiling beans) and are accessed many times to stir, add other ingredients, and then to ladle out the contents for serving. Accessibility, a primary performance characteristic, is clearly reflected in vessel morphology.

Transportability of the cooking vessels is rated as "medium" because both are carried when full and empty. Hot pots are taken off the fire with the help of a rattan tool that looks much like a belt, which is slid over the top of the rim and fits nicely around the neck (Fig. 2.3). Hot pots can then be moved off the fire without touching the hot ceramic surface. Kalinga vessels are also made so that they can be nested and stacked. Potters transport the vessels in this way, as do women returning from the water source, where the vessels are washed and then filled with water (Fig. 2.4). Two or three nested cooking pots filled with water are carried back to the house on a woman's head, and the water from these vessels then fills the water pots.

The water vessel (*immosso*), with low accessibility, stability, and transportability is clearly a vessel designed for liquid storage. Stability is the only performance characteristics that could be higher in these types of vessels, but the Kalinga compensate for low stability by placing the vessels on rattan rings (Fig. 2.5). Once in place on the shelf, the water vessels are rarely moved.

Fig. 2.3 A pot being placed on the fire with the use of a rattan pot carrier (From Skibo (1992), p. 66)

Fig. 2.4 Carrying nested pots, filled with water, back from the water source (From Skibo (1992), p. 77)

Fig. 2.5 Pots in use resting on rattan rings (From Skibo (1992), p. 66)

Heating effectiveness is a secondary performance characteristic but is still important to the overall performance of these two cooking vessels. The objective in rice cooking is to bring the contents to a boil as fast as possible, and heating effectiveness of the rice cooking pots is increased by the smaller orifice. Rice cooking pots are also covered while on the fire, which also increases heating effectiveness. Because heating effectiveness is such an important performance characteristic for rice-cooking vessels, it is no surprise that aluminum pots had almost completely replaced their ceramic counterparts (Skibo 1994). Vegetable meat pots, in contrast, with their wider mouth have poorer heating effectiveness and are also left uncovered while on the fire. The goal for vegetable meat cooking is to bring the contents to a simmering temperature but without boiling and boil over. Consequently, poorer heating effectiveness is preferred because it permits the pot to stay on the fire for a long period without boil-over, which leads to the inconvenience of a doused fire.

Paste Composition: Temper (Type, Size, Shape, Quantity) and Clay (Type, Chemistry)

Owen Rye is a potter who, much like some of the early flintknappers like Don Crabtree pointed the way for functionally based lithic analysis, contributed significantly to the functional study of pottery and our ability to link technical choices to performance (Rye 1976, 1977, 1981; Rye and Evans 1976). His 1976 article, “Keeping your temper under control,” is not only one of my favorite titles but also important for understanding the clay-temper dynamic in traditional pottery. Rye spent a great deal of time replicating various types of ceramics and, much like Crabtree, believed that replication is an important means to understand a traditional technology. The importance of the early flintknappers, like Crabtree and Bordes, is that they played a big role in understanding a technology that was no longer in use—a dead technology. Ceramic technology, of course, never died, and one can visit a local pottery studio where people might be performing tasks similar to those of early Neolithic potters of Europe or Woodland potters of the Eastern United States. Because pottery technology never “died,” there is a tendency to take it for granted. After all, most of us made functional vessels in grade school and coerced our mothers to display these works of “art.” But just because a 10-year-old child can make a pot does not mean that it is a simple technology. Pottery technology is much like playing a harmonica, where anyone can play a recognizable tune with just a little instruction, but it takes years of practice to bend notes and master the Blues’ riffs of James Cotton or Howlin’ Wolf. It is researchers like Rye, and Shepard (1956) before him, who paved the way for archaeologists to better understand the complexities of making pottery. One of the wonderful legacies of the earliest flintknappers is that there is the unwritten rule that anyone who studies lithics should be able to perform at least rudimentary flintknapping so that they can learn firsthand the skill involved in this craft. Unfortunately, a parallel does not exist among many ceramic analysts (with some notable exceptions such as the Lieden or Scandinavian Schools discussed above). I would think that Owen Rye would agree with the statement that anyone who studies ceramics should also have experience with making and or replicating pottery. Although there are many books on pottery, as there are now many books on flintknapping, the knowledge and appreciation for the craft that one acquires with hands-on experience is invaluable. I said at the outset that ethnoarchaeology changed forever the way I view pottery and its relationship to people. The same can be said about replicative experiments with clay. It is one thing to read about how, for example, temper affects workability, firing temperature impacts thermal shock, or how a smudge is applied, but it is another thing to feel the workability of wet clay change as organic temper is added or to feel the heat of a kiln as a red hot vessel is removed for smudging.

The relationship between morphology and techno-function has a long history because, in part, it is much easier to perceive the relationship between a vessel’s orifice diameter or shape and likely use. The relationship between temper and techno-function took a bit more convincing and is still a work in progress. As Bronitsky and Hamer (1986, pp. 89–90) note, temper type has long been considered an attribute most tied to cultural factors instead of techno-function. Although temper selection in some instances may be related to socio-, ideo, or emotive function, archaeologists have started to explore how the choice of a particular temper might have an impact on how the vessel performs during manufacture and use (Braun 1978, 1983; Bronitsky 1986; DeBoer 1984; Reid 1984; Steponaitis 1983, 1984).

In the mid-1980s while I was still a graduate student at the University of Arizona, I walked into the newly formed Laboratory of Traditional Technology and saw

Gordon Bronitsky kneading a lump of clay on top of a wooden crate. Michael Schiffer created the lab and acquired space in the Haury Building with a mix of creativity and bravado (see Schiffer 1995, pp. 22–24). I was the first graduate assistant and was given the honorary title of Assistant Director of the laboratory, which had no space. But Schiffer and I acquired several truck loads of donated scientific equipment, some of them packed in wooden crates. We stacked the wooden crates and odd assortments of equipment in the hallway of the building until some of the department's faculty started to complain about the mess and congestion. The Department Chair asked us to move the equipment into a recently vacated room on the first floor of the building. We were instructed that this was only a temporary move, as the Department had other plans for the space. But we moved in, quickly put a sign on the door, and a quarter century later and counting the Laboratory of Traditional Technology still resides in that same room. The equipment, however, was donated to surplus property at the University, who sold it at auction, with the Lab getting a portion of the proceeds. A good mentor like Mike Schiffer teaches many important lessons, but none was more practical than how to acquire space and funds in a university system.

It was in the midst of this move that Gordon Bronitsky appeared, fresh from a Fulbright in Holland at the University of Leiden's Laboratory of Ceramic Studies. There he studied with van As and others who had a long-standing interest in the relationship between ceramic technology and use. Bronitsky advocated a materials science approach to archaeological ceramics (Bronitsky 1986; Bronitsky and Hamer 1986). Schiffer was, and still is, a studio potter, but Bronitsky introduced a new way to look at ceramics. I had a long-standing interest in prehistoric ceramics and also a growing interest in experimentation and ethnoarchaeology. In 1987 I took a sojourn from the lab to join Longacre in the Philippines to conduct the research that would become *Pottery Function* (1992). Thus, the initial direction of the Laboratory of Traditional Technology was created by this convergence of people and ideas. There was a flurry of replicative experiments in the next several years that contributed greatly to our understanding of the relationships between temper, firing temperature, and surface treatment and ceramic performance in manufacture and use.

The first of the experiments had to do with the effect of temper on vessel performance. I participated in an American Anthropological Association symposium, organized by Bronitsky, where I met Kenneth Reid, who had excavated the site of Nebo Hill in Kansas. Through careful recovery methods he found small sherds (crumbs) of Late Archaic fiber-tempered pottery. This was one of the northernmost locations for Late Archaic pottery, which led Reid (1984) to suggest that perhaps the distribution of the pottery type, which was confined primarily to the southeastern United States, was created in part by noncultural formation processes—freeze thaw cycles. In fact he found a correlation in the distribution of pottery and the number of below freezing days. Though just a second year graduate student, I approached Ken Reid after the session and stated that we could test this hypothesis in the newly formed Laboratory of Traditional Technology. When I told Mike Schiffer of the plan he got to work and somehow acquired a heavily used but still functional freeze-thaw chamber. That led to a series of experiments that looked at the relationship between temper-type and firing temperature and vulnerability to breakdown in freeze thaw cycles (Skibo et al. 1989). Reid was right: low-fired fiber-tempered pottery was indeed very vulnerable to breakdown. But we also used this opportunity to look at the performance advantages that fiber-tempered pottery might have. The results of these tests are discussed below.

Recording Paste (Clay and Temper) Variability

Chemical and mineralogical characterization of pottery has a long history in archaeology, for we are interested in learning where pottery was made (e.g., Abbott 2000; Carter et al. 2011; Neff 1992; Neff and Bishop 1988; Stoltman 1989, 1991, 2011; see Rice 1987, 1996b; Velde and Druc 1998; for a review of the various techniques). This area of study is, of course, of critical importance as it provides basic information on which to build inferences about the organization of production, exchange systems, and political economy. There have been many studies throughout the pottery making world that have used a variety of characterization techniques to speak to these important issues (Abbott 2000; Rice 1996b; Bishop et al. 1982; Fargher 2007; Middleton and Freestone 1991; Neff 1992; Stoltman 1989, 1991). Sourcing clay and temper will always be the primary concern in this type of analysis, but these same characterization techniques can also be applied to understanding intended function. The underlying assumption is that potters select clay and temper usually within a short distance from the point of manufacture. There are a lot of ethoarchaeological data to support this generalization (Arnold 1985; Arthur 2006, p. 31; Longacre 1985; Neupert 2000). Clay and temper are difficult to transport, so there is a strong correlation between clay and temper sources and the location of manufacture. Arnold (1985, pp. 31–57) has done the most extensive examination of this relationship and has found that most clay and temper are found within 7 km of the potters workshop. Although potters choose nearby clay and temper, they still do have choices among the nearby sources. It is these choices that are of interest here (see Neupert 2000).

Performance Characteristics and Paste Composition

Paste composition (clay and temper) affect performance both in manufacture and use. Manufacturing performance characteristics include workability, and ease of manufacture.

Workability is a potter's assessment of the clay in relation to specific forming techniques (for present purposes, hand-building). As Bronitsky (1986, pp. 212–218) notes, three clay properties are of interest to the potter: controllability, formability, and plasticity. Potters usually collapse these properties by feel into a general category of workability (Rice 1987, pp. 60–63; Rye 1981, p. 21). Potters assess workability by testing the clay's ability to bend, as in a coil, without cracking, and to hold the form under pressure. Clay can be "soft," which means the paste deforms easily but does not hold up under pressure, to "stiff," in which the clay is hard to form yet holds up well under pressure. Workability is based on the relationship between clay mineralogy, water content, presence of organics, and temper. For example, generally speaking clay because less workable—more stiff—as more mineral temper is added. Some large vessels, however, may require a stiffer paste, and adding more temper would create that effect. Dry organic temper, such as chopped grass, can make a very soft, plastic, sticky clay workable because it absorbs some of the moisture (Skibo et al. 1989).

Ease of Manufacture is a component of workability in that it is an assessment of how much time and effort is necessary in the construction of a vessel. Some pots are manufactured in stages sometimes over several days and require various tools and skills to produce, while other pots are made in one sitting and a potter can go from wet clay to finished fired vessel in one day. Temper and paste properties play a significant role in ease of manufacture. For example, a pot with 40% mineral temper, which is common in cooking pots, can be very difficult to manufacture. The clay is excessively stiff, prone to cracking when bent, and the surfaces are not easily smoothed. Less temper, let's say 20%, would increase the ease of manufacture but reduce its effectiveness as a cooking pot. We demonstrated (Skibo et al. 1989) that ease of manufacture was a primary performance characteristic for Late Archaic fiber-tempered pots in the eastern United States. If potters were interested in making a vessel in one sitting, they could collect surface clay, which is often excessively plastic and too sticky to be workable, but add organic temper to absorb the moisture and increase workability. Such a vessel would then be dried next to the fire and then placed into the fire where the clay could sinter, making a serviceable cooking pot. Expediency is important in these contexts.

Some of the performance characteristics important in use include thermal shock resistance, cooling effectiveness, portability, impact resistance, and abrasion resistance.

Thermal shock resistance is the ability of a vessel to withstand repeated exposure to heat without cracking. If a pot is used for boiling, then the interior would not exceed 100 °C, while the exterior could be 500 °C to 600 °C. The outer surface expands, creating tensile stresses that form micro cracks. Unless impeded, these micro cracks will pass through the entire vessel and result in catastrophic failure. A vessel with low or no thermal shock resistance would break with the first exposure to heat. Anything that interrupts these micro cracks, like temper or pore spaces, increases thermal shock resistance. It is no coincidence, therefore, that cooking vessels around the world often have a heavily tempered paste.

Cooling effectiveness refers specifically to water storage vessels. Pots having some permeability will permit the passage of water to the exterior surface where it evaporates, removing heat and thus cooling the vessel's contents (Schiffer 1988). Although permeability is influenced also by firing temperature and surface treatments, paste characteristics can also alter cooling effectiveness. Thus pots with much more mineral temper have greater permeability.

Portability simply refers to how easy it is to transport the vessel over short or long distances. Certainly size, shape, strength, and the availability of other technologies affect portability considerably, but so can paste. For example, organic tempered pottery can be up to 30% lighter than similar sand tempered pottery, which could be a factor in vessel portability (Skibo et al. 1989)

Impact resistance is the ability of a pot to resist impacts, which is the most common way vessels ultimately break. Pottery, compared to other containers such as baskets or skin bags, has very low impact resistance, but because of other important performance characteristics ceramics are used regardless of the high probability that they will break one day from an impact. It has been shown that there is a significant relationship between temper type, amount and size and impact resistance (Bronitsky and Hamer 1986; Mabry et al. 1988; Neupert 1994).

Finally, *abrasion resistance* is the ability of the vessel to resist the loss of surface material through various types of cultural or noncultural processes such as trampling or fluvial transport. Temper type and amount can alter the abrasion resistance of pottery significantly (Skibo and Schiffer 1987; Vaz Pinto et al. 1987). For example, organic tempered pottery is more prone to abrasion under a variety of conditions than similarly made mineral tempered pottery.

To illustrate the relationship between paste composition and performance, let's turn to a series of experiments focused on understanding the use of organic temper in the Late Archaic of the Southeastern United States. This case study illustrates how temper and clay selection affect workability and ease of manufacture, portability, heating effectiveness, thermal shock resistance, and abrasion resistance.

Case Study: Late Archaic Pottery

The Early Woodland in the Eastern United States was initially defined by the appearance of pottery but better dated sites and more careful excavation revealed that Late Archaic hunter-gatherers were actually the first potters in North America (Reid 1984). This is a story that is repeated in many parts of the world as no longer can archaeologists simply equate the appearance of pottery with the "Neolithic Revolution" and the transition to more settled life and plant cultivation. Pre-agricultural hunter-gatherers are often the first potters in a region (Harry and Frink 2009; Harry et al. 2009; Frink and Harry 2008; Jordan and Zvelebil 2009; Sassaman 1993; Skibo et al. 2009). Many of these hunter-gatherer potters tempered their vessels with organic matter of some sort, usually a kind of dried grass.

Prior to our work the choice of organic temper was often given some form of "cultural" explanation, such as the people were making a transition from baskets to pottery and grass temper was a bridge between these two technologies. Such explanations did not consider how a temper selection might influence the performance of the vessel in manufacture or use (see also Sassaman 1993). Our experiments considered two general questions; Why did Late Archaic potters use organic temper, and why do all potters across the Eastern United States switch to sand temper during the Early Woodland?

The results of the experiments can be summarized in a performance matrix (Table 2.2).

Table 2.2 A performance matrix for late Archaic and Woodland pottery technology (Adapted from Schiffer and Skibo 1987, p. 607)

Performance characteristic	Late archaic	Woodland
Ease of manufacture (expediency of manufacture)	+	−
Portability	+	−
Heating effectiveness	−	+
Impact resistance	−	+
Thermal shock resistance	−	+
Abrasion resistance	−	+

Based on this series of experiments, organic tempered pottery scores better than comparable sand tempered pottery in two important performance characteristics—ease of manufacture and portability. In terms of portability, I noted above that organic tempered pottery is lighter than sand tempered pottery of equivalent form. Although overall weight is not the only issue in portability it could certainly play a significant role under some conditions. We concluded, however, that ease of manufacture was the most important and thus primary performance characteristic for the Late Archaic potters of the Southeastern United States.

Recall that ease of manufacture is a suite of performance characteristics that includes plasticity, green strength, and drying rate, among others. The aspect of ease of manufacture that we think explains the presence of organic temper in this 2,000 B.C. pottery relates to expediency of manufacture. If one wants to make a pot quickly, perhaps even in one sitting, the fastest way to do that would be to collect wet clay, which is abundant in the Southeast United States. Such alluvial clay, however, is excessively plastic, sticking to the potter's hands and to surfaces to such an extent that forming a vessel is virtually impossible. Our experiments have shown that adding mineral temper does not ameliorate this excessive plasticity, but that adding chopped dry organic matter, as in Late Archaic pottery, dries the paste and increases workability to the point where a vessel can be formed. Simple open forms, as was common in this technology, can be made using the slab technique. Such a vessel could then be dried quickly next to the fire and then placed directly in the fire. Late Archaic pottery was fired to a very low temperature that could be reached in a simple open fire.

In order to better visualize the appearance of pottery in the Southeast and then the transition to mineral tempered pottery, imagine that you are part of a band of hunter-gatherers in what is today Georgia arriving at a Fall campsite. Your group has been coming to this same campsite for generations to harvest shellfish and to collect the local nuts and other autumn resources. At this campsite there is a need for cooking vessels to process food (The story is a little blank here because it is still unknown what was processed in these pots—an analysis of absorbed residues is needed on these collections). Your group arrived at the campsite by mid-morning, dug up some wet clay, added chopped dry grass, and made simple vessels very quickly. In the early evening the vessels were placed in the fire and then pulled out the next morning. After just a few hours of work the small group had a serviceable cooking pot that could have been placed directly over the fire.

The transition to mineral tempered pottery that occurred in the Eastern Woodlands and in many other parts of the world can also be explored by examining the performance matrix. Mineral tempered pottery score higher on all other performance characteristics related to cooking pots and vessel durability: thermal shock resistance, heating effectiveness, impact resistance, and abrasion resistance. Once the Woodland potters became more committed to ceramic technology, they made choices better suited to their lifeway and cooking vessels. If expediency was no longer a concern, potters likely collected dry clay, ground it up, added temper and water, and perhaps let the clay sit for a time (aging it) before making vessels. Such a process would take several days instead of just 12 h or so for the Late Archaic vessels.

Some have suggested that the poor heating effectiveness of organic tempered vessels might be because the containers were used for indirect heating with hot rocks instead of placing them directly over a fire (Reid 1989; Sassaman 1993). If such were the case, then you would actually want a vessel with poor heating effectiveness to retain the heat instead of conducting it through the wall (Reid 1984). In the case of the Late Archaic vessels, however, Beck et al. (2002) found evidence of exterior soot on a significant number of sherds from a sample. Sassaman (1993) also found evidence of sooting on the collection he analyzed, thus it is certain that a good portion of the early pottery was used over a fire. In many cooking and hearth situations, exterior sooting may be absent on the base and the upper half of the vessel. Such a vessel, when broken into sherds, would have evidence of sooting on less than half (and likely closer to a third) of the sherds even though the vessel was used exclusively over a fire. Sassaman (1993), however, found that sites on the coast had sherds with more evidence of sooting than those on the interior. Consequently, he suggests that fiber-tempered pottery in the Savannah River Basin was more likely used in indirect heating. This is an interesting case study that involves the social performance of both soapstone objects (used in indirect heating) and ceramic vessels and I revisit it in Chap. 3. I cannot rule out hot-rock boiling in ceramic containers, as thick, open-mouthed fiber-tempered vessels could serve that role nicely, but it does not surprise me that there is also significant evidence that many of these vessels were used over a fire. Indeed, the primary performance advantage of ceramic vessels over wood, bark, or skin containers is that they can be placed over a fire.

Case Study: Shell Tempered Pottery

In North American archaeology perhaps the most infamous temper is shell, which was added to pottery throughout much of Eastern North America during the Late Woodland/Early Mississippian Period (AD 700–1100) (Boszhardt 2008; Dunnel and Feathers 1991; Feathers 2006, 2009; Feathers and Peacock 2008; Lafferty and Roberts 2008; Pauketat and Emerson 1991; Rafferty and Peacock 2008; Roper et al. 2010; Sabo and Hilliard 2008). It has generated so much interest because its appearance coincides with the introduction of maize and then its subsequent dominance in the diets of many groups during this period. Shell tempered pottery also appears during the rise of Cahokia, one of North America's greatest prehistoric cities with perhaps as many as 15,000 residents but whose influence is seen over tens of thousands of square miles (see Pauketat 2004).

Did the shell tempered cooking pot play a role in this most interesting political and economic transition? Vincent Steponaitis (1983, 1984) was one of the first to suggest that it might. Based on an analysis of pottery from the site of Moundville, in Alabama, he concluded that shell temper was added to the pots to enhance techno-functional performance. He noted that the non-cooking vessels were tempered with finely ground shell whereas the cooking vessels had coarse shell. He conducted tests on the pottery itself and concluded that the coarsely tempered cooking ware would have greater resistance to thermal shock and mechanical stress. Although these results were preliminary, in part because the tests were performed on pottery recovered from archaeological context, and thus had reduced strength (1984, p. 114), Steponaitis transformed the way that archaeologists look at shell-tempered pottery. "If there is a general lesson to be learned from the results obtained so far, it is that archaeologists should be much more circumspect about regarding all the variability they see in ceramics as being purely stylistic" (Steponaitis 1984, p. 115).

Bronitsky and Hamer (1986) did a series of replicative experiments that tested the performance of various tempers, including shell, under conditions of impact and thermal shock. Instead of using archaeological specimens, as was done by Steponaitis, they produced ceramic test briquettes and found that burned shell temper produced samples that were considerably more durable. The most thorough examination of shell temper in the Eastern United States, however, has been conducted by James Feathers (Dunnel and Feathers 1991; Feathers 1989, 1990, 2006, 2009; Feathers and Peacock 2008; Feathers and Scott 1989). Focusing on pottery produced in southeastern Missouri, Feathers concluded that shell tempered pottery had significantly higher strength (toughness and thermal shock resistance) than comparable sand tempered pottery, which is in basic agreement with the results first reported by Steponaitis (1984). He argues that potters made the transition to shell temper in southeastern Missouri because of this improved techno-functional performance. But Feathers (2006, p. 116) goes on to note that we cannot simply use this explanation for the "pan-Eastern spatial and temporal distribution" of shell-tempered pottery. In fact the timing of the spread of shell-tempered pottery, its relationship to the appearance of corn, changes in the socio-political landscape and other historical factors must be considered and Feathers argues, and I agree, that it is unlikely that this simple functional explanation can account for the appearance and spread of shell-tempered pottery throughout this vast region.

We have noted elsewhere that "technologies are context dependent, their form and prevalence contingent upon local, historically constituted conditions" (Skibo and Schiffer 2008, p. 67; Schiffer 2005, 2011). In terms of the adoption and use of shell temper across the Eastern United States, the devil is certainly in the details as it is up to the archaeologist to construct empirically grounded narratives for this change that take into account the techno-functional advantages of shell temper but also relevant contextual factors. As a technology, such as shell tempered pottery, gets transferred from community to community, the vessels get redesigned as new sources of clay and shell are used, and potters make changes to the recipe that are in line with their own technological traditions. Moreover, new performance characteristics might be important in these new communities that account for changes to the pottery. These types of textured historical narratives can be built upon a behavioral foundation for the adoption, use, and transfer of technology from one community to the next (Schiffer 2002, 2005, 2011; Schiffer and Skibo 1987, 1997; Skibo and Schiffer 2001, 2008).

Another fundamental issue in explaining the invention, and widespread adoption of shell-tempered pottery (using experimental data) is that of behavioral significance (Schiffer and Skibo 1987). Feathers (2006) also notes the importance of behavioral significance but uses different terminology. Behavioral significance means that just because shell temper increases thermal shock resistance, it does not necessarily follow that prehistoric potters were aware of this strength difference and, even if they were aware of it, that they assigned it important in the adoption of shell temper. We maintain that behavioral significance differs from statistical significance. When we conduct strength tests we are apt to find that a change in temper creates a change in strength that is statistically significant. But statistical significance does not correlate necessarily with behavioral significance, which is the ability of the potter or pot user to actually notice and assign importance to the difference in strength. It is up to the archaeologist to argue for behavioral significance of a particular performance characteristic on the basis of other lines of evidence (what the vessel was used for, how was it made, societal factors, etc.). This is the reason for constructing the performance matrix, which helps the researcher to discern patterns in the performance characteristics of each technology.

Firing Temperature

Pottery is human-made stone, and what creates this transformation from clay to ceramic is heat. Traditional handmade earthenware pottery is fired either in an open-fire, usually for a short period of time, or in closed kilns of various types, which usually involves longer firing times and higher temperatures (see Rice 1987, pp. 153–163 for a review). Gosselain (1992) has shown that firing temperatures in open and kiln fires are extremely variable and, in fact, firing temperatures overlap considerably in the two regimes. Thus, potters have little control of the temperature within the kiln once the fire is lit. What potters can control, however, is the firing time. Open-fires usually reach temperature quickly, and overall firing times are usually between 20 and 30 min. Kiln fires, however, reach a maximum temperature slowly and hold that temperature considerably longer (Gosselain 1992). Because actual firing temperature is a function of time, temperature, and atmosphere, potters do have some control over this important technical property through choosing fuels, method of stacking, etc. (Rice 1987; Tite 1995). Tite (1995, 1999) finds that open firing temperatures are between 500°C and 900°C but most are between 600°C and 800°C. Temperatures in kilns range from 600°C to 1,000°C but most are between 750°C and 950°C. Actual firing temperature of pottery, which is based on changes in the mineralogy or microstructure, are estimates of total heat input (time, temperature, atmosphere). Tite (1999, p. 189) suggests that actual firing temperature of open fires is between 550°C and 750°C and 750°C to 950°C for kiln fires.

How Firing Temperature Is Estimated

"Mineralogical changes dependent on firing temperature include the breakdown of clay minerals, the decomposition of calcite, and the formation of high temperature phases such as spinel, gehlenite, wollastonite and mullite" (Tite 1995, p. 37). A variety of techniques from the simple to the complex have been used to estimate firing temperature. These range from hardness tests and color comparison to examination of the extent of vitrification of the clay minerals using a scanning electron microscope (Orton et al. 1993, pp. 133–135; Rice 1987, pp. 426–435).

These techniques all work to varying degrees of accuracy and one's choice of technique depends on how accurate a measurement of firing temperature is needed. Anyone can do simple refiring tests or scratch tests to get an impression of relative hardness and, presumably, firing temperature, but not everyone has the skills and funds for scanning electron microscopy. But because firing temperature is very important for understanding vessel performance in use (see below) and can be used to infer the type of firing regime, many analysts find it necessary to get highly accurate estimates. One of my favorite and relatively underutilized methods is thermal expansion measurement, which can be determined with a relatively simple device referred to as a "dilatometer."

One reason I have such a warm feeling for this device is because Michael Schiffer got an ancient dilatometer donated to the Laboratory of Traditional Technology shortly after it was founded. Steven Falconer was the first to use this device, which looked like it came directly from Dr. Frankenstein's laboratory. Steve got the machine going and used it to estimate firing temperatures for his research on ceramics from the Jordon Valley (Falconer 1987, 1995). Estimating firing temperature through thermal expansion analysis is based on the simple idea that reheated ceramics expand up to the point at which they were originally fired, after which the ceramic resumes sintering and begins to shrink. A dilatometer has a furnace that heats the ceramic, and a push rod measures the linear expansion of the sample, which is plotted against temperature. Because rate of heating and other factors can affect firing temperature estimates, analysts usually employ a method of reheating the sample and applying a correction formula first proposed by Tite (1969).

Performance Characteristics and Firing Temperature

The performance characteristics influenced by firing temperature include, strength (e.g., impact and abrasion resistance), thermal shock resistance, and permeability. These performance characteristics were described earlier but let me review how firing temperature can affect them. Mabry et al. (1988) demonstrate that there is an incremental increase in *strength*, measured in impact resistance, as firing temperature increases. Strength can be measured in other ways such as a using a ball-on-three-ball technique (Neupert 1994) or by assessing abrasion resistance (Schiffer and Skibo 1989). As Shepard (1956, p. 130) notes, ceramic strength would be an effective way to classify pottery if it could be "measured satisfactorily." To that end, a good deal of effort has been put into designing behaviorally relevant measures of pottery strength including impact resistance (Mabry et al. 1988) and biaxial flexure (Neupert 1994; see Pierce 2005 for a comparison of various techniques). The advantage of the impact tester is that it measures a behaviorally relevant performance characteristic as impacts are one of the most common reasons for ceramic breakage. The disadvantage of the impact tester is that it is best suited to assess impact resistance on flat, experimentally made samples. This type of testing is only relevant when attempting to determine the effect of a particular technical choice (such as temper type, surface treatment, or firing temperature) in a very controlled environment. Neupert's (1994) method of testing tensile strength with the ball-on-three-ball device has the advantage of being able to test strength on curved specimens that can include archaeological samples. For example, Beck (2002) demonstrates that Hohokam Red-on-buff pottery from southwestern Arizona increase in strength over time, which she suggests might have resulted from higher firing temperatures.

Thermal Shock Resistance generally decreases as firing temperature goes up as sintering reduces pore space, which impedes micro crack propagation. Low fired pottery has more pore space and thus higher thermal shock resistance (see Harry et al. 2009). Similarly, as firing temperature increases pore space and water *permeability* goes down. Completely vitrified pottery, such as porcelains, are impermeable.

Surface Treatments

Archaeologists have a long tradition of recording various surface treatments as they are essential for creating and describing various stylistic traditions (see Shepard 1956, pp. 65–72). For example, in the American Southwest vessels that are polished would be distinguished typologically from a vessel that was slipped and then polished. Likewise, the direction of cord-markings on the exterior of pottery from the Midwestern United States is enough to distinguish one type from another. Painting, in some ways the most infamous of the surface treatments because of its ability to inform on socio-functions as well as serve important chronological and special markers, has long been recorded in minute detail. Experiments have shown that, like temper, and firing temperature, surface treatments play an important role in vessel performance from reducing permeability to increase heating effectiveness, to evoking powerful religious emotions.

How are Surface Treatments are Recorded

Archaeologists have become quite adept at recording surface treatments, as many can be properly identified with the naked eye or with low power magnification (see

Rice 1987). In archaeological laboratories across the globe analysts record surface treatments, from finger-smoothed and textured to slipped and glazed.

Pottery surface treatments are unique in that some are applied before and others after firing. Pre-firing surface treatments applied while the clay is still workable include: finger-smoothed, tool smoothed, textured, and corrugated. Pre-firing treatments applied when the clay is bone-dry include but are not limited to, slipped, polished, and painted. Post-firing surface treatments include smudging, painting, and various forms of organic surface treatments such as resins or fats. The latter surface treatment is likely one that is routinely missed by analysts as they often do not survive in the post-depositional environment (Skibo et al. 1997). For example, the Kalinga apply a pine resin to their vessels, but sherds in the local midden show no evidence of it. Indeed, ethnographically post-firing organic surface treatments are routinely applied as a means to reduce permeability of low-fired wares. One can infer that similarly low-fired pottery recovered from archaeological context would also have been excessively permeable when in use and that prehistoric potters likely applied some form of post-firing organic surface treatment that is no longer visible on the surface of excavated sherds.

Glazes, which are glasses, can be applied to bone dry vessels in a one-stage process, as in some traditional Japanese potteries. Often, however, glazes are applied after the first ("bisque") firing and then refiring at a higher temperature (requiring a kiln) to achieve complete sintering (Rice 1987, pp. 98–102). Glazing, especially on a vessel's interior, also has the effect of making a vessel largely impermeable to water.

Performance Characteristics and Surface Treatments

Surface treatments influence a number of techno-functional performance characteristics including thermal shock resistance, permeability, abrasion resistance, and heating effectiveness. Surface treatments such as painting also may perform socio-, ideo-, and emotive functions. For example, Ramos Polychrome, or Salado Polychrome in the American Southwest, or Ramey Incised in the Midwest performed functions related to ritual and religious/political identity. These types of inferences, however, are context dependent, and thus I will leave that aside for now and discuss how various surface treatments can affect techno-functional performance regardless of time or space.

A series of experiments, combined with ethnographic and archaeological observations as well as materials science principles, have laid a strong foundation for understanding the relationship between various surface treatments and vessel performance during manufacture and use. One of the most important performance characteristics for cooking vessels is thermal shock resistance, which is influenced by a number of surface treatments. Schiffer et al. (1994) demonstrate that interior and exterior surface treatments significantly influence a pottery vessel's resistance to both thermal shock cracking and thermal spalling. Interior surface treatments that have some permeability increased a vessel's thermal shock resistance. That is because water in vessel's wall reduces the temperature differences between the interior and exterior of the vessels, and so lowers thermal stress. Thus, impermeable vessels tend to be more susceptible to thermal shock. However, highly permeable vessels were prone to thermal spalling, as water turned to steam as it exited the exterior surface and caused spalling. Any type of exterior textured surface (e.g., simulated cord-marked, corrugated, and stuccoed), however, improved a vessel's thermal shock resistance. Texturing of many varieties is found on cooking pots around the globe, suggesting that thermal shock resistance is a primary performance characteristic that was improved in many cases by having a roughened exterior surface.

Focusing just on corrugation, common on ancient Puebloan vessels of the American Southwest, Pierce (2005) evaluated the cost and performance characteristics of corrugation found on the base, upper body, and neck of the vessel. He found that simulated Puebloan vessels with corrugated exteriors improved the thermal shock resistance and thus extended vessel use-life. Interestingly, creating Puebloan-style vessels with exposed coils increases production time considerably (see also Young and Stone 1990). It takes far longer to make corrugated vessels with narrow, even, overlapping coils than it does to make a vessel with a smooth surface. Although the potter must take time to smooth the exterior of a uncorrugated vessel, a great deal of time is saved if a potter can add large coils and be less concerned with keeping the coil overlaps even. As Pierce's study shows, ancient Puebloan potters chose a surface treatment that was more time-consuming to make but greatly increased the vessel's thermal shock resistance and thus use-life. But given the many interactions among technical choices and performance characteristics, one cannot merely claim that exterior surfaces were always corrugated to improve thermal shock resistance.

Heating effectiveness and evaporative cooling effectiveness are also influenced considerably by surface treatments (Harry et al. 2009; Schiffer 1988, 1990). Young and Stone (1990) tested how corrugation might influence heating effectiveness. One of the long held functional explanations for corrugation is that it increases the exterior surface area of the vessel thus exposing a greater area to heat and, presumably, increasing heating effectiveness. This is an intuitively satisfying correlation because one can easily imagine that it would be important in many cooking situations to increase heating effectiveness especially if fire wood was scarce. Young and Stone (1990) made replicas of Southwestern plainware and corrugated pottery and performed some experimental cooking. They found that the corrugated vessels did not heat up the contents of the vessel faster than the plainware vessels. Nor did they find that the corrugated vessels cooled faster than the plainware vessels. But as the experiments described above demonstrate (Pierce 2005; Schiffer et al. 1994), corrugation does enhance thermal shock resistance. The Young and Stone (1990) study provides an important lesson in archaeological inference—assumptions about the techno-functional performance of any technology need to be tested, even those that seem to have strong intuitive backing.

Potters often use surface treatments to control permeability, which affects heating effectiveness and evaporative cooling effectiveness. In several experiments Mike Schiffer explored these effects. Mike had a serious hip injury and surgery in the late 1980s that significantly reduced his mobility. During his long recovery he hobbled down to the Laboratory of Traditional Technology and made test vessels with various surface treatments, put them through a battery of heating and cooling experiments and obtained important results (Schiffer 1988, 1990). In low-fired, earthenware cooking pots potters must contend with a serious issue—such pots are excessively water permeable. Not only can the liquid contents simply seep out of a permeable vessel, but even small amounts of water on the exterior of the pot significantly reduce heating effectiveness. As mentioned earlier, the evaporating water on the exterior actually removes heat from the surface and can keep water in a vessel from ever boiling. The deleterious impact of water permeability is illustrated by Kalinga cooking vessels, which are removed hot from the firing and a pine resin is melted onto the interior surface. During use and washing the pine resin gradually wears wears off and after about 3 months Kalinga women will no longer use them for cooking because water in the pots will not boil. This is especially a problem for rice cooking pots, which the cooks try to bring to a boil as quickly as possible. This ethnoarchaeological observation is backed up by Schiffer's (1990) experiments where he found that the greater the water loss the longer it took to heat water in the vessel. Testing surface treatments such as slip and polish, smudged, finger smoothed, and resin coated, he found that the vessels with the least permeable interior surfaces had the greatest heating effectiveness.

In a related series of experiments he examined the relationship between various surface treatments and evaporative cooling effectiveness (Schiffer 1988). This test was initiated by the observation that people living in arid lands often prefer ceramic water storage containers because the water stays cooler. It is based on the principle that evaporating water on the exterior of vessels takes away heat and thus keeps the vessel and its contents noticeably cooler. His experiments showed that in low-fired vessels evaporative cooling effectiveness for low-fired vessels is indeed controlled by the permeability of surface treatments.

Surface treatments can also influence a vessel's overall strength, which has been assessed through flexural strength or tensile strength (Harry et al. 2009) and abrasion resistance (Schiffer and Skibo 1989). Experiments have shown that surface treatments greatly affect abrasion resistance (Skibo et al. 1997). Smudging and resin coatings provided the greatest abrasion resistance, whereas slipped and polished and textured performed worst. Understanding abrasion resistance of surface treatments has implications for use-alteration analysis (Chap. 4), vessel performance in use and maintenance, as well as in responses of pottery to noncultural formation processes.

Case Study: Thule Pottery

A fascinating ceramic technology is found among Arctic potters of the Thule Culture from about AD 500 to the nineteenth century. Using archaeological, ethnographic, and experimental data, Karen Harry and Liam Frink have explored how these hunter-gatherer vessels were manufactured and used in a unique social and environmental context (Frink and Harry 2008; Harry and Frink 2009; Harry et al. 2009). To call these vessels "ceramics" may be a stretch as they were extremely low-fired—often

Table 2.3 A performance matrix for Thule pottery (Adapted from Harry et al. (2009))

Performance characteristic	No surface treatment	Seal blood and oil
Heating effectiveness	−	+
Tensile strength	−	+

little more than fired hardened because little sintering has taken place. Nonetheless, the investigators argue that these vessels were used directly over a fire to parboil meat. However, such low-fired pottery, being extremely permeable, has poor heating effectiveness. To compensate for the low-strength and high permeability of their low-fired ceramics, Thule potters coated the interior surfaces with seal blood and seal oil. The experiments of Harry et al. (2009) demonstrated that low-fired ceramics coated with seal blood were much stronger than similar vessels lacking a surface treatment. Experimentally created vessels coated with seal blood and oil were also able to bring water to a boil about 10 min faster than untreated vessels, if they survived at all, as untreated vessels tended to disintegrate. Although the performance matrix (Table 2.3) is over simplified, it illustrates the stark contrasts in performance of the replicated Thule pottery. Heating effectiveness is a primary performance characteristic in this case, the investigators argue, because of the lack of firewood in Arctic regions.

