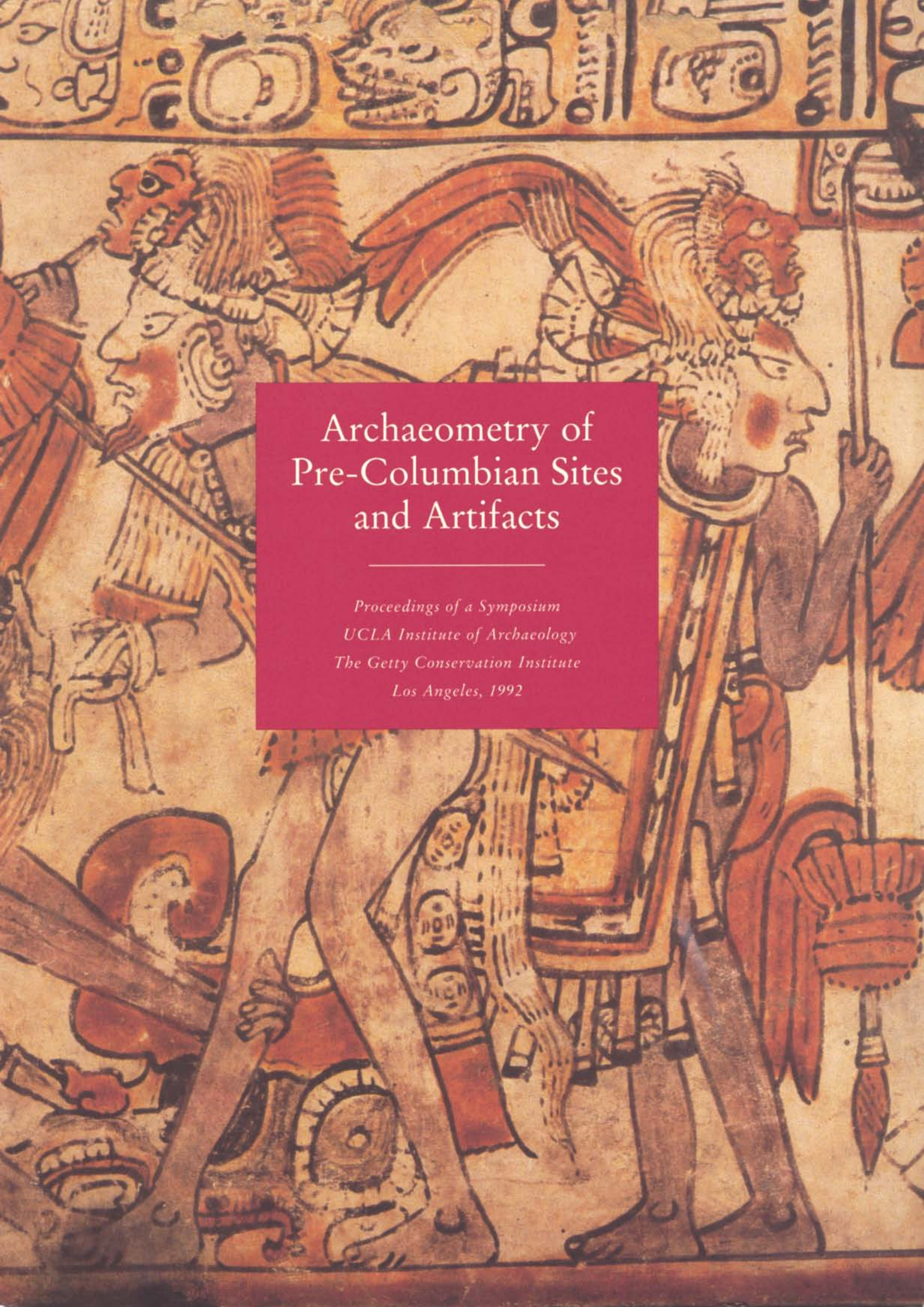

Archaeometry of Pre-Columbian Sites and Artifacts

Proceedings of a Symposium
UCLA Institute of Archaeology
The Getty Conservation Institute
Los Angeles, 1992

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Proceedings of a Symposium organized
by the UCLA Institute of Archaeology
and the Getty Conservation Institute
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David A. Scott and Pieter Meyers, editors

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Foreword

As part of its mission to preserve cultural heritage throughout the world, the Getty Conservation Institute maintains an ongoing interest in the preservation of archaeological objects and sites. The Institute was pleased, therefore, to help sponsor the 28th International Archaeometry Symposium, hosted in March 1992 by the University of California at Los Angeles, Fowler Museum of Cultural History and jointly sponsored by the UCLA Institute of Archaeology.

As part of the quincentennial celebration marking the arrival of Christopher Columbus in the Americas, the Getty Conservation Institute supported a session specifically devoted to Pre-Columbian materials, culture, and sites. The symposium's organizers, Timothy Earl, director of the Institute of Archaeology, UCLA; Pieter Meyers, head of Conservation at the Los Angeles County Museum of Art; and David A. Scott, head of Museum Services at the Getty Conservation Institute, brought together a wide array of interesting and seminal speakers on this theme. The twenty articles in this volume, selected from the wide range of topics covered at the conference, reflect the organizers' success in providing an overview of current research in the scientific examination of the material culture of ancient South and North America.

We hope the varied approaches to the study of Pre-Columbian materials presented here will stimulate interest in archaeometry worldwide and will call attention to the need for further study in this important and exciting field.

Miguel Angel Corzo
Director
Getty Conservation Institute

Preface

Simply defined, archaeometry is the application of scientific techniques of investigation and analysis to archaeology. Along with developing new methods of archaeological prospecting and dating techniques, the principal aim of this discipline is the investigation of the technology, composition, and structure of ancient materials—research that is of fundamental concern to conservation science.

In recent years a major increase of interest in archaeometry has taken place among the scientific community. The journal *Archaeometry* was originally started as an outlet for the work of the Research Laboratory for Art and Archaeology, University of Oxford, in the 1960s. Since that time, the growing interest in archaeometry has provided important information to assist curators, conservators, field archaeologists, and art historians. The titles of various conferences and journals indicate the field's related, interdisciplinary concerns; these include: *Materials Issues in Art and Archaeology, Archaeological Science,* and *Archaeological Chemistry.*

The International Archaeometry Symposium, a meeting that has been held in most continents of the world for three decades, continues to excite the interest of scholars and scientists involved in various aspects of the study of ancient materials. In March 1992, the 28th International Archaeometry Symposium was held at the University of California at Los Angeles, Fowler Museum of Cultural History. The conference was jointly sponsored by the UCLA Institute of Archaeology, and the Getty Conservation Institute, which organized a special session on Pre-Columbian materials. The organizing committee sought out speakers to ensure that a broad range of topics dealing with Pre-Columbian archaeometry would be presented. In addition, some of the scientists at the conference who presented poster sessions focusing on work in the Americas were also invited to present their research in the form of an article for this volume.

The opportunity to survey a number of different investigations linked by their concern for Pre-Columbian materials in one volume is comparatively rare. The twenty articles in this volume fall into five principal areas of examination: anthropology and materials science, ceramics, stone and obsidian, metals, and archaeological sites and dating. The contributions include a detailed study of pottery from the Maya region by Ronald Bishop; several studies of obsidian, geologically restricted material whose source can sometimes be determined by analytical techniques; and Ellen Howe's examination of the use of silver and lead from the Mantaro Valley in Peru. Izumi Shimada offers an extensive discussion of the important Sican site at Batán Grande in Peru, and John Merkel provides further information on the production of copper at this important smelting complex. Heather Lechtman's provocative analysis of the cultural aspects of materials science offers many examples from ancient Peru of the metals technology in the Pre-Hispanic period.

Luis Barba's study of archaeological sites in Mexico using surface methodologies offers an innovative, low-cost solution to the problems of recording and investigating archaeological remains without the necessity of undertaking excavations. Given the extraordinary diversity and number of archaeological sites in Mexico, this information is of significant practical value. Problems related to the conservation of archaeological information are also brought to light by Noreen Tuross, who discusses the preservation of molecular structure in partially fossilized or degraded material. Conservators would normally choose to consolidate such material with a synthetic resin to stabilize it or strengthen it sufficiently to allow it to be stored or lifted from the site. The fact that this conservation procedure may damage the preservation of DNA or other organic components is emphasized here.

This volume, with its range of topics and approaches to the study of Pre-Columbian materials, is presented in the hopes that it will provide a most interesting and educational experience and inspire further investigations that involve both archaeometry and conservation.

In addition to thanking my colleagues, Timothy Earl and Pieter Meyers, for their cooperation and expertise in helping to organize the conference, I would also like to acknowlege the invaluable work provided by the reviewers who gave of their time to evaluate the manuscripts submitted for publication: Warwick Bray, Department of Pre-History, Institute of Archaeology, University College London; S. Terry Childs, Center for African Studies, University of Florida; Thomas H. Day, Department of Pre-History, Research School of Pacific Studies, The Australian National University, Canberra; Christopher B. Donnan, director, Fowler Museum of Cultural History, University of California, Los Angeles; R.P. Evershed, Department of Biochemistry, University of Liverpool, England; Stuart Fleming, scientific director, MASCA, University Museum of Philadelphia; David C. Grove, Department of Anthropology, University of Illinois; Ellen Howe, Department of Objects Conservation, Metropolitan Museum of Art, New York; P. J. Julig, Geophysics Division, Department of Physics, University of Toronto, Canada; Heather Lechtman, director, Center for Materials Research in Archaeology and Ethnology, Massachusetts Institute of Technology; John Merkel, Department of Conservation, Institute of Archaeology, University College London; Andrew Oddy, Keeper of Conservation, British Museum, London; Jack M. Ogden, Independent Art Research, Cambridge, England; Stavros Papamarinopoulos, Athens, Greece; Gerwulf Schneider, Arbeitsgruppe Archaometrie, Institut fur Anorganische und Analytische Chemie, Freie Universitat Berlin, Germany; M. Steven Shackley, P.A. Hearst Museum of Anthropology, University of California, Berkeley; P. R. Smith, Department of Chemistry and Biological Chemistry, University of Essex, Colchester, England; Ken Thomas, Department of Environment, Institute of Archaeology, University College London; Mike Tite, director, Research Laboratory for Archaeology and the History of Art, Oxford, England; M. T. Wilson, Department of Chemistry and Biological Chemistry, University of Essex, Colchester, England; and Lambertus van Zeist, director, Conservation Analytical Laboratory, Smithsonian Institution, Washington, D.C.

In the preparation of these proceedings for publication, I also wish to thank the staff of the Getty Conservation Institute publications department, Irina Averkieff, Dinah Berland, and Jacki Gallagher. Invaluable work on the manuscript was also carried out by independent editorial consultant Diane Woo.

David A. Scott

Anthropology and Materials Science

The Materials Science of Material Culture: Examples from the Andean Past

HEATHER LECHTMAN

In 1992 we commemorated the first confrontation between the peoples of Europe and the peoples of the Americas. I do not believe that in the Americas the commemoration was a celebration anywhere. Native Americans were not celebrating. The peoples of Latin America surely were not celebrating. Perhaps it is only in the universities, among anthropologists and humanists generally, that there is a quality of celebration—not for the historical event, but in the exhilaration that comes when we think we catch a glimpse of how people today or in the past confront the world and manage it. It is a celebration of the human condition as a social and quintessentially cultural condition. The year 1992 focused attention on how American peoples made worlds that worked for them. It focused, too, on how those worlds were destroyed by the European invasions and their aftermaths. As John Murra, the renowned ethnohistorian of Andean society, has said, the question for the Andean world must be: Why were we once so rich, and now we are so poor (pers. comm. 1980)? What did it take for Tawantinsuyu, the vast Inka empire, to stand as a first world state in 1532; what was lost in its passage to third world status? The richness that we celebrate as anthropologists, historians, and scientists is the many ways people have devised to know the world and to live in it. It is, ultimately, the richness of culture.

If culture is what we are after, how do we find it on a prehistoric landscape, the landscape that furnishes archaeologists with their primary data, a landscape barren of people? Albert Spaulding, in his 1987 Distinguished Lecture to the American Anthropological Association, gave us his appreciation of archaeology. Archaeology, he said, is prehistoric ethnography (Spaulding 1988). As ethnography, archaeology must attend to the fundamental concept that underlies all anthropological inquiry: the concept of culture, that set of learned expectations and understandings shared by human groups that makes intelligible the world they live in. Spaulding further insisted that archaeological theory and interpretation should match in complexity the complexity of human behavior; in other words, that archaeology should attend to the reconstruction of past mental activity as well as past physical activity—that we should not shy away from such an effort. How do we accomplish this challenge, when the prehistoric field which archaeologists confront to glean understanding of culture are environments that preserve only the physical artifacts of past human production, that part of social life we have come to call material culture, including items some scholars would call art?

I use the term *material culture* as it has generally come to be understood: first, as the inventory of artifacts produced and used by a society, and second, as connoting the physical manifestations of culture. For Henry Glassie, "Material culture embraces those segments of human learning which provide a person with plans, methods, and reasons for producing things that can be seen and touched" (1968:2). It entails cultural statements, physically embodied. Material culture is not merely a reflection of human behavior, it is an aspect of human behavior (Rathje 1977:37). Through the study of artifacts, present and past, we attempt to appreciate the belief systems of the communities that produced those artifacts. Some archaeologists—and I am among them—feel that it is within our reach to grasp the symbolic significance of the material remains of prehistory. That is, a major concern of material culture studies of prehistory must be not only with how peoples of the past actively constructed and represented the social world, but also with the symbolic relations between past artifacts and past peoples—how the artifacts signified for the people who used them (Miller and Tilley 1984:4–5).

In asking prehistoric ethnography to examine culture, it seems that we press archaeology to its methodological limits. But that is in large part because our attention to material culture has focused almost exclusively on the artifact and how it was used. Rarely have we considered the artifact as the end product of a series of technological activities, placing at the focus of our attention the technological behavior itself, not merely the end product of such behavior. Anthropologists, art historians, and most archaeologists have sought to understand items of material culture primarily as they function in society, investigating their use, their meaning, their sacredness, their power, their transfer or exchange. A few also appreciate artifacts, regardless of their size or setting, as the realization of production sequences, of technological performance (Hosler 1986, 1988a, n.d.; Lemonnier 1986). If we consider preindustrial production, for example, each object represents the culmination of a series of technical procedures in which materials of nature are transformed into items of culture. What many years of laboratory research have demonstrated is that such technological behavior—the rendering of the object—is in itself cultural, involving judgments, values, attitudes, skills, knowledge, and choices that inform the rendering intimately. It is not only that people make things through technology, but that they do so in culturally determined ways that markedly govern the outcome, whether that be a work of art or a fishhook.

The splitting of technological performance, or process, and its product into two separate analytical categories is unfortunate because the two cannot and should not be meaningfully divorced. Both the study of the technology of production of material culture and the study of the technological styles that characterize technologies of production attend to behavior, and it is in the domain of behavior that culture resides (Lechtman 1991). Furthermore, archaeology's methodological limits are considerably enhanced once technology shares center stage with the products of technology. We add to the anthropological tool kit the perspectives and the analytical repertoire of materials science and materials engineering. Our ability as archaeologists to reconstruct prehistoric technological sequences depends upon our ability as materials scientists and engineers (Hosler 1986, 1988b, n.d.).

Each artifact we excavate is not only the product of a series of technological actions, but also the source of precise information about the history of its own manufacture. The stages in the physical processing of any object are identifiable through laboratory investigations that have developed within the fields of materials science and materials engineering. Our ability to reconstruct such processing is based upon the characteristic of materials to record in their microstructures the history of the formation of those structures; that is to say, the history of their rendering. Thus, as I have argued for a long time, what we can and do excavate in archaeology are technologies (Lechtman 1977), the technical events that went into the manufacture of items irrespective of the social arenas in which they were used.

What is it, exactly, that we derive from a materials analytical investigation of artifacts, in particular of artifacts from prehistory? Fundamentally, as Hosler has shown, we learn about human decisions, the exercise of choice (Hosler 1986, n.d.). Each material presents to the artisan or to the engineer a spectrum of invariant properties, grounded in the physics of matter, which influence the way in which the material can be managed. Some properties constrain the material for certain uses; others are particularly suitable and exhibit a wide range of tolerance for development. What makes materials responsive to culture is the constancy of their physicochemical properties (Hosler 1986, n.d.; Smith 1975). The systematic laboratory investigation of artifacts to determine how groups of people have managed the properties of specific materials in the production of material culture has led some of us to suggest that technologies are themselves stylistic—that technological activities are culturally patterned systems of behavior that exhibit style (Lechtman 1977). The essence of technological style lies not only in the recognition of pattern in the technical events, but also in the recognition of the cultural pattern or patterns of which the style is an expression. Although we can in many instances determine the technological styles that underlay the production of particular sets of artifacts, as archaeologists it is far more difficult to argue from there to the cultural choices, values, attitudes, and ideologies that informed the technological behavior. Nevertheless, the task for us is to continue to examine and to describe the culture of technologies, because our goal is not to write a history of technology; it is to explore the anthropology of technology. And, for the archaeologist, that exploration happens to occur on a prehistoric landscape.

Let me offer, as an example of this materials-based approach, the results of some of my own work on Andean metallurgy and its products during the Pre-Columbian era. Unlike Old World metal technologies, which emphasized the mechanical properties of metals, Andean metallurgies focused elsewhere. Color was the single property of metal, whose achievement and manipulation stimulated the most innovative and sophisticated developments of the technology. In Europe and the Near East the manufacture of bronze and iron tools of war, agricultural tools, and wheeled conveyances provided avenues of utility enabling the metallurgical revolutions of the Bronze and Iron ages. In the Andes, the locus of attention of the metallurgy is not to be found in the realm of utility but in the realm of the symbolic. Metals carried and displayed the content or message of status, wealth, and political power and reinforced the affective power of religious objects. Thus Andean metallurgy received its greatest stimulus in the arena dominated by status and political display, and the objects that carried such normative power lay squarely within the aesthetic locus of Andean societies—objects such as elaborate ear spools and nose ornaments, pectorals, death masks, religious cult paraphernalia, architectural furnishings, and so forth. An underlying cultural value system that strongly influenced the visual manifestation of status and power was a color symbolism oriented about the colors of silver and gold. The thrust of Andean metallurgy lay in the development of metals, alloys, and fabrication procedures that would realize those properties essential to the proper cultural performance of metal objects. The property that metalworkers sought to control above all others was color, most specifically the colors silver and gold (Lechtman 1984a).

Once color becomes the focus of property development, we are dealing with the metallurgy of surfaces, because the color of a metal object resides at its surface (Lechtman 1984b). It may exhibit another color underneath. Almost all other metallurgical traditions achieved color change on metal objects by covering one metal with another, as in the gilding of copper through the direct application of gold leaf or a gold-mercury amalgam to its surface. The Andean tradition emphasized an entirely different approach. Artisans fashioned objects from copper-based alloys that contained in their structure the metal whose color was to appear at the surface of the piece. Objects that were to look silver in color were made of copper-silver alloys; those to appear golden were fashioned from *tumbaga*, the alloy of copper and gold. Whichever the desired color, the metal responsible for that color, as it would ultimately appear at the surface, had to be inside the object; it had to be a constituent of the alloy itself. The alloy was almost invariably an alloy of copper. In manufacturing such objects, smiths used chemical means involving naturally occurring corrosive minerals to remove from the surfaces of the objects those constituents of the alloy—such as copper or silver—that were unwanted there, leaving the desired metal in situ. Such procedures for producing a colored metal surface on a metal substrate have been termed *depletion systems*. They deplete the surface of the undesired metal, thereby enriching it in what will become the carrier of color (Lechtman 1988). The contrast between the Andean approach and those of most other metallurgies is striking. Systems that achieve color change by covering one metal with another hide what is underneath. Depletion systems transform surfaces by selectively developing at the surface certain properties of the material that lies beneath. Other systems cover and hide. Andean systems develop and enhance.

By the time of the Spanish invasion of Mexico, Central America, and South America in the sixteenth century, Andean alloys and their enrichment properties were in common use throughout the New World, having swept north from the Andes, where they had maintained their importance for almost two millennia. They constitute the most significant contribution of the New World to the repertoire of alloy systems developed among ancient societies.

In the Central Andes, these copper-rich alloys were used primarily to produce silver- and gold-colored objects made of sheet metal, as the Andean tradition of metalworking was predominantly a working or hammering tradition, a tradition that plastically deformed metal as a solid material. But in Colombia and Central America, these very same alloys were used to fashion objects made by lost-wax casting; there, the coloring system was fitted to a metalworking tradition that revolved about shaping metal as a liquid material.

There has been considerable discussion about why these copper-based alloys and their depletion and enrichment coloring systems had the impact they had, why they spread so far, accommodating to the markedly disparate metalworking traditions of the various societies that adopted them (Lechtman 1979; Root 1951). Answers have invoked the economy of the system—that one can spread one's gold and silver much farther if objects are made of tumbaga-like alloys rather than from the pure metals. Other arguments claim that tumbagas made casting easier and made objects harder. None of these explanations, however, accounts for the persistence and widespread use of these alloy systems throughout the Americas for nearly two millennia. I have suggested that the force behind this unusual metallurgical tradition, or what we may certainly call a technological style, was ideological (Lechtman 1984a). The basis of Andean enrichment systems seems to be the incorporation of the essential ingredient—the gold or the silver—into the very body of the object. The essence of the object, that which appears superficially to be true of it, must also be inside it. In fact, the object is not that object unless it contains within it the essential quality. Translated into metallurgical terms, the alloy used to make the object must contain the metal that is later developed and enhanced at its surface and that becomes the visual hallmark of the object.

The increasing attention of Andean smiths to surface phenomena, and their sophistication in developing metallurgical and chemical systems to transform metal surfaces, reflects the importance of the surface as the visible manifestation of an inner state or an inner property. The surface became the location where aspects of the inner state were realized and enhanced. Surfaces are, after all, boundaries between an inner condition and an external reality or environment. The surface is where the two meet. It is the place of communication, the seat of greatest information content. And it was the condition of the surface of a metal object that often gained it entry into the sphere of items of art.

As we see from the Andean material, objects that functioned within the aesthetic locus of Andean society are there as much by virtue of their rendering as by their formal style. The styles of Andean technologies strongly influenced the spheres of cultural activity and perceptions in which such objects functioned.

What is most important about the Pre-Columbian metallurgy example is that a hypothesis (incorporation of essences) that seeks to account for and to explain the materials analytical data could not have been formulated except upon laboratory investigation of the technological system of production. That the hypothesis calls for a cultural explanation of the materials data stems from critical examination and elimination of several other plausible economic and technical explanations (Lechtman 1979). Some testing—outlined briefly below—has, I believe, lent strength to its explanatory relevance.

On other occasions (Lechtman 1984a, 1993) I have suggested that one way to test hypotheses concerning incorporation of essences as an ideological motif underlying the elaboration of Andean metal-gilding technologies and its possible contribution to a general style of technological behavior within Andean society would be to examine other key technologies. Cloth production was unequivocally the most important arena of Andean material culture, and the manufacture of cloth required technologies that were fundamental to Andean society. Do concerns such as the incorporation of essences appear to have operated in the elaborate weaving techniques utilized by Andean specialists in the prehistoric period?

In comparing Andean weaving with any of the other great traditions of cloth manufacture, whether Asian or European, nowhere else do we find such an elaboration of and commitment to a broad range of weaving techniques based on loom yarn manipulation: the preponderant use of structural as opposed to suprastructural techniques for realizing the patterns carried by the finished cloth. When a design or pattern is achieved through suprastructural means, the design is added to a completed woven web. Its removal from that web would in no way affect the integrity of the cloth, which acts as a support for the design but is otherwise structurally unchanged by it. Embroidered designs fall in this category, as do brocading and painted cloth; dyed textiles, achieved by tie-dye or, in a sense, ikat, are also included in this group. Such techniques were used by Andean weavers. In contrast, designs achieved by structural means are realized through the manipulation of warp and weft yarns during the process of weaving so that the design emerges from the structural rendering of the web. To remove the design would be to destroy—literally to unweave—the cloth. Tapestry techniques; double-, triple-, and quadruple-cloth techniques; gauze weaves; warp-patterned weaves; discontinuous warp or scaffold weaves; and plain weaves are only some of the Andean cloth production types whose characteristics are achieved through manipulation of the structural elements of the fabric. There is no question that the primary creative direction of Andean weaving lay in the rich elaboration of structural techniques, in the playing out of a structural technological style.

What we must ask is whether the visual message borne by the design motifs had to be contained in and generated by the very structure of the fabric itself. Just as with the depletion coloring of metals, does there come a point at which the technology itself becomes the medium for the expression of message? In the case of Andean highland weaving, intricate manipulations of many warp planes and myriad weft yarns were, strictly speaking, unnecessary to the accomplishment of the designs. But Andean weaving seems to have responded to notions of the visual, surface message as emerging from underlying, invisible structural relations. Andean weaving insists that message be embodied in and expressed by structure.

Metal and cloth technologies received great stimulus and cultural support within the normative realm of Andean societies. Both served to enhance the normative power of the state, a power based on the allocation and manipulation of esteem, prestige, and ritual symbols (Etzioni 1961; Lechtman 1993). Both were information-bearing technologies, the purpose of whose products was in large measure the communication of message, so that the very design of the technologies, the styles of technological performance, had to be consonant with those purposes (Lechtman 1993). It seems clear that key Andean technologies associated with cloth and metal production shared stylistic modes, perhaps because those modes were expressions of cultural ideals, incorporating ideological concerns of the society at large.

An ethnographic test of the hypothesis linking Andean metallurgical style with ideology may be found in Gerardo Reichel-Dolmatoff's (1981) ethnographic research among the Desana and other Tukanoan peoples of the Northwest Amazon, in what is today the nation of Colombia. Desana wear ornaments such as necklaces and ear pendants of silver, but in former times these adornments were also made of gold. Ear pendants are often made of copper. A Desana tale that describes the tradition of metallurgy in the rainforests of the Northwest Amazon speaks of two metals: white and yellow. Reichel-Dolmatoff learned from his informants that what the tale designates "as 'white and yellow' does not refer to actual metallic colors, but to abstract qualities, to an invisible 'white' creative force, and to a visible and material yellow potential" (1981:21). The Desana explained that "these two forces met and mingled in different proportions. The basic material state was the visible sun, associated with gold and with human semen, while the 'whiteness' was a modifying abstract cosmic force which heightened or diminished the quality of the golden component" (1981:21).

Yellow is symbolically the most important color to the Desana, who name some thirty different hues, intensities, and values ranging from a pale yellowish to a deep orange color. In Tukanoan color symbolism white and yellow are associated with male potency. Complementary to this male color symbolism of white/yellow there is a color range of reddish hues. Red is said to be a female color. The color combination of yellow/red stands, therefore, for male/female fertility and fecundity (Reichel-Dolmatoff 1981:21):

> In Tukanoan mythology and cosmology the sun represents a male-fertilizing principle associated with the yellow color range, while the moon is female. Her colors are variable because they depend entirely upon the influence of the sun; they range from yellow-green to a dark red-orange and to blue-violet. . . . Ideally, the sun fertilizes a brilliant New Moon which [then] . . . passes through a sequence of yellowish, reddish, and copper-colored phases which are compared to . . . the process of embryonic development.

Copper, in this thought system, is considered a material of transformation. Thus the process of fertilization, of transformation, and of birth—in other words, Desana concepts of potency, generation, and growth—is held to be a model of metallurgical combinations. For the purposes of our discussion here, it is a model for alloying, for combining copper, silver, and gold in the preparation of the alloys of tumbaga. To quote Reichel-Dolmatoff: "The main importance of personal metal adornments [among present-day Tukanoan peoples] lies in their symbolic associations expressed in their alloys, coloring, shape, and odor" (1981:22).

From this perspective, it is in every way reasonable to consider that the Inka insistence upon the colors of silver and gold, and the deep-seated Andean commitment to the alloys of tumbaga and to the procedures that transform the copper of those alloys to silver or to gold—a commitment that was prevalent for millennia throughout the entire Andean culture area and that, as we have seen, persists in the Amazon lowlands today—expressed an equation, the equation of power with the control of certain metals; metals that, when alloyed and transformed, embodied and communicated the continuity of the royal lineage and, therefore, of the Inka state. The laboratory analytical data are congruent with the ethnographic and ethnohistoric data.

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Biography

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Ceramics

Pre-Columbian Pottery: Research in the Maya Region

RONALD L. BISHOP

> *The strange subject matter of Maya art should not militate against its real artistic merits, for the finest products of an inspired imagination are always worthy of respectful study.*
>
> HERBERT SPINDEN, *A Study of Maya Art*

Pre-Columbian ceramics have long been a focus of archaeological study, for their stylistic attributes have utility as sensitive markers, reflecting developmental changes in time and space. For approximately sixty years, albeit with less widespread attention, the compositional characteristics of ceramic pastes have also been a subject of extensive investigation. And, as the goals of archaeology have changed from a focus on cultural identities and chronological sequences toward social, political, and economic processes, investigations into the operation of exchange systems have drawn increasingly upon compositional data in an effort to provide a more objective basis for interpreting ancient social relationships.

Interest in ceramic exchange stems, in part, from its role in local or regional systems of human interaction, which involves mediation among modes of human behavior, cultural institutions, ideology, and the natural environment. Developments in analytical technology that are used to investigate exchange fostered archaeological attention at a time when the presence, form, and modification in exchange systems became recognized as factors in the development of stratified societies (Earle and Ericson 1977; Hirth 1984). While there is a tendency for some archaeologists to use the words *exchange* and *trade* interchangeably, there is an advantage to follow the suggestion of Kenneth Hirth (1984) and separate them. Of the two terms, *trade* is the more limited, representing only one aspect of exchange, "the acquisition and/or distribution of material goods" (Hirth 1984:15). Although more limited in scope than is the investigation of exchange, a determination of trade is highly amenable to an "archaeometric" approach through the direct linking of a characterized resource procurement area with the artifacts produced from that source. Alternatively, finished products may be linked indirectly to a presumed source area by the judicious use of the criterion of abundance, whereby the relative concentration of a product may suggest a probable source (Bishop, Rands, and Holley 1982:301).

Exchange, according to Hirth (1984:15), is a "provisioning" mechanism, one that "reinforces relationships both between individuals and within the cultural subsystems in which they operate." The form, content, and mechanisms of an exchange system will vary widely from one society to another as will its impact on other aspects of each society. The control and exploitation of some resources may lead to such competition that organizational complexity will be increased while at other times exchange will represent or reinforce prior social relationships as ideological, social, and economic factors converge in a particular natural and cultural setting.

While much interest may lie, for example, in the extent to which the production and distribution of pottery reflect aspects of organizational phenomena, data produced in the study of exchange—or even trade—have often contributed little more than descriptions about the distribution of ancient materials (e.g., object *x* was made from materials of source *y*). This has resulted in part from studies that are predominately methodologically focused in contrast to those investigations that would seek to interpret a single component of study within the context of other types of available information and thus contribute toward the explanation of the archaeological record (DeAtley and Bishop 1991). Interest in more synthetic interpretations, such as those pertaining to the operation of exchange as a system, precludes reliance on any single class of cultural material, no matter how scientifically rigorous the investigation. I have suggested elsewhere that archaeology has at its disposal tremendous instrumental capability, much of which is not being used effectively (Bishop 1992). If the research into the structure and function of exchange systems is to advance beyond its present state, and if the objective of ceramic compositional analysis is to be more than a methodological exercise, the problems, analytical procedures, data analyses, and interpretations must all be contextualized. This involves far more than just the physical associations of specimens in time and space. While variations in general patterns can be analyzed, it must be acknowledged that each association has its own particular history and intangible meaning. Context therefore implies—in fact, necessitates—recognition of the interplay of both physical meaning and past "symbolic" meaning (see Hodder 1982, 1991). Ceramic compositional data sets and those data pertaining to other components of an exchange system can be profitably viewed as part of an open system wherein a maximum amount of information can be factored into a "best fit" with both archaeological and analytical information.

Unfortunately, no generally accepted theoretical framework has yet been developed that promotes the necessary level of interdisciplinary integration. This constitutes a great limitation on archaeological interpretation, for only within a theoretical context, whether explicitly or implicitly stated, are significant questions about the past distinguished from those that are less significant, where descriptive data derived from scientific measurement are transformed into a systematized body of archaeological knowledge. While efforts to bridge between data and interpretation continue (e.g., Schiffer and Skibo 1987; Neff 1992), awareness of the need for providing a greater cultural and historical context for analytically based ceramic research will contribute to establishing the relevancy and sufficiency of compositional analysis.

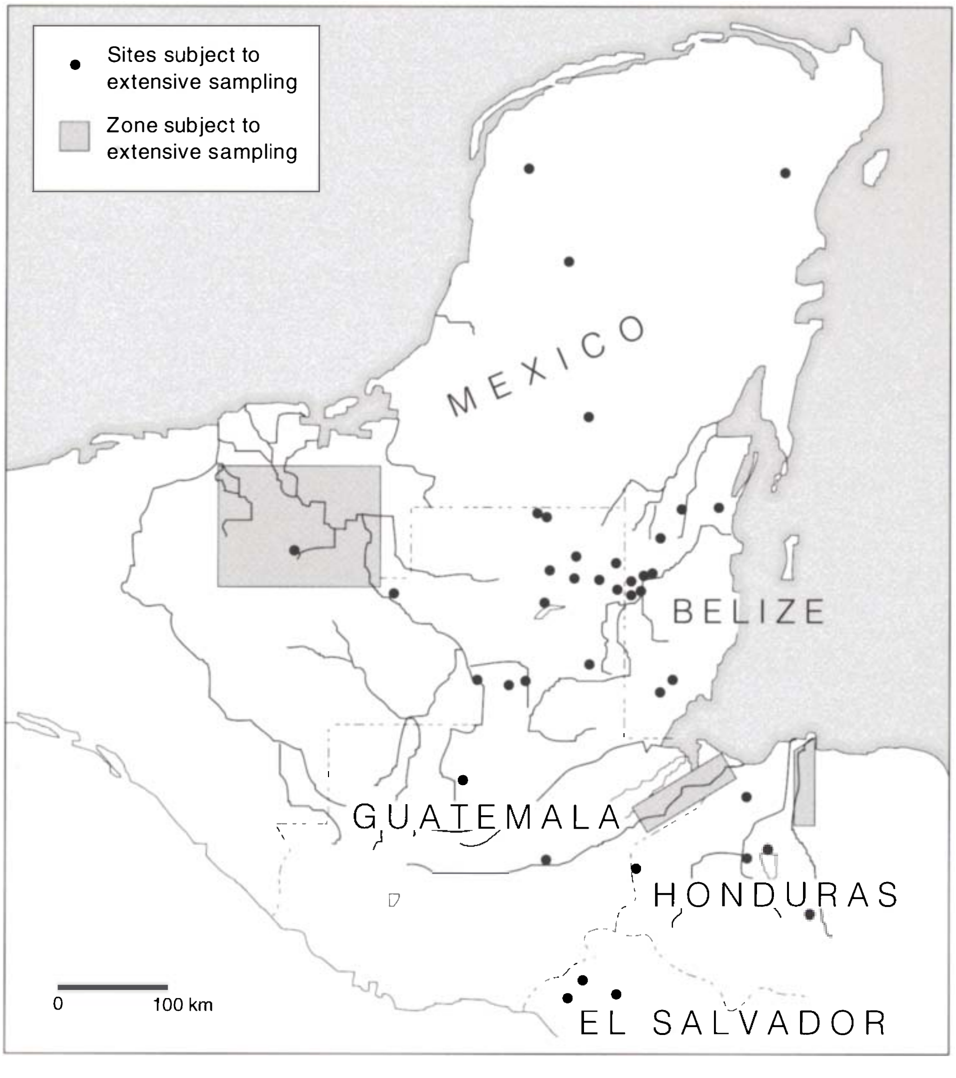
This paper presents several examples of compositional research involving archaeological ceramics that are being conducted to further archaeological understanding of social and economic relationships among the ancient Maya of southern

Mexico and Central America. In doing so, the discussion illustrates the nature or direction of archaeological interpretation that is being pursued through the specific linkage of chemically based paste compositional data to other types of archaeological information. Specific attention is given to the effects of sampling and the use of multiple-level archaeological data sets in one area of the world where compositional data, especially those from instrumental neutron activation, now amount to several thousand analyses.[1]

The Maya

The ancient Maya occupied an area that encompasses southern Mexico, including the Yucatán Peninsula, Guatemala, Belize, and parts of western Honduras and El Salvador (Fig. 1). The discovery of Maya "cities" and their wondrous art stirred the passions of a late nineteenth-century public that eagerly awaited news of this mysterious people whose past was being reborn from the Central American jungles. As information grew, the Maya, like Greek culture, were idealized as cerebral and peaceful, especially the latter when viewed in contrast to the Aztec culture of central Mexico, where warfare was frequent in order to obtain human sacrifices for insatiable gods. Over time the Apollonian view of the Maya underwent considerable

FIGURE 1. *Map of the Maya area. Sites and survey areas that are subjects of intensive sampling by the Maya Ceramics Project. Pacific Coastal Guatemala and the majority of the Guatemalan highland sites have been omitted. Area of the Palenque survey is shown in large shaded area.*



revision (e.g., Rands 1952). Today, the ancient Maya are viewed as human, seeking political advantage through trade and warfare, propitiation before the gods through bloodletting and human sacrifice, and even having a high time through rectal injections of fermented beverages.

The Maya area is divided physiographically into the northern and southern lowlands, Guatemalan highlands, and Pacific coastal plain. The commonly accepted "core" area of the Maya lies in the southern lowlands, where Maya society evolved from village farming settlements into a highly stratified society with civic-ceremonial centers administered by a social elite. During the Late Classic period (600–830 C.E.), groups in the southern lowlands reached their cultural apogee with striking achievements in the construction of monumental architecture, the erection of carved stone monuments or stelae, a system of writing and calendrics, and other manifestations of a flourishing civilization. The primary economic networks were of a local nature that, when intersecting with other local networks, tended to integrate the economy at a more inclusive regional level (Rice 1987:77). Eventually, internal pressures and increased warfare among neighboring groups led to a societal collapse that in the core zone resulted in widespread abandonment of civic-ceremonial centers and the surrounding countryside by 900 C.E.

Ceramic Composition, Exchange, and New World Context

It is likely that the first compositional analyses of New World ceramics were achieved through petrographic methods in Belgium by Wihlem Prinz at the request of Anatole Bamps (1884). This pioneering effort was followed by study in Sweden of U.S. southwestern Mesa Verde pottery by Gustaf Nordenskiöld (1893:75, 81, 84; R. H. Thompson 1991). After the turn of the century, petrographic techniques continued to be used in benchmark ceramic studies by Sigvald Linné (1925) in South America, Frederick R. Matson (1935, 1936, 1937, 1939) in Texas, Indiana, and Michigan, and by Anna O. Shepard (e.g., 1936, 1942) in the U.S. southwest. Linné (1942) later directed petrographic examination of Thin Orange pottery from central Mexico, while Matson turned his attention to the Eastern Mediterranean and Central Asia (for Matson's bibliography, see Kolb 1988). It was Anna Shepard who, with the support of the Carnegie Institution of Washington and the "Dean" of American Archaeology, Alfred V. Kidder, proceeded to develop a methodology for ceramic technological study of pottery from the Southwest. She eventually transferred that methodology into the Carnegie programs of archaeological research on the ancient Maya (Bishop 1991; Cordell 1991; Rands 1991).

Chemical analyses of ceramic pastes had a slightly later start. During the 1920s, Shepard and her mentor, Wesley Bradfield, were involved in a study of New Mexican Mimbres pottery. One aspect of the research attempted to link the pottery to a potentially used clay source through the analysis of the clay and ceramic paste by classical wet chemical methods. The work, however, was demanding and slow. After being exposed to the potential of petrographic examination during the visit of geologist Arthur Cole Spenser to the Mimbres excavations, the program of chemical analysis was halted, and Shepard proceeded to embark on a professional career that would be noted for the use of petrographic analysis, diligent examinations, and a cautious approach to reporting analytical data (R. H. Thompson 1991; Bishop 1991).

For Shepard, chemistry remained primarily as a means of determining the composition of glazes or paints (Shepard 1968:145). New possibilities arose, however, when physical chemist Edward Sayre explored the use of nuclear methods of chemical analysis to answer archaeological questions. Ceramic specimens for this pioneering study included Maya Fine Orange and Fine Gray pottery from Guatemala. Provided with a scintillation detector and the computational power of a pencil, Sayre and his co-workers produced the first instrumental neutron activation analysis data of pottery, reporting the relative amounts of manganese, sodium, lanthanum, scandium, and chromium (Sayre et al. 1958). The study also marked the first time that the interpretation of the significance of the ceramic data was later found to be wrong (Sayre et al. 1958; Rainey and Ralph 1966; compare Bishop and Rands 1982).

Shepard (1966) reacted cautiously to these new developments of paste characterization. As a recognized authority, she could deal a severe blow to the efforts of others when she considered their procedures to be faulty (e.g., Shepard 1939, comments on Hawley and Hawley 1938). Based upon her early experience and coupled with her awareness of complexities of a ceramic system, Shepard believed that chemical analysis of ceramic paste was subject to criticism, especially when conducted "without reference to geological and geochemical conditions" (Shepard 1965:vii; see also Shepard 1966; Bennyhoff and Heizer 1965). It is significant, therefore, that after hearing Sayre sometime in the late 1960s describe the instrumental neutron activation analysis program being conducted at Brookhaven National Laboratory, Shepard withdrew her presentation of a paper critical of such efforts (Edward Sayre, pers. comm. 1992).

The decade of the 1970s was one that witnessed great advances in neutron activation methods, including improvements in detectors, development of faster and more stable electronics, and the evolution of computer technology. Due to personal interests of researchers and historical factors, Brookhaven National Laboratory emerged as the major center for the chemical analysis of New World pottery. Sayre was joined by radiochemist Garman Harbottle. Their studies benefited by the cooperation of several New World archaeologists but especially by the efforts of Mayanist Robert L. Rands, who diligently attempted to integrate the analytical data within a broader archeological context. My own involvement in the Brookhaven effort began in 1973. Over the next ten years the early work of determining the source of Maya Fine Orange and Fine Gray pottery was expanded to investigate trade among the major Maya civic-ceremonial center of Palenque and smaller nearby sites. Other research was initiated to address general questions of ceramic production and distribution throughout the Maya area and even into Lower Central America. In 1982, following the deconstruction of American science by the Reagan administration, these investigations were evicted from the Brookhaven Laboratory but later became part of the Conservation Analytical Laboratory's research programs at the Smithsonian Institution. Other institutions have carried out intermittent or small-scale compositional research on New World pottery (e.g., Culbert and Schwalbe 1987; Foust et al. 1989; Lombard 1987a, 1987b). However, it is only recently that a major new resource has emerged for the characterization of Pre-Columbian materials as part of an analytical program supported by the National Science Foundation at the University of Missouri Research Reactor facility.

Since the first analyses, New World compositional studies based on neutron activation have evolved in terms of both instrumentation and purpose. As reviewed recently by Marilyn Beaudry (1991), research prior to the mid-1980s was in a "formative period." This was a time of getting acquainted with our tools and our concepts. Gradually, a few of the early projects were published (e.g., Rands et al. 1975; Harbottle and Sayre 1975; Rands and Bishop 1980; Bishop and Rands 1982; Rands et al. 1982). While the search for "local" versus "nonlocal" ceramics continued, more attention became focused on the social context of ceramic production and distribution. Later studies often moved beyond the more instrumentally oriented earlier work and explored such topics as the fit between instrumental sensitivity and specificity of archaeological questions, the roles natural and cultural factors play in influencing processing, use, discard, and postdepositional alteration of ceramic materials, and the need to match data-handling techniques to particular data and questions. Examples of the evolution of Maya ceramic compositional studies and current research directions are given below.

The reader is cautioned that in selecting the various examples I have attempted to paint an expansive landscape in a small space. This necessitates that many details are omitted; this is especially true in the area of data presentation. For more detailed information about previously published investigations the reader can consult the cited work. For those investigations that are still in progress, I apologize ahead of time for not presenting sufficient data to allow the reader to know precisely how I moved from analytical step A to step B.

Sampling: Fine Orange and Fine Gray Pottery

Purgamentum init, exit purgamentum. No matter how it is expressed, the admonishment of "garbage in, garbage out" is relevant to the design of a sampling strategy in ceramic compositional investigations. The days of archaeometrists selecting sherds from barrels of miscellaneous pottery or of archaeologists submitting one to *n* samples of some typological category without attention to macro characteristics of paste are, hopefully, drawing to a close. Sampling must be sufficient, in numbers and inclusiveness of ceramic category, to maximize the possibility of addressing clearly stated research objectives.

As the compositional databases for the Maya and other regions of Mesoamerica have grown in size, there has been a concomitant increase in sampling the range of variation of ceramic products within a given ceramic class. This has led to several consequences: (1) newly analyzed samples will belong to groups already defined, thereby increasing the accuracy of the group characterization; (2) new analyses will increase numerically the pottery belonging to previously represented but unrecognized groups so that grouping tendencies will be seen; (3) new analyses will contain sufficient numbers of samples to constitute observable groups, members of which were not previously analyzed; (4) new analyses, and perhaps previous analyses, will not show any archaeologically significant tendency to form groups. This latter situation may arise as the result of cultural practices that did not result in the repeated use and preparation of specific resources (for example, Rosales Incised pottery of southwestern Nicaragua and northwestern Costa Rica [Bishop et al. 1988]) or from natural factors where the boundaries between geochemically based compositional differences are blurred. Additional blurring, of course, can be introduced to a data set through analytical error in the compositional determination (Gilmore 1991). The following two examples illustrate the impact that sampling can have on the archaeological interpretation.

Fine Gray and Fine Orange (Fig. 2) are typologically recognized classes of Late or Terminal Classic (750–900 C.E.) pottery that are of special interest in Maya prehistory, for they occur largely at the termination of Maya civilization in the

FIGURE 2a–d. *Fine Orange and Fine Gray ware: (a) Provincia Plano-relief type, Tecolpan (Maya Ceramics Project archive MSY377/17929); (b) Chablekal type, Cueva de Sangre, Dos Pilas region (DPCS30/17248); (c) Pabellon modeled-carved, Uaxactún (MS1231/15303); (d) Silho Orange, nonprovenienced (MS1252/15360). Samples (a), (b), and (d) downstream Usumacinta production source; (c) upstream (off Usumacinta) production source.*

southern lowlands. This pottery was the subject of the earliest Brookhaven National Laboratory analyses (Sayre et al. 1958), and attempts to identify the source(s) of production have continued intermittently for more than thirty years (Sayre et al. 1971; Sabloff 1982; Harbottle and Sayre 1975). A summary of the major patterns observed in the compositional data was presented a decade ago (Bishop and Rands 1982; Rands et al. 1982), but a substantial number of newly analyzed Fine Orange and Fine Gray specimens required a new evaluation of the material (Fig. 3; Rands and Bishop n.d.).

In 1982, slightly more than one-half of the 154 analyses by instrumental neutron activation analysis were attributed to one of five chemically based paste compositional reference units. Owing to similarity in compositional patterns that were thought to correlate with a linear region of production along the Usumacinta River, its feeders and floodplain, some of the groups were merged to form three larger units and subsequently projected onto axes derived by a three-group discriminant analysis (Fig. 4a) (Bishop and Rands 1982:fig. 10). The largest group, low and toward the center of the plot, consists of samples with site memberships from along the lower Usumacinta River, whereas the pottery represented by the grouped data

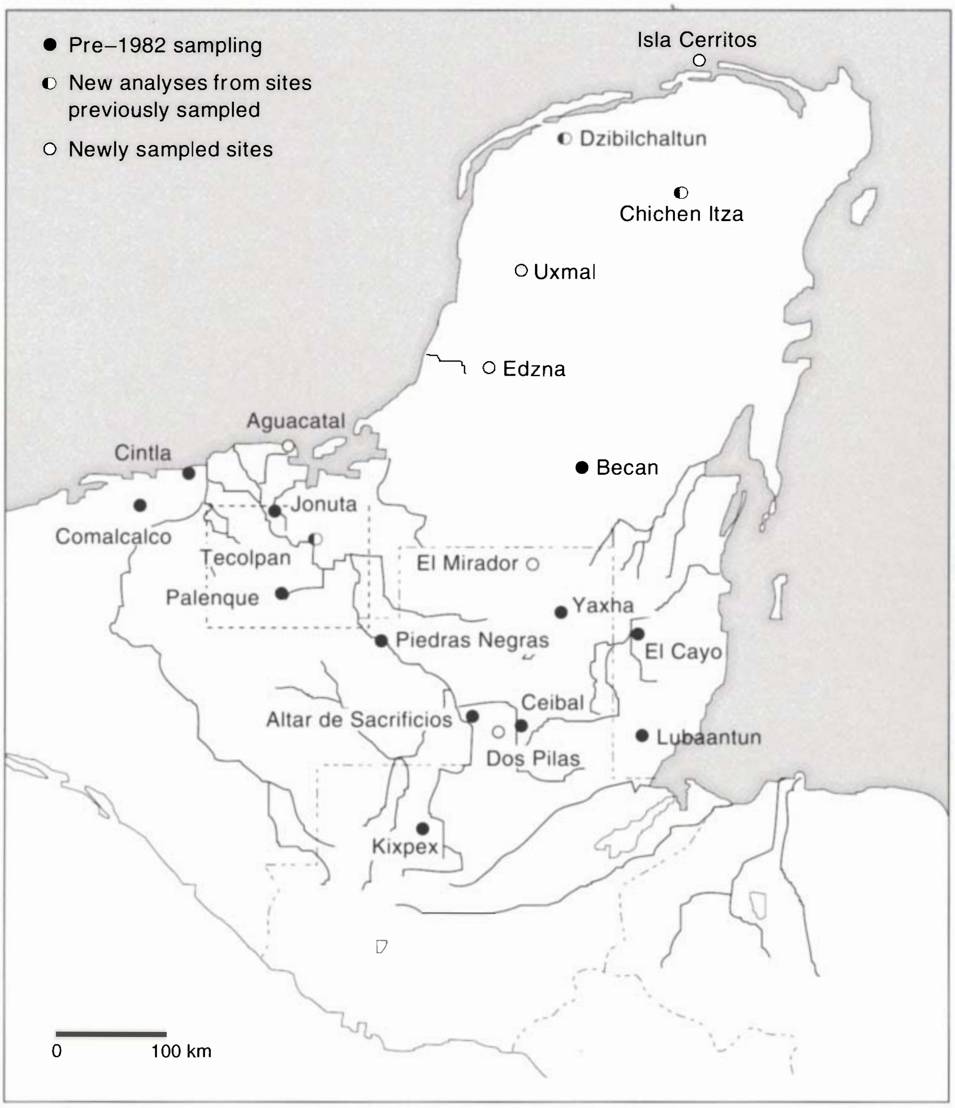


FIGURE 3. *Map of Maya area showing sampling locations for Fine Orange and Fine Gray ware.*

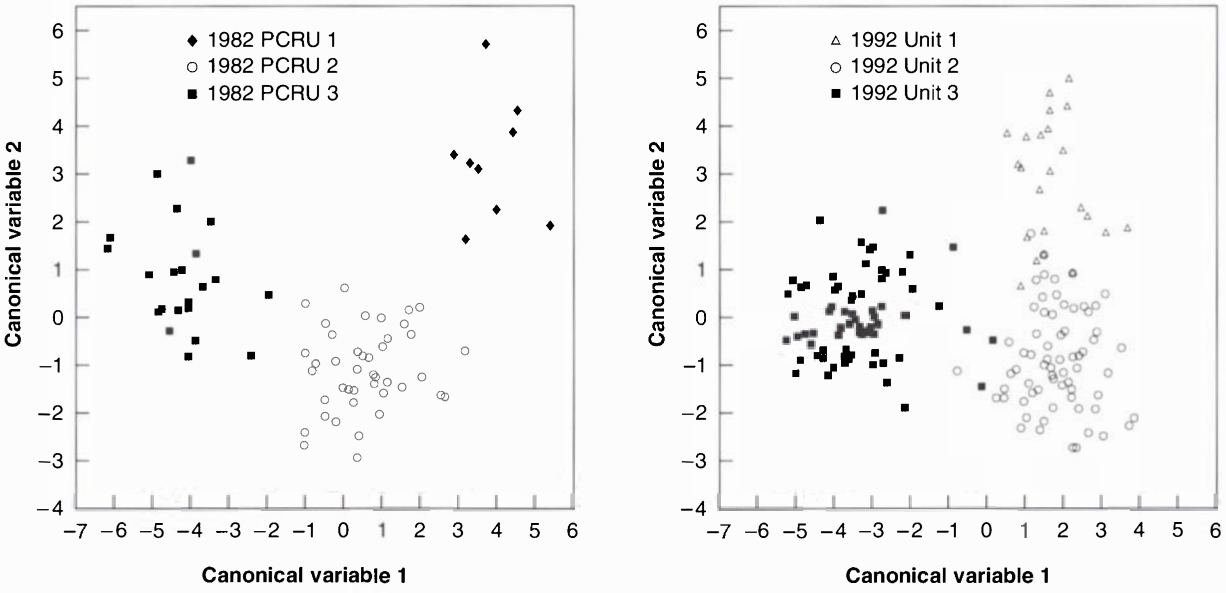


FIGURE 4a, b. *The chart on the left (a) is a discriminant analysis plot of Fine Orange and Fine Gray ware. Paste compositional reference groups from the 1982 study. The post-1982 sampling still results in a three-group partition, although two of the previous determined groups have been merged into one reference unit. The chart on the right (b) is a discriminant analysis plot summarizing grouping tendencies within Fine Orange and Fine Gray ware. The group at the top of this plot has a single-site provenience on the Usumacinta River delta and was not represented in the earlier study.*

points on the right side of the plot is from sites located on or near the upper Usumacinta. Typological and petrographic findings correlate with the chemical data to give support to the upstream-downstream attributions. Of particular interest is the small cluster of analyses at the top, left, for five of the nine samples are of the Silho ceramic group, traditionally associated with temporally later, more "Mexicanized" Maya groups (see Brainerd 1958:276–77). Three of the group members had site proveniences in northern Yucatán, well removed from the Usumacinta drainage, thus suggesting support for a hypothesis that proposes a more northern location of Fine Orange production (Ball 1978). Four analyzed sherds of the Silho ceramic group were not chemically allocated to any of the reference groups.

The interpretation of the compositional pattern for the previously analyzed group containing members of the Silho ceramic group has been altered as a result of substantially increased sampling of specimens from the Mexican states of Yucatán and Campeche and from the Lower Usumacinta sites. The number of analyses of Fine Orange and Fine Gray samples has increased from 154 to 542. While a full summary of the new data is in preparation (Rands and Bishop n.d.), the new discriminant analysis plot in Figure 4b summarizes grouping tendencies within the Fine Orange and Fine Gray pottery. Samples from the site of Aguacatal had not been sampled previously and can be seen to form a small group whose distinctiveness probably relates their production from the deltaic clays at the mouth of the Usumacinta River (triangle symbol). For the larger groups identified earlier, there has remained a clearly observable separation between a more refined Upstream reference group (square symbol) and a single group consisting of pottery from the Lower Usumacinta sites (circle). The Lower Usumacinta group, however, now includes the Fine Orange and Fine Gray pottery recovered from the northern states of Campeche and Yucatán. This partitioning of the expanded data set is supported by the compositional "match" of analyses of Lower Usumacinta clays to the group of pottery from the downstream sites. A failure to have found the compositional overlap for Fine Orange and Fine Gray pottery from the Lower Usumacinta, Campeche, and Yucatecan sites seems to be most likely attributable to earlier sampling limitations. Clearly, previous archaeological interpretation must now be altered to accommodate the data that indicate a Lower Usumacinta production source for the Yucatecan and Campeche Fine Orange and some of the Fine Gray pottery.

Modeling Sampled Variation

Ceramic characterization has most often been attempted on a particular class of pottery (e.g., Fine Orange ware, as discussed above, or Plumbate [Neff 1984, 1988a, 1988b; Neff and Bishop 1988]), or by reference to a specific site or time period (e.g., Lubaantún [Hammond et al. 1976]). Many of these studies place considerable emphasis on numerical taxonomy and attempt to seek discrete and even exhaustive partitions of the data matrices. A statement of "pottery manufactured at or immediately near the ruins of site *x*" or "pottery produced within a subregion of *y*" are examples of this classificatory effort. Experience with certain procedures lends itself to an almost repetitive sequence of steps involving elemental transformations, data set partitioning often through cluster analysis, and subsequent trial group verification by some single- or multiple-group evaluative technique (see Harbottle 1976, 1982; Bishop, Rands, and Holley 1982; Bishop, Harbottle, and Sayre 1982; Pollard 1986).

Deriving groups of compositionally similar pottery is only one way to seek patterning in a data matrix. With an unpredictable ratio of increased heterogeneity relative to a group-oriented pattern that accompanies the formation of large databases, the merit of modeling "trends" or "patterned variation" within data sets has grown. Attention to trends in the data is not, in itself, new. The evaluation of a spread of some form of compositional data over one or many dimensions has been with us for some time. Histograms, scatterplots, principal components, and factor analysis are only a few well-known techniques used to observe trends in data. What is fairly new, however, is the explicit use of "trend data" as the basis of archaeological interpretation (e.g., Bishop 1980; Rands and Bishop 1980; Neff 1992; Neff et al. 1989; Neff et al. 1992).

In a study that is important for the systemization of sampling design as well as for its reasoned approach to the investigation of ceramic production in a difficult environment, Hector Neff and his colleagues have relied heavily upon the regional trends and the degree of correspondences between the natural variation in clays and the observed variation in ceramic materials along Pacific Coastal Escuintla, Guatemala (Fig. 5). The coastal plain lies west of a chain of quaternary volcanoes, hence the sediments are derived from airborne, broadly deposited volcanic ash and other volcanic debris. Rivers formed in the volcanic uplands cut and mix sediments as they flow into the ocean. As the result of the sedimentary conditions, this is an area that is not readily seen as conducive to a compositionally based investigation. However, an underlying premise for the work in this area is that "to the extent that regional trends are characterized adequately, any particular ceramic compositional profile may be assigned to a likely zone of origin within the region, even though, in

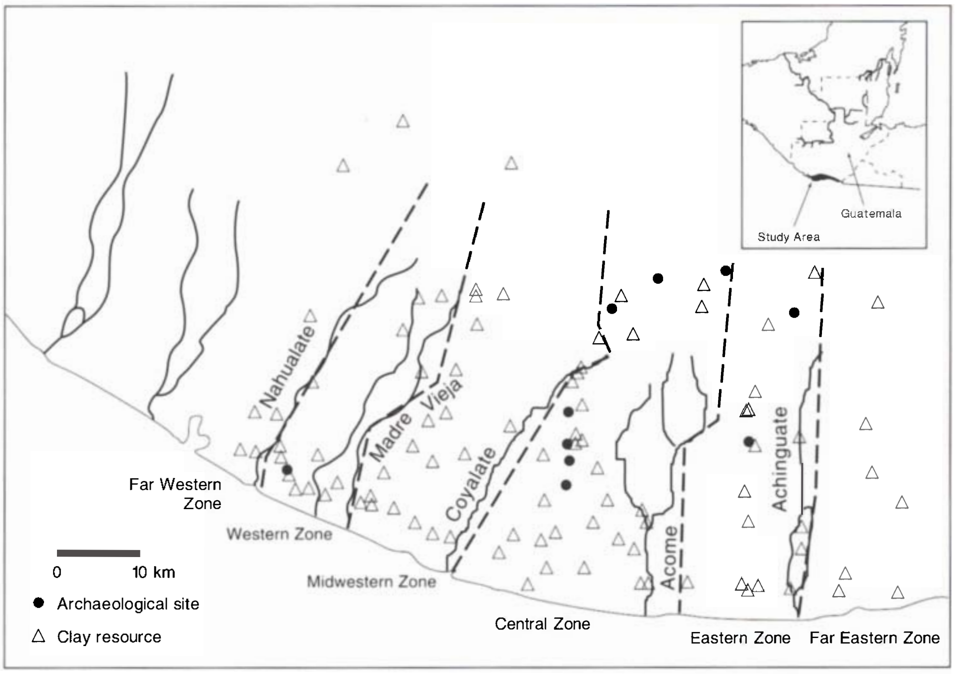


FIGURE 5. *Map of Pacific Coastal Guatemala study area.*

the vast majority of cases, *the exact locations exploited by ancient potters will not have been sampled*" (Neff et al. 1992:61, emphasis added).

Using neutron activation to obtain data on clays from fifty-five sampling locations (Fig. 5), the researchers were able to observe strong west-to-east trends. While the samples from the extreme eastern side of the sampling are differentiable from those far to the west (Figs. 6, 7), data from samples between the extremes are intermediate. Based on the clay data obtained from stratigraphic columns that revealed considerable heterogeneity, there is a more or less continuous gradation in elemental abundance as one moves from one side of the survey zone to the other. These data were used to establish a compositional baseline against which archaeologically meaningful patterns in the composition of the pottery from the coastal plain could be evaluated. Only through the systematic sampling and chemical analysis by a highly sensitive and precise technique, and informed by mineralogical data to

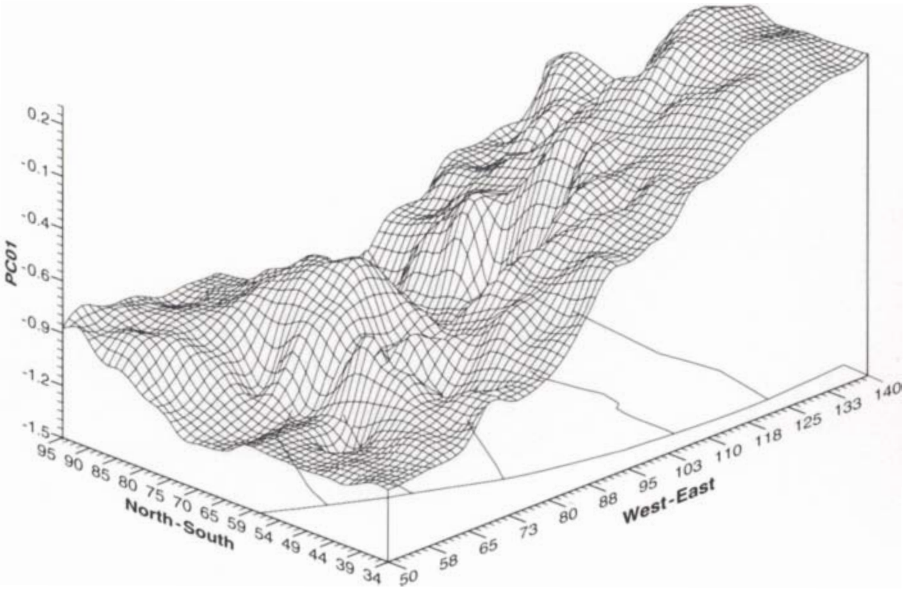


FIGURE 6. *Three-dimensional projection surfaces describing regional trends in nonstandardized scores on principal component 1 using neutron activation data from the analysis of sampled clays (Neff et al. 1992).*

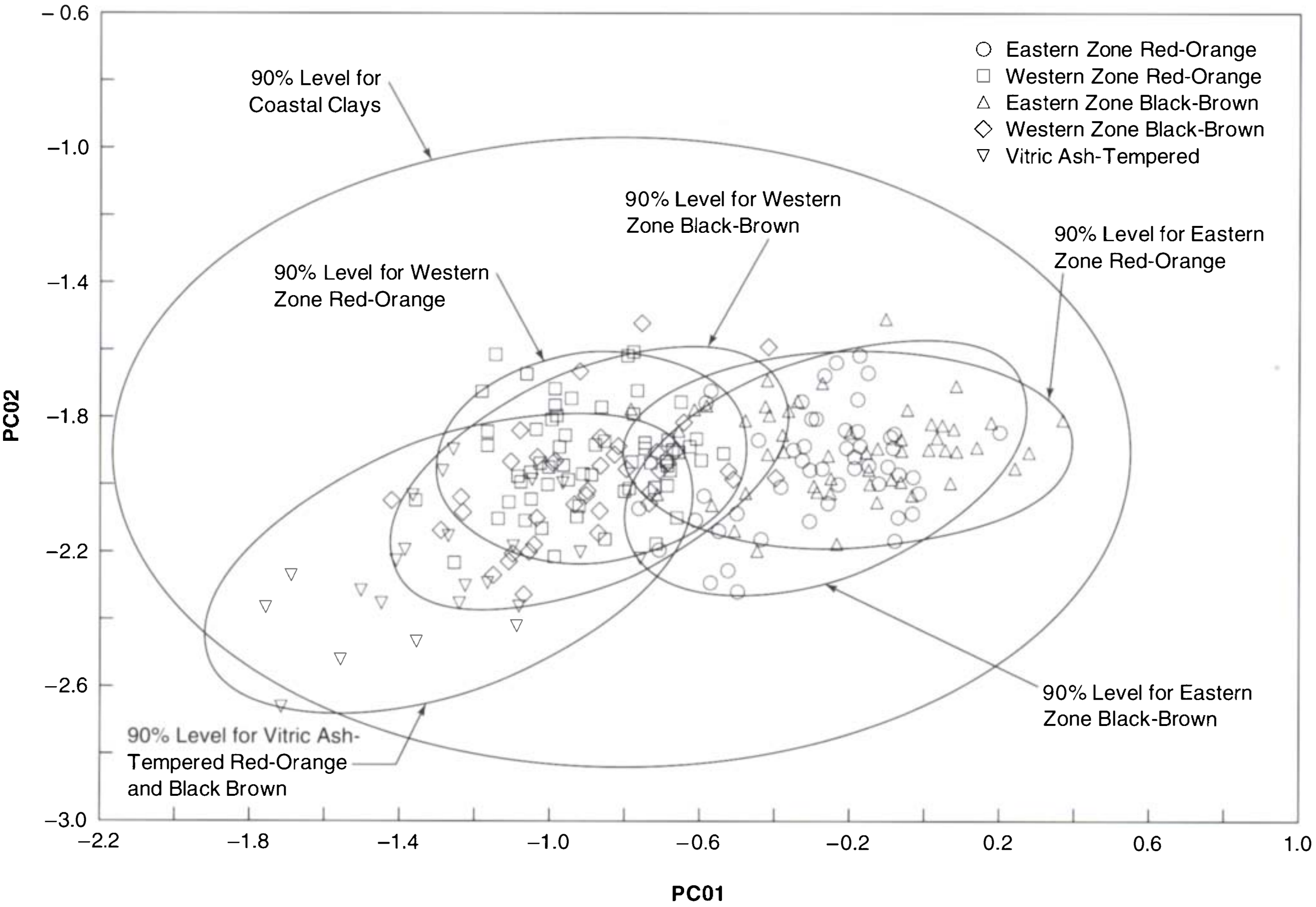


FIGURE 7. *Principal components plot showing eastern and western groups of Late Formative through Early Classic Red-Orange and Black-Brown pottery relative to variation found in analysis of raw clays from Pacific coastal Guatemala. Components-based neutron activation data. (For general discussion of the project, see Neff et al. 1992; Bove et al. 1992.)*

supplement the observation of elemental trends, was it possible to accurately allocate analyzed pottery to subareas of the coastal plain (Neff et al. 1992; Bove et al. 1992).

Paste Composition and Sociocultural Integration: The Greater Palenque Survey

Nowhere in the Maya lowlands has the nature of ceramic changes been investigated more intensively than the environs of the site of Palenque in the western part of the Maya southern lowlands (Figs. 1, 8). In the Late Classic period (approximately 600–850 C.E.) Palenque was a major civic-ceremonial center that held a position of religious and economic dominance over smaller neighboring sites. The region of intensive archaeological survey encompasses approximately 7200 square kilometers and includes thirty-three sites of varying topographic setting, size, and duration. Although some sites are up to 70 km distant from Palenque, the main focus of research is a hypothesized "sustaining" area of greatest site density within a 20–30 km radius. To document the ceremonial and economic development of the ceremonial center and changes in its relationship with the satellite sites, a detailed investigation of the pottery was undertaken that attempts to establish relative patterns in ceramic production, consumption, and exchange at the intraregional level. This ceramic research provides data that are critical for choosing among alternative sociocultural models (Rands 1967; Rands and Bishop 1980; see also Rice 1987).