Karen Harry and Liam Frink demonstrated that by combining archaeological evidence, ethnography, ethnohistoric reports, and experiments they could put these puzzling, under-fired, Artic ceramics into proper context. Such a multifaceted approach helps to tease out the factors involved in the manufacture and use of this or any pottery. Their studies provide important new insights not only into Thule pottery but also into hunter-gatherer pottery studies in general (e.g., Eerkens 2003, 2004; Eerkens et al. 2002; Reid 1989, 1990; Sassaman 1995; Simms and Bright 1997).

Inferring Intended Function: Primary and Secondary Performance Characteristics, and Derivative Choices

Understanding the performance of any pottery requires that we understand primary and secondary performance characteristics as well as the derivative technical choices that go into a design (Frink and Harry 2008; Harry et al. 2009). A primary performance characteristic is one that is weighted highly in the performance matrix, whereas a secondary performance characteristic is important but not the driving force behind the potter's technical choices. If a technical choice deleteriously affects another performance characteristic, a derivative choice is often made as compensation. Let us return to the humble cooking pot, one of my favorite technologies, which is often the most common type of vessel made and used in a region, and about whose design I have discussed on many occasions (Skibo 1994, 2009; Skibo and Schiffer 1987, 1995; Skibo et al. 1989). The cooking pot provides an instructive example of the complexities involved in the making even the most mundane of technologies and the derivative technical choices that may be required.

A primary performance characteristic of pottery is thermal shock resistance. It is relatively easy to make a vessel but it is much more difficult to make one that can survive the repeated thermal stresses of a cooking fire for more than a few heating-cooling cycles. As discussed earlier, several technical choices enhance thermal shock resistance, including keeping the firing temperature low, adding large amounts of temper, texturing or corrugating the exterior surface, and creating a vessel with a globular shape. These are choices routinely seen in cooking vessels around the world (Skibo and Schiffer 1995). The assumption has long been that these heavily tempered, low-fired, rough textured ("crudware") vessels are made this way because potters care little about appearance of this everyday cookware (Frink and Harry 2008). I have long contended, however, that this characterization is inappropriate. Cooking pots are often "ugly," as Frink and Harry (2008) refer to them, because of the imperative to increase thermal shock resistance—not because the potters do not care. In fact cooking pots often require more skill and time to construct than vessels that are more aesthetically pleasing. Our experiments have shown that creating a vessel with up to 40% temper (which is common in cooking vessels) is somewhat difficult and texturing or corrugation can add considerably to construction time (Pierce 2005). So instead of thinking of these vessels as simple constructions thrown together without care, we need to consider them as significant technological achievements (Harry et al. 2009, p. 35).

Technical choices that improve thermal shock resistance, however, can adversely affect other performance characteristics, thus the need for derivative choices to "correct" for these problems. As the Harry and Frink (2009) experiments demonstrated, a low firing temperature also creates a vessel with high water permeability. If the vessel is used for moist cooking (i.e., boiling), then this permeability will significantly decrease heating effectiveness to the point where the vessel's contents never reach a boil. But derivative choices, particularly an interior surface treatment, can reduce or eliminate water permeability. Thus it is no surprise that cooking pots around the globe often have an interior surface treatment, which can reduce permeability but also in some cases increase impact or tensile strength of the vessel. Low firing temperatures also create vessels with reduced strength, which can also be improved by selecting certain surface treatments (such as resin) that both reduces permeability but also increases strength.

Cooking pots made at the household level are also an important technology because it is most often made and used by women (Skibo and Schiffer 1995). Many technologies studied by archaeologists are presumed to have been male-related. Thus studying pottery gives us the opportunity to understand how women solved functional problems in the design of a life-sustaining technology. Although men may be involved in various steps of household pottery manufacture (such as collecting firewood, digging and transporting clay, or carrying finished vessels), the ethnographic record clearly demonstrates that this technology is dominated by women throughout its behavioral chain. Thus, when we point out that potters at the household level made technical choices to increase thermal shock resistance or reduce permeability we are talking about women making these choices. This is significant because all early pottery manufacture was done at the household level, and in many parts of the world (such as much of North America) it is presumed that all vessels in prehistory were made at the household level and thus by women.

Is It Just About Techno-function?

From the discussion above one might get the impression that I give great favor to techno-functional performance. From a theoretical perspective, this is not the case as the model used here includes socio-, ideo, and emotive performance in the design and use of technology. In a number of case studies we have argued that various non techno-functional performance characteristics are of primary importance (Schiffer 2011; Skibo 1994; Skibo and Schiffer 2008; Skibo and Walker 2002; Walker and Schiffer 2006). Although some scholars emphasize what we would call socio-function over techno-function (e.g., Gosselain 1998; Lemonnier 1986, 1992), I would argue that this approach is an incomplete examination of the manufacture and use of a technology. Our focus on pottery, and in particular utilitarian wares, was a purposeful investigation of technical choices, like temper type and surface treatment, which had previously been given various cultural and social explanations. Our goal was to fill this lacuna, not suggest that techno-functional performance explains all aspects of all technologies. But in terms of cooking pots, which has been our focus in experiments, we do argue that techno-functional performance characteristics like thermal shock resistance are primary. However, there are many ceramic types, like Salado and Ramos Polychrome in the American Southwest, and Ramey Incised in the Midwest, whose socio- and ideo-functional performance characteristics are primary. Crown (1994), for example, argues that ideo-functional performance best explains why Salado Polychrome appears across a wide area. Although these vessels were made locally with different clays, the potters took great care in replicating the distinctive Salado designs, so much so that without chemical sourcing techniques one might easily conclude that the pots were made in a central location and then distributed. This cult-like emulation speaks to important ideo-functional performance.

Case Study: Metal Pots and Symbolic Performance

During the Kalinga ethnoarchaeological research, I discovered that nearly all Guina-ang households had enough metal pots for everyday cooking, yet ceramic vessels were still being made and used. That is because Guina-ang cooks used metal pots only for rice cooking (91% of the recorded cases) but ceramic vessels were still used for 98% of the vegetable and meat cooking. This differential replacement of pottery vessels by metal pots can be easily explained by considering the performance advantages of each vessel (Skibo 1994). As noted above, the objective of rice cooking is to bring water to boil as quickly as possible, and so the Guina-ang cooks preferred metal pots because of their much greater heating effectiveness. Vegetable-meat cooking, however, often required long-term simmering, thus ceramic vessels, with their lower heating effectiveness, were better suited for this task. In fact, vessels with a higher heating effectiveness that come rapidly to a boil are avoided for such cooking because boil-over is not only a time-consuming nuisance but may also douse the fire. Ceramic pots, with their lower heating effectiveness, can sit on the fire at simmering temperatures without much tending and fear of boil-over.

The use of metal pots by the women of Guina-ang in the late 1980s also involved an important symbolic performance characteristic. The women insisted on scrubbing metal pots with sand after each use to restore their original shine. The time spent washing metal pots was significantly greater than that devoted to ceramic pots. Because soot impregnates the exterior surface of the vessels, Kalinga women exert a great deal of effort, by hand or foot and a rag and sand slurry, to make them shiny again. Such behavior has no techno-functional advantage and, in fact, it shortens the metal vessel's use-life because the vigorous scrubbing thins the vessel wall and eventually renders them easy to puncture. So what explains this extreme cleaning behavior? The answer is that the metal vessel's socio- and ideo-functions are enhanced by their visual appearance—shininess—when being stored in the home.

Everyday Kalinga ceramic pots are usually stored and stacked on shelves that line the wall or are placed directly on the floor near the wall. Larger pots used for gatherings such as funerals or weddings are placed in the rafters out of sight. Metal pots, however, whether large or small are all hung above the hearth from the rafters for all to see. In fact, these shiny vessels are one of the first things that catch one's eye when entering a home and indicate a household's wealth or modernity for all to see. Kalinga women could hang sooted metal pots but they would not have the same visual performance. Clearly, symbolic performance, even in everyday cooking pots, can play a significant role during use.

From Sherds to Intended Function

When I was a graduate student in the mid-1980s I looked forward to getting each issue of *American Antiquity*, opening the package with great enthusiasm (online accessibility of journals has taken away this simple pleasure). Cracking open the April, 1986 issue I immediately spotted in the table of contents David Hally's article, "The Identification of Vessel Function: A Case Study from Northwest Georgia." His analysis of sixteenth century pottery was a practical application of the approach that we were advocating primarily from an experimental and ethnoarchaeological point of view. I was so impressed with Hally's work that I contacted him immediately and invited him to be an outside reader of my dissertation, and he accepted. I reread the article in preparation for this book and I am still impressed (see also Box in Chap. 3). If one seeks a good model to follow for a ceramic analysis, this timeless paper should be consulted. Kenneth Sassaman's (1993, 1995, 2002) work in the

Southeastern United States also provides an excellent example of how to integrate social performance of vessels with utilitarian performance to elucidate the complexities of technological change. He notes that "a social perspective on technological innovation does not preclude the need for detailed technofunctional analyses" (Sassaman 1993, p. 4).

In the 1990s I became aware of the work of Eric Blinman and Dean Wilson (Wilson and Blinman 1993, 1995; Wilson et al. 1996) that focused on ceramics from northern New Mexico, and the work of Michael Whalen (1994) on Jornada Mogollon pottery in the southern part of that state. These works in the American Southwest provide sound examples of bringing sherd data to bear on behavioral inference. More recent examples of forward-looking functional analysis are provided by Karen Harry and Liam Frink (Frink and Harry 2008; Harry and Frink 2009; Harry et al. 2009) in their work from the extreme northern part of the American continent. Izumi Shimada's (Shimada 2007; Shimada and Wagner 2007) holistic approach to pottery production and other technologies from Peru is also noteworthy for its integration of many lines of evidence, including experimentation and archeometric analyses. Other examples of innovative ceramic studies include Margaret Beck's (Beck 2006, 2009) analysis from the American Southwest and Valentine Roux's (2003, 2010) work in the southern Levant. Roux's work is especially important because she too combines technical analyses, with ethnoarchaeology and experimentation to infer how vessels were made and used.

The above examples are just a fraction of the fine functional studies going on now (see also Arthur 2001; Falconer 1995; Feathers 2006; López Varela et al. 2002; K. Nelson 2010; Silva 2008; Sullivan 1989), many of which are done in cultural resource management contexts (e.g., Hays-Gilpin and van Hartesveld 1998; Heidke 1999; Stark and Heidke 1998). My examples are also biased toward North America (for European examples, see van As 2004; Buko and Pela 1997; Pavlů 1996; Roux 2003; Stilborg 1997; Vieugué et al. 2008). But these are the types of analysis that I aspire to, and from which I borrowed heavily in the discussion that follows.

These analyses are able to use sherd data, which dominates the archaeological record, and make inferences about vessel function because they share some or all of following analytical steps. First, think in terms of whole vessels. Archaeologists find sherds, but to make inferences about function we must use whole vessels as our unit of analysis. One way to accomplish this is to implement an intensive refitting or at least a vessel grouping program that estimates the minimum number of vessels that could have created the sherd assemblage. As Sullivan (2008; Sullivan et al. 1991) notes, studies that conduct intensive refitting and conjoining obtain important clues about cultural and noncultural formation processes and lead to stronger inferences about vessel use-life and site function (see also Chapman and Gaydarska 2007).

Second, employ appropriate ethnographic information. Hally (1986) and Frink and Harry (2008; See also Harry and Frink 2009; Harry et al. 2009; Sassaman 1993) integrated ethnographic observations on pottery manufacture and use into their analyses. There are, of course, important things to consider when using ethnographic data, but these researchers demonstrate how such data can be used profitably in the study of ceramic assemblages.

Third, record the physical properties but think in terms of technical choices and relevant performance characteristics. Whalen (1994), in an analysis of a large ceramic assemblage from the southwestern United States, demonstrates how a researcher can move from a discussion of technical choices such as surface treatments, firing temperature, and morphology to inferences about intended functions (see also Falconer 1995; Harry et al. 2009; Sassaman 1993; Skibo et al. 2009).

Fourth, infer the relationship between technical choices and intended functions in the assemblage's social and environmental context. Ideally, correlations between technical choices and performance should be made initially in a controlled experimental setting (e.g., Bronitsky and Hamer 1986); this is then followed by more field-based experiments that take into account local contextual factors. Pierce (2005) and Harry et al. (2009) employ generalized knowledge about the relationship between technical choices and performance characteristics and then perform more specialized experiments that take into consideration the local contexts. Others, such as Shimada and Wagner (2007), Shimada (2007), see also Sassman (1993), may not focus on conducting their own experiments (though they have done some) but their analyses use principles derived through experimentation, ethnoarchaeology, and materials science, which are integrated with a detailed understanding of the ceramic technology and other important contextual information. This enables them to conduct with great success what they call a "holistic" approach to pottery production.

Fifth and finally, augment inferences about intended function with an analysis of use-alteration traces (residue, abrasion, and carbonization). As I illustrated in Chaps. 3, 4, and 5, a number of researchers now routinely incorporate use-alteration traces into their ceramic analyses, which help them to better understand the overall function of their ceramics.

The rest of this book is dedicated to describing how these use-alterations form, how they can be recorded, and how then can inform on the actual functions of vessels.

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Chapter 3
Sooting and Carbonization

> *To judge from the paucity of published references, few archaeologists take note of soot deposits on the pottery they are analyzing and fewer still seem to recognize it as evidence of vessel use. (Hally 1983a, p. 7)*

One primary advantage of ceramic vessels, in comparison to other containers, is that they can be placed directly over or in a fire to process its contents. There are, however, multiple ways that this can be done and many different processing strategies. For example, a pot can be placed in a fire, on supports, or suspended over a fire to boil, simmer, or roast its contents. If an archaeologist is interested in inferring cooking-related activities, then patterns of external or internal carbonization can provide important clues.

Patterns of exterior carbonization, or sooting from the cooking fire, are controlled by a number of factors including the type of wood, distance from fire, hearth arrangement, temperature of the ceramic surface, and whether the contents are being cooked with water (boiled or simmered), or without water (roasted, boiled until water is removed, reheated). The patterns of internal carbonization, which is the charring of food, is dependent upon the type of food cooked, the temperature of the fire and the ceramic surface, and the presence of water as in boiling or simmering. In this chapter, I examine the processes that govern formation of internal and exterior carbon deposits and illustrate how the patterns of carbonization can be used to infer cooking activities.

Archaeologists have long noticed that some of their vessels and sherds have internal carbonization (including charred encrustations) or external sooting. If recorded at all, these data were used simply to suggest that the vessels were placed over a fire (e.g., Hill 1970, p. 49; Turner and Lofgren 1966, p. 123). Hally (1983a) was one of the first to systematically examine carbonization in an analysis of Barnett Phase sites in northwestern Georgia. Focusing exclusively on exterior sooting, he learned more than whether the vessels had been used over a fire. Patterns of sooting enabled him to infer that some pots were suspended while others were placed on pot

J.M. Skibo, *Understanding Pottery Function*, Manuals in Archaeological Method, Theory and Technique, DOI 10.1007/978-1-4614-4199-1_3,

supports, and that two vessel types, identical except for size, were used in different ways—the smaller pot was used over a fire while the larger one was not.

Hally's study was one inspiration for my analysis of carbonization patterns in the Kalinga ethnoarchaeologial research. His work focused exclusively on exteriors, but my Kalinga research examined both internal and external carbonization. The Kalinga study was instructive because the cooks used a variety of techniques that resulted in very different carbonization patterns. Generalizations from the Kalinga observations, and augmenting them with experiments, I formulated principles that describe the formation of carbon deposits. These results are offered below.

Kalinga Vessels and Internal and External Carbonization

The Kalinga

When I was a fourth year graduate student, Bill Longacre returned from the Philippines and made a presentation to the faculty. He had conducted research among the Kalinga a decade earlier but had been unable to return because of political unrest brought about by the government's plan to build large hydroelectric dams that would flood the Kalinga homeland. The Kalinga took up arms and had successfully turned away these attempts, but had also made travel and research in the area dangerous. Longacre noted in his talk that the dramatic "People Power Revolution" and Corazon Aquino's rise to power had made it possible again to do research among the Kalinga (see Skibo 1999). Aquino's second act as President was to cancel the hydroelectric dam project, and so the Kalinga put down their arms and peace was somewhat restored to the region. Longacre discussed his plan to write an NSF proposal that would bring in a team of graduate student researchers to study a range of ethnoarchaeological topics, including, to my surprise, what he called "pottery use-wear." I was thrilled as I had already been thinking about a use-alteration study. I signed on immediately as it was clear that the first step in a complete investigation of the processes that form use-alteration traces was an ethnoarchaeological study of pottery users.

The Kalinga live in the Cordillera Central Mountains, a rugged range in the north-central section of the Philippine island of Luzon (Fig. 3.1). In the Pasil River Valley, where the Kalinga Ethnoarchaeological Project (KEP) took place, people still rely primarily on intensive wet rice cultivation (Fig. 3.2), supplemented with some swidden horticulture (e.g., beans, peas, taro, camote, eggplant, and squash) and arboriculture (e.g., coconut, mango, and banana). Numerous wild plants and animals are also harvested when available. Animals such as deer, lizards, bats, fish and birds are taken when present as well as a variety of insects (e.g., ants, bees, locusts). Domesticated animals such as the water buffalo, dog, chicken, and duck are also owned by many households and provide additional sources of protein, usually on special occasions. Alhough their diet could be quite diverse at different times of the year, rice is the staple crop and it is consumed several times daily. Rice fields are owned by individual households but they are planted and harvested communally (Lawless 1977). Two crops of rice are grown each year, one in the dry

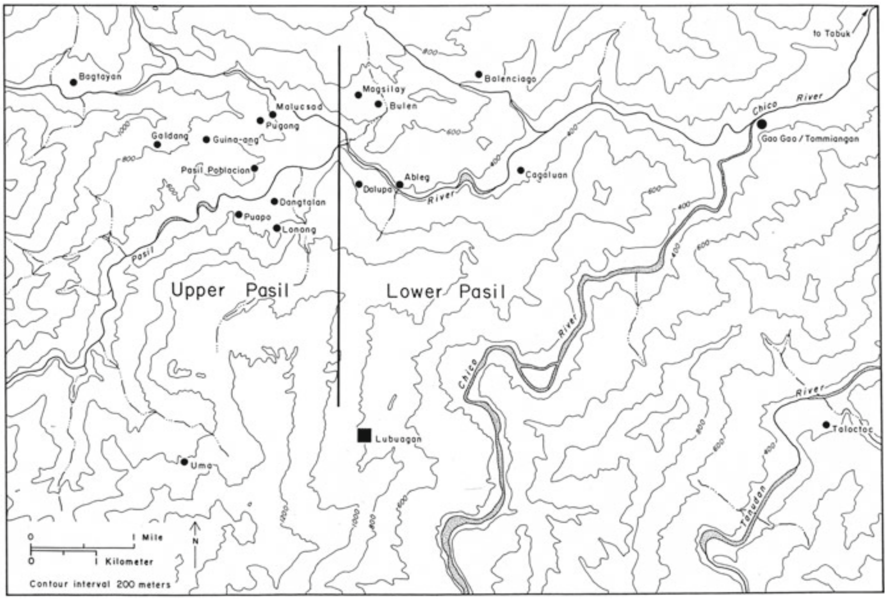

Fig. 3.1 Kalinga villages in the Pasil River Valley (From Stark and Skibo 2007, p. 102)

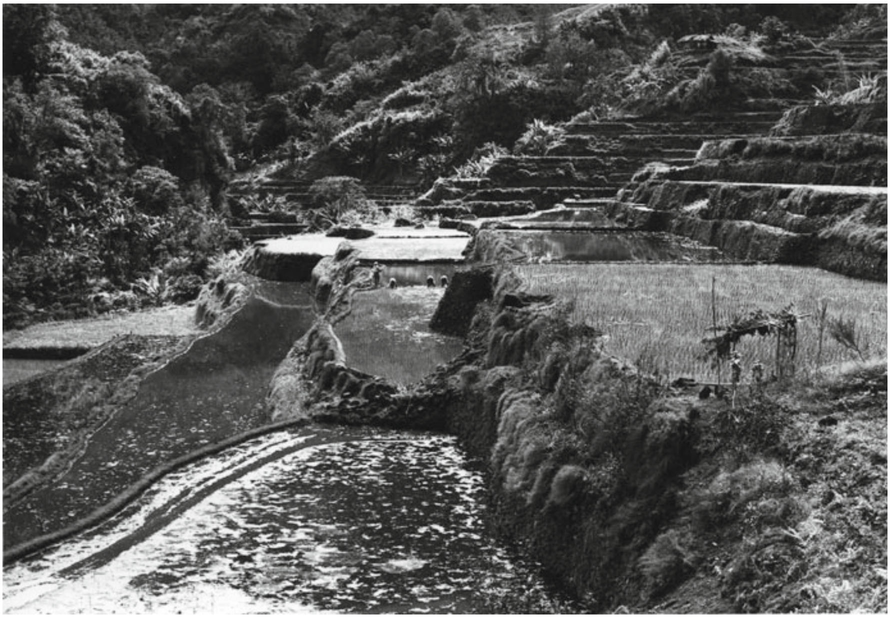

Fig. 3.2 Terraced wet rice cultivation near the village of Guina-ang (From Skibo 1992, p. 2)

Fig. 3.3 Kalinga houses

season, harvested in April, and the other in the wet season and harvested in January. A number of varieties of rice are cultivated including one used to make sweet rice cakes. Each village also has one or more small stores that bring in outside products such as sugar, flour, oil and a variety of prepared foods and other products (e.g., cigarettes, soda pop, and alcohol). Itinerant traders ("Traveling stores") also frequent villages bringing in a variety of outside products.

There have been significant political and economic changes in the region over the years, but transactions are still dominated by the barter system (Stark 1991, 1994). Despite the introduction of political institutions by the Philippine government, and before them the Americans and Spanish, leadership in the communities is controlled by a group of respected male elders (*pangats*) who resolve disputes and negotiate all forms of grievances. *Pangats* also help maintain the peace pacts (*bodong*) for which the Kalinga are quite renowned, at least from an anthropological perspective (Bacdayan 1967; Barton 1949; Dozier 1966). The *bodong* is a codified system of custom law that came about to not only end tribal war and blood feuding, but also to execute justice should crimes be committed between *bodong* holding units.

The household is the basic economic and social unit (Takaki 1977; Trostel 1994), typically consisting of a married couple and children but often including others such as aged parents, unmarried adult children, and even newly married children and their spouses. Traditional houses, consisting of one or two rooms, are made of woven bamboo and sit on poles; the primary living area is the second floor (Fig. 3.3). Other house styles are now made occasionally so that the first floor is sometimes occupied as well. Houses have a single hearth, which is a roughly square, slightly raised platform about a meter on a side (Fig. 3.4). The side boards of the hearth are about 5–10 cm high and hold in packed earth or in some cases concrete. Cooking is done by squatting next to

Fig. 3.4 Kalinga kitchen showing the raised hearth, a vessel on the fire, firewood drying above the fire and pots in storage on the shelf on *right* (From Skibo 1992, p. 31)

the hearth or sitting on a small stool. The fire is made in the center of the hearth and the pots sit on three pot supports (*chalpong*) usually made of ceramic. The *chalpong* hold the pot so that its base is about 15 cm about the hearth surface.

The Kalinga Ethnoarchaeological Project

The KEP began in the mid-1970s and is, arguably, the longest running ethnoarchaeogical project in the world (for a review see Stark and Skibo 2007; Longacre 1974, 1981, 1985, 1991; Longacre and Skibo 1994; Longacre et al. 1991). The project's original intent was to better understand the intergenerational transmission of pottery-making knowledge, with a focus on design style (Longacre 1974). The learning framework of pottery making was the weak link in the inferential chain proposed by the "ceramic sociologists," which were the first case studies of the New (or Processual) Archaeology (Binford and Binford 1968). Carter Ranch, Broken K Pueblo and the other case studies, which were part of Paul S. Martin's Southwestern Expedition, set a new agenda for archaeological method and theory and ushered in the modern era of ethnoarchaeological research (Skibo 2009).

The New Archaeology and Ceramic Sociology

The first wave of baby boomers are now reaching retirement, but the gray and thinning hair and AARP cards should not obscure the fact that this generation fomented change in virtually all aspects of society. Although many will long debate the causes and consequences of the rebellious 1960s, few would argue that it started with vehement opposition to the Viet Nam War, which spread to other aspects of society and culture. There was a concerted effort to reject everything about one's parental generation, including politics, music, clothes, and even science. Archaeology was certainly swept up in this wave of change as middle-class kids entered college and Ph.D. programs in droves, content on throwing out their father's archaeology (for a thorough exploration of this period see O'Brien et al. 2005). The mantra at that time was to make archaeology more anthropological; the center for this activity, for the "New Archaeology," was the University of Chicago during the early and mid-1960s.

Every revolution needs a prophet and for archaeology that was Lewis Binford, who arrived at the University of Chicago in 1961. Graduate students during this time, a virtual Who's Who of the second half of the twentieth century, included William Longacre, James Hill, Kent Flannery, Stuart Struever, James Brown, Robert Whallon, Patty Jo Watson, and Frank Hole, among others (Longacre 2000, p. 293) (Fig. 3.5). This Shakespearean convergence of people and ideas is extremely important in the history of archaeology. "There is a tide in the affairs of men. Which, taken at the flood, leads to fortune." These are the words of Brutus in Act 4 of *Julius Caesar* who argued that the time was right to attack. But it also applies equally to this miraculous time in American archaeology. O'Brien et al. (2005, pp. 37–38) refer to the "swagger" of this young group of archaeologists with Binford leading the way, reproaching the discipline's old guard ("traditionalists") for their nonscientific approach to archaeology. But revolutionary change is a two-part process that includes not just critiquing the maladies of the status quo but also providing effective remedies. This is one reason why Walter Taylor's earlier call for radical change in archaeology (Taylor 1948) did not gain traction. He may have critiqued the traditional archaeologists and their approach to the discipline effectively but he did not have, like Binford at Chicago, a comprehensive and comprehensible alternative as well as a gaggle of graduate students eager to implement the "New Archaeology" (see Binford and Binford 1968).

Among the most noteworthy and influential of the early case studies, were the excavations done at Carter Ranch and Broken K Pueblos by Bill Longacre and James Hill. Longacre and Hill were students of Paul Martin, a Curator at the Field Museum of Natural History, who had been conducting archaeological research in the Southwestern United States since the 1930s. Although Martin had made his reputation conducting the type of culture-historical research that

(continued)

Fig. 3.5 Bill Longacre conducting ethnoarchaeological research, circa 1988 (From Skibo 1999, p. 111)

the New Archaeologists were rejecting, he had an open mind and a teaching style that permitted Longacre, Hill, and others to push the boundaries of archaeological method and theory. As Longacre (2000, pp. 293–294) describes it, Constance Cronin, a social anthropologist, was hired by Paul Martin to look at the designs on Snowflake Black-on-White, a pottery style that was not well described. It was Cronin (1962) who first suggested that variability in the designs styles could be the result of kinship and "the seeds of Ceramic Sociology were sewn" (Longacre 2000, p. 294).

Martin, Director of the Southwestern Archaeological Expedition with its headquarters in Vernon, Arizona, permitted Longacre to design a strategy for the upcoming 1961 field season. This project would pursue the notion of

(continued)

inferring things like post-marital residence patterns from the design variability on decorated ceramics. When Longacre returned to the University of Chicago for Fall semester Lewis Binford had been hired and he quickly influenced graduate students by mixing in neoevolutionary theory, sampling, and the importance of statistical inference in research design (Longacre 2000, p. 294). This convergence of people and ideas had a profound impact on Longacre's work. As he states in the introduction to his dissertation, "This monograph may be viewed as a contribution in the continuing debate over the possibility that archaeology, as an integral part of anthropology, can advance general anthropological theory" (Longacre 1970, p. 1).

The goal of Longacre's (1970) monograph, *Archaeology as Anthropology: A Case Study*, and what Hill (1970, p. vii) refers to as a sequel to this work, *Broken K Pueblo: Prehistoric Social Organization in the American Southwest*, was simply to do something anthropological with archaeological materials. There was nothing more anthropological at the time than the subject of social organization, especially at the University of Chicago, so it was logical for these young archaeologists to try inferring *prehistoric* social organization. The strategy they employed was quite clever. They proposed that if Carter Ranch and Broken K, the twelfth-thirteenth century pueblos in east-central Arizona (see O'Brien et al. 2005, p. 43), had matrilineal social organization and matrilocal residence rules, and women were the potters, then perhaps evidence of this pattern would be recorded in the pottery itself, which they found at these sites in abundance.

They assumed that mothers would teach daughters to make pottery and so preferences in the painted designs on these intricately decorated black-on-white vessels would pass on from one generation to the next through what they called "micro-traditions." If these same daughters lived next to their mothers after marriage, then archaeologists should be able to find clusters of design elements representing micro-traditions in various parts of the pueblo—assuming that they were practicing matrilocal residence.

Both Longacre (1970) and Hill (1970) did indeed find clusters of design elements on the sherds excavated at Carter Ranch and Broken K Pueblos. Based on these clusters, both researchers argued that the prehistoric inhabitants had matrilineal descent and matrilocal residence rules. This was a clever idea that met the challenge thrown down by their professor, Lewis Binford, that archaeology should be anthropology (1962). By showing that prehistorians could reconstruct social organization, archaeologists were demonstrating that they could be part of the larger debate in anthropology, no longer confined to the boring and old-fashioned (in their minds) questions of classification and typology.

In the mid-1980s Mike Schiffer and I visited Broken K Pueblo (Fig. 3.6). Today it is a few low mounds strewn with ceramics on a windswept terrace of the Hay Hollow Valley. Its appearance today belies the site's significance to

(continued)

Fig. 3.6 Mike Schiffer at Broken K Pueblo in the Hay Hollow Valley, Arizona

the archaeological community. These reports, published humbly as numbers 17 and 18 in the *Anthropological Papers of the University of Arizona* have been cited hundreds of times.

Both of these reports, however, were not without detractors soon after they were published. Researchers questioned aspects of the analysis such as the usage of a computer program used to identify the clusters (e.g., Lischka 1975; Plog 1978), and the assumption that mothers teach daughters to make pottery (Stanislawski 1973). As was mentioned earlier, the latter question was what motivated Longacre to conduct ethnoarchaeological research among the Kalinga, for he realized that we needed to explore the processes involved in the intergenerational transmission of pottery making. But the most critical flaw of these early studies is that they did not take into account the formation processes of the archaeological record.

This lacuna prompted a two-phase reanalysis of the Broken K material (Schiffer 1989; Skibo et al. 1989). Broken K was chosen for the reanalysis because Hill's follow-up study included more of the raw data needed to assess the life histories of the sherds used in the analysis. In order for Hill's analysis to work it had to have been conducted on a "Pompeii-like" assemblage (Schiffer 1989). That is, design elements had to be recorded from sherds and whole vessels deposited in the rooms as a result of activities in those very same rooms (as primary or de facto refuse). However, if a room was trash-

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filled, common in these types of pueblos, it would contain the remnants of broken vessels but they could have come from anywhere in the pueblo as abandoned rooms were used for trash disposal by people living in occupied rooms. Using published reports only, Schiffer (1989) noted that there were only 12 restorable vessels from the collection, which would be an extremely low number if the pottery had come mainly from primary or de facto refuse. Schiffer argued that many of the rooms used in the study were abandoned late and did contain de facto refuse, which would be ideal for Hill's study, but the lack of restorable pots from such an assemblage was puzzling. Schiffer proposed the "missed pot hypothesis," which states that there were actually a lot more restorable vessels in the collection than were identified by the excavators or the lab personal. These missed pots, according to Schiffer, had a deleterious impact on Hill's factor analyses, as a single design element often occurs many times on a vessel. When this design element gets redundantly recorded on sherds it can create structure in the design element data. Phase II of the Broken K reanalysis was designed to test the missed pot hypothesis and to explore further the formation processes of the assemblage.

Rooms selected for refitting and matching to a parent vessel were those identified by Schiffer as having the highest probability of containing missed pots. Unfortunately, 25–35 % of the accessioned ceramic material could not be located. Despite the incomplete sample, an additional seven whole or partially reconstructable decorated vessels were identified. In addition, 12 restorable or partially restorable plainware or corrugatged pots were identified, bringing the total number of whole vessels to 31 (Fig. 3.7). Schiffer was right, there are many missed pots that make up the Broken K ceramic collection. But did these whole vessels lead to redundantly recorded design elements that skewed the factor analyses?

There were 32 high-frequency design elements. Evidence for reconstructable pots or conjoinable sherds was found for 25 of these design elements. For example, five instances of design element 146 (Fig. 3.8) from Hill's study occur on the floor of Room 30. Such a cluster of design elements creates structure in the data. But it was found that all five of the design elements come from a single partially reconstructable bowl. Similarly, Hill found a cluster of six instances of design element 110 (Fig. 3.8) on the floor of room 64, and our reanalysis learned that all six come from a single partially conjoinable rim (Fig. 3.9). The reanalysis confirmed that the Broken K ceramic assemblage contained many more whole vessels and that redundantly recorded design elements created much of the structure in the factor analyses. The sobering conclusion calls into question whether there is any clustering at all in the design element data attributable to social organization.

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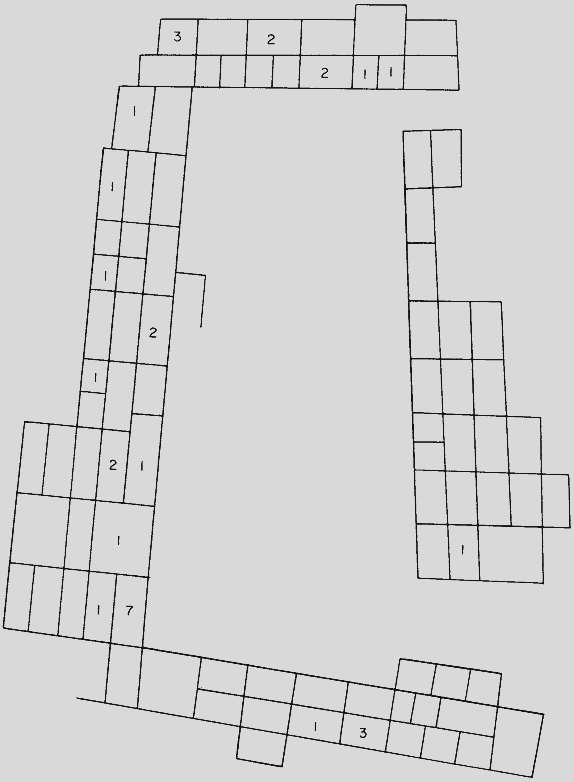

Fig. 3.7 Schematic drawing of Broken K Pueblo rooms with total numbers of whole vessels identified in reanalysis (From Skibo et al. 1989, p. 395)

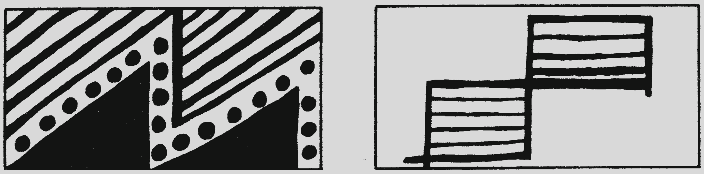

Fig. 3.8 Design elements 110 (*left*) and 146 (From Skibo et al. 1989, p. 396)

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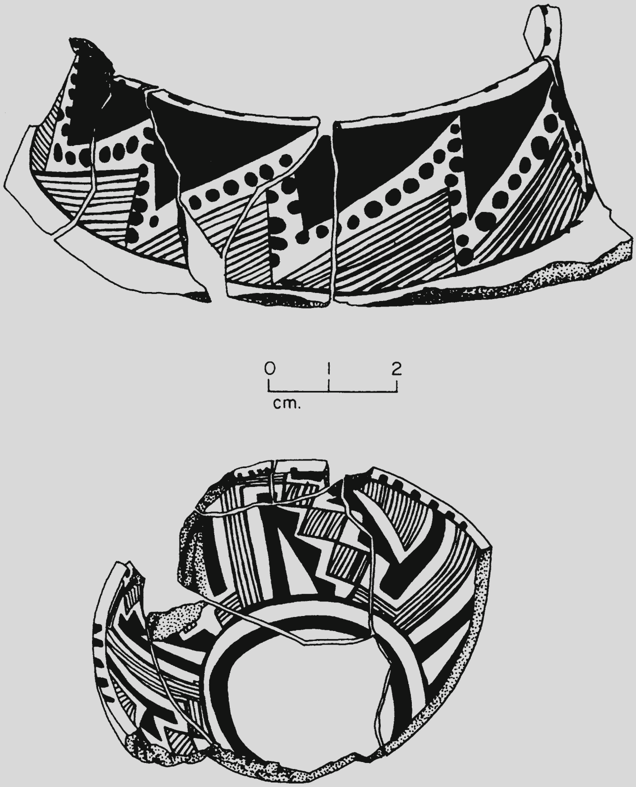

Fig. 3.9 Conjoinable sherds with repeated occurrences of design element 110 (*top*) and a partially reconstructable vessel with repeated occurrences of design element 146 (From Skibo et al. 1989, p. 397)

Although this and other studies have undermined claims made by the first case studies of the New Archaeology, their importance has not thereby been diminished. Binford and the Chicago "Mafia" (O'Brien et al. 2005, p. 37) forever changed archaeological method and theory.

I call it the "modern era" in ethnoarchaeology because one can find evidence of archaeologists doing ethnographic fieldwork beginning in the early twentieth century (e.g., Fewkes 1900). But the modern era was driven by new questions because new generation of archaeologists realized that they did not possess the inferential tools to properly address the types of questions that prehistorians were now posing. Longacre, in particular, realized that a weak link in the inference about social organization in the American Southwest was the assumption that mothers teach daughters how to make and design pottery. And so he asked, was this the case? To address this question Longacre initiated the KEP in the mid-1970s.

Fig. 3.10 Village of Guina-ang, home of the use-alteration study (From Skibo 1999, p. 39)

Longacre did a year-long stay among the Kalinga in 1975–1976 but was unable to return as planned in 1979 for reasons noted above. With the help of Kalinga assistants, however, he was able to continue collecting pottery census data (Graves 1991, 1994). After the return of political stability to the Pasil Valley, Longacre initiated an ambitious project for 1987–1988 that included nearly a dozen researchers from the University of Arizona, the University of the Philippines and the National Museum of the Philippines. Three villages (Dangtalan, Dalupa, and Guina-ang) formed the home base for this research, which included pottery production, standardization, use-life, distribution, consumption, and use (See Stark and Skibo 2007 for a review). Marking the fourth decade of the KEP, Margaret Beck returned to the Pasil Valley in 2001 and focused on ceramic deposition and various issues of formation processes (Beck 2003, 2006, 2009; Beck and Hill, 2007).