As mentioned above, compositional investigations should make increased utility of a methodology that seeks a "best fit" among varying types of data in order to provide a contexturalization of the compositional information (Bishop, Rands, and

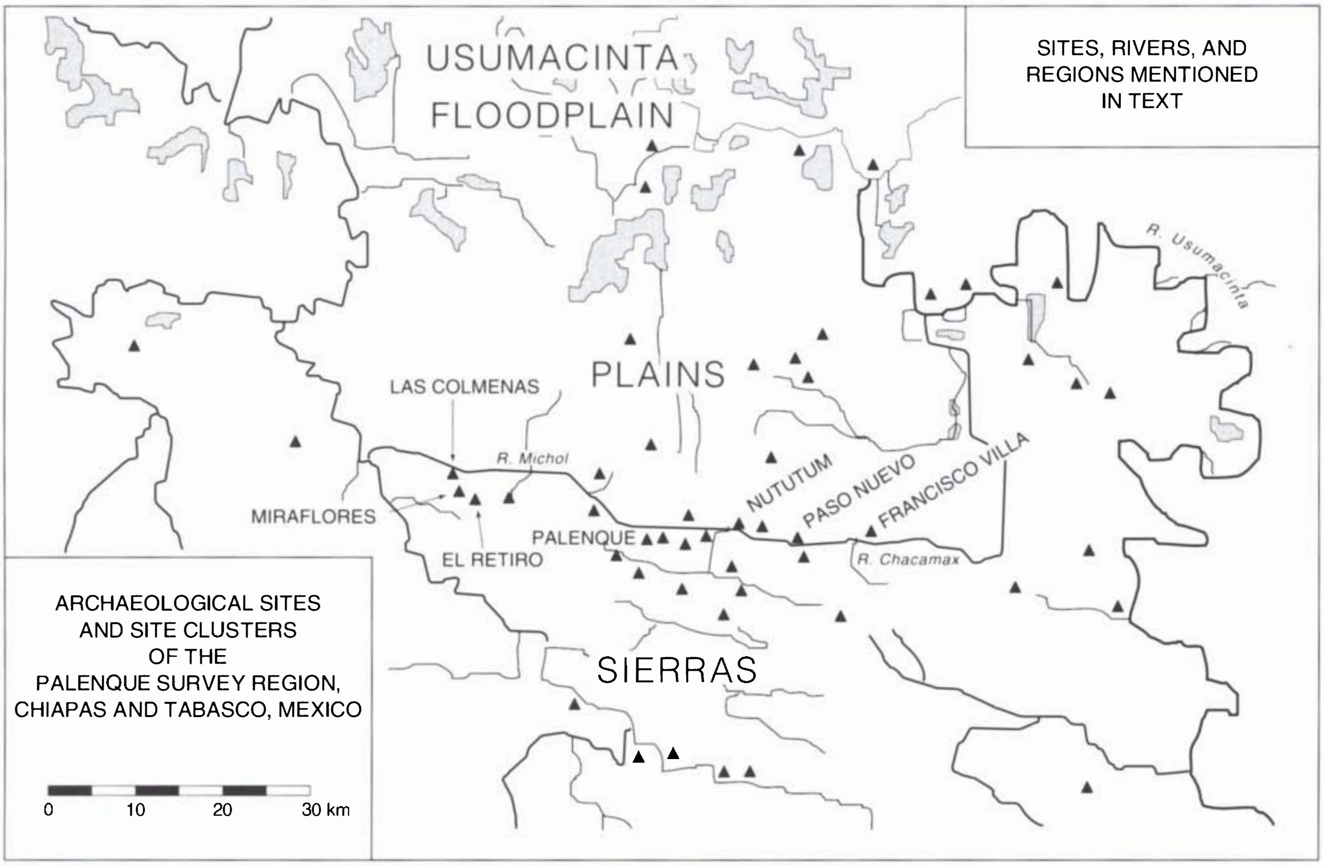


FIGURE 8. *Map of the archaeological site, site clusters, and physiographic-compositional regions of the Palenque survey. Sites identified along the Rio Michol are those glossed as "West" in text. Similarly, those identified along the Rio Chacamax are designated as "East."*

Holley 1982:319–20; Rands and Weimer 1992). Compositional patterns that are found to correlate with other attributes (e.g., spatial, temporal, formal, stylistic) become more secure, even when sample sizes of chemically analyzed specimens lie below a number of specimens that might be desirable for more rigorous statistical evaluation. Interpretations based on principals of best fit or correlational models unfortunately remain at a descriptive level of usage (Sebastian and Judge 1988:4–6) and, in themselves, do not tell us anything about the people responsible for creating the patterns we observe. Nevertheless, the very step of evaluating compositional data relative to its correlates with other data sets can assist in deriving "meaning" for ceramic distributional patterns. The use of a best fit among multiple data sets has been used extensively in the investigation of Palenque's patterns of ceramic exchange.

The physiographic and geological variation within the research area contributes to microzonal variation in clays and tempers available for pottery, thereby offering an almost ideal setting for a compositionally based investigation. Palenque is located on the first escarpment of the folded Chiapas-Tabasco Low Sierra foothills. This environment of the Low Sierra contains ceramic resources derived from the weathering of Miocene and Pliocene sandstones. The nonplastic inclusions of the pastes tend to be relatively abundant and angular and, under partial oxidization, the pottery often has a reddish-brown color. (Under controlled conditions, many of the ceramics refire to red.) North of the sierra lie the Plains, a heavily weathered Pleistocene terrace. In contrast to Low Sierra pottery, ceramics produced from resources in the Plains are more yellow-brown in color and consist of extensively weathered inclusions in lesser quantity. Some minerals, such as biotite, that are found in sierra resources are absent. To the far north is the northern Usumacinta zone and the floodplain of the Lower Usumacinta River, whose origin lies in the Guatemala highlands. Volcanic ash, absent from the Plains and Low Sierra environments, occurs as natural inclusions in the Usumacinta clays that tend to fire to a buff color. To these three major regions can be added a narrow physiographic zone at the immediate base of the sierra whose compositional characteristics are transitional to those of the Plains.

One of the strongest contrasts between the ceramic resources of the Low Sierra and those of the Plains is observed in the abundance of opal phytoliths. These siliceous mineraloids are formed in silica-accumulating plants and ultimately become part of the sedimentary cycle. While maize, a staple of Maya diet, is a silica accumulator, the high rainfall and steep runoff of the sierra largely prevents the accumulation of opal phytoliths in the Low Sierra clays. Rather, they are transported into the Plains, where various grasses and sedges produce phytoliths themselves. Plains pottery, therefore, made from resources in flatlands away from the base of the Low Sierra, tends to contain high abundances of phytolithic components as part of its clay fraction.

Low-fired pottery (below 650 °C), heavy rainfall, and acid soils mitigate against reliance on traditional modes of ceramic analysis, which rely on surface finish and decoration. If for no other reason than necessity, therefore, variation in ceramic attributes of form and plastic decoration have been supplemented by unusually intensive attention paid to the paste characteristics. The current compositional database consists of approximately 100,000 binocular characterizations of paste texture-temper properties; 2,500 ceramics evaluated for color in regular, wet, and refired state; 1,500 petrographic rank-order quantified analyses; and more than 2,300 analyses by instrumental neutron activation. Within this database, analytical sensitivity among color, petrographic, and chemical data varies depending on the specific period, subareal focus, or ceramic class under consideration.

Sampling for compositional characterization has been broad but problem specific. Palenque's local pottery and potentially intrusive ceramics at the site have been sampled with attention paid to covariation with technology, functional class, stylistic features, and change through time. Throughout the survey area, sampling has been "Palenque-focused," which emphasizes but is not restricted to the analysis of pottery with modal or formal relationships that are similar to that which occurs at the major center. We have not attempted to isolate the patterns of exchange that might have taken place among the small, neighboring sites on a scale of sampling equal to that at Palenque. With this lesser sampling, inferences about the local production at the survey sites are made by resorting to the use of broader compositional patterns that could potentially include several sites from within one of the physiographic units.

To date, archaeological interpretation of the compositional, or production loci, differences within the Palenque survey area have been reported primarily on a broad regional level (e.g., Rands 1967, 1987; Rands and Bishop 1980; Rands and Weimer 1992). Here, I will use findings about various Late Classic form classes to illustrate the interrelationships among archaeological, petrographic, and chemical variables.

The framework of the Classic period sequence at Palenque rests on strong ceramic traditions that "show cohesiveness in paste, technology, and broad categories of vessel shape that should relate to function, as well as in certain aspects of surface finish" (Rands 1987:206). Prominent at Palenque is a "red-brown paste tradition," which it shares with other sites in the Low Sierra. In general the ceramic paste has a textural range that places it within what could be a "tempered" category, characteristically containing medium-to-fine quartz sand. A minority of the red-brown ceramics are of a slightly finer texture with a greater predominance of silt-size rather than medium sand-size nonplastic inclusions. Mode changes within shape attributes of basin-bowl and plate forms assist in defining chronological divisions within the red-brown paste tradition. Compositionally, the relative consistency of a dominant mineralogical and chemical pattern within the red-brown pottery tradition that endured for 600 years contributes to our accuracy of inferring what pottery may have been locally produced.

In addition to the red-brown paste tradition of basin-bowls and plates, the preponderance of other ceramics produced at Palenque or in its immediate vicinity are more ritually oriented: cache vessels, incense burner stands, and figurines (Fig. 9). The incense burner stand is not a receptacle for an offering but rather serves to receive a conical-shaped vessel that is used as the burner. The stands are iconographically elaborate, frequently adorned with symbols associated with the sun god or jaguar deity. Figurines, although a single form class, actually represent several different modes of production: mold-made figurines, mold-made and hand-modeled figurines, and hand-made figurines. All of these types of figurines are represented in the "local" Palenque compositional profiles and while not all of the figurines recovered in the survey area are attributed to Palenque manufacture, the number of figurines that are attests strongly to the ritualistic character of Palenque production.

Against the characterized body of Palenque's locally produced pottery and within the context of mineralogically or chemically differentiable pastes for other subregions within the survey, changing patterns involving the importation of predominately utility and open-serving forms have been determined. These patterns

Figure 9. *Ceramic form classes representing local production in the immediate vicinity of Palenque: (a) incense burner stand (Murcielagos); (b) figurine head; (c) basin-bowl (Motiepa); (d) cache vessel (Murcielagos); (e) dish (Balunte). All excavated at Palenque.*

allow the formulation or testing of various models that can account for the observed patterns of production and distribution.

Prudence Rice (1987) has noted that no structures have been found in the Maya region that would indicate the presence of central markets, storerooms, or identified workshops, but she follows William Coe (1967:73) and others who have observed that the open plazas of the civic-ceremonial centers could have been used to support market activities. Combining the archaeological data from Tikal with ethnographic analogy for modern pottery production activities in the Guatemalan highlands (Reina and Hill 1978), Rice suggests that some ceramic form classes could be the result of intracommunity specialization, although she finds no evidence "to support a strong directive role for Classic centers in regional economies, at least *in terms of traditional archaeological indicators* of centralized systems of production and exchange" (1987:77, emphasis added). This generalization, however, may be subject to modification.

New data sets reflecting the breakthroughs in hieroglyphic decipherment (Culbert 1988) and the emergence of regionally specific trends in ceramic compositional patterning are providing potential for new "archaeological indicators" of maintenance and change in economic and political organization. The following scenario is based on spatial and temporal patterns in selected ceramic classes or form modes and ceramic production as inferred from the compositional data (Rands 1974, 1977; Rands and Bishop 1980; Rands et al. 1982; Schele 1986). While subject to further substantiation, change within the ceramic patterns covaries with change in rulership, architectural achievements, and other aspects of Palenque society suggesting some level of elite administrative involvement in determining the nature and directionality of Palenque's system of exchange (Fig. 10).

The earliest Classic period at Palenque is Picota (150–350 C.E.). No architectural features have been recovered that are assignable to this period, during which time social organization probably was loosely organized at the village level. Picota marks the beginning of the sustained red-brown paste ceramic tradition and shows some continuities with traits from an earlier Pre-Classic period. Certain ceramic traits show correspondence to those observed at other Maya civic-ceremonial sites but these traits are spread widely through the southern Maya lowlands. Overall, Picota ceramics represent localized concepts of shape and decoration.

The Motiepa ceramic complex (350–500 C.E.) includes the Maya core area or "Petén-derived" styles, most likely emanating from the southern Usumacinta zone (central and upper Usumacinta River vicinity) and adjacent regions (e.g., Piedras Negras), in addition to modifications in the local tradition. While some of the pottery, including gloss surface pottery with carbonate temper, is imported from the southern Usumacinta zone, a few ceramics suggest local imitation. Recorded in later inscriptions but relating to this period is a record of the Palenque rulers, starting with the accession of Bahlum-Kuk I to office in 431 C.E. and followed by two other rulers in 435 and 487 C.E. (All dates for the accession to rulership at Palenque are taken from Schele 1986:111.) The evidence observed in the recording of rulers and by ceramic links to the southern Usumacinta zone and indirectly to the Maya core

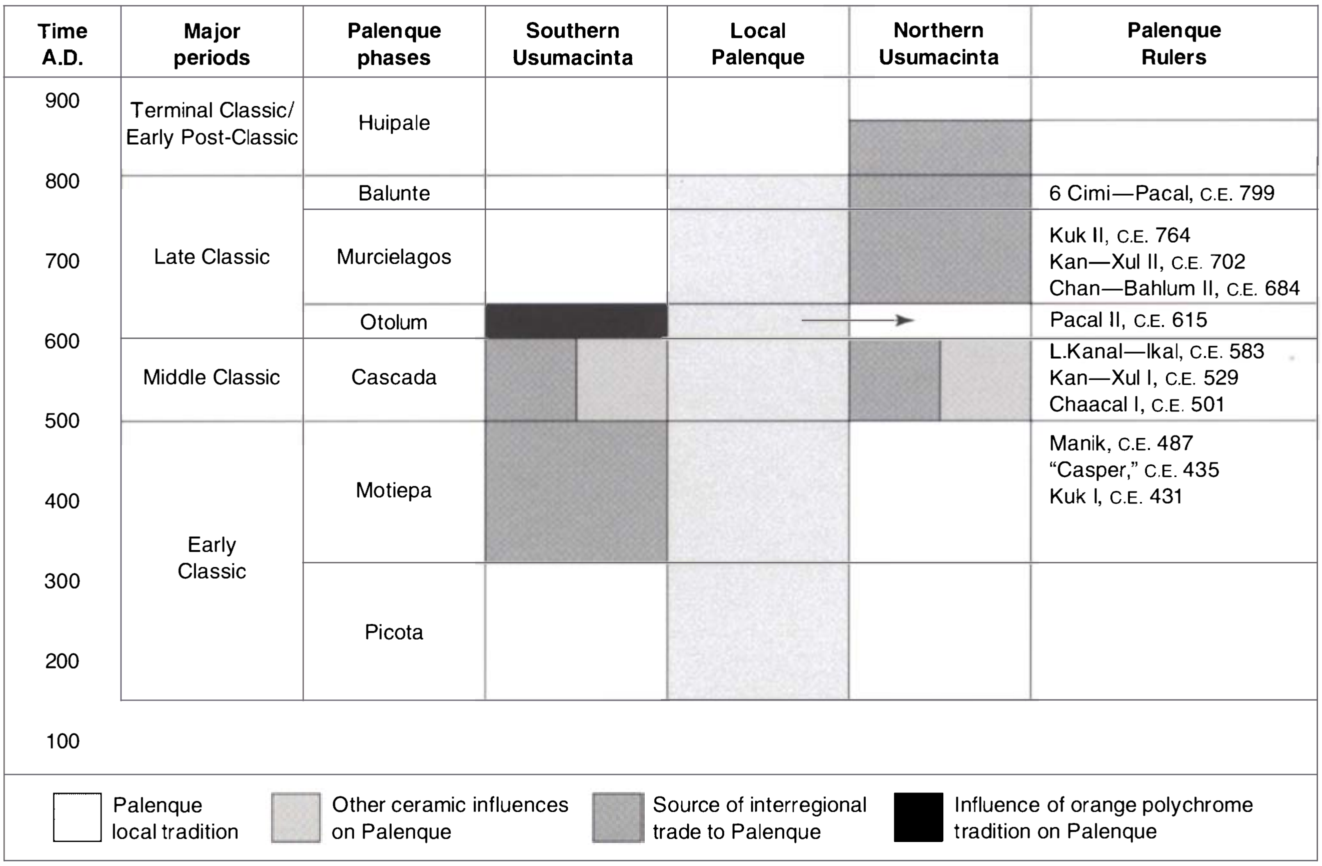


Figure 10. *Chronological chart correlating ceramic phases at Palenque with sources of ceramic influence or trade and with dynastic rule. "Sources" are generalized, extending beyond the southern and northern Usumacinta, respectively.*

area reflects the evolution of the previously locally oriented village on the Maya periphery toward a more hierarchically organized society.

Motiepa was followed by the Cascada ceramic complex (500–600 C.E.), which is defined in part by modifications within the local ceramic tradition. Fine paste pottery greatly increases in quantity. Perhaps there was less importation of pottery than in Motiepa, but exotic ceramics seem to reflect a larger number of sources for ceramic goods or concepts (Rands 1987:218–19). Ceramic links to the Maya core area via the southern Usumacinta zone become more attenuated or less strongly focused, although it was during Cascada that classically vaulted tomb construction is first known at Palenque.

The following Otolum period (600–864? C.E.) is one of a strongly localized orientation and great building activity. The period essentially spans the long and important rule of Pacal II, who ascended to rulership at the age of twelve in 615 C.E. His reign was the longest of Palenque's rulers, lasting until his death in 684 C.E. During Otolum, contacts with the southern Usumacinta zone apparently grew weak or were intentionally reworked into localized patterns as Palenque grew more involved with nearby sites generally lying east and west along the first escarpment of the Low Sierra. Architectural construction at Palenque included the Templo Olvidado, the Conde, major construction in the Palace, and all but minor modification of the Temple of the Inscriptions, a temple-pyramid built to hold Pacal's tomb.

Palenque extended its influence toward the northern Usumacinta zone in the Otolum period. The previous directionality of stimulus and receptor were reversed as innovations in form and decoration of Palenque pottery were elaborated or otherwise modified by artisans of the more northern sites. Palenque's increasing importance is found particularly along the escarpment, at sites along the Rio Michol in the western part of the survey. A building at the western site of El Retiro (Blom and La Farge 1926–27:161–64), perhaps built sometime near the transition of Otolum to the following Murcielagos period, is similar in architectural design to a series of structures at Palenque. Present in the west also is the recording of the Palenque emblem glyph, found in inscriptions at both El Retiro and Miraflores, that signifies inclusion within the Palenque polity (Schele and Freidel 1990:58–60).

Especially notable in the ceramic assemblage for this period is a wide everted-rim tripod plate (Fig. 11a). Its exterior is unslipped, slip or painting being confined to the everted lip or less frequently extending to the vessel interior. Although Palenque became a major source of ceramic innovation, certain aspects of the locally produced pottery still responded to some outside influences as seen in its reworking of a contemporary, widely spread orange polychrome tradition. At Palenque, however, the orange polychrome decoration found on the Otolum plate form is geometric rather than figural and lacks the gloss treatment that was typical of the core area. Fully within the red-brown, sand-tempered paste tradition, the wide everted-rim plate occurs principally at Palenque with lesser occurrence at sites to the west along the Rio Michol (Fig. 8) (Rands 1974:63). The presence of this distinctive plate and other Palenque-like pottery at the western sites of El Retiro, Miraflores, and Las Colmenas offers a special opportunity to investigate aspects of Palenque's relationship to the smaller centers.

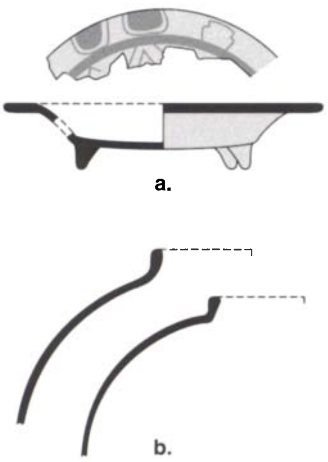
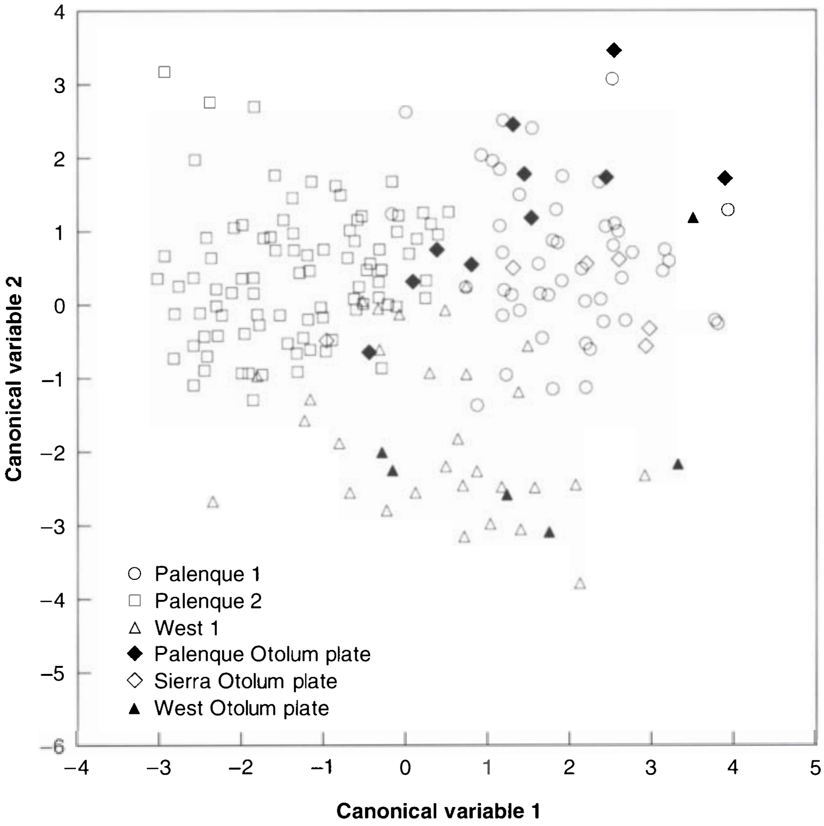


FIGURE 11a, b. *Illustrations of: (a) wide everted-rim tripod plate, red-black-orange, Otolum ceramic complex, Palenque; and (b) short (stubby) vertical-neck globular jars with thickened rims, Balunte ceramic complex.*

A previous observation based on neutron activation data was that the western sites produced the Otolum everted-rim plate locally as well as importing it from Palenque (Bishop 1975). This finding has been substantiated through analyses of additional samples as shown in Figure 12. In this figure, axes derived by linear discriminant analysis are used to illustrate major compositional differentiation among selected Palenque ceramic compositional groups and a group from the western sites of El Retiro, Miraflores, and Las Colmenas that has a "sierras composition." The Palenque units shown in the plot are made up almost exclusively of red-brown basin-bowls, figurines, cache vessels, and incense burner stands. Palenque compositional unit 1 is closely related, albeit separable from the other Palenque specimens. While the same inventory of form classes are present in both Palenque groups 1 and 2, the Otolum wide everted-rim plate is more abundantly represented in group 1. Differentiable from both of these Palenque units is the group representing the western sites' production including the distinctive Otolum form of plate. Overall, the compositional patterns for production and distribution of the Otolum wide-everted rim plate suggest that during Otolum and extending through the following period the western sites were closely linked to Palenque. This interpretation is supported by the presence of Palenque emblem glyphs, particular conventions of ceramic forms, and other compositional and archaeological data.

During the succeeding Murcielagos period (684–750 C.E.) the direct red-black-orange polychrome painted, everted-rim Otolum plate disappears, and resist paint decoration and incising increase. The elaborate incense burner stands were pro-

FIGURE 12. *Discriminant analysis plot showing Palenque reference groups 1 and 2 and one group from sites along the Rio Michol to the west of Palenque. Separate symbols have been assigned to the Otolum wide everted-rim form to call attention to its sources of production at Palenque and also in the west. One specimen with a western site provenience can be seen at the upper right of the plot in the Palenque 1 cluster, signifying production at Palenque with movement to a western site, where it was archaeologically recovered. Elemental loadings for the discriminant axes reflect a complex pattern of minor differences among the depicted groups that are based on the Palenque-Low Sierra compositional patterns.*



duced in quantity. The northern Usumacinta fine paste ceramic tradition, disrupted during Otolum, again becomes prominent. Thin-walled pottery becomes common. The ceramic assemblage expands beyond the localized production focus of the preceding period, especially with a greater percentage of imported pottery showing ties northward toward the Usumacinta floodplain. Architectural construction continues at Palenque after the death of Pacal, with important stylistic innovations during the reign of his son, Chan-Bahlum II. Kan-Xul II, a second son of Pacal, ascended to rulership in 702 C.E. but was removed through his capture in 720 C.E. and ultimate execution in Toniná, a Classic period civic-ceremonial center in the Ocosingo valley, 60 km southwest of Palenque (Schele and Freidel 1990:469). Rulership following Kan-Xul apparently did not offer much job security, as three rulers followed during the next twenty years.

The Balunte period (750–810? C.E.) shows further decline in use of painted pottery but a rise in buff-brown paste classes. Dishes with Z-angle profiles and large hollow feet (Fig. 9e) and several beaker forms are diagnostic of the period. As reflected in the compositional data, primary contacts appear to be from unidentified locations relatively close to Palenque, perhaps along the base of the escarpment. Slightly more distant contacts are to the north, with groups that apparently moved from the Low Sierra into the Plains. Evidence for these contacts can be observed in the compositional data for light-buff jars and basins that were produced in the Plains and exported to Palenque. For example, compositional data for a diagnostic jar form with a short, stubby neck (Fig. 11b) suggest economic links between Palenque with sites to the west but more strongly with sites with the Plains complying to the east along the Chacamax River (Fig. 8). In Figures 13a and 13b the

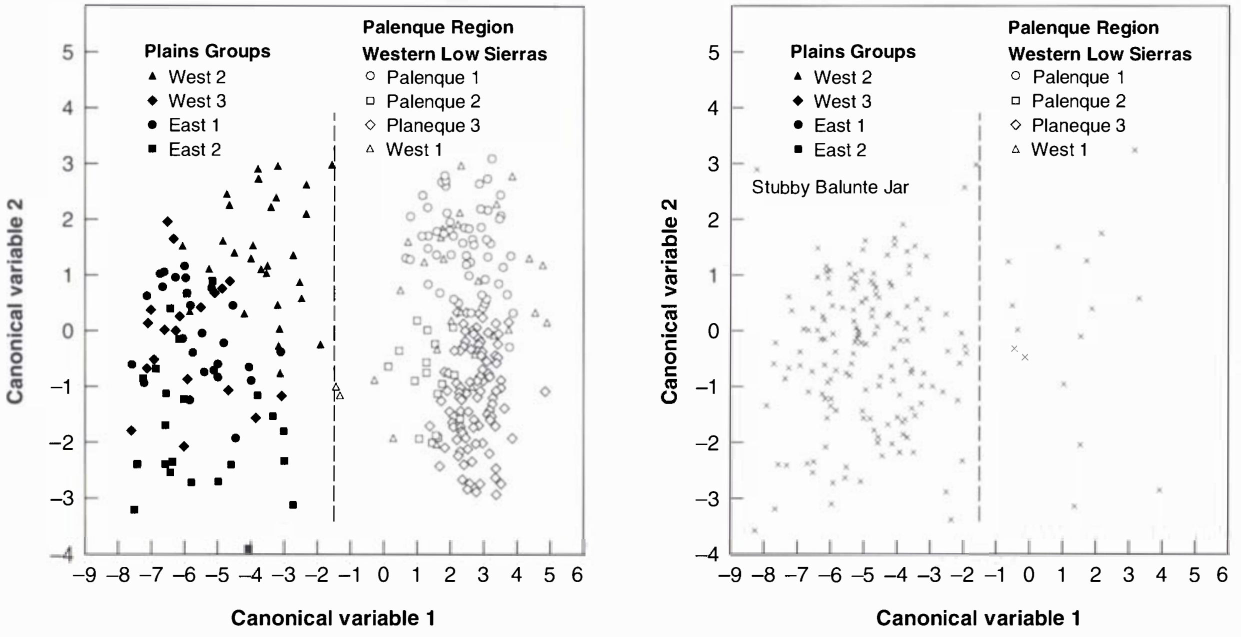


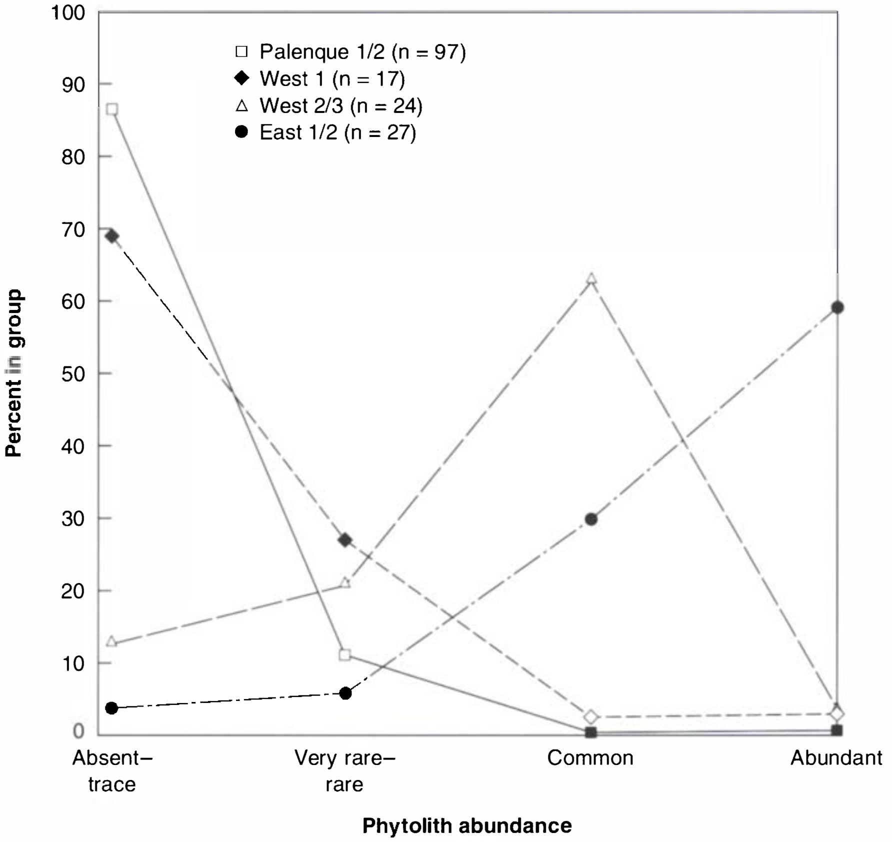
FIGURE 13a, b. *Discriminant analysis plots. A vertical dashed line has been added to call attention to the left-right differences. Plot on the left (a) shows major compositional difference between groups from the Palenque-Low Sierra groups (right side of the graph) and those from eastern and western Plains sites (Fig. 8). Plot on the right (b) shows the projection of instrumental neutron activation analysis data. Data for stubby Balunte jar form onto the same discriminant axes. Numbers of stubby Balunte jars, already present in the groups plotted on the left side of this graph, have been augmented with similar forms that were not members of the represented reference groups.*

discriminant analysis plot of compositional groups representing local Palenque ceramic production and a group with a western Low Sierra composition are shown to be separable from groups with site proveniences east or west of Palenque having Plains compositions. When the data obtained from analyses of stubby-necked Balunte jars are projected onto the same pair of axes, the compositional affiliation of the jars with the Plains rather than Low Sierra is readily apparent.

Phytolithic abundance (Fig. 14) strongly supports the chemical pattern of intraregional compositional differentiation and location for stubby-necked Balunte jar production. Whether the stubby Balunte jar was produced from the specific Chacamax sites sampled in the survey or from other sites in the general vicinity is somewhat secondary compared to the demonstration that this region appears to be strongly incorporated within Palenque's ritual and economic spheres as inferred by the presence of Palenque-produced figurines and incense burner stands at the Chacamax sites and stubby-necked jars imported by Palenque.

The foregoing has been a highly selective sketch of some of the changes that have been noted during the investigation of the changing relationship of the civic-ceremonial center of Palenque with its satellite sites (Fig. 10). Based on patterns of ceramic composition and more traditional types of archaeological data, both long- and short-distance *intra*regional exchange of pottery existed within the survey area and varied by period. The changes in these patterns involved utilitarian, serving, and ritual ceramic objects and must have reflected multiple influences, including administrative regulation. Whatever Palenque's previous role as a central place, the rule of Pacal and his successors was clearly one of subregional dominance and was marked by shifting economic and political strategies. Among the locally made ceramics, those with a ritual function can be inferred to have reinforced the individual status or power of the ruling elite. The exportation of ritual ceramics to localities close to Palenque or movement of pottery via pilgrimages to shrines validating territorial boundaries would reflect an interest in integrating various regions into the Palenque

FIGURE 14. *Line graph showing phytolith abundance. The relative absence or scarce occurrence of phytoliths in the clay resources of the Palenque and West 1 groups (Low Sierra) is contrasted with the common to abundant phytolith presence in the Plains resources (West* $^2/_3$ *and East* $^1/_2$*). Groups relate to those shown in Figure 13 except that Palenque group 3, consisting mostly of figurines, is omitted because of lack of petrographic data.*



polity—a linkage that was reinforced by exportation to Palenque of certain utilitarian ceramics from particular sustaining areas. Changes in the directionality of Palenque's importation and exportation also may have had an adaptive value in promoting greater security for the polity (Flannery 1968; see also Brumfiel and Earle 1987). Although Flannery (1968) discussed the adaptive value of exchange from an interregional perspective, "encouraged" production and exchange could have fulfilled a similar function more locally.

Maya archaeology is now replete with vestiges of warfare among neighboring centers (Fig. 15) (and examples in Demarest 1978; Johnston 1985; Schele and Freidel 1990). Moreover, there is increasing evidence that the nature of warfare changed from largely limited ritualistic activities that maintained an equitable level of intersite relationships (Freidel 1986; Schele and Mathews 1992) to an intensified or destructive form involving territorial expansion (Johnston 1985; Demarest et al. 1988). The capture and execution of Kan-Xul II in 702 C.E. by the ruler of Toniná is indicative of political instability within the Low Sierra. Was the development of the Late Murcielagos-Early Balunte sites in the northern Plains a result of population and agricultural pressures in the Low Sierra, a wish to be removed from political instability, a buffer against outside aggression, or a move to be closer to the northern groups that were figuring more prominently in Palenque's social, economic, and possibly political activities? As always, more questions arise than are answered by present data or understanding. What becomes clear as we continue to seek the "best fit" among our data sets is that several alternative models will need to be evaluated.

Pattern Variation Among Maya Painted Pottery

The formal or typological nature of the Palenque pottery discussed above had little more than infrequent modal correspondence or generalized resemblances to the pottery produced at other major Maya civic-ceremonial centers of the southern lowlands. In the core area, painted decoration gave expression to strong ceramic traditions. Although forming the bulwark of Maya temporal and spatial systematics, the painted ceramics were long ignored for what they reveal about aspects of social and economic activity (Fig. 15). The usual fragmentary condition of the archaeologically recovered pottery makes it difficult to use for detailed stylistic analysis. However, in one study the polychrome-painted tradition of the Classic period was divided stylistically into three subregions thought to reflect general patterns of trade, possible political alignments, or contact beyond the subregion (e.g., Adams 1971:159, 161). Unfortunately, while generalized style-based groupings can be made, they are often of limited utility because of the uncertainty as to where the polychromes were manufactured.

In 1975, Jeremy Sabloff (1975:236) suggested that questions pertaining to possible ceramic trade among Maya sites could be addressed by a program of instrumental neutron activation analysis comparable to that undertaken for the Palenque region. The suggestion made by the pioneering Maya ceramist Robert E. Smith that there might have been as many as a dozen manufacturing centers for polychrome pottery in the southern lowlands during the Late Classic (Sabloff 1975:132) could also be evaluated. It indeed seemed clear that a compositionally based study of Classic Maya polychrome pottery should be undertaken, for scholars attribute important iconographically elaborate vessels to various production areas impressionistically and then draw social or political inferences from such subjective attributions (e.g., Adams 1971:69–77; Coggins 1988:107–17).

Another impetus for a compositionally based, regionwide characterization of Maya polychrome paste variation was the conjecture of Michael Coe's 1973 publication of *The Maya Scribe and His World.* In this ground-breaking book, he suggested that the elaborately painted ceramic vessels, such as the one shown in Figure 16, were created to be buried with deceased elite and that scenes painted on the vessels related to activities that took place in Xibalbá, the Maya underworld, as described in a six-

FIGURE 15. *Late Classic Maya polychrome cylinder. Nonprovenienced.*

FIGURE 16. *Late Classic Maya polychrome cylinder. Nonprovenienced. Height 19.3 cm; diameter 16.2 cm. Maya Ceramics Project Archive MS0158/10656. Duke University Museum of Art, accession 1976.93. Scene depicts one of the paddler twins in a canoe conveying a soul to the underworld.*

teenth-century Maya book from the Guatemalan highlands, the *Popol Vuh.* While not discounting the possibility that some of the scenes might relate to historical events, similar to those demonstrated for carved Maya monuments (Proskouriakoff 1960, 1963, 1964), Michael Coe (1978) interpreted the vessels as instruments to prepare the dead for their journey into a world metaphorically depicted as one of ritual and dread expectation.

About the same time that Coe's *Maya Scribe* appeared, major advances were being made in the study of Maya hieroglyphics (e.g., Mathews and Schele 1974; Schele 1974). Rather than supporting the prevailing notion of calendrical purpose, the hieroglyphs were shown to follow a spoken form of Maya, affirming an earlier suggestion made by Russian scholar Yuri Knorozov (1952; in English 1958). Even when the specific glyphic constructions could not be deciphered, the function of the glyphs frequently could be determined (Schele and Freidel 1990:37–63). A method for reading recorded texts that accompanied the visual presentation of historical events was unfolding rapidly, with potential data occurring not only on carved monuments or wall panels but also on pottery. Thus, thematic renderings of subjects illustrating birth, life, accession, death, and apotheosis were found to be linked with calendrical, historical, or ritual textual content. This ushered in an entirely new source of information on the ancient Maya, one found to inform on intra- and interregional relationships and political organization (Culbert 1988).

It is a sad fact that Maya pottery sufficiently intact to study for its now recognized thematic and epigraphic value is known largely from collections of specimens that have been looted from their archaeological site and sold on an economically fed art market. Bereft of context, their scientific value is immeasurably lessened (Pendergast 1991; Taschek and Ball 1992), usually to little more than formal descriptions (e.g., Quirarte 1979). Given, however, the developments in iconographic and epigraphic analysis, and the success of instrumental neutron activation analysis in the Palenque region, it appeared feasible to use a paste compositional approach to address the issue of Late Classic Maya ceramic production and distribution regionwide.[2] Minimally, the proposition of one or many production centers could be evaluated.

A more important component, however, was the attempt to ascertain the loci of ceramic production and the pattern of ceramic dispersal among producing and consuming sites. With a sufficiently thorough regional characterization of the central Maya lowlands, a compositionally based investigation could attribute the compositional profiles for the iconographically and epigraphically elaborate but nonprovenienced specimens to a highly delimited production source area, or possibly, site. This would permit an objective, spatial perspective for the interpretation of the scenes, glyphic texts, and informational context—either ritual or historical—of whole vessels. It was obvious from the start of the project that these objectives would be achievable only through the use of an extensive database of chemically based reference materials derived from archaeologically excavated pottery and through a long-term program to broadly model compositional variation throughout the ancient Maya world. In pursuing these goals, the project would provide data, if indirectly, pertaining to organizational aspects of ceramic production as mediated by elite consumptive patterns. Even in the absence of attribution, the potential of evaluating the compositional cohesion, or lack of it, among members of stylistically defined groups informs on the existence of workshops and, potentially, individual painting styles.

The Maya Ceramics Project began in 1978, supplementing the Palenque region program of analysis by investigating excavated Late Classic pottery from various sites that was curated at the Peabody Museum.[3] Since then the project has received sampling access to many national and international collections of professionally excavated as well as nonprovenienced pottery (see distribution of intensively sampled lowland Maya sites, Fig. 1). To date, approximately 12,000 analyses of pottery samples have been carried out by neutron activation analysis, including approximately 1,600 whole vessels. The interpretative activities using this increasingly unwieldy database are being furthered significantly by the continuing collaboration of archaeologist and art historian Dorie Reents-Budet, who joined the project in 1981 (Bishop et al. 1985a, 1985b; Reents 1985, 1986, 1987; Reents and Bishop 1985, 1987). A synthesis of regionwide compositional variation is in progress; in the interim, however, the large size and geographic coverage of the database has provided a unique background against which more site-specific questions of local versus nonlocal production have been addressed. Reference to many of these projects can be found in Beaudry (1991).

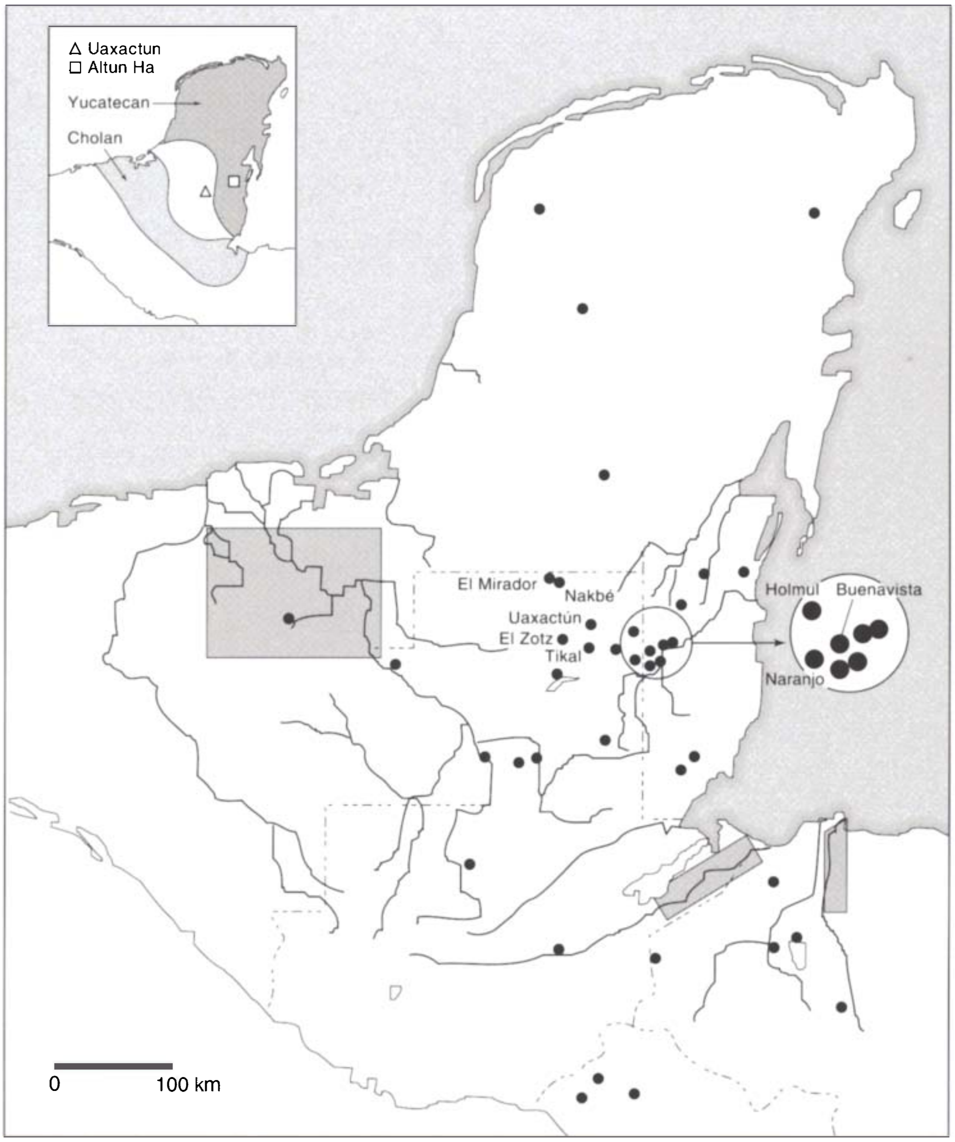
Prior to presenting examples of findings that have been made, a caveat is necessary. A successful characterization of the ceramic production of a targeted site or region results from a combination of several factors, including research specificity, geological diversity, archaeological recovery, site duration, and nature of past social processes responsible for the pottery we study. These factors influence the content and form of the archaeological record. It is not surprising, therefore, that despite the large size of our existing database, dependent as it is on largely fortuitous and variably intensive sampling, coverage is often less than adequate. It is also frequently the case that many sites require the formation of multiple reference groups to reflect more adequately the covariations of paste, form, decoration, and temporal placement. Nevertheless, within the limits of our sampling, compositional group differences have been found that can differentiate among the pottery produced at sites, some of which are separated by only a few kilometers (Bishop et al. 1985a).

A Dancer Plate Example

A simple example of an archaeological inference that can be strengthened by compositional data is found in the Late Classic production of polychrome tripod plates (Fig. 17). This type of pottery was abundant at Tikal (Fig. 18) during the Late Classic period. Ceramic decoration included the occasional presence of bands, with or without glyphs, around the inside of the rim and a human or animal figure in the dish center. In one version of this general stylistic program, the central figure reminds one of a celebrant, implying a quality of motion with legs in a position of dance. This theme of the "priestly celebrant" is noted by Clemency Coggins (1975:269) as one that underwent refinement at both Tikal and Uaxactún. She also notes that the most sophisticated example from Uaxactún (Smith 1955:fig. 73a) was recovered from an elite burial and in its more elaborate, more " 'calligraphic' style is closely related to the plates of Tikal" (Coggins 1975:269).

FIGURE 17. *Late Classic Maya polychrome plate. Nonprovenienced; compositionally attributed to Tikal. Dimensions not recorded. Maya Ceramics Project Archive S0657/13667.*

FIGURE 18. *Map of the Maya area naming central Petén core area sites of Tikal, Uaxactún, and El Zotz and the Guatemalan-Belize border sites of Holmul, Naranjo, and Buenavista del Cayo. Insert map: Classic period distribution of Cholan and Yucatecan speakers (after Schele and Freidel 1990:fig. 1:2).*



Was the Late Classic polychrome pottery of Uaxactún and Tikal made in only one center as once suggested by Tikal ceramicist T. Patrick Culbert (cited in Sabloff 1975:236)? If so, similarity of compositional profiles might be observable in the data from analyses of the dancer plates. A discriminant analysis plot of analytical data for groups with site proveniences at Tikal, Uaxactún, and El Zotz (Fig. 18) is shown in Figure 19. Within this part of the Maya core area, site-specific patterns within the Late Classic polychrome volcanic ash-tempered ceramic pastes are found that differ only minorly over a 300–500-year period. When compared to the compositional differences observed among the pottery produced at these sites, we can evaluate, for example, the question of the dancer plate production. To date, all of the approximately thirty priestly celebrant or dancer plates that have been analyzed have compositional patterns that are comparable with other pottery attributed to Tikal. Plates were produced at nearby sites such as that of Uaxactún (Fig. 20), but not, however, in the dancer program.[4] It is likely that the different styles of plate decoration, once the vessels are attributed to their production loci, are one more reflection of the hierarchical relations that existed between giant Tikal and significantly smaller Uaxactún.

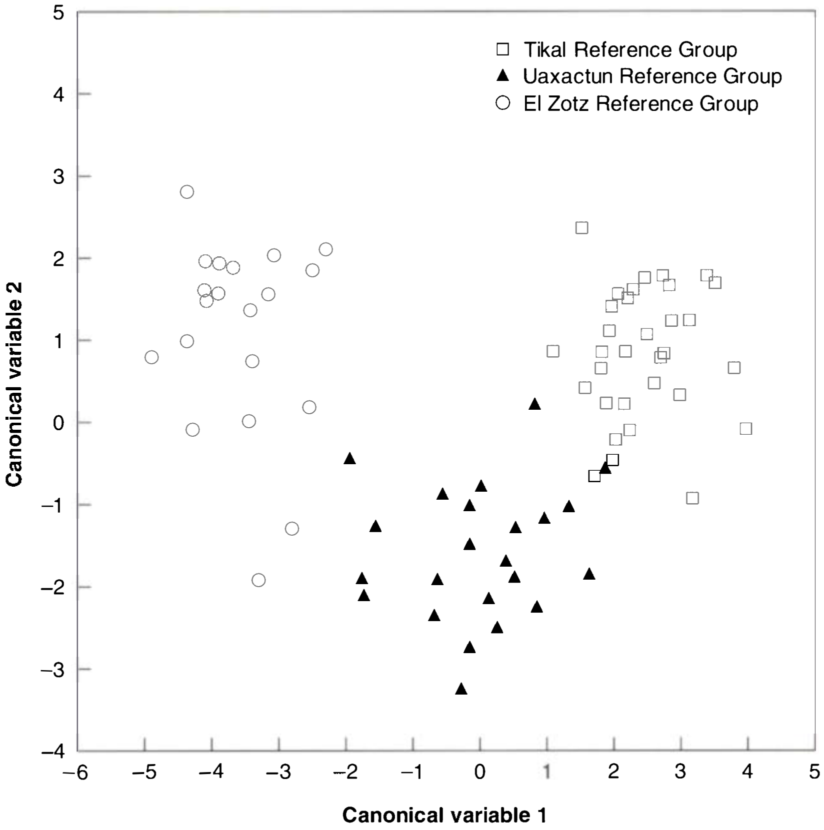


Figure 19. *Discriminant analysis plot for instrumental neutron activation analysis data for Tikal, Uaxactún, and El Zotz.*

Figure 20. *Late Classic Maya polychrome plate. Nonprovenienced; compositionally attributed to Uaxactún. Height 8.6 cm; diameter 31.5 cm. Maya Ceramics Project Archive MS0392/10976. Duke University Museum of Art, accession 8.1980.27.*

Workshops, Codex Pots, and Scribes

Codex-style ceramics employ a fine, almost calligraphic, black-brown line on white or yellowish-cream background and constitute a highly distinctive style of pottery in a manner reminiscent of Maya folding-screen books (Fig. 21). Scenes frequently are framed at the vessel rim and base by red or black bands. Virtually unknown earlier, great numbers of these carbonate-tempered vessels appeared in the late 1970s.

Figure 21. *Late Classic Maya Codex-style vase. A seated god with Moan bird headdress is engaged with female attendants while two deities sacrifice a bound captive. (For extended discussion of the scene, see M. Coe 1978:16–21.) Maya Ceramic Project Archive MS1404. The Art Museum, Princeton University, accession 75–17.*

The iconography of many of the scenes depicted is extraordinarily complex, consisting of hieroglyphic bands and cartouches, planetary or sky bands, and historical or mythological scenes. Following Coe's theory that many of the scenes found on the Maya vessels relate to the afterlife (M. Coe 1973), Francis Robicsek and Donald Hales (1981) assembled a large photographic corpus of 330 Codex vessels, approximately one-half of which they considered to be fragments from a single mythological story. Using stylistic criteria, some of the vessels were attributed to individual artists or to several production areas, widely dispersed throughout the southern Maya lowlands.

One rumored source for at least some of the Codex pottery was near the modern habitation of Carmelita in the Guatemalan northern Petén. The strength of this association probably stemmed from the fact that Carmelita has served for many years as a place where Maya vessels changed hands from the campesinos who loot them from the ruins to the middlemen who sell them into the world art market. Based on the evaluation of the neutron activation data obtained from the study of fifty-nine Codex-style vessels, I concluded that these data were consistent with production from a single, if generalized, source but cautioned that more vessels in this style needed to be analyzed prior to attaching significance to variations observed in the data set (Bishop, quoted in Robicsek and Hales 1981:239–40).

Subsequent analysis of additional vessels caused Reents-Budet and Bishop to conclude that a source for the Codex-style pottery was located somewhere north-northwest of Uaxactún and south of El Mirador (Fig. 18) at the Guatemalan-Mexican border (Reents and Bishop 1987). Later support for this conclusion was obtained through the excavation program of Richard Hansen (Hansen et al. 1991), who recovered Codex pottery in its archaeological context at the site of Nakbé, located between Uaxactún and El Mirador and northeast of Carmelita.

Among the ceramics recovered by Hansen was an elegant fragment with a Maya scribe (Fig. 22) nearly identical to scribe scenes previously illustrated by Robicsek and Hales (1981, vessels 63, 62; Hansen et al. 1991:230). The Codex-style pottery is presumed to have been produced in abundance but over a relatively short time. If these highly similar scenes were painted by only a few artists *and* if the vessels were prepared from the same resources, then we should be able to see a strong

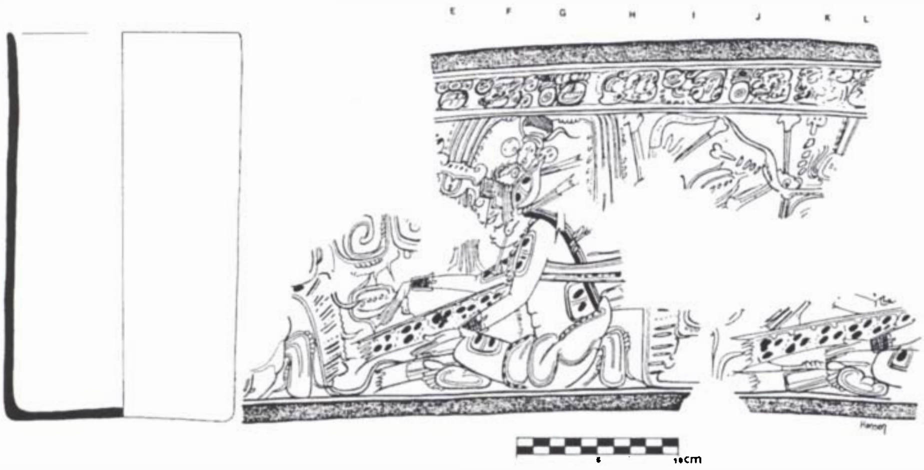


FIGURE 22. *Late Classic Maya Codex-style scribe vase excavated at Nakbé, north-central Petén, Guatemala.*

FIGURE 23. *Late Classic Maya Codex-style scribe vase. Nonprovenienced. Maya Ceramics Project MS0357.*

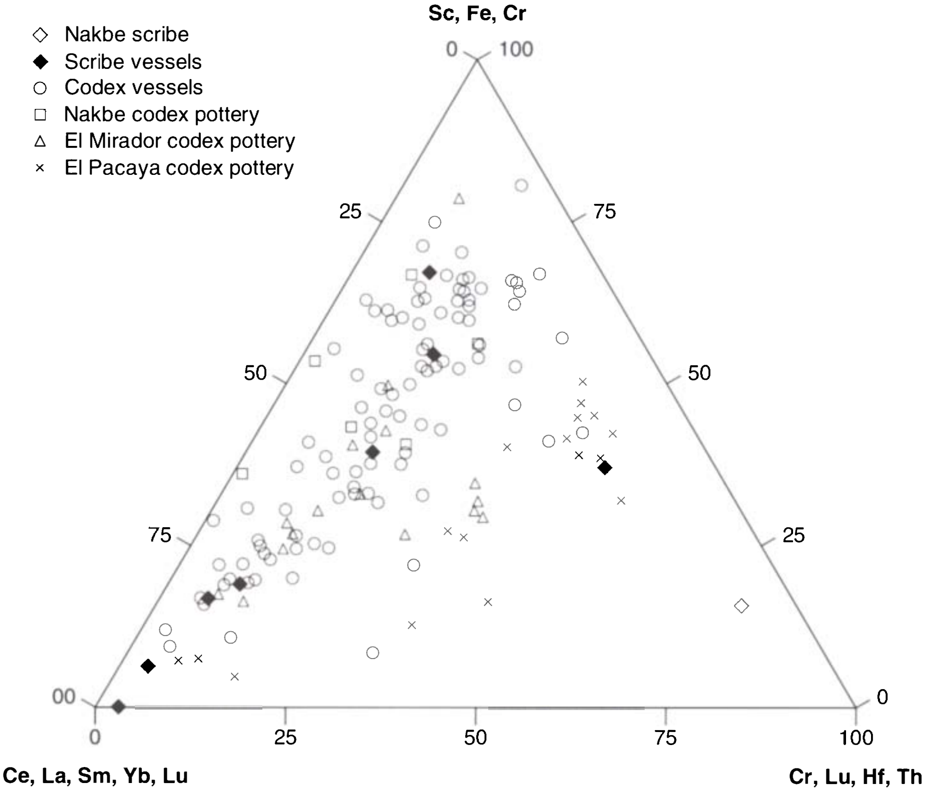
correlation between style and composition, lending weight to the possible existence of a specialized workshop within the style.

A Q-mode factor analysis was carried out on neutron activation data for 154 Codex-style specimens consisting of whole specimens, excavated sherds, and a single Nakbé clay sample (Hansen et al. 1991). Ten vessels with scenes depicting scribes (e.g., Fig. 23), including the excavated Nakbé specimen, were included. Interestingly, the Nakbé scribe specimen was observed to be a sample that was compositionally divergent from all of the previously analyzed Codex pottery (Fig. 24). (The divergent compositional pattern was verified through the analysis of an additional fragment from this vessel.) Overall, the pattern of the data shown in Figure 24 reveals that the patterns of the scribe vessels show little close compositional similarity to one another within the corpus of Codex pottery, and decreases, therefore, the likelihood that a single workshop was responsible for producing these vessels. Unfortunately, we do not have analytical data for the Robicsek and Hales (1981) vessel 62 to which the Nakbé fragment stylistically is most similar. Should that vessel be analyzed, the resulting data would do little to support the notion that any single workshop was involved in the production of the scribe vessels.

Holmul Rulership Combined with Accessory Information

Within the corpus of Maya polychromes is a distinctive style of ceramic characterized by the use of red or orange paint on cream slip. Associated through excavation

FIGURE 24. *Three-component diagram based on a Q-mode factor analysis of Codex-style pottery. Data derived by neutron activation; elements juxtaposed at apices reflect significant contribution to the calculated end members.*



with the site of Holmul at the Guatemala-Belize border (Fig. 18), these vessels share a similar rendering of iconographic program and hieroglyphic text. Although the vessels were commonly considered to be derived from a general manufacturing area that included Holmul, stylistic diversity within the corpus of whole vessels studied by Reents-Budet (Figs. 25, 26; Reents 1985) suggested the presence of multiple workshops or sites of production.

The chemically analyzed whole vessels in the Holmul style were divisible into two style groups reflecting, among other aspects, size of figures portrayed, size and elaborateness of personal accoutrements, delineation of form, and rendering of glyphic texts (Reents 1985). The painting style of one group made use of greater design mass, often filling almost 90% of the design field, including the representation of comparatively small figures possessing relatively larger backracks. The figures were often outlined in red to render shape, and outlining was again used to enclose rectilinear glyphic blocks consisting of numerous titles and personal names.

Inspection of the chemical data demonstrated a clear compositional separation between Reents's two major style groups (Fig. 27). The larger group was found to be compositionally anchored at Holmul through similarity with the analyses of sherds excavated from that site by Merwin in 1911 (Merwin and Vaillant 1932). The extent of paste variation within this Holmul group, however, suggests not one but rather the likelihood of multiple production loci within the Holmul area. The other stylistic and chemical group contains fewer members and therefore has a less firm attribution. Ceramics with "matching" paste compositions are from the site of Naranjo, the data obtained from the analyses of sherds now in the Peabody Museum or Museo Nacional de Guatemala, collected from the backdirt of looters' pits at the ruins by Ian Graham. The trace element data, therefore, were able to rein-

FIGURE 25. *Holmul-style polychrome cylinder. Nonprovenienced; compositionally attributed to Holmul. Holmul young lord or "dancer" with elaborate backrack faces a dwarf. Glyph band at top of vessel is a Primary Standard Sequence. Height 24.2 cm; diameter 16.1 cm. Maya Ceramics Project Archive MS1127/14506. Duke University Museum of Art, accession 1982.41.3.*

FIGURE 26. *Holmul-style polychrome plate. Nonprovenienced; compositionally attributed to the Naranjo group. Circular text on the bottom of the plate encircles a central figure seated on a throne. Height 11.9; diameter 36.5 cm. Maya Ceramic Project Archive MS0956/12558. Collections of Juan U. Maegli, Guatemala.*

force the group divisions made stylistically, indicate several production events or loci in or about the site of Holmul, and suggest a second major production location of the Holmul-style pottery possibly in or near the ruins of Naranjo.

Evaluation of the paste compositional data and thematic data assists in forming questions about political events in the Holmul-Naranjo area. Unraveling the stylistic

FIGURE 27. *Bivariate plot of elemental concentrations of europium and lanthanum that serve to illustrate the separation of the Holmul and Naranjo groups. Ellipses are drawn at the 90% confidence interval. Figure redrawn from Reents (1985:fig. 45).*

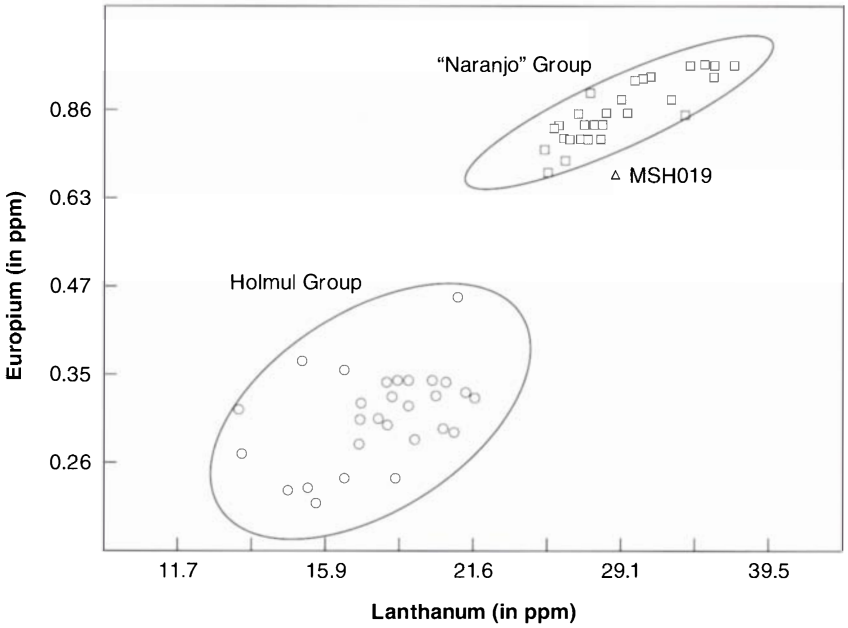


FIGURE 28. *Two views of Holmul-style vessel excavated in-situ at Holmul, Guatemala, building F, group 1 by Merwin during 1910–12 excavations at the site (Merwin and Vaillant 1932). Maya Ceramics Project Archive MSH019. Peabody Museum of Archaeology and Ethnology, accession C–5666.*

diversity into patterns of production locations had further importance because a protagonist named on one of the excavated vessels from a Holmul burial (Fig. 28) is Lord Flint Face, also known as Ruler 4 of a lineage from the site of Naranjo located approximately 25 km south of Holmul. The compositional data place the vessel just outside of the confidence interval used in characterizing the Holmul group, yet sufficiently close that production within the general Holmul region, rather than in the vicinity of Naranjo, is inferred. The plate bears text stating that the protagonist of the interior scene is of Naranjo lineage and a descendant of Naranjo's Lord Flint Face, Naranjo's Ruler 4. Several glyphic elements, including nominals and titles, establish correspondence to other vessels or monuments that share the common feature of being associated with the site of Naranjo.

Since the plate was likely made after Lord Flint Face's control of the throne, Reents (1985:241) further suggests a probable manufacturing period for the plate as lying between 793 and 810 C.E. While little is known about shifting social events at Holmul, Naranjo is known through the historical content of its erected monuments to have been a formidable force in the region. Its rulers were defeated by warriors from nearby Caracol in 642 C.E., but under the leadership of Smoking Squirrel, who ascended to the throne in 693 C.E., the Naranjo dynasty was reinvigorated. Naranjo went on to dominate a large portion of the Petén that stretched to the Petexbatún center of Dos Pilas (Schele and Freidel 1990:171–95). A question of interest, however, surrounds why an individual with ties to Naranjo came to be buried at Holmul. Considering the degree to which the titles in the text stress the individual's relationship to the Naranjo lineage, Reents (1985:246–47) offers the interpretation that the body accompanying the plate is that of a minor member of the dynasty, such as a nephew or second son. Whatever the exact role occupied by the individual buried, the presence of the plate can be taken to indicate that Naranjo's influence or rule, just prior to the period of the Maya collapse, still included Holmul.

Holmul-style Workshops?

Within the stylistic diversity of the Holmul-style pottery, a range can be found in the degree of control exercised over painting technique and hieroglyphic knowledge. At the one end is the pottery reflecting the least control. In the middle is the largest group represented by vessels that, while demonstrating somewhat greater technical control within the style, contain a number of "short cuts" using, for example, short glyphic phrases or repetition of glyphs, variable line consistency, and/or abbreviated iconographic programs. A final group reflects the finest artistry, merging meticulous brushwork, complex iconographic programs, and long glyphic texts identifying individuals and ruling dynasties (Reents 1985:160–66). The resources in terms of time and labor to produce these latter vessels, Reents suggests, could only be under elite sponsorship. Production within this style, therefore, could have been carried out by different workshops for different segments of the population: the simplest feigning little but the form for a lower segment of the society, while the iconographically elaborate, glyphically literate pottery was created for the ruling elite.

It has been mentioned that the strength of secure attribution of the Holmul style pottery was greater for Holmul than for Naranjo. Analyses now under way of pottery from the recently excavated site of Buenavista del Cayo (Fig. 18) promise to greatly expand our knowledge of style and compositional covariation for this group of pottery (Taschek and Ball 1992). Buenavista was a small civic-ceremonial center in Belize near the Guatemalan border. The excavations have revealed evidence for the presence of an artisan workshop producing pottery in a variety of styles within a general Holmul-style tradition and the workshop is closely associated with a palace structure, suggesting the presence of artists "attached" to center elite (see Earle 1981:230; Brumfiel and Earle 1987:5–6).

While we await the forthcoming compositional data from Buenavista, there is already evidence suggesting that artists did not paint exclusively within a single style. For example, Holmul-style vessel MS1374 (Fig. 29) is nearly identical in cylindrical shape and size to vessel MS1375 (Fig. 30); the latter, while painted in a style using black line on a cream background, shows marked calligraphic similarities with the former. The vessels' close relationship is also revealed by the name phase correspondences in the glyphic texts. These similarities are so striking that Reents

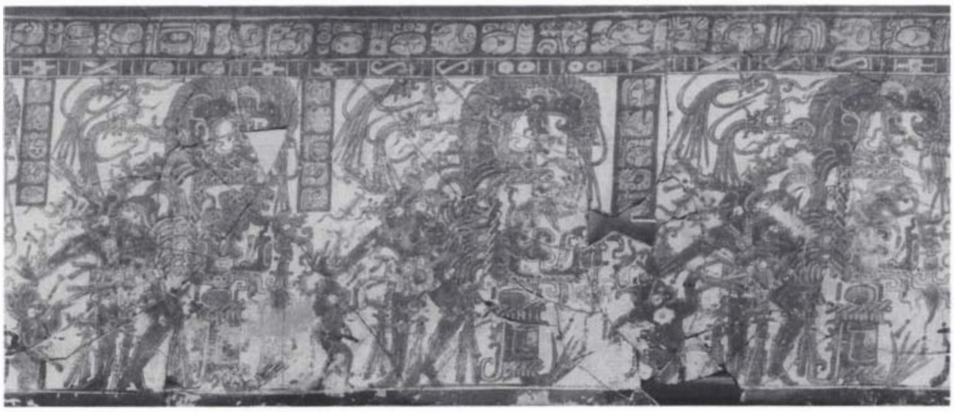
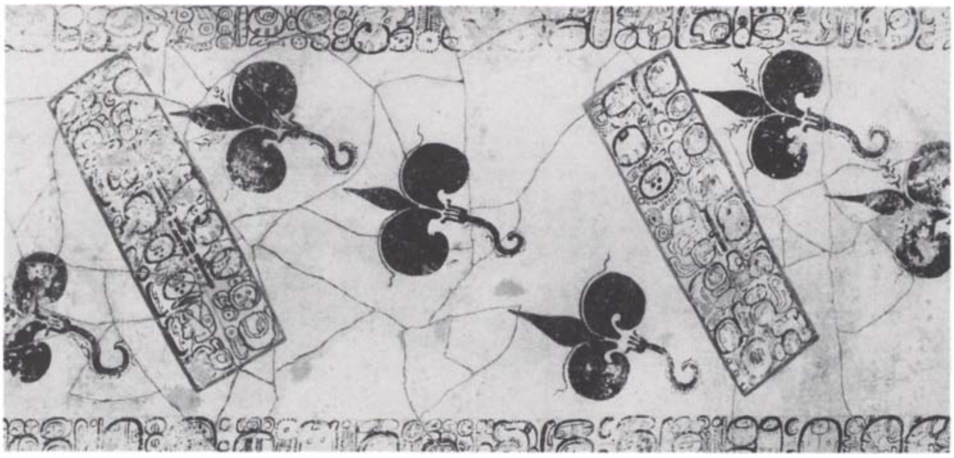


FIGURE 29. *Holmul-style vessel. Nonprovenienced; compositionally attributed to Holmul. Height 20.4 cm. Maya Ceramics Project Archive MS1374.*

FIGURE 30. *Maya cylinder. Nonprovenienced; compositionally attributed to Holmul. Although not executed in the Holmul-dancer program, this vessel is identical—within the range of analytical and sampling error observed for standard reference materials—in paste compositional characteristics to Holmul-style vessel MS1374 (Fig. 29). Height 24.1 cm. Maya Ceramics Project Archive MS1375.*



(1985:163) suggests they may represent production by a single artist, perhaps at a single period of time. Support for a shared production relationship for these two vessels comes from the compositional data revealing chemical profiles that are identical within the limits of analytical error for each elemental determination (Table 1).

Comparing the data for the production of Codex-style pottery with compositional variation observed for ceramics from the Holmul region, we seem to have contradictory or at least supplemental information. The compositional data for the Codex-style vessels provides evidence for the painting of extremely similar scenes on vessels produced from different resources. In contrast, vessels such as MS1374 and MS1375, described above, possibly are painted by the same artist working within different styles. If one were to extrapolate from these limited data, it is probable that a learned artist was attached to an elite institution or to a member of an

TABLE 1. *Comparison of elemental concentration in MS1374 and MS1375 relative to one group sigma for SRM679 brick clay. Numbers in parentheses represent one group sigma obtained from elemental data on seven analyses of SRM679 brick clay reference material as determined under standard conditions (Blackman 1986).*

		MS1374	MS1375	SRM679 Brick Clay
Sc	ppm	8.490	8.770	(2.4)
Cr	ppm	21.700	21.000	(2.4)
Fe	%	2.160	2.200	(3.0)
Co	ppm	5.710	5.850	(3.4)
Rb	ppm	160.000	175.000	(10.5)
Sb	ppm	170.000	150.000	(10.6)
Cs	ppm	7.620	7.130	(4.0)
Ba	ppm	653.000	780.000	(11.4)
La	ppm	35.200	33.500	(1.2)
Ce	ppm	68.100	65.600	(2.2)
Sm	ppm	6.280	6.030	(1.1)
Eu	ppm	0.897	0.889	(1.7)
Yb	ppm	3.040	3.260	(8.3)
Lu	ppm	0.478	0.478	(9.0)
Hf	ppm	6.810	6.270	(3.9)
Ta	ppm	0.767	0.774	(7.7)
Th	ppm	13.100	12.900	(2.9)

elite lineage. Or, perhaps the painter who was capable of rending iconographically and epigraphically complex ceramic art with the freedom to range beyond a given style was, himself, a member of an elite lineage. The more abundant representatives of a particular style, as in the case of the Codex-style specimens, are more likely to be the product of workshops. Beyond this, given the broken ceramic debris recovered next to an elite structure at Buenavista, the new possibility of a "palace workshop" emerges that might be comparable to that known to have existed in the court of the Aztec king Montezuma (Sahagún 1954).

Linguistic Mapping Through Compositional Research

In the course of research being conducted to meet a given set of objectives, new and significant possibilities can emerge—ones that were completely unforeseen at the beginning of the project. This is surely the case with the emerging potential for linguistic and dialectical mapping of the Maya region. I have referred earlier to the opening of new insights into myriad aspects of Maya society afforded by the advances made in the decipherment of Maya hieroglyphics. While the glyphs found on Maya vases once were described as primarily "decorative" in nature (J. E. S. Thompson 1962:14–18), sufficient regularities in one pattern lead Michael Coe (1973) to identify this repetitive group as the Primary Standard Sequence (e.g., Figs. 29, 30). Finding no correspondence between this sequence of glyphs with the scenes that accompanied it, Coe suggested that the sequence may have served as a sort of ritual chant or prayer that prepared the dead for the journey into the underworld.

Hieroglyphic decipherment since Coe's original suggestion has found the Primary Standard Sequence to have a strong syntactic integrity that permits various substitutions and elaboration (for review of the decipherment of the Primary Standard Sequence, see Stuart 1989; MacLeod 1990). Depending upon its length the text can contain the name of the possessor or person for whom the vessel was commissioned, the form of vessel, its contents, the manner of the vessel's decoration, and the name of the scribe or painter. The Primary Standard Sequence represents, therefore, a fairly standardized way of ritually "tagging" the vessel for its owner or commissioner (Stuart 1989:154). And, more provocatively, variations in the execution of the glyphs may reflect aspects of social or spatial differentiation.

The identification of the language spoken in the various civic-ceremonial centers is a long-standing concern to students of the ancient Maya. While Cholan and Yucatecan are known to have been spoken in particular regions (Kaufman 1979; Justeson and Campbell 1984), the language for a vast area in between is ambiguous (Fig. 18, insert map). If we were able to chart changes in the use or influence of one language in preference to another we could obtain a better understanding of a subregion's history. The glyphic Primary Standard Sequence is regarded primarily as Cholan both in its development and in the majority of its constituents (MacLeod 1990:478), but loans of non-Cholan forms of glyphs and dialectical variations in the glyphic elements are the subject of a unique investigation by linguist and epigrapher Barbara MacLeod in collaboration with epigrapher and anthropologist Nikolai Grube. Whereas the vast majority of Maya pottery was previously of little use for such research because of the lack of provenience, MacLeod and Grube are using the stylistic and compositional attribution findings to study the distribution pattern of dialectical variation.

For example, in the Primary Standard Sequence of a vessel compositionally attributed to the Maya core area site of Uaxactún (Fig. 18, insert map), the presence of *y-ich u-huh-bal* or *y-ich ts'ib-al* and *uch'ib* or *y-uch'ib* are indicators that Cholan was the language spoken by the producer of the vessel. When corroborated with other vessels sharing similar linguistic features, they would point to Cholan as the language spoken at Uaxactún. At a more detailed level, however, the absence of particular linguistic features and the presence of others perhaps reflect a particular dialectical form of the language. In contrast to the Uaxactún vessel's Cholan inscription, pottery in a "Belizean-style," which is currently only compositionally attributed to northern Belize, has its own particular version of the Primary Standard Sequence that includes a glyphic "smoke" affix (Fig. 31, arrow). MacLeod has read this glyph to mean "remember" in Yucatecan and Cholan and she relates it to a similar glyph reading "was recorded" that occurs in northern Yucatán. If we can merge linguistically reflected social distances with economic or political information obtained through the compositional analysis of Maya pottery, we will move ahead substantially in our creation of models that assist in explaining the archaeological record.

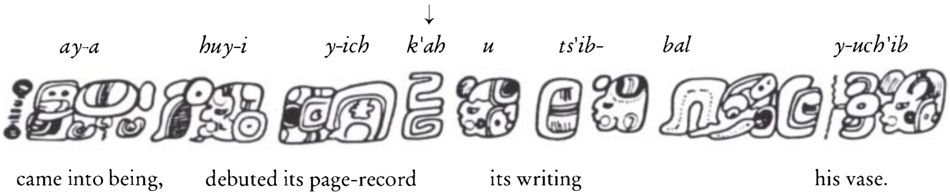


Figure 31. *Primary Standard Sequence glyph band for vessel compositionally attributed to northern Belize.*

A merger of the diverse data sets—paste compositional, stylistic, archaeological, epigraphic, and linguistic—is just beginning. Nevertheless, it can already be seen that close interdisciplinary collaboration and the interpretation of compositional data within the context of other types of archaeological data contribute to our understanding of the richness, variety, and history of Maya culture.

Conclusions

Our growing understanding of many of the conceptual and methodological complexities associated with ceramic composition in the Maya region is being advanced through mutually reinforcing research into economic, social, ideological, and historical systems. The archaeological record did not form within a closed system but rather one that was open, one that was affected by wider natural and social environments. We must remain aware of this fact if we are to make meaningful interpretations of the empirical data generated by compositional investigations.

Pottery production and consumption represents only one component of an exchange or redistribution system that is, itself, only a partitive reflection of the past. Compositionally based investigations that use experimental methods of classical sciences limit variation even further to an analysis of the physical and chemical variability of ceramic paste. These investigations have had demonstrable success in identifying specific production sites, but the reason for these successes lies not in the scientific world but in understanding the human processes underlying the formation of the archaeological record. The exercise of certain decisions over others, if carried out in a more or less repetitive manner, may result in a cultural patterning that, if of sufficient temporal duration, may fluoresce into a cultural tradition. These patterns and traditions, the changes within them, and the reasons behind their development, alteration, and decline are the true research objectives.

Our inferences about the compositional data must be drawn from a perspective that recognizes the natural, economic, social, and ideological contexts in which choices were made. A compositional analysis incorporates these choices of actions indirectly, and in the Maya region, as elsewhere, only through the fullest possible archaeological contextualization will the indirect patterns be revealed.

Working with Maya ceramics at this time, at an interface between the analytical sciences, archaeology, epigraphy, anthropology, and art history, is demanding but rewarding. We have passed the phase of methodological development, improved the research designs, amassed large databases that give perspective to specific projects, come to appreciate variation as well as central tendency, and learned to view statistics heuristically. In general, we are evolving compositional projects to a stage where we may see more clearly the multifaceted, substantive contributions to archaeology that lie ahead. The pace continues.

Acknowledgments

The author wishes to acknowledge collectively the directors and curators of many museums in the United States who opened their displays and storerooms for research. He also expresses his gratitude to institutions and individuals in Central America who have been extremely supportive of the Maya Ceramics Project, especially Dora G. Gonzales, director of the Museo Nacional de Guatemala; Rolando Roberto Rubio C., archaeologist and former curator of the Museo Popol Vuh; Fernando Sánchez, director of the Museo Popol Vuh; Juan Pedro LaPorte, archaeologist with the University of San Carlos, Guatemala; and Harriot Topsey and John Morris, commissioners of the Department of Archaeology, Belize. Juan U. Maegli of the Tecum Corporation, Guillermo Mata, and Federico Fashen of Guatemala also deserve recognition for advancing the project. Permission to take samples of archaeological collections in Mexico has been given by Garcia Cook, director of Archaeology at the Instituto Nacional de Antropología e Historia (INAH) and Lorena Mirambell Silva, Presidente de Consejo de Arqueología, INAH. Crucial support for our research in Yucatán has been given by Alfred Barrera Rúbio, director of the Centro Regional de INAH, Merida; Pedro Schmidt, director of the Museo Cantón, Merida; and archaeologists Fernando Robles Castellanos, Syviane Boucher, and Ramón Carrasco.

Finally, he expresses his gratitude to the many Maya archaeologists who have assisted the project through granting access to their excavated materials and offering welcome advice and collegial criticism.

Notes

1. The author's use of discriminant analysis is only as a graphical mode of presentation. The groups selected for illustration have been determined to be compositionally differentiated from other groups similarly formed in the data set as evaluated according to various criteria. For discussion of a general approach to data analyses, see Bishop, Harbottle, and Sayre 1982; Bishop and Neff 1989.
2. Working both with excavated and nonprovenienced, looted pottery is a sensitive issue and no one in the archaeological community wishes to encourage the destruction of archaeological sites. Scholarly attention to and especially the scientific analysis and interpretation of a nonprovenienced vessel has been interpreted by some as granting favorable attention to a looted object, thereby encouraging collecting, and through it, continued looting. To the extent that this is true—to any degree—a thin line is walked between the tradeoff in the scholarly accumulation of knowledge and an unfortunate consequence of that knowledge. Science has, of course, confronted similar issues of even greater impact (e.g., Wiseman 1984). While acknowledging a vast shade of gray between polar black and white, I trust the contributions of the project will be, on the "hole," positive.
3. The Maya Ceramics Project was initiated through the cooperation of the Research Laboratory of the Museum of Fine Arts, Boston, and the Department of Chemistry at Brookhaven National Laboratory. Work at the latter institution was under the auspices of the U. S. Department of Energy with funding for the creation of an analytical database of unique scope provided by Landon T. Clay of Boston. From the project's inception the continuous support of Garman Harbottle, Edward V. Sayre, and Lambertus van Zelst has been indispensable. Dorie Reents-Budet's participation in the project originally was made possible through the support of C. C. (Todd) Aikins of Wichita, Kansas. Through the cooperation of former Director C. C. Lamberg-Karlovsky and Bowditch Professor Gordon R. Willey, the vast collections of vessels and fragments of the Peabody Museum were made available for study. Their willingness to see justified research advance, even in light of minor removal of part of the ceramic paste, is commensurate within their pursuit of objectively based scholarship.
4. The author has yet to sample the well-known dancer plate from Uaxactún (Smith 1955:fig. 72, a:1).

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Biography

Ronald L. Bishop is senior research archaeologist at the Conservation Analytical Laboratory of the Smithsonian Institution. His research interests are interdisciplinary, combining chemistry, geology, and numerical analysis to address questions of ancient social organization through the investigation of material trade and exchange. He is best known for his research in the Maya region, in the Lower Central American region of northwestern Costa Rica and southwestern Nicaragua, and on Hopi yellow-firing ceramic production and distribution.

Kiln Firing at Batán Grande: Today and in Formative Times

Ursel Wagner, Rupert Gebhard,
Enver Murad, Josef Riederer,
Izumi Shimada, and Fritz Wagner

Archaeological Aspects

Ceramics from the Formative era (ca. 1800–500 B.C.E.) in the Peruvian Andes are of high artistic and technological quality. Until recent times, relevant information had been derived mainly from analyses of the sherds, rendering our picture of pottery production incomplete. Workshops and kilns dating to this era had not yet been found.

This situation changed with the discovery and excavation (1985–90) of a large number of Formative kilns along a 500 m stretch of the abandoned, 5 m deep Poma Canal, which cuts through the middle of the Poma National Archaeological Reserve in the Batán Grande region in the coastal area of northern Peru (Shimada et al. 1990). An analysis of kiln size, shape, and discoloration patterns suggests that these kilns were used for pottery making. These patterns show a clear continuity over four stratigraphic positions from the earliest period, dating to about 800–700 B.C.E. (Middle Cupisnique period) at the bottom of the canal, to the latest period, dating to about 400 C.E. All kilns appear to have been associated with hand-formed (as opposed to mold-made) ceramics. Many are so well preserved that ancient firing conditions can be effectively studied. This chapter compares data from the test firing of a Cupisnique kiln at the excavation site with technical analyses of associated ceramics and laboratory firing experiments.

Description of the Kilns

Thus far, the remains of fifty-seven kilns in small clusters have been documented along a 500 m stretch of the bottom and sides of the Poma Canal. Nearly all are double-chamber kilns with flaring chimneys oriented north-south to north-southwest in accordance with the prevalent diurnal wind direction. Kiln size and shape variation are shown in Figure 1. Two overlapping circular or oval chambers are dug into a clay-rich soil, the upper half of which is lined with a mixture of clay and local

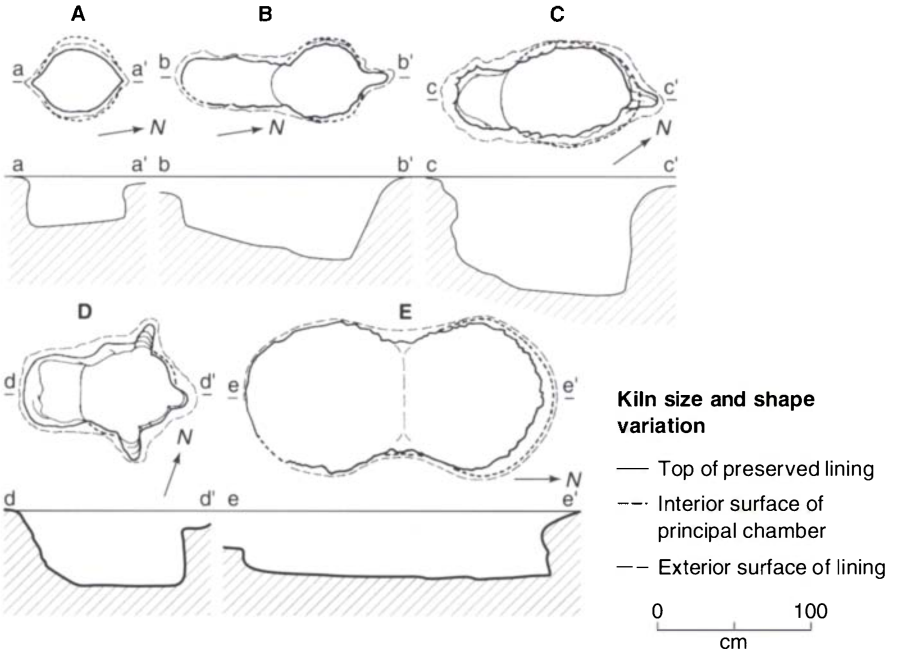


FIGURE 1. *Kiln size and shape variation.*

plant leaves. The larger and deeper principal chamber (typically measuring 60 cm in width, 70 cm in depth below ground surface, and 70–140 cm in length) has inward-curving sides and an intensely heat-discolored chimney. The antechamber is considerably smaller and less heat-discolored and hardened. It is therefore likely that the latter was used only for setting the fire and controlling the kiln atmosphere. The bottom of the main chamber is invariably covered with ash and charcoal lumps from locally abundant *algarrobo (Prosopis julifora)* wood.

Test Firing of the Kilns

Three test firings, designated as IV-A, IV-B, and IV-C (Shimada et al. 1991), were performed in the authentic kiln 38 (Fig. 2). In addition, several test firings were conducted in a replica kiln. Only experiments IV-B and IV-C will be discussed here. As

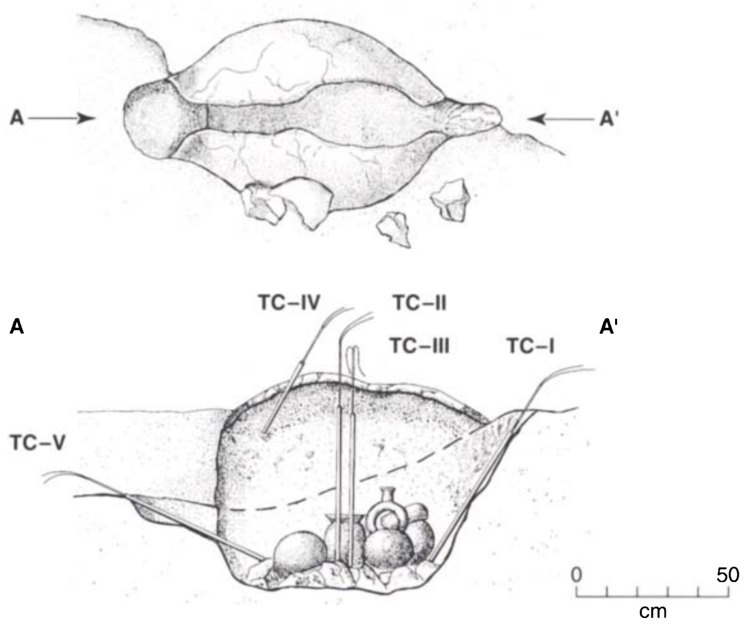


FIGURE 2. *Top view and section through the middle of the test kiln, showing the locations of the five thermocouples (TCs).*

in ancient times, the local *algarrobo* wood was used as fuel, and the fire was started with the rapidly burning *zapote (Caparis angulata)* leaves. In experiment IV-B the maximum temperature reached was about 650 °C. In experiment IV-C the temperature was monitored more precisely by five Ni/CrNi thermocouples (TCs). The positions of the TCs in the kiln and the measured change of the firing temperature over time are shown in Figures 2 and 3. After 55 minutes, more fuel was loaded into the kiln. The highest temperature of almost 800 °C was reached near TC-V, where 750 °C was exceeded for about 45 minutes. During that period, red glowing charcoal had developed at the bottom of the kiln.

Materials

Several samples were taken from different locations in kilns 38 and 51. Kiln 38 had been used in the test-firing experiments, while kiln 51 had not been refired. Two clay samples for laboratory studies and the sand-tempered clay used for embedding the tips of the thermocouples were collected next to the site of kiln 38. They stem from two horizontal clay deposits (stratum 10c) in the trench of Poma Canal and are slightly different in color. These clays will henceforth be referred to as Batán Grande clay. One of the clays (16-1) has been studied in detail, whereas only a few experiments have been performed on the second clay (16-2). The protective clay covers on the tips of the thermocouples were removed after the firing and used as substitutes for pieces of pottery in the laboratory studies by Mössbauer spectroscopy. The temperature of the thermocouples was shown by solving the heat transfer equation to follow the temperature of the kiln atmosphere with a time constant of the order of a few minutes. Replica pottery, made by Victor Chang using clay from strata VII and XIII and applying procedures believed to emulate those used by the potters of the Formative period, was fired in kiln 38 during experiment IV-B together with a number of small bricks (Shimada et al. 1991; Wagner et al. 1991). Some of this pottery was again fired in kiln 38 during experiment IV-C.

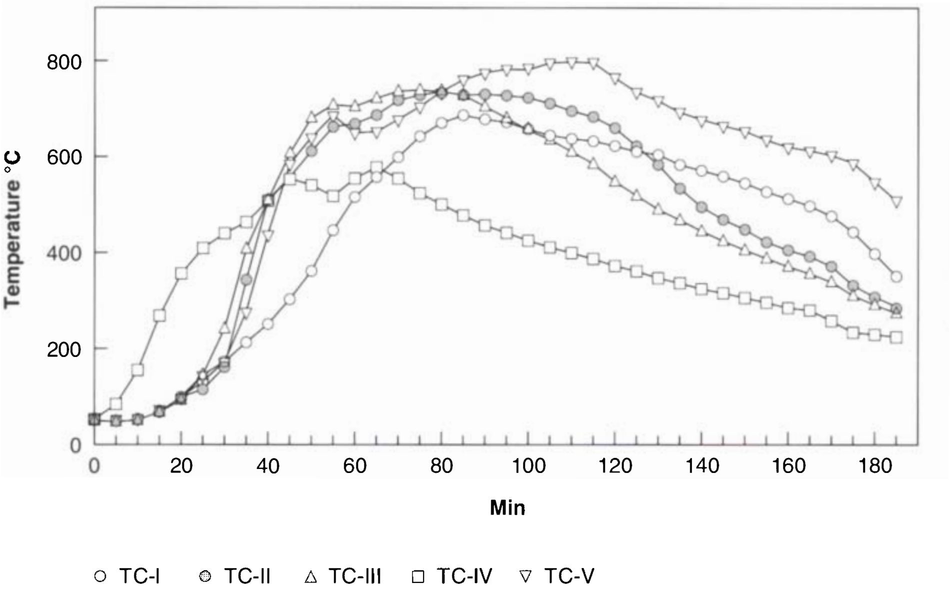


FIGURE 3. *Temperatures measured during test firing of kiln 38. The temperatures for the five different Ni/CrNi thermocouples, I–V, are plotted against the firing time in minutes.*

Thirty-three ancient sherds found in the kiln excavation area were also available for investigation.

Methods and Results

Neutron activation analysis, X-ray diffraction, thin-section optical microscopy, Mössbauer spectroscopy, and the determination of colors have been combined in an attempt to elucidate how Formative pottery was produced.

Neutron Activation Analysis

Formative pottery from Batán Grande was extensively studied by Neff and Glascock (1990), who applied neutron activation analysis and concluded that raw materials were used for kiln construction as well as for pottery making. We restricted our neutron activation studies to material needed for an interpretation of our firing experiments. Three main elements and seventeen trace elements were determined in duplicate samples with GSP-1 as the standard (Harbottle 1982). A cluster analysis of the logarithms of the concentration data using the "average linkage" method yields three groups and several samples that cannot be grouped, possibly due to the small number of studied specimens. A schematic dendrogram is shown in Figure 4.

Of the twenty-three members of the first group, twenty are Formative sherds and three are kiln material. Except for three ancient sherds, the second group contains only recent material. The replica pots and the small bricks found in this group are made from the same sand-tempered clay. The two local clays collected for the laboratory experiments are also members of this group. The clay covers of the thermocouples belong to the third group together with kiln material. The unattributed samples are Formative sherds. A Mahalanobis treatment of all samples except for the last ten in the dendrogram yields an average group membership probability of 85 ± 17% (Harbottle 1990). The average group membership probability increases to 92.5 ± 7.5% if only groups 1 and 2 are tested together, and to 99.8 ± 0.05% if the first group is tested alone. Although ancient samples dominate in group 1 and recent samples dominate in groups 2 and 3, the differences between the groups do not

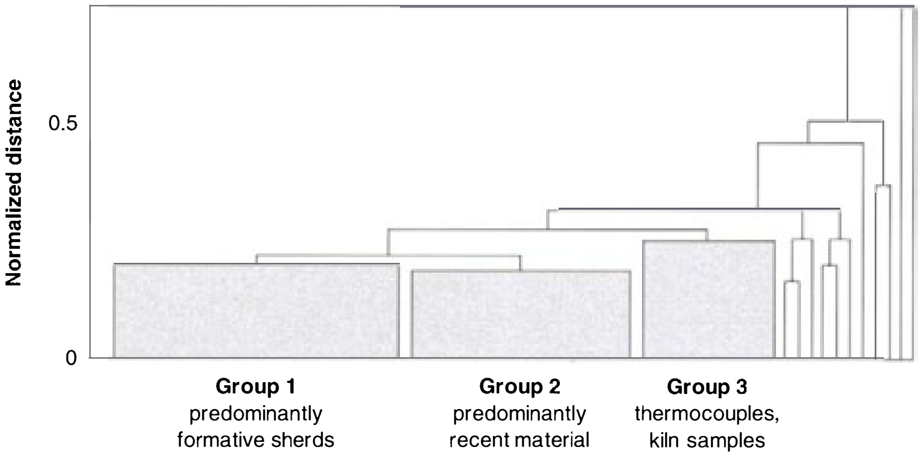


Figure 4. *Schematic dendrogram of clay samples, samples from kilns 38 and 51, and ceramic samples from the Batán Grande kiln site.*

appear to be significant. The second and third group, the clays and the kiln samples, are less homogeneous than the ceramics.

X-ray Diffraction and Thin-Section Microscopy

For X-ray analysis, Batán Grande clay was separated in a <20 µ fraction and a coarse rest. About 60% illite, 20% smectite, 20% kaolinite, and some mixed-layer clay minerals are present in the fine fraction. The iron oxides escape detection by X-ray diffraction because they are present only in minor amounts. In Batán Grande clay 16-2, 50% illite and 30% smectite, were observed. Feldspars and amphiboles are clearly visible in the diagrams. Kaolinite dehydroxylates at about 400 °C during heating in air, while illite disappears between 900 ° and 950 °C. A strong peak at 4.02 Å shows that cristobalite forms at the latter temperatures. The hematite peak at 2.68 Å was first observed on firing at 650 °C. The amphibole peaks appear sporadically in the X-ray diagrams of the samples after heating to different temperatures, although they should not be affected by heating up to 900 °C. This is attributed to an inhomogeneous distribution of this mineral in the clay rather than to an effect of firing. The clay covers of TC-I and TC-II still contained illite after the kiln firing, in agreement with the maximum temperatures of 685 ° and 780 °C reached during the firing cycle.

A petrographic analysis of polished thin sections of thirteen sherds from Batán Grande has been performed by Killick (1990), who described the material as self-tempered. Killick observed a large proportion of coarse-grained detrital minerals. The main minerals were quartz, alkali- and plagioclase feldspars, biotite mica, green amphibole, and small crystals of blue anatase or brown rutile.

We have studied thin sections of eight additional sherds and of two TC covers under a polarized light microscope. The mineral content of the material is relatively homogeneous, although the structure, especially the grain size and the amount of temper, varies to some degree. The variety of temper is a characteristic feature of the ceramics from Batán Grande. Plagioclase, microcline, biotite, muscovite, and hornblende occur together with accessories, opaque minerals, and rock inclusions. The microscopic properties of the mineral components are unusual. Quartz is almost undeformed, and fissures and inclusions are rare. Plagioclase in the form of albite twins is frequent. The mineral is unweathered and exhibits a strong zonar structure characteristic of volcanic origin. Orthoclase is often cloudy and visibly weathered. Next to plagioclase, green-brown hornblende with a distinct cleavage is the main component of the ceramics from Batán Grande. Biotite, occurring in large plates that are often weathered and contain inclusions of accessory and opaque minerals, is a common temper. Muscovite is rare. Epidote in the form of aggregates is more frequent than in other ceramics. Fresh opaque minerals and major amounts of iron oxyhydroxide inclusions due to weathered iron-bearing ore minerals are also observed.

The primary mineral content in the studied samples from Batán Grande is diverse. It allows a reliable classification of ceramics from this site despite the large variety of mineral components. It is worth noting that no strong differences between Formative and contemporary material have been observed.

Mössbauer Spectroscopy

Mössbauer spectroscopy provides information on the iron-bearing components in clays and pottery. The iron in clays may be present as structural Fe^{2+} or Fe^{3+} in the silicate structures of the clay minerals, in other silicates, and in particles of iron oxides or oxyhydroxides adhering to the clay mineral particles. The structural iron in silicates is paramagnetic at room temperature and even at liquid helium temperature (4.2 K) in most cases; therefore, it usually gives rise to electric quadrupole doublets in the Mössbauer spectra (Fig. 5). Well-crystallized iron oxides show the characteristic six-line pattern arising from the magnetic hyperfine interaction. If particle sizes are less than about 100 Å, as is frequently the case in pottery, the six-line pattern collapses due to fast superparamagnetic relaxation except at cryogenic temperatures. The oxides then also contribute to the quadrupole doublets in the middle of the spectra. Measurements at low temperatures are necessary to block such relaxation processes. To distinguish between superparamagnetic oxides and structural iron, extraction of the iron oxides with bicarbonate-buffered sodium dithionite has proven useful (Mehra and Jackson 1960).

Clay from Batán Grande

Both clays contain 4.5% total Fe; 1.1% Fe can be extracted by sodium dithionite treatment. The room temperature Mössbauer spectrum (Fig. 6) shows a large quadrupole doublet arising from paramagnetic and/or superparamagnetic Fe^{3+}, a quadrupole doublet due to paramagnetic Fe^{2+}, and a small amount of hematite with a particle size large enough to produce a six-line Mössbauer pattern at room temperature. The magnetic Mössbauer fraction increases substantially from 10% at room temperature to about 42% at 4.2 K. A second sextet with parameters characteristic of goethite is also present at 4.2 K. A weak additional broad absorption can be attributed either to a magnetically ordered material with a wide distribution of hyperfine fields or to slow relaxation of paramagnetic iron in the clay minerals and/or various other minerals present. After sodium dithionite extraction of the

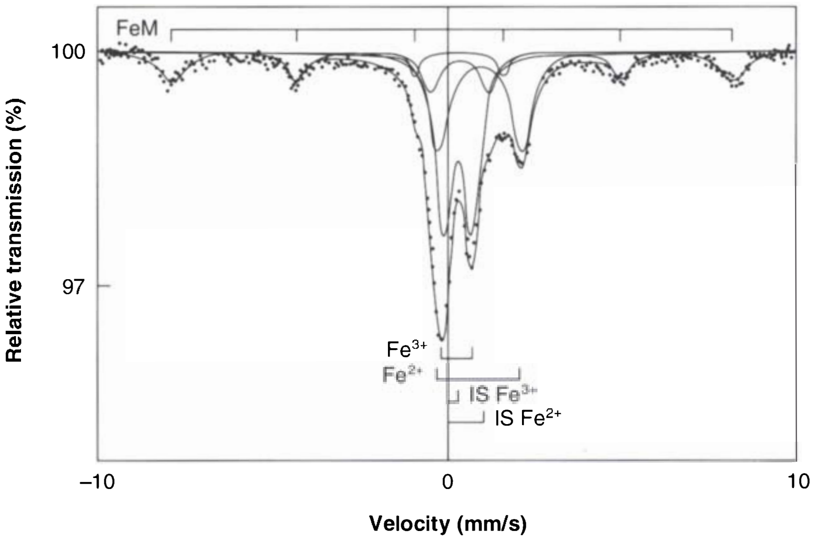
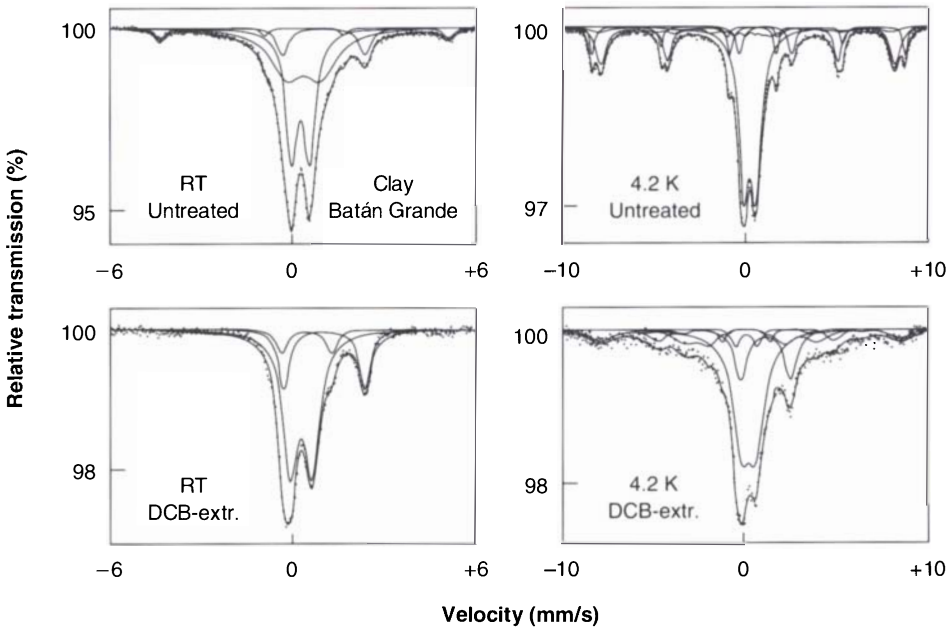


FIGURE 5. *Explanation of the relevant Mössbauer parameters; the spectrum is that of the core of sherd PC-57 found in kiln 25.*

FIGURE 6. *Mössbauer spectra of Batán Grande clay taken at room temperature and 4.2 K (top row) and of samples extracted with bicarbonate-buffered sodium dithionite (bottom row).*



oxidic components, the six-line pattern and the broad inner doublet have disappeared in the room-temperature spectrum (Fig. 6). Most of the change observed on cooling to 4.2 K is due to the appearance of a nearly unstructured background representing about half of the area of the spectrum. This feature can be presumably ascribed to slow paramagnetic relaxation of Fe^{3+} in the clay minerals and/or in the other minerals present in the clay. The notion that the broad background could arise from poorly crystallized oxidic phases can be ruled out because these have been removed by sodium dithionite extraction.

Laboratory Firing of the Clays

When the clays are fired at different temperatures, the iron oxides and other minerals present in the raw materials undergo characteristic changes, which are reflected in the Mössbauer spectra. For a meaningful interpretation of the Mössbauer spectra of ceramics, the firing behavior of the raw material must be understood.

To study Batán Grande clay 16-1 we have used three different firing procedures: (1) Clay samples are fired in air at increasing temperatures; (2) samples are first reduced with charcoal in a closed vessel for 3 hours at 800 °C and subsequently refired in air; and (3) samples are reduced only at different temperatures. (Procedure 3 is not discussed here.) Firing in air took place in 3-hour and 48-hour periods. Firing was carried out at temperatures between 50 and 1250 °C in steps of 50 °C. For each temperature a fresh sample was used. Mössbauer spectra were measured at room temperature and at 4.2 K. Batán Grande clay 16-2 was only fired in air for 48-hour periods. The results are shown in Figures 6–10.

For firing in air, the quadrupole splitting of the Fe^{3+} species and the relative areas of iron not showing magnetic hyperfine splitting in the Mössbauer pattern are plotted in Figure 7 against the firing temperature for heating periods of 3 hours and 48 hours. The Mössbauer spectra are shown in Figure 8. The quadrupole splitting exhibits a substantial increase on firing between 350 and 500 °C due to the distortion of the octahedral symmetry of the iron sites during the dehydroxylation process in the clay minerals. Clay 16-1 shows an unusual behavior, namely a further rise in the quadrupole splitting of the Fe^{3+} species near 650 °C. This rise is only very slight after the 3-hour firing period; it is altogether absent in clay 16-2. Decomposition of illite cannot be responsible for this feature, since illite persists up to 900 ° or 950 °C, as was shown by X-ray diffraction. Moreover, illite generally contains little iron. Apart from this peculiarity, there is no relevant difference in the firing behavior of clays 16-1 and 16-2. The total breakdown of the clay structures on firing above about 750 °C results in a decrease of the Fe^{3+} quadrupole splitting and of the nonmagnetic fraction (Fig. 7). The duration of firing has only a moderate influence on product formation. Compared to 48-hour firing, heating for 3 hours requires somewhat higher temperatures for the increases of Fe^{3+} quadrupole splitting between 300 ° and 600 °C and for hematite formation above 750 °C. Mössbauer parameters measured for the clay covers of the thermocouples are plotted at the

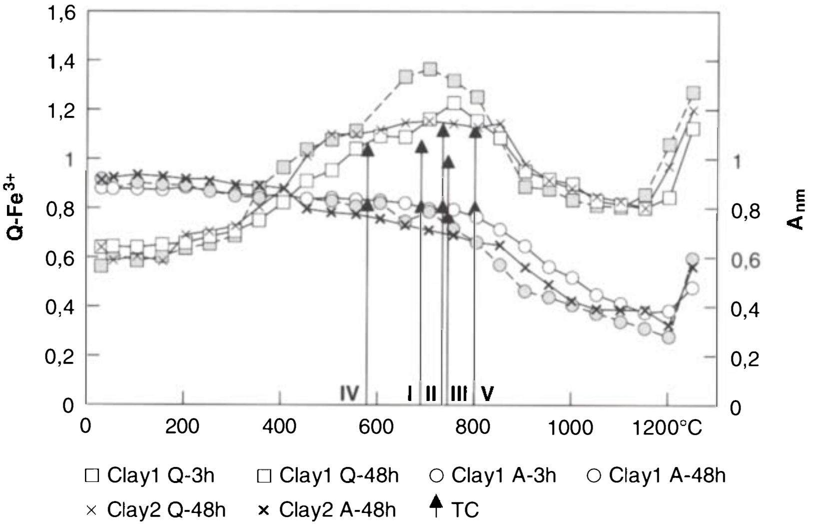


FIGURE 7. *Firing of Batán Grande clay 16-1 and 16-2 in air: dependence of relevant Mössbauer parameters measured at room temperature on the firing temperature for 3-hour and 48-hour firing periods. Clay 16-2 was heated for 48-hour periods only. Q-Fe^{3+} is the mean quadrupole splitting of the Fe^{3+} species. A_{nm} is the fraction of nonmagnetic iron (Fe^{2+} plus Fe^{3+}). The triangles represent data for the clay lumps covering the thermocouples used during the field firing experiment in kiln 38.*

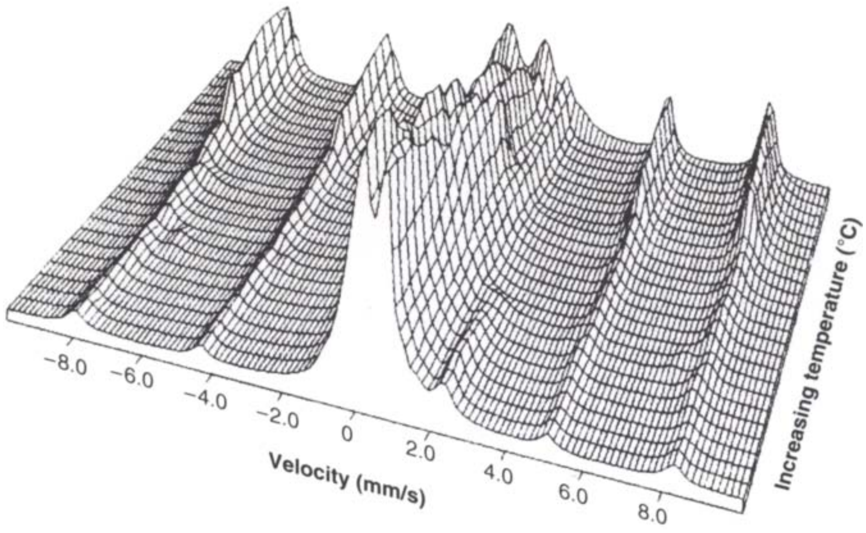


FIGURE 8. *Dependence of the Mössbauer spectra measured at room temperature of Batán Grande clay 16-1 on the temperature of firing in air for 48 hours.*

maximum temperatures reached during the test firing. The data agree with the laboratory firing curve of clay 16-1 for heating periods of 3 hours and also with the curve of clay 16-2 fired for 48 hours. Agreement with the 48-hour curve of clay 16-1 is poor because of the peculiar shape of this curve between 600 and 800 °C.

At 4.2 K, the hematite sextet and other magnetically ordered phases are predominant on firing between 750 and 1000 °C, and the Fe^{3+} doublet is very weak (Figs. 9, 10). At still higher firing temperatures, iron-bearing silicates and spinel-type compounds start to form, while the hematite content decreases again. The agreement between the laboratory firing curve for clay 16-1 and the data for the covers of the thermocouples is better than the agreement between the firing curve and the data for the room-temperature measurements. This could be an indication that the second rise in the room-temperature firing curve for clay 16-1 might be connected with an intermediate form of hematite that is superparamagnetic at room temperature and hence contributes to the Fe^{3+} doublet, but gives a sextet pattern at 4.2 K.

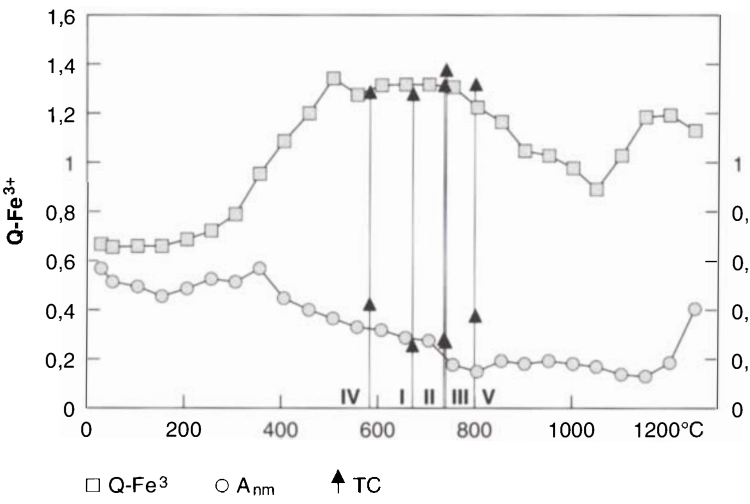


FIGURE 9. *Firing of Batán Grande clay 16-1 in air: dependence of relevant Mössbauer parameters measured at 4.2 K on the firing temperature for 48-hour firing periods. Q-Fe^{3+} is the quadrupole splitting of the Fe^{3+} species. A_{nm} is the fraction of nonmagnetic iron (Fe^{2+} plus Fe^{3+}). The triangles represent the parameters for clay lumps used to cover the thermocouples during the field firing experiment in kiln 38.*

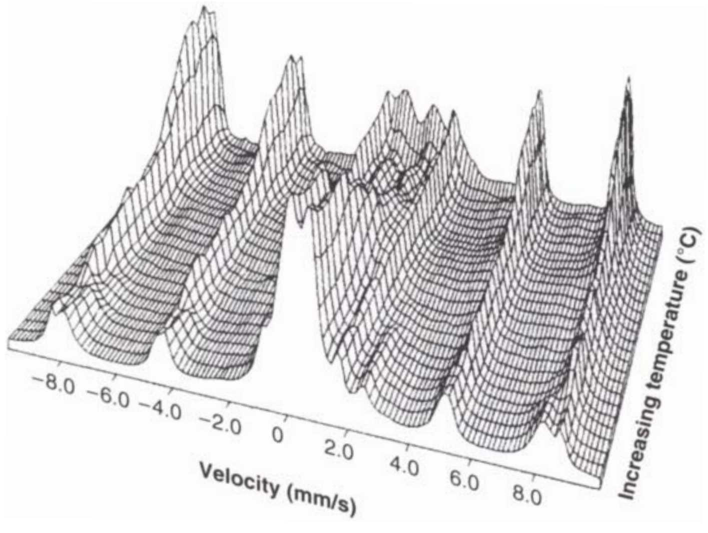


FIGURE 10. *Dependence of the Mössbauer spectra measured at 4.2 K of Batán Grande clay 16-1 on the temperature of firing in air for 48 hours.*

After firing at 750 °C, 28% of the iron is hematite, showing a six-line pattern at room temperature (Fig. 11). This value remains almost constant down to 4.2 K. A small part of the hematite is so well crystallized that it undergoes the Morin transition, leading to a minor asymmetry of the hematite sextet (Riederer et al. 1979). The striking change observed on cooling to 4.2 K is due to the appearance of a nearly unstructured absorption representing about half of the area of the spectrum. This feature is particularly pronounced in Batán Grande clay fired at 750 °C (Fig. 11), but it is already observed more weakly in the spectrum of the fresh clay (Fig. 6). Presumably it can be ascribed to slow paramagnetic relaxation of Fe^{3+} in the clay minerals or the products formed from them during firing. Alternatively, magnetically ordered structural Fe^{3+} in the silicates could give rise to the background. It is possible that both explanations hold for different fractions of the sample. As in the fresh clay, the broad absorption cannot stem from poorly crystallized oxidic phases, because these were removed by the sodium dithionite extraction.

In an attempt to assess the influence of changes in the kiln atmosphere during the firing, samples first reduced in a closed vessel with charcoal for 3 hours at 800 °C were subsequently subjected to the same firing procedure in air as was discussed above. In this procedure the temperature region up to 700 °C is dominated by the oxidation of the Fe^{2+} species (Figs. 12, 13), which requires somewhat higher temperatures when the firing lasts for 3 hours instead of 48 hours. The same is true for the fraction of nonmagnetic iron at temperatures above 700 °C. Fe^{2+} species formed during reduction at 800 °C are thus sufficiently stable to withstand oxidation in air at temperatures up to 650 °C. The quadrupole splitting of the Fe^{3+} component, which appears only as the Fe^{2+} is being oxidized, stays practically unchanged up to 1150 °C and never reaches the high values observed on direct firing in air (Fig. 7). In agreement with the fact that oxygen was rather freely admitted during test firing IV-C in kiln 38, the Mössbauer parameters observed in the covers of the thermocouples do not coincide with the parameters shown in Figure 12.

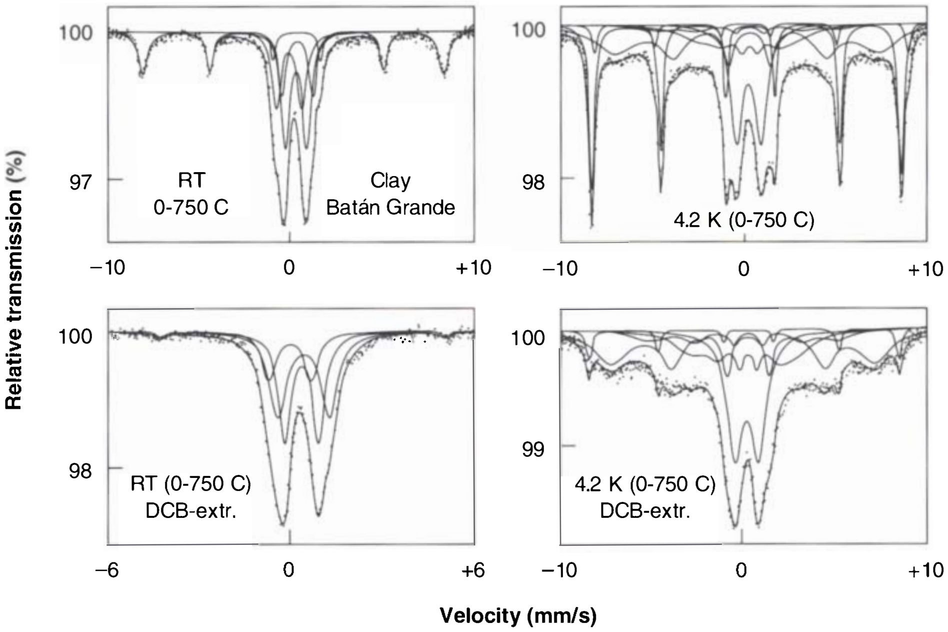


FIGURE 11. *Mössbauer spectra of Batán Grande clay fired in air at 750 °C, taken at room temperature and 4.2 K before (top row) and after (bottom row) sodium dithionite extraction of the oxidic phases. A minor hematite contribution still present after sodium dithionite treatment probably results from particles embedded in other components produced during firing.*

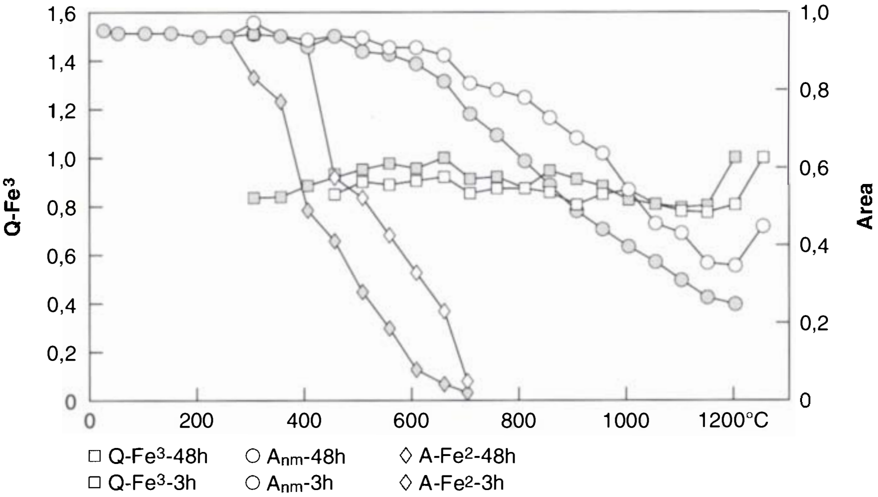


FIGURE 12. *Firing of Batán Grande clay 16-1 in air after a reduction at 800 °C for 3 hours: dependence of relevant Mössbauer parameters measured at room temperature on the firing temperature for 3-hour and 48-hour firing periods. Q-Fe^{3+} is the quadrupole splitting of the Fe^{3+} species. A$_{nm}$ is the fraction of nonmagnetic iron (Fe^{2+} plus Fe^{3+}), and A-Fe^{2+} is the area of the Fe^{2+} components.*

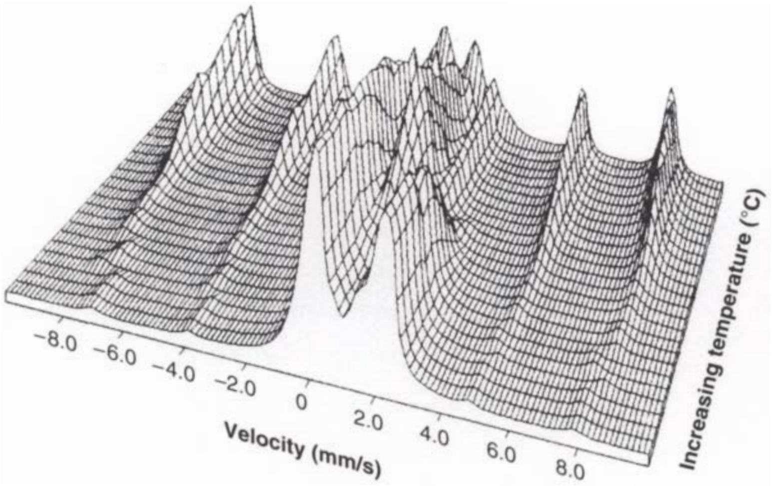


FIGURE 13. *Dependence of the Mössbauer spectra of Batán Grande clay measured at room temperature on the firing temperature in air for 48 hours, following a preceding reduction at 800 °C.*

Assessment of the Firing Conditions

In a simplified picture, no changes in the Mössbauer parameters are to be expected on laboratory refiring until the refiring temperature exceeds the original firing temperature. Even at lower refiring temperatures, however, changes in the Mössbauer parameters may occur if the atmosphere during refiring differs from that during the original firing, or if the sherds have undergone weathering during burial. Therefore, the refiring of sherds can provide information on the original firing conditions and weathering effects (Gebhard et al. 1988; Ellfroth 1991).

This procedure is rather time-consuming. However, maximum firing temperatures of ceramics can also be estimated, albeit with poorer accuracy, by comparing the Mössbauer parameters measured for the sherds with those obtained by laboratory firing of model clays (Wagner et al. 1986; Ulbert et al. 1988; Wagner et al. 1988). The fraction of nonmagnetic iron species (A$_{nm}$) and the Fe^{3+} quadrupole splitting (Q-Fe^{3+}) are the most useful parameters for this purpose. Material from the core of the sherds should be taken for this approach, since complications may arise,

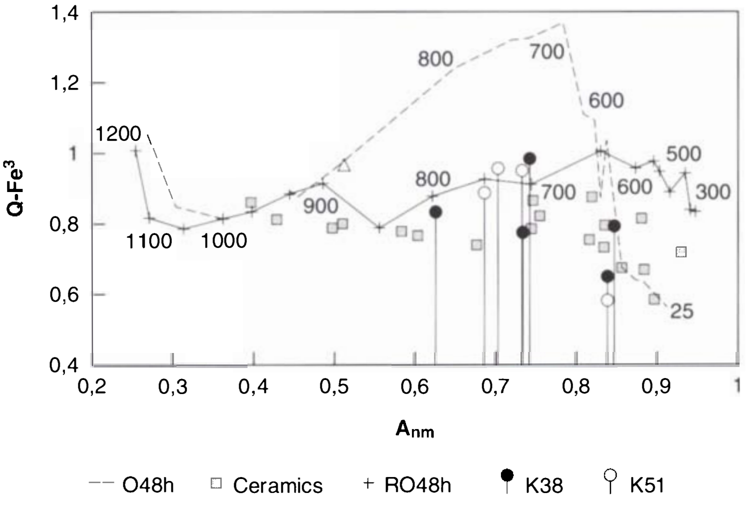


Figure 14. *Estimation of maximum firing temperature. The* Fe^{3+} *quadrupole splittings observed in Batán Grande clay fired in air for 48 hours at increasing temperatures, without (dotted line) and with (solid line) a preceding reduction for 3 hours at 800 °C, are plotted against* A_{nm}*, the fraction of nonmagnetic iron (*Fe^{2+} *plus* Fe^{3+}*). The firing temperatures in °C are given at the individual points. Parameters observed in material from kilns 38 and 51 and in a number of the studied ceramics are included for comparison.*

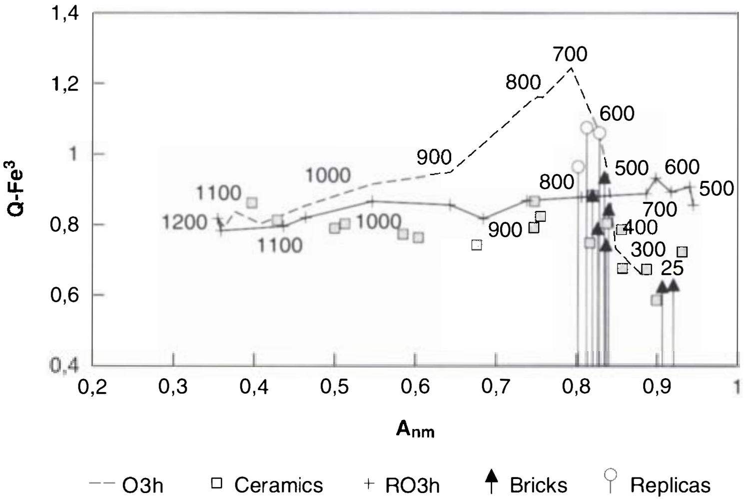
for instance, from oxidation in the outer layers at the end of the firing cycle. In the following, such a comparison will be attempted for various ceramic items from the Batán Grande project.

Kiln linings. Five samples from the entrance, the bottom, and the main chamber of kiln 51, which was not refired, and samples from the equivalent locations of kiln 38, which had been test fired since its excavation, were studied. The room temperature Mössbauer parameters of these samples were plotted together with the reference curves of Batán Grande clay for 48-hour firing periods with and without a preceding reduction at 800 °C (Fig. 14). The data indicate that kiln 51 had been exposed to temperatures between 700 and 800 °C in antiquity, the same temperatures that were reached during test firing IV-C of kiln 38. The Mössbauer spectra of the material on the bottom of kiln 51 was similar to those of the fresh Batán Grande clay, and thus appear to have accumulated in the main chamber since the kiln was last fired in antiquity. The sample taken from the chimney of kiln 38 also had not experienced high temperatures.

Small bricks, replica pots, and ceramics. The Mössbauer parameters observed for the seven small bricks that had been fired in experiment IV-B are shown in Figure 15 together with the reference curves for 3-hour laboratory firing periods. The bricks have apparently experienced only very low temperatures during the short test firing in IV-B. Agreement is best with laboratory procedures 2 and 3, the latter of which is not discussed here. The data for the replica pots fired in experiment IV-C agree with the predominantly oxidizing firing conditions during this test.

Data points for sherds found in the kiln excavation area are included in Figures 13 and 14. According to their room-temperature Mössbauer parameters, the different sherds have experienced temperatures in the whole region up to about 1100 °C. For the sherds with large nonmagnetic fractions, the observed Fe^{3+} quadrupole splittings are generally smaller than those for the reference curves. This may be due to the fact that most of the sherds served as kiln filling and have been fired repeatedly under different conditions. The fact that the sherds do not exactly match the clays, as shown by neutron activation analysis, is a less likely reason for this discrepancy, especially since sherds and material from the covers of the thermocouples

FIGURE 15. *Same as Figure 14, for 3-hour firing periods. The small bricks and replica ceramics are included for comparison.*



were indistinguishable by thin-section microscopy. It is remarkable that a number of sherds were subjected to rather low temperatures not exceeding 600 °C.

Color Determination

The sequence of colors that develop during the systematic firing of clays in different atmospheres is dominated by the iron content (Hess and Perlman 1974). We have determined the colors for the different procedures used in the laboratory firings of Batán Grande clay and for the covers of the thermocouples, the materials from the kilns, the replica pots, and the small bricks using the JIS Standard Soil Color Chart, which is based on the Munsell system. Each color is characterized by the hue, giving the dominant spectral color; the value, giving the relative lightness; and the chroma, giving the relative purity of the spectral color. The hue and the chroma are characteristic for changes in kiln atmosphere and firing temperatures, whereas small differences in value often depend only on the grain size. The color changes for the respective firing series are listed in Tables 1 and 2.

The optical determination of the colors of prehistoric pottery is often difficult because the sherds are multicolored on the surface and/or have differently colored layers. In such cases only the dominant colors of each sherd were determined. To this end, monochrome layers of the sherds were separated and powdered. By comparing the colors of each sherd with the color of the clay fired in the laboratory, ranges of possible firing temperatures were estimated for all sherds by the most similar value obtained in one of the laboratory firing series previously described.

The colors of the covers of the thermocouples show fair agreement with the temperatures measured in situ and the colors of the laboratory fired clay, if one takes into account that the thermocouples reached the maximum temperatures for rather short periods only (Fig. 4). The colors of material from kilns 51 and 38 fit with the colors of the laboratory firing series between 650 and 750 °C and 48-hour heating periods.

The interpretation of the colors of the sherds is more difficult because quite a number of them would have been heated several times, since they stem from kiln

Table 1. *Colors according to the JIS Standard Soil Color Chart observed on firing of Batán Grande clay (16-1) in air for 3 hours (Δ) and for 48 hours (∇) at different temperatures. Colors for identical 48-hour firing of Batán Grande clay (16-2) are also given (O), as well as colors for the thermocouple coverings from firing of kiln 38 (⊗).*

		Firing Temperature																									
		25	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250
2.5	5/1																										○
Y	6/1																										▽
	7/4	○	○	○	○																						
10YR	6/3	△▽	△▽	△▽	△▽	△																					
2.5	6/4					▽	△▽	△																			
YR	6/6					○	○	○▽	○	△△▽▽	△▽	△▽	△▽	△⊗	⊗		○										
	5/8									○	○	○	○	○													
	6/8													▽	△▽	△											
5YR	6/6															○	○△	○△	○	○	○	○					
	5/8														○												
	6/8															▽	▽	▽	△▽	△▽	△	△	△				
2.5	4/4																							▽	△	△	
YR	4/6																						▽	○			△
	4/8																					▽		△			
	5/8																						○				
10R	4/1																								▽		
	4/3																								○		
	5/8																									○	
7.5R	4/1																									▽	

Table 2. *Colors according to the JIS Standard Soil Color Chart observed on firing Batán Grande clay (16-1) in air at different temperatures after a preceding reduction at 800 °C for 3 hours (Δ) and 48 hours (∇).*

		Firing Temperature																									
		25	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250
2.5	6/2									▽	△	△															○
Y	6/3										▽																▽
10	6/3	△▽	△▽	△▽	△▽	△▽	△▽	△	△																		
YR	6/1							▽	▽	△																	
	6/3												△														
	6/4											▽		△▽													
7.5	6/6												▽	○	△												
YR	6/8															△	△										
5YR	6/6														▽			△	△								
	6/8															▽	▽	▽	△▽	△▽	△▽		△▽				
2.5	4/4																								▽		
YR	4/6																								△		
	4/8																					△		△▽			
	5/8																					▽					
10R	4/1																										△▽
	4/3																									△▽	
	5/8																							▽		△	

fillings or were used to cover the kilns. The colors of three out of thirty-three sherds did not match the colors observed in the laboratory firing series. For the others, several different ranges of firing temperatures can be established: Three sherds were fired between 300 and 500 °C (group 1), seven sherds between 500 and 650 °C (group 2), ten sherds between 650 and 850 °C (group 3), two sherds between 800 and 1000 °C (group 4), and eight sherds between 1000 and 1150 °C (group 5).

The sherds of groups 1 and 2 possibly come from broken pots that were only preheated. Group 3 corresponds to the temperatures recorded during firing experiments IV-B and IV-C. Group 5 may be explained by a different firing technique or as products of kilns different from those found at Batán Grande so far.

Conclusions

Data obtained by different methods have been combined in the assessment of the firing procedures used in Batán Grande pottery production. Materials were characterized by neutron activation analysis, X-ray diffraction, thin-section microscopy, and color determination. Only minor differences in the trace element contents are observed between recent clays and sherds found at the kiln site. The most characteristic property of the raw material—its high detrital mineral content—has not changed significantly over time. Recent clays could therefore be used as model materials for laboratory and field studies. Some of the Formative sherds from the kiln site have been fired at temperatures below 600 °C, which results in pottery of poor quality. The sherds could belong to preheated pots broken before firing. This can be understood if it is assumed that we are dealing with the waste of the Batán Grande pottery production, that is, with sherds fired at largely different temperatures and in many instances more than once when used as kiln fillings or coverings. As such material cannot be characteristic for the ceramic wares produced at Batán Grande, sherds from nearby settlements would have to be studied next.

The samples from laboratory and field firing experiments were characterized by means of their Mössbauer spectra. Their results can be consistently understood. The systematic determination of color values is less accurate in the characterization of the firing conditions but much faster than Mössbauer spectroscopy.

In the firing experiment in kiln 38, temperatures up to 800 °C were reached. Even higher temperatures could presumably be achieved if more fuel were used and the fire maintained for longer periods. The construction of the kilns leaves it to the ingenuity of the potter to direct the course of the firing as desired. Oxidizing or reducing environments could be generated by admission or exclusion of air or a sequence of both in order to achieve the desired coloration effects. Analyses of samples from the lining of Formative kiln 51 yield ancient firing temperatures between 600 and 800 °C, temperatures that could be easily achieved in our test firings. Considering this, the occurrence of a substantial number of sherds that have been exposed to temperatures above 900 °C is surprising and warrants further investigation.

Acknowledgments

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Ceramics Among the Hohokam: Modeling Social Organization and Exchange

David R. Abbott and
David M. Schaller

The organization and development of prehistoric populations are central themes for archaeological research. Archaeologists have sought to describe the patterns of human interaction within and between prehistoric communities and to determine the social, economic, and environmental factors that influenced and conditioned changes in organization.

Reconstructing prehistoric organization largely boils down to documenting who was interacting with whom and in what manner. Particularly important and especially difficult to accomplish in this regard is tracing the interaction between neighboring populations that were closely related socially. Close social relationships form the core of human organizational structures but are often poorly visible archaeologically. The basic data for reconstructing behavioral correlates consist of variation in physical remains, which tends to decrease in relation to social and geographical distance. As a result, organizational models are sometimes quite coarse, lacking the detail that illuminates the relationships between social units at a local scale.

It has been said that patterns of exchange are the most important evidence bearing on the nature of prehistoric social organization (F. Plog 1984:218). Social relationships are expressed cross-culturally with the exchange of material goods (Mauss 1967; Sahlins 1972). In the American Southwest, the exchange of pottery in particular provides important insights because of the abundance and widespread occurrence of ceramics at even the smallest habitation sites. Also, the American Southwest is rich in geological diversity, which is reflected in the considerable compositional variation of the pottery, often at a geographically fine scale. These circumstances endow the Southwest with the quantity and diversity of information that make it especially conducive to the study of prehistoric social organization.

The diversity of Southwestern ceramics enables researchers to model the ancient patterns of interaction between socially and spatially close populations as well as those of more distant relationships. In this paper, three obstacles are identified that usually must be overcome before realizing that potential. Two of them can be surmounted with a methodology that depends on ceramic petrography, supplemented with electron microprobe assays. Under specific conditions, this combination of techniques is effective for tracing short-distance exchange patterns. The utility and strengths of the methodology are illustrated with a case study involving Hohokam utilitarian ceramics in the lower Salt River valley in Arizona. These ceramics were often exchanged prehistorically and can be sourced inexpensively with remarkable precision. The results provide the first quantitative measure of interaction between Hohokam populations that lived only a few kilometers apart. Such data are particularly useful for investigating the configuration of Hohokam social relationships and the factors that influenced and conditioned its development.

Obstacles to Building Organizational Models

An organizational model can be conceptualized as a matrix of dyadic relationships between social units (e.g., Hage and Harary 1983). Such models that are built on ceramic exchange data will always be incomplete because not all social relationships were expressed with the transfer of pots. Nonetheless, when pottery was frequently exchanged, detailed models can be constructed that are sufficient to test many ideas about the processes of organizational development and change. To do so, however, requires the surmounting of three obstacles: precision, specificity, and quantity. Organizational models become more detailed as the size of the social units is decreased and the total number of dyadic relationships between all of the social units is increased. The first obstacle to be overcome, therefore, is precision—linking ceramic compositional data with specific, geographically fine-scale production zones. Unless the pottery produced by neighboring groups is mutually distinguishable, there is no chance of tracing the movement of ceramics between the groups and establishing their relationship to one another.

A further complication regarding precision involves the distinction between the production source (pottery-making group) of a ceramic and the natural source of the raw materials used to produce it (Rands and Bishop 1980:19). Human action and choice can create a disparity between where the ceramic raw materials were obtained and the location of the pottery-making group that used them (Shepard 1958:452). As examples, raw materials can be imported into a production area; the same raw material source can be exploited by many pottery-making groups; a single set of potters can use different raw materials for vessels of different intended functions; and even though potters tend to minimize the effort to gather their materials (Arnold 1985:50–55), there can be multiple sources of raw materials within an acceptable radius. The selection and movement of raw materials are especially troublesome when attempting to distinguish the pottery from production sources corresponding to relatively small and spatially proximate populations. Simply tying the constituents of a ceramic fabric to a raw-material source can be insufficient for building organizational models. Such models are based on the interaction between social units, and thus the ceramics produced from particular raw materials must be correlated with a particular pottery-making group in order to trace the exchange between groups.

The second and third obstacles to model building arise because a matrix of the exchange between groups is incomplete without knowing their social position relative to one another and how frequently they interacted. The obstacle of specificity involves the social distance between the units. The obstacle of quantity concerns the intensity of the units' relationship.

Social distance is accessible archaeologically because, in exchange contexts, the social distance between exchanging parties is linked to the social setting in which the exchange occurs, the value of the goods exchanged, and the mode of production (e.g., specialists vs. nonspecialists) used to manufacture the goods (see Bohannon 1955; Dalton 1967; Malinowski 1961; Mauss 1967; Sahlins 1972; Salisbury 1962; Strathern 1971). Determining these factors and overcoming the specificity obstacle are beyond the scope of compositional analysis alone and will be considered further only in passing.

In regard to quantity, the intensity of interaction is of concern because its measurement is related to the cost and quickness with which ceramics can be sourced. Intensity corresponds to the frequency of exchange, which requires large samples in order to be measured accurately. Consequently, when building a useful model, the quantity obstacle must be overcome, typically by sourcing a large number of ceramics.