Guina-ang and the Pottery Use-Alteration Study

Guina-ang, the largest and oldest village in the Pasil River Valley, sits on a commanding ridge-top position on the north side of valley (Fig. 3.10). The village played a small role in the Philippine Revolution around the turn of the twentieth century as General Emilio Aguinaldo stayed there for a short time when he was on the run from American soldiers (Skibo 1999, pp. 33–37). After the U.S. Navy had defeated the Spanish in the Battle of Manila, Aguinaldo and the Filipino Revolutionary forces declared the Philippines a sovereign nation. After the Spanish-American War, Spain ceded the Philippines to the United States, which led to a bloody series of battles and Aguinaldo's exile to the mountains where he was eventually captured. A relatively

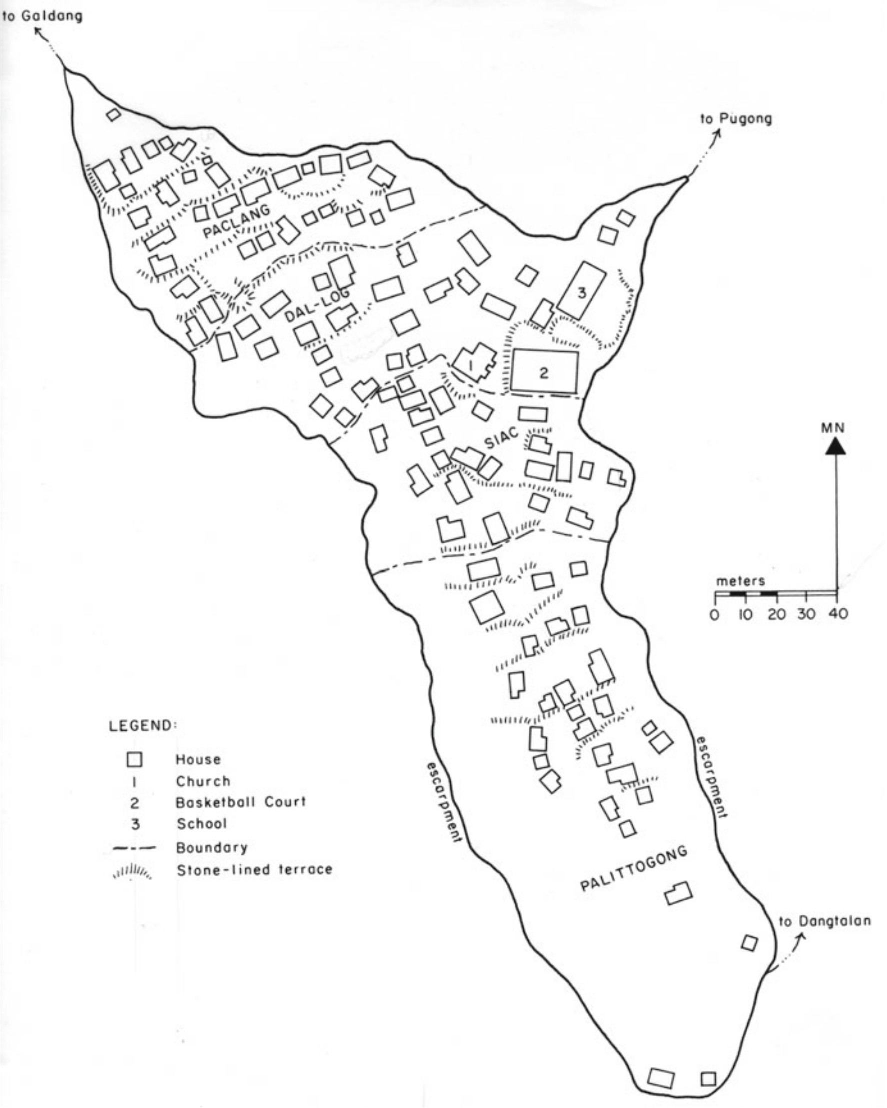

Fig. 3.11 Map of Guina-ang, circa 1988 (From Skibo 1992, p. 59)

wide trail leading into Guina-ang, suitable for horses and built by the Spanish in the nineteenth century, is a tangible reminder that this extremely isolated village has, at times, had significant contact with outsiders.

In 1988 Guina-ang was composed of 102 houses (Fig. 3.11) divided into four ward-like divisions: Paclang, Dal-log, Siac, and Palittogong. Guina-ang is a pottery-consuming village that obtained most of its vessels from the pottery-producing villages—Dangtalan and Dalupa—either by traveling to the villages or obtaining them from the potters that routinely visit (Aronson et al. 1994; Stark 1991, 1992, 1994).

Kalinga Vessels

As noted in Chap. 2, the Kalinga traditionally produced and used three types of vessels (Fig. 2.1): vegetable-meat cooking (*oppaya*), rice cooking (*ittoyom*), and water storage *(immosso*) (Longacre 1981). By the late 1980s potters had also started to make various non-pottery forms (Stark 1995). Despite boiling rice most often in metal pots, Kalinga cooks at the turn of the twenty-first century are still using locally-made ceramic vessels (Beck and Hill 2007).

Recall that vegetable-meat cooking pots are generally squatter and have a more out-flared rim as well as a larger orifice diameter relative to vessel size than the rice cooking pots. They are made in four size classes: small, medium, large, and very large. Small and medium-sized vessels are typically used by families for everyday cooking, depending upon the number of people being fed, and the two larger sizes are reserved for special occasions including village-wide ceremonies such as funerals and weddings. Rice cooking pots are taller and have a more restricted orifice diameter and a less out-flaring rim and are made in three size classes: small, medium, and large (the large vessels are reserved for village-wide ceremonies).

Pottery used in Guina-ang was most often made in the nearby villages of Dalupa and Dangtalan. Traditionally, pottery was made only in the dry season (February-June) but more recently it has taken place throughout much of the year (Stark 1991). Pottery manufacturing techniques, first described by Longacre (1981), remained quite similar right into the twenty-first century. Raw clay is obtained from a number of nearby sources, which naturally contains a good deal of nonplastic material. Although larger stones might be removed, no temper is added. Dry clay is pounded and then water is added until the clay becomes workable. Potters use a combination of paddle-and-anvil to form the base, coil-and-scrape to shape the upper portion of the vessel, and hand modeling to begin the forming process. After wedging, a ball of clay is placed on a wooden plate that is rotated during manufacture (Fig. 3.12). To begin, the potter hollows out the center of the ball with a combination of scraping and hand modeling. Once this wedge of clay begins to form walls, the potter scrapes away clay from the interior walls, which she uses to form large, short coils. As the plate is rotated, the potter pinches and smoothes the coils onto the walls, which quickly grow taller as the vessel walls become thinner (Fig. 3.13). Final thinning of the upper wall is done by scraping either with the potter’s fingers or a tool. The rim is formed by grasping the top of the vessel with a moistened rag, then turning the wooden plate slowly while flaring out the rim (Fig. 3.14). The potter then adds the decoration, which is the stamped and incised marking usually applied to the exterior neck.

As a vessel dries to leather-hard the potter may thin the walls further by scraping the surface with the edge of cut metal can or other suitable tool. The lower half of the vessel is then shaped with the use of a paddle and anvil, which stretches and thins the base (Fig. 3.15). After additional drying, a thin wash of clay minus the natural sand is applied to the surface and the potter may do some further scraping to smooth uneven surfaces. The potter then polishes the exterior with a smooth stone, which results in a surface that is not lustrous but is very smooth to the touch. Red

Fig. 3.12 Clay is placed on a wooden plate that is rotated during manufacture

Fig. 3.13 Applying coils

Fig. 3.14 Flaring out the rim

Fig. 3.15 Shaping the base with a paddle and anvil

Fig. 3.16 Stacked vessels ready for firing (From Skibo 1992, p. 9)

hematite paint may then be applied to the entire exterior of water vessels and to the neck area of cooking vessels (in Dangtalan).

Communal firing takes place outside the village. Pots are stacked several tiers high and then fuel (bamboo, grass, rice stalks) is placed over the vessels and then ignited (Fig. 3.16). The fire burns hot and for a relatively short period (around 20 min), so that the vessels' actual firing temperature is relatively low. Pots are removed from the fire while they are still hot and a tree resin (*lita-o*) is applied to the interior and exterior rim of cooking vessels and the interior and sometimes exterior of water vessels. The resin is hard but melts on the hot surfaces giving them a shiny, glaze-like appearance.

Field Collection Strategy

The core of the use-alteration study was the observation of pottery in use (e.g., cooking, carrying, cleaning, storing) throughout the daily cycle, from before the morning meal to the storage of the pots after the evening meal. Forty households were observed in this manner, resulting in detailed notes and a photographic record of all pottery use activity (see also Kobayashi 1994, 1996). In addition to these detailed observations, I obtained with the help of English speaking Kalinga assistants, a complete pottery inventory of each of the households, as well as an economic survey and census (similar data were recorded in Dangtalan and Dalupa). Included in this inventory were data for each vessel in use in 1988—i.e., type, size, and when and how obtained. Information was collected on 2,481 ceramic and metal vessels from Guina-ang.

At the end of the research period, new pots were exchanged for 189 pots that were currently in use; the majority of the vessels were obtained from the 40 households from which we collected more extensive vessel use data. These vessels, which are currently housed in the Arizona State Museum, served as study collection.

As I look at the Kalinga pots today I often wonder what the people of Guina-ang really thought about our focus on what they consider to be utterly mundane, everyday objects. Perhaps they considered us a bit crazy and you cannot blame them. But one of the unintentional impacts our research had on the community (and all projects will have impacts) was to empower the women—who were the potters and primary cooks. The men often seemed dismayed that we would be concerned with watching their wives and mothers cook and use pots instead of taking an avid interest in what they considered more important: rice fields, and water buffalo. The women, of course, reveled in the fact that we had traveled thousands of miles and paid close attention to their work. But even the women must have been curious about the work of Margaret Beck (2003, 2006), the last member of the KEP to conduct research in the Pasil Valley, for she was interested in studying where people threw their trash. Although cultural formation processes are of great importance to archaeologists, one can see how such an interest might seem odd to the Kalinga. The people from the village of Dalupa, where she worked, had a number of secondary refuse areas, and she was able to record where each household threw its broken pots. The result was a fascinating study of how social factors, proximity, and other variables influence the locations of trash disposal Beck and Hill (2007). Archaeologists who try to infer past behavior from pottery in refuse areas have to be concerned about the life history of these artifacts. Fortunately, Margaret's work goes a long way toward unraveling the complexities of this process.

Kalinga Pottery Use

Everyday cooking in a Kalinga household is done with a group of pots (4–10) stored near the hearth. The larger, ceremonial pots are usually stored in the rafters and they are taken down only for communal feasts such as weddings or funerals. My description of pottery use is confined to the everyday cooking of rice and vegetables and meat, as the different activities associated with each are reflected in internal carbonization and external sooting, attrition, and residues. Although much rice cooking is done in metal vessels, I restrict my description to ceramic pots.

Fig. 3.17 A layer of interwoven leaves is placed inside rice cooking pots to keep the rice from sticking to the pot (From Skibo 1992, p. 68)

Rice is usually consumed but not necessarily cooked at each meal. Left-over rice can be reheated and eaten especially for the noonday meal. The standard measure of rice is the *"chupa*" which is about 350 cc. A pot of appropriate size (small, medium, or large) is selected according to the number of people being fed. Ideally, rice will fill the vessel to the neck when cooked. So a small vessel is used to feed 1–2 people, a medium vessel is used for a small family, and so forth. Before rice is added to the pot, a layer of interwoven leaves (*apin)* is placed on the interior surface (Fig. 3.17). The leaves keep the rice from sticking and make washing easier.

After the rice is rinsed, an appropriate amount is scooped by hand into the *ittoyom*, and water is added up to the neck. The vessel is covered with a metal lid borrowed from an appropriately-sized metal pot; traditional ceramic lids have been replaced almost completely by the metal covers. In the first stage of rice cooking, the vessel is placed on the three pot supports on the hearth (Fig. 3.18), and a hot fire is made with wood that has been drying above the hearth, and the water is brought to a boil. The vessel is usually left unattended until or just before it boils (usually from 15 to 25 min). When boiling begins the cover may be lifted off several times and the rice loosened with the handle of a wooden spatula (*edjus*). Soon after the rice boils the pot is taken off the fire with the rattan carrier and put next to the fire in the simmer position, but still on the hearth (Fig. 3.19). The cook puts hot coals from the fire beneath the pot, where it sits an inch or so of the fire, which is then used to cook the vegetables or meat. While in the simmer position, the rice pot is rotated about a third of a turn, three or four times. After the appropriate amount of water is removed from the rice through evaporation but without burning, the vessel is removed from the simmer position and placed away from the fire on a rattan ring or directly on the hearth soil. Rice is removed from the vessel with the *edjus*, the spatula-like wooden tool.

Fig. 3.18 Rice cooking pots, filled to the neck with water, is placed on the fire (From Skibo 1992, p. 68)

Fig. 3.19 Rice cooking pot (*on left*) sits on a bed of coals in the simmer position while the vegetable/meat pot is on the fire (From Skibo 1992, p. 70)

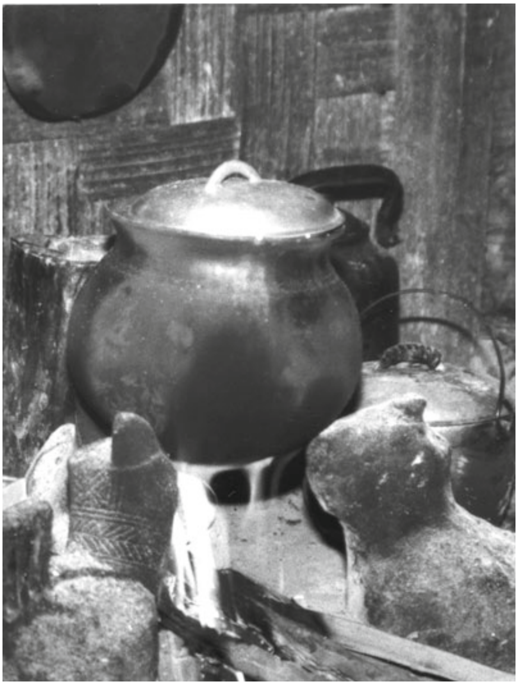

Fig. 3.20 Dull gray soot covers the pot exterior soon after being placed on the fire (From Skibo 1992, p. 69)

Vegetable meat cooking in the *oppaya* is more variable because different vegetables and meats require cooking times ranging from 20 min to 2 h. Beans and peas, for example, take a long time to cook and are boiled before and then again after rice cooking. But other items are usually boiled while the rice pot is in the simmer position. In cooking vegetables and meat, unlike rice, vessels are filled only one-third to one-half with water. Vegetable/meat pots are typically on the fire much longer than rice pots, as the objective is not only to bring the contents to boil but also to maintain a simmering temperature. Consequently, vegetable/meat cooking in the *oppaya* takes a good deal of monitoring because the fire needs to be adjusted and the contents assessed to limit boil-over. Once cooked sufficiently, the contents of the *oppaya* are removed from the fire with the rattan pot carrier and placed on a rattan ring or directly on the hearth soil.

The different activities associated with rice and vegetable/meat cooking is reflected in the patterns of internal carbonization and external sooting.

Kalinga Internal and External Carbonization Patterns

Soon after a Kalinga cooking pot is placed on the fire, the exterior surfaces are covered by soot from the fire (Fig. 3.20). Once the pot cools, a dull-gray soot layer will come off when touched, and so is easily washed off by the Kalinga pot washers (Fig. 3.21). In addition, some of the soot also penetrates or at least adheres

Fig. 3.21 Pot washing takes place in one of the many gravity fed "water spots"

tenaciously to the exterior surface and cannot be removed without also removing the exterior layer of the ceramic. It is the soot that adheres to the ceramic fabric that is of interest here because it is preserved archaeologically.

At first glance the exterior of used, washed Kalinga cooking vessels seem to be completely covered by a glossy soot. More careful examination, however, reveals that the exteriors have some unsooted, or oxidized, patches and also different types of soot (glossy vs. flat black) in different parts of the vessel. Understanding the activities of cooking through an examination of sooting requires first that you identify the patches and patterns of soot and oxidation. The Kalinga rice and vegetable/meat cooking vessels provide good examples (Figs. 3.22 and 3.23).

Internal Carbonization

Rice Cooking Pots. The most common type of carbonization pattern on the interior of a rice cooking pot is a band of carbonization on the mid-interior side and a patch on the base. Although there is some variability owing to the number of times the vessel has been used and skill of the cook, most vessels maintain this type of carbonization pattern throughout their use-life.

What causes this pattern? Interior carbonization is caused by absence of water and the charring of food that either adheres to the surface or is absorbed into the wall. There are three patches of carbonization or noncarbonization on the interior of rice pots. In pots used in moist cooking, the interior of the vessel wall will not exceed 100°C, which is too low for any food to char. Consequently, the non carbonized

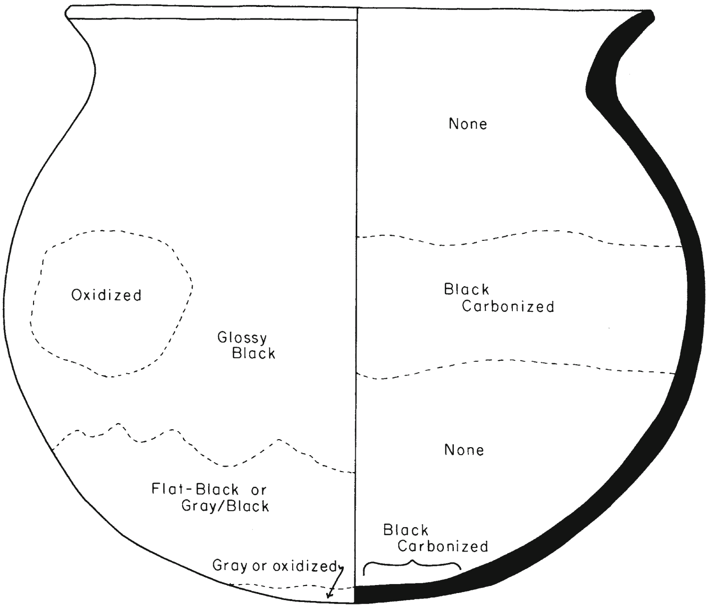

Fig. 3.22 Carbon deposits on interior and exterior of rice cooking pots (From Skibo 1992, p. 149)

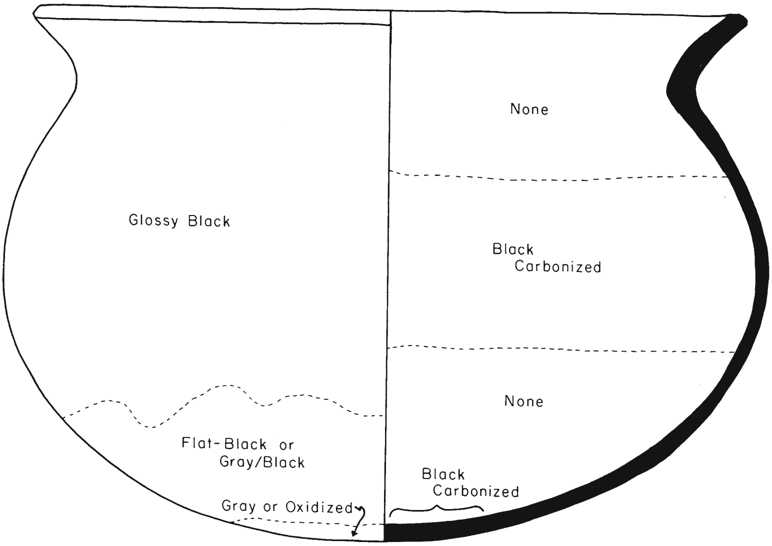

Fig. 3.23 Carbon deposits on interior and exterior of vegetable/meat pots (From Skibo 1992, p. 150)

areas of the interior of rice pots never reached temperatures above 300 °C, when food begins to char.

The patch of carbonization on the base is formed during two stages of rice cooking. As the rice comes to a boil a paste like residue collects on the interior surface. The hottest area on the vessel is the base, and this paste can begin to char before the water boils and is removed from the fire. Most of the basal carbonization, however, occurs as the vessel sits on a bed of coals in the simmer position next to the fire. The objective of this final stage of rice cooking is to remove the remainder of the water in the vessel and many times the rice is visibly charred on the base during this stage of cooking.

The carbonized patch that forms a mid-line ring on the interior of the vessel is also formed while the vessel is in the simmer position. The cook's objective while the pot is in the simmer position is to remove the remainder of the water without charring the rice. The cook will rotate the vessel three or so times while in the simmer position to remove the water without charring. In most cooking episodes, however, there will be some charring of the rice in the simmer position, which will leave a round patch of carbonization at the spot closest to the fire. If the pot were to be used just a few times the result would be several near round patches on the mid-interior side. After many uses, however, these individual patches gradually close together forming the ring of carbonization that one finds on most rice pots.

Vegetable/Meat Cooking Pots. Vegetable/meat pots always have a band of carbonization along the mid-line of the mid-interior side, but it is usually wider than the one formed on the rice cooking pots. They also will sometimes have a patch of carbonization on the base but this occurs far less frequently than the similarly placed patch on the rice cooking pots.

What causes this pattern? As on the rice cooking pots, interior carbonization is created when the interior of the vessel reaches a temperature high enough to char food. This does not occur over most of the interior surface because these are boiling pots and the interior surfaces (below the water line) will not reach temperatures much above 100 °C. When boiling meat or vegetables, however, grease or fine food particles float to the surface during simmering and adhere to the vessel wall at the water line. As the water level drops during cooking, these adhering food particles char because the vessel wall can reach much higher temperatures above the water line. Over time, this process creates the band of carbonization found on all vegetable meat cooking pots.

Sometimes a patch of carbonization also occurs on the interior base where the heat from the fire is most intense. I suspect that some small water born food particles sink to the base where they pass into the vessel wall. Interior resin coating reduces water permeability but does not stop it so that water-born organic matter can enter the wall during cooking especially in older, heavily used vessels that have increased permeability. The charring of this matter occurs during the next cooking episode when the vessel is first put on the fire and before water has had a chance to penetrate the vessel wall. In the first few minutes of cooking the temperature of the wall will get high enough to create carbonization. It is also possible that the resin could carbonize some here as well.

Fig. 3.24 Pottery sooting pattern. Note that fluffy dull gray soot does not occur directly over pot supports (From Skibo 1992, p. 155)

External Carbonization

The carbon deposited on the exterior of rice cooking pots is caused by the deposition of the by-products of wood combustion—soot. Kalinga pots are covered with soot soon after being placed on the fire. Note that in Fig. 3.24, the soot extends right to the rim in the regions not protected by the pot supports. Some of the soot is washed off, but a good deal of the airborne carbonized matter either adheres to or penetrates the surface and becomes permanently (relatively) part of the ceramic fabric. Attesting to the durability of exterior soot, Sassaman (1993), found sooting on the earliest pottery (2000 B.C.) in North America (see also Beck et al. 2002).

The exterior of the rice and vegetable/meat cooking pots share three distinct patches of carbonization or oxidation (in this work carbonization or sooting patches also refers to zones where the soot was never deposited or has become oxidized). The first patch consists of a layer of gray or flat-black soot that extends from the base to approximately half way between the base and the vessel's mid-line. The relative size of this patch depends on vessel size; the patch extends farther up the side, sometimes to the mid-line, of smaller vessels and is be more restricted to the base of the larger vessels. The second patch starts at the border of the gray soot patch and extends to the rim. Here the soot has a glossy or lustrous quality. The soot can build up over time and even begin to chip away on older, more heavily used vessels. The third patch is directly on the base, closest to the fire. Here the soot layer is either very thin or completely oxidized so that the ceramic surface is exposed.

Rice cooking pots often have an additional patch of oxidation on the mid-exterior wall. This patch often corresponds directly to carbonized patches on the interior of the vessel, which gradually grow into the band that circles the interior midline.

What causes this pattern? The rice and vegetable meat cooking pots have some similarities in sooting patterns because they are placed on the pot supports in the same way, and the same type of fire heats the contents. Thus the three dominant sooting patterns—the glossy black patch on the upper portion, the gray/black patch on the lower third or so of the vessel, and the oxidized patch on the base—occur on most cooking vessels. There is, however, some variability in the oxidized patches because their presence depends solely on the last cooking event. If the pot was taken off when the fire was burning hot, the oxidized patch will remain. If, however, the pot was removed while the fire was cooler but still smoking, some soot may be deposited—this would be most common on vegetable/meat pots as rice pots are always taken off the fire when it is hot. Because rice pots are also placed on a small bed of coals in the final stage of cooking, some oxidation may also occur at this time.

The Kalinga research, along with some experiments, allowed me to begin to understand the principles involved in the creation of external and internal carbonization patterns. To begin to apply these findings to prehistoric data, however, requires that we explore further the principles involved in external sooting and internal carbonization.

Principles for External Sooting

What Is Soot

The combustion of wood creates pyrolysis products that include hydrocarbons, carbon monoxide, carbon dioxide, and a carbonaceous residue consisting of "variable quantities of carbonaceous and inorganic solids in conjunction with absorbed and occluded organic tars and resins" (Medalia and Rivin 1982, p. 481; see also Cachier 1989; Goldberg 1985). Although the literature that focuses on airborne emissions from wood combustion is voluminous, owing especially to their deleterious effects on health (Murr and Garza 2009; Murr et al. 2008) and their role in climate change, little has been written on the type of soot created by uncontrolled wood combustion that is deposited on pottery surfaces (but see Hally 1983a). Soot deposited on a ceramic vessel, often kept cooler relative to the fire because it holds water, is a situation unique to archaeology. In addition, archaeologists must consider that we are looking at the soot that is not only deposited by such a fire, but also the matter that survives vessel washing and various post-depositional processes.

Because there is so little relevant literature on the process of soot deposition on pottery, experiments are necessary to fill that void. These experiments are not focused on the chemical nature of the pyrolysis products but rather on the patterns created because of factors related to cooking such as the temperature of the fire, type of wood, presence or absence of moisture in the vessel, and distance from the fire.

Soot Patches

Experiments (see also Hally 1983b) and observations among the Kalinga have shown that three patches of soot are deposited on the exterior of ceramic vessels on an open fire. Although the type of wood, distance from fire, and the presence of moisture all affect the patterning, the critical variable is the temperature of the pot's surface. The first type of soot is deposited soon after a pot is put on or in a fire and it often covers the entire vessel from the base to the shoulder (Fig. 3.24). If there is no wind and the smoke from the fire rises straight up, this soot layer will not be deposited on vessels above the shoulder provided that its orifice diameter is less than the maximum diameter, as on Kalinga rice cooking pots. The soot layer is flat black and fluffy and it consists of coke, fragments of char and ash (Medalia and Rivin 1982). This type of soot can be easily rubbed off with light wiping especially with water, as when the vessels are lightly washed or rinsed. Even unwashed pots, if deposited in open-air settings, would lose this soot layer owing to percolating water, bioturbation, and other post-depositional processes. Because this transient layer of soot would not likely survive the various the effects of cultural and noncultural processes, it is not considered further.

Hally and Pottery Function

David J. Hally, Emeritus Professor of Anthropology at the University of Georgia, spent three plus decades investigating the late prehistoric Mississippian Period in northwest Georgia. His research culminated in the 2008 volume, *King: The Social Archaeology of a Late Mississippian Town in Northwestern Georgia*, which examined the structures of individual households and of the community and latter's position in the larger regional political system. What interests me here is Hally's analysis of the ceramics from this region, which was documented in three papers published in the mid-1980s (Hally 1983a, b, 1986). Although this work is now more than a quarter century old, it is a timeless example of inferring pottery function by integrating use-alteration traces (sooting and abrasion), technical properties of the ceramics, performance characteristics, and ethnographic reports.

(continued)

Ethnographies, travel records, and other historical documents, when they exist are critical to studies such as these. It is rare to find specific sections on pottery function so this information must often be gleaned from other discussions about food or diet. The Southeastern United States has excellent ethnographic descriptions (e.g., Swanton 1946) that permitted Hally to gather quite specific information about food processing and vessel usage. Critical among these was the discussions about the different foods (meat, vegetables, nuts) that were boiled and the various steps using different vessels that were often required to prepare food.

After Hally developed a firm grasp of the various food processing techniques, he moved to the analysis of ceramic collections from the Little Egypt and King sites. The ceramic data included 82 vessels and 4,500 sherds. On the basis of formal technical properties, Hally identified 8 vessel shapes and 13 shape-size combinations. What sets Hally's analysis apart is when he grouped what I call technical choices into a number of performance characteristics including stability, capacity, accessibility, heating effectiveness, and thermal shock resistance. These data were combined with some use-alteration traces, which enabled him to infer how each of the 13 vessel types were used. The use-alteration component of his analysis sets it apart from others, but it the essential final step in a complete functional analysis.

The second type of soot, which is more permanently (relatively) affixed to the ceramic surface, also consists of coke, char, and ash with the addition of carbon cenospheres, a form of resin. These resin droplets, which come from the unburnt resins of wood fuel, are drawn up with the rising gases and then solidify when they come into contact with a sufficiently cool surface. This type of soot is black and sometimes has a lustrous quality. Once the resin cools, it produces a hard, waterproof layer that is very resistant to breakdown in the depositional environment. The oldest pottery in North America, Late Archaic fiber-tempered ware from the southeastern United States has evidence of this type of soot on the exterior surface (Beck et al. 2002; Sassaman 1993) despite being buried in a semi-tropical climate.

The third exterior patch is the absence of soot or at least a reduced amount of soot. The result is a surface that varies from light gray, which is a light coating of soot, to a completely oxidized surface. This type of oxidized patch occurs when the temperature of the ceramic surface approaches 400 °C. At this temperature any soot is burned away and no new soot can be deposited on such a hot surface. Kalinga pots sometimes have an oxidized patch on their base. This is especially true on rice pots as the temperature of the ceramic will heat up to the critical temperature (300–400°C) near the end of rice boiling when most of the water is removed from the vessel. If vessels are used in boiling food, the water will suppress the temperature of the vessel wall and temperatures will not reach 300–400 °C. Kalinga rice pots also get oxidized patches on the sides of the vessel during the last stage of rice cooking as the pot sits aside the fire to remove the remaining moisture. Because little or no water remains in the vessel (or in its wall), temperatures exceed 300 °C so soot is removed.

An absence of soot on the base could also be the result of the way the pot was supported in the fire. If, for example, a vessel was placed directly on the ground and a fire built around it, the base would lack soot.

Exterior soot reflects both the last cooking episode and long-term use. Each time a vessel is put over the fire the sooting sequence is repeated: transient fluffy soot is deposited over the entire vessel, soot with airborne resin adheres to the surface, and, possibly, an oxidized patch is created if the surface exceeds the critical temperature (between 300 and 400 °C). Consequently, exterior soot observed on archaeological samples reflects, primarily, the last cooking episode, with one major exception: long-term accretional sooting. This type of soot, seen clearly on Kalinga vessels, results from the buildup of a glossy, resinous layer that can become so thick that it begins to chip off. A similar pattern could be found on archaeological vessels if they had been used over long periods.

Temperature is the key variable in soot deposition. Temperature of the fire and of the ceramic surface determine the pattern of the three types of soot described above. Several factors affect temperature, including type and quantity of fuel, distance of vessel above the flames, presence or absence of water in the vessel, and hearth design. For the following discussion, I collapse these factors into three general categories: temperature of fire, distance from fire, and mode of cooking.

Temperature of Fire

The temperature of the cooking fire, determined by a number of factors, can change appreciably throughout just one cooking sequence. The type of wood or other fuel affects the temperature of the fire as well as the amount of resins given off. If the fire is very hot and the vessel's surface approaches 400 °C, no soot is deposited.

Distance from Fire

Pot supports as used by the Kalinga are a common form of hearth design found worldwide. The tripod-like support keeps the vessel stable and positions it above the fire, which permits maximum heating. During each cooking episode, no soot is deposited where the supports touch the pots, but after repeated use these unsooted regions become evenly sooted. Many different hearth designs are found worldwide that range from placing the vessel directly in the fire to suspending it over the fire. Of course no soot is deposited on the base if the vessel is put directly in the fire, but with most hearth designs the key variable is the temperature of the vessel surface.

Mode of Cooking

The method of cooking also influences soot deposition. If cooking is done in the wet mode (boiling), the pot's surface will stay relatively cool as water that seeps through the vessel wall will evaporate and cool the surface. Consequently, even in the hottest fires soot will be deposited directly on the base of vessels. When the dry mode is used (as in roasting or reheating food), the surface of the vessel can reach very high temperatures and oxidized patches on the base are common.

Case Study: Late Archaic Pottery and Exterior Sooting

In Chap. 2, I discussed the earliest pottery in the Southeastern United States in terms of the relationship between technical choices and vessel performance. It was found that Late Archaic fiber-tempered pottery was an expediently made technology. If you want to make a vessel quickly, the fastest way to do that is to dig up wet clay that is overly plastic, add organic temper that both dries the clay and makes it workable as well as performing the other important functions of temper (reducing shrinking and cracking and improving thermal shock resistance). A key factor in understanding this early pottery is to know how it was actually used. Sassaman (1993) was the first to integrate use-alteration, in this case exterior sooting, into a more holistic understanding of the transition to the manufacture and use of Late Archaic pottery.

Sassaman (1993) and Sassaman and Rudolphi (2001) perspective, not unlike the one advocated here, is to look at the manufacture and use of Late Archaic pottery broadly, considering the performance of these vessels that includes (in my terms) social as well as utilitarian performance. One important finding in his analysis is that interior sites, in the Savannah River Basin, had fiber-tempered pottery with far less evidence for cooking over the fire than similar vessels on the coast. Sassaman (1993, p. 159) observed exterior soot on 42 % of the fiber-tempered pottery recovered from coastal sites and only 5 % from vessels at interior riverine sites. Beck et al. (2002) also inspected a sample of sherds from interior riverine and coastal sites, which enabled them to confirm the general pattern in exterior sooting that Sassaman first identified—interior sites have primarily unsooted exteriors whereas coastal sites have a high percentage of sherds with exterior sooting. Beck et al. (2002) caution that because Late Archaic pottery is often very low-fired (500–700 °C), they are susceptible to abrasion through various post-depositional processes (see also Reid 1984). A series of experiments by Beck et al. (2002) demonstrate that a moderate amount of surface abrasion can remove any evidence of sooting. Consequently, they recommend that only sherds in a well-preserved state should be examined for exterior sooting. Despite these caveats, their research supports Sassaman's finding that people on the coast were putting their vessels on a fire for direct heating and the people in the interior were not. This is where the story gets interesting.

Compared to organic containers, the great advantage of pottery is that it can be put directly over a fire for direct heating—usually boiling. Making this move enabled people around the world to discover the “joys” of boiled food. And some foods that became staples of the Neolithic, like beans or rice, are made palatable only with boiling. So the fact that there is a large, well-preserved and documented collection of pottery with no exterior soot from the interior sites along the Savannah River Basin surprises to me. The use-alteration evidence is unequivocal—they are not using the vessels over a fire. Sassaman suggests that they were being used for indirect heating, or hot rock boiling.

Hot rock boiling would have been a technique familiar to the people of the prehistoric Southeast as it was no doubt for people around the world (K. Nelson 2010). Based on a series of experiments conducted by my colleagues and I (Drapalik et al. 2010), it is a very effective means to heat water quickly and even maintain a simmering temperature for a long period. And as Reid (1990; see also Sassaman 1993; Sassaman and Rudolphi 2001) correctly notes, the design of Late Archaic pottery is well suited to hot-rock boiling. The wide mouths and open design would have permitted rocks to be easily placed in the vessel and then removed; moreover, the thick-walled design and low-fired paste created a vessel that could have “functioned as a kind of primitive thermos” (Reid 1990, p. 16). So these simple vessels could have served as containers for hot-rock boiling. But why would they use them for direct heating on the coast and hot-rock boiling in the interior?

Sassaman also provides us with a possible explanation relating to the presence of soapstone objects, which were manufactured and used only at the interior riverine sites. From about 3000 B.C., well before the appearance of pottery in the Savannah River Valley, people were making soapstone slabs (roughly 8 by 10 cm and 2 cm thick) for indirect cooking (Sassaman 1993; Sassaman and Rudolphi 2001). The slabs, which are easily fashioned from the relatively soft talc like stone perform better than quartzite and most other rocks because they are prone to thermal shock cracking. Soapstone, in contrast, has not only high thermal shock resistance but also wonderful heat retention properties as it is used today in heating stoves and cookware. Archaic sites throughout North America are often littered with fire-cracked rock presumably because of its frequent use in indirect cooking (Skibo et al. 2009; Thoms 2009). The soapstone objects had, in many cases, a perforation that enabled the slabs to be transferred “with a stick or antler tine from heat to container and back” (Sassaman and Rudolphi 2001, p. 415). It should be noted that soapstone slabs used for indirect cooking should not be confused with soapstone containers, which often have evidence for sooting and placement directly over a fire (Sassaman 1993, p. 181; Truncer 2004). These containers sometimes appeared earlier than ceramic pots but in many cases were manufactured and used alongside ceramic containers (Sassaman 2006; Truncer 2004). Regardless, it is of interest that this was an important technology in some regions that seems to have played a significant role in the adoption and use of pottery containers.

Sassaman argues that soapstone technology performed a number of important social functions related to gender, intergroup relationships, and post-marital residence rules. One of the more fascinating aspects of this case of technological resistance and change is the role that gender may have played. Pottery world-wide is predominately a female technology when made at the household level (Skibo and Schiffer 1995), so one is justified in inferring that the first potters in the Southeast were women. Sassaman (1993, p. 219) introduces the possibility that soapstone manufacture and exchange might have been a technology controlled by men. The manufacture and use of ceramic containers directly over the fire would have made the manufacture of soapstone slabs obsolete. Consequently, there could have been resistance to a technology that would replace soapstone because of its social ramifications. The fiber-tempered vessels at these interior sites were used for indirect cooking presumably with soapstone slabs, thus both technologies were operating side-by-side for a time. The people on the coast, however, did not have soapstone technology and were less resistance to adopting fiber-tempered ceramic containers for use over a fire.

Any technological change involves down-the-line social and technological ramifications, and new technologies could be limited by social constraints (Schiffer 2011, pp. 43–53). And perhaps this transpired in the transition of placing pottery directly over a fire. A short-term compromise could have arisen in the region because social performance characteristics were so important for the male-related soapstone slabs. For a time, at least, the technologies were combined so that the soapstone objects were used as hot-rocks in indirect heating.

Because Sassaman combined use-alteration traces, utilitarian performance characteristics and other technologies and their related social performance characteristics, he was able to provide a fuller picture of the adoption and use of this important technology. And the “soapstone hypothesis” is attractive because it involves social performance characteristics associated with soapstone slab, manufacture, distribution and use, which impeded, for a time, the use of ceramic vessels over an open fire.

As much as I like this explanation, it introduces more questions. If soapstone/hot rock boiling was so effective (both in cooking and in performing important social functions) why did pottery appear in this region at all? What is the evidence that fiber-tempered ceramics were used for indirect (hot-rock) heating? Is it possible that the vessels were used for direct heating over a fire and no soot was deposited (such could be the case for parching over hot coals)? What is the evidence that soapstone slabs were used for heating in indirect cooking? Although the circumstantial evidence is strong that these vessels were used in hot-rock boiling, Sassaman’s reconstruction could be better supported with direct evidence of this activity. There are two ways that this could be done. Vessels with unsooted exteriors should be examined for lipids. If the vessels were used for hot rock boiling then lipids from their contents should have been absorbed by the vessel wall. The soapstone slabs could also be examined for evidence of thermal alteration (Jim Burton, personal communication 2012), and for lipid residues. There is a means, through the examination of fire-cracked-rock lipids, to demonstrate the presence of hot-rock boiling (Skibo et al. 2009). Lipid and other organic residue analyses are discussed in more detail in Chap. 5. Finally, if these low-fired vessels were used for hot rock boiling then there should also be abrasion on the interior surfaces. Sassaman’s work on the early pottery from this region is innovative and it should be pursed further with these and other types of tests.