Unfortunately, many compositional studies have produced descriptive results that have been called sterile because their goals were stated in the most general provenience-related terms and lack the integration of technical data with social inferences (Beaudry 1991:250). This sterility may result in part from the difficulties of linking compositional data from ceramics with specific, geographically fine-scale production areas (precision), and expanding the investigation beyond the expensive, "high-tech" assays of a few samples to the inexpensive, "low-tech" analysis of many samples (quantity).

Ceramic Sourcing Methodology

Surmounting the obstacles of precision and quantity can be done under certain conditions using ceramic petrography integrated with electron microprobe assays. Petrographic analysis is, of course, not new in the American Southwest (e.g., Shepard 1936); however, its use there in conjunction with electron microprobe assays is new. A petrographic approach for sourcing prehistoric pottery was first advocated by Anna Shepard (1936; 1939; 1942; 1965; 1980:viii–xi) more than fifty years ago (see also Jones 1986:56; Rands 1987; Rice 1978; S. Plog 1980). It is curious to note, however, that more recently in the Hohokam culture area, ceramic petrography has been judged by both geologists and archaeologists to have minimal utility (Antieau 1981:30; Fournier 1989:583; Robert T. O'Hare cited in Doyel 1974:273–74). Contrary to these opinions, the primary focus in this study is placed on the temper because of its advantage in correlating ceramics with particular production sources and permitting many pieces of pottery to be sourced quickly and inexpensively.

Determining the source of temper, which occurs in geographically isolated solid outcrops, is an effective way to source ceramics for several reasons. First, the sand used as temper often displays considerable diversity in mineralogy and in the variety of rock fragment types present. Second, temper can be readily identified in ceramic thin sections using polarized-light microscopy. Third, the geographic distribution of rock types and minerals is well documented by geologic maps. In many areas of the American Southwest, there is considerable variability in bedrock geology and, by direct inference, sand deposits that may have been exploited as temper sources. Therefore, the identification of temper in pottery sherds has the primary advantage of allowing direct correlation of temper to specific, often fine-scale, geographic areas.

Other analytical techniques are necessary to determine the production areas that were associated with particular temper sources. Assays of the clay fraction, as accomplished by electron microprobe analysis (Birks 1971; Freestone 1982), are particularly useful. With this technique, the composition of selected points in the clay matrix of a polished ceramic section can be determined. The careful selection of points to be analyzed can greatly minimize the contaminating influence of the temper, thus providing compositional data about the clay fraction that complements and is largely independent of the fraction that pertains to the temper. In this way, the microprobe has an advantage over bulk techniques, which measure the chemical composition of the entire ceramic, clay, and temper fractions together (see also Bishop 1980:48; Bishop and Rands 1982; Neff, Bishop, and Arnold 1988; Neff, Bishop, and Sayre 1988, 1989; Shepard 1966).

The measured clay chemistry usually cannot be directly correlated with specific clay deposits without extensive mapping and sampling of the clay beds in the project area. However, the correlation between clay and temper type in ceramics can be determined. A strong correlation between temper and clay can demonstrate the use of locally available materials, thereby making temper an excellent indicator of production source. On the other hand, if temper and clay do not covary, then the exploitation of multiple-temper varieties by pottery-making groups may be indicated.

Estimating the intensity of interaction between groups is also likely to be solved by focusing on the temper. Once the temper in all of the ceramic varieties found in a particular area has been identified through petrographic methods, it is possible to determine the temper in nearly all of the ceramics found in that area by observation with a standard low-powered stereomicroscope. These identifications are accomplished by carefully comparing sherds containing unidentified temper with sherd remnants whose temper has been identified through petrographic methods.

Petrographic, Chemical, and Geologic Conditions for Success

The purpose of ceramic provenience studies based on petrography and microprobe analysis is to relate the temper particles in pottery to specific production areas. The more fine-scale the areas, the greater the precision with which patterns of prehistoric interaction can be reconstructed.The success of this complex task depends on several factors. First, the pottery must contain sand temper that is sufficiently distinctive to correlate it with a bedrock source. Sand temper can be readily identified using thin-section petrography. Second, reference materials from the study area must be available. This usually takes the form of thin sections made from bedrock or sand. Third, the geographic distribution of rocks, which are the sources of sand deposits, must be known. The precision with which ceramics can be sourced in a particular area is primarily dependent on the geologic diversity found in the area and how well that diversity is documented in the form of geologic maps. This means that accurate geologic maps of an appropriate scale must be available for the potential source region of the temper found in a ceramic. As a minimum, suitable geologic maps should be available for a 10 to 20 km radius around the archaeological site where the ceramics being studied are found. This radius approaches the maximum distance that ethnographic potters will travel to obtain temper (Arnold 1985:50–55). Fourth, the rock type that served as the parent material for the temper found in a ceramic must crop out in a limited portion of the potential source region. In other words, it is impossible to source ceramics in a geologically uniform area. Finally, a variety of chemically distinctive clay types must have been exploited by prehistoric potters in the project area; otherwise, it will not be possible to measure the association between clay and temper type, which is crucial for correlating temper types with particular pottery-making groups.

If all of these conditions are met, then sourcing large numbers of ceramics to a particular subregion of a larger study area should be straightforward. These conditions will not be satisfied everywhere, of course. Where they are not satisfied, other approaches will be more appropriate. Nevertheless, in the American Southwest, where the geological and ceramic compositional variation is considerable, suitable conditions often do exist.

Steps in the Analysis

The following approach for sourcing ceramics is recommended when the conditions described above are satisfied. First, the temper types employed in the project area must be identified with appropriate methods. Sand-size crystalline grains employed as temper can be identified most efficiently through petrographic analysis of thin sections made from ceramics (Shepard 1980; Rice 1987). In addition to identifying the mineralogy of the temper, this method also allows rock fragments to be identified on the basis of the textural relationships displayed by their mineralogical constituents. Sherds selected for petrographic analysis should include representatives of every temper variety identified through macroscopic methods. These identifications will characterize the range of ceramic variability present at a site.

Second, potential natural sources of the material employed as ceramic temper must be identified by comparison with reference materials of known origin. A reference collection of thin sections made from all potential bedrock sources of temper in the study area provides a basis for direct comparison with inclusions found in the sherds. The reference collection is selected by obtaining samples from every geological unit identified on geologic maps of the study area. Few samples will be needed from areas dominated by rock types known to be relatively homogeneous, such as granite, whereas more samples will be needed from areas containing rock types, such as schist, that tend to exhibit greater mineralogical and textural diversity.

Third, the material weathering from a bedrock source may be found at any point downslope of the parent material. Therefore, a sand composition zone is defined by outlining the area downslope of the outcrop for each sand variety by reference to appropriate geologic and topographic maps. Sediment distribution patterns are more complicated in areas where glacial or eolian processes have played a major role in sediment transport. However, in most parts of the American Southwest, these processes have been relatively insignificant when compared to conventional alluvial processes. Sand composition can be defined on the basis of the presence of particular mineral or rock fragments; the presence of minerals of a certain size, color, or chemical composition; or by the co-occurrence of particular mineral or rock varieties. In the ideal case, each zone will have some unique compositional aspect.

Fourth, sherd remnants whose temper has been identified through petrographic methods should be examined carefully with a standard low-powered stereomicroscope to identify macroscopically diagnostic qualities of the distinctive rock or mineral inclusions that characterize each sand zone. For example, if one sand composition type is defined by the presence of mica schist fragments and another is defined by the presence of hornblende-bearing metamorphic rock fragments, the sherds containing mica crystals visible under the microscope can be assigned to the one category, and sherds containing recognizable hornblende crystals can be assigned to the other category. This step is crucial because it allows sourcing of temper in a set of ceramics far larger than those that are thin-sectioned.

Fifth, the production area that corresponds to each temper type should be determined. Perhaps the most effective procedure is to test the hypothesis that the potters who lived in the project area exploited the nearest available temper source. This hypothesis corresponds to the simple situation where the division of the cultural landscape into different production areas coincides with the division of the geological landscape into different sand composition zones. Also, it has a high prior probability of being correct because, as Arnold (1985:50–55) has shown, potters tend to minimize the effort expended to procure their temper and transport it over short distances.

Support for the hypothesis is demonstrated in three ways. The first is in accordance with the criterion of archaeological abundance, which states that pottery of a particular variety should normally have been manufactured in the locality in which it is best represented (Rands and Bishop 1980:20). The most abundant pottery variety at a particular site should have the temper type that naturally occurs closest to the site. Second, the clay associated in ceramics with the closest available temper type should be different from the clay associated with other temper types found in the other ceramics at the site. If so, then a nonrandom association between clay and temper would be indicated, presumably because the different ceramic varieties were manufactured by different populations. Third, the ceramic vessels tempered with the closest available temper type should exhibit a full range of vessel forms. If not, then the potters at a site may have tempered vessels intended for different functions with different sand types. Lack of support for the hypothesis would imply a more complicated raw-material procurement situation, requiring the formulation and testing of additional hypotheses to account for the discrepancy between the cultural and geological landscapes.

Hohokam Ceramic Exchange in the Lower Salt River Valley: A Case Study

In the lower Salt River valley in Arizona, prehistoric Hohokam potters used diverse sand varieties as temper for their ceramics. Diverse bedrock types, whose geographic distribution is well documented, are also found in this area. Based largely on temper petrography, the exchanges of thousands of plainware ceramics have been identified over distances as short as 5 km. These data, as discussed below, are quantified measurements of social and economic interaction that are suitable for investigating Hohokam organization and the degree to which it was conditioned by the management of their extensive irrigation network. In the context of intracultural organization, tracing the movement of the plainware containers identifies with high resolution the connections between socially close and geographically proximate populations. Moreover, the identified instances of social and economic contacts are built into full-blown patterns of interaction because the sample sizes are large.

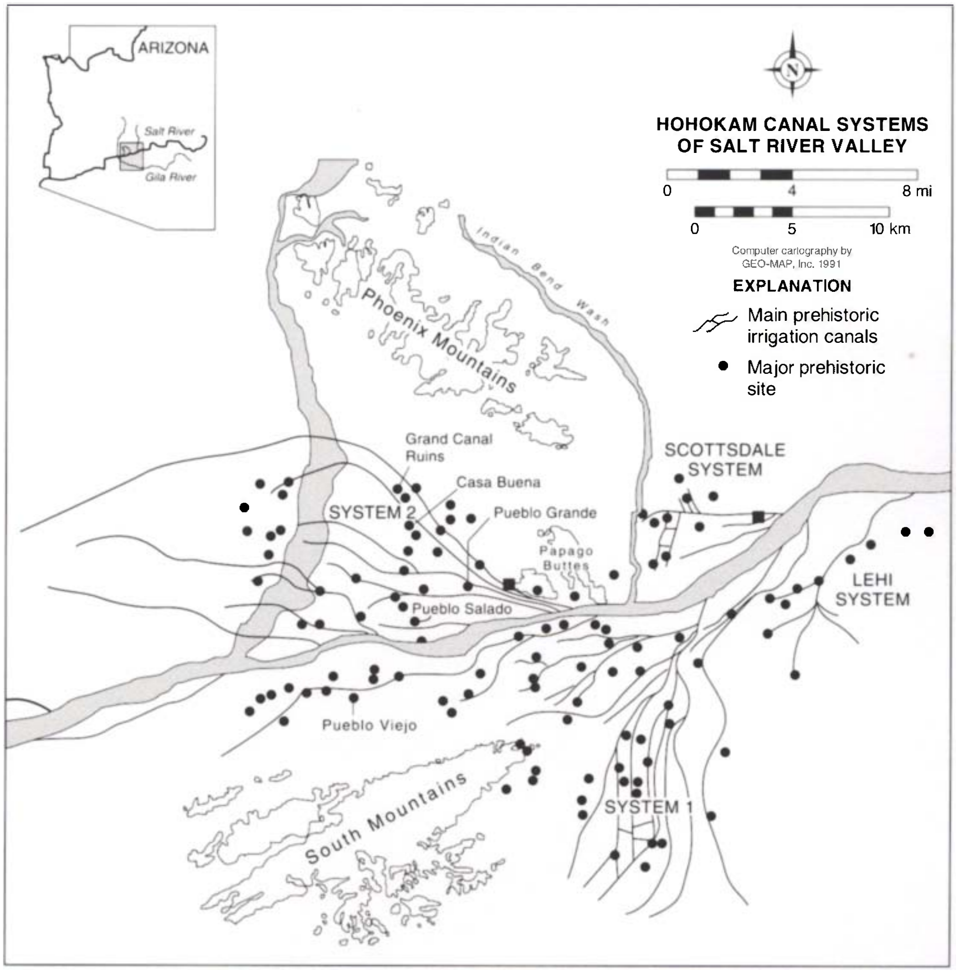
The Hohokam

The Hohokam were a remarkable neolithic people who continuously inhabited sedentary villages and successfully farmed their desert environment for more than a millennium. Occupying the Phoenix basin and adjacent areas of south-central Arizona from about 1–1450 C.E., the Hohokam are perhaps best known for their irrigation works. They engineered and operated some of the largest and most impressive canal networks of the prehistoric New World. In the Phoenix area, hundreds of kilometers of ditches transported water from the Salt River to fields and habitation areas spread out along the canal routes. Archaeologists divide the Phoenix-area network into four primary canal systems, each of which includes a set of canals with a common headgate location, and the associated settlements (Fig. 1).

During the Classic period (ca. 1100–1450 C.E.), platform mounds were constructed at villages roughly 5 km apart and are thought to be integrated components in managing water delivery (Crown 1988; Gregory and Nials 1985). Their regular spacing and the roughly uniform distribution of other sites testify to some form of equitable water apportionment and regulation. The degree to which these relationships governed other aspects of Hohokam life remains to be determined.

For instance, it has been suggested that canal systems were sociological entities perceptible to the Hohokam and played some role in everyday life for much of the population (Gregory and Nials 1985). In fact, some analysts argue that by the Classic period the bulk of organizational relationships between populations was focused on the irrigation network (Doyel 1981; Schroeder 1953). If this is true, then one would expect that a large measure of the interaction during the Classic period would have been between people who lived in the same canal system, with much less

Figure 1. *Hohokam canal systems of the lower Salt River valley, Arizona, with some site locations.*



interaction between people who lived in different canal systems. The compositional analysis of Hohokam plainware pottery has made it possible to gauge such interactions by tracing ceramic exchanges both within and between canal systems.

Compositional Analysis

Conditions for the analysis. Prior to the present study, several Hohokam plainware varieties were recognized based on temper type, including three types of metamorphic rock fragments and a general "sand" category (Abbott and Gregory 1988; Cable and Gould 1988; Doyel and Elson 1985; Weaver 1973). Their distinctions indicated that the temper found in plainware was sufficiently variable to attempt a provenience study based on petrography.

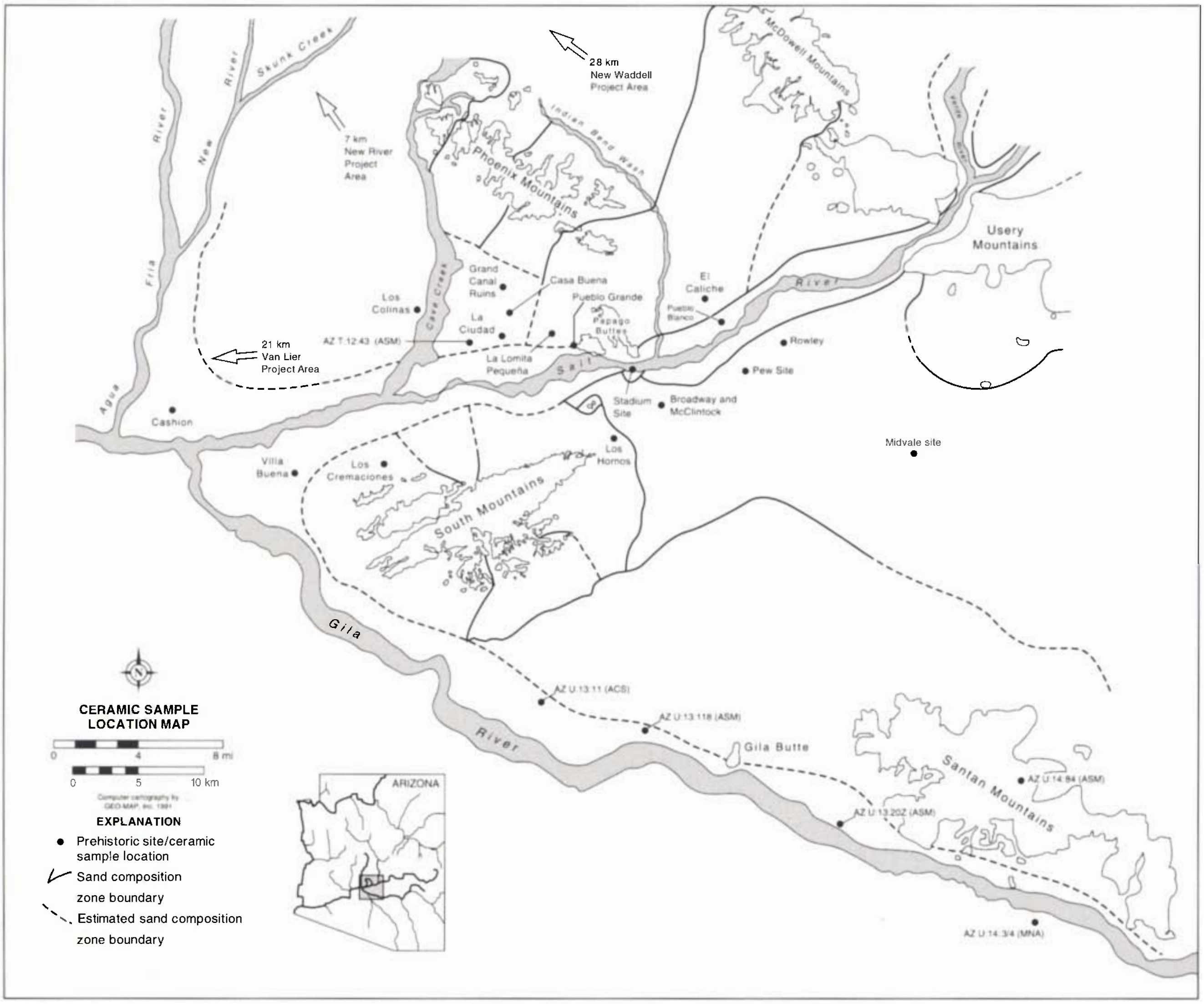
Also, approximately twenty-five geologic and soils maps, many unpublished, were located for the Phoenix area. Even though these maps had varying scales and degrees of precision, the set as a whole provided sufficient coverage of the lower Salt River valley to permit correlations between bedrock units and ceramic temper. In addition, the maps displayed a considerable variation in rock types and showed that many types were confined to limited portions of the study area.

The compositional analysis was undertaken in conjunction with excavations by Soil Systems, Inc., at the site of Pueblo Grande. The excavations concentrated almost exclusively on the Classic period component. Pueblo Grande was perhaps the largest Hohokam village in the Phoenix area. It was centrally located in the lower Salt River valley at the headgates of Canal System 2 (see Fig. 1) and was undoubtedly influential in the regional settlement system during the Classic period.

Step 1: Identifying temper types. The first step in the analysis was to document to a considerable degree the range of variation in plainware temper from the lower Salt River valley. A sample of 120 plainware sherds was thin-sectioned from Pueblo Grande. Also, nearly 300 thin sections, which were made during earlier projects at other sites, were reexamined. Finally, for good spatial coverage, 120 plainware sherds from ten other sites were thin-sectioned. Figure 2 shows the locations of all sites. The results from these petrographic analyses showed, with some exceptions discussed below, that each sherd largely contained fragments of a single rock type. Moreover, the temper fragments were typically angular, indicating that they were procured near their bedrock source. This result was important because it demonstrated that the temper had not been obtained from the Salt River bed, which contains variegated and rounded sand.

Step 2: Comparing temper with reference materials. During a limited geological survey, hand specimens were obtained from each of the geologic units that were identified on the geologic maps (Fig. 3). The survey also permitted the necessary

FIGURE 2. *Site locations of the thin-section samples.*



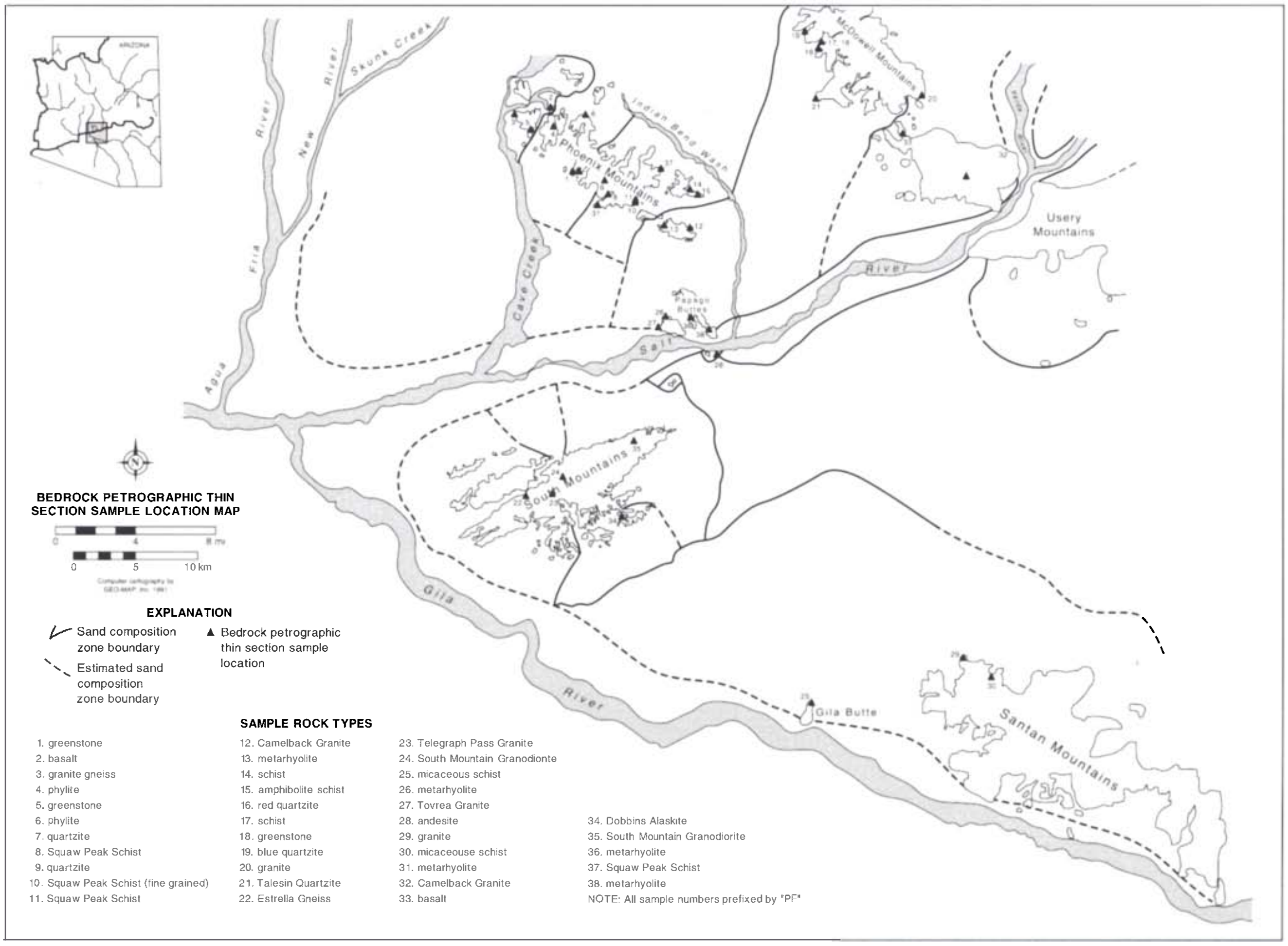


Figure 3. *Site locations of the thin-section samples from bedrock units.*

cross-checks to establish the correspondence between the maps. A portion of each hand sample was thin-sectioned to establish a reference collection, which was used with polarized-light microscopy to compare ceramic temper with bedrock sources. It was demonstrated that the temper in most sherds could be correlated to bedrock exposures of one of six rock types: Camelback granite, Squaw Peak schist, phyllite, South Mountain granodiorite, Estrella gneiss, and micaceous schist. Other rock types crop out in the valley, such as greenstone, basalt, and andesite, but occurred rarely in pottery or did not occur at all.

Apart from the six abundant temper varieties, there were some exceptions. An additional variety of sherds containing a mix of two rock types, Camelback granite and Squaw Peak schist, was present in large frequencies. Sand deposits composed of this mixture are found in one area of the lower Salt River valley (see section below), and thus the temper in these sherds may have been derived from there. Also, among the nearly 500 ceramic thin sections, one sample was tempered with quartzite, two contained primarily andesite temper, and one contained major amounts of basalt. These three rock types also crop out in the study area in limited geographical distributions.

Step 3: Sourcing temper. Once it was determined which rock types were important to Hohokam potters for temper, the geographical distribution of the source zones (bedrock and erosional sand deposits) was delimited for each. Nine sand composition zones were defined (Fig. 4). Six zones correspond to the six temper

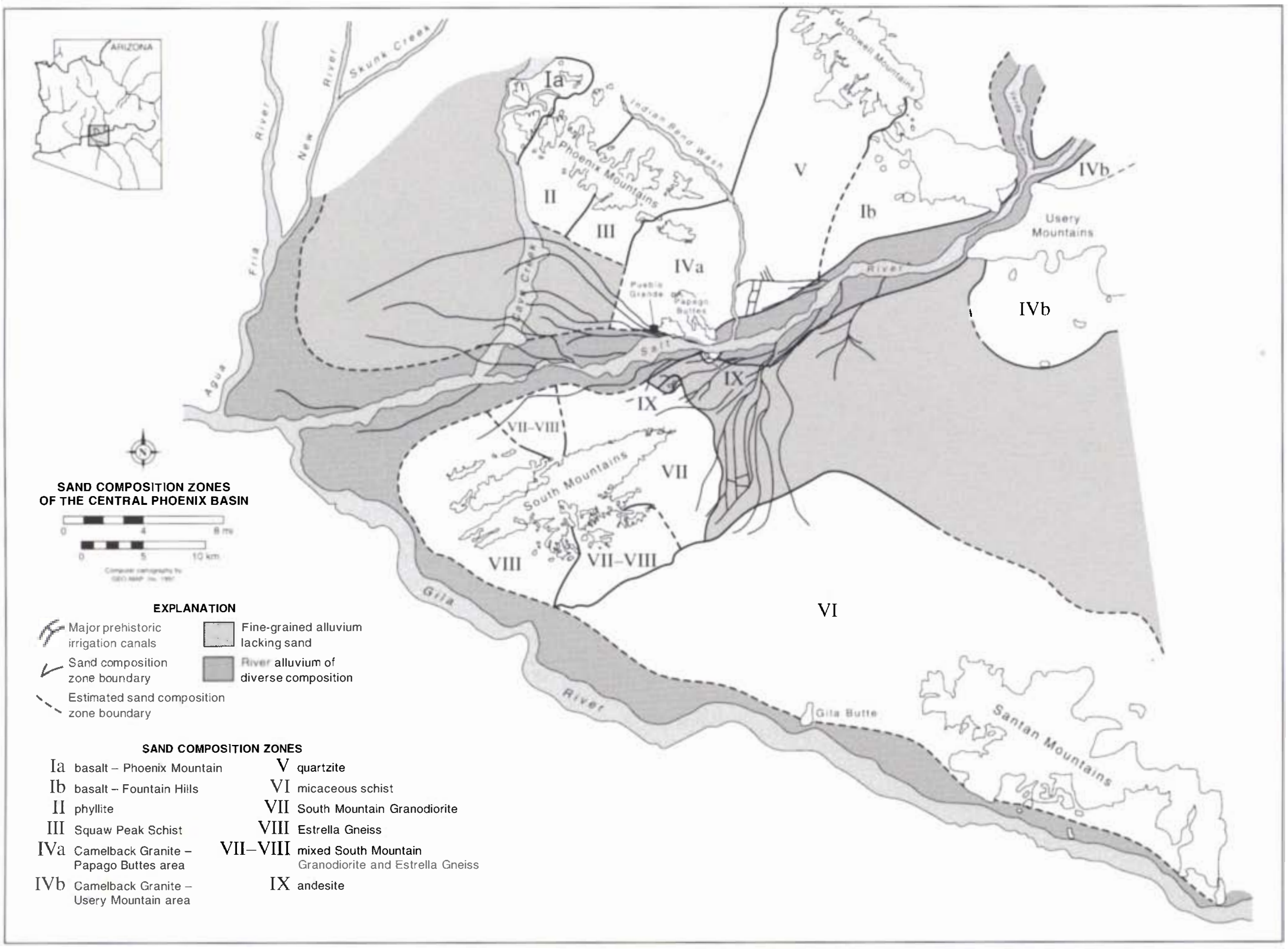


FIGURE 4. *Sand composition zones of the central Phoenix basin.*

varieties identified during the sherd analysis. For completeness, three zones were added that correlate with the sherds tempered with quartzite, andesite, and basalt.

The zonal boundaries are derived by topographic relief and the alluvial and colluvial movement of sediments toward the Salt River. In the study area, the zones largely do not overlap because, in the Phoenix area, bedrock of diverse varieties crops out in isolated exposures surrounded by alluvium. Sand derived from the weathering of each exposure is separated from other sands by river drainages. Sand of mixed composition is found only in the major riverbeds such as that of the Salt River. Sand containing both Camelback granite and Squaw Peak schist is expected along the boundary between their respective zones.

The construction of the sand composition zone map, in effect, establishes the geographical source of the temper in the nearly 500 sherds examined during the thin-section analysis. The next step in the study was undertaken to expand this result to thousands of additional ceramics.

Step 4: Expanding the analysis. An important criterion applied to select sherds for thin-section analysis was their size. The sherds chosen were sufficiently large to yield both an adequate thin section and a remnant that could be examined with a standard low-powered stereomicroscope. As an additional aid, a portion of each rock sample in the reference collection was crushed to temper-size particles for comparing temper with raw material of known composition and origin. By examining the sherd remnants, applying the petrographic information obtained from their related thin sections, and comparing them to the crushed reference samples, criteria were developed for distinguishing the six temper types with low-tech equipment (Abbott n.d.-a). These criteria were then applied to sort approximately fifteen thousand plainware ceramics from Pueblo Grande.

Step 5: Establishing the correspondence between temper and production source. Pueblo Grande is located in the Camelback granite sand composition zone, and, not surprisingly, most of the plainware pottery at the site is tempered with arkosic sand derived from the granite. Moreover, a full suite of vessel forms was tempered with arkosic sand, as would be expected of locally made pottery. However, there are substantial numbers of sherds at Pueblo Grande that contain temper from the other five zones as well. It was necessary to determine whether these varieties were imported to Pueblo Grande or were produced by local potters who obtained their temper from more distant sources.

To distinguish the local from the imported pottery at Pueblo Grande, chemical assays of the clay fraction in sherds were performed by using an electron microprobe.[1] The analytical strategy follows one commonly used in Europe (Poole and Finch 1972; Tubb et al. 1980; Widemann et al. 1975), where specimens having a questionable origin are analyzed and compared to reference groups whose origins are known.

In the present study, sherds of the predominate variety from five Hohokam settlements were used as the reference groups, including the phyllite varieties at Las Colinas (Abbott 1988) and La Ciudad (Henderson 1987), the Squaw Peak schist variety at Grand Canal Ruins (Lane 1989), the South Mountain granodiorite variety at Los Hornos (personal observation by the senior author of the collection at Arizona State University), and the granitic-tempered pottery at Pueblo Grande (Fig. 5). It was assumed that assays of these sherds establish the chemical composition of the local pottery clay at each of the respective sites. The specimens whose origin was in question were from Pueblo Grande and contain either phyllite, Squaw Peak schist, South Mountain granodiorite, or a mixture of arkosic sand and Squaw Peak schist. If they were manufactured at Pueblo Grande, their clay portion should chemically correspond to that of the Pueblo Grande granitic variety. On the other hand, if they were imported to Pueblo Grande, then their clay fractions should be unlike those in the Pueblo Grande reference group and should be similar to one or more of the other groups.

Five spots on each sherd were assayed, each about the size of a period on this page. The percentages of the eight chemical elements were determined. The Na:Al ratios for all assays pertaining to each sherd were checked for consistency as a test for chemical leaching. Spots that proved problematic in this regard were eliminated. For each sherd, the assays were averaged to produce mean percentages of each chemical element. The marginal distributions of these data were then examined. The data for several elements were skewed and were made quasi-normal with a log transformation. Finally, all of the marginal distributions were standardized using Z scores in order to give equal weighting to all variables.

An important initial assumption was that different clays were exploited by the potters at different sites. This assumption was supported by numerous and exten-

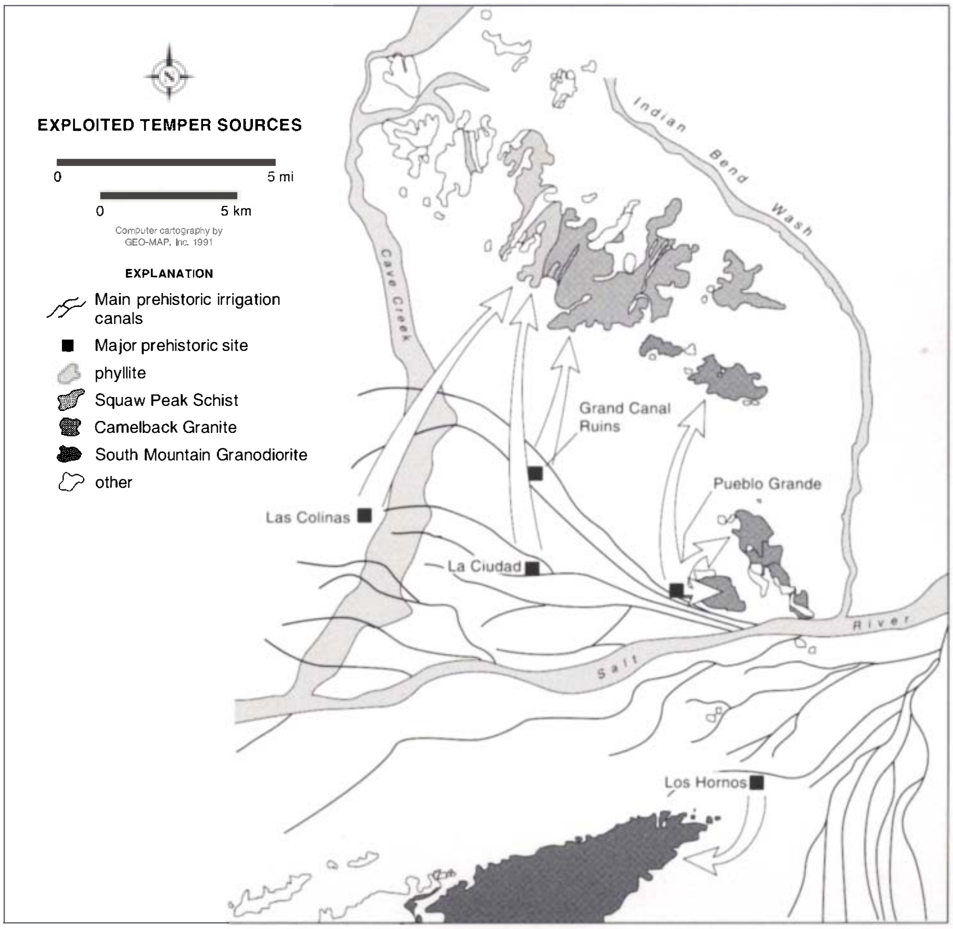


Figure 5. *Exploited temper sources from five Hohokam settlements.*

sive clay deposits in the lower Salt River valley (Bruck 1983; Hoyos-Patiño 1985). These clays had a high silt content, which also characterized the clay paste in the plainware pottery. If, however, the Hohokam potters routinely used clay deposits that accumulated in canals, this assumption could have been false. The differences between the reference groups were tested using Hotelling's T^2, which determined the probability that the groups' centroids were the same (Johnson and Wichern 1982:179–80). The results showed that four of the five reference groups were different (Table 1). The two reference groups that could not be statistically separated were those from Las Colinas and La Ciudad. They were combined for the remainder of the analysis into a single phyllite reference group.

Table 1. *Results of multivariate tests of differences of reference group centroids using Hotelling's T^2 statistic. Figures in parentheses indicate probability value.*

Reference Group	La Ciudad	Las Colinas	Grand Canal	Los Hornos
Las Colinas	0.630 (.169)			
Grand Canal	4.721 (.000)	5.511 (.000)		
Los Hornos	10.39 (.000)	11.40 (.000)	8.054 (.000)	
Pueblo Grande	10.82 (.000)	9.238 (.000)	4.241 (.000)	1.806 (.000)

Discriminant analysis (Johnson and Wichern 1982:461–531) was then used to investigate the unknown cases from Pueblo Grande (Table 2). It created a factor space in which the centroids of the four reference groups were maximally separated by appropriately weighting and linearly combining the eight chemical variables (Fig. 6). The unknown cases were then mapped into this space and, based on their position, were assigned to one of the four reference groups. Those assigned to groups other than Pueblo Grande were clearly unlike the Pueblo Grande pottery and probably were imported to the site.

For illustration, the location of the Squaw Peak schist unknowns in the factor space is presented in Figure 7. Most of the Squaw Peak schist unknowns fall into the Squaw Peak schist reference group from Grand Canal Ruins (Table 3). In addition, the phyllite unknowns tend to be associated with the phyllite reference group from Las Colinas and La Ciudad, and the South Mountain granodiorite unknowns closely cluster with the Los Hornos reference group, which also contains South Mountain granodiorite temper. On the other hand, many of the unknowns containing both arkosic sand and Squaw Peak schist are most like the reference group from Pueblo Grande (see Table 3). With few exceptions (and excluding the pottery with

TABLE 2. *Results from the discriminant analysis to determine the origin of the Pueblo Grande specimens.*

DISCRIMINANT FACTORS

Factor	Eigenvalue	Pct of Variance	Cumulative Pct
1	5.9734	74.04	74.04
2	1.7163	21.27	95.31

FACTOR LOADINGS

Element	Factor 1	Factor 2
Ca	.64499	−.34489
Mg	.50686	−.28141
Na	.32969	.80476
Al	−.35574	.38784
K	.08909	−.30754
Fe	−.22367	−.10461
Si	.02623	−.17281
Ti	−.17656	−.09218

CLASSIFICATION TABLE

Actual Group	Predicted Group Membership				
	La Cuidad Las Colinas	Grand Canal Ruins	Los Hornos	Pueblo Grande	Total
La Cuidad Las Colinas	30	0	0	0	30
Grand Canal Ruins	1	16	0	0	17
Los Hornos	0	1	20	1	22
Pueblo Grande	0	1	2	11	14

92.8% correctly classified

Figure 6. *Discriminant factor space in which the four reference groups were distributed by weighting and combining the chemical variables.*

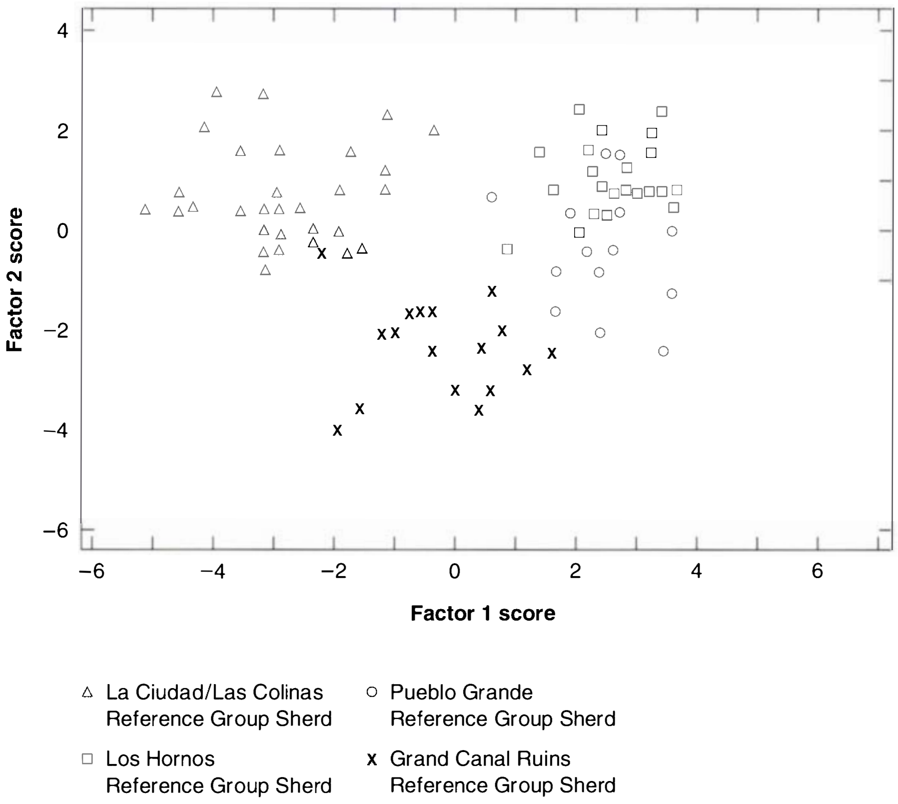
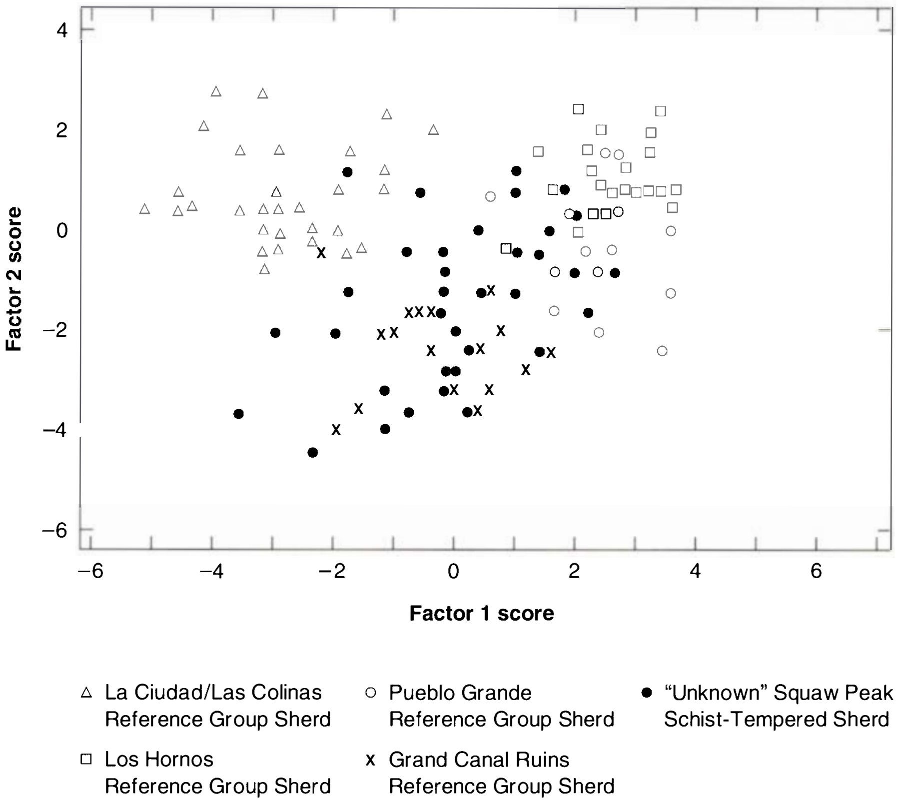


Figure 7. *Locations of unknown sherds containing Squaw Peak schist in the discriminant factor space.*



mixtures of arkosic sand and Squaw Peak schist), temper and clay type covary, indicating that temper type probably is closely related to production source. Therefore, the pottery at Pueblo Grande containing pure amounts of Squaw Peak schist, phyllite, and South Mountain granodiorite were probably imported to Pueblo Grande.

Table 3. *Classification table for the unknown cases from Pueblo Grande.*

Unknown Group	Predicted Group Membership				
	La Ciudad/ Las Colinas	Grand Canal Ruins	Los Hornos	Pueblo Grande	Total
Squaw Peak schist	2	23	1	9	35
Phyllite	9	6	0	6	21
South Mountain granodiorite	0	1	14	7	22
Arkosic sand w/ Squaw Peak schist	2	2	1	8	13

The cases containing the mixture of arkosic sand and Squaw Peak schist probably represent a subvariety produced at Pueblo Grande.

Those unknown cases that were assigned to the Pueblo Grande reference group are the subjects of additional analysis. Some possibly were not produced at Pueblo Grande. An important assumption of the discriminant analysis technique was that all of the relevant reference groups were included when the factor space was defined. In effect, for the present analysis, four pigeonholes were created, and all of the unknown cases were forced into one of the holes. Some cases, however, may not truly belong with any of the four reference groups, including the one from Pueblo Grande, but rather with a group not identified in the analysis. These cases are subjects of additional research, the results of which are slated for future publication (Abbott n.d.-c).

Results from Pueblo Grande[2]

The petrographic and microprobe analyses established that during the Classic period, temper type was an excellent indicator of production source for plainware pottery. Using a low-powered stereomicroscope, the temper was identified in about 15,000 plainware sherds from Pueblo Grande. About 55% contained either arkosic sand or arkosic sand mixed with Squaw Peak schist. Most or all of these cases undoubtedly were the products of Pueblo Grande potters. On the other hand, the phyllite-tempered pottery (16%) probably was imported mostly from the west end of Canal System 2; the pottery containing pure amounts of Squaw Peak schist (11%) probably was derived from settlements in the central portion of Canal System 2; and the variety tempered with South Mountain granodiorite (14%) came from south of the Salt River in Canal System 1. Other more distant sources probably contributed to the varieties with Estrella gneiss (2%) and micaceous schist (2.5%). Also, a rim sherd analysis revealed that the distinguishable vessel forms were distributed similarly among all of the plainware varieties. Apparently, the exchange between Pueblo Grande and other villages in the lower Salt River valley was not focused on particular vessel forms. Plainware pottery was the utilitarian ware of the Hohokam and probably was produced in most villages by nonspecialists (Haury 1976:191–92). There is no evidence to indicate that particular varieties of plainware pots were preferred for use in formal social contexts, such as mortuary offerings or in ceremonial settings. Consequently, it is likely that plainware pottery was the kind of low-valued item that is ethnographically known to circulate among kinsmen or other closely cooperating parties (Bohannon 1955; Mauss 1967; Sahlins 1972; Salisbury 1962; Sillitoe 1978; Strathern 1971; Suttles 1960). As such, the pattern of plainware exchanges probably corresponds to the web of close social ties in Hohokam society.

Contrary to current theory, the data show that the Classic period population at Pueblo Grande regularly interacted with people living beyond Canal System 2. Moreover, the intensity of interaction, as indicated by the percentage of each imported variety, indicates that the frequency of interaction largely corresponded to geographic distance.[3]

Additional Results

Understanding the role of Pueblo Grande in the regional settlement system is essential for realistically modeling Hohokam organization in the lower Salt River valley. The Pueblo Grande results indicate that other factors besides hydraulic management were important for organizing Hohokam social interaction. However, the available data from four other Classic period sites support the idea that membership in a canal system was a crucial factor that conditioned social relationships. Moreover, these comparative data seem to indicate that the inhabitants at Pueblo Grande were set apart from their neighbors at other villages because they had regional interests that went beyond their own canal system. Using standard procedures with low-tech equipment, four small data sets have been generated. By examining the temper, the production sources of plainware mortuary vessels from Grand Canal Ruins (n=128) and Casa Buena (n=45) have been identified (Abbott n.d.-b). These villages are located in the central reaches of Canal System 2 (Fig. 1). Also, 1,330 plainware sherds and 28 plainware whole vessels from Pueblo Viejo have been examined to identify their production source (Abbott 1993). Pueblo Viejo is located south of the Salt River, outside Canal System 2 (Fig. 1). Finally, the ceramics from Pueblo Salado, a small village located north of the Salt River in the vicinity of Canal System 2 (Fig. 1), are currently being investigated. Despite its location, Pueblo Salado probably did not depend on villages in Canal System 2 for water delivery because its associated canal had a separate headgate location (David Greenwald, director, Pueblo Salado Project, pers. comm. 1992).

The ceramic data from all four sites indicate the importance of membership in a canal system for structuring social interaction. Unlike the population at Pueblo Grande, the inhabitants of these sites did not receive many pots from beyond their own canal network. On the one hand, at Grand Canal Ruins and Casa Buena only 5 and 7% of the plainware pots, respectively, were obtained from production sources outside Canal System 2. On the other hand, 12 and 25% of the vessels, respectively, were obtained from either the east end or west end of their canal system. At Pueblo Viejo, south of Canal System 2, only 0.8% of the plainware sherds and none of the whole vessels were imported from Canal System 2. Finally, preliminary evidence indicates that, except in trace amounts, Squaw Peak schist and phyllite-tempered plainware pottery did not occur at Pueblo Salado (Mary-Ellen Walsh-Anduze, project ceramist, pers. comm. 1992). These varieties were the utilitarian wares of the people living in the central and western reaches of Canal System 2. Therefore, the inhabitants at Pueblo Salado, who were not members in that canal system but were spatially proximate to the Canal System 2 populations, did not interact with their neighbors in the manner that their neighbors interacted among themselves.

In comparison to the other four sites, the exchange pattern at Pueblo Grande is unique. Pueblo Grande was one of the largest and most centrally located villages during the Classic period. Perhaps the degree to which its residents received pottery from other villages indicates that Pueblo Grande was a seat of central authority for coordinating activities valleywide as well as activities within Canal System 2. At this time, it would be imprudent to draw firm conclusions about the structure of valley-wide interaction, because the number of Classic period sites far exceeds the few sites that have been studied to date. Nonetheless, a useful and provocative organizational model has been derived, which is subject to further testing.

Conclusion

The complementary use of petrography and electron microprobe assays has overcome two obstacles of ceramic provenience studies: the precise definition of production sources, and sourcing enough pottery to quantify the exchange interactions. As a result, a detailed model has begun to emerge from the ceramic studies about the social relationships between Hohokam populations in the lower Salt River valley, and the factors that influenced and conditioned their organization. Currently, the data indicate that the groups who lived within a canal system were closely tied together socially, although one large and centrally located village, Pueblo Grande, may have had a preeminent role during the Classic period. As the regional database takes shape, other factors can be investigated that potentially influenced social interaction, such as village size, position within a canal system (near the headgates, in the center, near the terminus), and the presence or absence of monumental public facilities. Much more refined and precise models of organization can be expected because, for the first time, the interaction between Hohokam populations, who lived only a few kilometers apart, is being measured directly, quantitatively, and inexpensively.

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Notes

1. A Joel JXA-8600 electron microprobe with Tracor-Northern TN 5600 automation and energy-dispersive analysis system was used to perform the assays. The microprobe directs a stream of high-energy electrons onto a small spot on the sample's surface and analyzes the energy levels or wavelengths of emitted X rays. In energy-dispersive spectroscopy, each chemical element present in the sample produces X rays of a characteristic energy level. The relative intensities of the X rays produced at each energy level are indicative of the relative abundance of each chemical element in the sample (Birks 1971). The X-ray detector is mounted at a takeoff angle of 40°. The X-ray detector live counting time was 50 seconds. Matrix effects were corrected with a ZAF algorithm, and the calibration of the equipment was accomplished with a Kakanui hornblende standard. The samples were coated with a 400 µ thick layer of carbon and analyzed using 15 kV filament voltage and a 10 Na defocused beam current.
2. The results reported here are preliminary. They are subject to change, although substantial changes are not expected.
3. A spatially constant population density is an untested assumption.

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Stone and Obsidian

New World Obsidian: Recent Investigations

MICHAEL D. GLASCOCK

Obsidian is a naturally occurring volcanic glass similar in chemical composition to granite and rhyolite but lacking in crystalline structure. The glass is formed when highly viscous molten lava cools at a rate slow enough to allow the volatile components in the lava to escape, but rapid enough to preclude crystallization. Its lack of crystalline structure gives obsidian a vitreous (glassy) luster. When a piece of obsidian is struck by a skilled craftsman, it yields conchoidal-shaped fractures. Because of its fracturing characteristics, obsidian produces some of the sharpest edges of all lithic materials. As a result, obsidian was a highly prized natural resource for prehistoric peoples who used it to manufacture sharp-edged implements and weapons.

Obsidian glass slowly devitrifies over time, losing the excellent fracturing characteristics for which it is so highly valued. As a consequence, the raw obsidian suitable for the production of implements necessarily comes from more recent volcanic formations, usually from the Tertiary period or younger.

To the archaeologist, studies of obsidian artifacts are useful for reconstructing the relationships between prehistoric societies and for studying resource procurement patterns, manufacturing processes, and distribution networks. In addition, because large quantities of obsidian were exchanged over a long period of time, it can form the basis for studies of changes in socioeconomic conditions. J. E. Clark (1981) identifies several characteristics of obsidian that place it in a unique role for archaeological study:

1. There are a limited number of sources. In the Western Hemisphere, the regions of volcanism exist in three main zones along the Pacific coast. These regions are: (a) the western regions of the United States and Canada, (b) Mesoamerica, including the central portions of Mexico and the highlands of Guatemala, and (c) western South America, along the central Andes mountain range. Moreover, many volcanic eruptions produce an obsidian with numerous phenocrysts, making them less suitable as sources of obsidian for chipping. Thus, quality

obsidian occurs with a degree of rarity that enhances its value and makes it an excellent marker of prehistoric exchange.

2. Obsidian artifacts are found in many locations and in different contexts (e.g., rural, elite, ceremonial) throughout the New World. It is evident that much exchange of obsidian for other goods took place during prehistoric times. For example, the obsidian artifacts found in the Hopewell sites in Ohio, Indiana, and Illinois are more than 2,000 km from the nearest possible sources. Huge quantities of obsidian are found at virtually all archaeological sites in Mesoamerica, even in remote areas hundreds of kilometers from sources. Finally, obsidian artifacts are found at numerous sites along the Pacific coast of South America. Evidence concerning the extensive exploitation of obsidian throughout the New World during Pre-Columbian times provides the archaeologist with a means of comparing the obsidian exchange patterns for different prehistoric sites.
3. Large quantities of obsidian debitage remain behind at the ancient quarries, where the initial blocks or cores of obsidian were prepared for transport to consumption zones. This gives archaeologists the opportunity to estimate the total amount of obsidian excavated and exchanged. For example, a single source at La Joya, Jalisco (a rather modest mining complex in western Mexico), is estimated by Weigand and Spence (1982) to have provided more than 13,000 tons of artifact-quality obsidian.
4. The artifacts retain many of their physical features from fabrication—scars, platform angles, and other distinguishing marks—that help to identify the manufacturing methods used. In addition to learning production techniques, the functions of tools and the skill of craftsmen can be inferred. It may also be possible to identify artifacts that were retooled or reused.
5. The fragile nature of the finished product means that obsidian has a high replacement rate and offers a means of examining the prehistoric economic conditions. Obviously, more wealthy societies or persons of elite stature were likely to consume more and higher quality obsidian than the less fortunate.
6. When fashioning tools and other items from obsidian, the chemical composition of the material remains unaltered. In most archaeological contexts, obsidian is a relatively indestructible material and is not easily contaminated or leached by its environment. Thus, archaeologists can have confidence that any artifact under examination closely resembles that which the prehistoric person used before it became lost or discarded.
7. Due to the high-temperature mixing that occurs when obsidian is formed, the chemical composition of the material at any particular source or flow is, with a few exceptions, homogeneous. Differences in composition between sources, however, are usually significant. Thus, the chemical fingerprinting of artifacts provides archaeologists with a highly precise method for sourcing. If the compositional data for all potential sources are well known, long-distance conveyance networks can be investigated with a high degree of confidence.
8. A freshly exposed obsidian surface absorbs water gradually with time, providing the archaeologist with a means of determining the original date when the

tool was produced. In addition, evidence of multiple dates for artifacts is useful in confirming tool remanufacture.

Considering these properties and the importance of obsidian to many Pre-Columbian societies in the Western Hemisphere, this is an appropriate time to review the present status of obsidian studies and to identify areas of future investigation. In particular, this discussion focuses on obsidian characterization in Mesoamerica and its relevance to sourcing and hydration dating.

Sourcing

Archaeologists have long sought methods for sourcing obsidian that are rapid, low-cost, nondestructive, and reliable. The earliest attempts (Fuller 1927) at sourcing involved physical examination of visual traits such as color, translucency, texture, and luster. Unfortunately, these properties are often incapable of distinguishing between different obsidian sources on a reliable basis. Assorted colors (clear, gray, black, reddish brown, reddish black) and various degrees of banding or mottling may occur within a single obsidian deposit. In spite of this, many archaeologists have devoted large amounts of time to sorting their obsidian collections according to these highly subjective criteria and have been unsuccessful in obtaining consistent results (Moholy-Nagy and Nelson 1990; Jackson and Love 1991).

Other methods investigated for sourcing include density measurements (Reeves and Armitage 1973), thermoluminescence (Huntley and Bailey 1978), Mössbauer spectroscopy (Longworth and Warren 1979), fission track analysis (Duranni et al. 1971), measurement of magnetic properties (McDougall et al. 1983), and the measurement of natural radioactivity (Leach et al. 1978). However, these techniques were found to have very limited applications. None of the methods has proven as successful as chemical compositional analysis in providing the desired success rate for differentiating between sources.

As a rhyolitic volcanic rock, the chemical composition of most obsidian ranges from about 70 to 76% SiO_2, 10 to 15% Al_2O_3, 3 to 5% Na_2O, 1 to 5% K_2O, and usually less than 2% total Fe_2O_3 and FeO. The peralkaline varieties of obsidian are somewhat higher in Fe. In addition, the initial water content of obsidian ranges from 0.1 to 0.3% and increases to about 3.5% by weight as rhyolitic obsidian gradually transforms into a less useful form of glass known as perlite. The remaining elements are present at concentrations far less than 1% and are often called the "trace-element contaminants" of the glass. It is, however, the presence of the trace and minor elements that furnishes the success of chemical analysis as a method of sourcing obsidian. This success occurs because the trace element compositions of the glass may differ by one or two orders of magnitude between sources, while the internal variations are usually much smaller. Thus, the chemical compositions of obsidian sources and artifacts serve as fingerprints by which comparisons are made.

In order to be an effective method for compositional analysis of obsidian specimens, the analytical technique must be (1) quantitative, (2) capable of excellent sensitivity and precision, (3) able to measure many elements, (4) independent of sample matrix, size, and shape effects, (5) rapid, and (6) available at reasonable cost. Among the chemical analysis techniques that have been used to characterize obsidian are optical emission spectroscopy (Hallam et al. 1976), atomic absorption spectroscopy (Wheeler and Clark 1977; Michels 1982), particle-induced X-ray emission (Duerden et al. 1984), inductively coupled plasma emission spectroscopy (Stevenson and McCurry 1990), X-ray fluorescence spectroscopy (Nelson 1985), and neutron activation analysis (Asaro et al. 1978). Of these methods, X-ray fluorescence and neutron activation analysis are commonly employed in the analysis of obsidian.

In X-ray fluorescence, a source of X rays irradiates the sample of obsidian, causing the displacement of atomic electrons from inner energy levels. As electrons from the outer (higher) energy levels repopulate the vacant inner (lower) energy levels, energy is emitted in the form of fluorescent X rays. Because the energy levels are unique for each element, the emitted X rays have characteristic energies that permit identifying the elements present in the sample. By measuring the intensities of emitted X rays, one can determine the quantities of elements present in the sample. In obsidian, the elements Na, K, Ti, Mn, Fe, Rb, Sr, Y, Zr, Nb, and Ba are frequently determined by X-ray fluorescence.

The principles of neutron activation analysis are slightly different in that samples are irradiated by thermal neutrons from a neutron source (usually a nuclear reactor). During irradiation, neutrons are captured by the nuclei of atoms in the sample. This process activates (induces energy excitation) the nuclei, which become somewhat unstable. During and after sample irradiation, these excited nuclei will emit gamma rays with unique energies at rates defined by the characteristic half-lives for each radioisotope. Identification of the gamma-ray energies and determination of their intensities permits a qualitative and quantitative analysis of the sample. Using routine neutron activation analysis on obsidian, the elements Ba, Ce, Cl, Co, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mn, Na, Nd, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Th, U, Yb, Zn, and Zr are available. If desired, the sensitivities of different subsets of these elements can be enhanced by varying the irradiation and measurement parameters.

In general, the X-ray fluorescence method is more available, more rapid, and less expensive than neutron activation analysis. However, the latter offers a greater number of elements with superior sensitivity, precision, and accuracy. In X-ray fluorescence, the whole artifact can be used without destruction. The sensitivity of neutron activation analysis to extremely small samples (~25 mg) means that only minor destruction of valuable artifacts is required.

Early Compositional Studies in the New World

The earliest reported compositional studies on obsidian in the New World are two frequently cited works involving different regions. The first study by Gordus et al. (1967) employed neutron activation analysis to trace the obsidian artifacts found in the Hopewell burial mounds to their origins in the Yellowstone National Park in Wyoming, a distance of almost 2,400 km. The second work was a report by Cobean et al. (1971), who applied X-ray fluorescence analysis on obsidian artifacts found in the Olmec site at San Lorenzo Tenochtitlan, Veracruz, Mexico, to emphasize the importance of long-distance trade in the rise of the Olmec civilization in Mesoamerica. As a result, the feasibility of using chemical analysis as a tool to gather information about prehistoric procurement and exchange systems was established.

The Mesoamerican region surpasses all other regions in the New World in the amount of effort directed toward compositional analysis of obsidian. An early example was a study by Hammond (1972), who employed X-ray fluorescence to analyze obsidian artifacts from the Classic period sites in the Maya lowland area. The data from this investigation suggested that the prehistoric trade routes involved waterborne transport from the highland sources to the coast of Belize. In addition, Hammond concluded that there was considerable competition between the sources for lowland markets.

Another Mesoamerican study by Pires-Ferreira (1973) used neutron activation analysis to measure the relative amounts of Mn and Na for Formative period obsidians found in the Valley of Oaxaca. The distance from Oaxaca to the nearest sources was several hundred kilometers. In addition, the Valley of Oaxaca was difficult to reach because it is surrounded by several ranges of high mountains. Pires-Ferreira proposed the existence of four competing obsidian exchange networks that supplied obsidian from two source areas located in central Mexico, the sources in the Guatemalan highlands, and a source of unknown location somewhere in Oaxaca. An unfortunate aspect of Pires-Ferreira's work was the use of relative count rates rather than absolute concentrations for the elements measured. As a result, her data are unique to her study and are useless to investigators from other laboratories.

Several X-ray fluorescence studies of obsidians from geologic sources in Mesoamerica were reported during the 1970s (Hester, Heizer, and Jack 1971; Hester, Jack, and Heizer 1971; Jack et al. 1972; Nelson et al. 1977; Stevenson et al. 1971). In these and other reports a significant number of the artifacts were not assigned to any known sources. Further evidence for the existence of several uncharacterized sources was also reported by Pastrana (1981). Thus there existed a recognized need to locate and characterize more sources in order to improve the success rate in future obsidian artifact sourcing studies.

A number of chemical characterizations of obsidians outside the Mesoamerican region also began in the early 1970s. An investigation by Bowman, Asaro, and Perlman (1973) employed neutron activation analysis on obsidian source samples from the volcanic flows at the Borax Lake source in northern California. This study found a single obsidian flow that exhibited an extreme variation in composition for some elements that extended over several orders of magnitude. Although at first glance such would appear to hinder the ability to assign a provenience, they observed that the compositional gradients between some elements were extraordinarily correlated. In fact, this coherence among the elements was so great that when correlations between elements were taken into consideration, the judgment of provenience for artifacts was just as definitive as if the source were very homogeneous.

The first compositional investigation of obsidians from South America was reported by Avila-Salinas (1975), who used optical emission spectroscopy to study artifacts from Tiwanaku culture sites near Lake Titicaca in Bolivia. Later, the

Berkeley group employed neutron activation analysis to analyze obsidian artifacts from sites in Peru, Ecuador, and Bolivia (Burger and Asaro 1977; Asaro et al. 1981). The latter investigations also identified a source at Mullumica, Ecuador, with large compositional gradients much like those observed at Borax Lake. In these studies, many artifact groups were formed, but again, the lack of a reference database on obsidian sources resulted in only a fraction of the artifacts being assigned to sources. This finding underscored the earlier message that comprehensive studies of obsidian sources were needed in South America.

Comprehensive investigations of sources in particular regions began in the late 1970s when Asaro et al. (1978) published the initial high-precision neutron activation analysis compositional data for what at that time were all known sources in the Guatemalan highlands. Later, a number of independent investigators (Nelson 1984; Hughes 1984; Sappington 1984; Shackley 1988) in the western United States began collecting source materials in different parts of that region and analyzing them by X-ray fluorescence. Unfortunately, even up to the present time, obsidian studies in South America have not kept pace with other regions of the New World.

Handling Compositional Data

The main objective of any obsidian sourcing study is to identify the particular source for each artifact to the exclusion of all other possible sources. There are six criteria that should be met in order to achieve this objective: (1) All sources must be located and adequately sampled; (2) a compositional library or database on sources must be established and maintained; (3) for individual sources, the intersource variability must be demonstrated to be greater than the intrasource variability; (4) a suitable set of elements must be identified that differentiates between all sources under consideration in a particular study; (5) the elements identified as useful for differentiating between sources must be determined for the artifact assemblage; and (6) as new sources are located, they should be sampled and included in the data bank.

In studies of obsidian sources using neutron activation analysis, one easily generates vast amounts of data. The handling of data, examination of the correlations between elements, and identification of a suitable set of elements to differentiate each source from all others are best accomplished by computerized data analysis. Descriptions of strategies for analyzing compositional data are given in Sayre (1975), Harbottle (1976), and Bishop and Neff (1989). A key requirement for compositional definition is that group size be adequate such that groups are amenable to multivariate statistical treatment.

As described by Sayre (1975), compositional groups are *centers of mass* in the compositional hyperspace described by the measured elemental concentrations. An individual group is characterized not only by the location of its centroid but also by the unique correlations between its elements. Because obsidian data are highly correlated, statistical procedures that calculate Mahalanobis distances are necessary to process multivariate data. The Mahalanobis Distance measure uses the euclidean distance between group centroid and individual specimen in *n*-dimensional space. In addition, the Mahalanobis Distance statistic incorporates the rate at which the density of data points decreases in all *n* dimensions from the group centroid toward the specimen. Because the statistic includes information about the correlations between pairs of elements as derived from the off-diagonal terms of the variance-covariance matrix, it permits calculation of membership probabilities. The significance between groups of specimens can be tested by Hotelling's T^2 statistic, which is the multivariate equivalent of the Student's t-statistic. Use of the Mahalanobis measure requires that specimen groups contain at least one more specimen than the number of dimensions under consideration. Ideally, the number should be several times greater than the number of elements.

At the Missouri University Research Reactor, we employ a series of statistical procedures written by Neff (1990) that include cluster analysis, principal components analysis, and canonical discriminant analysis. The programs enable group membership classifications based on probabilities calculated from Mahalanobis Distance measures. Guidelines for employing these programs are described in Glascock (1992).

The Data Bank for Mesoamerican Obsidians at the Missouri University Research Reactor

Perhaps the most ambitious study of obsidian was initiated in 1980 by Robert Cobean with support from the National Science Foundation (BNS 79-15409) and the University of Missouri. Cobean and other archaeologists from Mexico's Instituto Nacional de Antropología e Historia collected 800 obsidian specimens (weighing a total of 710 kg) from thirty volcanic sources in central Mexico for the purpose of establishing a database of chemically characterized Mexican obsidians. Several of the source systems extended over areas greater than 15 km by 25 km. Therefore, a comprehensive sampling program was necessary to permit investigation of possible inhomogeneities in sources. The number of samples collected from individual sources varied from 10 to 150 depending on the size of each source. Further goals of the investigation were to locate the specific quarrying areas for artifacts and to resolve provenience for artifacts with anomalous fingerprints.

The samples were shipped to the University of Missouri and analyzed by neutron activation analysis using the facilities of the Missouri University Research Reactor. Procedures described by Vogt et al. (1982) and Graham et al. (1982) were successful in collecting concentrations for twenty-eight elements per specimen on a routine basis using two irradiations and three analytical measurements. More than half of the elements were measured with precisions of 1–2%. Glascock et al. (1988) and Cobean et al. (1991) report large portions of the compositional data from this project.

Besides the issues regarding the collection of high-quality data on a large number of elements, our laboratory also engaged in an intercalibration study to assess the comparability of compositional data generated in different laboratories, using different analytical procedures. Compositional analyses were performed on the different reference materials employed by the Berkeley Lab (Perlman's pottery) and

Brookhaven (Ohio Red clay), where more than 2,000 source and artifact specimens from the New World were analyzed during the past two decades. The intercalibration permits merging these data into a single database such that the combined obsidian database now at the Missouri University Research Reactor Center represents one of the most comprehensive collection of obsidian data in the New World.