Principles for Internal Carbonization

Internal carbonization is caused by the charring of food. Unlike exterior soot, which rests on the surface of the vessel, internal carbonization can both lay on the surface and also penetrate the wall. Carbonized food, usually in the form of encrustation near the rim interior or exterior, is interesting and useful when found but it is far less common than carbonization that has penetrated the vessel wall. Not only can carbonized food be washed off by the vessel user, but this adhering layer is also much more prone to removal in the depositional environment. Nonetheless, when encrustations are found, the location should be noted and care should be taken not to remove it during washing. These encrustations have been successfully radiocarbon dated and also analyzed to identify what was being cooked (e.g., Malainey 2011; Reber and Hart 2008; Hart and Lovis 2007; Lovis 1990; see also Chap. 5). The presence of carbonized encrustations also provides important clues to cooking behavior. For example, in the Upper Midwest and Great Lakes region in the United States, encrustations are often found near rims (interior or exterior) suggesting that these vessels were used as stew pots, rarely washed or even taken from the fire (see Kooiman 2012).

I focus the discussion here on carbonization within the vessel wall for a couple of reasons. Although some important cooking behaviors can be inferred from encrustations, as noted above, the same general principles govern both visible encrustations and carbonization in the vessel wall. Visible encrustations are also uncommon on cooking vessels worldwide whereas carbonization within the vessel wall is very common, though infrequently recorded. That is because carbonization on sherds may be misidentified as soot or a fire clouds, if recorded at all, and on whole vessels researchers rarely make the effort to peer inside a vessel and record such traces. After years of wandering about in the whole pot rooms of museums I can affirm that most cooking vessels will have this type of internal carbonization.

Temperature of the ceramic surface is the primary factor responsible for the deposition of internal carbonization. The vessel wall must reach between 300 °C and 400 °C for carbonization to occur, which depends on several cooking related factors.

Mode of Cooking: Wet/Dry

If one could determine the function of prehistoric cooking pots around the world, my guess is that the majority were used directly over the fire in the wet cooking mode. Although as mentioned above, foods can be boiled indirectly with hot-rocks, this may not be the effective way to process many foods. If hot-rock boiling was generally effective, why the need for pottery at all?

The answer may be that hot rock boiling may be an effective way to boil water but it does not work that well for foods that need to be cooked for a long time. Perhaps the greatest performance advantage in wet mode cooking is not boiling but rather long-term simmering. In fact a number of important foods, like many kinds of

Fig. 3.25 Roasting coffee in a reused cooking vessel

beans, are made palatable only after boiling for an hour or more. Because hot-rock boiling takes constant monitoring and more active participation by the cook, it would be far less effective for long term simmering than ceramic pots. The ceramic cooking pot can stay on the fire indefinitely and maintain a simmering temperature without boil-over. Because I suggest that the simmering pot is such an important part of traditional cooking it is vital that we be able to infer it from use-alteration traces.

Cooking in the wet mode can be inferred because carbonization does not occur until surface temperatures reach between 300 °C and 400 °C. Below the water line interior vessel temperatures do not exceed 100 °C, so no carbonization occurs. But as shown by Kalinga vegetable/meat pots (wet mode cooking vessels), a band of carbonization forms at the water line. Fats and other food particles rise to the surface, penetrate the vessel wall, and are carbonized above the water level because surface temperatures can exceed the 300–400 °C threshold. A ring of carbonization at the water line is the use-alteration signature trace for cooking in the wet mode.

Thus, in the wet mode of cooking, the most important factor for determining wet mode cooking is the band of carbonization at the water line. Below this line no carbonization is formed because water inside the vessel keeps the ceramic surface at about 100 °C. Just above the water line, however, temperatures can reach above 300–400° enabling fats and other food particles floating on the surface of water to adhere or become absorbed into the interior vessel wall and become carbonized.

In the dry cooking mode, temperatures can exceed 300–400 °C and so carbonization occurs throughout the interior. A good example is Kalinga coffee roasting pots, which are reused cooking pots. Coffee, and occasionally beans, peas, or chilis, are roasted by putting a vessel on the hearth supports at a 45° angle (Fig. 3.25). A moderately hot fire is built and then the cook stirs the contents of the vessel the entire time it is on the fire. The interior of such pots are entirely covered with a thick layer of carbonization. It should be noted, however, that this carbonization layer only occurs on the surface and will not penetrate the vessel wall, as often occurs in wet mode cooking. The latter can have carbonization within the vessel wall because water-born organics can penetrate the porous vessel wall and then become carbonized.

Wet and dry modes are the two cooking extremes. Although each is common prehistorically, there are cooking techniques that fall between these extremes. For example, some food processing requires the complete removal of water, as in Kalinga rice cooking. In such cases, near the end of the cooking episode as the remaining water is removed, interior carbonization can occur. Continued simmering of thick stews, soups, or gruels may become so dry that carbonization occurs at places where the surface temperatures exceed the critical threshold. A cereal grain, boiled in water or milk, could easily have a patch of carbonization near the interior base. The Kalinga sticky rice (*chaycot*) is boiled down to a gruel-like consistency and carbonization does occur on the pots near the base. In this case the carbonization occurs as both an encrustation and as carbonization beneath the surface.

My analysis of *chaycot* cooking was not originally planned. In fact, I rarely saw it during my usual observations of everyday cooking. Nonetheless, I did fortuitously observe its preparation and I ate it with pleasure on a number of occasions—sometimes in several different homes in a single evening. When we first arrived in Guinaang, it was an intense period of excitement as non-Kalinga living in this small village was unusual. During the first week before our real research began I probably ate *chaycot* several times every day as we were invited to various households; refusing such invitations would have been considered insulting. I learned early on just to eat a few bites of the sweet, sticky treat—a small but socially acceptable amount. Although there are a number of varieties of *chaycot*, in each case the rice was boiled down to a gruel-like consistency creating the tell-tale patch of carbonization on the base.

Other Factors

Although the presence or absence of water in the vessel is by far the most important determinant of the internal temperature of the ceramic surface, there are secondary factors as well, including hearth design, vessel placement, type of fuel, and vessel size. Although hearth design and vessel placement (e.g., in or over the fire) are seldom discussed in archaeological reports, these factors should receive more attention for they affect interior and exterior carbonization. The most common type of hearth design ethnographically, and likely prehistorically, is the one employed by the Kalinga; three supports hold the vessel above the fire (Fig. 3.26). Such a design not only provides a stable platform for round-bottom vessels, but it also gives the cook some control over the fire's temperature by permitting the easy addition or removal of fuel. This type of design has the potential to create a very hot fire directly on the

Fig. 3.26 A rice cooking pot on the three pot supports in a Kalinga hearth

vessel's base that, if the contents were sufficiently dry, would raise the wall's temperature past the critical point, creating interior interior carbonization.

Other hearth designs include suspension over a fire, placement directly on the ground and a fire built around it, and formal stoves. Regardless of design, the critical variable for internal carbonization is that the interior temperature must reach between 300 and 400 °C.

Fuels burn at various temperatures and this variation can have an effect on internal soot deposition. Generally, lignin-rich softwoods can generate more heat (Tillman 1978, pp. 67–68), but they also have higher moisture content and thus burn less efficiently. It was also found during the Kalinga study that the pot's size influences interior carbonization. In particular, large Kalinga pots have more basal carbonization. Fire is more intense with these pots because the heat is not dispersed up the sides. Also, it is more difficult to bring the contents to a boil so the fire is hotter and cooking takes longer, which increases the possibility that there will be water removal at the base and thus carbonization.

Case Study: Origins of Pottery on the Colorado Plateau

Walk into any art gallery that carries pottery and you will likely see vessels from the American Southwest. Both prehistoric and contemporary potters on the Colorado Plateau, of what is now the four corners of Arizona, New Mexico, Colorado, and

Fig. 3.27 Black-on-white pottery characteristic of the prehistoric people of the Four Corners region of the American Southwest

Utah, have a well-deserved reputation for exquisite craftsmanship. Of particular note are the black-on-white or the black, red, and white polychromes with their delicate and elaborate painted designs (Fig. 3.27). From an archaeological perspective, this pottery tradition not only marks the passage of time or demarcates cultural traditions (Kidder 1924), but also enables the construction of inferences about virtually every aspect of past society from diet and demography to religion and social organization. In fact, the classic case studies of the New Archaeology (Hill 1970; Longacre 1970) were based on the spatial distributions of design elements on the magnificently painted black-on-white vessels from the twelfth and thirteenth centuries. Despite the importance of pottery for archaeology in the American Southwest very little attention has been given to the origins of this important technology.

One of my goals after *Pottery Function* was published was to explore ways to apply what I had learned about the formation of use-alteration traces to prehistoric questions and collections. It was during this time that I became acquainted with Eric Blinman, a like-minded archaeologist with a long career in New Mexico focused on Ancestral Pueblo ceramics. Eric not only has a keen understanding of the ceramic technology of the region (Blinman 1988), but he is also skilled at replicating many traditional forms. Along with colleague Dean Wilson, Blinman explored an early brownware tradition—ca. A.D. 200–300—that represents the region's first pottery (Blinman and Wilson 1994; Wilson and Blinman 1993, 1994, 1995; Wilson et al. 1996; for a full discussion of the study, see Skibo and Blinman 1999 and Skibo and Schiffer 2008, pp. 3–52).

Fig. 3.28 Seed jar. One of the most common types from the earliest pottery period on the Colorado Plateau

The pottery has a number of regional names, but it is a relatively well-made plain polished brownware (Wilson 1996). This pan-Ancestral Pueblo ceramic tradition was locally made with self-tempered alluvial clays rich in iron. Although there seems to be some variability in manufacturing techniques, most vessels seemed to have been made with the coil-and-scrape technique, and they usually have polished exteriors.

Although there is morphological variability, the most common shape is the globular neckless jar (Fig. 3.28). In the local vernacular, these vessels are referred to as "seed jars" because the shapes continue into the late prehistoric and historic periods when they were used for storage. But as you will see below on the basis of use-alteration traces, and in particular the interior carbonization, this functional label is a misnomer.

Our analysis focused on the seed jar forms whose formal and technical properties alone (globular in shape, thin-walled, lightly polished, restricted orifice) suggest important inferences about these vessels' function and performance.

Intended Function and Performance of the Seed Jar

Globular Shape. Vessel shapes approaching spheres have a design that imparts great strength both in manufacture and in use. Spherical shapes have high green strength and would be less likely to crack from the strains resulting from drying and shrinking of the paste. This would have been especially true of the alluvial higher shrinkage clays used to make vessels of the brownware tradition . Any vessel might crack with excessive shrinkage, but shapes approaching spherical have the greatest overall resistance to cracking during drying. Moreover, this shape imbues a vessel with greater resistance to the thermal shock during firing. Such a vessel also has much strength in use because it is better able to withstand the strains of thermal shock without catastrophic breakage; and spherical designs are better able to distribute the weight of their contents and thus reduce the risk of breakage from internal loading.

Restricted Orifice. These vessels have a restricted orifice, and vessel strength varies inversely with orifice diameter. These types of openings are also easily covered or plugged, and so can protect the vessel's contents. But even an uncovered seed jar shape would limit the amount of heat lost during cooking and also reduce the risk of spilling during transport. Such a restricted orifice, however, also suffers some performance limitations. For example, it is difficult to access the contents of the vessel by hand or with a tool, and such a vessel opening is not conducive to pouring out liquid contents.

Polished Exterior. The exterior of many seed jars can be described as lightly polished. Although a polishing stone had been rubbed on the exterior surface, the coarseness of the paste, exposed temper, and overall uneven surface gave vessels an appearance of having only a light polish.

Polishing, of course, can be an important visual performance characteristic but it also has an impact on utilitarian performance characteristics such as water permeability (Schiffer 1988). As noted in Chap. 2, in low-fired cooking pots, permeability is a concern because water that seeps to the exterior surface reduces heating effectiveness by evaporating, thereby cooling the surface of the vessel, which may prevent boiling. Kalinga cooks retire cooking vessels once the interior resin has worn away because they are no longer effective for cooking. Schiffer (1988b) has shown that interior and exterior surface treatments, like polishing, can significantly reduce water permeability. But exterior polishing is often not seen on cooking pots; when water reaches the exterior surface and encounters a low permeability barrier such as polishing, spalling may occur as the water turns to steam and blows through the polished surface (Schiffer 1990; Schiffer et al. 1994). This may be why brownware seed jars have the lightly polished exteriors. There is enough polish to reduce permeability but not enough to prevent the steam from escaping without causing spalls.

Heavily Tempered, Thin Walled, Low Firing Temperature. I combine these technical choices because they are associated with the primary performance characteristic of cooking pots, thermal shock resistance, which is the ability to withstand repeated heating and cooling without cracking or breaking. When a vessel is put over a fire there can easily be a 400 °C difference in temperature between the interior and exterior of the vessel wall, which creates tremendous strains on the vessel. The reason why cooking pots, worldwide, last on average from just several months to a little over a year (Longacre 1985; Tani and Longacre 1999; Shott 1996; Varien and Mills 1997) is that they eventually do succumb to thermal shock even though potters may go to great lengths to increase thermal shock resistance. The most common and effective way to increase thermal shock resistance is by adding large amounts of temper, as was discussed in Chap. 2. The first potters on the Colorado Plateau who made the brownware seem to have used this strategy. They also fired the early brownware at a relatively low temperature. Low-fired pottery has greater porosity and these pores have the same effect as temper—interrupting the microcracks. Finally, thin-walled vessels suffer less strain from thermal shock, and the brownware pots have very thin walls. Consequently, the first potters on the Colorado Plateau created a vessel with high thermal shock resistance that would have performed well for cooking.

The seed jar vessels are not just well designed for cooking. If I were going to start from scratch and design a vessel that could perform at a relatively high level for the greatest number of techno-functions, I would make it just like these early potters. Not only do the pots score high in thermal shock resistance, but the globular shape imparts appreciable strength, permitting the vessel to perform at a high level in storage and transport of contents. In addition, these vessels have a low center of gravity, despite their spherical shape, making them very stable in the upright position. The only performance characteristic on which these vessels score low is accessibility (because of the restricted orifice diameter), and so they would perform poorly when pouring liquids. Even so, on the basis of their form and performance characteristics, we might consider these vessels to be the pottery equivalent of the Swiss Army Knife, able to perform a variety of techno-functions reasonably well.

Carbonization, Actual Function, and Performance of the Seed Jar

The analysis of carbonization patterns was done on whole and partially reconstructed vessels from three sites in northeastern Arizona, Flattop, Sivu’ovi, and the Prayer Rock Caves. Both Sivu’ovi (Burton 1991) and Flattop (Wendorf 1950) are in the Petrified National Forest and the material is curated at the Western Archeological and Conservation Center in Tucson, Arizona. The Prayer Rock Caves are in the Prayer Rock District of the Navajo Indian Reservation; the sites were excavated by Earl Morris in the 1930s (Morris 1980). These vessels are curated at the Arizona State Museum.

Both facilities have cavernous “pot rooms” with row after row of shelves filled with 2,000 years of the Southwest’s ceramic history. As a person interested in ceramics, I find a walk through such rooms a thrilling experience. I marvel at the skill and artistic sense of the prehistoric potters, as my eyes glance back and forth among the beautifully painted black-on-white vessels, the infamous Mimbres bowls with zoomorphic decoration, or the masterfully made polychrome pots from later prehistory. But the vessels that interest me most are usually in the back aisles, as cooking vessels are the ugly stepsisters of the ceramic world. Covered with soot (hopefully), highly tempered and low-fired, these vessels seldom adorn the cover of a book or catch the eye of a Southwestern art aficionado. But these are just the types of vessels that have important use-alteration traces.

Whole vessels are rare, so this study was based just on a couple of dozen whole vessels from sites that yielded tens of thousands of sherds. Our analysis of the internal and external carbonization patterns confirmed what we inferred from the technical choices: these vessels were used in a variety of ways. The first observation is

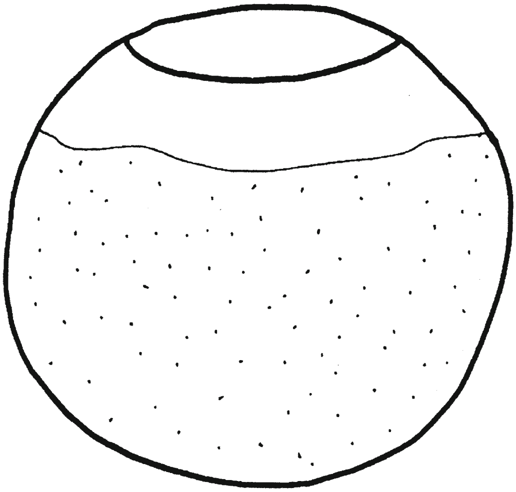

Fig. 3.29 Interior carbonization pattern typical of dry mode cooking (From Skibo and Schiffer 2008, p. 48)

that many have evidence of use over a fire. This alone is an interesting finding, for many Southwesternists assumed that because they have a "seed jar" shape their primary function was storage. I cannot rule out a storage use, but the majority of the vessels were also clearly used for cooking. The internal carbonization patterns provided the most interesting traces of cooking behavior. These carbonization patterns occurred along a continuum from no carbonization to completely carbonized; they can be broken down into three cooking modes: wet, dry, and mixed.

Wet mode cooking, or boiling, created a carbonization band at the water level (Fig. 3.29). As was described earlier, when food is boiled the temperature of the interior ceramic surface does not exceed 100 °C. However, at and above the water line the temperature can exceed 100 °C, causing carbonization of fats and food particles as the temperature reaches the critical temperature (300 and 400 °C). Some of these vessels were used exclusively for cooking in the wet mode, as the only carbonization visible was along the interior mid-line, which would have been the water level in wet mode boiling.

The second mode of cooking that was identified by the examination of internal carbonization patterns was the dry mode, which leaves carbonization covering much of the interior surface (Fig. 3.30). In the dry cooking mode there is little or no water in the vessel, so the interior surface can reach the critical temperature and food particles may carbonize. Roasting or parching seeds or nuts could cause this type of internal carbonization pattern. This type of complete carbonization may also occur during the wet mode if the water level was very low. For example, cooking stew or a gruel until much of the water had evaporated could cause organics to carbonize on the interior surface.

The third cooking mode, mixed wet and dry, leaves a ring of carbonization at the water line characteristic of wet mode cooking but also produces heavy carbonization at the base. The contents of the vessel were boiled in the wet mode until much

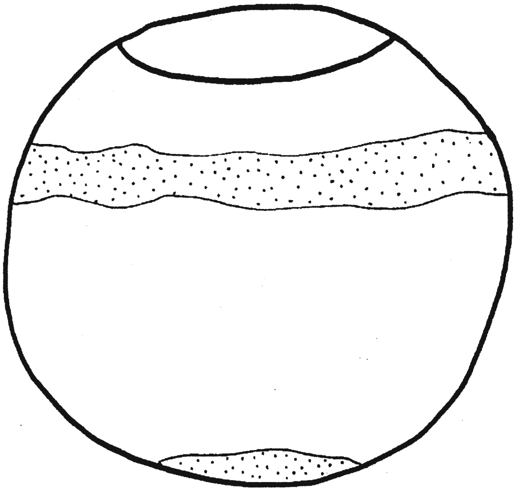

Fig. 3.30 Interior carbonization pattern typical of wet mode cooking (From Skibo and Schiffer 2008, p. 49)

of the water had been removed and carbonization started at the base, which would have received the most heat. A similar kind of carbonization pattern occurred on Kalinga rice pots, which are used in wet mode cooking but the goal is to remove the water through boiling. Leaving a rice pot too long on the fire would char the rice at the base, and create internal carbonization.

In summary, an examination of both the intended and actual functions of the earliest pottery on the Colorado Plateau provided some interesting results. Based just on technical choices, the vessels are the Swiss Army Knife of the pottery world, performing reasonably well in cooking, storage, and transport. Use-alteration traces support the inferences drawn from the technical choices, as there is direct evidence that the vessels were used over the fire in both wet and dry cooking modes. But not all of the vessels had evidence of being used over the fire, and some attritional use-alteration traces that suggest that some vessels were used in fermentation (Chap. 4).

Whole vessels or at least large fragments are preferable for recording the traces of internal and external carbonization patterns. But every archaeologist knows that whole vessels are exceptional finds; we are mainly left with piles of sherds from which to draw our inferences. Below I discuss a strategy that can be employed by the analyst to both record carbonization patterns and also infer pottery use.

Recording External and Internal Carbonization on Prehistoric Collections

I have visited ceramic labs all over the United States and now around the world from China, to Brazil, and France. It is gratifying to note that analysts in many labs are now routinely recording use-alteration traces. One lesson from visits to ceramic collections worldwide is that there is a great deal of ceramic and use-alteration diversity, and thus analytic strategies have to be designed to match this diversity and also serve the archaeologists' research questions. With that said there are also some practical steps that can be taken by analysts when they are both recording and drawing inferences from carbonization and sooting patterns.

Start with Whole Vessels

I realize, of course, that whole or reconstructable vessels are rare in many regions. Before you stop reading and move to the next section, let me assure you that I feel your pain. I have been working on Grand Island in Michigan since 2001 and have not come close to finding a whole or reconstructable vessel. In fact, the post-depositional formation processes in this region, most notably freeze-thaw, reduce the ceramics to mere crumbs. We get excited when we find a sherd more than a few centimeters long with the interior and exterior surfaces intact. But I am going to demonstrate how even in this unpromising situation whole vessels are still important to a complete examination of use-alteration traces.

Although I may work for the rest of my career on Grand Island and not find anything close to a whole vessel, at nearby sites whole vessels have been excavated. These sites were excavated long ago, but their collections now reside in museums and collection facilities (see Kooiman 2012). For any study of sooting and carbonization patterns, these whole vessels can serve as the starting point of the analysis. Sometimes these vessels have been long forgotten and perhaps not examined for years or even decades, if ever. This is so in my study area, but, happily, there are dozens of whole or at least partially reconstructable vessels that can serve as the baseline for my study.

Whole and reconstructed vessels are best for this analysis, but large fragments may also suffice. Large fragments, preferably from the rim to the base, are all that are necessary to start a use-alteration analysis. Ideally, there should be a sample of vessels or vessel fragments from each size and morphological type. If so, then you have the foundation for the recording of carbonization and sooting patterns even if there is not a single whole vessel in your collection. But even if you did not have many whole vessels or there are gaps in the morphological types, whole vessels should still be the analytic unit—even if sherds make up the assemblage.

One of the analytical traps of doing a use-alteration or any type of ceramic analysis is that sometimes the sherds become a unit of analysis. In any ceramic analysis the analysts needs to insure that their research questions and analysis strategy is guided by the fact that the whole vessel is the unit of analysis. If such is the case, use-alteration analysis could be done on only a sample of the vessels/sherds.

Recording Use Carbonization and Sooting Patterns on Whole Vessels

Although external carbonization and sooting traces can be highly variable, we should be concerned not with idiosyncratic sooting patches but rather general patterns. I have found that sketches are the best way to quickly and accurately record sooting patches on whole vessels. A long tradition of scientific and technical drawing in archaeology furnishes models for recording ceramic variability in detail, but in most cases such drawings are unnecessary for initial data recording. The strategy I found most effective is to craft roughly measured sketches that can be recorded by any analyst with just a small amount of instruction (A similar strategy is used for recording attrition, as described in Chap. 4).

The first step in the recording requires one to have a general idea of the range of morphological types. On this basis, recording sheets can be constructed for each type, which consists of the profile drawing of the pots on which internal and external carbonization patches can be recorded (for examples see Figs. 3.22 and 3.23). Armed with a measuring tool, a relatively quick sketch can be made of the internal and external traces. In most cases carbonization patches will be radially symmetrical but if they are not then two use-alteration profile recording sheets can be used to represent both front and back sides of the pot. Interior carbonization patterns are very difficult to accurately record but that is okay because, in the end, the most useful data are the patches and patterns that repeat on vessel types. A great many use-related variables, not to mention post-depositional processes, are involved in the ultimate size, shape, and overall characteristics of a patch, and that is why general sketches are the most useful. These, when combined, provide the analyst with relevant information for inferring actual vessel function.

Recording Use-Alteration Traces on Sherds

The presence or absence of sooting and carbonization is easily recorded when processing large batches of sherds. Minimally, it is useful to know if the patterns are found on the vessel's interior (carbonization) or exterior (sooting). If the sherd's location on the vessel (e.g., rim, body, neck, base) is known, this information will be helpful when constructing inferences, especially if some whole vessel data are available. In that case, the sherd evidence can augment what has been learned from the whole vessels.

However, as the case study drawn from Sassaman's (1993) work from the Southeastern United States shows, even the presence or absence of sooting or carbonization can be informative. In this case, use-alteration traces were recorded just from sherds, yet patterning in these data led to important conclusions about cooking behavior.

Fig. 3.31 Fire clouds created during firing on an unused Kalinga vessel

Trickery

Another important reason to start with whole vessels is that cooking is not the only way that a vessel's surface can become carbonized; moreover, a host of post-depositional processes can remove the traces of carbonization. Additive processes include carbon deposition during vessel firing (fire clouds) and in a fire, such as the burning of a structure.

Fire clouds are random patches of carbonization, usually on the exterior of vessels, that commonly occur on pots fired in the open or in pits. As Shepard (1956, p. 92) notes, fire clouding "occurs where fuel comes in contact with the ware or where a jet of gas from a smoky flame strikes it" (see also Rye 1981, pp. 120–121). Figure 3.31 provides a good illustration of fire clouds on an unused Kalinga vessel. This carbonization has actually become part of the ceramic body and cannot be removed without scraping away some of the ceramic surface. In this way, fire clouds are just like smudging, the process of purposefully creating a reducing atmosphere during firing to create, in the presence of organic matter, a blackened surface (Longacre et al. 2000; Rice 1987, p. 158; Schiffer 1988, 1990; Shepard 1956, pp. 88–89; Skibo et al. 1997). But whether smudging, fire clouding, or exterior sooting, all are similar in that carbonized matter is deposited on, and in some cases slightly in, the vessel wall. The only difference between sooting and smudging or fire clouding is that the latter two processes permit penetration of carbon beneath the surface. The depth of this carbon layer, however, is often very shallow and difficult to see in cross-section with the naked eye. Perhaps it would be possible to distinguish a fire-cloud from sooting in cross-section with measurements taken under magnification, but this is probably unnecessary for most research questions. The primary factor distinguishing carbon deposited as soot during use from carbon deposited during firing is in the patterns.

The trickery here is not with fire clouds, as this can be identified readily by an experienced analyst, as it is the purposeful blackening of an entire surface, but this is seldom done with cooking vessels. But fire clouds do often occur on cooking pots and on first inspection may mimic sooting. The main difference is that fire clouds occur randomly on the vessel. They are called fire clouds because they are amorphous blobs that resemble cumulous clouds. On whole vessels or large sherds, exterior fire clouds and sooting are easily discriminated because the latter tends to be radially symmetrically in patterns that recur on different vessels (of the same morphological type). However, on sherds fire clouds can be mistaken for sooting. Fire clouds, however, are not as common as sooting. It is important to note that fire clouds rarely occur on the interior of jars, especially below the rim, so that if an analyst suspects that fire clouding may be skewing the exterior sooting data, they could rely more on interior evidence.

Exposure to any type of fire or high heat could alter carbonization patterns, as in structure fires (whether by accident or deliberate burning), which is a common occurrence in the American Southwest (Walker 1998) and affects any vessels on the floors. Two effects may result from exposure to a fire. If the heat is intense and oxygen plentiful, carbonization patches deposited during use could be removed. And if a vessel's access to oxygen is restricted, as when a roof collapses and deposits debris on the floor and its contents, soot could accumulate on the vessel. Both situations occurred on the whole vessels from the Prayer Rock Cave collection that I discussed earlier in this chapter. Thirty-seven whole seed jars were identified and recorded for this study. It became immediately apparent, however, that both interior and exterior carbonization had been altered in some vessels during the burning of the structures. In some cases, evidence of cooking-related carbonization seems to have been removed; indeed, the house fire was so intense that not only were all traces of carbonization removed but the heat seems to have refired the vessel slightly. More commonly, however, the vessel accrued additional carbonization. In all cases, the post-use carbonization could be distinguished easily from sooting. For example, some of the pots were completely carbonized except where they met the floor, wall, or fallen timbers during the fire. Because such carbonization is identical to sooting from a cooking fire, the best way to distinguish post-use deposition of carbon is from the patterning. In my study I simply removed from the sample any vessels that had clear evidence of post-use fire alteration. Making this discrimination would be difficult on sherds alone, but in most cases there is clear evidence from nonceramic data that a room or house had burned. In such cases it would be wise to avoid doing carbonization analysis on sherds.

Carbonized organic material in general is very resistant to breakdown in the post-depositional environment. The resins in wood smoke firmly affix soot to vessel exteriors, and interior charring of food often extends into the vessel wall. As has been shown (Beck et al. 2002; Sassaman 1993), exterior soot survives on the oldest pottery in North America. As mentioned above, Beck et al. (2002) demonstrate that exterior sooting—especially on low-fired ceramics—is prone to removal through abrasive processes. Their experiments indicated that abrasion effectively removes soot from replicated ceramic samples. Surface abrasion, however, should be evident on sherds, and so the analyst should be able to remove abraded samples.

Inferences

Once the carbonization data have been compiled, the researcher can begin to draw inferences about the cooking activity. Questions that can be answered with these data include: Was the vessel used over a fire for direct cooking? What was the hearth design? Were the contents cooked in the wet mode (boiling), dry mode (roasting or reheating), or mixed (stewing)? These data, when combined with the other use-alteration traces, can provide direct evidence for actual pottery use over a fire.

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Chapter 4
Attrition

> *The analysis of wear patterns on ceramic vessels is an area of study which previously has not been fully exploited for deriving behavioral inferences (Bray 1982, p. 133)*

The first publication for an archaeologist is remembered like a first kiss. Anytime I have the opportunity I like to ask archaeologists what their first publication was, the answer usually includes a faraway gaze as they recall the thrill of seeing their name in print. In most cases the first publications are in obscure periodicals and infrequently cited, and my first published paper is no exception, "Fluvial Sherd Abrasion and the Interpretation of Surface Remains on Southwestern Bajadas" (1987). A look at Google Scholar reveals that it has been cited just 10 times—three of them by me. This publication did not rock the archaeological world but it changed my life. It not only got me hooked on scholarly publication, but it turned my attention to abraded ceramics through not only natural but also cultural processes.

In this chapter I first outline the principles of ceramic attrition. Then I discuss Kalinga ceramics, which provide a sound baseline for attritional analysis. In order to illustrate inference building on the basis of attrition evidence I then turn to several examples, using prehistoric, ethnographic, and historic ceramics, which successfully employed various kinds of abrasion to make inferences about use.

Research along the Ruelas Drainage, where the data were recovered for my first publication, was done as part of the Tucson Basin Project, a large scale survey that took place in the 1980s just ahead of explosive expansion of the Tucson metropolitan area (see Fish et al. 1992a; Madsen et al. 1993). Under the direction of Paul Fish, the project involved a 100% survey of 100 square miles and the recording of thousands of sites. Working for the Tucson Basin Project not only paid my bills while I was a graduate student, but it also introduced me to Hohokam archaeology. I walked hundreds of miles as part of that project and recorded countless sites created by the hunter-gatherers of the Archaic Period through the large villages of Hohokam farmers to historic period settlers. One of the anomalies of that survey was a paucity of sites found on the *bajada* associated within the Ruelas Drainage, which was then a braided

J.M. Skibo, *Understanding Pottery Function*, Manuals in Archaeological Method, Theory and Technique, DOI 10.1007/978-1-4614-4199-1_4,

series of unentrenched dry washes up to 400 m wide (now a golf course). *Bajadas* are the rolling foothills between the river valley and the small mountain ranges typical of this basin-and range-geomorphological province. Although few sites were found on the *bajada*, particularly around the Ruelas Drainage system, thousands of isolated artifacts were identified. The question that resulted from this curious distribution was whether the artifacts were the result of activity on the *bajada*, perhaps drying farming

Northern Tucson Basin Project

The start of the Tucson Basin Project, the brain child of Paul Fish, Suzanne Fish, and John Madsen, roughly coincided with my arrival at the University of Arizona. As a wide-eyed new graduate student I did not realize at the time the tremendous significance of the project, which is one of the few large-scale 100% coverage surveys in North America and the only such survey in the American Southwest. The Hohokam, desert farmers who constructed extensive irrigation canals and associated platform mound communities, attained a relatively high degree of socio-political complexity after about A.D. 1200. They are best known, however, from the Phoenix basin (see Abbott 2000) and the hundreds of miles of canals and associated sites that were quickly buried or destroyed in the face of the tremendous population explosion. Ninety miles to the south, Tucson too had been growing and certainly many sites had been lost to that development as well, but north of the city was mostly undeveloped State Land. Paul Fish was responsible for management of the cultural resources. He and his colleagues saw this as an opportunity to do a large scale, 100% coverage survey of 100 square miles. This was a brilliant strategy that not only helped manage the cultural resources in the face of constant requests for development of this highly valuable property, but it created a regional data base of sites and permitted an unprecedented understanding of settlement patterns throughout the cultural sequence (Fish et al. 1989, 1992a).

The 100% survey involved teams of archaeologists doing pedestrian survey at 30 m intervals (this is where my much younger legs were useful). Because of the lack of soil development and great surface visibility, evidence for sites in the form of artifacts or features were easily identified. Hundreds of sites were recorded along with thousands of isolated finds (see Madsen et al. 1993 for an overview of the research).

Although these data have been used in a number of studies (Bayman 1995, 2001, 2002; Downum 1993; Field 1992; Roth 1992, 1995, 2000; Skibo 1989), my favorite part of this large-scale program has to do with the study of the Classic Period Hohokam, the Marana Mound, and evidence for widespread agave cultivation (Downum and Madsen 1993; Fish et al. 1985, 1992b).

The Marana Mound was first recorded by Ellsworth Huntington in 1914 but then "lost" to the archaeological community for a time because the area had been disturbed significantly by mechanical activity during the construction of

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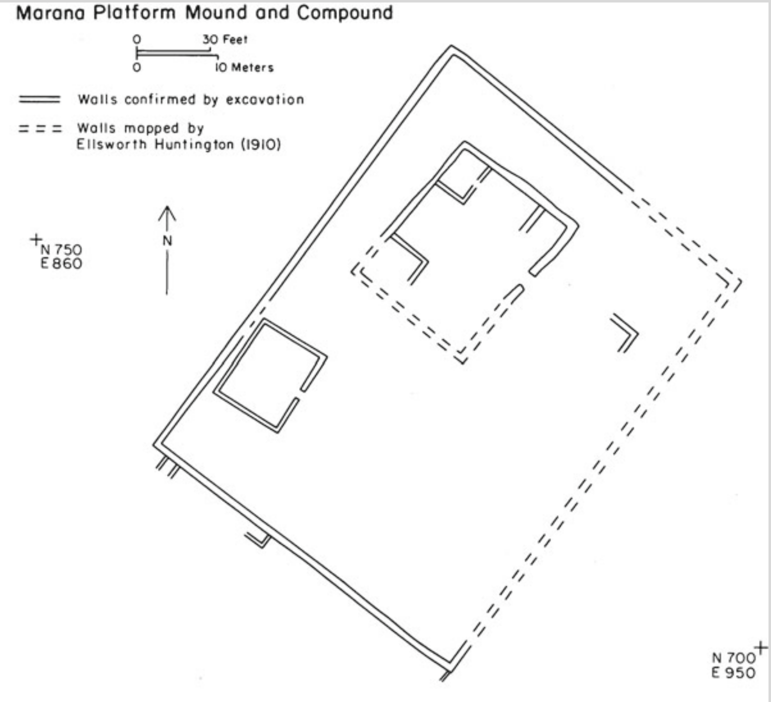

Fig. 4.1 The Marana Mound and compound (From Fish et al. 1992a, p. 28)

a modern cattle tank and it was believed that the mound had been destroyed (Downum and Madsen 1993, p. 133). More careful survey revealed, however, that the mound had not been significantly impacted by this activity. The mound is rectangular and about 15 m by 20 m in size and about 2.5 m high (Fig. 4.1) (Fish et al. 1989, 1992). The mound was surrounded by a compound wall that encompasses about 2,700 m^2 (Fish et al. 1992b, pp. 27–28). Surrounding the mound is an extremely large site, over a million and a half square meters, which consists of compounds, houses, and trash middens.

Platform mound settlements are most traditionally located at the heads of large irrigation canals found in the Hohokam heartland in what is today the Phoenix metropolitan area. Although there is evidence that there was a canal that connected the Santa Cruz River to the fields surrounding the platform mound, the mound and the people of this community seem to be involved in the cultivation of agave (Fish et al. 1985, 1992). Located in what S. Fish et al. (1992, pp. 31–33) refer to as Zone 2, which is located just uphill from the mound, are fields dedicated to the cultivation and processing of agave, which does not naturally grow at this elevation. Here are found 42,000 rock piles covering over 2 square miles along with roasting pits, and various terrace alignments (Fig. 4.2). The rock piles retain more moisture and permit the plants to grow at these lower elevations. The agave would have served a number

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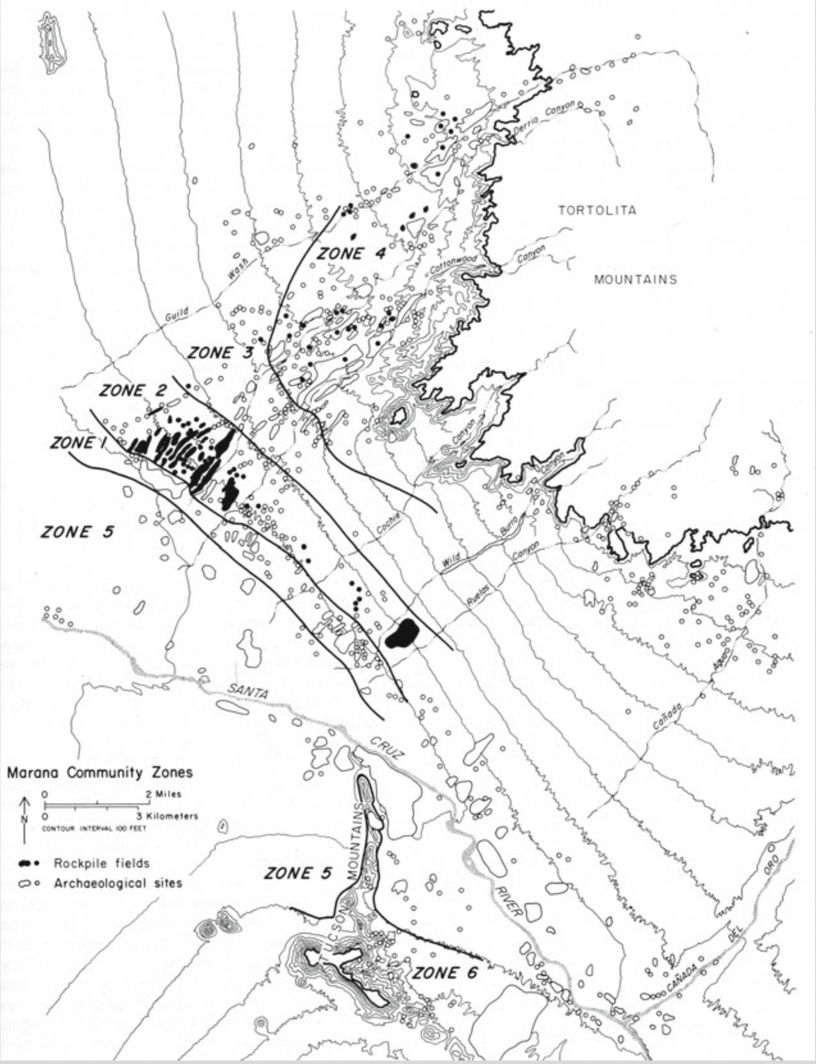


Fig. 4.2 Agave rock pile fields just northeast of the Marana Mound (From Fish et al. 1992, p. 33)

of purposes; it could be eaten, the fibers from the leaves can be used to make textiles, and of course the hearts can be turned into alcohol.

As once predicted, much of the land that was part of the Tucson Basin Survey has now been developed. So the wisdom of the Tucson Basin Survey was not only in properly managing cultural resources in the face of oncoming impacts, but in creating an unprecedented data base that permitted archaeologists to look at larger scale patterns of site distributions and the development of social complexity based in large part on dry farming of agave.

or trail systems, or if the sherds had actually washed down from larger (presumably village) sites situated at the junction of the *bajada* and the mountains.

The *bajadas* are characterized by a series of washes, or dry streambeds, like the Ruelas Wash, which fill with water during the monsoon season in the late summer and early fall. These torrential storms fill these washes and their tributaries quickly with very fast moving water. A good deal of erosion can take place during these storms and, presumably, the movement of cultural material as well.

To test whether the sherds within the Ruelas Drainage *bajada* were the result of activity in this area or came from the large upstream sites and were deposited by fluvial action, I convinced a few friends to come with me on a Saturday and collect sherds along a segment of the 3.2 km drainage. This segment extended from the edge of the *bajada* and the valley floor upstream to the juncture of the wash and the Tortolita Mountains, where a number of ceramic-bearing sites were located. The working hypothesis was that if the sherds derived from these large sites in the mountains, then they should be progressively more eroded as one moves down the wash. If, however, the sherds resulted from activities along the drainage, then they should be found at various stages of erosion.

Ninety-six sherds were collected during our transects up the wash and their locations were noted. Once back in the lab, I placed the sherds into three stages of abrasion based on edge rounding and degree of surface attrition. Analysis of the sherds demonstrated that abrasion did indeed increase with distance down the wash, suggesting that they had been deposited by fluvial processes not cultural activity. One of the lingering questions after the field study was how ceramic erosion is affected by variability in sherd attributes such as hardness. To answer this question, we conducted a controlled experiment with Hohokam sherds of various types, which were abraded in rock tumblers. This experiment demonstrated that the sherds entered the various stages of abrasion at relatively the same rate regardless of technological variability. Although this study was never heavily cited (though I just cited it one more time), it did lead to a series of experiments in the Laboratory of Traditional Technology on ceramic technology, which examined in much more depth the processes of ceramic abrasion and other attrition processes (O'Brien 1990; Schiffer and Skibo 1989; Skibo and Schiffer 1987; Vaz Pinto et al. 1987).

Principles of Ceramic Attrition

In the study of use-alteration, I refer to "attrition" as the more general category of processes that remove ceramic material through either abrasive or nonabrasive processes. My interest in ceramic attrition came from three different but overlapping interests. First was the exploration of the potter's technical choices that could improve various use-related performance characteristics (see Chap. 2). Resistance to attrition was considered to be a performance characteristic that could concern a potter. So, for example, a potter could increase abrasion resistance by raising the firing temperature or applying a slip or polish to the surface. Or a potter could choose a rough, textured, open exterior surface treatment on water jars to reduce exfoliation through salt erosion. Second, my experience in the Ruelas Drainage study had alerted me to the importance of ceramic abrasion in the identification of artifact, site, and regional formation processes (Schiffer 1987). In my study of Late Archaic pottery from the Southeastern United States (Skibo et al. 1989), I had also explored the impact of freeze-thaw cycles on the breakdown of sherds, which was first documented by Reid (1984). Finally, my examination of abrasion as a use-alteration trace led me to try to understand the variables affecting ceramic abrasion. As in lithic use-wear analysis, the attributes of the source material affect the use traces as do the nature of the activity that created it.

Ceramic surface attrition is defined as the removal or deformation of ceramic surfaces that occur in a variety of use and non-use contexts throughout a vessel's life history. Surface attrition during use includes a variety of abrasive and nonabrasive processes that take place during cooking, cleaning, storing, and other activities of the vessel's primary function. Vessels can, however, have a number of secondary uses as they travel along the behavioral chain and when their primary function ceases. For example, once a cooking pot develops a crack it may be used to store seed or other dry commodity. These activities can also leave attritional traces. Even after a vessel is broken, the sherds can be recycled for use as scoops, scrapers or other tools, which are interactions that also leave traces. And these sherds, once deposited, can also be subjected to a number of natural processes, such as wetting and drying, wind (as in sand blasting), and freezing and thawing, which can cause various kinds of attrition before the material is recovered by archaeologists. It is up to the researcher to both record the various traces and then infer how and when they were made. These attritional marks are potentially the richest use-alteration traces because they implicate various components of the use activity such as the user characteristics, context of use, actions of use, time and frequency of use, and vessel contents. Moreover, attritional traces can be insightful clues as to the post-depositional history of the ceramic material.

Use-Attrition: Abrasive Processes

Provisional principles of ceramic abrasion were first set forth by Schiffer and Skibo (1989), who divided the processes into three determinants: properties of the ceramic, properties of the abrader, and nature of the ceramic-abrader contact. Ceramic properties that affect abrasion resistance include strength, the presence of pores, cracks, or voids, properties of the temper particles (hardness, shape, size, quantity, distribution, and orientation), and the shape and surface characteristics of the ceramic. Several factors control the strength of the fired paste including clay chemistry and mineralogy, and firing atmosphere, but the most influential is firing temperature. In a series of experiments (Skibo et al. 1989; Vaz Pinto et al. 1987) it was demonstrated clearly that as firing temperature goes up, abrasion resistance increases dramatically.

The nature of the ceramic surface can also affect abrasion resistance considerably. A smooth, polished surface has greater abrasion resistance than one with textures, pores, cracks or voids. Accordingly, organic temper that burns out during firing creates pores and a ceramic body of high porosity that is more susceptible to abrasion. Processes of manufacture sometimes create cracks and voids, yielding a surface topography that is more easily abraded.

The hardness, size, quantity, distribution, and orientation of temper particles can influence ceramic abrasion. If, for example, the temper is harder than the surrounding ceramic, as is often the case in mineral-tempered pottery, the temper will impede abrasion. The Ruelas Drainage study found that sand temper became pedestalled in advanced stages of abrasion, as the clay around each particle eroded away. On the other hand, when softer than the fired clay the temper may be eroded more rapidly. For example, shell-tempered pottery common in the Midwest United States during the Mississippian Period could have a lower abrasion resistance because the shell would be softer than the clay. Shell can be quite hard, but when used as temper it must first be heated, which reduces its strength.

Finally, the nature of the pottery surface can influence abrasion. Various resins and coatings are common on low-fired pottery around the world. These post-firing treatments are most often applied to reduce water permeability but they could also directly affect abrasion resistance. And, as discussed in the previous chapter with reference to Kalinga pottery, sometimes exterior sooting itself becomes a surface treatment. As I show below, important abrasive traces were recorded not on the ceramic fabric but on the accumulated exterior sooting.

The characteristics of the abrader, such as hardness, shape, and size, can also influence the abrasive process significantly (Schiffer and Skibo 1989, pp. 108–111). One of the critical variables is size (Skibo and Schiffer 1987): an abrader smaller in diameter than the distance between mineral temper particles tends to cause greater abrasion. This would be relevant in cases where a water pot is tipped or dragged across a dirt floor, where the surface consists of very small but hard particles, or a vessel is placed and perhaps turned on stones in the hearth. The latter could be a very abrasive situation except that the abrader is so large it contacts only the temper particles, and thus reduces abrasion. One could also envision how tools made of different materials could abrade the surfaces differently in food preparation. A wood ladle or spoon would likely cause far less abrasion than a one made of metal.

Finally, the nature of the ceramic-abrader contact is also important in abrasive trace formation (Schiffer and Skibo 1989, pp. 111–113). Abrasion requires movement of the ceramic, abrader, or both. Factors important here are the directionality, rate, and force of the contact between the ceramic and abrader. All things being equal, the greater the rate and force of the relative contact the greater the abrasion. However, this relationship may not be linear if the abraded surface's topography is so altered that it affects subsequent contacts, and thus reduces the rate of abrasion (e.g., once a very well-polished surface is eroded away, the paste beneath might abrade more rapidly). There are other complicating factors as well. In many abrasive situations there is not only an abrader and the ceramic but also a substrate. A good example of this situation is the washing of Kalinga pots with sand: the abrader is sand and the substrate is the woman's hand. Moreover, pot washing involves water, which has been found to significantly increase the rate of abrasion in a variety of situations.

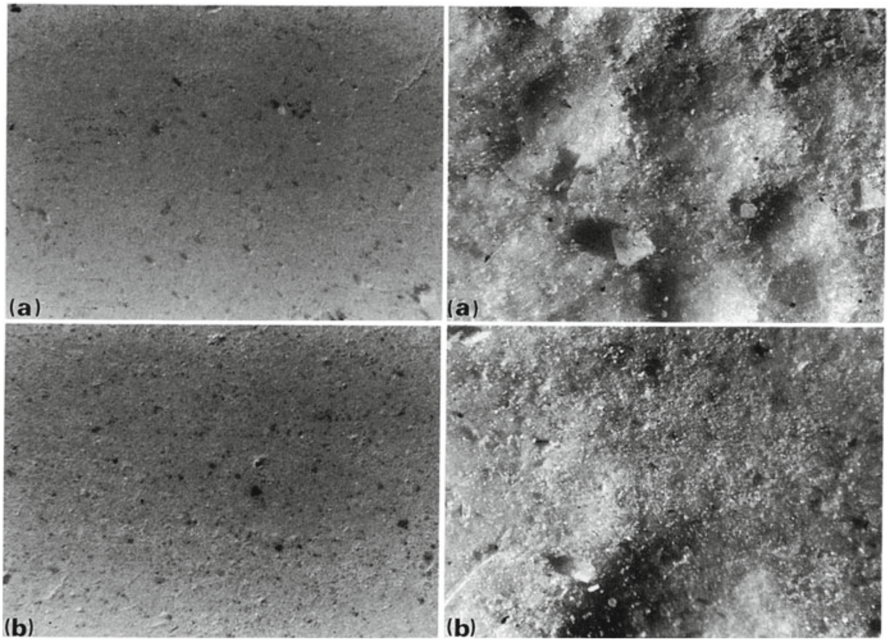


Fig. 4.3 Experimentally created ceramic before (*left*) and after salt erosion (*right*) (x.04) (From O'Brien 1990, p. 397)

Use Attrition: Nonabrasive Processes

Three common kinds of nonabrasive attritional processes occur during the use of low-fired pottery; erosion caused through fermentation, vaporization of water, and salt crystallization. During fermentation when liquid penetrates the interior wall, escaping carbon dioxide and other gases expand and escape just below the surface and create erosion. This was first observed in seed jars that represent the earliest pottery on the Colorado Plateau (see example in Chap. 3), and has been subsequently discussed in great detail by John Arthur (2003). These case studies are reviewed below.

Water-permeable vessels used in arid environments are especially vulnerable to surface erosion owing to salt crystallization, a second kind of nonabrasive use-alteration trace. When vessels are used for water storage or as flower pots, water permeates the walls, carrying salts from their contents and perhaps, also, from the clay. As the water evaporates, salt crystals form just beneath the surface. If there is not enough pore volume for crystal growth, then the exterior surface tends to exfoliate (Fig. 4.3). O'Brien (1990) simulated this process in the laboratory, confirming the basic mechanism. This process also affects to sherds on the surface of refuse deposits, which can supply salt from wood ash and urine.

The vaporization of water just below a pot's surface can create thermal spalling in two situations. First, if the vessel is empty but the walls are still saturated and heat is applied, the interior wall may undergo spalling provided that the surface has reduced permeability (as in polishing, slipping, or resin-coating). This occurs in specialized types of cooking where water is removed during the final stage (e.g., the last stage of rice cooking discussed below). In the second situation, heat is applied to a vessel containing water. If the water saturates the wall but reaches a less permeable exterior surface, then steam forms just below the surface and causes spalling (Schiffer et al. 1994).

These three common nonabrasive attritional processes all require water-permeable vessels. Although higher firing temperatures strengthen the vessel and potentially reduce attrition, it is very difficult to construct an open-fired vessel that utterly lacks water permeability. Consequently, erosion and spalling are important use-alteration traces that may provide strong evidence for inferring water storage and alcohol production. The latter activity, I note, is often difficult to discern in prehistory. Consequently, the case study below explores this trace in more detail.

Use-Attrition Terms

There are two important terms in the identification of use-attrition: marks and patches (see Schiffer 1989, pp. 194–196). A single attritional event can create a mark, which is the lowest level use-attrition trace. Examples include a scratch, pit, chip, nick, or spall.

A patch is created by repetition of an activity during the normal use of a vessel. Sets of use activities are associated with different vessel types and the processing, storage, or transport of different contents. Individual acts (or contact events) can leave a mark on a vessel, but the repeated use activities that turn marks into patches are of signal importance for inferring activities. In many cases single acts (or contacts) do not cause a discernible mark, but when the action is repeated many times a visible patch may form. In addition, individual marks may not be visible in a patch if many repetitions have completely removed the original exterior surface. In these cases, a patch may have a center and periphery; on the periphery individual marks may be identifiable. The attributes of marks and patches, as described below, provide vital clues to various types of use behavior.

Case Study: Kalinga

The study of Kalinga pottery-use behavior served as a baseline for understanding the relationship between an activity and its attritional traces. I discuss the attrition on Kalinga cooking pots in detail below, as they proved to be instructive for setting forth the foundations for use-attrition analysis. This discussion is followed by several case studies that illustrate how attritional traces on prehistoric pottery can be used to infer use behavior.

I focus on the Kalinga pots used for cooking rice and boiling vegetables and meat. These vessels should already be familiar, for their uses were discussed in Chap. 3. Here I add details as needed to understand their attritional traces.

Kalinga Pottery Surfaces and Other Relevant Technical Properties

For any analysis of attrition it is necessary to understand the vessel surfaces and something about the potter's technical choices during manufacture. The nature of the surface (smooth, rough, polished, slipped, resin coated, etc.) and the technical properties (paste hardness, temper type and size, etc.) critically affect the susceptibility of pottery to acquiring attritional traces during use. The clay used in making the vessels from Dangtalan and Dalupa vessels is primarily montmorillonite, which contains a large amount of naturally occurring aplastic materials. The aplastic, or tempering, materials consisted of quartz grains up to 4.0 mm in size, long, angular grains of biotite mica (up to 3 mm in size), and various siliceous minerals (up to 3.0 mm in size) (Aronson et al. 1994, p. 91). Montmorillonite has a high drying shrinkage and so the large amount of natural tempering conveniently compensates for the excessive shrinkage and potential cracking. Aronson et al. (1994) also note that Kalinga pots are fired at a very low temperature, reaching only 600–650°C. The presence of fluxing agents like potassia and iron oxide reduced the sintering temperature, which had the effect of increasing the hardness in relation to the firing temperature. Nonetheless, Kalinga vessels have a relatively low hardness (Aronson et al. 1994, p. 105) and would be prone to acquiring attritional traces during use.

Kalinga cooking pots are polished on the exterior and interior surfaces, resulting in surfaces that are very smooth but not lustrous. The action of polishing also floats a layer of fine clay to the surface, obscuring many of the temper particles even though the vessels are heavily tempered. Firing takes place in less than 20 min in a fast burning bonfire fueled mostly with rice stalks and small branches (Longacre 1981). In addition to low hardness, the pots also have high permeability and porosity. Because of the excessive water permeability, which interferes with heating effectiveness, the vessels are pulled from the fire while still red hot and the interior surface and the exterior lip is coated with a resin obtained from a local coniferous tree. The resin, when cooled, creates a near water-impermeable layer. However, as noted (in Chap. 2 above), once the resin wears away (usually after several months of use), the pot no longer heats effectively, and so Kalinga women stop using them for cooking. However, they are reused in a number of non-cooking activities (storage, pig feeding, etc.). While intact, the resin layer serves as a barrier to attrition, but many kinds of use-attrition traces can be seen in the resin layer. Unfortunately, the resin layer does not preserve in the post-depositional environment under most conditions.

As illustrated in Chap. 3, the exterior of a cooking pot gets covered completely with a layer of soot after just several uses. After a time, this highly resinous soot

Fig. 4.4 Kalinga rice (*left*) and vegetable/meat pots

builds up to a point that it can actually start chipping away. When it is this thick, the soot can serve as a barrier to abrasion. Nonetheless, I found that all exterior abrasion patches extended through the soot layer. But in some cases subtle attritional traces, such as scratches, are visible in the soot layer and so could be used to draw inferences about use. Unlike resin, this soot layer would survive in most depositional environments.

Use Attrition on Kalinga Pots

Kalinga vegetable/meat and rice cooking pots (Fig. 4.4) had attritional patches on nine separate areas of the vessel (Fig. 4.5). The use-attrition traces on each of these areas is discussed below and then matched to specific use-activities. In this discussion special attention is given to characteristics of the abrader and the abrader-pottery contact. There is some overlap in use-attrition traces between the vegetable/meat and rice pots, which one would expect as there are some shared cooking use-activities, but significant differences implicate differences in cooking activities.

Exterior Base

Cooking pots have an abrasive patch slightly larger than the area of the pot that comes into contact with the ground. The patches were from 3 to 6 cm in diameter and varied because of the size of the vessel and length of time the vessel was in active use. Clearly, this region of the pot was in contact with one or more abraders

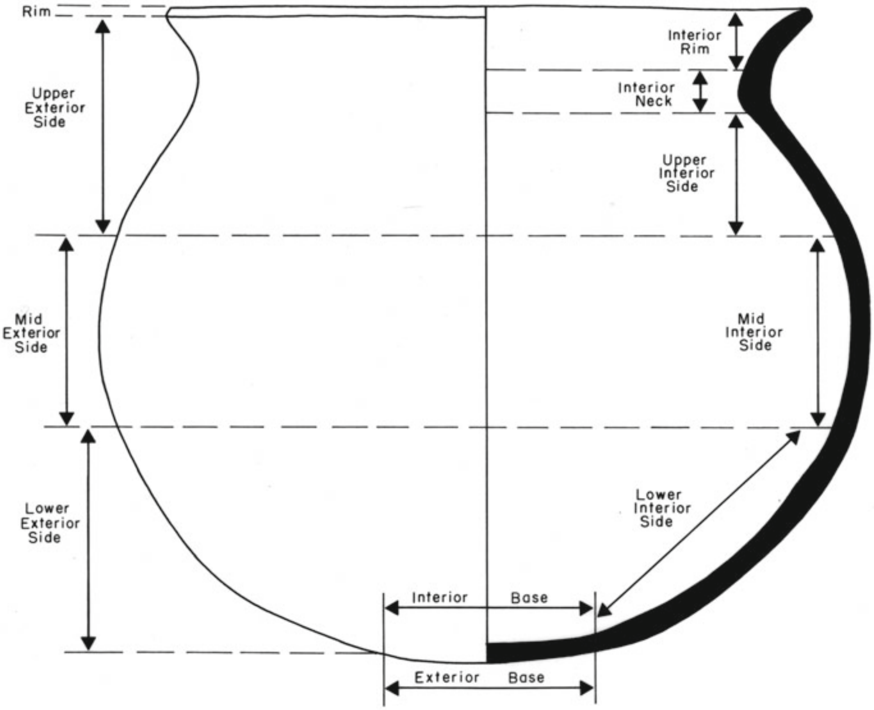


Fig. 4.5 Vessel location terminology and location of attritional patches (From Skibo 1992, p. 114)

while in the upright position. The observed actions that created this patch were: (1) setting the empty pot down on the hearth soil (compacted soil), bamboo floor, and ground surface (soil or concrete) near the water source, (2) setting a full pot down on the ground during serving, which entails rotating and sometimes tipping the vessel while it rests on a rattan pot rest, the hearth soil, or the bamboo floor, (3) turning the full rice cooking pots on a bed of coals while in the third stage of cooking, (4) sliding the pot while empty or full along the hearth soil or bamboo floor, and (5) rubbing the pot during washing with one's hand and sometimes with sand, leaves, rice chaff, a wet cloth, or charcoal. I describe in detail below the attributes of the patch and how they are associated with the observed use-activity.

In the most heavily used pots, both a completely eroded center patch and periphery can be discerned. The center, which is usually the only area that comes in direct contact with the ground, often exhibits pits and pedestalled temper. The periphery often has individual marks, like pits, scratches, and gouges. The center of this patch is always in contact with the ground when the pot sits upright, whereas the periphery only comes in contact with an abrader when the vessel is tipped slightly. On vessels used less frequently only the center has abrasive traces, which are similar to the marks on the periphery of the heavily used vessels. The marks observed on the

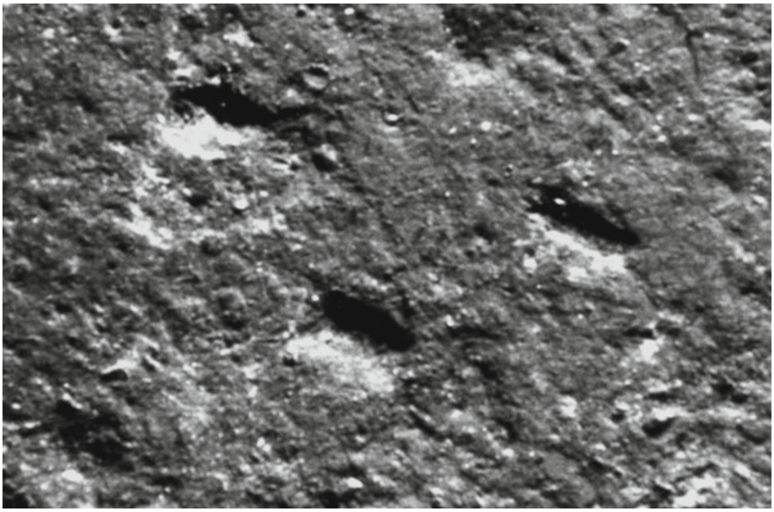


Fig. 4.6 Attritional pits on the exterior base (length of frame is approximately 13 mm) (From Skibo 1992, p. 116)

exterior base are pits (nicks and gouges), pedestalled temper, and scratches; each of these is described in more detail below.

Pits (Fig. 4.6) are caused by the removal of temper and by small chips, nicks, and gouges from single impacts between the vessel and an abrader. These impacts seem to be the primary agent responsible for the pits on the exterior base. A mark of this type is likely caused by a forceful contact from roughly a 90° angle with a small abrader (small enough to make the pit) that is harder than the ceramic surface. The action likely responsible for this mark is the setting down of a full pot on the hearth soil, which consists of fine sand grains that create the pits or small gouges. Vessels are set down on the ground a number of times daily, including at the water sources when being washed, and these activities could cause some pitting. But most of these pits were probably created during the more forceful contact at the hearth when the vessels are full.

Pedestalled temper (Fig. 4.7), first noted in the Ruelas drainage study (Skibo 1987), is created when the ceramic comes in contact with an abrader that has a diameter less than the diameter between the temper particles (see also Schiffer and Skibo 1989). The nature of the contact must be gentle enough to remove the ceramic material around the temper particles without dislodging the temper. Pedestalled temper occurs most often in the center of the patch where it contacts the hearth soil, which has a granular texture. The use-activity that created pedestalled temper on this patch is the turning and tipping of the pot on the hearth soil.

Scratches (Fig. 4.8) of varied width, depth, and orientation occur on the exterior base. There is a tendency, however, for the scratches to travel from the center of the

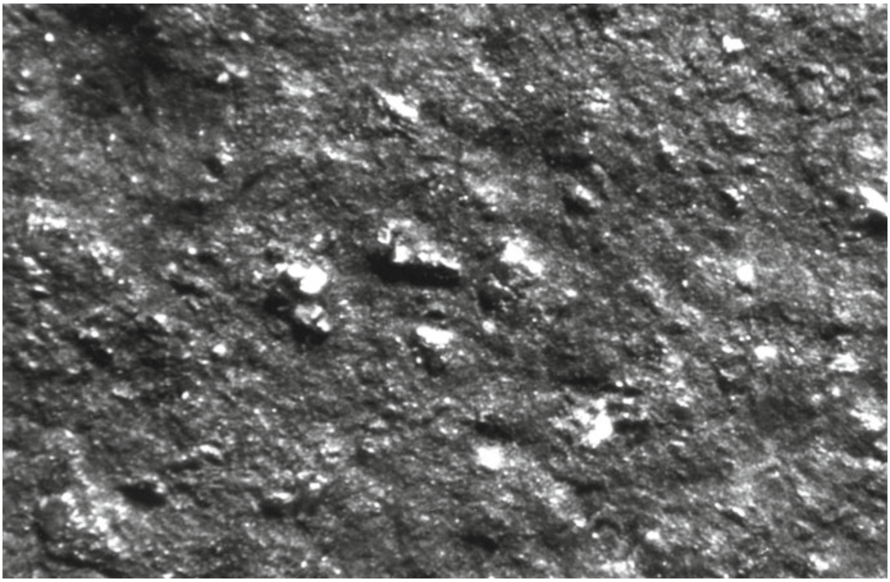


Fig. 4.7 Pedestalled temper on the exterior base of a cooking pot (length of frame is approximately 3 mm) (From Skibo 1992, p. 117)

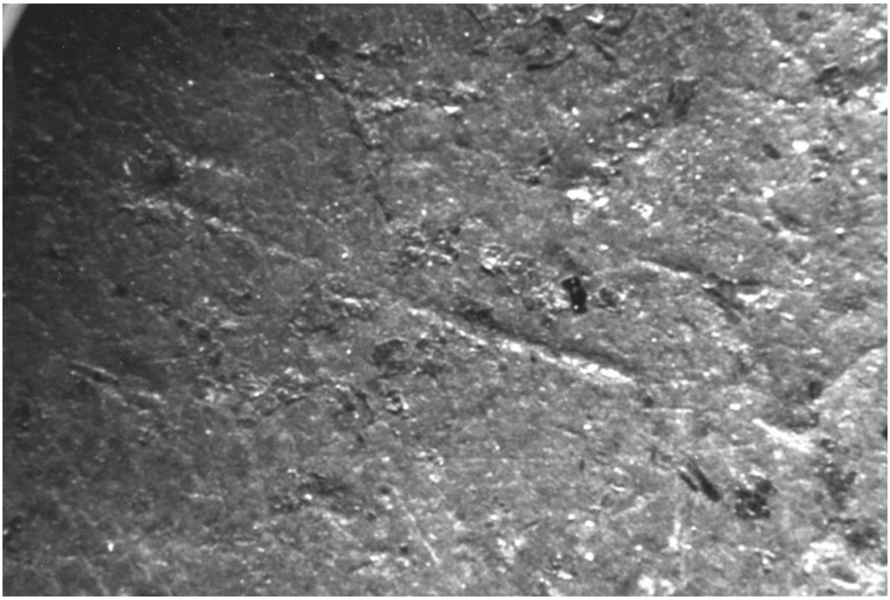


Fig. 4.8 Scratches on exterior base (length of frame is 7 mm) (From Skibo 1992, p. 118)

patch to the periphery particularly on the vegetable-meat cooking pots (The criteria for determining directionality are discussed below). The use-activity most responsible for this trace is the dragging of the pot along the hearth soil, with its hard quartz particles, during serving of the food. Some cooks also have a tendency to slide the pots on the base for a short distance as they are picked up by the rim.

To summarize, the exterior bases of cooking vessels have traces that suggest that the vessel had contact with a small abrader in three types of situations: (1) a forceful impact at a 90° angle creating the pits, (2) gentle abrasive contact creating the pedestalled temper, and (3) a contact that involved movement, which created the scratches. Most of these traces were created as the pot was manipulated on the hearth soil before and after cooking. Full pots are set down on the hearth, turned while serving, and often dragged for a short distance. The rice and vegetable/meat pots had near identical traces, because the use-activities for each vessel type have much in common. However, I now turn to some use-activities that leave no attritional traces.

Use without an abrasive trace. Rice pots have a use-activity unique to that vessel; it involves contact with the exterior base but leaves no traces. In the third stage of rice cooking the vessels are lifted off the hearth pot supports and set down next to the fire on a bed of coals. The pots are rotated several times during the 10–20 min that they spend in this position. While the vessels are being rotated there is grinding noise. My first reaction was to expect rotational scratches on the exterior base. But there is no abrasive trace of this activity: the hot coals are not abraders and they prevent the base from contacting with the abrasive hearth soil. Although this important use-activity leaves no apparent attritional trace, carbon deposits and attrition on other parts of the vessel furnish clear evidence of the third stage of rice cooking.

Several additional use activities occur routinely; although having contact with the exterior base they leave no trace because the abrader is less hard than the ceramic surface. The pots are often placed, then tipped and turned, on a rattan ring, which serves as a stable support for the pots; they are found near the hearth and throughout the kitchen. Because the rings are made of a local rattan which is softer than the ceramic surface, this contact leaves no traces. It is possible that polishing could occur from this activity, but none was observed in this region. Cooking vessels are often routinely placed on the house floors, which are made of split bamboo. Bamboo, like rattan, is much softer than the ceramic surface, and so even when the pot is manipulated on the floor no visible traces result. Finally, washing activities that impart fine scratches to most of the vessel are absent from the base. There are two reasons for the absence of washing scratches. First, the base of a cooking pot lacks glossy soot, which abrades easily and records the fine scratches. Second, the more intensive abrasion from pot-floor contact obliterates the subtle abrasive marks from washing.

Lower Exterior Side

This section of the exterior (Fig. 4.5) is dominated by traces created during washing, including deep scratches oriented parallel to the rim and randomly directed fine scratches. The use activities observed during the Kalinga research that affect this

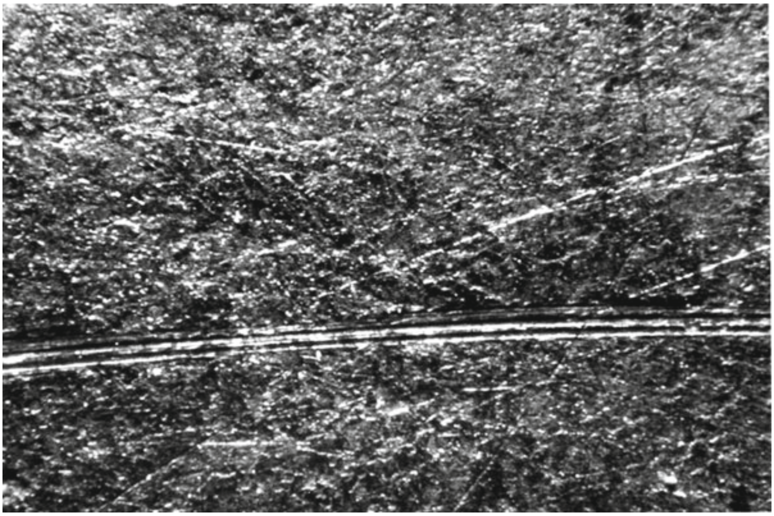


Fig. 4.9 Linear scratches on the lower exterior side (length of frame is approximately 7 mm) (From Skibo 1992, p. 120)

area were (1) rotating the vessel on the ground or cement while washing the interior of the pot; (2) washing the exterior by rubbing by hand with sand, rice chaff, a wet cloth, or sometimes charcoal; and (3) contact with the ceramic or stone pot rests while on the hearth.

The lower exterior side, along with the mid-exterior side, has the heaviest soot layer. The soot is so thick that it preserves many of the use-attrition traces and especially the randomly oriented fine scratches, which otherwise might not have been produced on the exterior surface. Although polished, the exteriors are still quite rough; the fine scratches need to form on a very smooth surface, almost to the point of a sheen, which the highly resinous soot layer provides. In the absence of such a soot layer, the fine scratches might appear only on a slipped-and-polished or glazed surface.

The most visible trace on the lower-exterior side is the linear scratches on the soot that also penetrate to the ceramic surface (Fig. 4.9). This trace occurs in a linear band from 2 to 4 cm wide, depending on the vessel's size and especially its age; the more heavily used pots have a wider band. From the attributes of this patch a number of inferences can be drawn about the abrader and the nature of the abrader/ceramic contact. Because of the linear orientation of the individual scratches one can infer that there is directional movement in the ceramic abrader contact. The individual scratches are short, less than 1 mm, and so the abrader is quite small. One can also infer that the contact is forceful because the temper is not pedestalled but rather dislodged. The action that creates this abrasive patch is done repeatedly and consistently. All cooking pots have this pattern, regardless of size, and there is little deviation from the linear orientation (parallel with the rim) of the scratches.

Finally, the orientation of the scratches furnishes information about the direction of the abrasive motion. The clearest indicator of directionality occurs on the edges

Fig. 4.10 Washing the exterior of a cooking pot (From Skibo 1992, p. 76)

of pits, either from dislodged temper or as the surface becomes eroded. These pits often have a teardrop shape as one edge of the pit becomes more eroded. The tail of the teardrop points in the direction of the abrasive action. Remarkably, these traces occur, with just a few exceptions, in one direction: clockwise, as one views the vessel from above. Linear scratches on the mid-exterior also have directionality, although in the opposite direction.

To summarize, the abrasive traces on the lower-exterior side supply evidence for inferring two kinds of use activity. One kind occurred through relatively light force, traveled in random directions, and was found only on the glossy carbonized soot layer. The other kind of use activity required much more force, traveled in mainly one direction, and was oriented parallel to the rim.

In case the reader hasn't figured it out yet, washing of the pots is responsible for the randomly oriented fine scratches on the glossy soot layer of the lower-exterior side. The fine scratches are produced as the vessel exteriors are gently washed by hand, scrubbed repeatedly with one or more substances—sand, rice chaff, leaves, charcoal, or a cloth rag. The most abrasive of these is sand, which is responsible for producing most of these random scratches. The pot washer rubs a hand over the pot with this abrasive mixture, usually in a circular motion (Fig. 4.10).

The linear scratches parallel to the rim are produced while the pot's interior is being washed (Fig. 4.11). The vessel is set directly on the ground, which places the lower-exterior side in contact with compact soil or concrete. In this position the vessel is rotated at least one complete revolution as interior is scrubbed. If the woman is right handed she scrubs with this hand and rotates the pot with her left hand in a

Fig. 4.11 Washing the interior of a cooking pot (From Skibo 1992, p. 76)

clockwise direction. The small number of pots whose scratches are oriented in the opposite direction were washed by left-handed women. Because both rice and vegetable/meat pots are washed in exactly the same way, they had indistinguishable abrasive traces on the lower-exterior side.

Use without an abrasive trace. Some use-activities involve contact with the lower-exterior side but leave no trace. The most important of these is the placement of the pot on the three hearth supports (usually made of ceramic or stone) while in the fire. The pots are put down gently because they are filled and heavy and there is never any twisting or turning while they are on the supports. What is more, the supports are covered with a thick layer of soot that cushions the contact. And even if there some abrasive traces had formed, they would be obliterated by the much more aggressive washing traces.

Mid-exterior Side

The abrasive traces in this zone are fine, randomly oriented scratches and deep linear scratches. These are identical to the traces found on the lower-exterior side

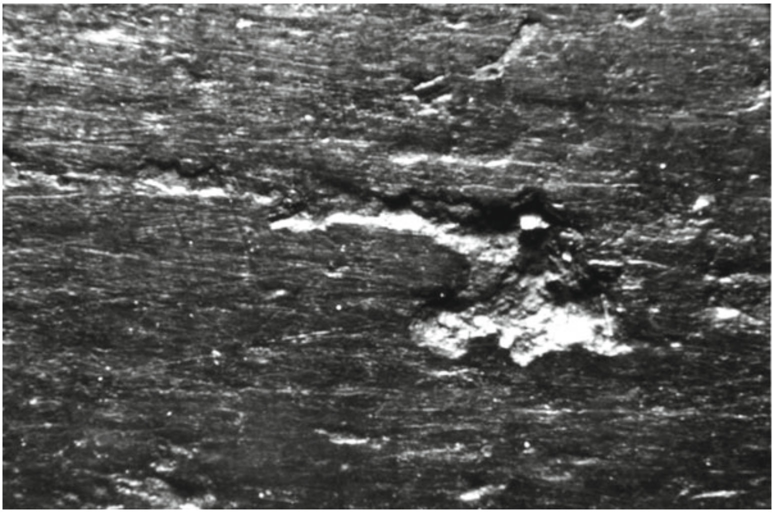


Fig. 4.12 Pit is eroded more on the left side, indicating direction of motion (length of frame is approximately 13 mm) (From Skibo 1992, p. 124)

with two notable exceptions. The linear scratches are more deeply incised on the mid-exterior side, and they were also produced by an abrasive action traveling in a counter-clockwise direction, for right-handed washers. This is the opposite direction of the rotation for interior vessel washing as the washer turns the pot while washing the exterior so that the base faces them (for interior washing the mouth of the vessel faces the washer). Vessel washing is also responsible for creating the fine scratches, which are produced by the circular washing action of the hand, often with sand, to remove the layer of dull soot on the exterior. The linear scratches parallel to the rim are produced as the washer rotates the vessel on the sand or concrete while the exterior is being washed. Recall that the linear scratches on the lower-exterior side were produced while the interior of the vessel was being washed. But the scratches on the mid-exterior side are more numerous and deeper because the woman rotates the pot many more times as she washes the exterior. Interior washing is usually not difficult, as little if any food adheres inside the cooking pots, but the Kalinga do remove the layer of dull gray soot on the exterior, which adheres loosely to the surface. Although this layer comes off relatively easily, it still requires a fair amount of scrubbing and water to get the exteriors clean.

The deep linear scratches enable directionality to be inferred as on the lower-exterior side (Fig. 4.12). The primary evidence for directionality is unequal abrasion of the small pits. The rims of these pits are more eroded in the direction of motion as is indicated in Fig. 4.13. Curiously, there is a rotational reversal during the washing of the interior and exterior of the pots (compare Figs. 4.10 and 4.11).