For example, in the state of Hidalgo, where many of the sources are chemically similar, twelve source systems were extensively sampled by more than 300 samples. Initial attempts to locate unique compositional patterns employed bivariate plots of several element pairs. Although most of the sources were clearly separated from one another, several neighboring sources were found to overlap significantly. To determine the most precise possible source assignment for artifacts coming from this region, it was desirable that some means for differentiating between the individual sources be identified. Through the application of principal components and canonical discriminant analysis, the sources were successfully differentiated (Glascock et al. 1988). This ability to differentiate between subsources in a system of geographically and chemically related sources is also important for the hydration dating of artifacts.

Recent Sourcing Investigations by the Missouri University Research Reactor

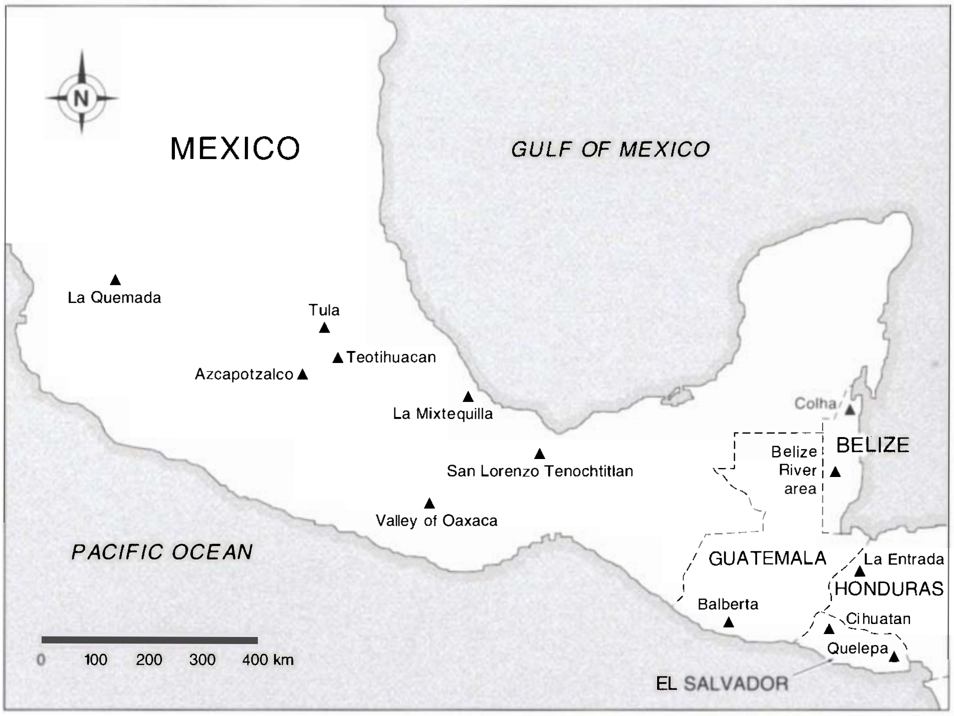
As a result of the center's obsidian source characterization study in central Mexico, word of the Missouri University Research Reactor's data bank is attracting the attention of other archaeologists working in Mesoamerica. Projects from along the Pacific coast of Guatemala, the interior and coastal areas of Belize, and from the Mexican states of Veracruz, Puebla, Hidalgo, and Oaxaca regularly submit artifacts for analysis. Table 1 lists archaeological sites from which artifacts have arrived for analysis. A map of these Mesoamerican sites is shown in Figure 1.

Because the primary goal is to eventually assign the source for every artifact, the archaeologists are instructed to submit source specimens for all new sources they

Table 1. *Obsidian sourcing investigations conducted at the Missouri University Research Reactor from 1987 to 1992.*

Investigator/Institution	Archaeological Site	Number of Artifacts
Cobean/INAH-Mexico	San Lorenzo, Veracruz, Mexico	65
Cobean/INAH-Mexico	Tula, Hidalgo, Mexico	120
Aoyama/IHAH-Honduras	La Entrada, Honduras	100
Lubensky/Missouri	Cihuatan, El Salvador	10
Trombold/Washington University	La Quemada, Zacatecas, Mexico	15
Finsten/McMaster	Jalieza, Oaxaca, Mexico	50
García-Chávez/INAH-Mexico	Azcapotzalco, Mexico	10
Stark/Arizona State	La Mixtequilla, Veracruz, Mexico	206
Hester/Texas	Colha, Belize	200
Ford/UC-Santa Barbara	Belize River Area	145
Bove/Guatemala	Balberta, Guatemala	140
Elam/Missouri	Valley of Oaxaca, Mexico	447
Andrews/Tulane	Quelepa, El Salvador	50
Cowgill/Arizona State	Teotihuacan, Mexico	150

FIGURE 1. *Map of archaeological sites in Mesoamerica that have provided obsidian artifacts for neutron activation analysis at the Missouri University Research Reactor.*



encounter during their fieldwork. In so doing, they further enhance our database. One can both compare previously unassigned artifacts to the new data and increase the likelihood of successful source assignments for future artifact analyses.

For example, one of our earliest investigations concerns 100 artifacts from the La Entrada region in Honduras (Glascock et al. 1990). The La Entrada region, situated in the western part of Honduras near the Guatemalan-Honduras border, is about 60 km northeast of the Mayan site at Copan. La Entrada is of particular interest because it lies in the transition zone between the homeland of the prehistoric Maya and less complex societies to the south and east. It was anticipated that the obsidian artifacts in this region would be sourced to the three primary sources in Guatemala (Ixtepeque, El Chayal, and San Martin Jilotepeque) and a source in Honduras at La Esperanza. Although this was true for sixty-seven of the artifacts as shown in Figure 2, the remaining thirty-three artifacts created two compositional groups, identified as sources X and Y, that were clearly different in composition from the anticipated sources. Interestingly, all of the unprovenienced artifacts were percussion flakes excavated from Pre-Classic contexts. An investigation of all Mesoamerican sources in the data bank failed to assign the two groups of artifacts to any previously reported sources in Guatemala, Honduras, or Mexico.

In 1990 a follow-up investigation in search of previously unknown sources was launched by Braswell (see Braswell and Glascock 1992), who collected specimens from a number of little-known sources in Guatemala. Figure 3 illustrates the individual characterizations of these sources by presenting the 95% confidence ellipses for cesium versus thorium. Unfortunately, these new sources were also found to be different from the unassigned La Entrada artifacts. As a consequence, the search for the geographic location of the missing sources is continuing. A recent collection of stream cobbles from the nearby Quimistan valley appear to be promising candidates for resolving the mystery regarding unknown sources X and Y.

FIGURE 2. *Scatterplot of Cs versus Th concentrations for obsidian artifacts from La Entrada, Honduras.*

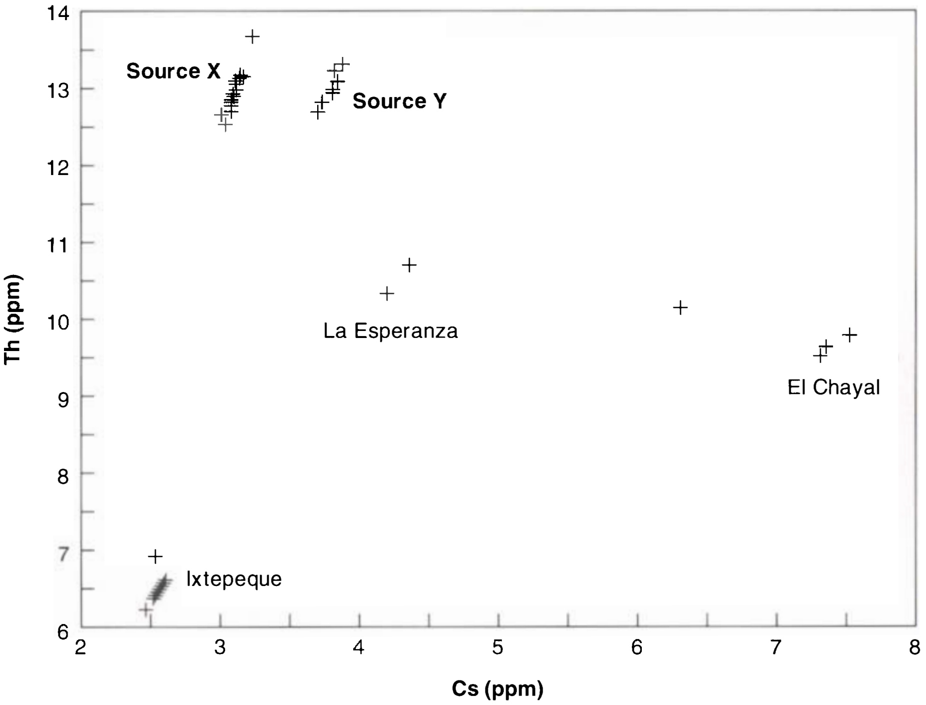
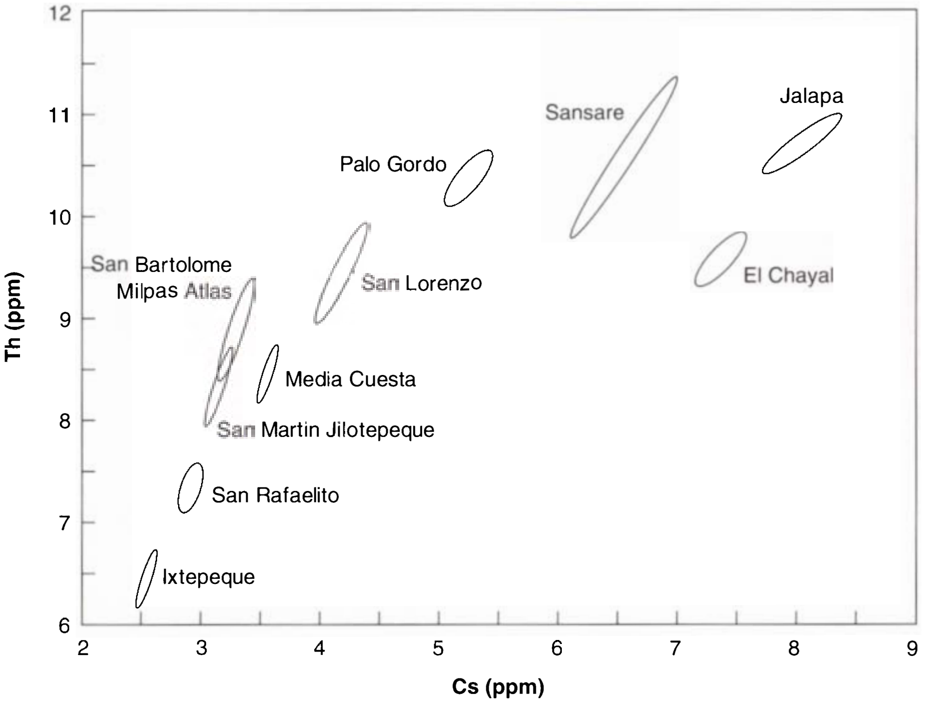


FIGURE 3. *Ninety-five percent confidence ellipses for Cs versus Th concentrations in obsidian sources from Guatemala.*



During this search, Braswell conducted an intensive sampling of the geographically complex source at San Martin Jilotepeque in Guatemala. The sampling strategy involved the recording of geographic coordinates for each collected specimen. A total of seventy-five specimens from obsidian outcrops in the San Martin Jilotepeque source area were submitted for analysis. The combination of geographic coordinates and chemical composition data for the obsidian permits mapping of compositional variations across the source. For example, as shown in Figure 4, a principal components analysis for a portion of these source data identifies a "core" group that coincides with all the artifacts previously sourced to San Martin Jilotepeque. However, a number of outlying source specimens are spread out and well separated from the

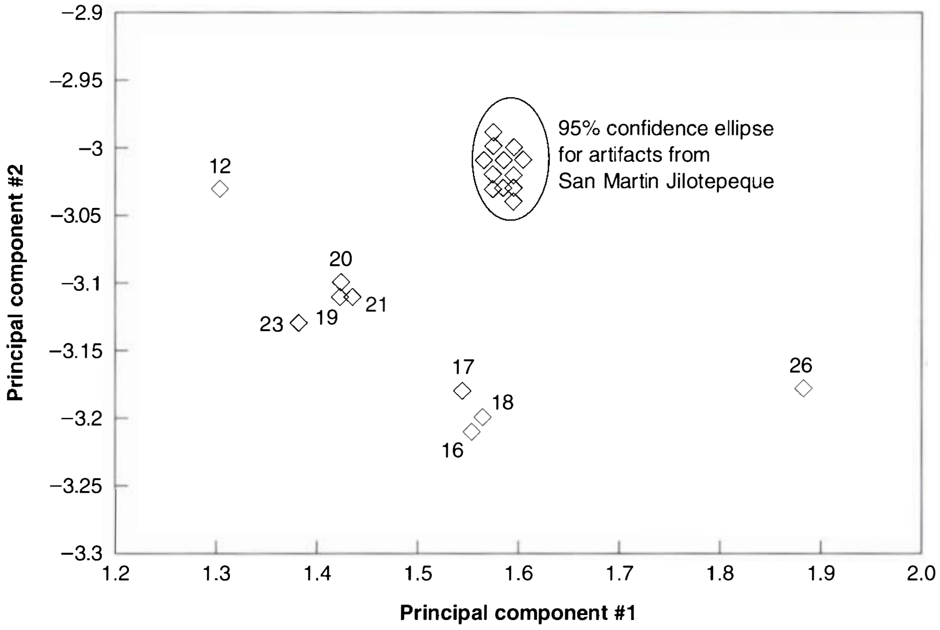


FIGURE 4. *Scatterplot of first and second principal components for obsidian source data from San Martin Jilotepeque source.*

core. The larger compositional envelope described by the outlying source specimens may be useful in assigning chemically anomalous artifacts.

Another method of displaying the data is presented in Figure 5, which shows the spatial variation on the first principal component plotted relative to sample location. When combined with the appropriate multivariate statistical procedures (Glascock 1992), these graphs have proven useful in identifying the main quarrying areas exploited by prehistoric obsidian miners. From these data we found that a sample assigned to an unknown source Z by McKillop et al. (1988) is consistent with the larger compositional envelope defined by all source specimens from San Martin Jilotepeque. It is likely that this and other chemically similar unassigned artifacts originated from quarries outside of the core quarrying area at San Martin Jilotepeque.

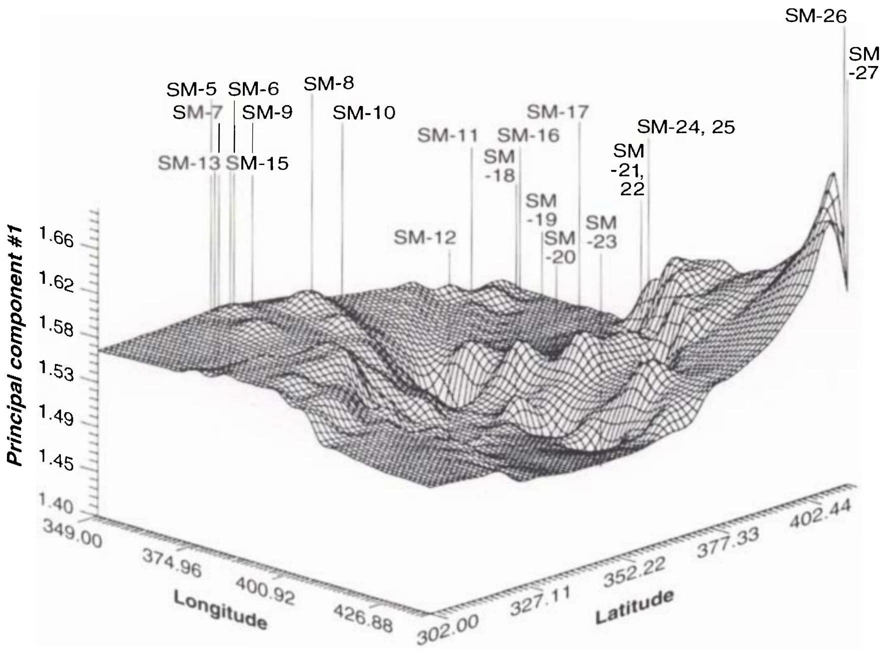


FIGURE 5. *Smoothed surface plot showing spatial variation of the first principal component plotted against longitude and latitude for the San Martin Jilotepeque source.*

Abbreviated Neutron Activation Analysis to Reduce Costs

The analytical costs for a full multi-element analysis of obsidian artifacts by neutron activation analysis is rather high ($125–$150 per sample at the Missouri University Research Reactor). Few archaeologists can afford these fees. In addition, because the number of obsidian samples that archaeologists want to analyze is potentially larger than our capacity to analyze samples, sample throughput eventually becomes a serious problem. Thus, to reduce costs and to increase sample throughput, we investigated an abbreviated neutron activation procedure for Mesoamerican obsidians.

Previous research on Guatemalan obsidians by Asaro et al. (1978) found that most artifacts were sourced to one of the three highland sources on the basis of only two or three elements (especially Mn and Na) determined from a single short-irradiation analysis. However, our study of the sources in Hidalgo (Glascock et al. 1988) found that several central Mexican source systems have overlapping fingerprints, and data for a much larger number of elements are necessary to differentiate between the sources. These points are best illustrated by Figures 6 and 7 for the Altotonga and Zaragoza sources located in eastern Mexico.

As a result, we explored the possibility of employing only those elements obtained from our short-irradiation neutron activation analysis procedure (Ba, Cl, Dy, K, Mn, and Na). In doing so, we optimized our procedures (irradiation, decay and counting times) to collect the data at the highest possible precision for this suite of elements. We also examined all compositional data in our database to identify sources to which we would feel confident in assigning an artifact using only the more limited suite of elements. Source assignments were made on a probability basis by comparing the artifact with the 95% confidence ellipsoid defined by a six-element fingerprint. Specifically, we required that any artifact being assigned to a source must be inside the 95% confidence ellipsoid for that source and outside all

FIGURE 6. *Scatterplot of logarithms of Mn versus Na concentrations for obsidian sources near the eastern coast of Mexico.*

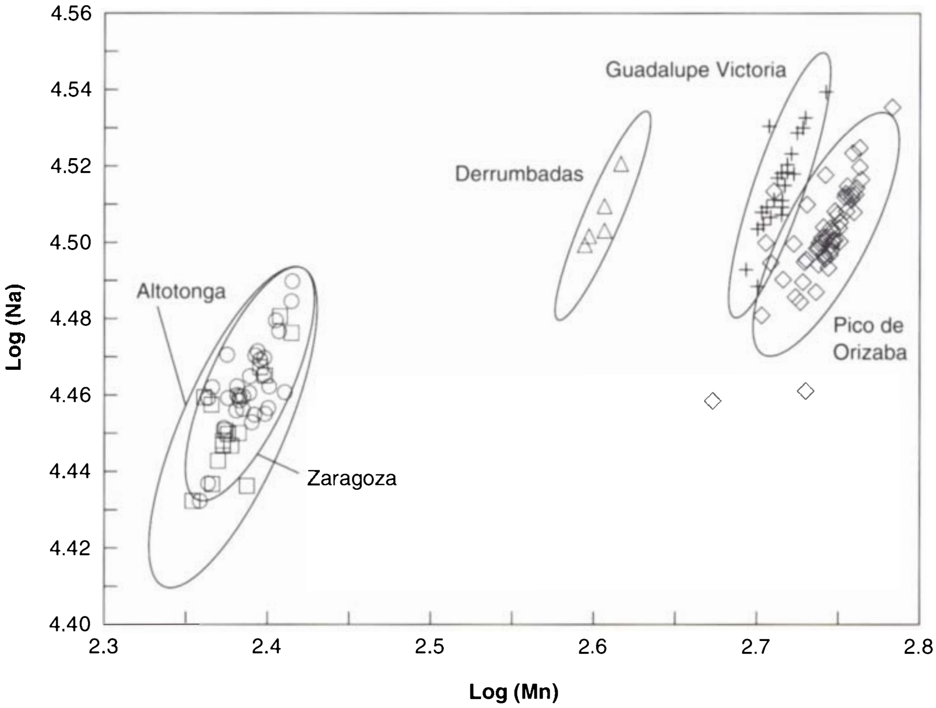
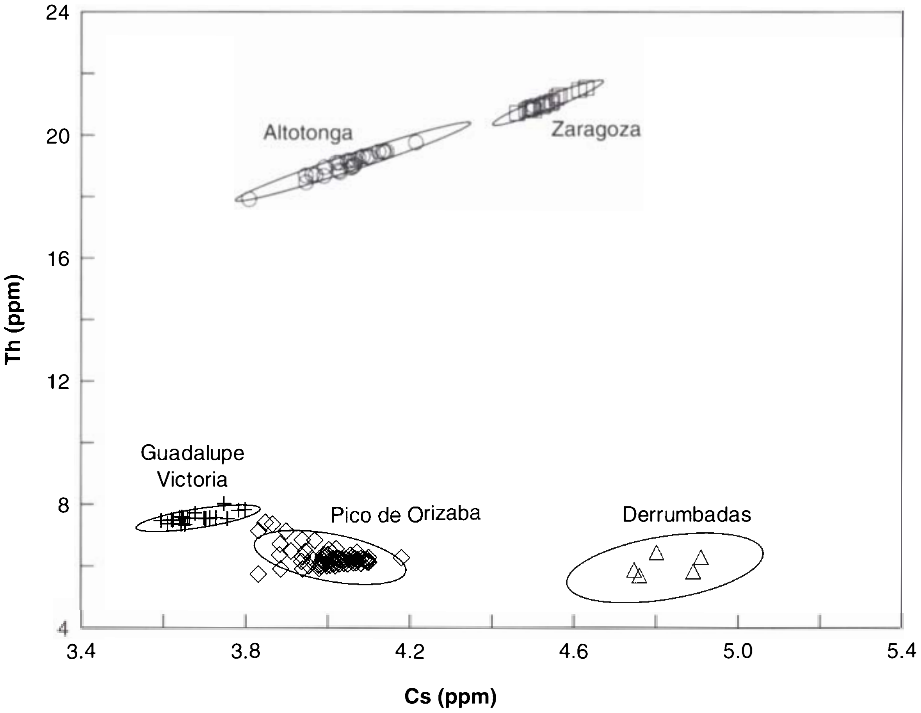


Figure 7. *Scatterplot of Cs versus Th concentrations for obsidian sources near the eastern coast of Mexico.*



other source ellipsoids. If the specimen was located outside all 95% confidence ellipsoids or if it was located inside two or more overlapping ellipsoids, then it was not assigned by the abbreviated neutron activation procedure alone. Specimens unassigned by the abbreviated procedure were submitted to the more expensive long-irradiation procedure and examined relative to the full suite of elements.

Our current experience with artifacts from Mexico and Guatemala finds that 90–95% of the artifacts in an assemblage can be assigned to sources using the abbreviated neutron activation procedure. Thus, these artifacts do not require the long-irradiation procedure to determine the remaining elements. Most of the remaining 5–10% of the artifacts can be assigned after the data from the long-irradiation procedure are included. As a result, our success rate in sourcing artifacts in most regions of Mesoamerica is about 99%. In addition, the revised analytical procedure results in a cost reduction of about 75% and greatly reduces the time required to analyze a majority of the obsidian artifacts we receive.

Relevance of Artifact Sourcing to Obsidian Hydration Dating

The method of obsidian hydration dating for dating archaeological contexts was first introduced by Friedman and Smith (1960). They also noted that obsidian materials from different sources appeared to hydrate at different rates.

Over the years there has been considerable debate and progress concerning the mechanism of the hydration process, the variables influencing hydration rates, and the application of obsidian hydration dating to archaeological problems. Reviews of this progress have been reported by Michels (1967), Ericson (1988), and García-Bárcena (1989).

The obsidian hydration dating method is based on the fact that a freshly exposed surface of obsidian slowly absorbs water from the surrounding atmosphere, forming a hydrated layer with a thickness related to the time of exposure. The penetration of water into the obsidian increases the density of the glass and changes the refractive index of the hydrated layer relative to the unhydrated glass. The hydrated layer is birefringent under crossed polars but visible in unpolarized light using an optical microscope. The thickness of hydration layers measured on archaeological obsidians ranges from 1 to about 30 µ depending on the age of the artifact.

The dating technique as originally proposed by Friedman and Smith (1960) relies on the use of a general diffusion equation that includes two variables, namely time and temperature. On the basis of a measurement on obsidian artifacts from different parts of the world, they found that the hydration thickness (a) increases as the square root of time, (b) is independent of relative humidity, (c) increases with temperature, and (d) is affected by the chemical composition of the obsidian. Using this information, Friedman and Smith (1960) proposed that hydration followed the rate equation: where µ is the thickness of the hydration layer, *k* is the rate of hydration (which is temperature dependent), and *t* is the number of years that the surface has been exposed.

After these initial findings, archaeologists attempting to apply the obsidian hydration technique were frustrated by the frequency of inaccurate dates (D. L. Clark 1961; Evans and Meggers 1960) because the factors involved were not adequately understood. Some of the frustration was caused by concern over the possibility of artifact reuse. In addition, there was a realization that separate rates of hydration were required for each archaeological environment and each obsidian source.

To avoid the problems associated with determination of hydration rates for individual sites, the method was initially treated as a very precise tool for relative dating (Michels 1967). Sequencing within a single site was generally successful since the obsidian artifacts from a single site were apt to be represented by only a few sources, and the variables influencing hydration should affect all obsidian at the site equally. However, this method tended to discourage comparisons between sites.

To go beyond simple artifact sequencing, Meighan et al. (1968) established hydration rates for obsidian in western Mexico by correlating obsidian artifacts with radiocarbon assays obtained on stratigraphically associated materials. This empirical method permitted the inexpensive accumulation of an absolute chronology for a large body of artifacts. However, the general scarcity of materials for radiocarbon dating and the problems in associating these materials with the obsidian were serious limitations to the effectiveness of the technique (Bell 1977). An alternative empirical strategy explored by Hall (1983), Jackson (1984), and Origer (1987) makes use of temporally diagnostic obsidian artifact forms.

Through laboratory experimental procedures involving accelerated (or induced) hydration rates, Friedman and Long (1976) demonstrated that for obsidian with a particular chemical composition, the hydration rate is related to temperature according to the Arrhenius equation: where *k* is the hydration rate (μm^2/1,000 years), *A* is a constant, *E* is the activation energy of the hydration process (J/mol), *R* is the universal gas constant (8.31441 J/mol/K), and *T* is the effective hydration temperature (K). Use of the constant derived from this method requires accurate determination of the source-specific preexponential term and activation energy as well as the effective hydration temperature at the archaeological site. The former are determined through induced hydration experiments. The most satisfactory method of determining effective hydration temperature is direct measurement at the archaeological site. However, an estimation derived from the mean air temperature measured at the site or at nearby weather stations with similar temperature is acceptable. The rate constants derived from this method have been applied to archaeological specimens with success in some areas and obvious errors in others.

Ericson (1988) recently identified a number of the remaining difficulties with obsidian hydration dating. In addition to errors in the measurement of hydration rims, these include an incomplete understanding of (a) the hydration process and rate development, (b) the effect of environmental variables including relative humidity, and (c) the effect of chemical composition. The hydration process and the effects of environmental variables have been the subject of directed research (Mazer et al. 1991; Scheetz and Stevenson 1988; Stevenson et al. 1989; Stevenson et al. 1987). The need to determine source-specific hydration rates has been advocated by Ericson and Berger (1976) and numerous others.

The investigations of obsidian sources reported here and elsewhere (Hughes 1988) have found that compositional variations in some source systems are large enough that questions concerning micro-proveniencing may be answerable. However, these same variations raise questions about the ability to date artifacts from these sources. These findings suggest that: (1) source-specific hydration rates be determined for individual sources or flows within sources, and (2) it is necessary to identify the source of the artifact before hydration dating.

Summary

In this limited space, it has not been possible to adequately discuss the complete literature available on New World obsidian and all of the analytical methods that have been employed. However, it is evident that the limited number of sources, wide exploitation in prehistoric times, and unique physical properties of obsidian make it one of the most important archaeological materials for reconstructing relationships between Pre-Columbian peoples in the New World.

The X-ray fluorescence and neutron activation analytical techniques are widely accepted as being the most reliable methods for fingerprinting sources and artifacts. Annually, analytical laboratories are conducting thousands of obsidian artifact analyses and making source assignments to large numbers of these artifacts. However, there are several regions of the New World (especially South America, western Mexico, and parts of the western United States) where source characterization studies are far from adequate and much more sample collection and analytical work remains to be accomplished.

Due to the large number of elements reported, neutron activation analysis has proven to be a particularly valuable method for identifying the specific quarrying areas and flows within sources that were exploited by the prehistoric peoples. The collection of all possible analytical data for individual sources continues to be strongly encouraged. The use of abbreviated neutron activation procedures for artifacts and application of multivariate statistical methods have greatly reduced the time and expense of neutron activation analysis to archaeologists.

The obsidian hydration dating method continues to be researched in hopes that it will arrive at its full potential as a tool that archaeologists can use more reliably. The natural partnership between these complementary functions of sourcing and dating provides obsidian with one of the most unique roles of any archaeological material.

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Biography

Michael D. Glascock is a senior research scientist and director of the Archaeometry Laboratory at the Research Reactor Center, University of Missouri-Columbia. He obtained a bachelor's degree in physics from the University of Missouri-Rolla (1971) and a Ph.D. in nuclear physics from Iowa State University (1975). His main research interests include applications of neutron activation analysis to archaeological and geological materials, quantitative methods, and the archaeology of Mesoamerica.

Obsidian Artifacts from Oaxaca, Mexico: Source Identification and Hydration Dating

J. Michael Elam,
Michael D. Glascock, and
Hector Neff

One of the main foci of archaeometric research has been to develop and improve methods of dating and sourcing artifacts (Harbottle 1982). Consequently, a number of techniques suitable to analysis of age and source have been developed that are applicable to a variety of archaeological materials. While the success of these investigations depends in part on the class of artifacts analyzed and is therefore variable, impressive results have been obtained with obsidian.

Obsidian is a volcanic glass that was widely used in ancient and prehistoric times throughout the world as a raw material for tools, weapons, and ornaments. Obsidian has two properties that make it of special importance for archaeological and archaeometric studies. First, variation in the elemental composition of obsidian is usually far greater between flows (sources) than within a flow, thus making it an ideal material for source studies via compositional analysis (Clark 1981; Drennan 1984). Additionally, the manufacture of artifacts from obsidian does not alter the composition of the raw material. The second advantageous property of obsidian is that it absorbs water by diffusion from the environment at a rate dependent on its chemical composition, ambient temperature, and relative humidity (Friedman and Smith 1960; Friedman and Long 1976; Michels et al. 1983; Ericson 1988; García-Bárcena 1989; Mazer et al. 1991). This property enables dating of the obsidian artifact by measurement of the hydration rind on the surface of the artifact. In sum, obsidian presents the archaeologist with a unique opportunity to study the direction, intensity, and extent of ancient exchange through source analysis, and at the same time can provide the requisite chronological framework for a diachronic perspective on exchange.

Clearly, obsidian sourcing and hydration dating are natural partners. Because the rate of hydration in obsidian is partially dependent on its chemical composition, every source of obsidian will have its own particular rate of hydration, with other variables being equal (Ambrose 1976). Accordingly, in order to determine the correct rate of hydration when dating a collection of obsidian artifacts, one needs to know the source(s) from which the artifacts derived. Sourcing by compositional analysis provides this answer. Conversely, the dates provided by hydration measurement produce the diachronic perspective required for an effective source study.

Strangely, this natural partnership between sourcing and hydration dating is often ignored. Many source studies of obsidian have tended to neglect or underemphasize diachronic shifts in obsidian acquisition in favor of static modeling of exchange systems or the social and/or political contexts of exchange (see, for example, Santley 1983, 1984; Spence 1982, 1984). Neglect of the potential of obsidian to provide excellent data on diachronic shifts in its exchange is due largely to two factors. The first is overreliance on ceramic chronologies that define broad time periods and in which observed temporal changes in other artifact classes are embedded. As a result, all diachronic changes in recovered artifacts are expressed relative to the ceramic chronology. This practice usually has the effect of blurring significant temporal changes in other artifact classes, since ceramic chronologies are based on seriations that may be insensitive to subtle changes in the archaeological record. Second, dates based on hydration rim measurement often have been found to be inaccurate or to disagree with other chronological data, a fact that derives largely from disagreement as to how the hydration process works and, therefore, as to what constitutes the key variables in determining the hydration rate (Mazer et al. 1991). Thus, attention to diachronic shifts in obsidian acquisition is limited and usually discussed only in the general terms of a ceramic chronology or more often in even broader temporal sequences (e.g., Formative, Classic, Post-Classic).

Recently, the Archaeometry Laboratory at the Missouri University Research Reactor has undertaken a study of using hydration dates as a means of identifying diachronic shifts in obsidian exchange patterns. This approach is based on the partnership between sourcing and hydration dating described above. It is hoped that this approach will improve our ability to describe diachronic shifts in obsidian acquisition and thus provide the necessary data for improved modeling of the economic, political, and social contexts of ancient exchange.

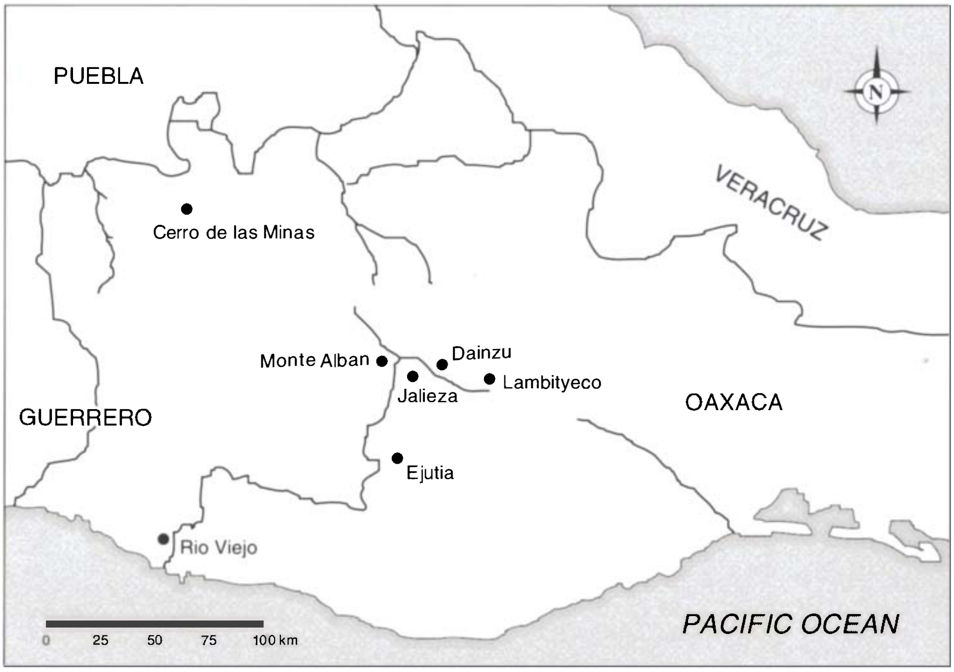
Objectives

The main objective of this report is to present the preliminary results of a detailed source and hydration dating study of a large sample of obsidian artifacts collected from seven sites in the Oaxaca region (Fig. 1). This general objective can be broken into four interrelated parts.

First, this project is one of a series undertaken by the Missouri University Research Reactor lab aimed at determining if the technique of combining sourcing and hydration dating is as feasible in practice as it is in theory. While the data presented in this paper concern only the Oaxaca region of Mexico, other studies along these lines are being carried out in other Mesoamerican regions.

The next two parts relate to methodology. The first of these will be a description of a new, high-precision, rapid method of instrumental neutron activation analysis for sourcing obsidian. This new method greatly increases the speed of

FIGURE 1. *Map depicting the location of Oaxaca and the principle obsidian sources exploited in Oaxaca during Post-Formative times.*



sourcing obsidian without sacrificing the precision of intensive neutron activation techniques. The sourcing results presented here were derived using this new technique. The second part relevant to methodology will be a presentation of the method used to date the obsidian artifacts by hydration measurement. This will include a presentation of the results obtained so far and will describe several of the problems that we encountered during this phase of the research. We will also present our tentative plans for directions of future study in obsidian hydration dating.

The final part involves interpreting the results obtained so far in the analysis of the Oaxacan material. This will include a discussion of the acquisition patterns revealed by the source analysis and what these may indicate about previously proposed models of obsidian exchange in Pre-Hispanic Oaxaca.

Materials

The samples analyzed in this study were acquired from seven sites in the Oaxaca region. Oaxaca was chosen as the setting of this study for several reasons. First, it is one of the primary regions of indigenous development of civilization in Mesoamerica and manifests a Pre-Hispanic cultural sequence that ranges from the late Paleolithic until the Spanish conquest (Kowalewski et al. 1989). Second, it has been the focus of archaeological investigation since the late 1930s, and a number of excavated collections of obsidian artifacts were available for study.

Third, Oaxaca is unusual relative to other areas of Mesoamerica in that it possesses no indigenous sources of obsidian. Consequently, all obsidian found in Oaxacan archaeological sites had to have been brought in over considerable distances. This fact makes Oaxaca an ideal locus for a diachronic study of obsidian acquisition. Fourth, source analysis of obsidian from Oaxaca is incomplete. Earlier studies were either directed solely at obsidian from Formative contexts (Pires-Ferreira 1975, 1976; Winter and Pires-Ferreira 1976), dealt only with obsidian from a single site, and/or were limited by small sample sizes (Winter 1989; Elam et al. 1990). Finally, data from such a study would be useful for clarifying several archaeological problems regarding the direction, extent and intensity of inter- and intraregional interaction and would contribute to the resolution of a question of settlement continuity within the Valley of Oaxaca.

A total of 497 specimens were selected from collections recovered at Monte Albán, Dainzu, Jalieza, Lambityeco, Ejutla, Cerro de las Minas, and Rio Viejo. Locations of these sites are shown in Figure 2. Wherever possible, the collections were randomly sampled using an interval sampling technique. However, many of the collections included numerous pieces that did not have enough material for the analytical techniques employed (specifically, a minimum of 500 mg of material is required for the neutron activation analysis and hydration dating). In those cases, selection was predicated on whether the piece had adequate material for the experiments. While this problem prevented statistical random sampling in several instances, it should not have seriously biased the sample in terms of skewing the sample in favor of one particular obsidian type or source.

Site Descriptions

In this section we briefly describe the sites from which we obtained obsidian for this study. Included in these descriptions are information about the culture-historical significance of the site; chronology, size, and characteristics of the obsidian sample selected; and the archaeological contexts of the sample.

Monte Albán. This is the largest and best-known site in Oaxaca. It has been extensively described by Blanton (1978) and has been the center of archaeological investigation for some sixty years (Flannery and Marcus 1990). The site was occupied more or less continuously from about 500 B.C.E. until the Spanish conquest (Blanton 1978). During the Classic period, it was one of the largest cities in

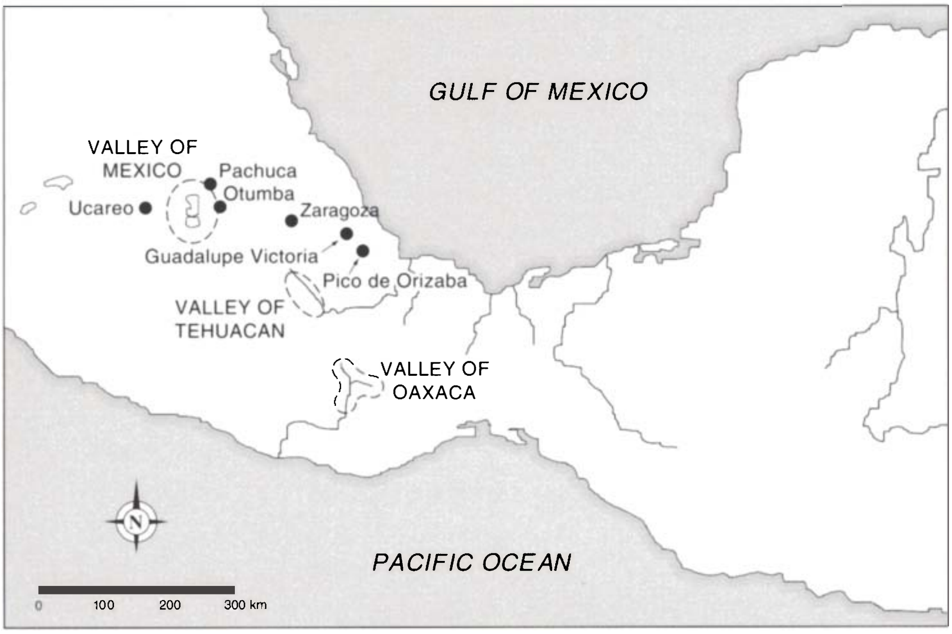


FIGURE 2. *Map showing the location of archaeological sites from which obsidian artifacts were collected.*

Mesoamerica and served as the capital of the Zapotec state. As the capital of the Zapotec state, Monte Albán also maintained economic and political ties with a number of regions outside of the Valley of Oaxaca including Teotihuacán (Redmond and Spencer 1983; Paddock 1983a; Marcus 1983a).

The sample selected from Monte Albán consists of 208 excavated pieces of obsidian, the majority of which are prismatic blades, though a few flakes and spent cores are also included. These artifacts come from a variety of contexts including house floors, tombs and burials, and building fill. Dates for these pieces, based on associated ceramics, span the entire Monte Albán sequence (periods I–V, 500 B.C.E.–1521 C.E.).

Dainzu. This site is located at the northern end of the Tlacolula arm of the Valley of Oaxaca. During the Late Formative and Early Classic periods, it was a major urban center manifesting a unique style in architecture and ceramics (Marcus 1983b; Kowalewski et al. 1989). Dainzu declined in importance during the late Classic and was eventually abandoned sometime in the Post-Classic.

Thirty pieces of obsidian were selected from recent excavations at Dainzu. This sample consists entirely of prismatic blades recovered mostly from construction fill. Ceramic associations indicate dates ranging from periods I through IIIa (500 B.C.E.–450 C.E.).

Jalieza. Jalieza is situated on a series of hills located along the juncture of the Valle Grande and Ocotlan arms of the Valley of Oaxaca. Jalieza is the second largest site in the Valley and has occupations datable to the Late Formative, though the major occupation of the site occurred during Early Classic and Early Post-Classic times (Kowalewski et al. 1989). During the Early Post-Classic (period IV), Jalieza superseded Monte Albán as the principal urban center in the Valley of Oaxaca.

A total of 103 samples were collected from Jalieza. The sample consisted primarily of prismatic blades, but several flakes and spent cores were included as well. The majority of these specimens were recovered by excavation on the residential terraces at the site, though a few of the specimens are from surface collections. Unlike the majority of samples in the other collections, most of the samples from Jalieza come from single-component contexts that are datable by associated ceramics to either period IIIa (200–450 C.E.) or period IV (750–950 C.E.). The first fifty of these samples were analyzed and reported earlier though no hydration dating of these artifacts was undertaken (Elam et al. 1990).

Lambityeco. Lambityeco is located near the modern town of Tlacolula in the Valley of Oaxaca and is but one small part of a larger archaeological zone known as Yegüih. Specifically, Lambityeco represents an area of occupation within the Yegüih archaeological zone that is datable entirely to the Early Post-Classic, or period IV (750–950 C.E.) (Paddock 1983b). Lambityeco was evidently one of a number of smaller urban centers that arose in the Valley of Oaxaca during the decline of Monte Albán. Lambityeco was an important center of craft production and was involved in the extraction of salt and in the manufacture of pottery (Paddock 1983b). Lambityeco is also important as it is the site that best defines the material culture of the Early Post-Classic in the Valley of Oaxaca.

Despite the extensive investigations (excavation and intensive survey) carried out at Lambityeco, only three specimens of obsidian, all prismatic blades from a period IV tomb, were obtained from this important site. Sadly, all of the collections of obsidian from these investigations have evidently been lost.

Ejutla. The site of Ejutla is located at the extreme southern terminus of the Valley of Oaxaca. This site has been the subject of recent investigations that have shown it to have been an urban center of some size and importance during the Terminal Formative and Early Classic (periods II–IIIa, 200 B.C.E.–450 C.E.). Ejutla was also a center of craft production and manufactured textiles, shell ornaments, pottery, and onyx bowls (Feinman and Nicholas 1988; Feinman personal communication August 1991).

A sample of 112 obsidian artifacts, mostly of prismatic blades, was collected from Ejutla. These samples were obtained by excavation in a midden that contained pottery datable to periods II (200 B.C.E.–200 C.E.) and IIIa (200–450 C.E.), though some period V (1250–1521 C.E.) ceramics were recovered from the upper levels.

Cerro de las Minas. This site is located in the Mixteca Baja region northwest of the Valley of Oaxaca. This small site is one of the earliest urban centers in the Mixteca and was similar in size and function to the better known site of Yucuita. It manifests occupations datable to Late Formative through the end of the Classic. The principal period of occupation was during the Classic period (Ñuiñe phase). Intensive excavations at Cerro de las Minas make it the most thoroughly investigated Classic period site in the Mixteca (Winter 1992).

Twenty-one samples of obsidian were sampled from collections excavated at Cerro de las Minas. These came primarily from building fill. Associated ceramics indicate a Classic period date for all except two, which were recovered from Terminal Formative contexts.

Rio Viejo. This site is located on the west bank of the Rio Verde, approximately 10 km from the Pacific coast of Oaxaca. The site is a small urban center that has occupations datable from Middle Formative times until the Classic, at which time it was the largest site in the lower Rio Verde valley (Joyce pers. comm. 1991).

Twenty obsidian artifacts, all prismatic blades with one exception, were selected from collections excavated at Rio Viejo. These came primarily from construction fill and are datable mainly to the Classic.

Methodology

This section discusses the analytical methods employed in sourcing and hydration dating of the obsidian artifacts selected for this study. While the source analysis is complete, the hydration dating remains unfinished.

Sourcing by Instrumental Neutron Activation Analysis

The Missouri University Research Reactor Archaeometry Laboratory has been involved in applying instrumental neutron activation analysis to the sourcing of obsidian since the late 1970s, when the program was first initiated (Vogt et al. 1989). Since that time, the lab has assembled the most comprehensive compositional database of Mesoamerican obsidian sources presently available (Glascock et al. 1988; Cobean et al. 1991). Currently, the lab is involved in refining the precision of the database through analysis of additional source specimens and is also working to increase the number of characterized sources through analysis of additional sources in Mesoamerica as well as North and South America.

The original method of analyzing obsidian developed by the lab involved a series of analyses including a prompt gamma analysis followed by short and long irradiations integrated with a series of short, mid- and long gamma ray spectroscopy measurements (Glascock et al. 1988; Cobean et al. 1991). This approach yields values for some twenty-eight elements often at a precision of less than 2%. The same method was used to characterize artifacts, and linkage to source was achieved through use of multivariate statistics (see Glascock 1992 for a summary). Unfortunately, while this approach provided high-precision values for a large number of elements, it was lengthy as well as costly and thus limited the utility and availability of the technique. However, the large amount of data produced by this technique enabled us to discover that differentiation of the sources was often due to only a few elements. We found that for most Mesoamerican sources, the key elements are Na, Mn, and Ba. This discovery led to the realization that if these elements could be measured at very high precision, artifact to source linkage could be securely based on just these few elements. This in turn led to the development of a rapid method of neutron activation sourcing for obsidian artifacts.

The rapid method developed by the lab is a variation of the short irradiation procedure that we have described elsewhere (Glascock et al. 1988; Cobean et al. 1991). Basically, it involves breaking off a small fragment of the obsidian artifact, which is then fractured into small chips. These are cleaned by alternating rinses with deionized water and acetone. Aliquots of the chips weighing about 100 mg are prepared and then sequentially irradiated in the reactor via a pneumatic tube system for 30 seconds in a thermal flux of 8×10^{13} $n.cm^{-2}.s^{-1}$. The aliquots are decayed for 25 minutes prior to spectrographic analysis on HP Ge detectors. Standard comparators run with the unknowns include NIST SRM-278 Obsidian Rock and NIST SRM-1633a Fly Ash. This procedure yields values at high precision (around 1%) for six elements: Ba, Cl, Dy, K, Mn, and Na. The main difference between this technique and the standard short irradiation procedure originally employed by the lab is the increased time of the irradiation (30 seconds vs. 5 seconds).

Source attribution is achieved by selecting pairs of elements, usually beginning with Na and Mn, and then comparing these values to those in the Missouri University Research Reactor obsidian source database. Comparison is done in two ways. The first is a simple eyeball comparison of the artifact values with the mean values of the sources in the database. Second, the paired element values of the artifacts are projected against the 95% confidence ellipses for those elements of the sources. This approach usually results in over 90% of the artifacts being sourced. Specimens that remain unattributed are then put through a long irradiation to determine longer half-life isotopes and then evaluated in the same fashion. This usually results in all artifacts being accurately sourced.

This procedure has several advantages. First, it is quick yet does not sacrifice precision. A large collection of artifacts (i.e., several hundred) can be almost completely sourced within a two- to three-week period (including sample preparation). The more intensive procedure used to characterize the source samples would require approximately four months to source the same number of artifacts. Second, it is less costly in terms of both labor and materials. The rapid neutron activation procedure requires fewer materials and less labor. The main expense of this technique is the polyethylene vials used to encapsulate the samples for irradiation. The long procedure is not only more labor intensive, but also requires more irradiation, detector, and computer time as well as the use of expensive high-purity quartz vials for sample encapsulation. Since the rapid procedure is so accurate, the need to use the full procedure is virtually eliminated and only employed on those specimens that cannot be attributed by the rapid procedure. Thus, the expense of a sourcing study is greatly curtailed. We estimate that the rapid neutron activation procedure is 75% less costly than the full procedure originally developed by the lab for obsidian source materials. Consequently, this increases both the utility and availability of neutron activation for sourcing obsidian.

As mentioned previously, one of the goals of the Oaxaca obsidian project was to determine if the rapid neutron activation technique could successfully source a large collection of obsidian that would undoubtedly derive from a number of different sources. To this end, the obsidian artifacts from Oaxaca were sourced using the rapid method just described. We should point out that only 400 of the 497 artifacts were analyzed by this technique. The other 97 artifacts (50 from Jalieza and 47 from Ejutla) were sourced prior to the development of the rapid technique.

The rapid technique sourced all but ten of the artifacts. This represents a success rate of 97.5%. The unattributed artifacts were then analyzed by the full neutron activation procedure. Of these ten, four were attributed to the Zaragoza, Puebla, source, three to the Ucareo, Michoacan, source, one to the Zacualtipan, Hidalgo, source, one to the Otumba, Mexico, source, and one remained unattributed. The Zaragoza, Ucareo, and Zacualtipan sources exhibit slight overlap of values for Na and Mn (the two key short half-life elements) but do not overlap on longer half-life elements such as Cs and Th. The Otumba piece simply had values that were somewhat outlying. The one unattributed piece was a spent core made on a mottled brown-black obsidian. Its coloration made it unique among the specimens in the Oaxaca collection. Consequently, we suspected from the beginning of the analysis that we would be unable to source it.

As the results from the Oaxaca material illustrate, the rapid neutron activation technique was extremely successful. When used in conjunction with the long neutron activation procedure in an incremental fashion, only one artifact was left unattributed. This results in a net success of 99.9% (the results of the source analysis are presented in Table 1 and will be discussed in detail in the interpretation section). In sum, this method represents a considerable improvement over the long procedure in terms of time and expense without any loss of accuracy.

TABLE 1. *This table depicts the percent breakdown of obsidian sources for Oaxaca. The number in parentheses is the number of specimens out of the total sample (n = 497) that were attributed to that source.*

Site	Pachuca	Ucareo	Zaragoza	Orizaba	Otumba	Paredon	G. Victoria	Zacualtipa	Pizzarin	Unattrib
Monte Albán	53% (111)	1% (3)	30% (63)	2% (4)	4% (9)	6% (12)	2.5% (5)	0% (0)	0% (0)	0.5% (1)
Dainzu	30% (9)	0% (0)	63% (19)	7% (2)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Jalieza	17.5% (18)	1.9% (2)	64.1% (66)	9.7% (10)	2.9% (3)	1% (1)	1.9% (2)	0% (0)	1% (1)	0% (0)
Lambityeco	0% (0)	33% (1)	66% (2)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Ejutla	8% (9)	37.5% (42)	39% (44)	2% (2)	10% (11)	3% (3)	0% (0)	0.5% (1)	0% (0)	0% (0)
Cerro de las Minas	24% (5)	33% (7)	10% (2)	0% (0)	19% (4)	0% (0)	14% (3)	0% (0)	0% (0)	0% (0)
Rio Viejo	50% (10)	10% (2)	15% (3)	10% (2)	10% (2)	0% (0)	5% (1)	0% (0)	0% (0)	0% (0)
Totals	33% (162)	11.5% (57)	40% (199)	4% (20)	6% (29)	3% (16)	2% (11)	0.2% (1)	0.2% (1)	0.2% (1)

Hydration Dating

The first step in obsidian hydration dating is to measure the width of the hydration rims of the artifacts. To accomplish this, we first cut a number of thin sections across the entire width of the artifacts. Several sections were cut per artifact in order to have extra in case of failure during the process of grinding the section to the appropriate thickness. The sections were adhered to petrographic microscopy slides and then hand ground using silicon carbide lapping compound (grit sizes of 220 and 600 were used) to a thickness of 30 µ. Cover slips were mounted and the slides allowed to sit for several days to insure that the mounting resin had adequate time to harden.

After the slides were prepared, we examined them with an Aus Jena microscope using a low power objective (10×) to see if the hydration rim was present. Failure to find the rim usually indicated that the rim had been ground or chipped off during the manufacture of the thin section. This necessitated making another slide. Normally, we experienced about a 10% failure rate in the production of slides.

Measurement of the hydration rims was done with an Aus Jena microscope mounted with a Vickers Image Splitting eyepiece. We used a 60× objective to measure the bands. We followed the recommendations of Stevenson et al. (1987) for locating the hydration rim by crossing the nicols and inserting a gypsum plate. Rotation of the stage highlights the hydration band in orange tones against a blue background. We then uncrossed the nicols, split the image, and obtained a measurement of the band width. We performed sixteen measurements per slide. Since the majority of the specimens are prismatic blades, which in cross section are trapezoidal, we tried to obtain four measurements per side. This was not always possible because in some instances the rim had been ground off of one side, or the thin section had been manufactured from a flake. In those instances, we obtained the measurements at locations in which the hydration rim was most visible. Another complication we encountered was the presence of significantly different band widths on a single specimen. For example, one edge might measure 4 µ while another might measure 7 µ. In these circumstances, the different edges were treated as if they were a separate specimen, and sixteen measurements would be taken along that edge. The rationale behind this strategy is that the different band widths probably represent two or more flaking episodes and therefore each one must be considered a datable event.

As we mentioned at the beginning of this section, the obsidian hydration dating segment of this project is incomplete. This is due primarily to a lack of time, which has prevented us from preparing and measuring the entire sample set. However, we have completed the measurements for all of the samples from Rio Viejo, Cerro de las Minas, and Dainzu. The mean rim width, standard deviation, and coefficient of variation for the specimens from these sites are presented in Table 2.

TABLE 2. *Hydration rim measurement data from the Missouri University Research Reactor (MURR) for artifacts from Rio Viejo (RV), Cerro de las Minas (CM), and Dainzu (DZ). Mean and standard deviation values are in microns (µ). The coefficient of variation (CV) is the percent standard deviation.*

MURR ID	Mean	Std	CV (%0)	Source
RV015	2.63	0.07	2.81	G. Victoria
RV004	2.86	0.16	5.70	Orizaba
RV020	3.01	0.06	2.07	Orizaba
RV005	4.03	0.14	3.37	Otumba
RV008	4.18	0.06	1.50	Otumba
RV016	1.15	0.05	4.35	Pachuca
RV003	2.07	0.08	3.93	Pachuca
RV010	3.42	0.13	3.72	Pachuca
RV011	4.73	0.15	3.09	Pachuca
RV019	5.02	0.23	4.56	Pachuca
RV017	5.11	0.16	3.22	Pachuca
RV014	5.27	0.08	1.42	Pachuca
RV001	5.95	0.16	2.71	Pachuca
RV009	6.16	0.12	1.99	Pachuca
RV002	6.41	0.17	2.60	Pachuca
RV012	5.15	0.17	3.40	Ucareo
RV013	6.31	0.09	1.44	Ucareo
RV007	4.42	0.09	1.98	Zaragoza
RV006	5.02	0.08	1.68	Zaragoza
RV018	6.39	0.21	3.25	Zaragoza
CM016E1	2.30	0.23	9.95	G. Victoria
CM016E2	3.77	0.13	3.57	G. Victoria
CM015	3.97	0.26	6.66	G. Victoria
CM007	4.98	0.09	1.82	G. Victoria
CM019	2.00	6.00	2.26	Otumba
CM018	2.25	0.11	5.00	Otumba
CM003	2.55	0.11	4.14	Otumba
CM002	2.56	0.22	8.41	Otumba
CM001	2.78	0.09	3.42	Pachuca
CM008	3.43	0.11	3.26	Pachuca
CM020	3.70	0.10	2.80	Pachuca
CM021	3.73	0.07	1.89	Pachuca
CM004	5.05	0.17	3.46	Pachuca
CM013	3.51	0.18	5.22	Ucareo
CM014	4.05	0.04	2.72	Ucareo
CM017	4.11	0.11	2.72	Ucareo
CM010	4.66	0.17	3.76	Ucareo
CM005	4.83	0.13	2.70	Ucareo

An inspection of this table reveals that the majority of the rims had widths ranging from 1 to 6 μ, though several specimens had unusually thick hydration rims. The sample identification codes (in the "MURR ID" column of Table 2) ending in the letter E and a number indicate that the artifact had several different band widths as described above. Thus, CM016E1 means Cerro de las Minas, specimen 16, edge one. The values associated with that ID code were derived solely from measurements along that edge.

Calculation of dates from hydration rims can be done in two ways. The first is to use experimentally derived rate constants (Michels et al. 1983; Stevenson et al. 1989). The other is to use association with radiocarbon dates or other well-dated contexts and derive a rate empirically (Findlow et al. 1975; Meighan 1976). The

TABLE 2 *continued.*

MURR ID	Mean	Std	CV (%0)	Source
CM012	5.25	0.08	1.54	Ucareo
CM009	5.79	0.20	3.47	Ucareo
CM006	4.25	0.11	2.48	Zaragoza
CM011	5.16	0.06	1.19	Zaragoza
DZ002E1	2.81	0.07	2.33	Orizaba
DZ011	2.96	0.14	4.85	Orizaba
DZ002E2	16.28	0.31	1.93	Orizaba
DZ019	2.44	0.10	4.23	Pachuca
DZ022	3.88	0.10	2.57	Pachuca
DZ012	3.93	0.08	1.95	Pachuca
DZ015	4.00	0.09	2.32	Pachuca
DZ023	4.08	0.10	2.43	Pachuca
DZ010	4.22	0.08	1.79	Pachuca
DZ007	4.50	0.09	2.05	Pachuca
DZ030	4.61	0.17	3.58	Pachuca
DZ017	5.93	0.26	4.39	Pachuca
DZ026	3.12	0.08	2.66	Zaragoza
DZ005	3.50	0.09	2.60	Zaragoza
DZ021	3.59	0.10	2.72	Zaragoza
DZ024	4.05	0.05	1.32	Zaragoza
DZ025	4.09	0.13	3.22	Zaragoza
DZ001	4.20	0.11	2.55	Zaragoza
DZ009	4.22	0.06	1.53	Zaragoza
DZ018	4.22	0.14	3.37	Zaragoza
DZ004	4.23	0.06	1.51	Zaragoza
DZ016	4.24	0.15	3.60	Zaragoza
DZ028	4.31	0.09	2.04	Zaragoza
DZ029	4.32	0.11	2.49	Zaragoza
DZ008	4.33	0.13	2.94	Zaragoza
DZ006	4.48	0.14	3.12	Zaragoza
DZ013	4.57	0.16	3.54	Zaragoza
DZ027	4.63	0.07	1.42	Zaragoza
DZ003	4.68	0.12	2.56	Zaragoza
DZ014	4.97	0.07	1.41	Zaragoza
DZ020E2	6.31	0.09	1.40	Zaragoza
DZ020E3	7.19	0.16	2.21	Zaragoza
DZ020E1	8.28	0.11	1.29	Zaragoza
DZ020E4	10.91	0.21	1.97	Zaragoza

empirically derived rate can then be applied to a set of unknown samples to produce dates. Both techniques have advantages and disadvantages.

In the former instance, use of experimental rates requires a knowledge of ground temperature at the site, which may not always be available. Perhaps of greater consequence is the fact that this approach implicitly assumes that the mechanisms that induce hydration in the laboratory will also function in approximately the same fashion in archaeological contexts. While this assumption is not unreasonable, conditions at archaeological sites have been found to fluctuate significantly enough to confound successful dating. In practice it has been found that different labs will produce different rate constants for the same obsidian source due to differing approaches to experimentally hydrating obsidian (Stevenson et al. 1989). Obviously, application of two different rates for the same obsidian will produce divergent dates. The advantage of this technique is that it has the potential to produce chronometric dates independently of other chronological information. In situations of relatively uniform environmental conditions and where variable source utilization is not a problem, the technique has produced very encouraging results (Webster and Freter 1990). In situations where these conditions are not met, the results can be disappointing (Smith and Doershuk 1991).

The second technique avoids some of the difficulties of identifying, controlling, and measuring the variables that are responsible for hydration. However, it requires that obsidian from securely dated contexts be sourced in order to provide calibration points from which to calculate source specific rates. If the available independent chronological evidence is of poor quality, then calculation of an empirical rate will be difficult or perhaps even impossible. When sufficient independent chronological information is available, this method has produced good results (Findlow et al. 1975; Meighan 1976).

In attempting to calculate dates for the results presented in Table 2, we initially decided to employ the method using the experimentally derived rate constants. Our decision to try this first was based on the fact that none of the sites for which we had rim measurements had enough securely dated contexts for the calculation of an empirical rate. However, this decision presented us with two problems. The first was obtaining ground temperature data. Since we did not have the opportunity to bury thermal cells at these sites, we used ambient air temperature data from climatic maps of the region. This data was input into Lee's (1969) temperature integration equation, the formula commonly used for calculating an effective hydration temperature (Michels 1986a, 1986b; Stevenson et al. 1989).

The second problem was more formidable. As we indicated above, successful implementation of this technique requires that each source have its own experimentally derived rate constant. Unfortunately, only two Mesoamerican obsidian sources, Pachuca and Otumba, have had rate constants determined. In Oaxaca, Pachuca is one of the major sources utilized, but Otumba is only a minor source. For the sites presented here, Pachuca comprises anywhere from 25 to 50% of the sample set, but Otumba is only represented in small percentages at Cerro de las Minas and Rio Viejo and is not found at Dainzu. Thus, we can only calculate dates for a small percentage of the material from these sites. Other important sources, such as Zaragoza, Ucareo, and Orizaba, have not had experimental rate constants determined. Therefore, artifacts made from these obsidians cannot be dated by experimental rate constants and subsequently must be temporarily ignored. This lack of experimentally derived hydration constants probably represents the main limiting factor to a diachronic study of obsidian exchange in Oaxaca and likely for most of highland Mesoamerica as well.

In spite of this problem, we decided to calculate dates for the Pachuca and Otumba specimens to see how well the calculated dates fit the site chronology derived from ceramic data. We used the hydration rate constants calculated by Michels (1986a, 1986b) for the Pachuca and Otumba sources and another rate for Pachuca calculated by Stevenson (personal communication March 1992). The results of these calculations are presented in Table 3.

Perusal of this table immediately reveals that there is considerable disparity between the dates derived from the two different rate constants. For Rio Viejo, the

TABLE 3. *Dates calculated from experimental hydration rate constants for the Pachuca and Otumba sources for artifacts from Rio Viejo (RV), Cerro de las Minas (CM), and Dainzu (DZ). Dates are presented as years before present (B.P.).*

MURR ID	Dates based on Michel's rate	Dates based on Stevenson's rate
RV005	1141	——*
RV008	1226	——*
RV016	52	75
RV003	169	242
RV010	464	666
RV011	887	1271
RV019	1000	1433
RV017	1035	1483
RV014	1102	1579
RV001	1405	2013
RV009	1504	2156
RV002	1625	2330
CM019	520	——*
CM018	661	——*
CM003	849	——*
CM002	859	——*
CM001	553	818
CM008	844	1248
CM020	981	1453
CM021	995	1472
CM004	1831	2709
DZ019	576	867
DZ022	1453	2185
DZ012	1491	2242
DZ015	1544	2321
DZ023	1607	2416
DZ010	1718	2583
DZ007	1956	2941
DZ030	2054	3088
DZ0017	3394	5102

——* = No rate for the Otumba source.

dates based upon Michel's rate are generally too late. Stevenson's rate produced dates more in line with those based on the ceramic evidence. Also, two of the specimens, RV016 and RV003, produced dates that are clearly anomalous regardless of the rate used. RV016 had an extremely thin hydration rim that was difficult to measure. The rim measured on RV003 was also thin. RV016 was found in a naturally deposited alluvium, and it is possible that depositional processes reduced or erased the hydration rim. RV003 comes from fill above a burial. The burial depth of RV003 may have been shallow, which might reduce the rate of hydration, thus diminishing the thickness of the rim (Mazer et al. 1991).

The situation at Cerro de las Minas is similar. Michel's rate produced dates that, with one exception (CM004), are much too late. Stevenson's rate produced dates more in line with the ceramic evidence, though they tend to be a little late as well. Dates for two of the artifacts were clearly out of the time range suggested by the ceramic evidence. One is somewhat late (CM001) and the other too early (CM004).

At Dainzu, the situation is reversed. Dates based on Michel's rate are more on target though they tend to be a little late. This is especially true for two, DZ012 and DZ023, which come from a sealed context associated entirely with period I (500–100 B.C.E.) pottery. Also, the date for DZ017 is too early. Dates based on Stevenson's rate are generally much too early.

Since the dates based on the experimental rate constants were largely unsatisfactory, we decided to reexamine the contextual data to see if there was any chance of constructing an empirical rate from which to calculate dates. The only site where there was material from a well-dated context was Dainzu, but this consisted of only two specimens, both of which sourced to Pachuca, from the sealed period I context. Since these specimens had rim widths that were very close (DZ012 = 3.93 μ, DZ023 = 4.08 μ), we decided to calculate a rate based on the average of these two specimens.

To calculate a rate, the authors took the average rim width (4.005) and ratioed it to the number of millennia that had passed since the end of period I (100 B.C.E. or 2.1 millennia). The end of period I was chosen, since the specimens were found sealed between two floors, and the most recent pottery found in association with the specimens was assignable to the end of period I. The deposits between the floors were, therefore, reasoned to be no later than the end of period I or, in other words, the lower floor was in use until the end of period I, when a new floor was constructed above it. Three sets of rates were calculated, one based on squared microns per unit time (which experimental data indicates is the appropriate progression), one based on microns raised to an exponent of 1.5 per unit time and a linear rate, microns per unit time. The rates derived by this method were then applied to the other measurements for the Pachuca artifacts to produce dates. The results of this technique are presented in Table 4.

Inspection of the dates produced by this procedure reveals that the linear rate resulted in dates that tend to fall within the range suggested by the ceramic chronology. Specifically, the majority fall into either period I or II, which ceramic and architectural evidence indicates was the main period of occupation at Dainzu (Marcus 1983b). DZ019 produced a date late in the Classic (period IIIb) which is not unreasonable, but DZ017 produced a date that is too early. Results from the squared rate

TABLE 4. *Dates for Pachuca artifacts from Dainzu using an empirical rate based on artifacts from a sealed context datable to 100 B.C.E. via ceramic associations. Dates are presented as years before present (B.P.).*

MURR ID	Linear Rate (rate = μ1)	Exponential Rate (rate = μ1.5)	Exponential Rate (rate = μ2)
DZ019	1282	1001	782
DZ022	2035	2003	1972
DZ012	2062	2043	2024
DZ015	2098	2097	2095
DZ023	2140	2160	2181
DZ010	2213	2271	2232
DZ007	2361	2504	2655
DZ030	2420	2597	2788
DZ017	3110	3785	4606

were quite similar to those produced by Stevenson's rate, but are also generally too old. The dates based upon the 1.5 exponential rate are a bit too old but are not totally off the mark. While the linear rate produced dates that fall within the range suggested by other chronological evidence, we must accept these dates cautiously since experimental work has clearly demonstrated that the rate of development of the hydration rim is squared microns per unit time.