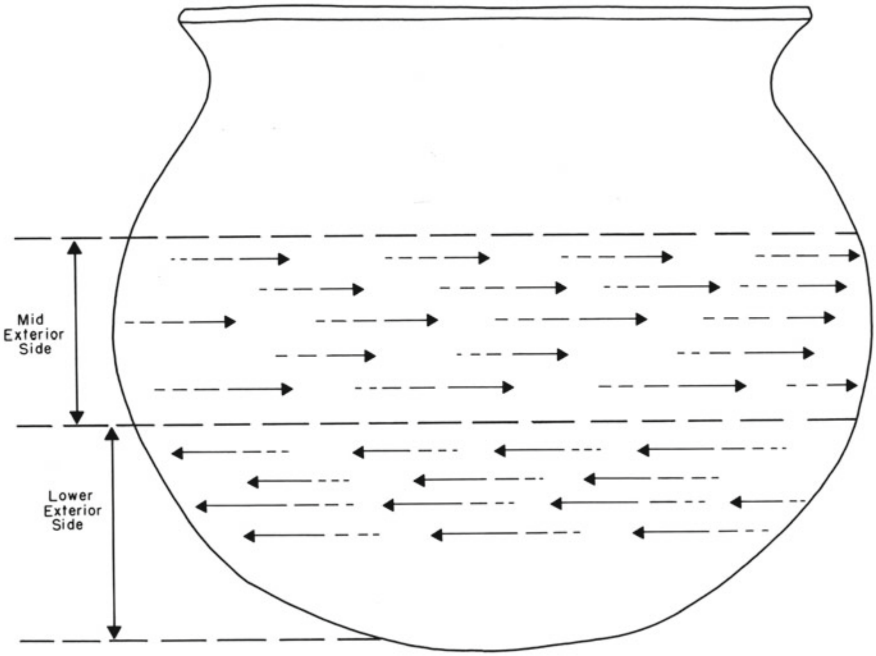


Fig. 4.13 Direction of abrasive action during washing. Vessel is rotated on the ground in opposite directions when washing the interior and exterior (From Skibo 1992, p. 125)

Upper-Exterior Side

This zone includes the shoulder and neck immediately adjacent to the rim (Fig. 4.5). This area in all cooking pots becomes coated with resin while hot. The necks are also the location of the *gili*, the incised and stamped decorations applied while the clay is still wet. Use activities that affect the upper-exterior side include lifting the pot off the fire with the rattan carrier (see Fig. 2.3), carrying the pot (full or empty) usually by grasping the rim with one hand, and scrubbing the pot by hand and with sand, rice chaff, etc., just as the rest of the exterior is washed.

In this zone the attrition occurs only on the resin (and sometimes soot) layer because none of the activities described above penetrate to the ceramic surface. Nonetheless, some traces of these low-abrasive activities (except washing) can be found. The neck up to the rim is very smooth to the touch and seems to have a light polish. This pseudo-polished surface consists of very fine scratches not visible to the naked eye (Fig. 4.14). The "polishing" occurs in the resin and resinous soot layer, not the ceramic surface. That the resin/soot layer has a lower abrasion resistance than the underlying ceramic suggests that the attrition was created by a very soft abrader. In this case, abrasion is caused by the rattan pot carrier and, to a lesser extent, the cook's hands as they grip the pot in this region. The very fine scratches are created as the rattan pot carrier is twisted slightly when it lifts the hot pots off

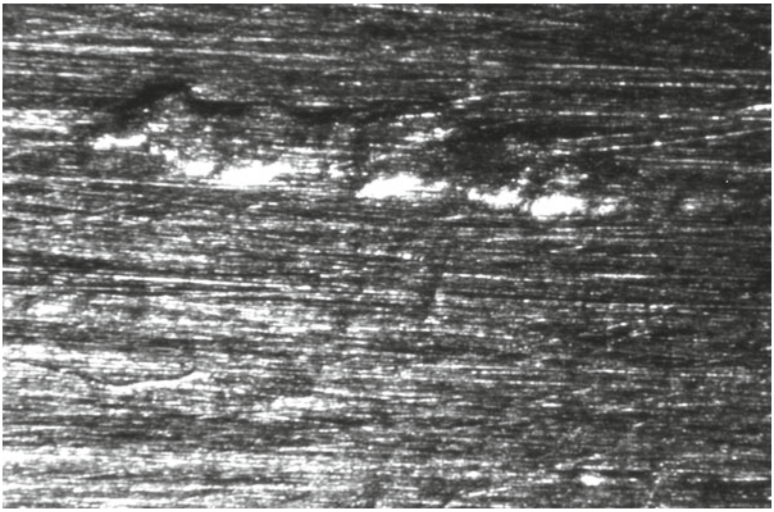


Fig. 4.14 The upper interior side has fine scratches, not visible to the naked eye, that creates a polish (length of frame is approximately 4.5 mm) (From Skibo 1992, p. 127)

the fire. There are also some fine washing scratches in this zone similar to what those found over the entire exterior.

The polishing about the neck is indicative of an abrasive contact with a soft abrader. If a similar patch were found on a prehistoric pot we might be justified in inferring that a carrier of some type was used. However, in most situations this trace would not survive in the depositional environment unless the vessel had been deposited in a way that preserved the organic pitch. Would this trace have formed on the ceramic surface in the absence of the resin? I doubt it. Because Kalinga pots last just several months, the frequency of the rattan-neck contact would likely be too low to create a visible trace on the ceramic. However, in cases of frequent repetition of this contact over long periods, some polishing might be visible.

Rim

This is the smallest attritional zone (Fig. 4.5) and is confined to just the lip of the vessel. Two attritional traces are found on the rim, large chips and linear scratches oriented parallel to the rim. The daily activities that affect the rim include covering the pots with metal lids, nesting the vessels for transport and storage, contact with the ground during washing along with scrubbing by hand, and grasping the pots by hand.

The trace found on all vessels is the horizontally oriented scratches that are created as rims come in contact with the concrete or packed earth as they are rotated during exterior washing. This zone becomes more worn with use to the point where some vessels have rims worn completely flat (Fig. 4.15). These scratches, often accompanied by pits instead of pedestalled temper suggest an aggressive abrasive

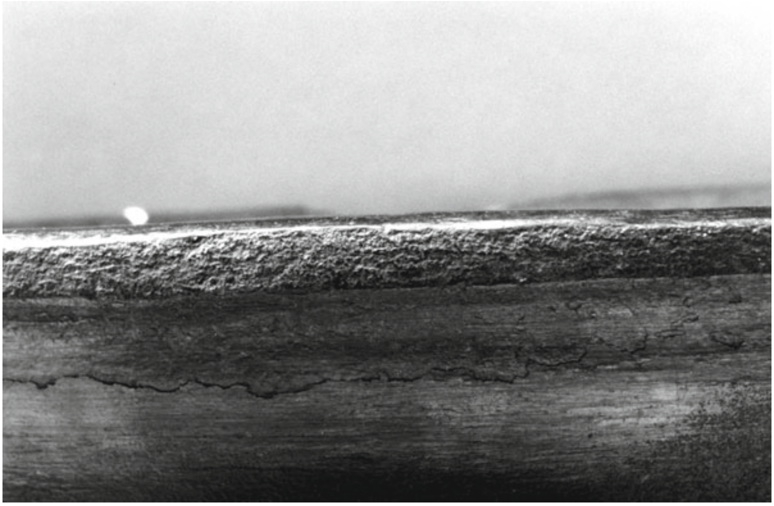
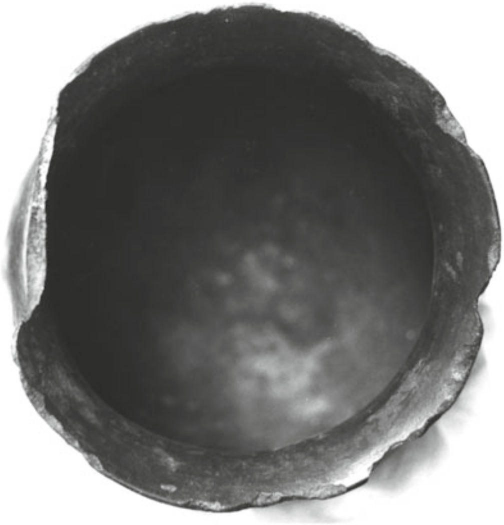


Fig. 4.15 Rim is worn nearly flat because of contact with the ground during washing (From Skibo 1992, p. 129)

Fig. 4.16 Heavily chipped vegetable/meat pot rim as seen from above (From Skibo 1992, p. 130)



action, traveling in the same direction as those found on the mid-exterior side. In fact, they also created during the same exterior washing action. The rim scratches are found on all cooking pots, but less extreme wear is seen on rice vessels because their less outflared rim and smaller mouth reduce the area in contact with the ground than the vegetable-meat pots.

About three-quarters of all daily-use cooking vessels in the village of Guina-ang have chipped rims (Fig. 4.16). Although the chips vary widely in shape and size, most seem to have been created as a result of single impacts. The shape of the chip often provided clues to the angle and direction of the blow, which most often came from the top of the rim. Vegetable-meat and rice-cooking pots have chipped rims at about the same rate, which suggests that the two cooking activities do not result in differential chipping. Although the vegetable-meat pots are covered and uncovered a number of times during one cooking episode whereas cooking rice requires far less monitoring, most of the chipping occurs while the pots are moved about in the house or to and from the washing spots. The most common type of impact observed was between two pots, especially when more than one was carried in one hand.

In summary, the exterior of the cooking vessels was a rich source of attritional traces. The most dominant traces, however, were the result of a relatively aggressive form of washing that involves rotating the pot on the ground while scrubbing by hand with abrasive material. The washing-related attritional traces indicate not only the directionality of the abrasive action but also the handedness of the washer. Other non-washing traces, such as rim chipping, neck polishing, and basal abrasion, did occur on both vegetable-meat and rice cooking pots, demonstrating the overall similarity of use-activities affecting the vessels'exteriors. However, as the following discussion indicates, the four interior attritional patches differ greatly in the two vessels forms.

Interior Rim and Neck

Two forms of attrition are found in this area: abrasion resulting in slightly pedestalled temper, and thermal spalling. Activities that create contacts in this area include stirring the contents, serving the food, placement of the pots next to the fire, and washing.

On vessels with evidence of extensive use (heavy sooting and exterior abrasive patches), there is abrasion on the interior neck at the narrowest point of the vessel's orifice. In this area the temper is pedestalled slightly, creating a surface that is slightly rough to the touch. In fact, this attrition is more easily felt than seen. The nature of this abrasive trace suggests that the abrader has a larger surface that can expose and slightly pedestal the temper in a relatively gentle abrader-ceramic contact. The abrader would have to be larger than the distance between the temper particles and be harder or as hard as the ceramic.

Both types of cooking pots have this patch of neck abrasion, but the vegetable/meat pots consistently have more abrasion in this region than the rice pots. This abrasion is caused by contact with either a metal or wooden ladle/spoon during cooking (Figs. 4.17 and 4.18). The vegetable/meat pots are stirred many times during cooking whereas only during serving do these tools enter the rice pots. I should also note that there is a concurrence in actual and intended use in this case, as the more restricted orifice of the rice pots suggests that they are accessed less frequently; the use-alteration traces confirm this correlation.

The second form of attrition situated on the interior neck is thermal spalls, which are found almost exclusively on rice pots. The spalls, which are roughly circular

Fig. 4.17 A metal ladle used to loosen and test rice (From Skibo 1992, p. 69)

Fig. 4.18 Removing vegetables from a vessel with a wooden ladle (From Skibo 1992, p. 72)

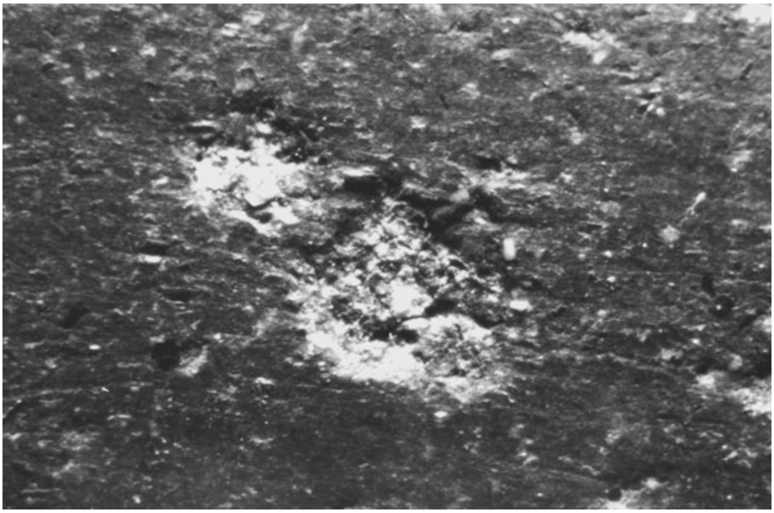


Fig. 4.19 Thermal spalls on the interior neck of a rice cooking pot (length of frame is approximately 7 mm) (From Skibo 1992, p. 136)

in shape and range in diameter from 1 to 3 mm (Fig. 4.19), also extend to the mid-interior side. The cause is water in the body of the pot that is heated to steam which, when escaping, spalls off a small portion of the interior surface. Four conditions are necessary for this thermal spalling to occur: (1) moisture in the vessel wall, (2) exterior heat, (3) the interior surface is less permeable than the underlying wall, and (4) immediately next to the interior surface the contents of the vessel must have reduced moisture. These four conditions occur in the rice pots only during the third stage of cooking, when the vessels are placed next to the fire in the simmer position. The water in the pot has been completely removed so that the moisture in the vessel vaporizes and escapes away from the source of the heat. In this case the escaping steam bumps up against the lower permeability polished interior and spalls are produced. Spalls are not produced during each cooking episode, only when the rice is left in the simmer position a bit too long, which is easy to do.

To summarize, there are two informative attritional traces on the interior neck and rim. From the abrasion on the neck one could infer that the contents of the vegetable/meat pots are manipulated with tools more often than the rice cooking pots, and this correlation was confirmed through observations of cooking behavior. In addition, thermal spalls, found only on the rice pots, were created when the water level inside the vessel falls during simmering.

Use Activity without an abrasive trace. Two important use-activities involve contact with the interior rim or neck but leave no trace. The first is covering with a metal lid. No evidence of this activity was found even though the pots, and especially the vegetable/meat pots, are covered and uncovered many times during cooking. The aluminum lids are light and do not seem to carry enough force to

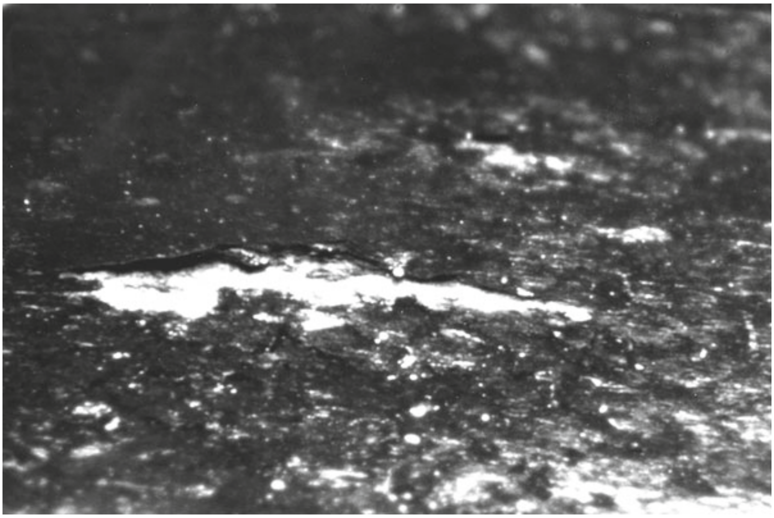


Fig. 4.20 Impact mark on the upper interior side (length of frame is approximately 7 mm) (From Skibo 1992, p. 138)

cause any attrition. The traditional ceramic lids would perhaps cause some attrition, but these were infrequently used during the observation period. The other major use-activity that creates contact in this zone is washing. Although washing leaves highly visible exterior traces, no washing traces were observed on the interior because very little scrubbing is necessary. Boiling, after all, leaves little food residue, and rice cooking is always done with a layer of leaves.

Upper Interior Side

The thermal spalls seen on the upper interior neck of the rice pots are also seen in this region and are formed by the same process as described above. However, some pitting is visible on the upper interior side of vegetable-meat pots. These pits have the appearance of single impact marks (Fig. 4.20). The pits are angled toward the rim and their points of initiation are usually on the lower side, toward the base. The attributes of these marks suggest that the abrader was harder than the ceramic, was traveling somewhat quickly, and was moving upward in a clockwise direction in the vessel.

The activity responsible for these pits is the stirring and serving of vegetables or meat, usually with a metal ladle. If the cook uses her right hand, which is usually the case, the ladle moves in a clockwise direction as viewed from the top, and ends up in a position nearest to the cook; the resultant impacts can create marks. Curiously, these kinds of impact marks are less prevalent on the smallest vegetable meat pots,

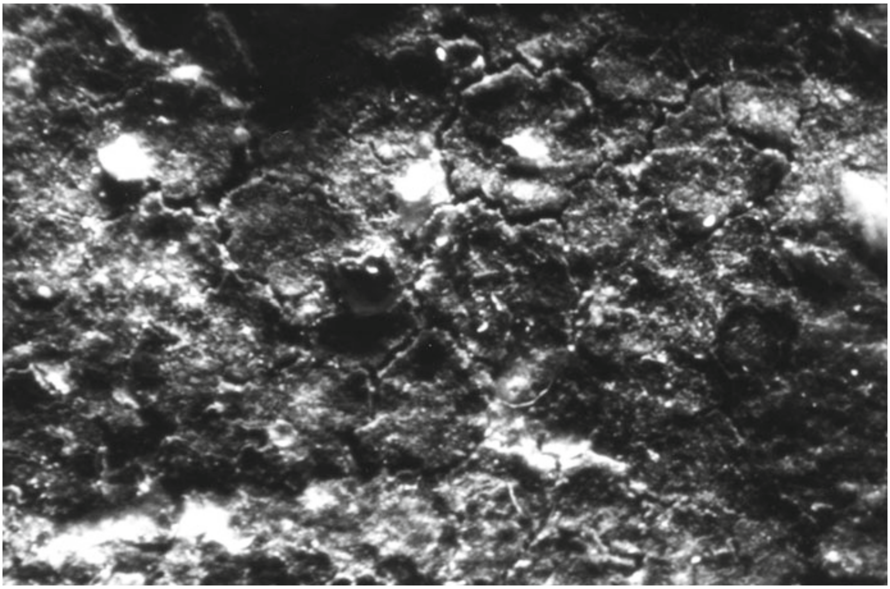


Fig. 4.21 Microscopic cracks on the interior of a thermal spall (length of frame is approximately 3 mm) (From Skibo 1992, p. 140)

presumably because the potter's hand is unable to move as quickly in the confined interior, and so marks are not consistently created.

Finally, fine scratches appear on the upper interior side, consistent with the kinds of traces created during washing (Note that the leaves are removed from the rice pots prior to washing). Although the scratches travel in all directions, the marks tend to be oriented parallel to the rim which is consistent with the rotational washing motion that occurs during cleaning.

Mid-interior Side

Besides the fine scratches inside all vessels, the only attritional trace in this region is thermal spalling, and as noted above these are only found on the rice pots. Although the spalls are found right up to the rim, their greatest density is in the mid-interior region, which corresponds with the internal patch of carbonization discussed in the previous chapter. A thermal spall can be distinguished from other attritional traces, such as an impact pit, based on its shape and consistent size. A pit caused by thermal spalling is almost round and in cross-section is either hemispherical or conical. The edge of the pit forms a sharp break but there is no evidence of impact or abrasion. On the Kalinga rice pots there was also some microscopic cracking in this region, perhaps also caused by escaping steam (Fig. 4.21).

Lower Interior Side and Base

The only significant attritional trace, in addition to the typical interior washing scratches, is some subtle abrasion on the base of the vegetable-meat pots. Some of the ceramic material has been removed without removing or pedestalling the temper. This suggests contact with a gentle abrader larger than the distance between the ceramic temper particles. The activity responsible for this attrition is stirring the contents during cooking with the metal ladle.

Summary

The exteriors of both pot types have relatively similar attritional traces, dominated by marks and patches left by washing. All cooking vessels get dirty and they are washed in the same manner. It was also learned that the exterior attritional trace varies according to the handedness of the washers. Because left-handed people are in the minority (ca. 10%), on a sample of pots we can identify the handedness of the washer—assuming that only one person is responsible—because of the small fraction of pots whose marks show a different rotational pattern.

The most striking aspect of the attritional analysis is that the rice and vegetable/meat pots had quite distinct interior attrition patterns owing to the different cooking activities associated with different foods. For example, thermal spalls were found only on the interior of the rice pots, and vegetable/meat pots had both individual impact marks and some basal attrition as a result of stirring. Rice pots did not have these traces.

Ants for Breakfast

In the process of thinking once again about Kalinga pottery use activities, it made me reflect on the hours spent huddled next to a fire not only watching the women prepare meals and handle their vessels, but also getting wrapped into their daily lives. While discussing or writing about the results of this ethnoarchaeological project the impression is often that their daily lives are being recorded by some type of detached observer hovering above the hearth having no effect on their lives and, conversely, the Kalinga having no effect on me. Neither is true.

When I look back at my original notes I sometimes find gaps, followed by a note that says something like, “rice was cooked but no notes taken.” My usual routine would be to record the size of the pot, the time it went on the fire, how many times it was rotated on the simmer position, and any details about the use of this vessel. But I also kept a separate notebook, which I filled in at night, which would report on more personal things like, for example, why I

(continued)

had been distracted and taken no notes on a particular day. On one occasion, the man of the house walked into the house in an agitated state saying that his water buffalo, one of their most prized possessions, had disappeared. He believed that someone had stolen it and he was in the process of rounding up a posse of sorts to track the animal and find the perpetrator. The woman of the house, certainly better at multi-tasking than I, was able to continue cooking while I could only focus on the unfolding drama. But a more common distraction was when someone in the house, maybe an aged parent or a teenager, would take this opportunity to interview me. Sometimes I was able to continue doing more work while other times it was difficult. In these times it reminded me a lot of the little town I grew up in. A person from another country visiting my town would have been a big event and a curiosity and my neighbors would have taken every opportunity ask them questions.

There were times, however, when these types of distractions began to impact the type of data I was recovering. My goal was to record everyday pottery use activities and to do this I visited a different house each day and stayed with them from when the hearth fire was first lit until the last pot was put away in the evening. Because I wanted to be polite about it, I would ask the homeowners the night before if I could come and visit their house the following day. They always said yes and by the next morning they had prepared the equivalent of my grandmas Thanksgiving feast. Clearly, this was not the way to record everyday cooking and pottery use. After consulting with my Kalinga assistants they said the only way to avoid this was to arrive unannounced before sunrise just when the fire was being lit. In my hometown that would have been unforgivably rude but in Guina-ang it was perfectly acceptable. Despite these precautions, on occasion the Kalinga cooks could do something a bit out of the ordinary because of my stay. There is no more dramatic instance then the morning I first had ants for breakfast (Skibo 1999).

One morning before dawn I arrived at a house that just so happened to harvest the day before a large collection of ants and ant larvae, which the Kalinga consider a treat. When I saw a different food being prepared that morning I could not tell what is was because of the dim light, but I dutifully recorded its Kalinga name and how things were cooked. Once it was time for breakfast and I put down my notebook and camera to share the meal. I realized that I was served a heaping, steaming pile of ants and ant larvae. Not to be rude I closed my eyes and took a few bites. It was not too bad—it tasted a bit like a nutty spinach salad with a light vinegarette dressing. When they asked me how it was I said, “delicious,” again not wanting to be rude. My hosts were thrilled. So thrilled, in fact, that when they found out where I was working the next morning they made a point of bringing over some more of the treat announcing how much I liked to have ants for breakfast. And so it continued for the next several weeks. If at least one household had harvested ants the previous day someone would track me down and make sure I had my “favorite” food.

Case Study: Griffiths and Bray

In any scholarly work it is important to understand the genesis of a particular idea or approach, and the analysis of attrition on ceramics can be traced to two seminal studies: the first by Dorothy Griffiths on eighteenth century lead-glazed earthenwares and the second by Alicia Bray on Mimbres Black-on-White pottery from the American Southwest. Not only were these studies the first systematic attempts to employ attritional traces for inferring vessel use, but their analytical techniques and conclusions have held up for decades. Accordingly, their studies deserve fuller elaboration here.

Griffiths focused on a fundamental advantage of use-alteration studies: the ability to infer actual use as distinct from intended use. As she notes, "since the consumer is equally an active agent in determining the specific use of an object, such information (that is functional categories of use) provides only a gross framework for beginning analysis of the utilization of objects recovered from a site" (Griffiths 1978, p. 68). For her study she examined eighteenth century lead-glazed ceramics because their surfaces are easily marked in use by knives, forks, and spoons. Although she homed in on attritional traces, especially cut marks and scratches, she recorded seven trace categories that seem generalizable to all glazed historical ceramics. These include fire-blackening, cracking or crazing, spalling, scratches, staining, etching, and deposits. The category "scratches" was further divided into seven varieties, including knife cuts, fork or spoon scratches, stirring scratches, beating marks, abrasion of the foot-ring, scouring scratches, and storage marks. She then introduced a strategy for making these types of marks more visible; the glaze was rubbed with a soft lead pencil, which facilitated the recording of the marks. Although Griffiths (1978, p. 69) demonstrated "that the study of use-marks is feasible with historic material" and showed effectively how it can be done, her suggestions do not seem to have been heeded by historical archaeologists. According to Google Scholar, Griffiths (1978) has been cited just 14 times and only 3 by historical archaeologists (accessed on September, 2011). Griffiths' study has little legacy in historical archaeology even though she provided the foundation for further—and potentially profitable—studies. I would encourage historical archaeologists to belatedly follow Griffiths' lead by recording use-alteration traces and employing them to infer modes of vessel use. For example, because similar ceramics are found in many regions of the world, one could compare the relationship between actual vessel use and social status, diet, ethnicity, etc. This is an advantage that historical archaeologists have over prehistorians who must deal with a tremendous amount of ceramic assemblage variability and thus susceptibility to abrasion.

Alicia Bray (1982) did an attritional analysis of Mimbres Black-on-White bowls housed in the Arizona State Museum. They were made in the American Southwest for a short time after A.D. 1000 and are found mainly in mortuary contexts. These vessels were ornately painted with human, animal, and geometric designs, and their symbolic significance to the people who made, used, and then interred them with their dead is unquestionable. Archaeologists have long speculated about the role of these vessels in Mimbres society. One thing was clear: there is evidence, in the form of attrition, that they were used before being placed as burial offerings. Although archaeologists had noticed the attrition on these beautifully painted vessels, Bray was the first to systematically record these traces and link this information to use behavior.

Unlike Griffiths' (1978) study, which demonstrated the information potential of attritional traces, Bray focused on a particular question: What was the functional role of these special vessels prior to their use as grave goods? Perhaps because Bray's study was problem-oriented, it has accrued more citations (25 as of September, 2011 according to Google Scholar) than the one performed by Griffiths. There is a practical lesson here: archaeologists are reluctant to adopt a new analytical strategy unless it is tied to a real historical problem. If Griffiths, for example, had concluded her methodological discussion with a short case study, I would predict that this technique might have had more traction. This does, however, create an opportunity for someone to apply this type of analysis comparatively to investigate how various historical populations, perhaps different ethnic groups or social classes in the same community, used their everyday dishes.

Bray (1982) examined 124 whole vessels, looking at evidence of wear, in the form of abrasion, on both exteriors and interiors. She created three stages of attrition: none, light, and moderate. Of the 124 vessels, 16.9% had moderate attrition, 48.4 % had light attrition, and 34.7% had no attrition. She then correlated these data with various vessel attributes, such as whether the design was geometric or representational, the precision of the painting, and the vessel size.

She found that just over 65% of the Mimbres bowls had evidence of use prior to their interment. Although the causes of the attrition were not investigated closely, she argued that the bowls were used in food preparation or serving and that the abrasion was the result of impact with a serving implement. Her results quantified what generations of Southwestern archaeologists had long noticed, that Mimbres bowls often had evidence of use in food preparation. About 35% of the bowls had no attritional evidence of use. Of course this does not mean that they were not used in food preparation as well; perhaps they were used so few times that no visible traces were created. Bray also found that the most finely painted vessels (the ones made with the highest skill and most precision) most often had little or no abrasion. Because Mimbres pots are so closely associated with mortuary contexts, one could infer that their use as preparation or serving vessels occurred in contexts of the death rituals as well. The majority of the vessels had some wear, suggesting that they had been used on multiple occasions before burial. But about a third of the vessels, and many of the more finely painted ones, had a different life history. Perhaps they were used just once, leaving no abrasive trace, before being placed in the grave. I will let Southwestern archaeologists argue over what this means. The significance here is that Bray's use-alteration study provided additional information about the life history of these vessels that, with further research, may lead to a fuller understanding of Mimbres mortuary rituals.

Case Study: Hardin and Mills

More recently, several studies that have incorporated attritional traces into their ceramic analysis to augment their inferences about past life. In the American Southwest, Hardin and Mills (2000) recorded attritional traces on an ethnographic collection of Zuni vessels to help them better understand the rates of stylistic change.

Their study focused on the Smithsonian Institution's Stevenson Collection of Zuni pottery that was obtained in the late nineteenth. Both authors have a long-term interest in the sources of Zuni ceramic variability (Hardin 1983, 1991; Mills 1995, 1999) and together examined issues surrounding stylistic change and vessel longevity. The Stevenson Collection is ideal for examining such an issue because the vessels (about 3,500 in total) were collected along with thousands of other objects from a single aggregated community between 1879 and 1885. Hardin and Mills used this unique collection to investigate the relationship between short-term stylistic replacement and vessel use-life.

The Hardin and Mills (2000) study was based on 952 decorated jars and bowls. Like the Mimbres potters described above, the historic Zuni were known for creating elaborately painted containers. But unlike the Mimbres, the Zuni used their painted polychrome vessels daily. Each vessel was well documented in terms of intended functional category and year of collection. Hardin and Mills understood, however, that learning the age of the vessel at the time of its collection was critical for understanding short-term stylistic change. In order to estimate use-life they focused on attritional traces (Hardin and Mills 2000, pp. 146–148).

Their analysis focused on three decorated vessel types: eating bowls, communal eating bowls, and bread bowls. Attritional traces from the exterior base and interior were recorded as a basis for creating a relative scale to estimate the vessel's age at the time of collection. Following Bray (1982), they built an ordinal scale for the vessel interiors based on the amount of abrasion on the painted surface: (1) absent, (2) low, where only scratches and individual marks are found, (3) moderate, when some of the decoration has become eroded, and (4) high, when the decoration is gone or nearly gone. Exterior abrasion was recorded using the same system; however, the exteriors were not painted and so their scale is based on the severity of slip erosion. This relatively simple and fast classification scheme provided important information about relative vessel use-life.

They found that the degree of attrition on bowl interiors was similar across the three vessel classes: the percentage of bowls in each of the four attritional classes was the same regardless of functional class. They did find, however, that exterior abrasion varied considerably with functional class. The smallest bowls were least worn, the medium bowls had a moderate amount of wear, and large bowls had the greatest. For example, about 29% of the small bowls had no or low attrition, about 10.5% of the medium bowls were in these categories, and none of the large bowls fell into these categories.

Hardin and Mills argue that the differential exterior abrasion is the result of 2 factors. The three bowl sizes were used differently—small bowls were individual eating bowls, medium ones were communal food bowls, and the large bowls were used for kneading and raising bread dough. It is no surprise that the largest bowls were most abraded; the reader can easily envision that bread-making activity involves actions that would have readily abraded the exterior bases. In terms of stylistic analysis, they suggest that vessels used differently should be analyzed differently. They also note that the very low abrasion on the exterior of the small bowls was the likely consequence of a relatively short use-life occasioned by breakage. Cross-culturally, smaller vessels generally have shorter use-lives, a correlate that

Hardin and Mills also attribute to small Zuni bowls. The later finding was particularly important to their investigation of Zuni pottery stylistic change.

Southwestern archaeologists use function in their stylistic analysis, most often discriminating between bowls and jars. But the study by Hardin and Mills illustrates that there can be patterns of stylistic variation even within these functional classes. The use-alteration analysis demonstrated that different size bowls had very different functions and use-lives, and differential patterns of stylistic variability.

The major point of the Hardin and Mills (2000) study is that stylistic analysis should incorporate vessel size and use as these variables are known to impact stylistic patterns. The relatively simple analysis of surface abrasion helped them to better understand vessel use and thus conduct a more refined stylistic analysis.

Case Study: Sherds as Tools

The Ruelas drainage study described above showed that attritional traces can be used to infer what happens to the vessels farther along the behavioral chain once they are broken and discarded. In that study the degree of abrasion of isolated sherds demonstrated that they had been transported by the movement of water, a noncultural formation process. But vessel fragments are also subject to a variety of cultural processes like trampling (Nielsen 1991) and recycling that can leave attritional traces. Indeed, the two case studies below, which consider how sherds may be recycled into tools, show how attritional traces can give important clues as to how vessel fragments were used in vessel manufacture and in agave processing.

López Varela et al. (2002; see also Vieugué et al. 2010) explored how recycled ceramic fragments were used as tools in pottery making. Their study took place at K’axob, the Late Classic Period site in northern Belize. Excavations had revealed extensive evidence of pottery making in the form of kilns, a clay gathering area, and a large collection of worked sherds inferred to have been tools used in pottery making. Seventy shaped ceramic fragments were analyzed with low-power microscopy and classified into smoothing, scraping, incising, polishing, and boring tools. Archaeologists in this region often observed shaped sherds and perhaps even suggested their use in pottery making based on comparisons with modern pottery making implements. The López Varela et al. (2002) study goes well beyond that by using the attributes of the abrasive traits to classify the implements into functional types. Then, by conducting experiments, they were able to strengthen their functional assignments.

Based on the directionality and attributes of the striations they distinguished smoothing tools from sherds used for polishing. The polishing tools had much smoother surfaces and unidirectional striations. They also identified incising tools, which had rounding, striations, and faceting on the distal end. Boring tools, in contrast, had striations oriented perpendicularly.

After the analysis was complete and they had assigned specific functions to the tools based just on their formal properties and abrasive traces, the authors still had some questions about their inferences. Although the sherd tools were found in a pottery making area, it was still unclear whether these tools were used to work other materials. In addition, based on the characteristics of the abrasive traces, they had assigned these tools very specific functions (i.e., smoothing, polishing, boring, and incising). Their experiments were designed to better understand how pottery making activities create abrasive traces so that they could then firmly link the prehistoric tools with those made experimentally. In this way their study was similar to many lithic use-wear studies in that trace creation has been found to be material specific. Consequently, many lithic use-wear studies follow the same strategy of first identifying wear traces microscopically and then performing replication experiments.

The experiments performed by López Varela et al. (2002) were very productive. Their experimentally made and used ceramic tools had use-alteration traces that could be matched to the prehistoric examples, which strengthened their arguments about tool function. It is important that they identified these tools as having functions because, as the author's note (2002, p. 1145), archaeologists have in the past tended at best to describe these sherds without comment or ignore them; at worst they are tossed out. Their study demonstrates, however, that these sherd tools are a vital part of a pottery making toolkit. This is especially important in areas that lack direct evidence for pottery making (such as pottery firing areas), and so the presence of these tools might be the only indicator of pottery making at a site (Sullivan 1988).

We return to the Tucson Basin for another example of people using sherds as tools (Sullivan et al. 1991; Van Buren et al. 1992). Located very near the Ruelas Drainage was a small site consisting of a roasting pit and several rock piles, thought to be used in agave cultivation (Fish et al. 1992a). The site was intensively excavated and the almost 900 sherds and 55 pieces of chipped stone were recovered in a tightly confined area surrounding the roasting pit. The site was initially excavated to better understand the nature of the activities conducted at these small sites and to explore how these temporary field camps fit into the larger system for dry farming of agave.

Excavated completely, the roasting pit was very similar to pits found among the larger rock pile fields believed to be part of large-scale agave cultivation. The pit was about 2.25 m in diameter and 1 m deep. The large amount of ash, fire-cracked rock, and artifacts around the pit suggests it was used repeatedly. The botanical analysis of the charred remains in the pit suggests that it was used to roast agave; a radiocarbon assay of the charred remains dates the use of the pit to about A.D. 1000, which is the late Pre-Classic Period in Hohokam chronology.

One of the goals of this excavation was to excavate all of the cultural material to explore the technology of agave processing and learn how space was used at these small sites. Sherds were sorted into vessel batches based on four technological attributes: paste characteristics (e.g., temper particle size, type and density), surface finish, core color, and wall thickness (see Sullivan 1989). After 115 sherds were excluded because they were either too small or eroded, 715 sherds were sorted according to these attributes.

The results of this exercise were quite informative. At total of 82 vessel fragments were identified, but none of them even approximated a partially reconstructed vessel. Conjoinable sherds were rare (only 7% of total) and more than half the vessels consisted of five or fewer sherds.

What activity would create such an assemblage? It appears that the sherds at this site were not the remains of vessels used and broken there but rather they represent pots previously broken at a village and brought to the site as sherds. Why would people transport sherds? The use-alteration traces suggest that they were used as tools in agave processing.

Two use-alteration traces were especially informative: carbonization and attrition. Almost 20% of the sherds had sooting, oxidation, over-firing, and other evidence of exposure to a fire. These sherds seemed to have been used in the roasting pit as nonflammable covers to keep the agave away from the coals and soil during baking (see Miksicek 1987, p. 226). There is also evidence that large sherds were used to dig the pit or to extract the contents after cooking. A number of sherds had edge abrasion with striations consistent with the action of digging.

Relatively large Pre-Classic habitation sites that date to about the same time as the roasting pit site are located just a couple of kilometers away. It would appear that as villagers prepared to go to the agave fields and roasting area they first stopped at the village midden or perhaps harvested large sherds from the broken vessels stacked next to their houses. Michael Deal (Deal 1985, 1998, pp. 115–140; Deal and Hagstrum 1995) in his ethnoarchaeological study of pottery deposition in the Central Maya highlands, referred to this behavior—i.e., stockpiling of broken vessels-as "provisional discard." Deal's original study was part of the Coxoh Ethnoarchaeology Project, which focused on material culture links between modern Maya and the prehistoric people in this region (Hayden 1988; Hayden and Cannon 1983, 1984b; Hayden and Nelson 1981). What is of interest here is Deal's analysis of the household as a depositional unit, particularly the multiple pathways that vessels and sherds take once they are no longer used for their primary function.

Provisional discard is the storage of damaged vessels or vessel fragments in out-of-the-way places that could be reused in several ways if repaired or recycled.

Coxoh Ethnoarcheological Project

The Coxoh Ethnoarchaeological Project (Hayden 1988; Hayden and Cannon 1984a, 1984b) was the brain child of Brian Hayden, an innovative thinker in archaeology with wide interests that range from the prehistory of the North American Northwest Coast (e.g., Hayden and Shulting 1997) and Upper Paleolithic Europe (e.g., Owens and Hayden 1997) to the ethnoarchaeology in several regions including Southeast Asia, Australia and the Maya Highlands (e.g., Hayden 2008, 2009). Although it is hard to categorize his research program, much of it has focused on hunter-gatherers with an emphasis on political development in these societies. As one of the more creative forces in archaeology it is no surprise that he directed a large-scale ethnoarchaeological project dedicated to creating material connections between the extinct Coxoh and the modern Maya (Deal 1998, p. xv). The focus was on households and the project collected data on family economics, social structure and other variables and the material culture within each household.