In many ways, these dates are much more satisfactory than those based on the experimental rate constants. Yet, these dates can be taken only as tentative or as a range of possibilities since they are based on an empirical rate that was derived from a single point (actually the average of two points). If more quality-independent chronological evidence were available, a curve-fitting technique similar to that used by Findlow et al. (1975) would yield a more theoretically satisfying rate since it would encompass variation over a significant range of time. Nevertheless, in the absence of agreed-upon experimental rate constants that yield acceptable dates, correlation with other chronological evidence, even if it is limited in scope or of low quality, may still be the most practical approach to obsidian hydration dating.

In reviewing the results obtained thus far, it might seem that they are disappointing enough to discourage further investigation into the potential of hydration dating to refine the chronological precision of obsidian source studies. However, such an action would be premature and, in fact, when one examines the results more closely, they are not as discouraging as a cursory glance would indicate. While the results do not reveal much about diachronic shifts in obsidian procurement in Oaxaca, largely because they are incomplete, they do at least indicate directions for methodological refinement. It seems to us that this is a necessary first step before the potential of the technique to provide a diachronic perspective on obsidian exchange can be fully evaluated.

Obviously, one of the first problems to be resolved is to obtain experimentally derived rate constants for at least the Zaragoza and Ucareo sources. Ideally, we would want to have rates for all of the sources identified in the Oaxaca material, but since the bulk of the material is from Zaragoza, Pachuca, and Ucareo, rates for these sources are most critical. Currently, we are collaborating with several labs to obtain these rates. We also intend to perform induced hydration experiments ourselves for the Zaragoza and Ucareo sources using the method suggested by Mazer et al. (1991).

Given the contradictory and rather inaccurate results obtained for the Pachuca specimens (Table 3), why should we pursue further use of experimental rates? We believe the following reasons justify continued investigation into the utility of experimental rates.

First, the results obtained by use of the two experimental rates were not unexpected. Meighan (1976) has noted that this will almost always result in divergent dates due to the different methods of experimentally hydrating obsidian in the laboratory (see, for example, Michels et al. 1983; Stevenson et al. 1989; Mazer et al. 1991). Nevertheless, experimentally derived rates probably provide the best means for identifying diachronic shifts in obsidian exchange patterns. Obviously, unless a single temporal scale is established, distinguishing temporally related changes in source usage would be impossible. Experimental rates, even if they do not agree between labs, will provide the calibration factors necessary to calibrate rim widths of one source against those of another source (Tremaine and Fredrickson 1988). Interestingly, this suggests that the accuracy of the dates in a calendrical sense may be largely irrelevant. As long as whatever rate employed intercalibrates the hydration rims to a single time scale, their actual calendric values are not important. Shifts in acquisition patterns can still be identified, which is the main objective of using hydration dating in the context of sourcing studies. Furthermore, use of associated chronological data, even of poor quality, will enable some correction of the inaccuracy of the dates. This in fact may be the best way of utilizing hydration dates as a means of acquiring a diachronic perspective on obsidian exchange.

A second reason for continued investigation of the experimental rates lies in the fact that some of the inaccuracy in the dates we calculated might lie in the use of incorrect temperature data. As we pointed out, it was not possible to bury thermal cells for the required length of time at each of these sites. In fact, when we began this project, we did not know how much obsidian from Oaxacan excavations would be available or from which sites. We therefore decided to rely on ambient air temperature data and Lee's (1969) temperature integration equation to calculate an effective hydration temperature rather than attempt to bury thermal cells ex post facto. Additionally, many of the sites are in remote areas and cannot be guarded year round (looting is a problem in Oaxaca), and thus there was no guarantee that the thermal cells would be there after a year of burial.

Stevenson et al. (1989) have suggested that use of ambient air temperature data in conjunction with Lee's (1969) temperature integration equation will result in calculation of faster hydration rates, since it does not accurately account for temperature fluctuations in the soil. Consequently, the resultant dates will be more recent than independent evidence would indicate. Stevenson et al. (1989) suggest another equation that they feel will more accurately account for ground temperature fluctuations. Unfortunately, this equation is somewhat complex and involves parameters that are not easily estimated from standard climatic data. A simpler approach might be to use the climatic maps for Oaxaca to identify a range of possible mean air temperatures and use these values to determine how, or if, they affect date calculations.

Another reason for reliance on experimental rates is the fact that there is, in Oaxaca, an extreme lack of independent chronological data for constructing an empirical rate, especially through the curve-fitting techniques advocated by Findlow et al. (1975) and Meighan (1976). There are no radiocarbon dates (or other chronometric dates) for any of the artifacts in the sample (at least so far), and most of the ceramic contexts are mixed. While the empirical rates that we calculated for Dainzu worked well, especially the linear rate, this is probably a fortuitous outcome. Since only a single point was used to construct the empirical rates, they are probably invalid because they do not encompass any variation in rim formation over time. At best, results from the single-point rates suggest only a range of age possibilities. If in the future appropriate independent dating evidence becomes available, we will use it to calculate empirical rates.

Interpretation

It should be emphasized that because the results of this project are preliminary, the authors cannot provide a complete interpretation of their archaeological implications. An attempt is made here, however, to present what the authors consider to be the significant aspects of results obtained so far in relation to archaeological studies of obsidian exchange in Oaxaca.

Sourcing Results

Table 1 indicates that ten sources were exploited by the ancient inhabitants of Oaxaca. We must emphasize that this list is not exclusive, as a larger sample would probably increase the number of sources represented. It would likely change the frequency of occurrence for some sources as well. The primary sources that supplied obsidian to Oaxaca (in order of precedence) are Zaragoza, Pachuca, and Ucareo. Minor sources include Otumba, Orizaba, Paredon, and Guadalupe Victoria. Rare sources are Pizzarin and Zacualtipan (both of which produce a poorer quality obsidian than the other sources). The percentages also illustrate some differences by site and by region.

The larger sites, such as Monte Albán and Jalieza, tend to have a larger number of different sources represented in their assemblages. This possibly indicates that the large sites, with their greater concentrations of population and resources, might have been able to acquire a greater variety of obsidian. One exception to this general pattern is Ejutla. While Ejutla was an urban center of some size during the Late Formative and Early Classic, it was still significantly smaller than either Monte Albán or Jalieza during the same periods. Yet it has almost as many sources represented in its assemblage as the larger sites. This could be a reflection of Ejutla's status as a center of craft production, which might have conferred an enhanced ability on its residents to acquire goods by long distance exchange (Feinman personal communication August 1991).

Regionally, sites within the Valley of Oaxaca (Monte Albán, Jalieza, Lambityeco and Dainzu) all have similar source patterns. Zaragoza is by far the dominant source at these sites though Monte Albán is an exception. At Monte Albán, the dominant source is Pachuca. This probably reflects the preference of the

Monte Albán elite for the fine, green Pachuca obsidian as well as their ability to acquire it. It also might be a reflection of Monte Albán's links to Teotihuacán, the central Mexican urban center that purportedly monopolized the production and distribution of Pachuca obsidian during the Classic period (Santley 1983). The valley pattern contrasts with that at Rio Viejo and Cerro de las Minas, where Pachuca was the dominant source and the other central Mexican sources (Otumba, Zaragoza, Ucareo) occur in nearly equal frequencies. This pattern possibly results from their being nearer the central Mexican sources and/or being heavily influenced by Teotihuacán domination of central Mexico.

Ejutla presents yet another pattern. Here the Ucareo and Zaragoza sources are codominant and Pachuca obsidian occurs only as a minor source. This probably reflects the wider range of exchange opportunities possessed by Ejutla, especially with west Mexico given the high percentage of Ucareo obsidian. Again, this may be due to Ejutla's status as a center for manufactured goods. In sum, the regional differences may be an indication of three different exchange networks or spheres. One was centered on the Valley of Oaxaca and was perhaps controlled by Monte Albán. Another served the mountains north and west of the Valley of Oaxaca as well as the western half of the Oaxacan coast. The third one seems to have been centered on Ejutla and resulted from that site's status as a craft production center.

These interpretations are tentative, it must be emphasized, as there is no good chronological control for shifts in acquisition patterns. Ceramic evidence is not of much help in this endeavor, as many of the artifacts in the sample came from mixed contexts. Additionally, data pertaining to ceramic associations for many of the artifacts are incomplete at this time, as a large percentage of the artifacts were obtained from very recent excavations. Once the obsidian hydration dating is complete, it will be possible to reassess these initial interpretations. The results should make it feasible to more fully test several of the models that have been proposed to explain obsidian acquisition in Oaxaca (Pires-Ferreira 1975, 1976; Santley 1983) and the role played by Monte Albán in acquiring and distributing obsidian in the Valley of Oaxaca (Finsten 1983; Kowalewski et al. 1989).

Obsidian Hydration Dating Results

Because we only have dates for the Pachuca and Otumba specimens in the samples thus far analyzed, we are not able to identify or analyze diachronic change in source acquisition. Nevertheless, a few trends can be identified from the dates that we have.

Perhaps most striking is the consistency of the dates for Cerro de las Minas. Michel's and Stevenson's rates for Pachuca as well as Michel's rate for Otumba tended to produce dates that are generally later than ceramic and other evidence would indicate is the case. This might possibly suggest that the ceramic chronology is inaccurate and that the site's principal occupation was from the Late Classic through the Post-Classic rather than from Terminal Formative to Early Classic. However, Cerro de las Minas is located in an extremely arid region of Oaxaca, and the relative humidities of the burial contexts may have been less than 100%. In such circumstances, dates based on experimental rates derived at 100% humidity will probably be underestimated (Mazer et al. 1991). Given this fact, it is probable that the hydration dates for Cerro de las Minas are too recent. This also suggests that an empirical approach to hydration dating would be more appropriate for the Cerro de las Minas materials.

Another possible trend that can be discerned in the data is that the Pachuca source seems to have been heavily utilized since at least Late Formative times and perhaps earlier. This assumes of course that the dates are largely accurate. This would tend to contradict some of the earlier interpretations for Oaxaca, which suggested that Pachuca obsidian was not a major source until the Classic period, when it was supplied in large quantities by Teotihuacán via links with Monte Albán (Pires-Ferreira 1975, 1976; Santley 1983; Kowalewski et al. 1989).

Another pattern of interest is that all of the Otumba samples dated thus far produced Post-Classic dates. Again assuming that the dates are more or less accurate, this trend would contradict previous predictions that Otumba would be a major source for Classic period Oaxaca (Santley 1983; Kowalewski et al. 1989). The dated sample of Otumba material is admittedly small, but should the other Otumba specimens produce similar dates, this would tend to disconfirm the hypothesis that the Otumba source was a principal supplier of obsidian during the Classic. If in fact this turns out to be the case, the sourcing evidence, which linked only 6% of the total Oaxaca sample to Otumba, combined with the dating evidence, would entirely refute this idea.

Conclusions

Perhaps the firmest conclusion that can be drawn from the results of this study relates to the utility of the rapid instrumental neutron activity analysis method. Clearly, it represents a very attractive method of sourcing obsidian in a quick, precise, and inexpensive fashion and thus makes neutron activation more cost competitive with other sourcing techniques such as energy dispersive X-ray fluorescence. We are continuing to investigate ways of further refining the technique, including experiments directed at reducing the length of irradiation time.

In regard to the dating segment of the project, the most obvious conclusion is that more work is needed to determine if obsidian hydration dating will produce the chronological resolution required to provide a fine-grained diachronic perspective on obsidian exchange. Despite the rather disappointing nature of the results so far, we still believe this approach has great potential. Evaluation of this possibility is going to require the calculation of rate constants for at least the major sources identified in the Oaxacan assemblages as well as more independent chronological information. Hopefully, both will be forthcoming. Futhermore, our experience thus far suggests that dates based on empirical rates tend to be more accurate than those based on experimental rate constants. We must stress, however, that this conclusion is tentative and only further, more detailed work with empirical rates, especially in a manner similar to that suggested by Meighan (1976) and Findlow et al. (1975), will determine if empirical rates are superior to those derived experimentally. Ultimately, as long as we can intercalibrate source differences to a single temporal scale, regardless of the method used, we will be able to make some determinations as to how obsidian acquisition patterns changed through time. Consequently, the absolute calendrical accuracy of the dates in this situation need not be 100%.

The results suggest only a few conclusions pertinent to the archaeology of Oaxaca. The hydration data, though incomplete, suggest three possible inferences. These rest, of course, on the assumption that the dates we have are not entirely inaccurate. First, the dating of Cerro de las Minas, based on ceramics, may be inaccurate. Second, the utilization of the Pachuca source seems to begin much earlier than originally thought. Finally, the utilization of the Otumba sources seems to occur much later than is currently believed.

The source patterns in Oaxaca suggest that acquisition of obsidian in post-Formative Oaxaca was directed entirely toward central Mexico. Zaragoza, Pachuca, and Ucareo are the main sources utilized by the ancient Oaxacans (Fig. 1). This general pattern contrasts with that delineated by Pires-Ferreira (1975, 1976) for the Formative periods in which obsidian was procured primarily from the Guadalupe Victoria source located in eastern Mexico. The data also suggest the presence of three exchange networks, one centered on the Valley of Oaxaca and perhaps controlled by Monte Albán, another centered on the mountains (the region known as the Mixteca), which supplied obsidian to the western coast of Oaxaca as well, and another centered on Ejutla, which had strong links to the west Mexican source of Ucareo. Evaluation of the various models of the social and political contexts of obsidian exchange (Pires-Ferreira 1975, 1976; Santley 1983; Finsten 1983; Kowalewski et al. 1989) must wait until we have better chronological control of the sample. We should point out that we hope to enlarge the size of the sample by including more material from sites in the Rio Verde region of coastal Oaxaca as well as from the important Post-Classic site of Yagul in the Valley of Oaxaca. Several of these sites have radiocarbon dates that might be suitable for developing empirical hydration rates. Consequently, data from these sites will better enable us to evaluate the various models of obsidian exchange in ancient Oaxaca.

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Obsidian from Pueblo Grande, Arizona: Modeling Social and Economic Patterns in Lithic Procurement

JANE PETERSON,
DOUGLAS R. MITCHELL, AND
M. STEVEN SHACKLEY

The social and economic organization of obsidian procurement has been a topic of particular interest in Hohokam archaeology since recent work (Shackley 1990, 1991) identifying and characterizing a number of sources throughout Arizona and northern Mexico (Fig. 1). The Pueblo Grande study was undertaken in the hope of enhancing the regional understanding of obsidian networks and expanding the analytical scope of obsidian X-ray fluorescence data sets. This chapter addresses three primary research goals. The first goal was to try to understand the acquisition networks for the obsidian used at the Hohokam site of Pueblo Grande. The relatively large sample of obsidian submitted for X-ray fluorescence source characterization was subdivided by artifact categories. This included cores, debitage, and formal and informal tools. Several distinctive patterns emerged among the various types of obsidian sources, suggesting that a variety of acquisition networks may have been at work prehistorically. Second, the Pueblo Grande obsidian data set is compared to other Hohokam sites. This regional synthesis of obsidian source data demonstrates that Pueblo Grande has a uniquely diverse assemblage. Furthermore, this diversity is maintained throughout the full length of the site's occupation. Finally, a study of intrasite spatial patterning as it relates to the diversity of obsidian source material is presented. In an attempt to understand the high source diversity, a model is explored that relates spatially discrete burial groups with certain obsidian procurement territories.

Pueblo Grande, one of the largest Hohokam sites known, is situated on the Salt River in present-day Phoenix (Fig. 2). During 1988–90, Soil Systems, Inc., excavated an estimated 20% of the site, comprising a north-south transect through the eastern side (Fig. 3). The excavated area was near a prehistoric platform mound, which is a large architectural feature that may have functioned as a focus of ceremonial activities, elite residences, or both. Occupation within the project area dates to approximately 1000–1450 C.E. Within this 450-year span, a three-phase site chronology is used based on ceramic seriation, absolute dates, and stratigraphic relationships. These phases correspond to the Pre-Classic, Classic, and Late or Terminal Classic.

FIGURE 1. *General location of obsidian sources in the Southwest (from Shackley 1990).*

At Pueblo Grande, these temporal intervals date to approximately 1000–1150, 1150–1350, and 1350–1450 C.E., respectively.

During the course of the excavations, discrete domestic areas and burial groups were defined at the site. These spatial divisions provide the basic units of analysis for the intrasite study.

A sample of 220 obsidian pieces, roughly 15% of the total obsidian assemblage, was chosen for this study (Peterson 1992). The trace element analyses were performed by M. Steven Shackley in the Department of Geology and Geophysics, University of California, Berkeley, using a Spectrace 440 energy-dispersive X-ray fluorescence spectrometer (United Scientific Corporation). The spectrometer is equipped with an Rh X-ray tube, a 50 kV X-ray generator, and a Tracor X-ray (Spectrace) TX 6100 X-ray analyzer using an IBM PC-based microprocessor and Tracor reduction software. The X-ray tube was operated at 30 kV, .20 mA, using a .127 mm Rh primary beam filter in an air path at 250 seconds livetime to generate X-ray intensity data for the elements lead (Pb), thorium (Th), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb). Trace element intensities

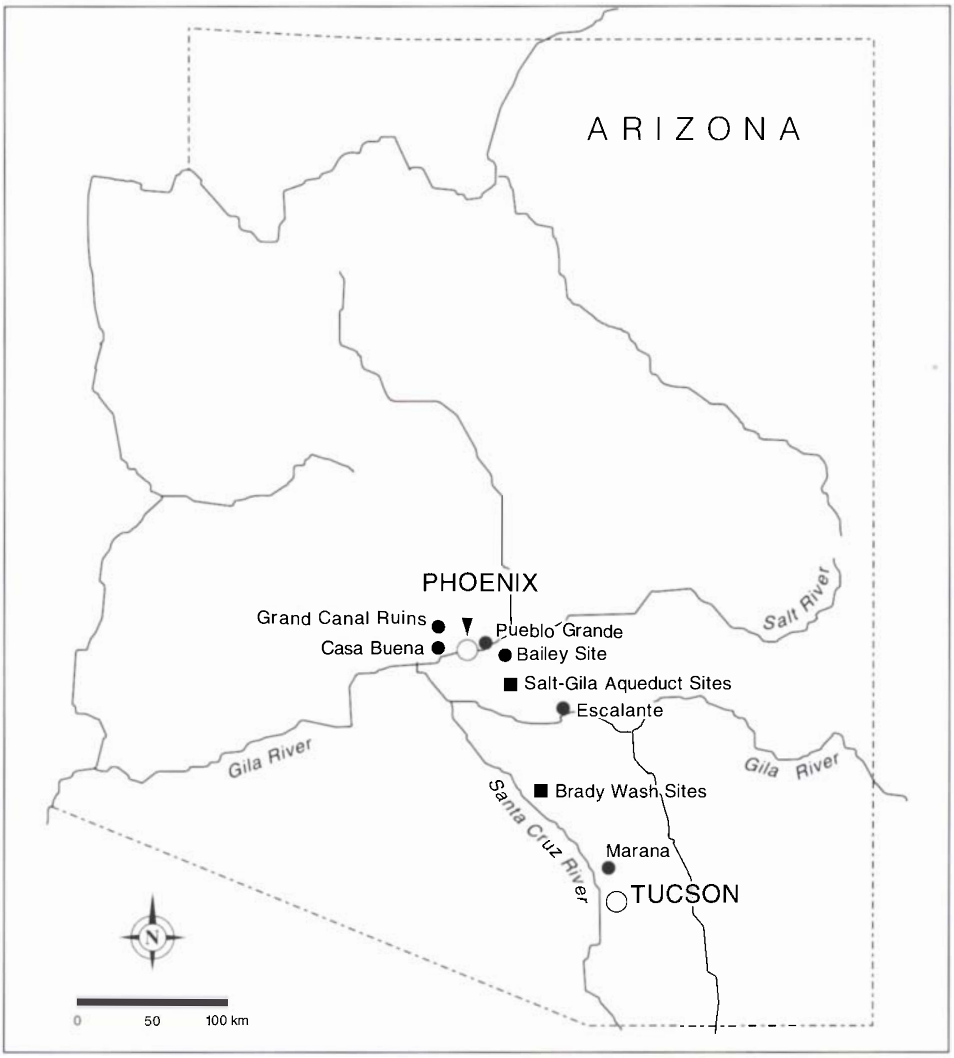


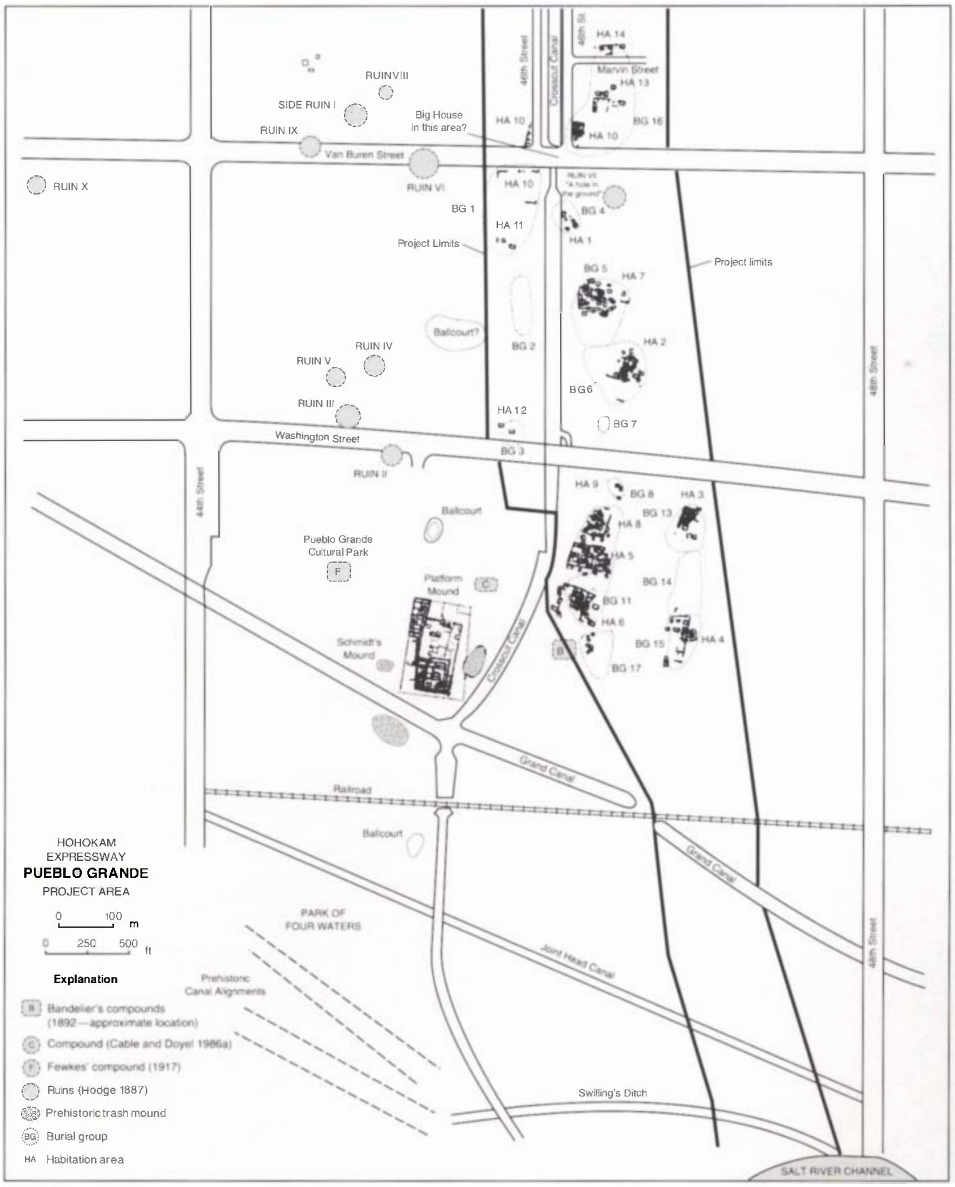
FIGURE 2. *Pueblo Grande and other archaeological sites with obsidian source data.*

were converted to concentration estimates by employing a least-squares calibration line established for each element from the analysis of up to 26 international rock standards certified by the U.S. Bureau of Standards, the U.S. Geological Survey, the Canadian Centre for Mineral and Energy Technology, and the Centre de Recherches Pétrographiques et Géochimiques in France (Govindaraju 1989). Further details concerning the petrological choice of these elements in Southwestern obsidians are available in Shackley (1988, 1990).

Production Stages

In considering first the question of obsidian acquisition, Figure 4 presents the obsidian source data with reference to the production stage categories. Five of the nine sources have both cores and debitage present: Government Mountain (210 km distant), Sauceda (110 km), Superior (80 km), Vulture (95 km), and Unknown A. Most of these sources are represented by the full spectrum of formal and informal tools as well. Clearly, some core reduction of these materials was taking place on-site. Obsidian from Los Vidrios (205 km distant), the source in northern Sonora, Mexico, has debitage and informal tools in small numbers. Despite the lack of cores and formal tools in the sample, it appears that some reduction or maintenance of the

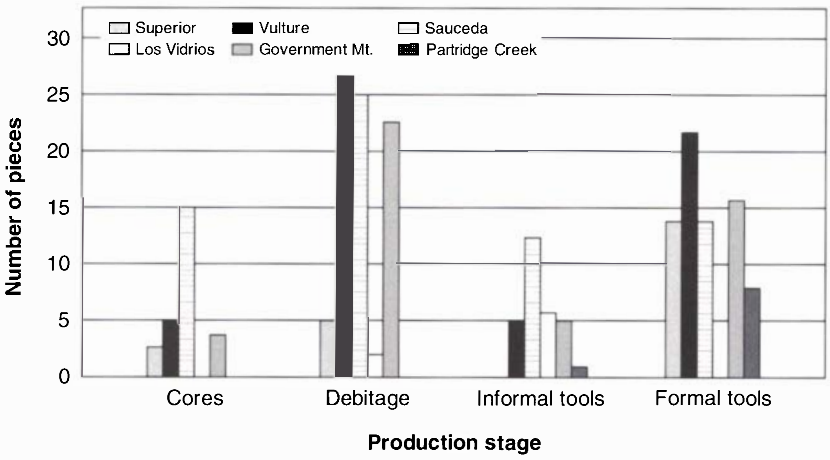
Figure 3. Pueblo Grande project area showing extent of excavations and depicting habitation areas and burial groups.



Los Vidrios material was also occurring at Pueblo Grande. The Partridge Creek obsidian, the material farthest from the site (225 km distant), exhibits different patterns. Eight of the nine pieces of Partridge Creek obsidian occur as projectile points, as does the single Tank Mountain (160 km distant) specimen. Despite the relatively small sample, it can be argued that this material was arriving at the site in the form of finished, complete tools.

From a stylistic examination, we can infer that two different cultural groups may have been manufacturing these points. Many of the Partridge Creek points are small, roughly triangular, and asymmetrical (Fig. 5). Some have side notching, some shallow serration. Overall they are very similar to points found across the site and made from a number of different kinds of obsidian. In contrast to these, there are a number of points made from the Partridge Creek obsidian that are morphologically distinctive. They have longer blades and deeper, more pronounced serration (Fig. 6). This type of point is characteristic of prehistoric groups in the northern part of Arizona (MacGregor 1941, 1951). And, in fact, several of the points manufactured from Government Mountain obsidian are also of this style.

FIGURE 4. *Obsidian sources and production stages (excluding indeterminate types and Tank Mountain).*



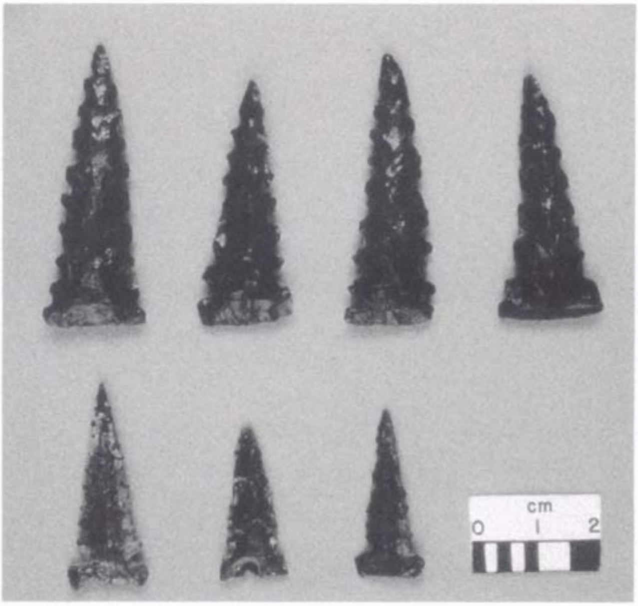


FIGURE 5. *Typical Classic period Hohokam projectile points found at Pueblo Grande. Slide AP2/T:4, Soil Systems, Inc., archives.*

FIGURE 6. *Elongated, deeply serrated projectile points from Pueblo Grande. Slide AP2/X:5, Soil Systems, Inc., archives.*

A general model of obsidian procurement for Pueblo Grande, then, should include a variety of acquisition strategies. For a majority of the obsidian, there is evidence for direct acquisition and on-site core reduction. For some, more distant sources, core reduction apparently takes place elsewhere, perhaps close to or at the source, in order to minimize transport costs. Some of these projectile points, which arrived fully formed at Pueblo Grande, appear to be the craftwork of Hohokam knappers reproducing a general, triangular projectile point style. Other points, conceivably, were manufactured by groups in the North and exchanged as finished products.

Realistically, larger models for trade and exchange throughout the American Southwest must consider and incorporate these results. The obsidian does not appear to have moved within a single interaction sphere. This is not surprising considering that the commodity certainly has both utilitarian and exotic aspects. Despite the complexities inherent in considering the spectrum of acquisition networks in operation, models built on less comprehensive notions appear increasingly naive.

Turning to the regional and intrasite aspects of our study, diversity measures are used to compare the obsidian X-ray fluorescence assemblages. These applications make use of a computer program designed by Keith Kintigh at Arizona State University to portray relative richness and evenness dimensions of diversity, controlling for the effects of sample size. The program calculates an expected diversity range for a range of sample sizes using Monte Carlo simulation techniques. These computations are then graphically displayed as a 90% confidence interval around the simulated model distribution (Kintigh 1984, 1989).

Regional Analyses

The Pueblo Grande assemblage is divided into three components for this discussion, roughly corresponding to the time periods—Pre-Classic, Classic, and Late or Terminal Classic—represented at the other Hohokam sites with X-ray fluorescence results. All the Pueblo Grande assemblages from the three occupational phases fall within the expected range for diversity, for the dimensions of both richness and evenness. The richness dimension is depicted in Figure 7. The only other site with an assemblage that is as diverse as expected is La Lomita Pequeña, a Pre-Classic site. However, sample size at this site is small enough to make the results questionable. In terms of the Pre-Classic assemblages, La Ciudad (C) and Ak-Chin (AC) are significantly more homogeneous in terms of both richness and evenness. Moving along in time, the Classic period assemblages are of particular interest. Before the Pueblo Grande study, the results of X-ray fluorescence studies had indicated that Classic-period sites seemed to have specialized in one or two obsidian sources (Shackley 1987, 1988, 1989). Clearly, this pattern of low Classic period diversity is not upheld at Pueblo Grande. In this respect Pueblo Grande differs markedly from the other Salt River sites (Grand Canal, Casa Buena, Bailey Site), Gila River sites (Brady Wash, Picacho South), and the Tucson Basin site of Marana. Finally, the Late Classic assemblage, for which there is no comparative material in the region, also falls squarely within the expected diversity range. This is again somewhat surprising, given present conceptions of the Late Classic phase as a period of significant, per-

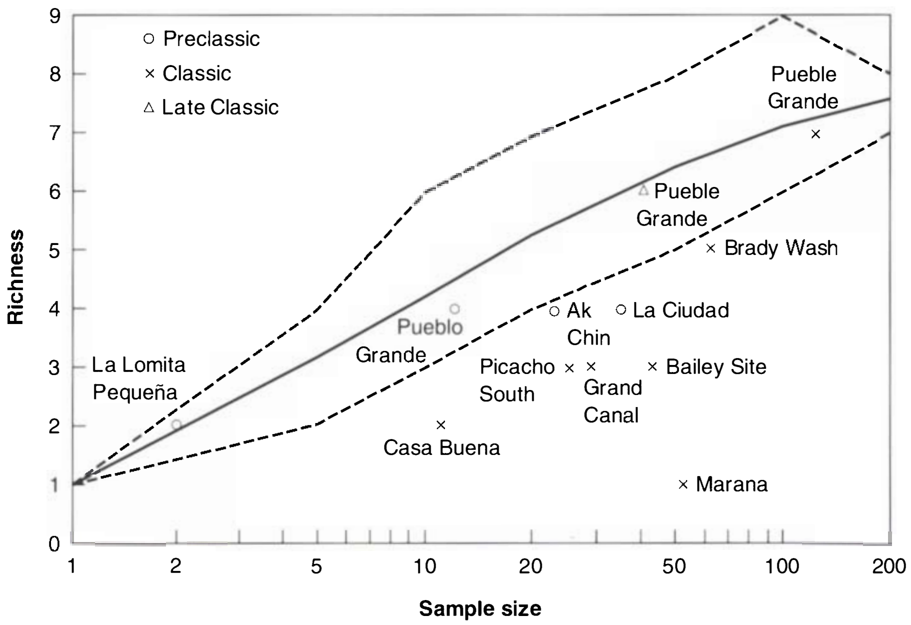


Figure 7. *Regional diversity among Hohokam sites, 90% interval plotted (richness dimension).*

haps disruptive, adaptive change (Doyel 1991; Sires 1984). Whatever these changes were, they had little visible impact on the types and proportions of obsidian coming into Pueblo Grande.

Possible explanations to account for the unique position of Pueblo Grande through time are varied. It is difficult to control for all the systemic and archaeological variables that are undoubtedly responsible in varying degrees. Site size and location may be influential factors but do not appear to be consistently at work. For instance, the increased distance of the Tucson Basin and Gila River sites from the northern Arizona sources helps explain the lack of obsidian from those areas, but not the lack of obsidian from sources farther south, such as Los Vidrios. Some of the sites are smaller than Pueblo Grande and could be reasonably expected to have used fewer sources. But other large sites in near proximity, such as La Ciudad, still have a relatively low diversity of obsidian types present.

Given the state of our knowledge, Pueblo Grande holds a unique position with respect to relatively high obsidian source diversity. Temporal explanations are untenable since the pattern is maintained throughout the three time periods considered here. Perhaps Pueblo Grande is outstanding in some other respect. The size, variety of ceremonial and elite architecture, and rich material culture, for example, suggest that Pueblo Grande is comparable with only a handful of large sites in the Hohokam area. These have been described as major economic and population centers (Wilcox 1991). Perhaps the population at Pueblo Grande was composed of a more diverse mix of family groups or specialists.

There is some archaeological evidence for at least one major influx of people into the village. At the beginning of the Classic period, demographic reconstructions suggest a threefold increase in the number of houses at the site (Mitchell 1993). If we assume that this is a direct reflection of population, then it would indicate an in-migration to the site because such an increase is well beyond the limits of natural population growth. This would be consistent with a general trend toward aggregation at the beginning of the Hohokam Classic period. The arrival of a number of different groups into the village could account for the obsidian diversity.

If the inference of direct raw material procurement for most of the Pueblo Grande obsidian is well founded, it is not difficult to imagine that different groups at the site had access to, or preference for, certain sources over others. Ethnographically, well-defined, family-based resource procurement territories have been documented for a variety of materials from saguaro fruit to clay (Castetter and Underhill 1935; Castetter and Bell 1942; Curtis 1962; Rice 1987). As the site population becomes more diverse, the obsidian assemblage diversity would conceivably increase at the same time. This supplies the first operating assumption for the study of intrasite patterning.

A correlate states that burial groups can be viewed as spatial analogs for some level of group affiliation. This position has been held by a number of researchers (Goldstein 1980; Henderson 1987; Mitchell 1992). If discrete burial areas define groups within the village, one might reasonably expect lower diversity levels within these groups, compared to the site as a whole; that is, all the sources were not being used by all the inhabitants. So, if procurement territory is influenced by group affiliation, it might prove interesting to look for patterning within the burial groups indicative of lower source diversity.

Intrasite Spatial Analysis

Seventeen burial groups were identified in the project area. All the burial groups were associated with habitation areas (Fig. 3). Our sample includes sixty-seven obsidian pieces from both inhumation and cremation burials in these areas. Preliminary analyses compared expected and observed values by source type within the burial groups. Several interesting patterns emerge. Spatially, many obsidian types are restricted to certain areas of the site. For instance, Partridge Creek occurs only in burial groups 11 and 16, while Los Vidrios is found only in Burial Group 6. Burial Group 5 contains the only specimens of Unknown A (four pieces) and a disproportionate amount of Vulture obsidian. Other burial groups seem to be dominated by a disproportionate amount of one type of obsidian: Government Mountain in Burial Group 6; Vulture in Burial Group 1. A series of chi-square tests (Table 1) conducted on the burial groups with sizable samples indicates that many of these relationships between particular burial groups and particular types of obsidian are significant. In all cases the strength of association measures are only moderately strong; nonetheless, these results suggest that some of the burial groups do display a preference for a single type or limited array of obsidian.

A second line of analysis was conducted to test these preliminary findings further. Since the samples from the various burial groups differ in size, and only a fraction of the obsidian per group was sourced, the diversity program was used again.

Interestingly, none of the burial groups falls above the 90% confidence interval (Figs. 8, 9). Several groups can be eliminated from discussion because of very small sample sizes, for example burial groups 14 and 17. Four groups fall well within the expected range of diversity: burial groups 6, 11, 13, and 15.

Of added interest here are the groups that fall below the expected values. With respect to richness—the number of different classes present—burial groups 1 and 16 fall well below the expected range of diversity (Fig. 8). In terms of evenness—the relative equality of representation of classes—Burial Group 5 also slips below the 90% expected diversity range (Fig. 9).

The sample from Burial Group 5 consists of twenty-one pieces from nine features: Thirteen of the pieces are from the Vulture source and four are from the Unknown A source. The burial group is located in the central part of the project area. Burial Group 16, in the northernmost excavated area, contained three pieces of obsidian from two burial features. All three were Partridge Creek obsidian. Eight pieces of obsidian were analyzed from Burial Group 1. All eight pieces, from five separate inhumations, were from the Vulture source. This area provides the strongest support for our model stating that individuals within the discrete burial groups, which appear to represent distinctive social units, had different access to, or preference for, certain obsidian sources.

Burial groups 1 and 16 are provocative from an additional intrasite standpoint as well. They are the two groups in closest proximity to a feature tentatively identified

Table 1. *Cross-tabulation of obsidian types by burial groups.*

Cross-tabulation of Vulture and all other obsidian types
by Burial Group 5 and all other burial groups

Observed count	Vulture	All other sources	Total
Expected count			
BG 5	13	8	21
	8.1	12.9	
All other BGs	13	33	46
	17.9	28.1	
Total	26	41	67

Chi-square = 5.53, df = 1
$.05 > p > .01$
Phi = .32 (moderately weak association)

Cross-tabulation of Vulture and all other obsidian types
by Burial Group 1 and all other burial groups

Observed count	Vulture	All other sources	Total
Expected count			
BG1	8	0	8
	3.1	4.9	
All other BGs	18	41	59
	22.9	36.1	
Total	26	41	67

Chi-square = 11.55, df = 1
$p < .01$
Phi = .46 (moderately strong association)

Cross-tabulation of Government Mt. and all other obsidian types
by Burial Group 6 and all other burial groups

Observed count	Government Mtn.	All other sources	Total
Expected count			
BG1	9	6	15
	3.6	11.4	
All other BGs	7	45	52
	12.4	39.6	
Total	16	51	67

Chi-square = 11.43, df = 1
$p < .01$
Phi = .46 (moderately strong association)

as a “Big House.” This three-story structure was identified and partially excavated by Frank Cushing in 1887. Current interpretations of the Big House phenomena suggest that, like platform mounds, they may have been elite residences and focal points for ceremonial activities (Wilcox 1991).

Taking all the intrasite patterns together, the results suggest that in some cases group affiliation can be monitored through obsidian source data. Furthermore, the

FIGURE 8. *Diversity among burial groups at Pueblo Grande, 90% interval plotted (richness dimension).*

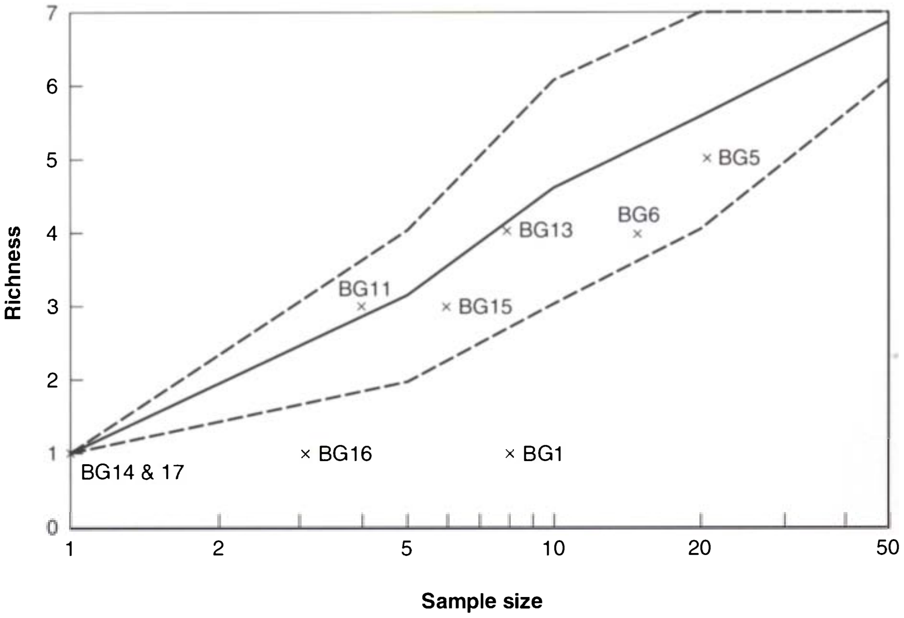
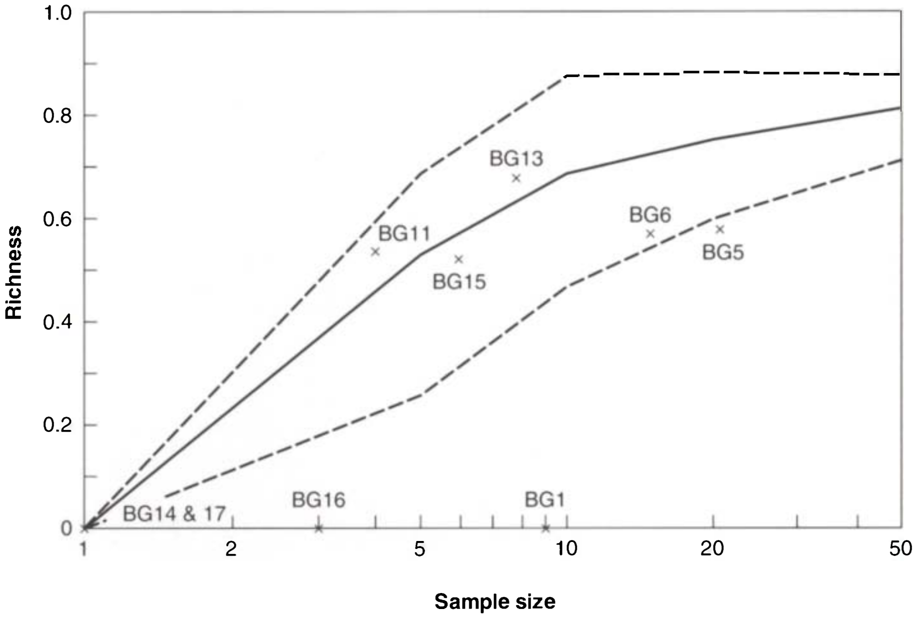


FIGURE 9. *Diversity among burial groups at Pueblo Grande, 90% interval plotted (evenness dimension).*



results indicate that the diversity of Pueblo Grande's assemblage can be tentatively linked to diversity in group composition at the site.

Summary

The results of these analyses show that obsidian source data can inform on a number of levels. First, variability in procurement strategies was documented. The fact that both direct acquisition and exchange of finished products occurred prehistorically implies that the material travels in both utilitarian and more formalized social contexts. In addition, Pueblo Grande's unique position with respect to obsidian diversity can be explored productively by giving causal import to social variables as well. The intrasite analyses support the notion that the high diversity may be due in part to unequal utilization of sources by different segments of the site's population.

Whether Pueblo Grande retains its unique status regarding the nature of the obsidian assemblage awaits similar large-scale obsidian studies.

Acknowledgments

The authors would like to thank the Arizona Department of Transportation, which provided the funding for the excavations at Pueblo Grande and the subsequent artifact analyses. Thanks also to Alison Dean, Michael Foster, and Geo-Map, Inc., for preparing the figures used here. Soil Systems, Inc., provided logistical support during the preparation of this paper.

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Biographies

Jane Peterson is completing the Ph.D. program in anthropology at Arizona State University, where she received her M.A. degree in 1988. She was director of lithic studies for the Pueblo Grande Research Project, which included the obsidian analysis. Peterson has conducted stone tool analyses on artifact assemblages from Ireland and Jordan, where she also spent several field seasons. She is currently gathering data from museum collections for her dissertation research.

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Beads from Sipan:
A Functional Analysis

LEONARD GORELICK AND
JOHN GWINNETT

A functional analysis was undertaken of beads excavated from the royal tomb at Sipan, Peru. The sample of beads selected at random were from the bracelets of the primary individual in the tomb, from the wrist of the figure on the large metal headdress (Alva 1988:537), and from the wrist of a metal figure sewn to a textile (Alva 1988:533). Many of the beads were remarkably tiny (Fig. 1).

FIGURE 1. *Scanning photomicrograph showing a comparison between the size of a bead from Sipan and the face of a one-cent piece.*

The purpose of this study was to determine the method of bead manufacture using functional analysis and scanning electron microscopy.

Samples

Fourteen beads in the corpus were studied. All were examined first by light optical microscopy. Following this screening, the beads were selected for detailed examination by scanning electron microscopy to identify their general morphology and marks left by the tools used in their manufacture.

An examination of two bead samples by George Harlow of the American Museum of Natural History using energy-dispersive spectrometry verified that the samples consisted of either sodalite or turquoise (Fig. 2).

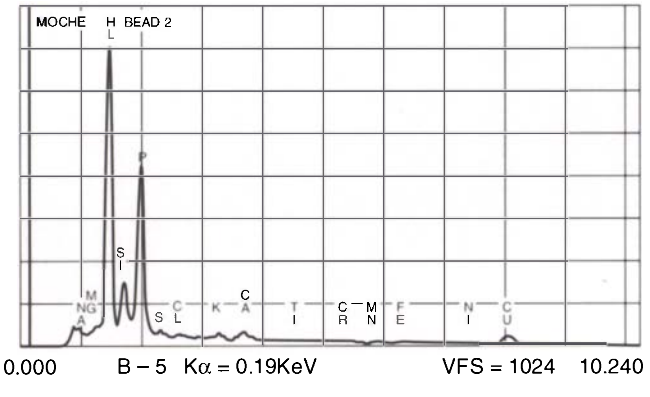


FIGURE 2. *Elemental display that served to verify the beads as either turquoise or sodalite.*

Microscopic Findings

All the beads were of the thin-disc type. The smallest was 1 mm in diameter and 0.3 mm in thickness. The largest was 2.8 mm in diameter and 1.3 mm in thickness. The smallest biconical drill holes ranged in diameter from outer 0.3 mm to inner 0.25 mm to outer 0.5 mm; and outer 1.7 mm to inner 0.7 mm to outer 1.0 mm.

All the beads varied in both outline and thickness. Shapes ranged from round to square to rectangular (Fig. 3). Some were parallel-sided (Fig. 4); others were nonparallel and tapered—that is, wedge-shaped (Fig. 5).

Most of the beads had some regions that appear to have been smoothed and/or polished (Fig. 6). The string holes were drilled from both ends, and some were severely biconical (Fig. 7). The pattern on the side wall was mostly mat, though some areas revealed shallow, concentric grooves (Fig. 8).

The two following hypotheses were formulated from the observations made on the corpus:

Hypothesis A

This hypothesis was tested experimentally: Turquoise beads were made first by sectioning to create a thin slab of turquoise, as is done in making mosaic fragments. Then a series of drill holes was made using a fine, tapered, pointed copper or bronze

FIGURE 3. *Scanning photomicrograph, top left, illustrating the range of shapes and sizes of beads in the Sipan collection. Magnification 15×.*

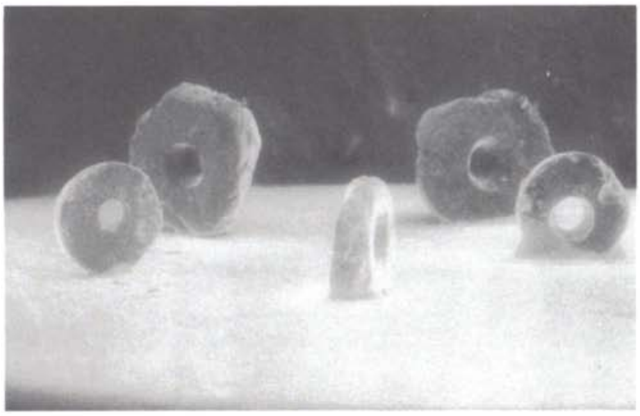


FIGURE 4. *Scanning photomicrograph, top right, illustrating the parallel form of the beads. Magnification 59×.*

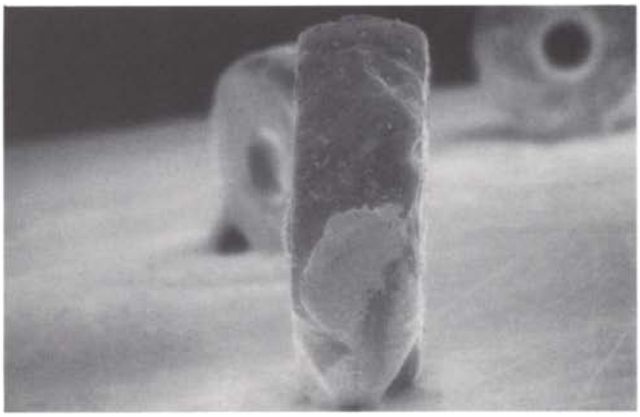


FIGURE 5. *Scanning photomicrograph, bottom left, illustrating the tapered form of the beads. Magnification 59×.*

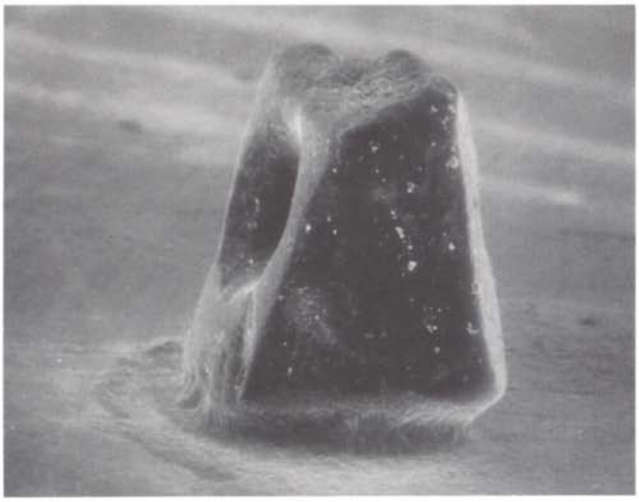
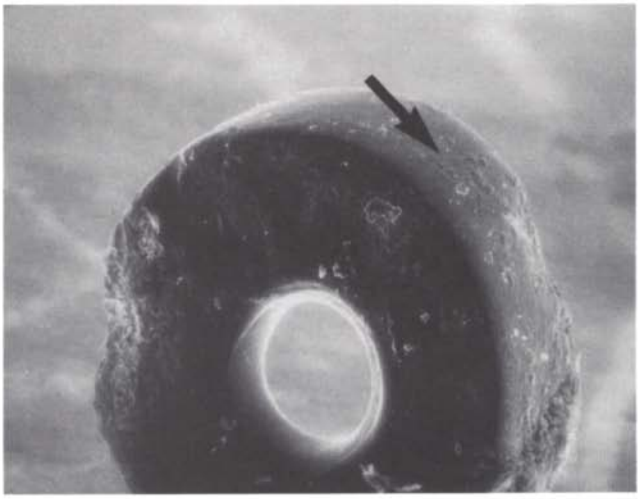
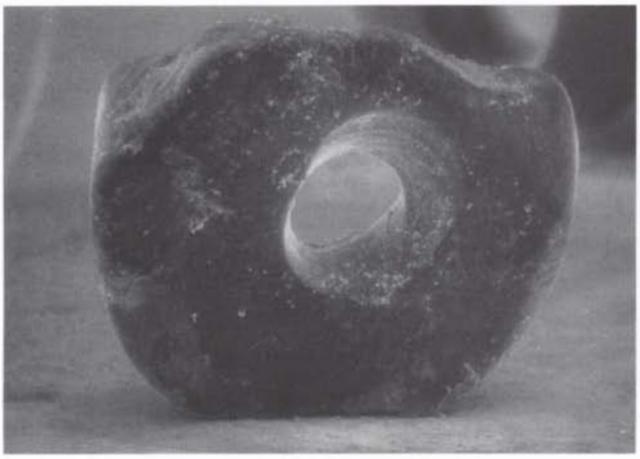


FIGURE 6. *Scanning photomicrograph, bottom right, showing the smooth, polished appearance of the outer surface (see arrow) of the beads. Magnification 59×.*





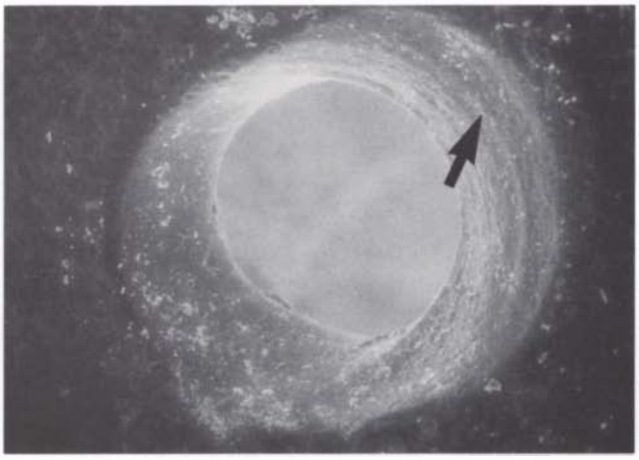


FIGURE 7. *Scanning photomicrograph showing evidence for biconical drilling in which the string hole tapers from each side toward the center of the bead. Magnification 59×.*

FIGURE 8. *Scanning photomicrograph of the side wall, showing shallow, concentric grooves (see arrow). Magnification 59×.*

drill with and without an olive oil slurry of crushed quartz abrasive. As a final step, the turquoise slab was scored in a circular manner just peripheral to the drill holes and then broken in an attempt to obtain a typical "bead" segment.

Experimental duplication. The result of the experimental test of the hypothesis was negative in that the point of the copper or bronze drill became rapidly blunted to produce a drill hole wider and more rounded than the drill holes in the original sample. The side wall was smooth (Fig. 9). Drilling went extremely slowly at a rate of 0.06 mm per minute, even without the abrasive. Considering the large numbers of beads manufactured and found in the excavation, this method would not seem to be practical. The drilling was not hastened by the surface application to the turquoise slab of the following chemicals—ammonia, acetic acid, and sodium hydroxide—to first "soften" the surface. Hydrochloric acid was too destructive. This avenue of investigation stemmed from Lechtman's (1971) evidence that the knowledge of natural chemicals in creating alloys was quite extensive. Finally, the scored substrate did not break as anticipated but resulted in a fracture of the scored bead. In fact, scoring was more difficult than drilling.

Hypothesis B

The turquoise beads were made from very small fragments that may have been remnants of polished mosaic turquoise artifacts, or they were fragments broken from a

FIGURE 9. *Scanning photomicrograph showing the side wall pattern of an experimental drill hole in turquoise using a copper drill. Magnification 15×.*

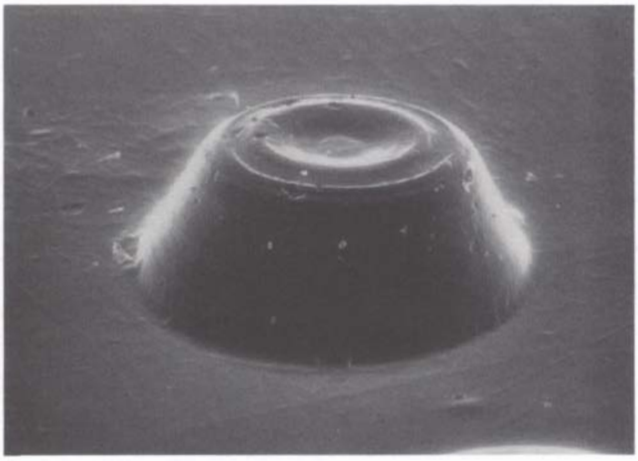


FIGURE 10. *Scanning photomicrograph showing a selection of fragments of different sizes and shapes made from a block of turquoise. Magnification 15×.*

slab of turquoise (Fig. 10) that had been thinned down and polished. These were drilled with a fine, pointed, chipped flint drill without the use of an abrasive.

Experimental Duplication

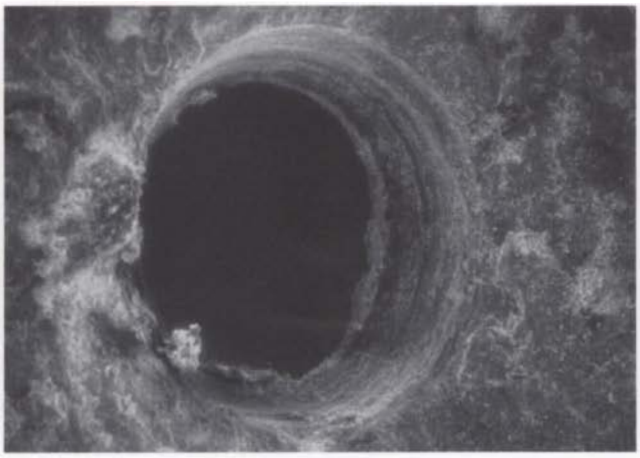
Drilling of selected small polished turquoise fragments required prior stabilization in wax. The flint drill was turned in a modern hand brace with minimum pressure. Perforation proceeded much more quickly (0.5 mm/min) than with the copper or bronze drill used in conjunction with a loose abrasive and oil lubricant (0.06 mm/min). This procedure resulted in duplication of the size, shape, and biconical nature of the drill holes (Fig. 11) seen in the Sipan sample. The sidewall grooves of the drill holes produced with flint had a similar pattern to that found on the original Sipan turquoise sample (Fig. 12). A mat surface was also produced with a worn flint drill.

Experimental duplication was not undertaken on sodalite at that time.

Conclusions

Based on a functional analysis of the small turquoise beads from Sipan, we have found that they could be duplicated using fragments broken from a thin, polished slab of turquoise. This slab might be similar to the turquoise slab from which the

FIGURES 11, 12. *Scanning photomicrographs of an experimental drill hole created with flint. The characteristics are similar to those found in the original Sipan beads (see Fig. 7). Magnification 12× and 118×.*



mosaics were made for inlays. The drilling pattern of grooved and mat sidewall and the biconical shape was duplicated only by using a pointed, chipped flint drill without an abrasive. All the characteristics of the holes in the beads could not be duplicated by using a copper or bronze drill with a loose abrasive of crushed quartz and olive oil as a lubricant; only the smooth sidewall pattern was duplicated.

One problem with our solution is that flint or chert drills have not been excavated, as yet, in Sipan. However, they are found in other nearby sites and could have been traded. It would be useful to study similar turquoise beads, if such exist from earlier precopper cultures. This would corroborate that flint drills were used on turquoise fragments.

According to Richard Berger (pers. comm. 1992), shell beads, equally minute in size to the turquoise beads from Sipan, have been found at the site of Cardal in the Laurin valley in the central valley of Peru. The site is dated at 1156–800 B.C.E., long before the use of copper tools. Perhaps there, too, the beads were drilled with flint.

While flint has not been found at Sipan, this may be an archaeological artifact in as much as no workshops were excavated. Even if flint or chert was not present in the region of Sipan, it is possible that it was present in nearby sites and traded.

Izumi Shimada (pers. comm. 1992) has described a limestone outcrop in the Valley of Laleche. Worked cherts have been excavated in the debris at Labotija. The site is dated from 1000 C.E. to the Spanish conquest. In addition, at the site of Wari in the central highland of Peru an abundance of chert tools and worked turquoise have been found. The site is dated from 700 to 800 C.E. Shimada found a vessel full of thousands of shell beads similar in their minute size to those excavated in Sipan. These were found in a tomb in the Valley of Lambayeque and were dated to 1000 C.E.

These reports are suggestive of the possibility that chert tools have been used for the drilling.

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Biographies

Leonard Gorelick holds an associate clinical professorship in the Department of Children's Dentistry at State University of New York, Stony Brook, and conducts a specialty practice in orthodontics. He is a graduate in dentistry and orthodontics of the New York University Dental School and has authored a number of papers relative to his professional field. As a collector and scholar of ancient Near Eastern seals, he has contributed over thirty papers on these unique artifacts and has received several grants to pursue his avocational interest in archaeology.

John Gwinnett is currently a professor of oral biology and pathology at the School of Dental Medicine at State University of New York, Stony Brook. He holds dental degrees from the University of Birmingham, England, and the Royal College of Surgeons of London. He also holds a Ph.D. in oral pathology and is a fellow of the Academy of Dental Materials. His primary research interests are with dental biomaterials, and he has authored more than 200 papers and coauthored six books on this subject. He has used scanning electron microscopy in the analysis of tool marks found in ancient objects and has published over thirty papers on the subject.

Metals

Silver and Lead in the Late Prehistory of the Mantaro Valley, Peru

Ellen G. Howe and
Ulrich Petersen

In 1982 and 1983, the Upper Mantaro Archaeological Research Project unearthed silver, copper, and lead artifacts in the Mantaro valley of the Peruvian central highlands. These metals were found at domestic sites of the Wanka cultures, dating to the Inka and immediate Pre-Inka period. Two hundred and forty-five pieces of metal, manufacturing debris, and ore were excavated at ten Wanka villages, towns, and centers situated on the alluvial plain and surrounding uplands of the Upper Mantaro valley. The valley is located between the eastern and western Cordilleras and near the modern town of Jauja (Fig. 1).[1] Among the metals were fifty-eight pieces of silver and silver-copper alloy, twenty-three pieces of metallic lead, and four samples of lead sulfide ore. The metal finds constitute the largest amount of prehistoric lead to be excavated in Peru and the first examples of silver and lead manufacturing waste to be found together at a prehistoric site.

Our objective in this study was to obtain basic information on technical and socioeconomic aspects of silver and lead metallurgy in Pre-Hispanic Peru. To date, chemical, metallographic, and X-ray diffraction studies have been completed and lead isotope analyses of Wanka silver and lead, as well as of nearby potential sources of ore, are under way. In this report, the chemical data are examined in light of the Upper Mantaro Archaeological Research Project's archaeological studies and a discussion of mineral resources in the central sierra. Ore sources are inferred and processes of metal production at Wanka sites are examined in conjunction with the changes in manufacturing and use that occurred after the Wanka were incorporated into the Inka empire.

Little is known about the technical processes used in silver metallurgy by the Inka and Pre-Inka. After the Spanish invasion, chroniclers commented frequently on the quantity and location of Inka silver and gold but rarely on technical aspects of production. Some chroniclers described what were thought to be the indigenous, Pre-Spanish techniques for the winning of silver, often in accounts of the rich colonial silver mine and ore-processing center of Potosi, Bolivia (Acosta 1880; Barba 1923; Ramirez 1935; Vega 1966). Their accounts describe the Pre-Hispanic use of

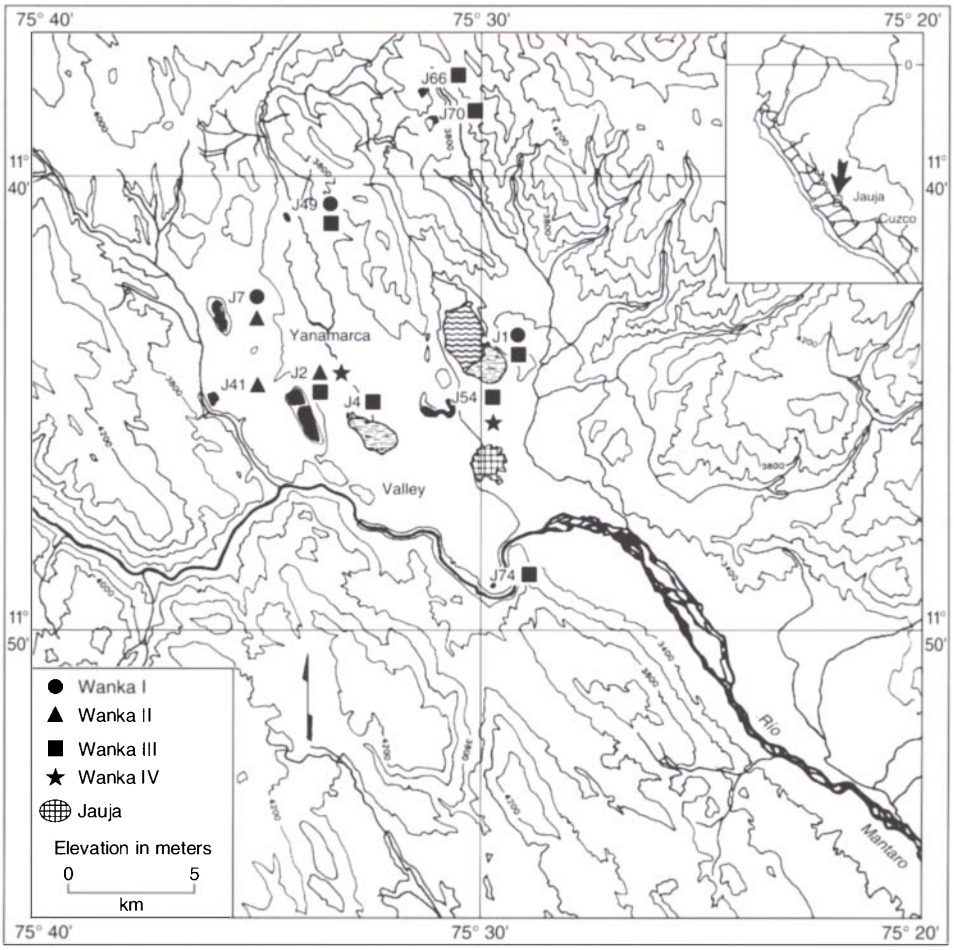


FIGURE 1. *Research area of the Upper Mantaro Archaeological Research Project, showing ten settlement sites that produced metallic artifacts or ore samples, from Wanka periods WI–II and Wanka III–IV. Sites shown are (J1) Pancan, (J2) Hatunmarca, (J4) Tragadero, (J7) Tunanmarca, (J41) Umpamalca, (J49) Ushnu, (J54) Marca, (J66) Puna site, (J70) Puna site, and (J74) Huancas. Arrow in upper right section points to the location of Juaja in Peru.*

silver or plumbiferous silver ores as well as separate refining techniques for silver purification. Although lead ores were abundant in the Andes and mentioned in several contexts by the chroniclers, they were never described as a primary source of silver for the Inka metalsmiths. Lead sulfide, referred to by the Quechua word *suruchec* (that which makes run or slip), is specifically mentioned as an additive to the smelting of silver ores, such as those at Potosi, that could not otherwise be smelted by themselves (Acosta 1894; Barba 1923; Vega 1966). Such accounts have led many to believe that the Inka were smelting silver-rich galena or silver ores with the aid of galena followed by cupellation to recover the silver from the lead-rich metal during refining (Lechtman 1976; G. Petersen 1970, 1972; Root 1949; Larco Hoyle 1947).

Unfortunately, no undisturbed Pre-Hispanic silver smelting, mining, or fabrication sites have ever been found in the Andes to either prove or disprove the chroniclers' accounts. Furthermore, by-products of silver or silver-lead ore processing—lead slag, litharge, or metallic lead objects—have not been reported in the archaeological literature. A small number of lead artifacts are known in Pre-Hispanic collections,[2] indicating the use of lead as early as the Moche period in the Early Intermediate period (100–800 C.E.) (Larco Hoyle 1947), and a group of lead cakes from Ancón, Peru, dating between the Middle Horizon and Late Horizon, are thought to represent a final stage in Pre-Hispanic silver purification regimes (Lechtman 1976).

Archaeological Context

The Upper Mantaro Archaeological Research Project was initiated to study the role of economic organization in the evolution of complex Andean society. It delineated three phases of the late prehistoric period in the Mantaro valley (Earle et al. 1980, 1987): Wanka I (WI), in the early part of the Late Intermediate period (1000–1350 C.E.), which had small Wanka settlements at low elevations in the valley; Wanka II (WII), during the last quarter of the Late Intermediate period (1350–1460 C.E.), in which the Wanka population was organized into warring chiefdoms, with settlements of up to 13,000 people located on high, fortified knolls; and, finally, Wanka III (WIII), in the Late Horizon period (1460–1533 C.E.) following the Inka conquest and organization of this region into a province of the empire. At this time the population was generally relocated among smaller, unfortified sites at lower elevations.

The research project's excavations focused on the basic structural space of a domestic householding unit, known as a patio group, comprised of two to eight circular stone structures facing onto a common patio space. Distinctions were made between Wanka "elite" and "commoner" households, and an initial description of the metals was compiled by Owen (1986). A ubiquity study by Owen (1986) showed that elites had access to substantially greater amounts of finished metal goods than did commoners, possessing four to five times as much silver (the high-status metal), two to two and a half times as much copper, and only a little more lead. Metalworking debris was not found concentrated in either social class in Wanka II, but in Wanka III it occurred overwhelmingly in elite households, indicating that in the Inka period, the elites assumed control of not only distribution but also the means of production (Owen 1986; Owen and Earle 1985).

Evidence of Metallurgy

Metallurgical hearths and ore-processing areas were not found at Wanka domestic sites. A large number of metal artifacts associated with manufacturing were excavated from general patio areas such as floor locations, burials, and middens. These artifacts are predominantly associated with late stages in metal manufacture (casting, sheet fabrication, and possibly alloying) and include pieces of casting waste, roughly shaped ingots, fabrication sheet scrap, a piece of provisionally identified copper "matte," and a few bits of isolated slag. Both copper and lead ores were excavated from the patios. Overall, the archaeological evidence points to certain types of metal production work having taken place at the patios or in nearby locations, but the amount and form of the debris vary with each of the three metals. This variation strongly suggests that there were important differences in production activities for lead, silver, and copper.

Metal Finds—Leads

Almost 50% of all Wanka lead artifacts are associated with manufacturing. Small and large bits of lead casting waste, rough ingots, cut sheet scrap, and lead sulfide-lead carbonate ores were found (Fig. 2, Table 1). The cast ingots include an Inka piece that has been systematically gouged, hammered, and scored with a sharp point. Two of the pieces of casting waste are so small that they are not likely to have been seen once they fell to the ground and were discovered only by archaeological screening. At the very least, the evidence indicates that cold-working, casting, and sheet-metal production probably took place within the residential settlements. Given the presence of lead ores, however, smelting also may have occurred here or in neighboring areas.

Finished lead objects were made by both casting and cold-working techniques Bolas—ball-like objects that can be laced with rope or thread and used in hunting or warfare—were cold-worked to shape in WII and sometimes cast in WIII (Fig. 3). One Inka period bola was inlaid with copper strips. Other objects include possible weights, ceramic mends, and plugs; a packet of folded sheet strips was found in a burial.

Lead's low status is indicated by Owen's study (1986): Lead is only slightly more prevalent in elite households than in commoner households. Amounts of lead artifacts increased during the Inka period but not to any marked degree. Changes in bola manufacturing techniques indicate that the Inka may have exerted considerable influence in lead production styles.

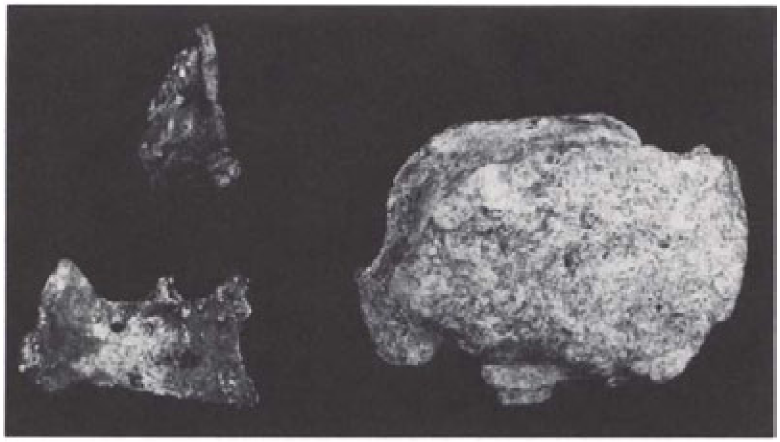
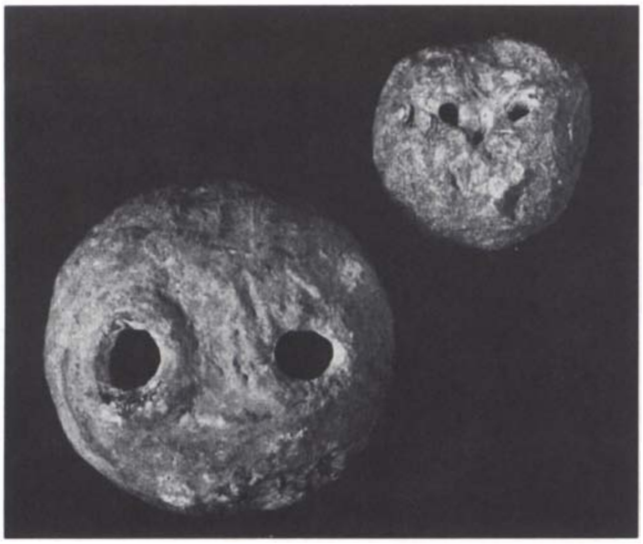


Figure 2. *Examples of Wanka lead artifacts associated with manufacturing. Top left: casting waste (Nº 99, WII). Length 1.8 cm, weight 2.39 g. Bottom left: cast and hammered sheet scrap (Nº 69, WII). Length 2.1 cm, weight 1.8 g. Right: ingot (Nº 63, WIII). Length 3.2 cm, weight 33.8 g.*

Table 1. *Analyses of Wanka ore samples.*

UMARP Number	Provenience	Period	Status	Mode of Analysis*	Determination
519	2 - 1 - 51 - 2 - 2 - 1	WIII	EI	X-ray diffraction	anglesite, cerussite, geocronite
				emission spectroscopy	0.1–1.0% Ag, Sn, and Cu; over 10% Fe
546	2 - 3 - 52 - 4 - 8 - 1	WII	EI	X-ray diffraction	cerussite, galena, and natron
675	2 - 3 - 55 - 2 - 3 - 1	WIII	EI	X-ray diffraction	cerussite, galena
				emission spectroscopy	1–10% Zn; 0.01–1.0% Ag
676	2 - 3 - 54 - 2 - 5 - 4	WIII	EI	X-ray diffraction	cerussite, galena
x	Mina San Pedro	modern	—	X-ray diffraction	cerussite, galena
				atomic absorption spectroscopy	see Table 4

*X-ray diffraction analyses by G. Wheeler and J. Frantz, The Metropolitan Museum of Art. Emission spectroscopy by E. Petro, Schwarzkopf Microanalytical Laboratory, Woodside, N.Y.



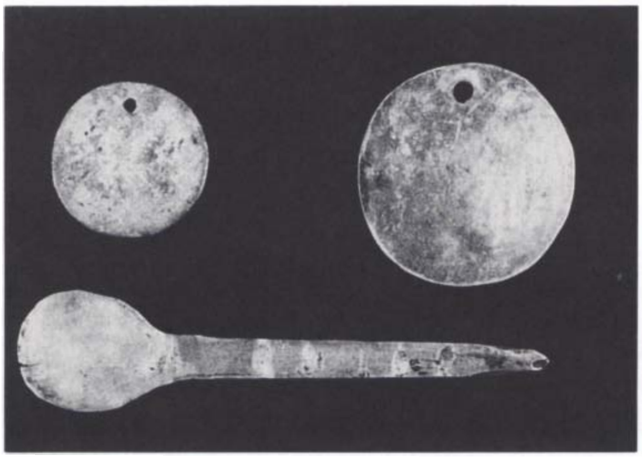


FIGURE 3. *Lead bolas from Wanka III. Left: cast bola, inlaid with copper strips (Nº 94). Width 3.4 cm, weight 168.0 g. Right: bola, cold-worked (Nº 522). Width 2.3 cm, weight 40.4 g.*

FIGURE 4. *Examples of Wanka silver artifacts. Top left: disk (Nº 73, WII). Diameter 1.5 cm, weight 0.37 g. Top right: disk (Nº 591, WII). Diameter 2.0 cm, weight 1.1 g. Bottom: tupu or pin (Nº 652, WIII). Length 4.8 cm, weight 1.7 g.*

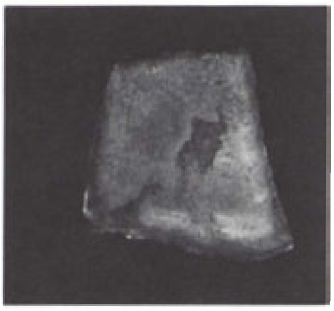


FIGURE 5. *Piece of hammered silver/copper alloy sheet used in fabrication process (Nº 87, WII). Lower and right edges show marks of a cutting tool. Length 1.35 cm, weight 0.41 g.*

Metal Finds—Silver

In Wanka silver, characteristics of both production and use are quite different from those of lead. Manufacturing artifacts represent no more than 5% of the total silver. Almost all the research project's silver pieces are finished artifacts: round sheet-metal disks sewn onto cloth or *tupus* (pins) used to hold together a shawl (Fig. 4). The three manufacturing artifacts are all sheet-metal scraps associated with fabrication work—the cutting out and working of silver sheet (Fig. 5). No silver ores, isolated pieces of smelting debris, or casting waste were ever uncovered to indicate that smelting or casting processes took place at the patios or somewhere nearby. Unlike the cases of both lead and copper, the archaeological evidence suggests that silver was essentially manufactured outside of the local area, excepting late stages of object production such as fabrication and possibly alloying.

Interestingly, silver production methods show little change with the Inka.[3] Fabrication processes were simple: Circular shapes were cut from hammered sheets of varying thickness (disks vary from 0.2 to 2.1 mm in thickness) and then pierced at the top to provide a hole for threading. Metallographic studies in conjunction with scanning electron microscopy/energy-dispersive spectroscopy (SEM-EDS) and the chemical studies described below indicate that in both WII and WIII, Wanka silver is heavily alloyed with copper, and some disks show interior, presumably original compositions with as much as 60% copper and greatly enriched surface layers (Fig. 6). The SEM-EDS analyses show that many disks typically have lower concentrations, generally from 12 to 30% copper. Consistent changes in alloy compositions between WII and WIII are not apparent. Lechtman has shown that silver-copper alloys were probably an early development in Andean metallurgy (1979, 1980, 1988).

The availability and use of silver show considerable change under Inka rule. Although metals in general increased greatly in number during Wanka III, the amount of silver in circulation decreased by almost half. This great loss of silver during Wanka III appears to corroborate ethnohistorical accounts that cite the Inka practice of extracting silver from local populations as a form of tribute (Owen 1986).

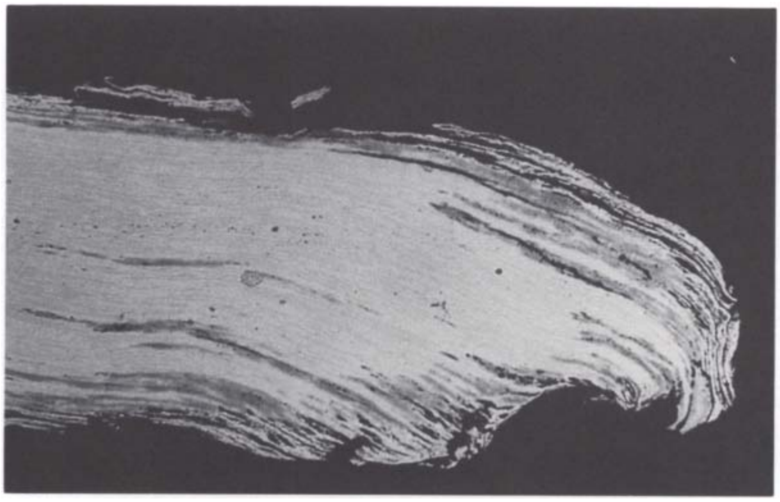


FIGURE 6. *Photomicrograph of a longitudinal section removed from the edge of surface-enriched silver/copper alloy tupu Nº 650. Magnification 7×. As polished. Semiquantitative analysis by SEM-EDS indicates that interior composition is 58% Cu and 42% Ag. Metallographic preparation by D. Harvey and SEM-EDS analysis by Mark Wypyski, The Metropolitan Museum of Art, New York.*

Metal Finds—Copper

Copper artifacts associated with manufacturing are for the most part unexamined in this study (see Owen 1986; Costin et al. 1989). However, only 15% of the total copper assemblage appears to be production related. Twelve pieces of copper ore, two small finds of copper slag, one small section of copper sheet scrap with chisel marks, and five roughly formed ingots or lugs of both copper and copper alloy were uncovered. Although evidence for local manufacturing is not as extensive as it is for lead, some copper ore processing, forging, and possible alloying took place at Wanka patios or, at the very least, somewhere close by.

More importantly, chemical analyses of nine of the copper artifacts (Table 2) supplemented by SEM-EDS work at The Metropolitan Museum of Art and electron microprobe work at Yale (Owen 1986) indicate that significant changes in copper compositions took place during the Late Intermediate period and Late Horizon: In Wanka I and earlier (noted as WO in Table 2), the copper artifacts appear to be pure

TABLE 2. *Atomic absorption analyses of Wanka copper.*[1]

UMARP Number	Provenience[2]	Date[3]	Status	Object	Fe %	Ni %	Cu %	Pb %	Sb %	Zn %	Sn %	As %	Ag %	Total %
5	1-804-0-0-5-4	WI?	?	shaft frag.	0	0	98.58	0.01	0.04	0	0	0.25	0.81	99.69
8	1-804-0-0-9-1	WO	Com	pin	0.07	0.01	99.05	0.01	0.03	0	0	0.02	0	99.19
66	7-1-2-1-1-1	WII	El	shaft frag.	0	0	97.74	0.59	0.04	0.01	0.02	0.85	0.01	99.26
84	41-1-2-2-3-1	WII	El	needle	0.28	0.01	100.1	0.01	0.04	0	0	0.09	0	100.56
56	54-1-2-1-1-1	WIII*	El	sheet strip	0.3	0.02	94.97	0.21	0.01	0	2.93	0.41	0.06	98.91
61	54-60-2-5-1	WIII*	El	sheet	0.1	0.01	96.44	0.13	0.08	0	1.77	0.42	0.19	99.14
44	54-1-60-2-5-1	WIII*	El	tweezer frag.	0.22	0.01	94.71	0.66	0.05	0.01	2.62	1.59	0.07	99.94
47	54-1-55-2-3-1	WIII*	El	lug/ingot	0.16	0.01	97.9	0.03	0.02	0.01	0	1.18	0.01	99.32
507	2-1-1-3-3-1	WIII	El	cast waste	0.05	NA	70.66	5.52	4.29	0.29	0.02	11.8	3.43	96.06
14	2-701-0-0-3-3	WIII	?	axe frag.	0.01	0	96.67	0.09	0.09	0.01	3.16	0.42	0.1	100.56

[1] Analyses (except Nº 507) by M. Dupas, Institute Royal de Patrimoine Artistique, Brussels, Belgium. Nº 507 analyzed by E. Petro, Schwarzkopf Microanalytical Laboratory, Woodside, N.Y. Nº 507 was also analyzed for sulfur (1.93%) and mercury cobalt, both of which, if present, are in concentrations below the level of detection. NA = not analyzed.

[2] Site 1 = Pancan. Site 7 = Tunanmarca. Site 41 = Umpamalca. Site 54 = Marca. Site 2 = Hatunmarca.

[3] Objects with * are from early colonial context, but it is assumed that they were made in WIII.

copper; in Wanka II, many are low arsenic copper alloys; and in Wanka III, under Inka rule, tin was apparently added to the pure copper to form tin bronze or to the low arsenic copper bronzes to form ternary alloys of copper, arsenic, and tin. As tin, in the form of cassiterite, would have been imported into the Mantaro from northern Bolivia, far to the south, its use in copper metallurgy is thought to reflect the Inka's partial control over local manufacture of bronze goods (Lechtman 1976, 1979, 1980; Owen 1986). One Inka period artifact, possibly a piece of smelting debris, appears to derive from the smelting of argentiferous tetrahedrite (Table 2: UMARP Nº 507) and shows considerable amounts of antimony, arsenic, lead, and silver.

The use of copper increased enormously during the Inka period. Four times as much copper was in use in WIII as in WII, and it is likely that copper served to supplant the silver removed as tribute by the Inka state during WIII (Owen 1986).

Geological Sources of the Silver and Lead

In central Peru there are many different ore deposits that could have provided the silver, lead, and copper ores smelted by the Wanka (Fig. 7) (Petersen 1965). The most likely sources for these metals would be the massive oxides, locally called *pacos*, that constitute the gossans of the Cu-Pb-Zn-Ag orebodies at Cerro de Pasco, Colquijirca, Morococha, and Yauricocha (respectively about 145, 140, 73, and 65 km to the north-northwest, north-northwest, west-northwest, and southwest of Jauja). The high silver content of parts of the gossan of Cerro de Pasco is legendary,

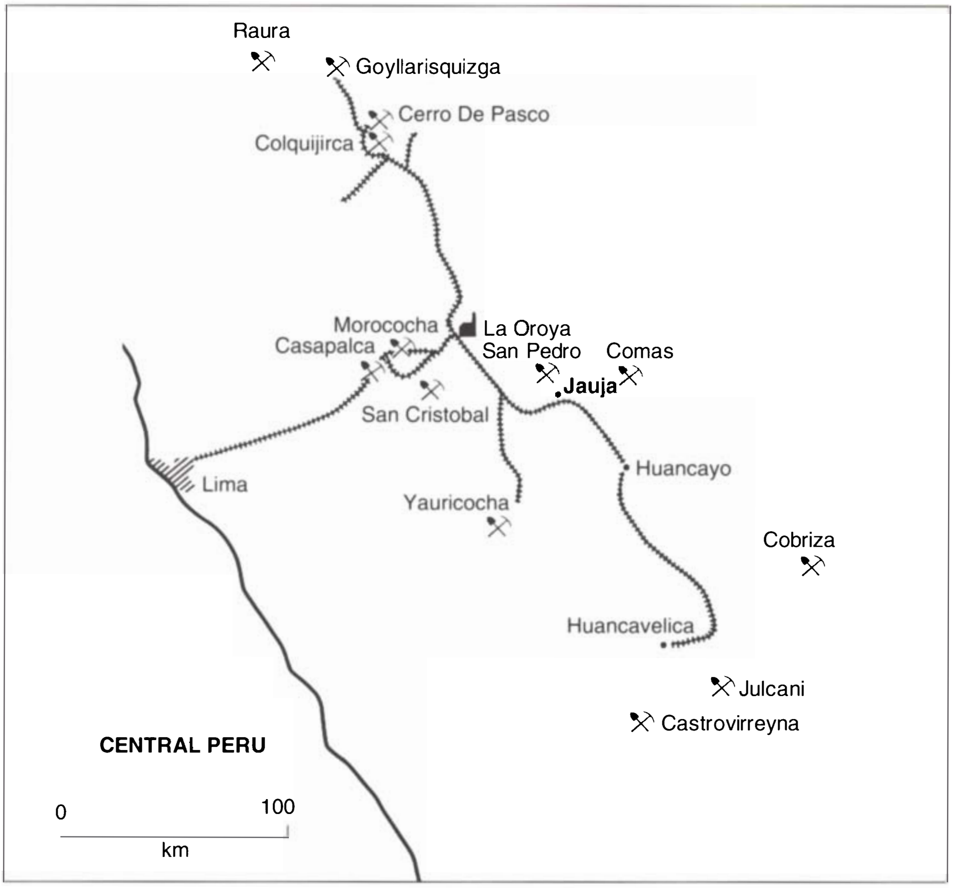


FIGURE 7. *Map of central Peru showing modern town of Jauja and mining sites that may have been the sources of Wanka copper, silver, and lead ores.*

and some of these silver-bearing oxides were still being mined very recently in the McCune pit. Also well known were the lead and silver contents of the Matagente gossan of Cerro de Pasco. Historically, the Colquijirca mine has been an important producer of silver, partly as wire silver (*colquijirca* means "silver hill" in Quechua). Analyses quoted by McKinstry (1936) indicate that the gossans have similar Pb and Zn values and lower Ag values than the hypogene ores (as expected, the gossans are also lower in Cu). The gossans of the Morococha orebodies are not as spectacular as the others but could have provided oxidized copper, silver, and/or lead ores. The spectacular Yauricocha gossans were particularly rich in oxide copper and silver minerals.

At Cerro de Pasco and Colquijirca the hypogene Cu-Ag orebodies are spatially separated from those containing Pb-Zn-Ag. Upon oxidation, most of the copper and practically all of the zinc were leached out. Hence, it appears likely that Pre-Hispanic miners encountered mainly oxide ores of silver or lead-silver, but one cannot exclude the possibility that some of the gossan was copper and silver bearing. At Morococha and Yauricocha the hypogene Cu-Ag and Pb-Zn-Ag ores are in close proximity. Therefore, their gossans are more likely to have contained variable proportions of oxide copper, silver, and lead minerals.

It is less likely that silver might have been obtained in Pre-Hispanic times from hypogene silver ores like the ones occurring at Casapalca, Julcani, and Castrovirreyna (located 83, 147, and 155 km west, southeast, and south of Jauja, respectively). In these ores, silver is mostly in tetrahedrite, $(Cu,Ag)_{10}(Fe,Zn)_2(Sb,As)_4S_{13}$, and other silver sulfosalts (Petersen et al. 1990).

With respect to lead sources, lead-bearing gossan materials may have been imported from the aforementioned ore deposits (particularly Cerro de Pasco, Colquijirca, Morococha, Yauricocha, and Casapalca), but the Wanka also had access to more readily available local lead-rich gossans. One is the San Pablo (or San Pedro) deposit, 15 km north-northwest of Jauja, and others are the Erlinda (Trembladera), Cristo Pobre, Santa Rosa (Sra. de Guadalupe), and Felicidad deposits of the Comas region, 42–45 km east of Jauja. These gossans are derived from hypogene Pb-Zn ores and therefore would contain mostly lead, with only very small amounts of silver (as evidenced by unpublished analyses of samples from Cristo Pobre taken by Ulrich Petersen in the early 1950s in the context of mineral exploration). Historically, these local deposits have been mined for lead content and never for silver.

Chemical Analyses

Although it is certain that native silver and/or other silver minerals, such as cerargyrite (AgCl), were accessible to Pre-Hispanic miners, it is not generally understood that these minerals, although abundant, were disseminated in the iron-rich pacos and seldom found as solid masses. Thus it would generally not have been possible to extract the silver from these ores without the use of lead to collect and dissolve the silver during smelting. Lead, if not already present within the ore, would have been added in the form of lead, lead metal, litharge, or lead-containing slag. Subsequent refining, the separation of the silver from the lead, would take place with cupellation. Evidence of cupellation is always visible in the presence of residual lead in the silver.

Table 3 presents the chemical data for the Wanka silver obtained by atomic absorption spectroscopy.[4] In all but one of the silver artifacts, silver and copper were found to be major elements, with lead a significant minor presence. In the one exception, Nº 30, an Inka disk, the copper content is very low (0.32%), and no lead above 97 ppm or gold above 48 ppm was detected. This disk is likely to be native silver smelted by reduction and without the use of lead. In all the other finished objects, however, copper concentrations are as high as 42% Cu; and SEM-EDS analyses of metallographic sections, as mentioned before, indicate even higher concentrations of copper in nonenriched sections. In cast scrap Nº 513, copper concentrations are exceptionally high, but microprobe analyses (Owen 1986) and SEM-EDS analyses indicate that the overall copper content is probably closer to 60%. Trace amounts of Au, Bi, Sb, Sn, Zn, and As are also occasionally present in the silver- copper alloys.

In all the other Wanka silver artifacts lead is present within the range of 0.2–1.64% and, in most cases, within the narrow range of 0.2–0.7% lead. Such consistent

Table 3. *Atomic absorption analyses of Wanka silver.*[1]

UMARP Number	Provenience[2]	Date[3]	Status	Object	Fe (ppm)	Ni (ppm)	Cu %	Pb %	Bi (ppm)	Au (ppm)	Sb (ppm)	Zn (ppm)	Sn (ppm)	As (ppm)	Ag %
26	49-703-0-0-2-1	WI	?	disk	223	<61	9.15	0.23	<33	<117	<33	<33	<66	720	89.53
67	7-2-53-6-1-1	WII	El	disk	551	<25	28.12	0.47	<246	885	<246	<25	<123	84	61.76
70	7-3-52-1-1-1	WII	El	disk	161	<38	12.45	1.64	352	<38	<383	<38	<38	31	85.40
72	7-3-51-1-2-1	WII	El	disk	807	<21	27.59	0.52	<209	318	<209	<21	<104	502	57.20
74	7-3-51-1-2-2	WII	El	disk	150	<25	34.08	0.4	<251	150	<251	<25	<124	1954	58.85
83	41-1-2-2-3-1	WII	El	disk	250	<24	9.62	0.34	<241	241	<241	<24	<120	577	78.66
86	41-1-3-4-3-1	WII	El	disk	428	<24	14.25	0.62	<238	190	<238	176	<119	1000	73.21
87	41-1-53-3-5-4	WII	El	sheet scrap	<41	<41	19.91	0.41	284	<121	2300	86	4100	49	76.50
626	41-6-1-1-3-6	WII	El	disk	278	<24	37.47	0.64	<267	375	<267	<27	<134	535	53.48
594	41-4-51-2-3-1	WII	Com	disk	264	<23	17.91	0.49	<236	424	707	<24	<118	285	73.96
586	7-7-3-1-1-1-1	WII	El	disk	<23	<23	28.89	0.37	693	<23	<46	<23	<46	1100	63.04
590	7-7-52-1-2-1	WII	El	disk	48	<24	14.23	0.3	194	<24	<48	<24	<48	113	80.43
501	2-1-1-1-3-1	WIII	El	disk	129	<22	20.87	0.6	1400	129	<215	<22	<108	16	73.66
513	2-1-1-4-4-1	WIII	El	cast sheet scrap	157	136	84.41	0.27	313	255	1100	125	8400	7100	9.47
530	2-3-1-4-3-1	WIII	El	disk	1200	77	27.85	0.25	364	214	<43	163	<43	9	56.40
537	2-3-52-2-3-1	WIII*	?	disk	491	93	28.98	0.2	510	162	232	78	<46	6	65.68
30	70-702-0-0-3-1	WIII	Com	disk	369	<24	0.32	<.009	<242	<48	<242	<24	<121	<3	96.27
29	66-702-0-0-4-1	WIII	Com	disk	149	<29	3.57	0.71	572	<57	<286	<29	<143	<3	93.17
650	54-7-1-2-3-1	WIII	El	tupu frag.	<46	<23	41.76	0.32	<232	325	464	<23	858	297	54.79
657	54-9-1-3-1-1	WIII	El	disk	<39	<20	19.22	0.58	582	<39	<194	<20	<97	689	77.61
651	54-9-1-1-2-1	WIII	El	disk	<26	<26	23.7	0.73	803	<26	<263	<26	<26	435	77.42
556	2-5-21-1-1-1	WIII	El	disk	149	<27	11.29	0.22	797	2900	<266	<27	6100	34	81.89

[1] Analyses by E. Petro, Schwarzkopf Microanalytical Laboratory, Woodside, N.Y. All 20 pieces of Wanka silver were also analyzed for mercury and cobalt; and, if present, these elements are in concentrations below the level of detection.

[2] Site 49 = Ushnu. Site 7 = Tunanmarca. Site 41 = Umpamalca. Site 2 = Hatunmarca. Site 54 = Marca. Sites 70 and 66 are puna sites.

[3] Objects with * are from an early colonial context. It is assumed that they were made during WIII.

and narrowly defined levels of lead within the silver-copper alloys, while not directly indicative of ore sources or smelting processes, are characteristic of silver that has been refined through cupellation. Comprehensive studies of cupelled silver in the ancient Mediterranean area have established that 0.05–2.5% is the range for residual lead in cupelled silver (Gale and Stos-Gale 1981). Wanka lead levels in silver, excepting disk Nº 30, even if recalibrated to account for the presence of copper in the alloy, remain well within this range, beginning in the Wanka I period and continuing through Wanka III. Although the evidence is by no means conclusive, the consistent presence of lead in the Wanka silver strongly indicates a source in silver-lead ores or silver ores smelted with the aid of lead.

Another investigator of Peruvian silver metallurgy, Clair Patterson (1971), in examining chemical compositions of Pre-Hispanic silver from the Moche culture, also notes the significant presence of lead. However, he interprets the presence of lead in Peruvian silver to be the result of reduction smelting of native silver in the presence of its supergene ore, cerargyrite. He claims that massive cerargyrite, unlike native silver, is often contaminated by lead and, if not removed from the surface of native silver before processing, can contribute significant amounts of lead to smelted native silver. While acknowledging that the lead impurities in Peruvian silver are present in the concentration range of cupelled silver, Patterson merely asserts that the Pre-Columbian metalsmiths were not capable of anything but reduction smelting and therefore could not have processed silver-lead ores. He also points out that extraordinary amounts of native silver were available to early miners (presumably refuting the need for smelting lead ores to win silver) but does not take into account that most native silver, even if abundant, was probably disseminated in the pacos and not available in solid masses for reduction smelting. Although some native silver could have been simply smelted, as in the case of UMARP's pure silver disk Nº 30, most silver minerals probably required the use of lead to concentrate the silver during smelting and oxidation regimes to cupel it.

Another source for the lead impurities in Wanka silver could be the copper used in alloying. However, correlation studies do not, in general, indicate a direct relation between copper and lead contents. Although mineralogical evidence points to the association of lead and silver, or silver and copper, it rarely shows the association of lead and copper; in fact, the atomic absorption data for the nine Wanka copper artifacts (Table 2) show that only very small amounts of lead are present in the pure copper artifacts of Wanka I or Wanka II. Three out of the four early period coppers (UMARP Nºˢ 5, 8, and 84) analyzed by atomic absorption spectroscopy have only 0.01% lead whereas the fourth has 0.59%. Later Wanka coppers have slightly greater amounts of lead (ingot Nº 507 is an exception in having over 5% lead), but there is no chemical evidence that the copper alloys of Wanka II and Wanka III were used for alloying with silver.

Gold is present in the silver-copper alloys in only small amounts, with Au to Ag ratios typically in the region of 5×10^{-4} but also ranging from less than 3×10^{-5} up to 3×10^{-3} in a few instances. Although gold, along with the platinum metals, is considered to be a reliable indicator of ore source in cupelled silver, it must be noted that gold in Wanka silver could also be introduced with the copper. Whether from the silver or the copper or both, however, the low concentrations of gold seen here are consistent with the low gold concentrations found in silver ores of the Central Andes region discussed earlier. The element bismuth, also suspected to be partially retained with the silver during cupellation, is occasionally detected in Wanka II and more often than not in Wanka III silver, in the range 0.03 to 0.14% bismuth. According to Patterson (1971), these concentrations are greater than expected for reduction-smelted native silver, falling within the range outlined for silver-rich galenas by Gale and Stos-Gale (1981). It should also be noted, however, that many silver ores of the central sierra, particularly from the aforementioned deposits to the north and west of the Mantaro valley, are bismuth-rich (U. Petersen 1965).

Given the chemical data for the Wanka silver, it might be expected that litharge, the by-product of silver cupellation, would be the source for Wanka lead metal. Surprisingly, the chemical data revealed that lead was probably produced independently of silver (Table 4). High silver concentrations in the lead (higher than those expected for smelted litharge) indicate that Wanka lead probably derives from the direct smelting of lead ores that have not been desilvered. In silver content, Wanka lead ranges from less than 33 ppm to 1.47% with an average of 0.03% Ag in Wanka II and 0.19% Ag in Wanka III. Comparisons with lead analyses from the ancient Mediterranean show that the silver levels in Wanka lead are appreciably higher than those found in smelted litharge from Siphnos (Gale and Stos-Gale 1981) and from Laurion (Conophagos 1980), though they are also slightly smaller than some silver

TABLE 4. *Atomic absorption analyses of Wanka lead and Mina San Pedro ore sample.*[1]

UMARP Number	Provenience[2]	Date[3]	Status	Object	Fe (ppm)	Cu (%)	Pb (%)	Bi (ppm)	As (ppm)	Zn (%)	Ag (%)	S (%)
69	7-2-52-2-1-1	WII	El	sheet scrap	187	<.004	96.84	<47	<3	<.0023	0.022	0.002
79	7-2-5-1-2-1	WII	El	cast. waste	<88	<.009	99.15	<88	<4	<.0044	0.009	0.002
577	7-7-2-3-2-1	WII	El	bola	<89	0.038	99.71	<89	40	<.0045	<.0045	0.0004
579	7-7-2-3-2-1	WII	El	bola	<84	<.008	99.55	<89	<4	<.0043	0.025	<.0005
580	7-7-2-3-2-1	WII	El	bola	<66	0.036	99.14	<66	18	<.0033	<.003	<.0005
99	41-1-2-2-2-2	WII	El	cast scrap	<61	<.006	99.95	<61	<3	<.0030	0.029	0.0008
588	7-7-51-1-2-1	WII	El	cast scrap	<278	0.036	99.23	<278	<14	<.0139	0.033	<.0020
649	7-7-52-1-2-1	WII	?	ceramic mend	<64	0.013	95.56	<64	9	<.0032	0.14	0.003
578	7-7-2-3-2-1	WII	El	bola	104	0.006	99.11	<104	93	<.0045	0.02	<.006
554	2-3-54-1-1-1	WIII	El	ingot	153	0.005	98.47	<51	77	<.0025	0.014	0.23
32	70-1-0-0-2-1	WIII	Com	bola	<75	<.007	99.58	<75	<75	<.0037	0.052	0.002
92	54-1-59-1-4-1	WIII	?	cast. waste	<49	<.005	99.18	<49	<3	<.0025	0.023	0.021
40	54-1-52-4-1-1	WIII*	El	bola	<105	<.010	98.41	<105	<5	<.0052	1.47	<.0025
41	54-1-53-5-2-1	WIII*	El	bola	<85	<.008	99.88	938	<4	<.0043	0.034	0.005
42	54-1-55-1-2-1	WIII*	El	bola	<69	0.048	98.91	<69	7	<.0034	0.21	0.007
63	54-1-54-4-2-1	WIII*	El	ingot	<83	<.008	99.45	<83	<4	<.0042	0.031	<.0004
663	54-10-1-3-4-6	WIII	Com	sheet	<52	0.008	97.25	<52	<3	<.0026	0.032	0.004
82	54-2-58-2-3-2	WIII	Com	lug	<62	0.009	99.51	<62	<3	<.0031	0.034	0.001
94	54-2-1-2-4-1	WIII	Com	bola	<71	<.007	99.33	<71	<4	<.0036	0.024	<.0004
x	San Pedro sample	—	—	ore	n.a.	0.002	82.51	n.a.	n.a.	0.034	0.0064	n.a.

[1] Analyses by E. Petro, Schwarzkopf Microanalytical Laboratory, Woodside, N.Y. The elements Sn, Au, and Sb were not detected in any of the samples; n.a. = not analyzed.

[2] Site 7 = Tunanmarca. Site 41 = Umpamalca. Site 2 = Hatunmarca. Site 70 = puna site 70. Site 54 = Marca.

[3] Objects with * are from an early colonial context. It is assumed that they were made during WIII.

values seen in Bronze Age lead that has not been desilvered (Stos-Gale and Gale 1982). Copper concentrations in the Wanka lead are low to very low, from less than 49 ppm to 483 ppm, with an average of 0.016% for both periods. No gold above 100 ppm was detected in any of the pieces.

A look at the chemical composition of a lead ore from the San Pedro mine to the north of Wanka sites confirms the likelihood that Wanka lead derives from the direct smelting of such ores. A hand-collected sample from the mine,[5] a mixture of lead sulfide and lead carbonate (Table 1), was found to contain 60 ppm of silver (the equivalent of 0.007 oz per ton of lead), a little zinc, and virtually no gold or copper (Table 4).

The similarities of the Wanka lead artifacts in not only their silver content (low values for argentiferous galena) but also their small amounts of gold and copper indicate that the Wanka lead could well result from the direct smelting of local ores. If one considers the large amount of labor required to transport lead or litharge from distant silver smelting sites to Wanka villages and the fact that lead sulfide, an easily smelted ore, was readily available from local Jauja-Comas mines, then it is plausible that the metals of silver and lead used in Wanka households were produced in different locations using separate ores.

Conclusion

The research presented in this paper demonstrates that the standard conception of lead metal occurring as a by-product of silver manufacturing is inappropriate for prehistoric metal production in the central sierra of Peru. It appears that lead in Wanka patios derives from the direct smelting of argentiferous lead ores from local deposits in the Jauja-Comas area. In contrast, silver from Wanka sites is thought to come from separate ores located outside the immediate region, most likely from the large oxide outcrops of the central sierra to the northwest and southwest of the Wanka sites. Local production activities for the two metals differed in that lead was probably smelted, cast, and worked at the patios, while the extractive metallurgy for silver probably took place elsewhere and local work may have been limited to fabrication activities. For Wanka silver, the chemical evidence strongly suggests that silver-lead ores were smelted and the silver then refined through the use of cupellation.

The Wanka, an isolated group of small warring chiefdoms, were conquered and incorporated into the Inka empire at the end of the Late Intermediate period. Dramatic changes were observed in copper production with the Inka conquest and arrival of the Tin Horizon, and it was expected that similar changes would be demonstrated in Wanka silver ore sources and production technologies. Instead, the Inka appeared to have exerted little control over the technical systems used to produce Wanka silver, while at the same time showing considerable involvement in its distribution and control.

Ongoing research of prehistoric silver and lead metallurgy in central Peru will address the question of ore sources through lead isotope analysis of Wanka metal, Wanka ore, and samples of ore from deposits in the central sierra that may have been exploited in the prehistoric period.

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Notes

1. Two Wanka sites were occupied until 1570 in the early colonial period, J2 and J54. Because the vast majority of deposition at these sites was prehistoric and because no changes in native metallurgical techniques were observed in any of the artifacts, it is assumed that Wanka IV copper, silver, and lead were produced within the metalworking traditions of Wanka III or earlier.
2. It is difficult to know whether larger amounts of lead have been found in prehistoric sites but merely ignored because of the metal's seemingly low value.
3. The finished artifacts of silver from both periods are predominantly thin sheet-metal disks, showing a bimodal distribution of a small 15 mm diameter and a large 23 mm diameter (Owen 1986).
4. Atomic absorption spectroscopy was used to analyze samples from twenty-two artifacts of Wanka silver and nineteen pieces of lead, forming a group of roughly ten of each metal from Wanka II and ten of each metal from Wanka III. Choices in sampling locations for atomic absorption spectroscopy were limited by object size and shape, making SEM-EDS examinations of metallographic disk sections necessary to determine distribution characteristics of copper and serve as a cross-check for atomic absorption spectroscopy. Also, restrictions set by the Instituto Nacional de Cultura in Lima and the small mass of many of the artifacts made it impossible to analyze a larger group of artifacts or to use some artifacts for all three forms of analysis, including mass spectrometry for lead isotope analysis.
5. Although the San Pedro mine has not been excavated, the area immediately surrounding it produced ceramic evidence of use in both colonial and prehistoric times (T. Earle, pers. comm. 1991).

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Pre-Hispanic Copper Alloy Production at Batán Grande, Peru: Interpretation of the Analytical Data for Ore Samples

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C. P. Swann, and R. Doonan

Technologically, the North Coast of Peru encompasses one of two major independent metallurgical traditions found in Pre-Hispanic South America. Starting with the Middle Sicán period, 900–1100 C.E., copper-arsenic alloys replace unalloyed copper to become the mainstay of the North Peruvian tradition. A number of papers have already been published concerning the copper smelting remains at Batán Grande (e.g., Shimada et al. 1982; Merkel and Shimada 1988; Shimada and Merkel 1991). This report will discuss evidence from technical investigations principally of the copper ore and iron ore specimens recovered from the site of Huaca del Pueblo Batán Grande. Recent archaeometallurgical surveys and excavations in the La Leche and extended into the Chancay valleys allow a better understanding of geographic and temporal variation in metallurgical remains. The Sicán Archaeological Project, under the direction of I. Shimada, is a long-term interdisciplinary study carried out over many seasons of fieldwork (1978–present). The archaeometallurgical project has developed in several phases with the specialists participating in the planning, excavation, surveying, sampling strategy, and analytical investigation. Analyses of the archaeometallurgical remains from Batán Grande were conducted through the following: Museum Applied Science Center for Archaeology (MASCA), University Museum, University of Pennsylvania; Bartol Research Foundation, Franklin Institute, University of Delaware; Peabody Museum, Harvard University; and the Institute of Archaeology, University College London.

Based on work to date, it appears that Batán Grande represents part of an extensive, regional network of copper alloy production sites. At present, six prehistoric mines and three distinct smelting sites have been identified and, in part, excavated in the Batán Grande area. The earliest remains of copper smelting furnaces date from circa 900–1100 C.E.

There has been much speculation concerning the ancient production of copper-arsenic alloys. Analyses of ore specimens recovered from excavation of the smelting sites indicate that the dominant copper mineral was malachite. It is critical to our reconstruction of the smelting process at Huaca del Pueblo Batán Grande that from the analysis of over forty samples of copper ores, very few had significant concentrations of arsenic (reported as As_2O_3 in the tables) above about 0.08%. Two specimens had about 0.2% As_2O_3. However, there were also two samples with concentrations at 9.7% As_2O_3 and 15.2% As_2O_3, which were different in color from the high-grade copper ore specimens from the site. Available fluxes, also collected at the smelting site of Huaca del Pueblo, included hematite and limonite. Six samples of iron ore flux from the smelting site were analyzed: only one had 5.1% As_2O_3; the others were below 0.05% As_2O_3. In the mining survey of the immediate area at a shallow ancient mine on Cerro Mellizo, arsenopyrite (FeAsS) and scorodite ($FeAsO_4 \cdot 2H_2O$) were identified. Results were confirmed by electron probe microanalysis and X-ray diffraction. The Batán Grande evidence best supports a model for alloy production using deliberate additions of local arsenic-rich ores along with local malachite and hematite in the smelting charges.

Introduction

While a number of theoretical models have been proposed for the production of copper-arsenic alloys in antiquity (see Charles 1967; McKerrell and Tylecote 1972; Lechtman 1979; Charles 1980; Zwicker 1980; Lechtman 1981; Tylecote 1991), most researchers believe that the discovery of copper-arsenic alloys was unintentional. For the earliest copper-arsenic alloys in the region of modern-day northern Peru, Lechtman (1979:4) reviewed compositional data for some twenty-five objects dated to the Early Intermediate period (ca. 300–500 C.E.) and suggested "either that minerals containing arsenic were occasionally added to the stock copper . . . or that a copper ore rich in arsenic was unknowingly smelted to give a high copper-arsenic alloy which was then fashioned into the ornaments."

Huaca del Pueblo Batán Grande (Fig. 1), does not represent the first or earliest production of copper-arsenic alloys investigated by the authors. Rather these samples are from a later period known as the Middle Sicán (900–1100 C.E.) when the use of copper-arsenic alloys became widespread in the region. In the evaluation of the archaeometallurgical remains at Batán Grande, the widespread, regular use of copper-arsenic alloys for both utilitarian as well as ceremonial objects during this Middle Sicán period must be emphasized.

Arsenical copper alloys must have been first produced by unintentional or accidental inclusions of arsenic-rich minerals along with the copper ore or iron ore flux used in smelting. A model for the production of copper-arsenic alloys is presented schematically in Figure 2. From underlying complex chalcopyrite ($CuFeS_2$) deposits, the weathered copper oxide-carbonate minerals near the present surface may have variable, residual minor, or trace concentrations of arsenic as well as lead and sulphur (see Deer et al. 1966; Patterson 1971; Stanton 1972; Gale, Stos-Gale, and Gilmore 1985). Arsenic also substitutes as an "impurity" on an atomic level with other elements such as sulphur or antimony in some minerals. Mixtures of arsenic-rich minerals (possibly arsenopyrite) can occur with more prevalent copper-rich minerals. For comparison, during the Early Bronze Age in Turkey, copper-arsenic

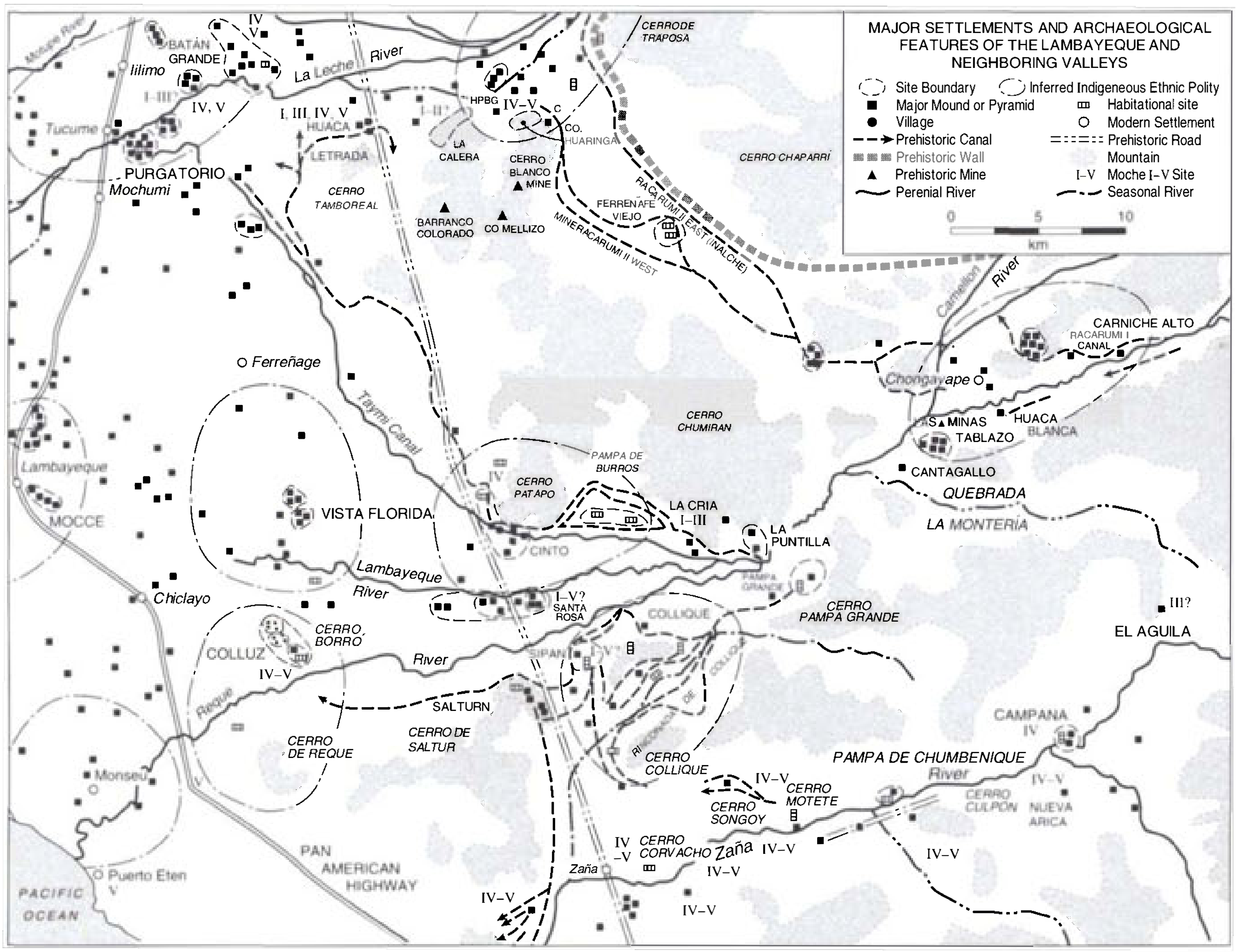
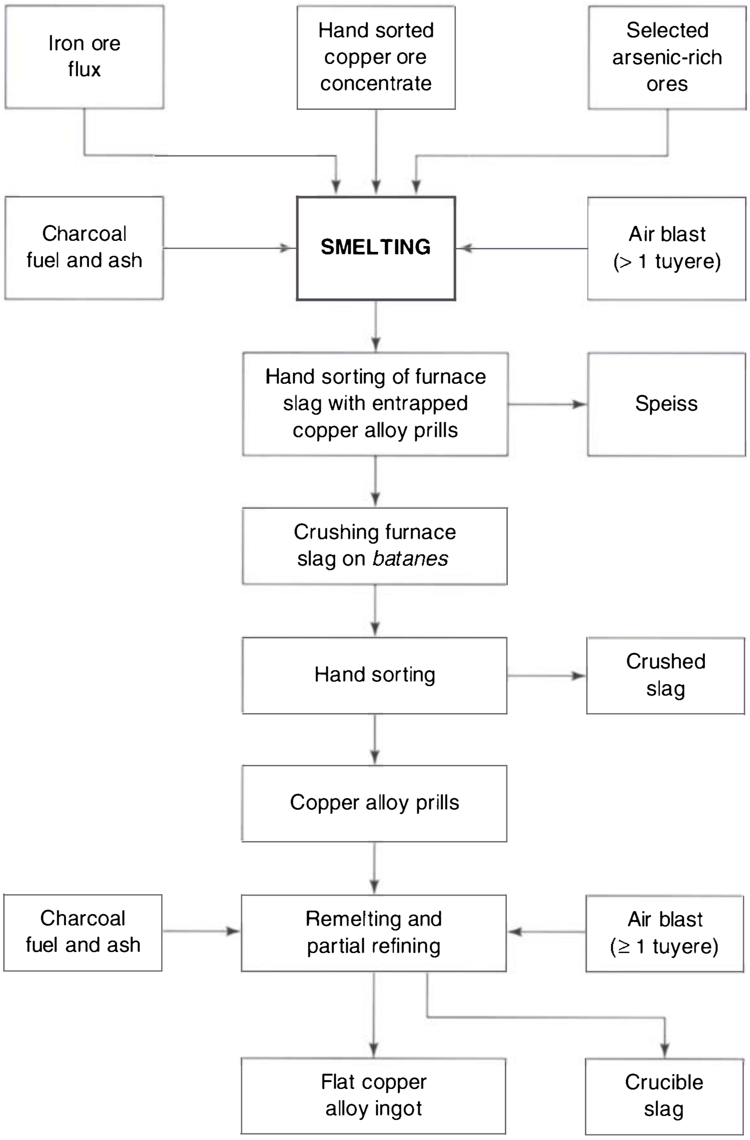


FIGURE 1. *Map of the Lambayeque and neighboring valleys in Peru, showing Batán Grande at upper left.*

alloy objects are common. There are only a few copper ore deposits where arsenic-rich minerals do occur (see de Jesus 1980). The dilemma, however, has been whether such mixtures were recognized or deliberately used in antiquity. Prevalent methods of ore beneficiation (i.e., hand sorting) would seem unable to separate a fine-grained mixture of arsenic-rich minerals from the more abundant copper minerals (see Merkel 1985). Under smelting-reducing conditions and with the use of an iron silicate slag, Lorenzen (1965) and Tylecote et al. (1977) observed in simulation smelting experiments that much of the arsenic in the charged copper ore and flux was recovered in the copper product. Likewise, lead, iron, and sulphur "impurities" in smelted black copper may also result from low concentrations of these elements in the copper ore or flux (see Tylecote et al. 1977; Merkel 1983; Merkel 1990). The trace element "fingerprint" for copper smelted from specific deposits, of course, arises predominantly from the minor and trace elements and mineral mixtures present in the ore and flux.

Early Cycladic copper-arsenic alloy production on the island of Kythnos in the Aegean has been interpreted as representative of such accidental production of copper-arsenic alloys directly from smelting (Gale, Papastamataki, Stos-Gale, and Leonis 1985:89). This model for accidental production is based on analyses of the remaining slag, metallic prills, and copper ore surface collected at the site. The metallic prills found in the slag were analyzed with electron probe microanalysis. The concentrations of arsenic ranged from 0.1% to 4.5% in the copper prills.

FIGURE 2. *Flow diagram proposed for the production of copper-arsenic alloys at Huaca del Pueblo Batán Grande for the Middle Sicán period.*



Elsewhere, Gale, Stos-Gale, and Gilmore (1985) extend this range for arsenic up to 7% for the alloys from Kythnos. Of the three copper ore fragments surface collected from the Kythnos slag heap, the concentrations of arsenic ranged from 0.03% to 0.44%. However, elsewhere on the island, copper ores were collected with arsenic concentrations ranging up to 2.18% As_2O_3. The authors of that study admit some reservations due to small sample numbers, but generally seem quite positive that copper-arsenic alloy production was accidental: "There is no question here of deliberate additions of arsenic in any form." In contrast, the article published by Gale, Stos-Gale, and Gilmore (1985:154) also notes: "The point is that at present there seems to be no way to distinguish between accidental and deliberate arsenical copper alloys." An assignment of intent as to whether accidental or deliberate alloying took place is, indeed, confounding.

Alternatively, sulphide minerals containing both copper and arsenic, such as enargite (Cu_3AsS_4) and tennantite (Cu_3AsS_3), may have been deliberately selected and smelted for the superior copper alloy product. Charles (1980) notes the metallic-gray appearance of these two minerals, which may have attracted attention in antiquity and argued against direct additions of other valuable arsenic-rich minerals to smelting charges as wasteful and uneconomic. Lechtman (1981) and Rapp (1988) favor the use of sulphide ores of copper and arsenic, such as enargite (Cu_3AsS_4), as most likely for the production of alloys. Nevertheless, these minerals are fairly rare in most copper deposits and unweathered sulphides would not be easily accessible from the surface, so the likelihood for this route toward regular production of copper-arsenic alloys would seem diminished. Due to greater accessibility in ancient times of the weathered surface and upper oxidized zones of complex sulphide deposits containing arsenopyrite (FeAsS), arsenates such as olivenite (Cu_2AsO_4OH) and clinoclase ($Cu_3AsO_4OH_3$) also should be considered likely for additions to produce copper-arsenic alloys (Rapp, 1988; Rostoker and Dvorak 1991). Another arsenic-rich mineral to be considered as a common component of weathered arsenopyrite ore deposits would include scorodite ($FeAsO_4 \cdot 2H_2O$), possibly with some remaining minor arsenopyrite (Merkel and Shimada 1988; Shimada and Merkel 1991).

If inadvertent concentrations of arsenic in the copper ore of the smelting charge are above some threshold level (variable with smelting conditions), then the copper-arsenic alloy product may appear different enough to attract special attention. After a period of accidental production of copper-arsenic alloys from smelting, de Jesus (1980) suggests for Early Bronze Age Anatolia that production became intentional with deliberate additions of arsenic-rich minerals. Gale, Stos-Gale, and Gilmore (1985) and Budd and Ottaway (1989) argue convincingly that ancient smiths may have been able to recognize only copper alloys with arsenic concentrations over about 2%.

At some point, to produce the desired copper-arsenic alloys more consistently, arsenic-rich minerals could have been deliberately added to the smelting charge (Fig. 2). Once specific arsenic-rich minerals in the charge were recognized as the cause of superior copper-arsenic alloy products, then systematic additions of the identified components to the smelting charge may have been deliberately repeated and even possibly controlled to some degree. In a modern sense, it would, of course, be very difficult to control proportions of arsenic and copper in a smelting charge. Thus, an excess of arsenic would be added, following the same logic for use of excess flux and fuel in ancient copper smelting as proposed by Merkel (1983, 1990). This deliberate attempt to reproduce copper-arsenic alloys as the desired product composition represents a significant development in the ancient history of metallurgy.

If an excess of arsenic-rich minerals were charged with the copper ore, then a by-product would be speiss (molten mixtures of arsenides and/or antimonides with metals such as iron, copper, cobalt, and nickel). Speiss forms in copper smelting only if considerable quantities of arsenic or antimony are present in the smelting charge (see Bachmann 1982; Rostoker and Dvorak 1991). There is no conclusive archaeometallurgical evidence yet that speiss had any secondary production use for the alloys in antiquity (compare Craddock et al. 1987; Zwicker 1991). It is interpreted as simply a waste product.

Matte is an iron sulphide with variable concentrations of copper that results from copper smelting with an excess of sulphur. Caley and Easby (1959) originally suggested that copper sulphide ores were smelted in Pre-Hispanic Peru. Their theory was based on an observed concentration range between 0.1 and 2.6% sulphur in finished artifacts. Patterson (1971) countered that such low concentrations of sulphur in finished artifacts were not the result of smelting copper sulphide ores, but rather the result of minor, residual concentrations of sulphur in weathered copper carbonate and copper oxide ores. Partial roasting of copper sulphide ores to remove the sulphur will also result in a partial decrease in the arsenic concentrations.

Secondary alloying with arsenic also may have taken place after smelting, possibly with the addition of arsenic-rich minerals directly to refined copper metal (see Rostoker and Dvorak 1991). There are several possibilities along these lines, such as the addition of arsenic-rich minerals to molten copper or perhaps by packing solid copper and arsenic-rich minerals together in a crucible before heating. It has also been suggested by Charles (1980), Rothenberg et al. (1988), and other researchers that master alloys with high concentrations of arsenic may have been combined with unalloyed copper to produce the desired compositions as required. While there is no clear archaeometallurgical evidence that this route was followed, it is nevertheless still a possibility under some conditions (see Merkel and Dever 1989).

In the finished copper-based artifacts of the Middle Sicán period, the observed concentrations of arsenic are variable but usually under about 6%. Lechtman (1981) published several histograms to indicate the range of compositions of copper-arsenic alloys from the North Coast, Peru. Possible reasons for variations in arsenic concentrations have been suggested by McKerrell and Tylecote (1972) and others. Accidental and variable contributions of arsenic in the copper ore are cited along with variable losses of arsenic in remelting or working.

Removal of some impurities such as arsenic are difficult by oxidation from molten copper (see Yazawa and Azakami 1969; Biswas and Davenport 1980). Even with the additional effect of charcoal ash in deliberate fire-refining of copper, it is still difficult to remove minor levels around 0.2% arsenic (Merkel 1983, 1990). At higher arsenic concentrations in copper, Charles (1967), McKerrell and Tylecote (1972), and Tylecote et al. (1977) describe deoxidizing effects of arsenic on copper and the substantial loss of arsenious oxide under oxidizing conditions. Arsenic is usually conserved and partitions with copper under reducing atmospheres in smelting (see Lorenzen 1965), but under oxidizing conditions such as roasting it is partially lost (McKerrell and Tylecote 1972). The possible retention or loss of arsenic from copper is a complex phenomenon depending in part on arsenic concentrations as well as partial pressure of oxygen above the molten metal, variable fuel ash effects, and mixing in the melt. As Lechtman (1981:116) observed: "Certainly copper mining and refining companies in Peru today face considerable problems in removing arsenic from their copper concentrates."

Most of these models for copper-arsenic alloy production have been tested experimentally relative to archaeometallurgical research. However, details of some work remain unpublished. During the mid-1970s, Eaton and McKerrell as well as Stickland and Charles reported that they had produced copper-arsenic alloys successfully by direct additions of arsenic-rich minerals (including sulphides) to copper under charcoal (Charles 1980; Tylecote and Merkel 1985). Reconstruction experiments that considered the relevant behavior of minor and trace concentrations of arsenic in copper smelting and refining have been conducted by Tylecote et al. (1977) and Merkel (1983, 1990). These results are noted only for minor and trace arsenic concentrations. Reconstruction smelting using a furnace at Batán Grande was published by Merkel and Shimada (1988) and Shimada and Merkel (1991), but the concentrations of arsenic in the ore and flux charges were kept deliberately low for safety. Laboratory smelting and alloying experiments producing complex copper-arsenic alloys were reported by Zwicker (1980), Pollard et al. (1990), Rostoker and Dvorak (1991), and Zwicker (1991). Experiments to produce copper-arsenic alloys also were conducted by Lechtman in 1984. These experiments are mentioned so far only as a short note in *Historical Metallurgy* (Tylecote 1985) and in a footnote in a recent paper by Lechtman (1991). According to these sources, three sets of experiments were undertaken successfully to produce arsenical copper: (1) additions of arsenic-rich minerals to molten copper, (2) smelting of roasted copper sulfarsenide ores, and (3) smelting of mixed copper sulfarsenide ores with copper oxide ores.

Although a number of successful experiments have been reported in the archaeometallurgical literature for the production of copper-arsenic alloys, it seems unlikely that some of these processes may have been employed satisfactorily and systematically at Batán Grande. This concept for an "industrial level" of production at Batán Grande necessitated critical evaluation of the development of an analytical research program relative to sampling strategies and possible statistical inferences for a detailed reconstruction of the process. What evidence or analytical data would support one model for production of copper-arsenic alloys over another model? How would it be possible to distinguish between accidental and deliberate alloying? The purpose of this report is to consider sampling in reference to the organization of the analytical program as well as the analytical results for the many ore samples from Huaca del Pueblo Batán Grande and the surrounding area. The knowledge and experience gained from the authors' work at Batán Grande has allowed them to promptly and successfully locate smelting areas in the Mid-Chancay Valley. The objective of the following is to compare compositional data and associational patterns for archaeometallurgical remains in order to gain a more complete understanding of regional aspects for copper-arsenic alloy production.

Sampling

During the excavation of Huaca del Pueblo, Batán Grande, samples of materials collected from copper production at the archaeological site and surrounding region were submitted for analysis to MASCA, University Museum (University of Pennsylvania), along with the Bartol Research Foundation, Franklin Institute (University of Delaware). Part of the work was completed at the Peabody Museum (Harvard University). These samples were judged by the archaeologists to include representative examples from each major class of material encountered during excavation (Shimada, pers. comm. 1984). However, the term *representative* is ambiguous in this case. This initial collection of submitted samples was found also to include uncommon or exotic materials as well as a "range" for some examples, as identified for each class. Such a mixed collection of ancient smelting debris reflects a biased sample of expected or preconceived classes of materials in the field (see Redman 1975; Bachmann 1982). The theoretical models developed for ancient industrial units (Rothenberg 1972) and recognized technological processes provide useful guides for "representative" sampling from anticipated activity areas. However, if the technology at a site is unusual or exceptional in some manner or the representative sampling were somehow insufficient, with perhaps some associated class of materials overlooked, then in terms of understanding the site as a whole, the results of an analytical investigation may be possibly quite misleading. Each and every aspect of an archaeometallurgical site needs to be explained in terms of the process metallurgy. Of course, it is economically impractical to analyze all of the ore, slag, and metal recovered from the excavation of a copper smelting site such as Huaca del Pueblo Batán Grande. Sampling is one of the most critical steps in the investigation of ancient technological processes (Bachmann 1980). However, in many archaeometallurgical projects, sampling strategies are frequently not sufficiently considered in the literature.

For the Batán Grande project, it is essential that the various levels of sampling be evaluated relative to the significance of the analytical data for each class of material. Subsamples were taken at least three times by different people before the material was finally analyzed. Furthermore, each level of sampling utilized somewhat different criteria. The approach utilized for Batán Grande represents rather complex levels of stratified, or "nested," samples, which in turn affects the interpretation and possible statistical inferences that could be made for copper production at the site.

There are numerous levels of natural processes, or "sampling," that already alter the proportions and other characteristics of materials from an archaeological site before excavation. Generally, factors such as perishable and nonperishable materials, diagenetic (e.g., weathering, leaching) changes, and spatial and cultural aspects of ancient behavior all affect the archaeological record (see Chenhall 1975). For archaeometallurgical sites, the situation is complicated by these factors and others. Obviously, the sampling strategy should be capable of detecting relevant ancient activities from material recovered from the excavation of the site. Based on sampling and analysis of industrial debris from a smelting site, it should be possible conceptually to reconstruct the technological process in detail. However, one of the significant activities that is necessarily encountered with an archaeometallurgical site is the past, deliberate discard of unwanted by-products or waste materials. It should be assumed that most of the metal products that were considered valuable, or at least economic to recover under the prevailing conditions, were actually recovered and thus removed from the site. The preservation and recognition of intermediate and/or final products from a process is often in itself unusual at a primary smelting site.

During the excavation at Batán Grande, archaeological "sampling" took place on spatial and chronological levels. It is felt by the excavator (Shimada) that the smelting areas at Batán Grande have been sufficiently identified. Of course, this does not mean that all of the smelting sites have been excavated at Batán Grande. Furthermore, the archaeometallurgical samples investigated in the present study are all dated to the Middle Sicán period. Consequently, the conclusions from this investigation are specific to this archaeological period.

Another level of sampling during excavation is based on the actual decision by the local workers or archaeology students either to keep a specimen or not to keep a specimen. This is a critical decision where bias can interfere with the resulting collection submitted for technical investigation. An excavator with a preconceived notion of what to expect or an excavator without advanced skills in recognition of industrial materials may indeed discard the specimens that are essential to the reconstruction of the process. For example, it has been suggested that lack of evidence for copper-tin alloy production may be, in part, due simply to nonrecognition by archaeologists of cassiterite (SnO_2) from archaeological sites (see Charles 1975). Similarly, it could be argued that a similar problem of ore misidentification exists for ancient production of copper-arsenic alloys.

At Huaca del Pueblo Batán Grande, all archaeometallurgical debris was collected and saved by an experienced crew and students. Data and artifacts were recorded by one-square-meter units. After preliminary field identification of materials classes and recording, an initial selection of "representative" samples was made by Shimada in 1984 for investigation at MASCA. Samples were selected on the basis of color, density, texture, and formal characteristics to include "representative" samples as well as a general range of some ores, slags, metals, and associated ceramics. The sampling procedure included examples of the highest to lowest grades of materials as well as a few exotic or unusual examples. However, there is no written documentation of just how exotic or unusual a specific specimen is from the available material remaining on-site. The ore, slag, and metal specimens recovered from the site were sampled at this stage of the investigation using a subjective, nonprobabilistic approach.

Since the quantity of material, which included the ranges, was still an unrealistically large number of samples, another level of sampling took place for selection of materials to export from Peru. In this case, some of the initially selected bags were excluded. Further selection took place to decrease the weight of each bag. Some samples, which were considered to be very similar, were not exported for analysis. Of course, this changed the proportions of "representative" materials, again. These practical decisions represent another "filter" affecting the final collection of samples.

Yet another level of sampling took place in the laboratory upon selection of specimens for extensive investigation. For example, in a bag containing multiple specimens, often only one was selected. Without having seen the full range of material in the field, it is not possible for an analyst to know how "representative" the final selected sample was for the bag or the recorded one-square-meter archaeological unit or site as a whole. In the descriptions of slag and ore sample selection from a single bag, selection criteria were not documented. Therefore, this could also affect the interpretation of analytical results for Huaca del Pueblo Batán Grande.

The major limitation of this approach is that information gathered from the analysis of "representative" samples collected in such a complex manner may not be used confidently to draw meaningful, statistically significant conclusions about the overall industry. In this specific case, the data would not be appropriate toward a confident reconstruction of the typical process because the relative qualities and proportions of each material type and grade had been altered by various levels of multistage sampling. For example, from the initial sample of submitted ore specimens collected from the site, it was uncertain what proportion of the total actually contained arsenic in significant concentrations to affect alloy production. Ranges for the samples presented in Tables 1a–1d show the variability between ore samples. Examples of both high-grade and low-grade ore are presented in Table 1c for specimens from two loci. One of each paired specimens (labeled M225A and M225B, and M307A and M307B) was selected as an example of sampling from a fairly subjective range. The use of range is an estimate of spread or variation. Thus, without a detailed statement of sampling procedures for the ore data in Table 1c, interpretation problems obviously arise. Since statistical estimates of mean, standard deviation, and other estimates assume random sampling and an underlying normal distribution, such calculations are inappropriate for the initial ore data from Huaca del Pueblo Batán Grande. Some questions cannot be resolved satisfactorily using such a complex "representative" sampling approach.

Analytical work on the Batán Grande samples was also done in a stepwise fashion in several stages, as new material from other sites was submitted for analysis and more specific questions were developed. Data from different analytical techniques are also significant, as will be discussed in the following section.

While "representative" sampling, as an impression of central tendency for an underlying normal distribution, would be valuable in some cases for ancient metal production sites, due to the potential complexity of some smelting processes, random sampling also may be necessary to detect unexpected classes of materials. Since all of the identified copper ore and iron ore specimens encountered in the excavation of Huaca del Pueblo were saved on site at Batán Grande, Peru, it was possible to sample as required from this initial collection. Additional sampling and further analysis of ore and crushed slag were undertaken by Merkel and Shimada in 1986 and 1987. The ore was sampled again in order to estimate better the background arsenic concentration in the copper ore recovered at the ancient smelting site. This was done in two stages. First, specimens of ore saved from the excavation of Huaca del Pueblo were again examined. No specimens of common arsenic minerals were observed among the complete collection of metallurgical material saved from the excavation. No information was available at the time concerning low and moderate concentrations of arsenic as the result of mixed mineral phases in the ore samples. Second, a random sample was made from this collection to characterize better local ore selection and allow a probabilistic reconstruction of the industry. On this basis, forty new samples of ore were selected randomly. In the laboratory, all of these samples were screened with X-ray fluorescence to detect arsenic concentrations above about 0.5%. The few specimens with detected arsenic were then submitted along with several other samples for full compositional analysis utilizing proton induced X-ray emission spectroscopy (PIXE) (see Fleming and Swann 1985).