(continued)

Although the data collected are clearly most relevant to those working at sites that are direct descendants of the modern Maya, the long-term importance of this work is in illustrating the connections between household material possessions and the various social and economic variables.

The project collected data in three villages, Chanal, San Mateo Ixtatan, and Aguacatenango. About 50 households from each village were studied, which included an inventory of material possessions, a map of their compound, and interviews of residents. Some of the more relevant findings relate to “where the garbage goes” (Hayden and Cannon 1983) and other household formation process issues, which are critical for archaeological inference. They also were able to make a number of correlations between material items and various economic variables that are important not just to Maya archaeologists but many others interested in making connections between population, social rank, sex ratios and other household variables and the material culture they possess. Although the project collected information on all material items, Michael Deal was primarily responsible for the analysis of pottery (Deal 1985, 1988, 1998; Deal and Hagstrum 1995).

Deal’s study focused on household pottery variability (frequency and type) and the spatial organization and patterning of pottery use behavior. He looked at these households in terms of pottery production, consumption and deposition (see also P. Arnold 1991). For example, he explored what factors influenced vessel production in terms of frequency and type variability. He found that the environmental conditions, like quality and availability of clay and temper, influence the types of vessels produced (see also Arnold 1985, 1993). He also notes that because pottery is made so infrequently and the teaching and learning periods so confined that technological variables (i.e., techno-functional performance) are stressed over stylistic. Deal also illustrates what one finds within potting and nonpotting households, which is important as evidence of pottery making in some regions prehistorically is difficult to identify (Sullivan 1988).

In terms of pottery diversity, among Deal’s findings is that vessel type and frequency is very sensitive to a households socioeconomic and demographic conditions. He also suggests, based on his data, that archaeologists should use measures of pottery diversity rather than frequency for inferring social status of household members. Finally, Deal makes significant contributions to formation process theory as he considers the household as a depositional unit. For archaeologists to make inferences from pottery we must continually sharpen our inferential focus by better understanding a vessel’s complete life history including how it was reused, recycled, discarded or put into a state of provisional discard (Deal 1985).

Like the work by a number of ceramic ethnoarchaeologists (e.g., Arnold 1985, 1991; Arthur 2006; David and Hennig 1972; DeBoer and Lathrop 1979; Kramer 1982; Longacre 1974), the work by Deal as part of the Coxoh Ethnoarchaeological Project will be a lasting contribution as people who make pottery at the household level are becoming increasingly rare.

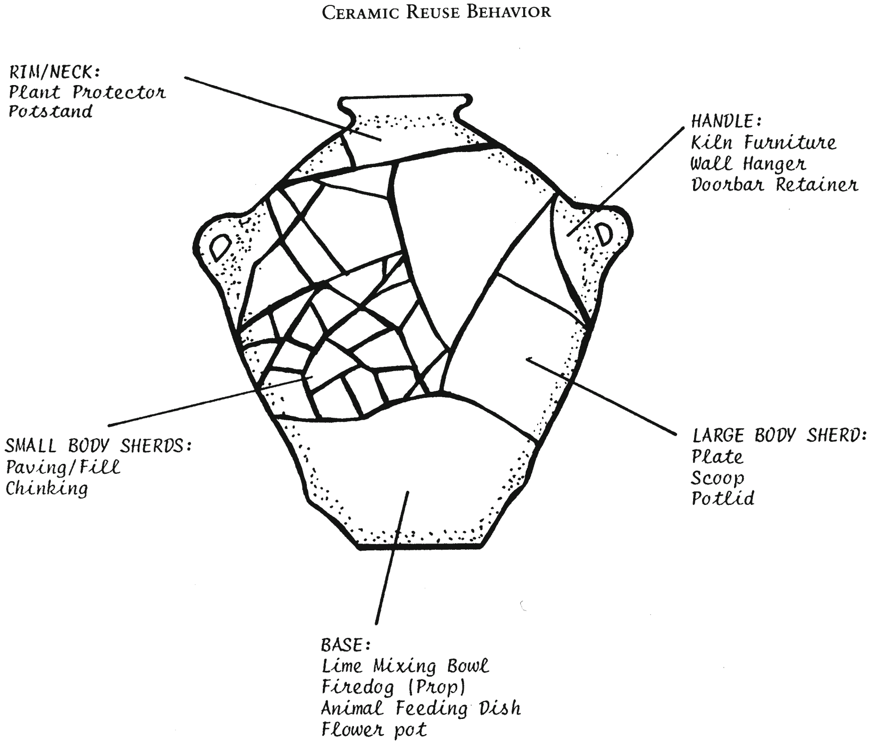


Fig. 4.22 Breakage patterns of Tzeltal water jar and possible recycling functions of various parts of the vessel (Deal and Hagstrum 1995, p. 125)

Figure 4.22 (Deal and Hagstrum 1995, p. 125) illustrates the many ways a Tzeltal Maya vessel could be recycled. Provisional discard in modern rural America is the old cars, washing machines, etc. that are stored at the edge of a field by the homeowner should they need spare parts for various farm projects. I grew up in a rural area and one of my teenage jobs in the spring was peeling the bark off freshly cut aspen that were then shipped to the paper mills. The tool for peeling the aspen was a "spud," made from a recycled car leaf spring harvested from a car in provisional discard.

Deal was interested in provisional discard because it greatly affected the life history of vessels and the way sherds eventually entered archaeological context at the household level. Just like the cars that line the fields and are gradually swallowed by the encroaching vegetation, many of the vessels in provisional discard are never used and so become part of the archaeological record.

One can envision pit houses of the Pre-Classic Hohokam lined with a row of provisionally discarded broken vessels that would have served as a ready supply of tools for the agave processing field house. Large sherds were collected and carried in a bag to the field camp where individual sherds were used dig the pit, as nonflammable covers to protect the agave from the soil and hot coals, and then as scoops to remove soil and fire cracked rock to prepare the pit for its next firing.

Case Study: Alcohol Fermentation

The fermentation of grains or fruits to make alcoholic beverages is found throughout the world and in some cases goes back millennia (Dietler 2006; McGovern et al. 1995, 2004; McGovern 2003). Patrick McGovern has spent over two decades trying to refine an analytical method for identifying the chemical markers of alcohol from residue recovered from pottery. The accuracy of these techniques, however, "is impeded by environmental and microbial degradation, modern contamination, human processing in antiquity, and the degree to which a region's natural resources have been adequately surveyed for biomarkers" (McGovern et al. 2004, p. 1795). This problem afflicts all chemical residue analysis and is discussed further in Chap. 5. But searching for the chemical signatures of alcohol production is even more difficult because one is not just looking for traces of rice, corn, or grapes, but also evidence that they were being fermented.

McGovern's strategy, illustrated most recently in his study of fermented beverages from the seventh millennium B.C. in China, is to combine a chemical analysis with archaeobotanical and archaeological evidence (McGovern et al. 2004). The chemical analysis involved a number of different methods: gas chromatography–mass spectrometry, high-performance liquid chromatography, Feigl spot tests, stable isotope analysis, and Fourier-transform infrared spectrometry. This shotgun approach is necessary because the chemical markers of fermentation in pottery residue are allusive. The archaeological evidence can sometimes be very helpful if, for example, a group had special ceramic vessels for alcohol production or consumption like the *teguino* vessels made by the Tarahumara, or Rarámuri, of southwestern Chihuahua, Mexico (e.g., Senior 1995). But special vessels are not necessary for this practice, and it seems that many groups fermented various products in their everyday storage or cooking jars. Consequently, the practice of fermentation and the consumption of alcohol can often go unnoticed prehistorically if there is not a special technology or if you lack the ability to perform the types of testing advocated by McGovern.

Our inability to have a straight-forward marker for fermentation is of particular concern because such a practice even among hunter-gatherers is often associated with feasting and important ritual activities (Dietler and Hayden 2001). As Dietler (2006, p. 242) observes, alcohol "has been a fundamentally important social, economic, and political artifact for millennia." Because of the importance of alcohol production and consumption worldwide it is imperative to refine our methods to infer its presence. Here I introduce an abrasive trace, interior pitting, which is often found in jars used in fermentation.

I first noticed interior pitting on seed jars in my study of the origins of pottery on the Colorado Plateau (Skibo and Blinman 1999; Skibo and Schiffer 2008, pp. 37–52). In Chap. 3 I discussed how the interior and exterior carbonization patterns on these vessels enabled us to infer their use in various cooking modes. But these same vessels were not just used for cooking, as a number of them had widespread interior spalling, which we have come to associate with fermentation.

Ten of the whole vessels that were part of this study had interior spalling. In some cases much of the entire interior surface has been completely eroded while in others patches of attrition and individual spalls could be identified. The spalling reaches almost to the rim, which contrasts with the interior carbonization that stopped at about the midline. At the time of the original study we suggested that alcohol fermentation processes were responsible for this trace but we had no direct evidence of this.

John Authur's study among the Gamo people of southwestern Ethiopia confirms that alcohol fermentation, in this case making beer, causes interior spalling similar to what we observed on seed jars from the Southwestern United States. Arthur (2003, p. 524) notes that beer fermentation creates a lactic acid forming bacteria that reduces the pH. If the vessel contents have a pH opposite to that of the clay the ceramic can be weakened. The spalling likely occurs as gases are formed in the fermenting liquid, which can penetrate into the walls of low-fired vessels. These escaping and rising gases spall off the weakened ceramic creating these eroded patches.

Arthur (2003, p. 516) notes that beer in Africa is "a crucially important foodstuff and associated with status and wealth activities, (but) few archaeological studies have attempted to identify beer production and consumption." All 63 of the Gamo beer vessels analyzed by Arthur had the characteristic interior spalling. The focus of his study, however, was the role that beer production and consumption played in the construction of political, social, and economic relationships. Beer consumption among the Gamo is restricted to wealthier households and thus the production and drinking of beer serves to maintain the strict social hierarchy of this society.

African societies such as the Gamo are not alone in stressing the important social, religious, political, and economic factors related to alcohol production and consumption. In Mesoamerica, alcohol plays a particularly important role at feasts (see Dietler

Arthur's Gamo Ethnoarchaeological Study

As prehistorians have become increasingly aware, it is essential to understand the life history of pottery if we are to make ever more specific inferences about human behavior from the ceramic data that we recover from archaeological context. This is not an easy task and we thus must draw upon all the tools available to understand how vessels are made, used, broken, recycled, and then finally deposited. What is more, because we continually want to squeeze ever more detailed information from prehistoric ceramics we must find ways to sharpen inferential tools at our disposal. We are very fortunate that even as we have entered the twenty-first century there are still people around the globe who still make pottery at the household level. One group, the Gamo of Ethiopia, have received a great deal of ethnoarchaeological attention over the past decade (Arthur 2002, 2003; Brandt 1996; Weedman 2006). I have already discussed John Arthur's contribution to pottery use-alteration, but his investigation of the Gamo pottery makers has become an instant classic in ceramic ethnoarchaeology (Arthur 2006).

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The Gamo of southern Ethiopia live in the mountains west of the Rift Valley. The Gamo grow and rely upon a number of domesticated crops including wheat, corn, barley and two indigenous domesticates, teff and enset. They live in small villages and three of them, Zuza, Guyla, and Etello, were the basis of Arthur's research. Zuza is located at a lower elevation (2,100 m) and Gula and Etello are found in the higher zone (2,600 m). The Gamo have strict rules of social hierarchy and caste membership is determined at birth and there is little social mobility. Although the Gamo are a single ethnic group of about 600,000 people, there is a great deal of cultural, social, and ecological variation both between and within communities. Arthur's study focused on how this diversity is reflected in pottery made in these communities.

Arthur spent 20 months among the Gamo and collected information on 1,058 vessels from 60 households within the three villages that represent all the castes and socioeconomic groups. Information for each vessel was recorded that included things like the age of the vessel, where it was purchased, and how it was used. In addition, he collected use-life information during his 20 month stay as well as in-depth interviews of potters. In short, Arthur conducted an excellent study among few remaining pottery makers that will serve as a treasure chest of information for ceramic archaeologists for years to come.

Arthur's focus on pottery throughout its life cycle has led to a number of noteworthy findings (see also Arthur 2002, 2003). This includes the relationship between socioeconomic status and pottery use (also discussed above) as well as how diet and environment influence the types of vessels made and purchased by the Gamo. Arthur's data also permitted him to provide important information on vessel use-life, which is a critical variable for the prehistorian trying to infer things like population, site function, and household wealth (Longacre 1985; Tani 1994). This is such an important variable that Arthur's contribution to this issue is critical. Finally, among Arthur's many findings is that vessels once broken are not simply deposited but rather can enter a number of reuse or recycling stages in their life history.

Sometimes ethnoarchaeological research does not impact prehistorians as it is not often clear how ethnographic data from a different region is applicable to questions raised by the archaeologists working with ancient ceramics from a very different region (see Skibo 2009). Although the work among the Gamo can be directly applied to some prehistoric groups in eastern Africa, the real contribution of Arthur's work is in demonstrating how inferences can or cannot be drawn between ceramics and a variety of behavioral variables. By employing the life history approach, Arthur illustrates the web of social, technical, and economic issues involved in the manufacture, use, breakage and deposition of ceramics that can be of use to ceramic archaeologists regardless of their region of interest. The value of this important work will be of use in archaeologists for years to come.

and Hayden 2001). Most communal activities among the Kalinga, such as weddings and funerals, involve the consumption of sugarcane wine, made locally and stored in large ceramic jars. The Kalinga also participate in a form of competitive feasting, seen throughout the Philippines ethnohistorically, in which the "primary goal was to achieve political domination through an ever-escalating cycle of feasting" (Junker 2001, p. 279). Alcohol consumption always plays a large role in such feasts.

Not all vessels suffer interior spalling from fermentation. The process requires that interior surfaces be permeable enough to permit the passage of at least some of the liquid contents into the walls. Very high-fired wares or those with impermeable surface treatments are highly resistant to this type of spalling. But such spalling would occur in most low-fired earthenwares of the type that dominated the archaeological record for millennia. Researchers that analyze these assemblages should seek interior spalling as it might be the only evidence that a group made a fermented beverage.

Recording Attritional Traces on Prehistoric Pottery

Just as in the recommendations for recording carbonization in Chap. 3, the analysis should start with whole or partially reconstructed vessels. That said, unlike carbonization, the analysis of attrition on sherds has proved useful for interpreting post-depositional formation processes and also the recycling of sherds as tools. So the attritional information on sherds can indeed be instructive. But most researchers will be interested in employing attritional traces to infer vessel use and this is best explored on larger pieces.

I have found that the best way to record attrition is to have a vessel outline template for each vessel class in the collection as described for recording carbonization in Chap. 3 (see Figs. 3.22 and 3.23 for examples). Two templates can be used for each vessel—one for the interior, the other for the exterior. The outlines of a sherd may also be drawn on these templates. As the researcher identifies patches or marks they are sketched on the templates. It is important to note the general shape, size, orientation, and location of the patches; diagnostic marks may be noted as well. These sketches represent the first pass through the collection. Ideally, attritional patterns will become evident that perhaps could be linked to vessel form or size. Once patterns of attrition and carbonization have been recognized, then individual vessels can be revisited for more detailed analysis, description, and perhaps photography.

In many collections, whole vessels are rare, and so use-alteration traces may also be recorded on sherds. As noted in Chap. 3, whole vessels in museum collections from earlier excavations can be inspected for use-alteration traces. Once these traces have been recorded—even on a few vessels—it is much easier to understand such traces when they occur on small fragments.

Accordingly, I recommend that use-alteration traces be recorded as batches of sherds are processed. This procedure not only informs on use-activities of the vessels, but also makes it possible, as the examples above demonstrate, to infer recycling of sherds for the manufacture and use of tools or to understand site or regional formation processes.

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Chapter 5
Residue

Mary Malainey

> *The field of organic residue analysis archaeology has witnessed spectacular developments in recent years, and there is now a well-developed understanding of where residues survive at archaeological sites and an appreciation of the major classes of biomarker likely to be encountered. (Evershed 2008, p. 915)*

Of the three use-alteration traces discussed in this book, the analysis of organic residue has received by far the most attention. There have been many applications, publications, research grants, and now even commercial labs performing the analysis. When I began the study of organic residues only a handful of researchers had attempted it with pottery (e.g., Condamin et al. 1976; Deal 1990; Deal and Silk 1989; Heron et al. 1991a, b; Hill and Evans 1989; Marchbanks 1989; Patrick et al. 1985; Rottländer 1990) with only moderate degrees of success. The many unanswered questions about the technique precluded it from becoming routine in ceramic analysis. How do organic residues survive in the depositional environment? Do organics in the soil migrate into buried pots and contaminate the sample? For cooking pots, how does heat alter the deposited residues? Which residues should be analyzed? Once residues are identified, are comparative collections available that would make accurate identifications possible? And finally, what are the best methods of extraction and analysis?

The Kalinga sample of used cooking pots provided a unique opportunity to answer some of these questions. Since the contents of the rice and vegetable/meat pots were known, I could test whether absorbed residues accurately reflect what had been boiled. At the time of the study, we did not know how residues would survive cooking fires and how accurately individual foods could be isolated in vessels that boiled multiple foods.

So, armed with a tremendous ethnographic collection and one high school chemistry class, I forged ahead. Thankfully, a fellow graduate student at the University of Arizona, Jeffrey Clark, had earned a B.S. in chemistry and also had worked for a

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time as a chemist. Jeff graciously volunteered his services and was instrumental to the success of our first at attempt at residue analysis.

At the time of the study it seemed that the greatest success had been in the investigation of lipids (Deal and Silk 1988; Marchbanks 1989; Rottländer 1990), which are naturally occurring molecules that include fats, waxes, and sterols. I focused on the fatty acids because they occur in different combinations and different proportions in all plants and animals, and the research thus far had suggested that they survive quite well in the depositional environment. Fatty acids have also been shown to travel into the vessel walls of low-fired pottery, where they become entombed and thus potentially protected from contamination. Thus, I chose to focus only on the fatty acids that had been absorbed into the vessel wall. Below I describe the strategy employed by Jeff and me and our results. In retrospect, I am surprised that we found anything useful in this analysis, as the techniques for extraction and analysis have improved dramatically since our study. In this chapter the study of Kalinga samples is described followed by a description of the analytical techniques that researchers may profitably employ to extract and identify lipids from pottery. The chapter concludes with several recent case studies that have successfully extracted, analyzed, and identified organic residues absorbed into the walls of low-fired pottery.

Kalinga Study

The strategy we employed took advantage of the fact that we knew exactly what had been cooked in the vessels. The problem was that at this time there was no library of fatty acid profiles to compare to the samples extracted from pottery, and so the first step was to prepare a control group that included an unused pot, the resin applied to the interior surfaces of the Kalinga pots rice, five types of commonly cooked Kalinga vegetables, and two types of meat. The second step involved removing organic residue from the interior of a sample of rice and vegetable/meat cooking pots. In the final step we extracted lipids from Kalinga "archaeological sherds" to assess the role that diagenesis has on lipids from the interior of the vessel walls. Fats were known to be resistant to breakdown but not without some transformation. The question we attempted to explore was how well the fatty acids were preserved in the walls of the sherds. In 1976, Longacre had excavated a midden from the community of Puapo and 10 of these sherds were analyzed.

To extract samples from the Kalinga pots we removed a 1-in. diameter sample using a coring tool and a high speed drill lubricated with a steady stream of distilled water. We removed the samples from the base of the pot, assuming that this would be the best location for the absorption and preservation of fatty acids (this turned out to be an incorrect assumption—see below). The exterior of the sherds was removed with a stainless steel spatula and a sample was then taken from what would have been the interior. The sherd powder was then mixed with 30 mL of Reagent Grade methanol and then placed on a magnetic stirrer/hot plate for 5 min heated to 50°C.

Approximately 5 mL aliquots were taken by pipette from the solution. The control samples were treated similarly except that the meat was cut into small pieces instead of ground up. Jeff and I then talked our way into the Mass Spectrometry Facility at the University of Arizona where they ran the samples using a combination of gas chromatography/mass spectrometry (GC/MS).

The sampling techniques have improved dramatically since our first attempts, but gas chromatography and mass spectrometry are still routinely used for isolating and then identifying components of the lipid sample. Despite the rudimentary techniques employed compared to today's standards, significant amounts of residue were recovered and identified by the GC/MS.

Fatty acids were found in all used pottery and in all Kalinga archaeological sherds. Clearly the cooking process deposited fatty acids into the porous vessel walls and they survived cooking temperatures. Nonetheless, many of the mono- and polyunsaturated fats seen in the tested raw foods were not identified in the used pots. For example, linoleic acid (18:2) was found in the greatest relative amounts in the raw rice but was not identified in the rice cooking pot residue. Linoleic acid is also referred to as octadecadienoic acid, which means it is composed of 18 carbon atoms and two double bonds. Similarly, alpha-linoleic acid (18:3) was identified in great amounts in some of the Kalinga vegetables but was not seen in the Kalinga pots. These acids are not only susceptible to breakdown, but because I sampled from the base of the pots it is possible that the organic residue was altered by normal cooking temperatures. Or perhaps these fatty acids simply may have become oxidized during the 1 year lag between their last cooking episode and when the samples were removed. Consequently, we did find fatty acids but there had been some breakdown from an unknown process. Because the cause and consequence of fatty acid diagenesis is critical to this analysis, we discuss it in detail below.

Even though I did not find exact matches between the raw foods and the pottery residues, I was able to make some general connections based upon the ratios of the three most common fatty acids, palmitic (16:0, hexadecanoic acid), stearic (18:0, octadecanoic acid), and oleic (18:1, octadecenoic acid). As Fig. 5.1 illustrates, the ratios of these fatty acids are a good way to roughly separate residues that come from meat and those that come from plants because meats generally have much higher levels of saturated fats.

The residues from the rice cooking pots and raw rice had very similar ratios of these three fatty acids (Fig. 5.2). But the vegetable/meat pots had wide-ranging ratios of palmitic, stearic, and oleic acids, which might be expected for a vessel employed to cook a variety of both plants and animals (Fig. 5.3). Similarly, the control samples (vegetables, pork, and chicken) had distinctive and varied ratios, but it was impossible to link specific meats or vegetables to what had been cooked in the vessels. Consequently, our techniques found fatty acids in the Kalinga pots, but it was difficult to identify specific residues and only very general conclusions could be drawn. For example, the rice and vegetable/meat pots had very distinctive and non-overlapping ratios of the three fatty acids, so one could conclude that different items had been cooked in them.

Beyond these general findings, little more could be concluded owing to the lack of recovery and identification of fatty acids. This could either be because we

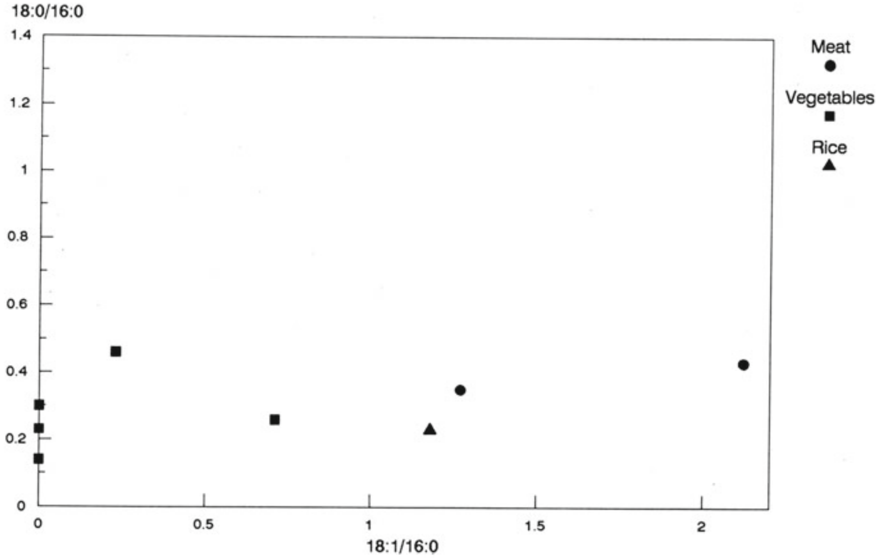

Fig. 5.1 Fatty acid ratios for meat, vegetables and rice (From Skibo 1992, p. 92)

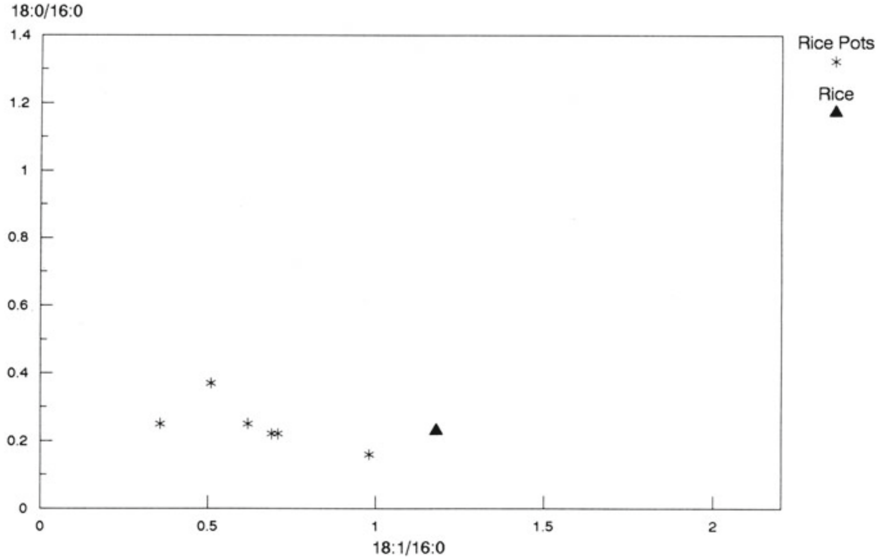

Fig. 5.2 Fatty acid ratios for rice and rice cooking pots (From Skibo 1992, p. 94)

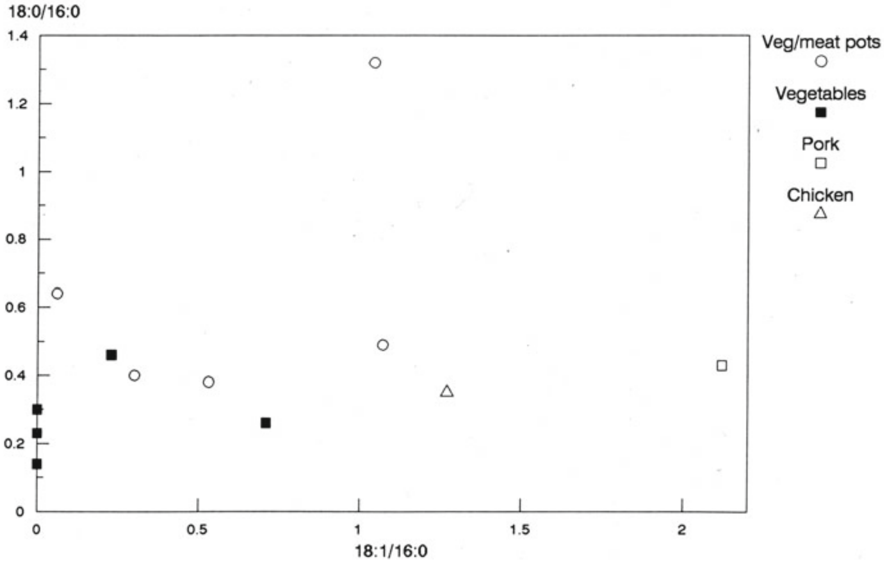

Fig. 5.3 Fatty acid rations for meat, vegetables and vegetable/meat pots (From Skibo 1992, p. 95)

took samples from the base of the pots (possibly degraded by heat), our extraction techniques were insufficient, or the fatty acids had been changed dramatically during the year between cooking and analysis.

The analysis of the fatty acids from the Kalinga sherds excavated from the midden demonstrated that they survive and that these vessels were once cooking pots, but there was evidence in the sample that some significant decomposition had taken place that would interfere with the comparison of ratios. The sherds had evidence of adipocere, the substance to which all less stable fatty acids are transformed; it is dominated by palmitic acid (16:0). The processes of decomposition are discussed in more detail below, but suffice it to say here that because of the dominance of palmitic acid in all sherds, it appeared that decomposition prevented specific identification of fatty acids in the samples.

In conclusion, the Kalinga residue study had a moderate degree of success. We demonstrated that fatty acids do survive cooking temperatures and that some general conclusions (meat or vegetable) could be drawn about what was cooked in the pots based on the ratio of palmitic, stearic, and oleic acids. Nonetheless, there were still a number of unanswered questions that would not permit archaeologists to routinely employ residue analysis. Although I believed at the time that fatty acid analysis with GC/MS was worth pursuing, I identified two general areas for further research: (1) developing a library of fatty acids for various plants and animals of interest in archaeology, and (2) understanding in greater detail the breakdown of fatty acids in cooking and in the depositional environment.

British Invasion

After my analysis was complete and my book in press, I read a short paper by Evershed, Heron, and Goad (1990). It was just four pages long but it was enough to convince me to never personally try this process again. Although Jeff Clark was very helpful and I could not have started the process without him, we were held back because we did not have unlimited access to a GC/MS, and our combined knowledge of lipid chemistry was meager. It was at this point that I understood the wisdom of the British tradition of "archaeometry," where, in this case, chemists and entire laboratories are dedicated to the analysis of organic residues recovered archaeologically. Charming a graduate assistant at the University of Arizona to let us use the GC/MS late at night was no match for a dedicated lab with post-docs working through the night resolving problems of extraction and analysis at rates that seemed to be, when compared to our study, close to light speed.

It felt like we were the archaeological equivalent of the Everly Brothers, the very successful music duo of the late 1950s and early 1960s who were on top of the music world until the day that John Lennon, Paul McCartney, George Harrison, and Ringo Starr landed in New York City. Although the Everly Brothers have their place in music history, they never again had a big hit after the British invasion of pop music, which began with the Beatles in 1964. Organic residue analysis had its own British invasion in the early 1990s in the form of Carl Heron, Richard Evershed, and others. I don't know if the Everly Brothers imagined that they would never again have a hit song after the Beatles arrived, but I certainly realized that my contribution to this area would not be in the chemistry lab trying to figure out if, for example, the lipid in my sample came from the contents of the prehistoric pottery or from the stop-cock grease on my glassware. Evershed, Heron, and others soon began to resolve the analytical problems that stopped me in my tracks as they successfully applied their techniques to prehistoric material (e.g., Charters et al. 1993; Evershed 1993; Evershed et al. 1990, 1992; Heron and Evershed 1993; Heron et al. 1991a).

By the late 1990s, Mary Malainey's work with fatty acids and pottery appeared. It had special relevance to my interests because she created a large lipid library of North American plants and animals (Malainey et al. 1999a). In addition, she made significant progress in understanding lipid decomposition from cooking and the effects of various noncultural formation processes over long periods of time (Malainey et al. 1999b), and so I teamed up with her for a short study on the origins of pottery on Grand Island (see below). In addition, I have asked her to co-author this chapter so that the reader will get an up-to-date description of the proper methods of extraction and organic residue analysis from pottery. The discussion of the techniques below has the level of detail that will be beyond what is necessary for most archaeologists who simply want to send away their sherds to a lab and find out what was cooked in them. But there will be some who have a background in chemistry and archaeology and have access to a lab who may want to personally conduct this research. The discussion below is designed for the latter. More casual readers may simply skim this the detailed description and move onto the case studies.

Approaches to Lipid Residue Analysis

A variety of lipid components have been used by archaeologists to identify the source of residues including fatty acids, triacylglycerols, sterols, waxes, and terpenes. The most commonly employed instrumental techniques involve component separation with gas chromatography: gas chromatography with a flame ionization detector (GC), gas chromatography with mass spectrometry (GC/MS) and recently, gas chromatography-combustion-isotope-ratio analysis (GC-C-IRMS). Of all the spectroscopic techniques employed in the analysis of archaeological pottery residues, analysts using infrared and Raman spectroscopy have garnered the most success. The following discussion of sample selection applies to all analytical techniques. A brief overview of archaeological lipid residue analysis using gas chromatography and related techniques is presented (see also Barnard et al. 2007a). See Malainey (2011a) for a more detailed description of archaeological lipid residues and the instruments used in their analysis.

Sample Selection

When selecting sherds for residue analysis, it is important to remember that the portion of a vessel most likely to retain lipids depends on its function. A sherd from the lower body could be selected to investigate residues absorbed into the walls of an unglazed earthenware vessel used for liquid storage. Other factors must be considered when selecting samples from cooking pots, in particular, the location of the heat source and the location of the lipids. Portions of the vessel positioned closest to the fire should not be sampled because residues have undergone the highest degree of thermal degradation. Since water and lipids do not mix and the density of lipids is less than water, the upper portion of boiling vessels should be targeted. This typically includes the lower portion of the shoulder, neck and lower portion of the rim of globular cooking vessels and corresponds to the maximum functional capacity of the pots. In some cases, the region is indicated by a “scum line” of carbonized residues on the vessel interior. Charters et al. (1993) reported that the concentration of lipids in rimsherds could be 10 times higher than body sherds and 30 times higher than the concentration in sherds from the base of the vessel. Malainey (2007a) found that when oven storage is used to accelerate oxidative decomposition of fatty acids, initial levels of C18:1 isomers are highest and rate of decomposition is slowest in residues recovered from the upper portion of vessels compared to those from the middle or lower portions. By selecting sherds from the upper portion of boiling vessels, the highest amount of the best preserved lipids will be recovered.

Research has shown that contamination of archaeological residues by soil lipids is negligible. Condamin et al. (1976) found that the concentration of fatty acids extracted from an amphora interior was eight times higher than from its exterior; the concentration of fatty acids in the soil in contact with the vessel wall was very low compared to those found inside the vessel wall. The researchers (1976) concluded the fatty acids in the vessel fabric originated from its former contents and the degree of contamination from the surroundings was negligible. Heron et al. (1991) compared the lipids in archaeological pottery to lipids in soil adhering to the sherds and to control soil samples. The sherds typically yielded more lipids per gram (60–4800 μg/g) than the adhering soil (30–510 μg/g); more importantly, the composition of lipids in the adhering soil resembled that of the control soil, not the sherds (Heron et al. 1991). Heron et al. (1991) argued that negligible migration of soil lipids occurs during burial and attributed the absence of contamination to the hydrophobic nature of the lipid molecules.

The possibility of contamination or modification of the residue through archaeological processing is of wider concern. Improper handling of sherds could result in the introduction of fingerprint oils (Evershed 1993) or other contaminants. Ideally archaeological samples for lipid residue analysis should be selected in the field. To prevent the introduction of contaminants, samples should only be handled with clean tools and gloved hands. It is preferable to examine unwashed artifacts, but it is possible to extract lipid residues from samples washed only in clean water. However, washing the sherd with water may lead to the loss of soluble residue components and can alter stable isotope values of residues (Morton 1989; Oudemans and Boon 1991); the addition of detergents, including baking soda, will cause some lipid components to dissolve. Visible residues may be lost if a brush is used to remove soil.

Phthalates, which are industrial plasticizers, are commonly detected in archaeological residues (Deal and Silk 1988; Oudemans and Boon 1991, p. 223). Possible sources of these chemicals include the plastic bags in which artifacts are stored after excavation and plastic pipette tips used to handle the residue extract in the laboratory. These contamination sources can be avoided through the use of paper bags or by wrapping samples set aside for residue analysis in lint-free tissue (such as KimWipes®) or aluminum foil before placing them in plastic bags. Pipetters and microdispensers fitted with glass tips should be used to transfer the extracted lipid residue in the lab.

Sample Processing Techniques

Lipid Extraction

The glassware and equipment used for the processing of lipid residues is commonly found in organic chemistry and food science laboratories but archaeological samples yield only trace amounts of degraded lipids that can easily be contaminated by modern fats and oils. For this reason, we strongly recommend that an experienced analyst using high grade solvents and dedicated equipment conduct the processing and analysis of archaeological residues. Lipid extraction involves organic solvents and must be conducted in a fume hood.

Prior to crushing, the surfaces of the sherd are ground off and discarded. Lipids are extracted by agitating the powdered sample from the core of the sherd with non-polar solvents, usually a mixture of chloroform and methanol, for several minutes in an ultrasonic bath (Evershed et al. 1990). The solution containing the extract is then either centrifuged or filtered into a separatory funnel (to remove solids) and may be washed to remove water-soluble contaminants. The chloroform layer, containing lipids, is isolated and the solvent removed with gentle heat using a rotary evaporator. This process yields the total lipid extract (TLE) because it contains all lipid components; it is re-dissolved in the extraction solvents and stored in a −20°C freezer under nitrogen to prevent decomposition. Prior to analysis with gas chromatography, fatty acid methyl ester and/or trimethylsilyl derivatives are usually prepared from a portion of the TLE; Gerhardt et al. (1990) are a noteworthy exception (see below).

Residues subjected to spectroscopic analyses do not require derivitization. Analysts at the PaleoResearch Institute use FT-IR spectroscopy to analyze the total lipid extracts of pottery samples without derivatization. Shillito et al. (2009) use FT-IR to screen for the presence of organic residues without prior extraction. The screening is performed on a small amount of ground pottery that has been mixed with dried potassium bromide (KBr) powder and pressed into a disc. Pottery samples found to contain organic residues were then submitted for analysis with GC/MS.

Preparation of Derivatives

Fatty acid methyl esters (FAMES) have lower boiling points than fatty acids and are less likely to decompose during analysis with gas chromatography. Fatty acid methyl esters can be prepared by treating the TLE with methanol that has been combined with an acid, such as hydrochloric or sulfuric (Malainey et al. 1999c), or boron trifluoride and methanol combined with a strong base, such as sodium hydroxide (Condamin et al. 1976; Deal 1990; Deal and Silk 1988; Heron 1989; Patrick et al. 1985). After a period of heating at 68°C, the FAMES are recovered, dried and dissolved in a volatile solvent such as iso-octane.

Trimethylsilyl (TMS) derivatives are prepared by adding an excess of N,O-bis (trimethylsilyl)-trifluoroacetamide (BSTFA) to the TLE (Evershed et al. 1990). The mixture is heated at 70°C for about 30 min and the resulting TMS-derivatives can be injected directly onto the GC column or dried and re-dissolved in hexane.

Gas Chromatography for the Analysis of Archaeological Lipid Residues

In general, analytical techniques work best on pure substances because complex mixtures yield results that are difficult to interpret. Archaeological lipid residues are mixtures of several fatty acids, sterols, mono-, di- and triacylglycerols, terpenoids, decomposition products, and various contaminants. Gas chromatography (GC) is used to separate the residue sample into its individual constituents to facilitate their identification. The instrument is basically a sophisticated oven into which a long, thin flexible fused silica column is installed. An angel hair pasta straw would have a much larger diameter than a GC column. The interior of the column is coated with a particular chemical, referred to as the stationary phase, which assists the separation process. Helium or hydrogen gas flowing through the column conveys sample constituents to the detector (Fig. 5.# Picture of a GC/MS).

Analysis involves injecting a solution containing derivatives of the total lipid extract onto the column at a relatively low temperature so that the solvent boils off first and is carried through the column, leaving behind the lipid components. As the oven temperature is increased, sample constituents with progressively higher boiling points and molecular weights are carried through the column. Interactions with the stationary phase can separate components with similar boiling points. Those with a higher affinity for the stationary phase pass through more slowly than those with a lower affinity. Think of the speed difference of someone slogging through mud versus someone walking on a dry path.

When separated components undergo combustion in a flame ionization detector (FID) as they emerge from the column, the analysis is called gas chromatography (GC). An FID only records the time since injection (retention time) and the relative amount of each separated component. Component identification is based on the retention times of standards run in the same operating conditions as the samples. If a large batch of samples is analyzed, standards should be run at the beginning, end and periodically in between to track any variations in retention times.

If components separated by gas chromatography are directed into a mass spectrometer, the analysis is called GC/MS. To put it simply, mass spectrometers are instruments that break apart molecules then count up and weigh the resulting pieces. Because all molecules of a pure substance are identical, they fracture in a fairly standard way. The distribution of pieces, or fragmentation pattern, of a separated component is compared to those in the National Institute of Standards and Technology (NIST) mass spectral database and/or other reference materials. There are over 200,000 unique compounds in the NIST database, some of which have similar fragmentation patterns. Identifications are based on the analyst's knowledge of the chemistry of the sample and the strength of the match between its fragmentation pattern and those of reference compounds.

The maximum temperature used to analyze FAMES with routine gas chromatography is about 250°C. This is well below what is required to analyze compounds with high boiling points and high molecular masses because they must enter the GC column in gaseous phase. Maximum temperatures of about 350°C and special GC columns are required for the analysis of lipids that share these properties, such as sterols, triacylglycerols, and waxes. This high temperature (HT) approach can be used to analyze samples using a GC either equipped with a FID (HT-GC) or one attached to a mass spectrometer (HT-GC/MS).

Gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) is used to perform compound-specific stable isotope analyses. After separation by gas chromatography, an isolated component undergoes combustion (e.g., at 850°C with copper (II) oxide) and the resulting carbon dioxide passes into the isotope ratio mass spectrometer. For archaeological lipid residues, ratios of the stable isotopes of carbon are typically targeted. The $\delta^{13}C$ of lipids in C_3 plants native to temperate zones is significantly more negative than those from C_4 plants, which are tropical grasses such as maize, millet, sugar cane, and sorghum. Smaller differences in stable carbon isotope values result from variations in how animals metabolize food.

The Problem of Diagenesis

Lipid residue analysts employ two different approaches to deal with diagensis: (1) they identify resilient sample components or characteristics that are unaltered by the effects of time or temperature, and (2) they determine diagenetic effects on composition and/or identify products of decomposition. The first requires the identification of specific molecules or properties of molecules that appear in both fresh, uncooked foods and highly degraded archaeological residues. The second approach involves modeling the effects of lipid decomposition through cooking experiments, exposure to conditions that simulate aging over archaeological time and/or the burial environment (see also Eerkens (2007)).

Identifications Based on Resilient Compounds or Characteristics

R.P. Evershed and his colleagues have championed residue identification through the application of the "archaeological biomarker concept." Biomarkers are molecules associated with a narrow range of substances so their presence enables a residue to be identified with a high degree of precision. Evershed (2008) notes that structures or distributions of molecules that appear in fresh substances and retained in decomposed residues can serve as "chemical fingerprints." Both specific compounds and characteristic distributions of lipids have been proposed as biomarkers for archaeological lipid residues.

Copley et al. (2001) used unusually high abundances of C12:0 and C14:0 and low levels of C16:0 and C18:0 to identify the fruit of either date or dom palms in ancient vessel residues. The fatty acids of palm fruit and the residue from one vessel both had C12:0 levels approaching 50% and C14:0 levels between 25% and 30%; levels of C16:0 and C18:0 were in the range of 20% and 5% or less, respectively (Copley et al. 2001; Fig. 3). Relatively higher levels of C18:0 in the residue of a second vessel indicated a combination of palm fruit and animal fat (Copley et al. 2001).

Evershed et al. (1997) noted several differences in the fatty acid compositions of nonruminant and ruminant animals. Residues from pigs, which are nonruminants, contained only one C18:1 isomer, Z-9-octadecanoic acid. The fat of ruminants, such as sheep and cattle, contained a mixture of C18:1 isomers with double bonds located at one of six different positions. In addition, a higher abundance of C15:0, C17:0, and C19:0 and branched-chain fatty acids were observed in the residues of ruminants.

The presence and distribution of certain lipid components provide information about the source of a residue. The HT-GC profiles of typical degraded animal fats are characterized by a range of odd and even numbered saturated and unsaturated fatty acids, with C16:0 and C18:0 forming the major peaks, monoacylglycerols with 16 and 18 acyl carbon atoms, diacylglycerols with 32, 34 and 36 acyl carbons, and triacylglycerols with 44–54 acyl carbon atoms; triacylglycerols in dairy fats have 40–54 acyl carbon atoms (Dudd and Evershed 1999). Beeswax can be identified on the basis of the distribution of n-alkanes, ranging from 23 to 33 carbon atoms in length, and long chain palmitic acid wax esters (Evershed et al. 2001).

Evershed et al. (1992, p. 199) suggested that "sterols are amongst the most important of the minor components of fats and oils used diagnostically in classifying the lipid extracts of potsherds." Although they are present in only small amounts, these molecules could be used to distinguish animal-derived residues, which contain cholesterol, from plant-derived residues, indicated by stigmasterol, β-sitosterol, and campesterol (Evershed 1993).

Gerhardt et al. (1990) demonstrated the potential utility of biomarkers in their examination of residues from intact Corinthian figure vases. Residues were extracted by washing the interior with non-polar solvents were then analyzed without first making either FAMES or TMS- derivatives. Gerhardt et al. (1990) reported that one type of vase contained hydrocarbons with between 14 and 27 carbons characteristic of flowers and other waxy plant parts. An oleoresin of pine, cypress, or juniper was also found, indicating the presence of perfumed oil in these vases. Cedrol and cedrene, found in cedarwood oil, were the major components of another residue.

Identifications Based on Decomposition Products

The fatty acid composition of fresh, uncooked plants and animals provides important baseline information, but criteria able to discriminate fresh foods may not be suitable for identifying highly degraded archaeological residues (Loy 1994; Marchbanks 1989; Skibo 1992). High levels of unsaturated fatty acids, those with at least one double bond between adjacent carbon atoms, occur in fresh fish and plants (Malainey et al. 1999a). Polyunsaturated fatty acids with three or more double bonds decompose the fastest, followed by those with two double bonds; monounsaturated fatty acids with one double bond decompose slowly (Solomons 1980; Frankel 1991; deMan 1992). Saturated fatty acids, sterols, or waxes are quite stable. Fatty acid compositions of cooking residues change over time, but these alterations can be modeled (Malainey 2007). It is possible to characterize archaeological residues on the basis of fatty acid composition if the effects of cooking and decomposition over long periods of time are understood. While absolute identifications are not possible, a wide-range of archaeological residues can be rapidly categorized.

Monosaturated C18:1 fatty acids have proven valuable for characterizing ancient residues because they decompose slowly (deMan 1992). Patrick et al. (1985) reported no polyunsaturated fatty acids were preserved in the brown flaky residue found on the inside of potsherds from South Africa but C18:1 isomers were present. They found the ratio of two 18:1 fatty acid isomers, oleic and vaccenic acid, in seal tissue was unaltered by boiling and extended periods of oven storage. The oleic acid to vaccenic acid ratio supported the conclusion that residue on pottery from South Africa was related to the preparation of seal (Patrick et al. 1985).

Relative amounts of medium chain fatty acids (the sum of C12:0, C14:0 and C15:0), C18:0 and C18:1 isomers in the sample are also useful for distinguishing degraded cooking residues (Malainey 1997; Malainey et al. 1999b). To start, the fatty acid compositions of more than 130 plants and animals used as food prior to European contact were determined using gas chromatography (Malainey 1997; Malainey et al. 1999a). Hierarchical cluster and principal component analyses showed that differences in the fatty acid composition generally corresponded to divisions that exist in nature. The effects of cooking and degradation over time on fatty acid compositions were then examined by cooking samples of meats, fish and plants, alone or combined, in replica vessels over an open fire (Malainey 1997; Malainey et al. 1999b). Changes in the composition were determined after a short term at room temperature and after 30 days at 75°C to simulate the processes of long-term decomposition. The relative percentages were calculated on the basis of the 10 fatty acids [C12:0, C14:0, C15:0, C16:0, C16:1, C17:0, C18:0, two C18:1 isomers (C18:1ω9 and C18:1ω11) and C18:2] that are either stable or degrade slowly and regularly appeared in archaeological residues.

As outlined by Malainey (2007a), an elevated level of C18:0 is associated with the presence of large herbivore products, javalina, and tropical seed oils. The relative amount of C18:1 isomers in the residue indicates the fat content of the material of origin. Medium chain (and very long chain) saturated fatty acids facilitate the discrimination between foods of plant origin and those of animal origin. The relative percentage of fatty acids can be used to identify reference foods that produce degraded residues with compositions similar to the archaeological sample.

Certain degradation products that form when saturated and unsaturated fatty acids are heated to high temperatures may provide insight into the origin of archaeological residues. Evershed (2008) suggests that a molecule formed by the thermal alteration or oxidative degradation of a specific biomarker can also serve as a biomarker if the chemical pathway connecting it to the source material has been established.

Researchers have found that different stable structures form when plant oils and animal-based fuels are burned in ceramic lamps. Copley et al. (2005) identified specific dihydroxy fatty acids that could serve as highly diagnostic biomarkers for the original oils in the lamps. They reported that the presence of different dihydroxy fatty acids could confirm the use of castor oil, radish oil, and animal fat in lamps.

Raven et al. (1997) reported that stable products form when the fatty acids (or triacylglycerols) found in animals are heated to temperatures in excess of 300°C. The reaction, called ketonic decarboxylation, results in the formation of mid-chain ketones with 31, 33 and 35 carbons. The ratio of the three ketones is 1:2:1, which is different from the ratio in higher plant waxes (Raven et al. 1997).

Polyunsaturated fatty acids (PUFA) are common in marine animals but their multiple double bonds cause them to degrade rapidly when exposed to heat, light and/or oxygen. Because PUFA are so unstable, researchers have proposed other means of identifying their presence in archaeological residues. Hansel et al. (2004) reported that PUFA with conjugated double bonds (i.e., when the double bonds alternate with single bonds) undergo reactions that cause the formation of ω-(o-alkylphenyl) alkanoic acids with 16–20 carbon atoms when heated to temperatures in excess of 250°C. Evershed et al. (2008) showed that different ω-(o-alkylphenyl) alkanoic acids form from thermal degradation of unsaturated fatty acids with one, two and three double bonds. In order to establish a marine origin, ω-(o-alkylphenyl) alkanoic acids with 18, 20 and possible 22 carbon atoms as well as isoprenoid fatty acids should be present in the residue (Evershed et al. 2008).

Compound-Specific Stable Isotope Analysis

Compound-specific stable isotope analysis using gas chromatography-combustion-isotope ratio mass spectrometry, GC-C-IRMS, has proven valuable for the identification of archaeological animal and plant residues. Stable carbon isotope ratio analysis can be performed on individual fatty acids in an archaeological residue, such as C16:0 and C18:0, or a biomarker. As outlined below, this approach has been effectively used in the United Kingdom to discriminate animal residues arising from porcine sources (pigs) and those arising from ruminants, such as cattle. An example of how GC-C-IRMS has been used in North America to identify maize residues in pottery is discussed below.

Evershed et al. (1997) used GC-C-IRMS analysis of the FAMEs of C16:0 and C18:0 to demonstrate differences in the functions of Neolithic Grooved Ware vessels dated to about 4500 BP. The stable carbon isotope values ($\delta^{13}C$) on C16:0 and C18:0 in residues from vessels interpreted as “dripping dishes” were less negative than residues from vessels interpreted as lamps. Furthermore, the fatty acid displaying the higher degree of ^{13}C enrichment also differed; C16:0 was enriched relative to C18:0 in the dripping dishes and the reverse is observed in the lamp (Evershed et al. 1997). Differences in stable carbon isotope values observed in archaeological residues correspond to those in reference porcine (pig) and cattle fats and showed the dripping dishes were used to catch porcine fat and that ruminant fat was burned in the lamps (Evershed et al. 1997). Later, Evershed et al. (2001) used the same approach to analyze residues from the Late Saxon/Medieval site of West Cotton. A plot of $\delta^{13}C$ of C16:0 against $\delta^{13}C$ of C18:0 clearly separated the fat of sheep and cows from the fat of pigs and horses; the $\delta^{13}C$ values of sheep and cows milk overlapped as did the $\delta^{13}C$ of fat of chickens and geese.

Mukherjee et al. (2008) used compound-specific isotope analysis to examine absorbed and surface residues from Grooved Ware sherds from sites in the British Isles. Stable carbon isotope values of C16:0 and C18:0 showed that 20 of these were predominantly porcine fats while other vessels contained dairy products, ruminant carcass and dairy products or mixtures of ruminant and porcine products. The occurrence of porcine fats was higher in vessel residues from ceremonial sites (40%) than in vessel residues from domestic sites (4%) (Mukherjee et al. 2008).

Infrared and Raman Spectroscopy

Spectroscopic techniques can be used to make unambiguous identifications of pure substances. The size and position of peaks of the sample form a chemical signature that can be matched to reference material. In mixed samples, the techniques provide a means of verifying the presence of certain functional groups or types of bonds.

IR and Raman spectroscopy detects the presence of specific groupings of atoms in the sample through the absorbance of IR light of a specific wavelength. While it has been recommended as a screening tool for the presence of organic residues for decades (Davies and Pollard 1988; Heron 1989; Shillito et al. 2009), infrared and Raman spectroscopy are now being employed for the identification of archaeological lipid residues. Regert (2007) suggests IR can be used to detect a variety of substances including pistacia and pine resins, birch bark tar, beeswax, copal and frankincense. Edwards et al. (1997) non-destructively examined the composition of organic resins adhering to the lids and lips of burial jars from a site in Vietnam and compared the composition to North American resin samples with FT-Raman spectroscopy; however, results from the destructive analysis of residues with GC/MS facilitated the establishment of the non-destructive FT-Raman database. FT-IR analyses of lipid extracts from archaeological pottery are performed at the PaleoResearch Institute; identifications are made by matching the wave number, and to a degree, amplitude of the infrared absorbance, of the sample with those of reference materials.

Case Study: Origins of Pottery in the Upper Great Lakes

I have a longstanding interest in the initial appearance of pottery. On Grand Island and the entire south shore of Lake Superior, pottery production and use appear quite late compared to regions not far south. The Early Woodland Period in the Eastern United States, by definition, is characterized by the appearance of pottery (circa 1000 BC). Using this type of classification Grand Island does not have an Early Woodland because the first evidence thus far for pottery is during the first centuries A.D., which is the Middle Woodland Period in the local chronology.

This raises two interesting questions related to pottery function. Why did pottery making appear so late given that the Grand Islanders certainly had knowledge of this technology for generations, as it was being made less than 50 miles away? From the archaeological record alone it appears that the people of Grand Island and the general region continued until contact with a hunter-gatherer life-style and thus were never part of the Woodland-like adaption that included the cultivation of plants and eventually domesticates. Given that there seems to be a good deal of continuity in the hunter-gatherer lifestyle throughout what is referred to as the Woodland Period, a related question is, Why did these people adopt pottery at all? After all, pottery is a technology that involves some investment. If the current technology was performing adequately, what changed in food processing, social networks, or other factors that prompted the Grand Islanders to start making pottery? In other words, what changed in the performance matrix so that the Grand Island women began to make pottery? The first step to answering these questions is to explore what was being processed in the early Grand Island vessels (see Skibo et al. (2009) for a complete discussion).

To put this particular case study in perspective, we must first understand something about the Late Archaic in the region. Grand Island is the location of the largest known Late Archaic sites in the region (Anderton 2004; Benchley et al. 1988; Drake et al. 2009; Skibo et al. 2009). Lake Superior during this period was eight meters higher, creating the characteristic Nippissing Ridges, which are the remnants of the beaches during this high water phase. Late Archaic sites are commonly found on these ridges that likely represent seasonal campsites on the shoreline so as to take advantage of spawning fish in the nearby shallows or harvest the berries, and ripening nuts and other foods in the late summer and early fall. What is unique about Late Archaic sites on Grand Island is the great quantity of fire-cracked-rock (FCR): it is often the most common artifact, and the surfaces of these sites are a virtual pavement of FCR (Benchley et al. 1988; Skibo et al. 2009). FCR appears at sites in the subsequent Woodland Periods and for that matter at any sites in the region, but it is not the most common artifact, suggesting that there was an important shift in activities that use fire in food processing. We proposed that the greater quantity of FCR at Late Archaic sites was the result of indirect heating with hot rocks in watertight baskets or other containers—commonly known as stone-boiling. Quenching hot rocks in water, we suggested, would cause the rocks to fracture because of thermal shock. Subsequent experiments (Drapalik et al. 2010) have demonstrated that stone boiling does cause thermal cracking and the production of FCR. If the inhabitants of Grand Island during the Late Archaic were stone boiling and thus creating an abundance of FCR, then it would be helpful to determine what was being boiled in these containers. Because water-born residues have been known to penetrate the microcracks in stone during indirect heating (Quigg et al. 2001), we tested FCR for the presence of fatty acids. A first step in understanding the transition to pottery is to explore the cooking technology in the pre-pottery stage and then to determine what was being processed in the earliest pots.

Six sherds and three fire-cracked rocks were analyzed. The artifacts come from two shoreline sites on Grand Island's Murray Bay. The FCR (quartzite, basalt, rhyolite) came from a dated feature at a Late Archaic site and the sherds came from two nearby Woodland sites. Samples were removed from the artifacts and the fatty acid extracts were analyzed by Malainey using the strategy outlined above.

Residues occurred in the sherds and the FCR. Evidence of nut oils were found in both the sherds and FCR. The presence of plant sterols, very high levels of C18:1 isomers, low levels of C18:0, and only traces of triacylglycerols in these residues are consistent with their identification as nut oils. Such high nut oil content and the lack of fats from other plants and animals (except in trace amounts in three samples) suggest that these pots were used mainly in nut oil rendering as was the FCR (see Skibo et al. 2009 for a complete discussion of GC/MS results). This suggests that nut (probably acorn and hazelnut) processing was also done with both indirect

Table 5.1 A comparison of the performance characteristics between direct heating (vessel placed on fire) and indirect heating (hot stones placed in container) for nut oil processing

Performance characteristic	Direct heating	Indirect heating
Heating effectiveness	+	+
Expediency	−	+
Cooking effectiveness (nut oil rendering)	+	−
Fuel efficiency	+	−
Ease of use (monitoring and temperature control)	+	−
Social performance	?	?

(stone boiling) and direct heating (in pottery). Evidence for nut oil rendering is not a surprise because there is both archaeological and ethnographic evidence for nut exploitation in the Upper Great Lakes going back thousands of years (Ball 1993; Densmore 1928, 1979, pp. 39–40; Dunham 2009; Yarnell 1964).

The key to understanding the origins of pottery on Grand Island is to determine what was being processed in the early vessels and in the technology for boiling foods that preceded pottery. The presence of nut oil rendering with both direct (ceramic vessel) and indirect (stone-boiling) heating on Grand Island provides us with crucial information for beginning to infer this important technological change. Using the performance-based approach, as described in Chap. 2, we can begin to understand why pottery manufacture and use appeared so late and why the transition to pottery took place around AD 1.

The performance matrix (see Table 5.1) provides a comparison between direct and indirect heating for the processing of nut oil.

Our experiments (Drapalik et al. 2010) have shown that indirect heating with hot rocks is a very effective way to bring water to boil—likely just as effective as direct heating. The only performance advantage for indirect heating is expediency, which is the amount of effort it would take to prepare a container for nut oil rendering. The advantage in this case goes to indirect heating, as one can assume that the hunter-gatherers of this region would have watertight containers made of wood, birch bark, or hide that they would also use for other functions. Consequently, heating water for nut oil rendering would be a very expedient process. Suitable rocks are readily available and could be heated in a camp fire. Nut oil rendering could take place without requiring any new technology.

Referring to Table 5.1 again, we can also begin to understand why the hunter-gatherers of Grand Island could have made the transition to pottery for nut oil rendering. Direct heating in ceramic vessels for nut oil rendering scores higher in cooking effectiveness, ease of use, and fuel efficiency. In this case it is the adoption, not the invention, of pottery that requires explanation. As noted above, the people of Grand Island knew about pottery technology but choose not to adopt it. It appears, therefore, that expediency and perhaps some social performance characteristics were weighted more heavily for hundreds of years before the decision was made to begin to use pottery.

Cooking effectiveness in this case refers to how well the vessels perform for nut oil rendering. In this activity, either with direct or indirect heating, the nuts are heated and the fats rise to the surface of the water where they can be skimmed off and preserved. Hard boiling of water is not ideal for rendering fat from bones or nuts because the roiling surface prevents the fats from coming to surface (Reid 1989, 1990). Direct heating in ceramic vessels is far more effective for this process because the temperature can be controlled and the water can be heated without violent roiling of the water, as occurs in hot rock boiling. It is easy to maintain a simmering temperature in a ceramic vessel but this is much more difficult with indirect heating. Another critical component is the amount of nut oil that would be lost during the process of adding and removing rocks during indirect heating.

Another component of cooking effectiveness is the amount of fat that can be rendered by direct and indirect heating. Although this is something that should be tested experimentally, I predict that more oil could be rendered with direct heating. The placing and removing of stones from the container would result in the loss of some nut oil. The fact that we find fats on the FCR suggests that this technique results in the loss of the vessel's precious contents. One would think that processing in a ceramic vessel would result in minimal loss of the contents once pore spaces were filled.

Frink and Harry (2008) note that direct heating takes less fuel than stone boiling. Although this would not have been such a pressing problem for prehistoric Grand Islanders as it was for the Thule of the Arctic, the collection of firewood is a constant concern for any hunter-gatherer. Based on the number and size of sites, the population of Grand Island seems greater during the Woodland Period, which could have put some stress on available firewood.

Ease of use refers to the fact that rendering in ceramic pots would have required less monitoring than indirect heating and also would have permitted a closer control of temperature. A ceramic pot can be put on a fire, nut meal could be added to the water, and with just a small amount of monitoring the oils could rise to the surface where they could be skimmed off. Indirect heating with rocks, however, is a more active and engaged process that also creates spikes in water temperature, which is not ideal for rendering of nut oil. In terms of ease of use, ceramic vessels score far higher than indirect heating.

What role did social performance play in this transition? Based on ethnographic and ethnoarchaeological research, one could predict that it must have played a role in the transition to pottery. It is fascinating that pottery making and using was taking place for generations very close to Grand Island. Sassaman (2010) has explored the many social mechanisms at work during this period throughout the Eastern United States and I cannot rule out the possibility that social performance was important to this transition to pottery. I do not have enough evidence at this point to explore the importance of social performance characteristics, but it is worth pursuing. I would recommend an expansion of the functional analysis done with the Grand Island pottery to include vessels made by a number of nearby potters. The analysis should include not only an exploration of vessel technofunction but also an effort to determine the location of manufacture. This information, coupled with a study of design variability, would lay the foundation for a more complete analysis of function that would include social performance.

Case Study: Late Prehistoric Pottery Function from Western Canada

Malainey (1997; Malainey et al. 2001) used gas chromatography to study more than 200 lipid residues extracted from Late Precontact period Aboriginal pottery from 18 sites in Western Canada. Sherds from unique vessels were selected from sites located on the open grasslands, the transition zone between the plains and parkland, the parkland proper, and the southern boreal forest to test hypothesized settlement and subsistence strategies. Identification criteria developed from the decomposition patterns of experimental residues were applied to archaeological vessel residues (Malainey et al. 1999b, c).

Residues were analyzed as fatty acid methyl esters and relative percentage compositions were calculated on the basis of ten fatty acids that regularly appeared in ancient residues (Malainey et al. 1999c). Almost 85% of the residues from grassland sites had very high levels of C18:0 and were identified as large herbivore products alone or combined with plants. About 12% had elevated levels of medium-chain saturated fatty acids indicating they were only used for the preparation of plants; there was little evidence of medium fat content foods, such as fish or corn. The dominance of large herbivore products decreased marginally in the residues from transition zone sites. They occurred less frequently in residues from parkland sites and were not detected in the 31 residues from southern boreal forest sites. This residue distribution was mirrored in the faunal remains and tool assemblages and supported the hypothesis that mobile hunter-gatherers of the North Plains wintered on the grasslands, close to large stable herds of bison. While eighteenth and early nineteenth century accounts from European traders and travelers indicate that the majority of winter camps and bison herds were in the grasslands, archaeologists assumed that both bison and humans would converge on the parklands in the late fall to avoid the inhospitable conditions of the treeless plains. Grassland inhabitants exploited fetal and newborn bison when adult females became fat-depleted. Peoples from the parkland and forest spent the late fall and winter on the northern edge of the grassland in order to access wintering bison; in the spring they exploited spring-spawning fish and other resources.

Vessels from this same region are currently being studied to investigate pottery function. Intact or largely reconstructed vessels are rarely recovered from sites in Western Canada but most ethnographic data on pottery function refers to whole vessels. For this reason, a computer-assisted design program was used to develop three-dimensional models from partial vessel reconstructions. In addition to the general characterizations based on fatty acid ratios, HT-GC and HT-GC/MS is being used to detect sterols and other lipid biomarkers and investigate the distribution of triacylglyerols.

Morphological analyses of the 3-D computer-assisted design models enable comparisons of a wide variety of parameters within and between vessel forms. Preliminary results indicate the existence of vessel shape-size categories and differences in the distribution of residues. Only a few vessel forms appear in parkland

and forests and size ranges are more restricted. About 45% of vessels from central and northern Saskatchewan have capacities between 6 and 8 L; large herbivore residues dominate vessels with the smallest capacities; medium fat content (probably fish) and plant residues are common in larger vessels. Almost 70% of vessels from the forests of eastern Manitoba have capacities between 16 and 24 L and the majority of these contain plant residues. Vessels from grassland sites display a much wider range of vessel forms and capacities but some shape-size categories exist. About 65% of straight rim vessels from grassland sites have capacities between 2 and 6 L, 59% of those with wedge lips are between 4 and 8 L and 35% of S-rim vessels are between 8 and 10 L; angled rim vessels are more evenly distributed over the size categories. Inter-site differences in vessel capacities are common. For example, the average capacity of S-rim vessels is 4.9 L at the Walter Felt site but 7.8 L at Lake Midden. In addition, the residue yields from highly decorated vessels tend to be lower than from undecorated or sparsely decorated vessels. The combination of additional analyses of morphology, decoration and lipid residues is providing insight into the function of different vessels, in particular, those types with dedicated purposes.

Case Study: Finding Evidence of Maize Processing in North America

The introduction and spread of maize use in North America is of great interest to archaeologists. The challenges of identifying a unique lipid biomarker for maize are outlined in Reber and Evershed (2004a, b) and Reber et al. (2004). The best candidate is a long chain alcohol called *n*-dotricontanol but it also occurs in other plants and insects. Reber and colleagues report that *n*-dotricontanol occurs in the waxes formed by panicoid grasses. Since this group includes the majority of tropical and subtropical grasses (Tzvelev 1989), it is not possible to prove that maize was processed in a vessel. However, if *n*-dotricontanol and the most common fatty acids, C16:0 and C18:0, in the residue were derived from C_4 plants, a strong argument for the presence of maize can be made (Reber and Evershed 2004a, b; Reber et al. 2004).

Maize is a C_4 plant so it is able to conserve water more efficiently during photosynthesis than a C_3 plant but the process results in a different distribution of the two stable isotopes of carbon, ^{12}C and ^{13}C (Malainey 2011). Compound-specific analysis with GC-C-IRMS is appropriate because gas chromatography isolates *n*-dotricontanol, C16:0 and C18:0 from the residue and stable carbon isotope analysis can show whether the source of these compounds was a C_4 or a C_3 plant (Reber and Evershed 2004a, b; Reber et al. 2004). Stable carbon isotope values between −19‰ and −21‰ suggest the *n*-dotricontanol was entirely or almost entirely derived from C_4 panicoid grasses, of which maize was the most probable source; $\delta^{13}C$ values on residues between −26‰ and −33‰ indicate a C_3 plant source or mixture of C_3 and C_4 plants.

By combining lipid residue analysis with paleoethnobotanical analysis and stable carbon isotope analysis of human remains, it was possible to show that lower-status individuals at Late Emergent Mississippian sites consumed proportionately more maize than high status individuals (Reber et al. 2004; Reber 2006). Stable isotope analysis of human skeletons from Mississippian sites in the American Bottom indicated that people living along the Mississippi River were less dependent upon it than groups living in other regions. Reber and Evershed (2004a) found the scarcity of maize in absorbed lipid residues from pottery manufactured during the Middle Woodland, Late Woodland, Emergent Mississippian and Mississippian periods surprising. However, the low occurrence of maize in vessel residues was consistent with results from paleoenthobotanical studies and bone stable isotope results from Mississippi Valley sites, which indicated maize served as a supplement to the traditional diet of C_3 plant and fish resources.

Maize was confirmed in only 8 of the 81 vessel residues submitted for compound specific analysis on the basis of *n*-dotricontanol and fatty acids from C_4 sources. Reber and Evershed (2004a) suggested that either vessels used to process maize were not sampled or that it was prepared without the use of pottery. Reber (2006) later reported that the stable carbon isotope ratios of *n*-dotricontanol and C16:0 in three Late Emergent vessel residues were close to those measured in residues from experimental pots in which only maize was cooked. These Mees-Nochta site vessels may have been used solely for the processing of maize; vessel residues from Halliday, a Missippippian site, show that maize was no longer cooked separately from other foods (Reber 2006).

Case Study: Origins of Pottery in Southeastern Arizona

Because there is no single answer for the origins of pottery in a region, individual researchers are left to tease out the complex set of social, environmental, and subsistence issues at play in the introduction and use of this important technology. The complexity of this issue requires that those attempting this research have firm control of the archaeological variability, which includes having well-dated deposits with pottery from unambiguous contexts and an understanding of the settlement and subsistence system. One such area is in southeastern Arizona where hundreds of archaeological projects have been undertaken ahead of the urban expansion in the Phoenix and Tucson Basins; this has created an rich data base. This is the homeland for the more well-known Hohokam irrigation agriculturalists and also a fascinating Archaic Period that has some of the earliest pottery in North America (see Heidke 1999; Mabry 2000). Heidke (1999) has recovered what he calls “incipient” plain ware forms from deposits that date to 2,100 BC. These were small vessels that seemed to have performed in ritual contexts and predated pottery used for utilitarian functions by hundreds of years.

It is in this context that Garraty (2011) examined the adoption of “practical domestic pottery” from this region that appears as early as 350 BC. It is interesting to note that the dominant vessel form during this period was globular, neckless jars similar to the earliest ceramic containers on the Colorado Plateau, described above. Garraty's objective was to determine the utilitarian function of these vessels based upon a large well-dated deposit at the Finch Camp Site, located about 80 km southeast of Phoenix. His study focused on two use-alteration traces: sooting and organic residue.

Garraty examined over a thousand sherds from features that ranged in date from 370 BC to AD 400, which correlates with the Late Cienega and Red Mountain Phases in the local chronology. He found evidence of sooting on 5% of the Late Cienega Phase and 16% of the Red Mountain Phase sherds. He correctly notes that these percentages do not equate with the percentage of vessels used for cooking because in many cases exterior sooting will cover only half or less of the exterior surface. As was demonstrated above in the Colorado Plateau study, Garraty's analysis demonstrated that these vessels were not just used for seed storage, an erroneous notion deeply rooted in Southwestern ceramic studies. These vessels were clearly used over the fire as well.

To learn what was being processed in these vessels, Garraty submitted 24 sherds to Mary Malainey for an analysis of fatty acids. The residue analysis confirmed that these vessels were used in cooking, as residue was found in 20 samples. Nine of the sherds had residue indicative of animals, such as deer, sheep, or elk, and nine sherds had evidence of plants, such as mesquite beans, prickly pear, and yucca. Two sherds had both plant and animal residues. These results are consistent with the other subsistence data recovered from the site, suggesting that this was a seasonal occupation where the people were exploiting a range of plants and animals. There is evidence for maize in the archaeobotanical data but, as noted above, it is difficult to identify maize in fatty acid residue alone, and it is also likely that maize was processed in this region without ceramic vessels.

Garraty concludes that the globular, neckless, seed jar forms are versatile containers that can perform well a number of food processing, storage, and transport functions. It is interesting that these same vessel forms represent the earliest pottery on the Colorado Plateau. But most importantly, Garraty demonstrated that reliable inferences about actual vessel use can be made with an examination of use-alteration traces (in this case sooting and residue). Without an examination of these traces archaeologists would continue to assume that the seed jar were solely used for storage. They may have been used as storage vessels, but there is now strong evidence based on use-alteration traces that the earliest pottery in the Southwest, which is dominated by seed jar forms in both southeastern Arizona and near the Four Corners, were used for additional functions.

Final Recommendations

There has been much success in residue analysis over the past several years as many of the problems that hindered earlier research have been resolved (Barnard and Eerkens 2007). The techniques have come a long way since my first fumbling efforts.

We are at the point today where residue analysis should become commonplace in ceramic studies. But, as any physical science tests applied in archaeology, whether C14 or various sourcing and characterization techniques, care must be taken in their application. At times archaeologists have treated such lab-oriented techniques as magical black boxes that provide them with immediate, clear-cut answers to their analytical questions. We should never forget that the archaeological record is fraught with trickery and the answers provided by the analytical lab are not "truth" but rather just a fillip to inference, and any resultant inferences must be critically assessed. Archaeologists who apply residue analysis to pottery in the future should consider the following recommendations.

The first and probably the most important recommendation is that we must do our best to understand the life history of the sherds being tested. A series of cultural and noncultural formation processes affect the ceramic from the moment it is fired until it is found and then sent to the lab for residue analysis. Residue can be added or subtracted at any point along this behavioral chain. The better the archaeologist knows the context of the sherds being analyzed, the more likely it is that the lab's results will be interpretable in terms of past human activities. Garraty's (2011) study provides a good example of the way that sherds should be sampled for analysis. He selected sherds that were recovered from unmixed contexts, in this case from features that had been C14 dated.

Becoming a Residue Analyst

A ceramicist interested in conducting residue analysis is advised to contact one of the research or commercial labs that have conducted the type of research applicable to their questions and the region of interest. That said, I suspect that some archaeologists would like to learn how to conduct this research and perhaps even set up their own lab. To explore how this could be done, I profile five researchers who routinely conduct residue analyses on prehistoric pottery. These researchers have taken very different routes to conducting residue analysis.

Richard Evershed, who is a professor of Biogeochemistry at the University of Bristol and Director of Bristol Biogeochemistry Research Center, represents one extreme in that his entire academic background is in chemistry. His research career is focused on applying biomolecular techniques to various fields that include archaeology, paleontology, and paleoenvironmental reconstruction. He depends on scholars in archaeology and other disciplines to provide him with research questions and materials to analyze; consequently, he and his team have examined the biomolecular side of the archaeological record from all over the world. The great advantage of this approach is that he

(continued)

specializes in the chemistry side of the equation and directs a lab so he has at his disposal the latest in equipment and techniques that permit him to nimbly respond to challenges that arise when analyzing ancient compounds. This was demonstrated in the early 1990s as he and his colleagues were able to quickly resolve some of the sticky analytical issues. Although the route taken by Evershed has led to important new discoveries, this is not a path available to most readers.

A different approach, illustrated by Mary Malainey and Eleanora Reber, is to have an advanced degree in archaeology and currently be part of a department of archaeology or anthropology. Both Malainey and Reber have undergraduate degrees in chemistry and did Ph.D. dissertations that applied organic residue analysis to questions of prehistory. They both operate labs dedicated to organic residue analysis but also specialize on a particular region. Reber focuses on the Midwest's American Bottom and especially on the emergence of the Mississippian Period and the identification of corn residues. Malainey's research focuses in Western Canada and the Great Plains, although in collaborations she has analyzed organic residue from pottery in many parts of North America. The advantage of this approach is that the researchers have training in archaeology and organic chemistry so that they can conduct the laboratory analyses themselves while at the same time be well versed in archaeological questions and problems.

Patrick McGovern, who is the Scientific Director of the Biomolecular Archaeology Laboratory at the University of Pennsylvania Museum in Philadelphia, is perhaps the best known scholar who followed in the same academic path as Malainey and Reber, as he has a undergraduate degree in chemistry and a doctorate in archaeology. His scholarly interests are unique because he focuses on a single issue, tracking down the origins and evolution of fermented beverages. He has demonstrated how this type of singular focus on a particularly elusive subject can lead to profitable results.

The final approach is illustrated by Jelmer Eerkens who has done most of his research on prehistoric hunter-gatherers in California and Nevada. He is the non-chemist in the group who has used a number of archaeometric techniques, including not only GC/MS in the study of lipids but also neutron activation and stable isotope analysis, to address questions arising in his own research. Eerkens' strategy in the application of lipid analysis is much like my own, and so I can appreciate the amount of effort it takes to learn enough in these related disciplines to apply the techniques correctly. An archaeologist must commit to investing much time to stay abreast of research in these interdisciplinary areas; Eerkens has succeeded in bridging between disciplines. An advantage of Eerkens' approach is that he is not married to a particular analytic strategy and so can select from the various archaeometric techniques currently in use to address his archaeological questions.

Second, residue analysis will provide more satisfying results if it is tied to a tight question that has been crafted in the context of a long-term commitment to an archaeological problem or a particular time period. There is no substitute for good old fashioned archaeological reconstruction that yields a firm understanding of the archaeological record of interest. Residue analysis that is more like a fishing expedition can be fun and sometimes yields positive results, but the archaeologist has a better chance of success if the study begins with a tight question. Were they boiling fish in these pots? Were they processing corn in the vessels? These are the kinds of questions that can, in principle, be definitively answered by residue analysis.

The last two recommendations were directed at archaeologists, but the third and final recommendation focuses on those who conduct this type of analysis. Although considerable progress has been made in perfecting the techniques and inferences to the point that they should become a regular part of many ceramic analyses, much remains to be done. Eerkens and Barnard (2007, p. 5) note that there is a lack of standardization in methods, different "schools" of analysis are working independently using different techniques, and there has not been enough discussion across these schools to cross-check the results. Barnard and Eerkens (2007) attempted to remedy this problem by bringing together residue analysts from these various schools to evaluate each other's work, which included a "round robin" test of an identical sample by several labs (Barnard et al. 2007b). This kind of exercise should be done routinely as a means to increase communication among analysts and to inform archaeologists as to which technique or techniques would be most appropriate for answering their questions.

A Concluding Comment

Archaeological reconstruction and explanation is not easy, and it gets progressively more difficult as we continually try to extract more information from the archaeological record to piece together past lives. Pottery is in some ways the ideal artifact in that it can be made a variety of ways to suit particular functions, it is a ubiquitous part of everyday life constantly being replenished, and pots break frequently yet preserve remarkable well once broken into sherd form. Consequently, archaeologists have used pottery to make all manner of inferences about the past, from diet and demography to religion and politics. The foundation of these inferences, however, is precise information on how these vessels were made and used—the intended and actual function. It is my hope that this book serves as at least a starting point for understanding function that will lead to better links between pottery and the people who made and used them.

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