As a related sampling problem, since the major quantity of slag from the site was crushed to allow recovery of metallic prills, the possibility also exists that uncrushed slag initially collected from around the furnaces and submitted for analy-

Table 1a. *Compositional analysis for copper ore samples from Huaca del Pueblo Batán Grande.*

	CONSTITUENT (%, BY WEIGHT)*											
Ref. No.	CuO	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	K_2O	Na_2O	As_2O_3	PbO	ZnO	SO_3
83-07a	9.13	2.17	62.5	1.19	16.0	0.46	6.04	1.26	0.029	0.0022	0.011	0.10
83-08b	4.85	3.50	72.3	5.23	3.95	7.99	0.95	0.64	0.012	0.0032	0.068	0.022
83-13a	13.0	33.3	16.0	11.9	4.97	7.25	0.11	11.0	0.028	0.017	1.52	0.087
83-33Aa	12.5	2.91	63.8	0.66	11.4	0.88	4.89	1.32	0.041	0.0036	0.017	0.44
83-33Ba	12.0	23.3	26.4	33.3	2.62	0.14	0.11	0.60	0.086	0.084	0.44	0.072
83-35b	3.49	9.87	33.7	36.3	11.1	0.37	2.07	0.58	0.020	0.023	0.021	0.10
83-36c	5.86	2.93	80.4	0.42	6.07	0.62	2.11	0.78	≤0.004	0.018	0.075	0.023
83-37a	3.70	6.28	36.6	35.5	13.8	0.56	0.35	1.15	0.011	0.012	0.27	0.10
83-39a	5.06	5.48	46.6	19.3	9.47	3.42	3.80	3.71	≤0.010	0.0043	1.36	0.088
83-40a	2.21	10.0	30.5	40.5	10.7	0.35	0.84	0.73	≤0.007	0.43	0.25	0.23
83-41a	0.57	0.85	95.7	0.59	0.36	0.14	0.83	0.44	≤0.007	0.025	0.068	0.027
83-42b	12.2	19.2	36.7	21.0	4.27	0.82	1.19	0.81	0.032	1.01	0.39	0.82
83-44a	11.1	21.1	31.1	31.6	1.57	0.69	0.20	0.07	0.051	0.0069	1.37	0.035
83-45b	0.80	3.59	75.9	0.52	3.44	14.2	0.73	0.43	≤0.004	0.0020	≤0.010	0.054

* The selective filter used here for PIXE analysis comprised 3.8 mg/cm^2 Al foil +15.0 mg/cm^2 mica + 7.5 mg/cm^2 V foil (Swann and Fleming 1990). Typical detection limits for the oxides reported here are: As_2O_3, 0.0040%; PbO, 0.0020%; ZnO, 0.010%; and SO_3, 0.042% (Swann and Fleming 1988; Fleming and Swann 1992).

Table 1b. *Compositional analysis for copper ore samples used in smelting experiments.*

	CONSTITUENT (%, BY WEIGHT)*											
Ref. No.	CuO	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	K_2O	Na_2O	As_2O_3	PbO	ZnO	SO_3
Ex1.Cuore	26.8	22.4	19.3	5.25	0.50	0.68	0.14	0.28	0.016	0.025	0.076	23.3
Ex2.Cuore	44.2	17.8	25.9	1.61	0.89	0.57	0.22	0.18	0.025	0.33	1.39	0.36
Ex3.Cuore	38.9	14.0	31.4	7.02	3.11	0.45	1.09	0.25	0.025	0.28	0.43	0.84

* The selective filter used here for PIXE analysis comprised 3.8 mg/cm2 Al foil +15.0 mg/cm2 mica + 7.5 mg/cm2 V foil (Swann and Fleming 1990). Typical detection limits for the oxides reported here are: As2O3, 0.0040%; PbO, 0.0020%; ZnO, 0.010%; and SO3, 0.042% (Swann and Fleming 1988).

Table 1c. *Compositional analysis for copper ore samples from Huaca del Pueblo Batán Grande.*

	CONSTITUENT (%, BY WEIGHT)*											
Ref. No.	CuO	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	K_2O	Na_2O	As_2O_3	PbO	ZnO	SO_3
M211	40.2	16.7	9.23	5.67	5.15	0.22	3.29	1.61	15.2	0.13	0.065	0.051
M225A	25.9	28.5	22.7	3.05	3.84	0.27	2.61	1.27	9.66	0.018	0.059	0.94
M225B	9.59	9.03	46.9	0.58	21.1	0.81	7.40	1.14	0.23	0.093	0.027	2.12
M269B	29.0	31.8	29.2	1.12	1.50	0.50	0.45	1.43	0.059	0.017	2.32	0.041
M307A	3.05	27.1	29.8	34.5	0.72	1.24	0.28	0.71	0.23	0.017	0.77	0.075
M307B	20.6	27.2	25.7	20.7	1.07	0.67	0.20	1.38	0.065	0.018	0.51	0.045

* The selective filter used here for PIXE analysis comprised 3.8 mg/cm^2 Al foil +15.0 mg/cm^2 mica + 7.5 mg/cm^2 V foil (Swann and Fleming 1990). Typical detection limits for the oxides reported here are: As_2O_3, 0.0040%; PbO, 0.0020%; ZnO, 0.010%; and SO_3, 0.042% (Swann and Fleming 1988; Fleming and Swann 1992).

TABLE 1d. *PIXE analysis of sample BG83-56A (not converted to oxides).*

	Elemental content (%, by wt)
Cu	1.740
Fe	35.700
Si	0.028
Ca	0.170
Al	0.075
Mg	≤0.180
K	0.019
Na	≤0.070
As	49.400
Pb	0.016
Zn	0.180
S	11.900

sis was actually discarded deliberately in antiquity. Obviously, the uncrushed slag was not "processed" in the same manner as the crushed slag. Accordingly, the uncrushed slag recovered from directly around the furnaces may not be typical or "representative" of the actual smelting process as practiced at Huaca del Pueblo. Thus, random samples of the crushed slag are more useful for making generalizations about the industry as a whole. It was necessary to sample the crushed slag in order to compare microanalytical results for prill and slag compositions.

Further descriptions of the sampling strategies relative to the development of specific research questions will be presented in the sections on each major class of material encountered among the metallurgical remains at Batán Grande (Shimada and Merkel n.d.). The excavation of complex metal production sites with multiple-step processes requires the use of several sampling strategies to characterize accurately the ancient industry.

Analytical Techniques

Various analytical techniques were employed in the study of the industrial remains from Batán Grande. The analytical program was coordinated by S. J. Fleming at MASCA. PIXE has been the major analytical technique used in this investigation (Fleming and Swann 1985; Swann and Fleming 1988; Swann and Fleming 1990; Fleming and Swann, n.d.). The PIXE analyses were undertaken by C. P. Swann at the University of Delaware.

The PIXE results have been supplemented by other techniques as a simple check and to pursue specific research questions that developed during the project. For example, X-ray fluorescence was used to screen ore samples collected from the site for arsenic compositions. This strategy allowed selection of samples for further characterization by PIXE and other analytical techniques such as atomic absorption spectroscopy, X-ray diffraction, electron probe microanalysis, scanning electron microscopy/energy-dispersive spectroscopy (SEM-EDS), and metallographic and petrographic microscopy. Metallic samples for atomic absorption spectroscopy were prepared according to Hughes et al. (1976), while slag and ore samples for this test were prepared following the method by Farrell et al. (1980). However, in crushing and grinding slag with entrapped metallic prills, some of the metal is inevitably lost on the surface of the grinding equipment, so the analytical results underestimate the actual metal content of the slag (Merkel 1983). Analytical facilities were used at the following locations: atomic absorption spectroscopy and SEM-EDS at the Laboratory for Research into the Structure of Materials, University of Pennsylvania; metallography and sample preparation at MASCA, University Museum, University of Pennsylvania; electron probe microanalysis at the Department of Earth and Planetary Sciences, Harvard University; atomic absorption spectroscopy in the Bone Chemistry Laboratory, Peabody Museum, Harvard University; and X-ray fluorescence and X-ray diffraction at the Center for Archaeological Research and Development, Peabody Museum, Harvard University. These various analytical techniques provide complementary compositional and mineralogical data. Techniques were selected for bulk compositional analysis, microanalysis, and phase identifications as available for each class of recovered material.

Copper Ore

The compositional data for ore in Tables 1a–1d were determined using PIXE. Table 1a presents the results for the initial set of samples collected during the excavation of the smelting site at Huaca del Pueblo. However, some of the samples should not be considered copper ore, such as 83-41a and 83-45b. Fleming (pers. comm. 1986) has divided these results into three classes based on macroscopic observations of color and relative density. Using such observations assumes similar skills of mineral recognition by the ancient workers at Batán Grande. Several publications have addressed the capabilities of ancient ore sorting and beneficiation in antiquity, which also argue for the recognition of adequate determinative skills by the ancient metalworkers (see Charles 1985; Merkel 1985). However, due to the many complexities of sampling and recognition of potential classes, the presentation of such tables makes a number of assumptions that may or may not be appropriate. Nevertheless, the most obvious distinctions between colors and relative densities of ore minerals and gangue seem clearly reasonable for Middle Sicán miners and skilled workers at Batán Grande.

Table 1b presents data for the copper ore collected from nearby Cerro Blanco and used in the reconstruction smelting experiments. These samples of ore were sorted by one of the authors (Merkel) initially to obtain the highest grade available. Note the differences between the quality of the ore used in the experiments and the quality of the ore collected from the smelting site at Huaca del Pueblo. The highest concentration of copper, presented as CuO in the tables, from Huaca del Pueblo is only 13.0% in Table 1a. In contrast, the ore used in the experiments was 44.2% and 38.9% CuO. Furthermore, the sulphur-sulphate concentrations (presented as SO_3 for the PIXE results) for the ore selected for experiment 1 are much higher than other sulphur values for ore samples from the archaeological site. Clearly, high-grade copper ore of several types is available today in the immediate area. Around Cerro Blanco, several modern but small local mining concerns are successful sporadically with fluctuating ore demand and prices. Due to likely maximization of smelting parameters using simple observational skills in antiquity (see Merkel 1983, 1990; Bamberger and Wincierz 1990), only the best-grade copper ore is assumed to have been smelted. Differences between Tables 1a and 1b reflect contrasting purpose and degree of ore sorting. Likewise, these differences also suggest that the ore dropped around the working furnaces was generally below the available highest grade copper ore presumably smelted.

Due to the low concentrations of arsenic detected in the initial sets of ore samples collected from the site and the ore selected for the smelting experiments, an additional source of arsenic in the smelting charge must be considered. Clearly, the low arsenic concentrations (reported as As_2O_3) below about 0.05% cannot account for the observed concentrations of arsenic in the copper prills in smelting slag from the site.

As discussed in the section on sampling, two of the authors (Merkel and Shimada) on several occasions went through all of the ore collected and saved from the excavation at Huaca del Pueblo. Again, none of the arsenic-rich minerals, such as arsenopyrite, enargite, and so forth, was identified as distinct, major phase specimens in the collection. Samples of forty mineral specimens were randomly selected for further analysis. The random sample was found to include variable ore grades as well as a few mixed mineralogical specimens with possible accessory arsenic-rich phases.

The rationale for preliminary use of X-ray fluorescence to screen these ore samples included low cost, speed, and simplicity among other factors. One side of each ore sample was ground and polished to prepare a flat surface quickly for analysis. Each ore specimen was then checked for the presence or absence of arsenic as a constituent. With such simple sample preparation and selected scanning over the characteristic wavelength for arsenic, the complete collection of specimens could be examined in a relatively short period of time. This was sufficient for screening the whole collection of ore specimens. The X-ray fluorescence equipment at the Peabody Museum was used for this preliminary work.

The few selected specimens with detected arsenic as well as several without arsenic as checks were then submitted for PIXE to obtain quantitative results for bulk compositions. In Table 1c, selection of samples M225B, M269B, M307A, and M307B with low concentrations of arsenic was based on subjective determinations using color and density of ore grade ranges from the bags of random samples from Huaca del Pueblo. In the sample labels, the final letter designation after the excavation loci number simply indicates a distinct fragment of ore taken from the bag for further analysis. The paired samples from M225, M307, and M269B allow some indication of a range, and certainly should not be used to estimate averages or any other descriptive measure of the characteristics of the majority of ore samples from each locus.

It is significant to note that the copper concentrations of two ore samples, M307B and M269B, actually collected from the excavated site are similar in grade to the ore used in the experiments. Furthermore, these two samples of ore from the smelting site are considerably higher in copper concentration than the ore samples analyzed using PIXE in the initial batch (Table 1a). This may reflect again a sampling bias in collection of representative samples by the excavators in the initial screening of samples. Better grade copper ores are available from the site than indicated from the initial selection of ore samples.

Since most ore specimens were mixtures of mineral phases, petrographic microscopy, X-ray diffraction, and electron probe microanalysis were used to identify the mineral components. This work was conducted on subsamples using equipment at MASCA by W. Vernon and by one author (Merkel) using equipment at the Peabody Museum and the Department of Earth and Planetary Sciences at Harvard University. This approach provided the data necessary for the identification and characterization of the ore collected from the excavation. Likewise, ore samples collected from modern, small-scale mines in the region were also analyzed for comparison. This sampling strategy allows further conclusions to be reached about the available grades of materials for ancient smelting.

From a random sample of forty ore specimens from Huaca del Pueblo, plus the other "representative" ore samples, only three samples of ore were found to have significant concentrations of arsenic: M211, M225A, and BG83-56. All of the other samples had concentrations of arsenic below approximately 0.5% as determined by PIXE and "screened" with X-ray fluorescence. Since the background concentrations of arsenic were not known for the initial sample taken at Batán Grande, in this sense it seems appropriate to include these data with the results for the random sample to increase the number of samples in the ore studies. Therefore, less than about 5% of the total of ore specimens from the site have significant concentrations of arsenic, which could conceivably produce the observed copper-arsenic alloys during smelting. This decreases the likelihood of regular production of copper-arsenic alloys by smelting naturally mixed ores during the Middle Sicán period at Huaca del Pueblo. The "traditional" metals industry of the Middle Sicán period is based on the widespread and systematic use of copper-arsenic alloys.

Among the ore samples recovered in the excavation of Huaca del Pueblo, arsenic was detected with X-ray fluorescence and subsequently measured with PIXE in ore samples M211 and M225A. Neither of these two specimens appears similar to high-grade copper ore samples. X-ray diffraction results for M211 indicated malachite and quartz with a small number of unidentified lines for other mixed phases. Sample M225A has detectable patterns for malachite, quartz, and minor arsenopyrite. The PIXE results are presented in Table 1c.

As part of our investigation of copper-alloy production at Batán Grande, an intensive mining survey of the surrounding area was conducted to locate potential sources of the required ores. BG83-56 is an ore sample from the nearby small-scale mine known as Cerro Mellizo, south of Batán Grande. This original package of ore totaled about 600 g. BG83-56A is the sample removed from this lot. X-ray diffraction analysis of BG83-56A best matched the patterns for arsenopyrite and scorodite. PIXE results for the same sample are presented in Table 1d. These are raw PIXE data. This specimen of scorodite is light green in color with a few flecks of arsenopyrite, but still quite different in appearance from the highest grade copper ore samples from the excavation. It seems very unlikely that the color difference between hand samples of scorodite, for example, and high-grade copper ore could be confused (see Charles 1980). The electron probe microanalysis results for the scorodite were 22.87% Fe, 0.71% Cu, 32.75% As, 0.29% S, and 43.39% O (oxygen confirmed by the same analysis). The arsenopyrite was 32.26% Fe, 0.00 %Cu, 47.11% As, 19.91% S, and 0.0% O. The matrix was 32.88% Fe, 1.33% Cu, 35.11% As, 0.08% S, and 30.59% O (difference). A lead sulphate (probably $PbSO_4$) was also identified with electron probe microanalysis. The phases were identified based on the X-ray diffraction results and agreement between the electron probe results and calculated compositional values for pure mineral phases.

Various lines of evidence around the modern prospection on Cerro Mellizo point to intensive prehistoric mining of surface deposits of arsenic-rich mineralization (Merkel and Shimada 1988; Shimada and Merkel 1991). While the mine can be confidently identified as Pre-Hispanic, dating remains imprecise as the associated paddle-stamped and blackware ceramics were abundantly manufactured from circa 900 C.E. to the time of the Spanish Conquest.

In the copper ore from Batán Grande there are characteristic, variable concentrations of iron. Although there is a low correlation between copper and iron concentrations for the data in the table, there are several examples of relatively high copper and iron concentrations together, as in samples 83-13a and 83-33b. These examples, however, are not numerous, and the copper ore at Batán Grande should not be considered self-fluxing. Theoretical mass balances for the Batán Grande furnace charges are dependent on corresponding SiO_2 concentrations along with the copper and iron and other major components. In the smelting experiments conducted at Batán Grande, for example, although the smelting efficiency was low, the results were acceptable with a copper ore to iron ore flux ratio of 1:1.

From our analytical investigation of the copper ores from Batán Grande, there is no evidence to suggest use of copper sulphide ores or roasting of copper sulphide ores for smelting charges at Batán Grande (compare Thorpe and Franklin 1984). Unfortunately, low ratios of iron to sulphur do not indicate use of copper sulphide ores (compare Ghaznavi 1976; Tylecote et al. 1977:Table 23; Epstein 1982). The observed differences in S and Fe concentrations for the experimental results reported by Tylecote et al. (1977) are more related to differences in ore-to-flux ratios and number of tuyeres (i.e., burning rate and CO-CO_2 ratios), than to a difference simply between smelting of copper oxide or copper sulphide ores. Furthermore, pyritic smelting was not practiced (compare Epstein 1982). As expected, most of the copper ore specimens collected from Huaca del Pueblo Batán Grande are malachite.

In conclusion, (1) approximately 95% of the copper ore samples recovered from Huaca del Pueblo are relatively free of arsenic (less than 0.5% As) based on PIXE results and screening with XRF, (2) the few observed examples of ore with moderate arsenic concentrations are recognizably different in appearance from the characteristic high-grade copper ore specimens from the site, and (3) all of the copper ore samples recovered from excavations at Huaca del Pueblo contain less than 2.0% sulphur based on the PIXE results (recalculated from assumed oxides).

Iron Ore Flux

Based on the compositions and quantity of smelting slag at Batán Grande, it is apparent that iron ore was deliberately added as flux in the smelting charges (see Shimada et al. 1982). Table 2a presents the PIXE data for iron ore samples recovered in the excavation. Based on examination and X-ray diffraction results, most of these samples are mixtures of hematite and goethite. However, the minor arsenic and lead concentrations in several of the samples are very important. Sample 83-38b is reported to have 5.1% As_2O_3, and sample 83-14a has 5.21% PbO. Given the theoretical quantities of iron ore flux used in smelting, substantial contributions of arsenic and lead could derive from the iron ore flux (see Merkel 1983, 1990). However, only a uniform arsenic concentration in the iron ore at Batán Grande would possibly account for systematic production of copper-arsenic alloys from smelting. The other five samples of iron ore in Table 2a have less than about 0.07% As, so it seems unlikely that the iron ore flux could have been a consistent source for arsenic in the smelting charges. The concentrations of lead are variable.

Iron ore flux was also collected from a modern mine at Cerro Blanco for use in the smelting experiments. The PIXE results are presented in Table 2b. The values for lead are variable, but the concentrations reported for arsenic in the iron ore flux are below 0.6% As_2O_3. These iron ore samples collected from Cerro Blanco seem generally comparable to samples (except 83-38b) from Huaca del Pueblo. In the smelting experiments reported by Merkel and Shimada (1988), these concentrations of arsenic in the iron ore flux resulted in concentrations of about 0.2–1.41% As in some of the recovered copper prills.

Although few iron ore samples from Huaca del Pueblo and the nearby mines have been fully investigated, based on the available analytical evidence, theoretical mass balances for arsenic, and reconstruction experiments (Merkel and Shimada 1988; Shimada and Merkel 1991), the concentrations of arsenic in the copper ore and iron ore flux are considered insufficient to produce consistently the observed copper-arsenic alloys from smelting at Huaca del Pueblo during the Middle Sicán.

Separate, deliberate additions of arsenic-rich ores along with copper carbonate ore and iron oxide flux in the smelting charge represents the most probable model for this archaeological period at Huaca del Pueblo. This conclusion, based on analysis of the available copper carbonate ore and iron ore flux samples recovered from

TABLE 2a. *Compositional analysis for iron ore samples from Huaca del Pueblo Batán Grande.*

	CONSTITUENT (%, BY WEIGHT)*											
Ref. No.	CuO	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	K_2O	Na_2O	As_2O_3	PbO	ZnO	SO_3
83-14A	2.15	73.0	13.8	0.30	0.26	≤0.13	0.082	0.34	0.071	5.21	1.04	3.16
83-19A	4.39	89.5	2.69	2.01	0.29	0.13	0.031	≤0.08	0.014	≤0.006	0.29	0.030
83-24B	1.13	39.1	18.5	5.06	4.97	0.73	4.13	1.13	≤0.008	≤0.006	0.030	23.7
83-34C	0.40	95.9	0.66	0.26	1.11	0.45	0.12	0.020	0.032	0.012	0.049	0.33
83-38B	0.74	81.2	3.82	0.96	2.61	1.58	0.48	0.30	5.1	≤0.008	1.66	1.16
83-43D	0.23	92.5	4.03	0.58	1.36	0.42	0.076	0.070	≤0.008	≤0.007	≤0.011	0.41

* The selective filter used here for PIXE analysis comprised 15.0 mg/cm^2 mica + 15.0 mg/cm^2 V foil (Swann and Fleming 1990). Typical detection limits for the oxides reported here are: As_2O_3, 0.0080%; PbO, 0.0060%; ZnO, 0.011%; and SO_3, 0.0062%.

TABLE 2b. *Compositional analysis for iron ore samples used in smelting experiments.*

	CONSTITUENT (%, BY WEIGHT)*											
Ref. No.	CuO	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	K_2O	Na_2O	As_2O_3	PbO	ZnO	SO_3
Ex1.Feore	2.21	67.2	13.8	22.0	2.39	0.49	1.30	0.35	0.38	0.49	0.28	1.68
Ex2.Feore	1.83	72.6	13.8	19.7	1.06	0.17	0.22	0.19	0.59	0.25	0.49	1.31
Ex3.Feore	0.042	79.0	13.8	13.7	3.93	0.31	0.098	0.25	0.051	0.060	0.70	0.21

* The selective filter used here for PIXE analysis comprised 3.8 mg/cm^2 Al foil +15.0 mg/cm^2 mica + 7.5 mg/cm^2 V foil (Swann and Fleming 1990). Typical detection limits for the oxides reported here are: As_2O_3, 0.0024%; PbO, 0.0026%; ZnO, 0.0048%; and SO_3, 0.0062% (Swann and Fleming 1988).

the archaeological sites, contradicts the earlier model for accidental alloying with arsenic and the use of copper sulphide ores proposed by Thorpe and Franklin (1984) from their preliminary study of copper ingots and prills from Batán Grande.

Results for the other classes of materials will be published in a forthcoming volume concerning the Sicán Archaeological Project (Shimada and Merkel, n.d.).

Relevance to Archaeometallurgical Surveying: A Case Study from the Mid-Chancay Valley

The recent survey of the mid-Chancay Valley was undertaken to evaluate the model for copper-arsenic alloy production devised for the north coast metallurgical process based on data from Batán Grande. The objective is to extend our study of compositional and associational patterns for metallurgical remains in the region. About three days of surface survey, collection, and test excavations were completed at the site known as Pampa del Tablazo. The site is situated some 65 km inland in the Chancay Valley (Fig. 1), immediately south of La Leche Valley. The experience gained from Batán Grande investigations facilitated our discovery of furnaces and associated remains at Pampa del Tablazo. It was the association of a *batán* and crushed slag within a walled-in area that led us to predict the nearby presence of smelting furnaces.

In Lechtman's (1976) survey of the North Coast of Peru, she identified a metallurgical site on the Pampa del Tablazo. It is this site that Lechtman (1991) has chosen to call Batánes del Tablazo, inferring that a collection made in the 1947–48 survey by Henry and Paula Reichlen originated from this location. In trying to establish a chronology for the site from the artifacts in the 1947–48 survey collection, Lechtman concluded that the site's occupation was from Middle Sicán to Early Chimú. The chronological indicators used by Lechtman were spindle whorls, *tumis*, tuyeres, and "feathers" (sheet-copper objects resembling feathers). The feathers and tumis documented by Lechtman have a clear Middle Sicán form and style documented at Huaca del Pueblo Batán Grande and other sites in Batán Grande. The feathers are normally arranged in bundles and included as grave goods in prestigious burials. At looted sites, they are often found discarded in backdirt from *huaquero* activities. It is certain that the feathers included in the Reichlen collection were from the backdirt from previous looting.

From our dating of surface ceramics from Pampa del Tablazo, the site is predominantly Late Sicán with a minor occupation during the Inca domination of the area in the late fifteenth and sixteenth centuries. Grave looting is minimal and the site is predominantly metallurgical. Therefore, it seems unlikely that the Reichlen collection originated from this site. Furthermore, local inquiries reveal that people are unfamiliar with any site called Batánes del Tablazo. Unless the Reichlen collection is mixed, a single site for Reichlen's collection with tumis and feathers must then exhibit evidence for both copper smelting and Middle Sicán burials. It is more likely that objects illustrated by Lechtman (1991) come from the site of Cantagallo (Fig. 1). Middle Sicán material is present at Cantagallo from looted burials, but not at Pampa del Tablazo. On additional survey work there is malachite at Cantagallo, and at one time there had been batánes, but the batánes have reportedly been removed to nearby homes.

Three distinct concentrations of low remaining walls and batánes within Pampa del Tablazo were selected for sampling and labeled 1A, 2A, and 3A (Fig. 3). These three locations provided metallurgical debris representing most of the stages of the smelting process as previously described for Batán Grande. The material collected from the surface included ores, tuyeres, crushed slag, slagged sherds, furnace fragments and lining. A total of seventeen batánes were still present at the site. There were others, however, that again had been removed recently for local use elsewhere.

Three types of ore were prevalent on the surface at Pampa del Tablazo. Within the radius of the 3A cluster of structures (Fig. 3), collections were made that included malachite, hematite, and cuprite. Small flecks of malachite also occurred across the whole site. The malachite was associated with mostly quartz gangue, but there were also numerous high-grade dressed mineral fragments. The high-grade specimens of malachite are thought to represent the actual grade of copper ore for smelting. Cuprite specimens were present in much lower numbers. It is important to emphasize the obvious properties of color and density, which would have been most relevant in copper ore beneficiation for smelting. The nearest modern copper mine to Pampa del Tablazo is only about 1.5 km to the northeast and is known as Cerro las Minas (see Lechtman 1976:15). While there is definite Pre-Hispanic occupation at the top of Cerro de las Minas, most of the mining remains are obviously modern, including bore holes around an adit. In a nearby undated shallow trench there are thin but rich veins of malachite. Lechtman (1976) identified malachite, covellite, cuprite, and chalcopyrite in the tailings from the modern mine. Clearly, there

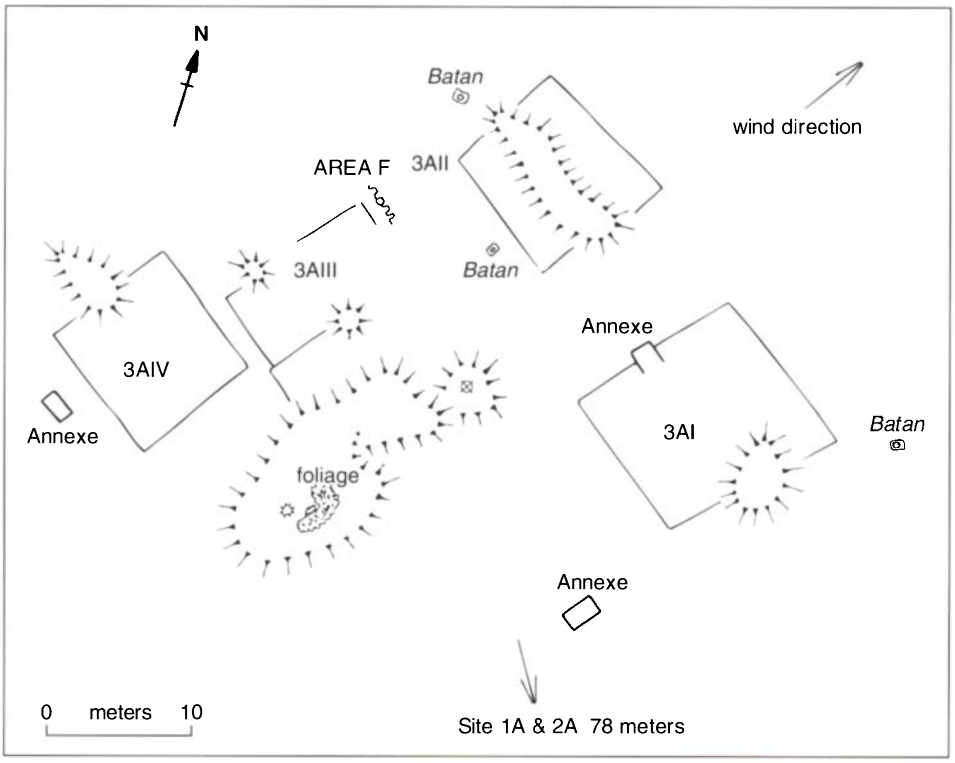


Figure 3. *Plan for one of the smelting areas (3A I, II, III, IV) investigated at Pampa del Tablazo. Remains of low stone walls are drawn as solid lines. Mounds of crushed slag, often overlying walls, are depicted by the patterns of short lines that radiate outward, corresponding to the limit of surface exposure. Furnaces excavated in area F were first detected by fragments of fired furnace wall lying on the surface.*

are accessible surface deposits of malachite in the immediate area to Pampa del Tablazo. The specimens of hematite are interpreted as flux (as at other smelting sites). It is important that no specimens of the enargite or other arsenic-rich minerals were identified in hand samples from the surface survey. As we await analysis of copper prills from the crushed slag at Pampa del Tablazo, it is anticipated that there should be a small number of ore specimens with arsenic-rich minerals from the site. Nevertheless, it is certainly clear from the authors' surveys and excavations at Huaca del Pueblo, Cerro Blanco, Cerro Mellizo, and now Pampa del Tablazo that enargite (Cu_3AsS_4) from the Andean highlands cannot represent "one of the main sources of supply of arsenic-bearing ores" in proportions as proposed by Lechtman (1991) for the coastal smelters.

Possible use of enargite ores as proposed by Lechtman (1991:63) centers on one critical sample: MIT3413. This hand sample is described in the text as "a piece of quartz rock with bright green mineralization distributed unevenly on the surface." The "bulk chemical analysis of a sample of this ore" as it is described by Lechtman (1991:63, 65) is 10% copper, 4.6% arsenic, 34.4% silicon using atomic absorption spectroscopy, and 0.23% sulphur by a combustion-titration method. Minor amounts of antimony, iron, and sulphur are also listed. In her Table 5, Lechtman, however, lists enargite (Cu_3AsS_4) first among the various phases present in this sample. The stoichiometric composition of enargite is 48.42% Cu, 19.02% As, and 32.56% S (Lechtman 1976:6). The largest enargite grain in this sample (Lechtman 1991:fig. 11) is illustrated only at high magnification (×100) and confirmed by electron probe microanalysis. This would not be visible in the hand sample. Although Lechtman does state that "inferences drawn from a single ore specimen must be made with caution," it should be emphasized that this complex specimen includes numerous phases (some very minor) but has the appearance of gangue (based on the description), and furthermore it is only one sample from uncertain provenance. Certainly, this cannot be sufficient evidence to argue for use of enargite ore from the highland for coastal smelters in the Chancay or La Leche valleys. As previously published (Merkel and Shimada 1988; Shimada and Merkel 1991), there is a complex, weathered arsenopyrite deposit at Cerro Mellizo near the copper deposits at Cerro Blanco (Fig. 1). There is another mine with arsenopyrite and evidence of Pre-Hispanic workings at Barranco Colorado, near Cerro Mellizo. Malachite and hematite are also abundant and easily recognizable minerals in the upper, weathered zone of the complex deposit at Cerro Mellizo. It should not be unexpected, then, if trace concentrations of other phases such as cornubite [$Cu_5(AsO_4)_2(OH)_4$] and even possibly enargite (Cu_3AsS_4) could also be dispersed within the complex weathered orebody at Cerro Mellizo and the other local mines. The presence of trace enargite inclusions in a gangue specimen need not necessarily indicate a distant source. Arsenopyrite (FeAsS) and weathered phases such as scorodite ($FeAsO_4 \cdot 2H_2O$) are present locally in relative abundance and thus should be considered the most likely deliberate additions to the smelting charge. Obviously, deliberate additions to a smelting charge would have to be readily recognizable as hand samples and present in quantity to be relevant for consistent production of copper-arsenic alloys as represented at the Batán Grande sites. Despite equivocal lead isotope data presented by Lechtman (1991), the most likely sources of the large quantity of copper ore, flux, and arsenic-rich mineralization for smelting in the Chancay and La Leche valleys would be, of course, the local deposits. At Huaca del Pueblo Batán Grande, there are large numbers of ore samples, mostly malachite and hematite. The proportions are similar at Pampa del Tablazo. At Huaca del Pueblo Batán Grande, arsenopyrite was identified in ore samples from excavated strata (Merkel and Shimada 1988); enargite was not found. As we await further survey and excavation at Pampa del Tablazo, no arsenic-rich hand samples have yet been identified.

As part of our investigation at Pampa del Tablazo, we also excavated a row of furnaces that were apparent just at the surface. Concentrations of furnace fragments first revealed the positions. Four furnaces appear to have been linked together alongside a low wall and operated as a unit. One of the furnaces was quite ruined, but the other three were practically intact with only the top walls slightly damaged. On the best-preserved furnace (Fig. 4), the furnace capacity is estimated up to a slag erosion level at about 3.8 L. The furnaces were spaced between 30 and 40 cm apart. The estimated furnace capacity and the distance separating the furnaces at Pampa del Tablazo are similar to those observed for the Middle Sicán furnaces at Huaca del Pueblo Batán Grande. The Chimú and Inca period furnaces were smaller, with an estimated functional capacity at about 1.5 L. Again, from the surrounding ceramic sherds and tuyere fragments, the site of Pampa del Tablazo is predominantly Late Sicán. A small number of Late Inca ceramic sherds are also present on-site. Noted differences from the Huaca del Pueblo Batán Grande material, especially the tuyere fragments, are viewed as chronological as well as geographic.

In summary, there are numerous specimens and fragments of copper ore and iron ore present on the surface at Pampa del Tablazo. There are smelting furnace remains, crushed slag, and tuyere fragments. Publications for Batán Grande and the recent surface survey and trial excavations at Pampa del Tablazo demonstrate that all components needed for the production of copper-arsenic alloys are indeed available within the La Leche and mid-Chancay region. It seems important, again, to emphasize the need for relevant fieldwork and appropriate sampling from archaeometallurgical sites.

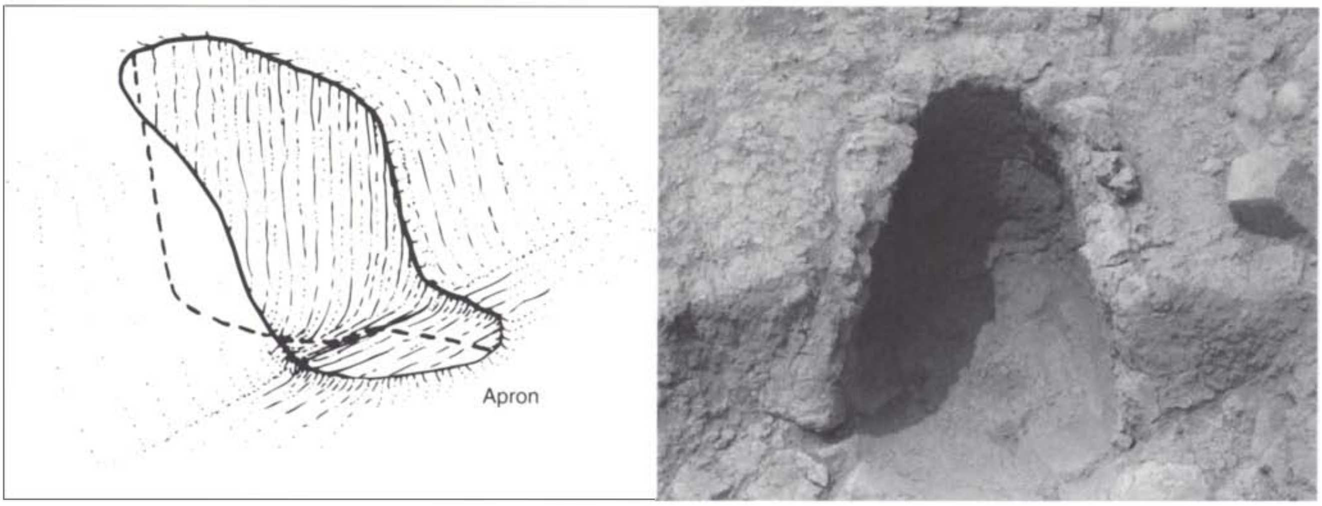


FIGURE 4. *Drawing (a) and photograph (b) of the best-preserved furnace in area F. The dimensions for this furnace are 24.7 cm from the upper rim to the deepest part of the bottom, 41.0 cm from the outer edge of the apron to the rear of the furnace, and 24.1 cm at the widest part of the furnace mouth at the level of the apron. This furnace was found intact with all original smoothed surfaces.*

Conclusions

One important assumption for statistical analysis that is often not emphasized in the archaeometallurgical literature is the selection of random samples. Using this additional sampling strategy, analytical data were obtained that suggest additional production steps beyond those previously published for Batán Grande (Epstein 1982; Shimada et al. 1983). This highlights the necessity of archaeological fieldwork by metallurgical specialists in the early phases of an investigation to ensure recognition of materials classes. Metallurgists and geologists must participate in the development of sampling strategies more suited toward answering specific interdisciplinary research questions. Again, each and every aspect of a complex archaeometallurgical site must be fully understood. Experience with experimental reconstructions provides an important perspective to define specific questions and develop appropriate sampling strategies. The overall point is to collect samples from which meaningful statistical inferences can be made toward understanding an ancient metallurgical process.

In earlier periods, unintentional use of arsenic-rich copper ores may have occurred. Some minor constituents, such as olivenite (Cu_2AsO_4OH), may not have been recognized in a complex mixed ore specimen (Pollard et al. 1990). It would not be possible to sort out by hand the minor constituents from a bulk ore (Merkel 1985). Alternatively, arsenic may have been first included with the flux, as iron ore sample 83-38b suggests with 4.60% As_2O_3. Nevertheless, compositional data for copper ore samples from around the smelting furnaces at Huaca del Pueblo Batán Grande show that the concentration of arsenic is typically well below 0.5% As_2O_3. Of the total number of ore specimens screened, about 95% have arsenic concentrations below this level. From the bulk mineral samples found around the smelting furnaces, the few examples with significant major concentrations (not minor or trace concentrations) of arsenic are different in appearance from typical specimens of high-grade malachite. Differences in mineral properties for major constituents in specimens as mined would seem sufficiently distinct and recognizable through sorting for deliberate use. Although the analyses of copper ore found around the furnaces represent somewhat fortuitous evidence as to the actual smelting charges, the sampling strategy and related technical characterizations of these ore minerals are nevertheless considered to be of the utmost importance in our understanding of the smelting process and the attempt to illustrate deliberate production of copper-arsenic alloys.

The presence of speiss fragments among the slag from Huaca del Pueblo Batán Grande is critical to the proposed reconstruction (Merkel and Shimada 1988). Although the recognized quantity at present of about 50 g is small, these samples were found among the slag samples submitted for analysis. The presence of this class of materials was unexpected by the archaeologists collecting the samples around the smelting furnaces. The identification of speiss in the field is very difficult without some metallurgical experience. Perhaps these few speiss samples were initially selected by the archaeologists because they seemed heavier than the usual slag samples of similar size. There are no field records that specifically address this sampling problem. The presence of speiss, along with the high-arsenic prills in the slag, is evidence of excessive charging of arsenic-rich ores into the smelting furnaces. Such an input of arsenic in the smelting charge based on mass balances, even with selective partitioning and enrichment into the copper, is far beyond that indicated from the analyses of only the copper ore and the iron ore specimens from the site. This is accepted as evidence that an arsenic-rich ore was deliberately added with the copper ore and iron ore flux in the smelting charges.

Arsenic-rich copper prills were the desired product from smelting (Shimada et al. 1982). There is no evidence that ingots were formed in the smelting furnace. The entrapped metallic prills were recovered by hand after crushing the slag from the smelting furnace on the batánes. The prills were then remelted with a subsequent decrease in arsenic concentrations due to oxidizing conditions. Two reported copper ingots with 2.76% As and 2.02% As from Cerro de los Cementerios in Batán Grande are "aggregate products made by the remelting of prills" (Epstein 1982) and on the order of 0.5 kg maximum. Copper prills in the slag from Huaca del Pueblo Batán Grande have concentrations of arsenic much higher than the two ingots and Middle Sicán finished objects.

The concentration of sulphur in the recovered copper ores is below 2%. Malachite was the most prevalent mineral in the high-grade ore samples. No examples of roasted copper sulphide ores were discovered. Simulation smelting experiments with dead-roasted copper sulphide ores have been undertaken by Tylecote et al. (1977) and Rostoker and Sadowski (1980). A review of the various compositional data for simulation smelting experiments suggests that a threshold value of about 10% sulphur in the smelting charge would begin to produce significant quantities of copper matte as a primary product. For example, charges with 18.5% sulphur are reported to have produced matte, while charges with 5.5% sulphur produced metallic copper with sulphide inclusions and a bulk sulphur concentration up to 0.7% (Ghaznavi 1976). Roasting and smelting of copper sulphide ores is not an applicable model for Batán Grande.

Reinterpreting analyses of finished objects, Patterson (1971) argued that copper sulphide ores were not smelted in South America before Spanish contact. Furthermore, as presented for Huaca del Pueblo, the copper ore recovered in the excavation of the smelting furnaces has concentrations of sulphur below 2%. The opposing position that copper sulphide ores were smelted based on analyses of crucible slag with matte droplets has been presented by Lechtman (1981) and again based on phase analyses of prills and ingots by Thorpe and Franklin (1984).

The controversy over interpreting evidence for smelting copper sulphide ores against copper oxide ores has arisen before in many times and places. In reference to a similar but much earlier claim that the presence of sulphur in certain ancient copper objects indicated the smelting of copper sulphide ores, W. Gowland (1899:275) responded:

> But these amounts of sulphur do not prove this at all, for most simple oxidised ores contain small proportions of iron and copper sulphides, in the form of pyrites, and such is the affinity of copper for sulphur, that when these ores are reduced the copper obtained will contain quite as much of the latter element as is shown in the

> analyses quoted by Wibel. I may say, too, that I have hardly ever smelted an oxidised ore on a large scale without finding sulphur in the resulting copper.

To make statistically meaningful inferences about the materials used and past industrial activities, random sampling from the remaining debris is required. In a sense, sampling is intended to reconstruct ancient quality control of materials. The use of "preconceived" classes of materials (perhaps excluding iron ore flux, speiss, or matte) from complex archaeometallurgical sites would not allow an accurate reconstruction of the process. From complex sites, however, it may not be until after laboratory analysis that some classes of material are recognized. In this instance, secondary sampling or the use of additional analytical techniques may be required as the investigation develops further, as is the case for Huaca del Pueblo Batán Grande and other La Leche Valley and mid-Chancay Valley sites. For the interpretation of past industrial behavior, such as that represented at Batán Grande for the Middle Sicán period, the development of a suitable sampling strategy, along with the program of technical characterizations, is of the utmost importance.

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Native Copper Technology and Society in Eastern North America

S. Terry Childs

Interest in the native copper technology of North America by scholars has vacillated over the last century. The primary objective of this paper is to document a recent but gentle revival of research in native copper manufacture, use, and circulation among Native American peoples, particularly those who lived in the northeastern United States. Accomplishment of this goal requires that native copper studies be placed in an historical perspective—one that critically synthesizes previous scholarship, looks at the recent and significant changes in research interests, and provides examples of those new trends. Despite some recent progress, it will be shown in this paper that considerably more effort is required before we can adequately ascertain the diverse ways in which the metal influenced Native American societies.

In the first of the following three sections, I look to the recent past and examine why the scholarship on North American native copper never received much attention through the last century and why we are only beginning to examine both the technical and social aspects of this technology. The second section documents present and future research trends, particularly those constructed around the premise that the production, use, and circulation of native copper constituted a dynamic, not a static, aspect of many Native American societies. Toward this end, I examine and synthesize several research foci that examine the cultural and noncultural factors that influenced the effects of native copper production and use on different Native American societies over time. These foci are: (1) the source of and accessibility to metal resources; (2) the techniques and skills of the native copper craftspeople; and (3) the social functions of copper.

In the final section, I present two case studies that highlight some of the research concerns that have arisen as some of the old assumptions about native copper and Native Americans have died out. Both cases involve groups of people from different periods of time who are rarely associated with metallurgy but who were clearly affected by the availability of copper. The first study concerns the hunter-foragers who buried their dead with significant amounts of native copper in Vermont during the Early Woodland period. The methods by which thousands of objects were manufactured and the source of the raw native copper are of principal interest. The second case study examines the resources, methods, and uses associated with two object types among the agriculturally based Iroquois in New York during the Early Contact period.

Native Copper Studies in an Historical Perspective

The following overview of native copper research focuses on the time period between approximately 1870 and 1970. It is not meant to be an exhaustive survey of every study on native copper during this period, but rather a commentary on general research orientations and perspectives.

Two important stimuli attracted research interest on American Indian metallurgy in the mid- to late 1800s: the excavation of elaborate copper sheet work from various mound sites in Ohio and the southeast, and random surface collections of large copper tools in the wide vicinity of the Upper Great Lakes. The discovery of these artifacts raised concerns over who made them (Native Americans or Europeans), how they were made[1] (smelting, melting, casting, alloying, hot forging, or cold forging), and the source of the metal (European or native copper). Archaeologists recognized early on that scientific analyses could answer many of these questions and forged a long-standing alliance with material scientists.

Several early researchers (Cushing 1894; Willoughby 1903; Greber and Ruhl 1989) undertook replicative experiments to investigate some of these questions. They demonstrated that indigenous peoples could have made various objects out of native copper by using the skills and tools developed for working stone and wood. Although they found that the process merely involved hammering and annealing with fire, Willoughby recognized the skill involved (Greber and Ruhl 1989). Moore (1903) undertook the sourcing question with chemical analyses and discovered significant elemental differences between objects made by indigenous peoples and those of probable European origin found in Contact period contexts. Metallography was later offered to detail indigenous native copper technology. Wilson and Sayre (1935) found that their four study objects were made by varying sequences of hammering, hot forging, and annealing.

When one examines the titles of these and other early studies (e.g., G. Phillips 1925, 1926), however, one word consistently appears: *primitive*. The connotations of this word set a tone and conceptual template that seems to have strongly affected scholarship on the metal technology of North America, like many other parts of the world, for years. Intellectual focus on social evolution and progress in the late 1800s caused scholars to place the procedure of hammering and annealing native copper nuggets on the lowest rung of technological development. They often made this evaluation with poor attention to the variety of skills involved, the objects made, or sometimes the level of sociopolitical development of the local culture. Furthermore, this assessment was often formed in relation to the "superior" metallurgies of Europe and South America as reflected by Joseph McGuire's comments in 1903:

"[T]he natives did possess and work copper rudely and as a malleable stone. But when copper is found in thin sheets and those sheets are embossed and ornamented with *repoussé* work; and when spear-heads are furnished with sockets, and the sockets are furnished with nail holes, we may safely assert that white influences are proven" (in Moore 1903:47).

This evolutionary approach, first promoted in the context of nineteenth- and twentieth-century ethnocentrism, continued until quite recently (Easby 1966), owing to poor recognition that significant technological variation and adaptation may have existed in North America over time.

These judgments became the basic working assumptions of many archaeologists for decades.[2] This was especially true of those archaeologists working in eastern North America who typically recovered small copper objects on an infrequent basis. In this context, they accepted the idea that all Pre-Columbian copper artifacts were made by the same "primitive" methods utilizing native copper from one general area, the Upper Great Lakes (e.g., Willoughby 1935; Willey 1966; Fowler 1972). Further support was supplied by intermittent metallographic evidence (Frank 1951; Bastian 1961; Drier 1961; Root 1961; Schroeder and Ruhl 1968; Fraikor et al. 1971) that focused on technological similarity and consistency over time and space. An unfortunate outcome of these generalities was that many archaeologists regarded the few copper-based metal objects they found as little more than a convenient means by which to date their sites: native copper = "before Columbus," and smelted or alloyed copper = "Post-Columbus" (e.g., Ritchie 1969).

Beginning in the 1960s, changes in archaeological method and theory helped redirect research foci associated with native copper studies. For example, Binford (1962) questioned the functions of the large copper objects from the "Old Copper Culture" in Michigan and Wisconsin. Scholars such as Cyril Smith (1965) began to focus on the skillfulness rather than the "primitiveness" of ancient metalworkers in North America. It is possible that this shift in orientation by a well-known material scientist impacted subsequent interest in technological variation in North America (e.g., Franklin et al. 1981). Scholars also began to recognize that some of the uniformity attached to native copper sources and production methods was affected by the small number of archaeological and geological samples analyzed or, sometimes, by inappropriate instrumentation with poor standardization. These considerations dramatically influenced subsequent sourcing studies that now examine dozens to hundreds of samples rather than one to five (Goad 1978; Rapp et al. 1980; Rapp, Allert, and Peters 1990; Hancock et al. 1991). Attention to sample size and archaeological context of the samples is beginning for metallographic studies. Finally, some attention to the sociocultural constraints in which native copper was manufactured, used, and circulated began to develop. These are explicated in the next section.

The Significance of Native Copper to Native American Societies

Complex relationships exist between technology, culture, and society. In this section I consider what some of those relationships were, how they affected the impact of native copper on ancient societies in eastern North America, and the methods by which they are being explored.

The Source of and Accessibility to Copper Resources

As mentioned above, many archaeologists have assumed for decades that any native copper found on eastern North American sites came from the Upper Great Lakes where resources were abundant. Although some recognized the economic implications of using a distant source and devised models of native copper trade (e.g., Ritchie 1965), many others did not consider the possibility that some indigenous groups may have had choices of materials and that many factors could have shaped those choices. Some possible influences include: social alliances and obligations between groups; political constraints on access to copper resources, particularly the more isolated ones; the physical characteristics of copper from different sources; labor constraints; the existing tool kit to exploit the material; the availability of comparable goods with which to trade for copper; and ideological considerations.

A few of these factors have been explored intermittently over the years using experimental and laboratory methods as well as ethnohistory. For example, Clark and Purdy (1982) suggested that skilled metalworkers in the Southeast used criteria such as malleability to distinguish between sources and to select desirable raw materials. Another example is the 1666 Jesuit view of the relationships between native copper and the spirit world for the Native Americans who lived along the shore of Lake Superior. The following is from the writings of Father Claude Allouez (Rickard 1934:272):

> One often finds at the bottom of the water [Lake Superior] pieces of pure copper of 10 and 20 pounds in weight. I have several times seen such pieces in the savages' hands; and since they are superstitious, they keep them as so many divinities, or as presents which the gods dwelling beneath the water have given them, and on which their welfare is to depend. For this reason they preserve these pieces of copper, wrapped up, among their most precious possessions. Some have kept them for more than fifty years, others have had them in their families from time immemorial, and cherish them as household gods.

It appears that the belief system of these people strongly influenced the quantity of copper exiting their land and, possibly, to whom it went.

Sharon Goad (1976, 1978, 1979, 1980; Goad and Noakes 1978) conducted one of the first systematic studies that tested and validated some earlier suggestions (Martin 1933; Rickard 1934; Howe 1942; Hurst and Larson 1958) that more localized sources of native copper existed and were exploited in prehistory. She focused on native copper sources in the southeastern United States and found that, over time, indigenous groups changed their sources from the Upper Great Lakes to the Appalachian Mountains. This development may reflect changes in trade patterns, the materials used to mark social differences, local control over the distribution of valued goods, and local availability of native copper. Changes in raw material, in turn, may have affected local copper-working techniques owing to distinct differences in copper nugget sizes (Leader 1988).

The work of Rapp (e.g., Rapp et al. 1980; Rapp, Henrickson, and Allert 1990), Veakis (1979), Franklin (Franklin et al. 1981), and colleagues supported the finding that Native Americans exploited many sources of native copper in prehistory. Various groups, then, might have chosen their source of raw or finished copper from several options. Some of the cultural factors listed above may have affected the outcome of those choices in different ways for different groups.

Extensive sourcing work remains to be done in eastern North America. The relatively recent recognition that sizable native copper deposits exist in the Bay of Fundy in eastern Canada may radically alter previous models concerning the movement of copper within New England and southern Canada. A predoctoral study on the sources of native copper in the New England area is presently being supervised by George Rapp. Finally, as scholars abandon their assumptions that Native Americans were passive recipients of superior European metal goods, new questions beg to be answered. What were the sources of European metal? How did different Native American groups perceive and work it? Some important work concerning these issues is commencing (Bradley 1987; Hammell 1987; Fitzgerald and Ramsden 1988; Hancock et al. 1991; Bradley and Childs 1991; Leader 1991).

The Techniques and Skills of the Metalworkers

As researchers better understand the sources of native copper found at eastern North American sites, they must also investigate the local producers. Were objects found made locally or acquired as finished pieces? If made locally, what techniques were used and what was the skill level of the craftspeople? Was native copper production a specialized craft or open to anyone? Relatedly, what was the sociopolitical and economic position of the craftspeople? What was their gender? Attempts to answer these questions require recognition that the importance of native copper and its producers varied among indigenous groups over time and space.

Systematic attempts have been made only recently to examine cross-cultural variability of native copper working. Franklin and her colleagues (1981) conducted a path-breaking study in the North American Arctic and Subarctic to delineate patterns of intergroup relations as indicated by technological similarities or differences. Interestingly, their work revealed no striking differences in the primary techniques of native copper working, including folding, hammering, annealing, and hot working, over this very large area. They did find some intergroup variation in secondary methods, such as riveting, cutting, perforating, or grinding. Whereas Franklin et al. (1981) view these secondary techniques as design preferences, Leader (1988) considers differences in the frequency of and reliance on these methods as important markers of technological and cultural variation. This debate requires further investigation since various techniques and tools can be used to fold, rivet, or cut objects, while other cultural factors can influence what techniques were used. Ruhl's important study of over 500 Hopewellian earspools, using stylistic and metallographic techniques, indicated considerable manufacturing variation (Greber and Ruhl 1989:145). More metallographic and archaeological work is vital to a comparative perspective on native copper technologies and the cultural systems that supported them.

Recently, too, attempts have been made to give the Native Americans who worked native copper over the last 6,000 years some social and economic identity apart from membership in a general culture group. Leader (1988) considered whether or not craft specialists existed in three societies over time. He proposed, using archaeological, technometric, and archaeometric (xeroradiography) evidence, that native copper workers were craft specialists at the Hopewell site in Ohio during the Middle Woodland period and at Etowah mound in Georgia during the Mississippian period. The craftspeople from the two sites used different forming techniques, made different types of objects, and may have held different positions within their societies.

To date, we have very few details about the social, political, and economic positions of native copper workers in different Native American cultures. Careful attention to archaeological clues, particularly at burial and workstation sites, must be a priority during future excavations at appropriate sites. Furthermore, it is well known that ritual was often an important component of preindustrial metalworking throughout the world. Evidence of ritual associated with native copper working at Native American sites may exist, especially since there is increasing ethnohistoric evidence for linkages between shamanism and native copper in some indigenous cultures.

The Social Functions and Value of Copper

The ultimate outcome of obtaining raw native copper and applying various manufacturing skills to it is to create an object that has purpose and meaning within a culture. The hypotheses pertaining to the functions of native copper in North American prehistory have a curious history. Whereas in most parts of the world metal first appears in the archaeological record as small, ornamental items, some of the earliest native copper objects from North America were the large celts, knives, spears, and piercing tools of the Old Copper Culture[3] around the Upper Great Lakes. Researchers long believed that the objects were made for utilitarian purposes, given their sizes and shapes and the local availability of raw native copper. Hypotheses followed that groups valued the metal, and the farther away they lived from the Upper Great Lakes, the less likely they were to use it for utilitarian purposes. The small size of most native copper objects found well away from this region has been used to support this idea. As researchers recognize a wide variety of native copper sources in prehistory, that Native Americans probably had choices, and that many cultural factors influenced the use(s) of an object, they are reconsidering the simplistic model which linked object function, value, and resource availability.

Binford (1962) was one of the first to question these ideas. He proposed that copper had social value to members of the Old Copper Culture, and they used the large objects as symbols of achieved status in an egalitarian society. Father Allouez's statement in 1666, quoted earlier in this section, indicates that Native Americans who lived near Lake Superior greatly revered copper and associated it with the spirit world. Clearly, distance to the source of raw material did not shape the way the metal was conceived by that culture group or probably by others.

Metallography, a laboratory technique that is woefully underutilized in native copper studies, is useful to the question of function. Systematic and preferential work hardening on certain portions of "tools" such as blade tips provides some solid evidence that the objects were intended for serious work. Vernon's study of thirty-five Old Copper Culture objects[4] supported Binford's hypothesis, since many more items were left in a fully annealed state than work hardened (Vernon 1986; Dunbar and Ruhl 1974). Leader (1988) refuted Vernon's findings based on experimental work. He proposed that the spear blades were intentionally annealed for utilitarian use because, in the work-hardened state, they quickly and permanently broke after a few stabs. An annealed blade could be reshaped after bending and then reused. This debate will be resolved only with more metallographic and experimental data. It is also imperative that objects from well-provenienced archaeological contexts be examined.

Many of the native copper objects found in eastern North America, particularly in the northeastern United States and southern Canada, are small and probably once served as "ornaments." The most prevalent object type found at Late Archaic through Late Woodland period sites in this region is rolled beads. The social, ceremonial, and ritual functions of beads are potentially large, however, and need to be carefully considered. While the archaeological context of native copper objects such as beads is critical to interpreting their social function and apparent value in a society, metallography can provide additional insight by examining the skills and effort used in their manufacture. The process of making rolled beads has been variously described and tested (Smith 1965; Schroeder and Ruhl 1968; Clark and Purdy 1982). Some scholars may generalize about the skills used to make these seemingly simple objects, but significant technical variation might have existed. An effort must be made to analyze these items and to build up a bank of metallographic data from well-provenienced contexts for comparative study.

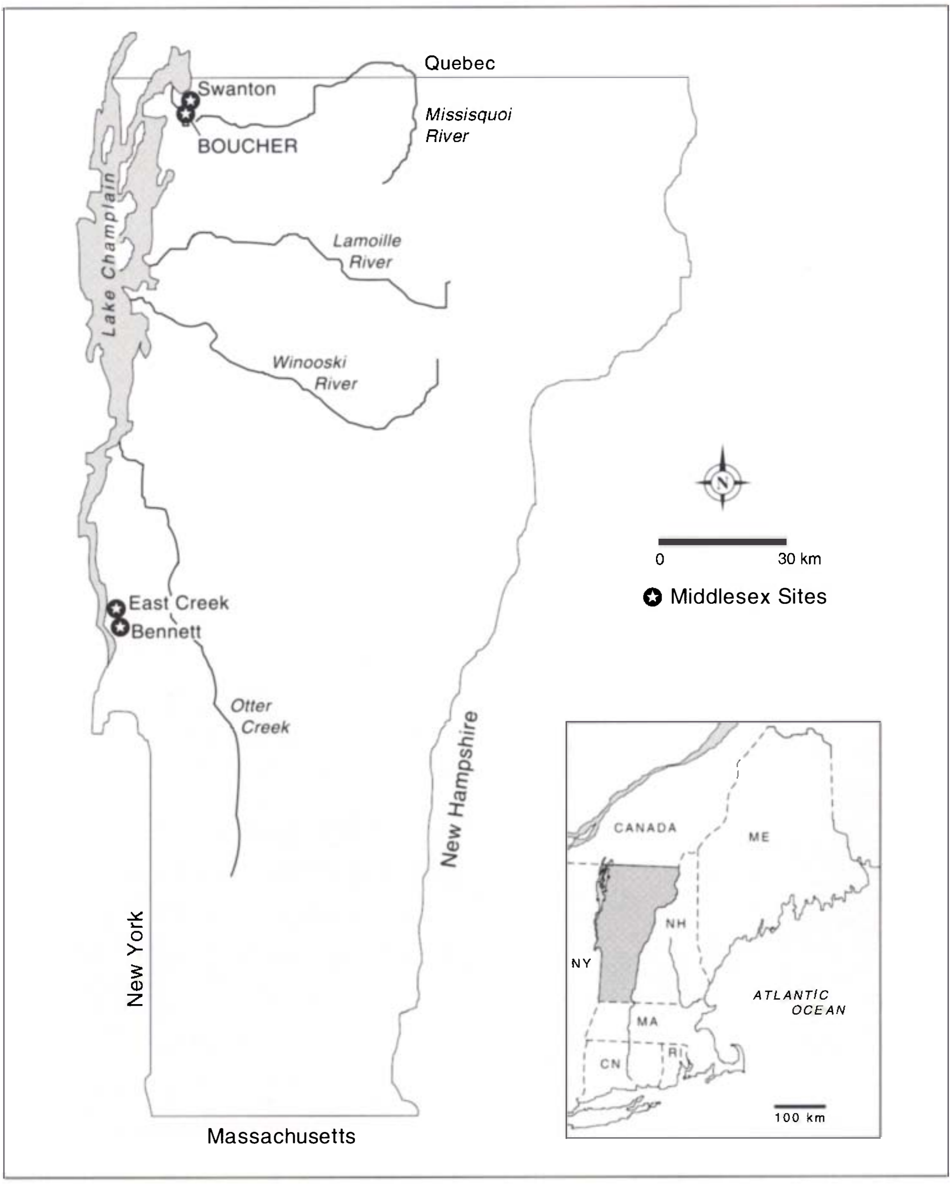
Two Case Studies From the Northeastern United States

Two Native American groups who used copper in the northeast are the foci of the final section. I selected these case studies because many archaeologists do not associate them with copper. This is because it is found intermittently at related sites or due to misconceptions concerning its local production or use. These studies also contribute to our understanding of the range of technological and cultural variation associated with metal use in North America.

The Boucher Cemetery and Early Woodland Peoples in Vermont[5]

The people buried at the Boucher cemetery in northern Vermont (Fig. 1) were foragers and hunters who lived in a roughly egalitarian society between 900 and 100 B.C.E. The variation, quantity, and preservation of the burial goods at Boucher are

Figure 1. *Map locating the Boucher cemetery site in northern Vermont. The Carnegie Museum of Natural History, Pittsburgh.*



impressive, particularly the copper and textiles. Of interest here is the large number (over 6,000) of native copper objects recovered in the burials and the opportunity they provide to investigate several important questions. These include identification of the source(s) of native copper found on northeastern sites, who made the objects, and what skills and techniques were used. Some tentative answers can be provided with metallographic and chemical analysis of selected Boucher artifacts, as well as comparisons with the data of other scholars. The archaeological context of these objects, however, is critical to this investigation and is presented first.

While the artifact assemblage, exotic material types and burial patterns at Boucher share common features with many northeastern sites, Heckenberger and colleagues (Heckenberger, Petersen, and Basa 1990; Heckenberger, Petersen, Basa, Cowie et al. 1990) argue that these features were initiated locally during the Late Archaic period (4000–1000 B.C.E.). Early Woodland trade networks, in which exotics may have circulated from as far west as Ohio, as far north as Quebec, and south of Cape Hatteras, were established during the Late Archaic and then broadly expanded. Evidence for the wide circulation of diverse goods during the Early

Woodland has resulted in the somewhat misleading model that considerable cultural uniformity existed throughout this area.

Figure 2. *Native copper strips and nuggets in a textile bag from the Boucher site. Length approximately 58 mm. The Carnegie Museum of Natural History, Pittsburgh.*

A minimum of eighty-four burial features, both interments and cremations, were found at the Boucher cemetery and copper was recovered in approximately half of these. Most of the finished copper were rolled beads, except for one awl with a wood handle (Heckenberger, Petersen, and Basa 1990:fig. 5). Native copper nuggets and strips were also found in a textile bag (Fig. 2), but from a burial with no preserved skeletal remains. Another copper nugget was recovered with a male individual, probably a young adult. The beads fit into three categories based on their size and shape (Heckenberger, Petersen, and Basa 1990:187). Type I beads, the most numerous, were made from hammered strips of varying thickness that were rolled so the ends either overlapped or abutted (Fig. 3). There are three general sizes of these beads, each of which varies from 1.5 to 10 mm in length. Type II beads are long cylinders of rolled sheet that vary in length from 10 to 181 mm (Fig. 4). The four Type III beads found were made from native copper nuggets and were probably rolled (Fig. 5).

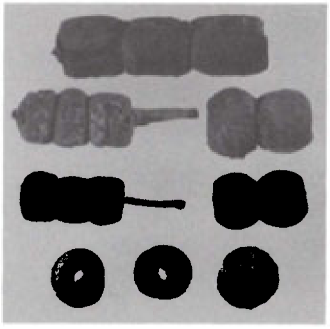
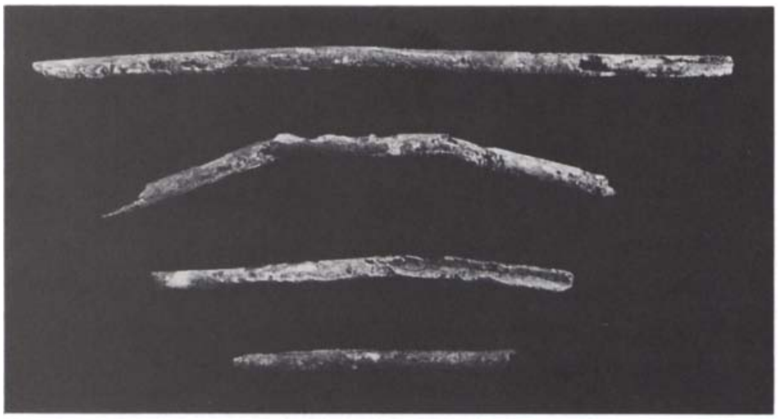


Figure 3. *Different sizes of Type I beads. Total length of the top row of beads: 33 mm. The Carnegie Museum of Natural History, Pittsburgh.*

The researchers (Heckenberger, Petersen, and Basa 1990; Heckenberger, Petersen, Basa, Cowie et al. 1990) argue that copper and personal adornment in general signaled group affiliation, particularly of individuals whose bodies were still recognizable at final interment, rather than achieved status or wealth. Interred individuals of all ages and both sexes had copper beads. In fact, over 80% of the primary interments (buried "in the flesh") included copper beads as opposed to the cremations and secondary (disarticulated) interments that seldom contained beads. Another outcome, intentional or not, of burying the copper and other exotics with the dead was to create a continued demand for the materials that maintained trade and social networks (Heckenberger, Petersen, and Basa 1990:213).

The proposed relationships between the copper beads and trade lead to questions of sourcing. Did the Boucher copper come from local or distant sources? If distant, did they come from the large sources to the west around the Upper Great Lakes, from the northeast along the Canadian coast, or from closer locations? Did the source(s) change over time? Were the different bead types manufactured in the same place or of the same materials? Many of these questions can be answered by chemical analysis of a representative sample. George Rapp is supervising such a study using atomic absorption analysis.

Figure 4. *Various Type II beads. Length of longest bead (top): 181 mm. The Carnegie Museum of Natural History, Pittsburgh.*



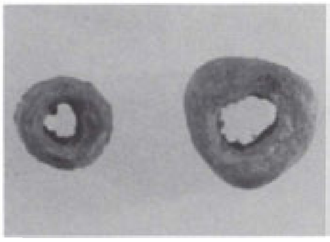


Figure 5. *Type III beads. Length: 14 mm (left bead), 18 mm (right bead). The Carnegie Museum of Natural History, Pittsburgh.*

The question of whether or not the numerous beads were made locally is difficult to assess at this time, although the bag of copper nuggets and strips, representing initial and intermediate stages of production, is good evidence of some local manufacture (Heckenberger, Petersen, and Basa 1990). Metallography, however, can be used to determine the fabrication techniques and skills employed, to suggest if changes occurred over time, and to consider technological variability and local adaptation over time and space through comparisons with other North American data sets.

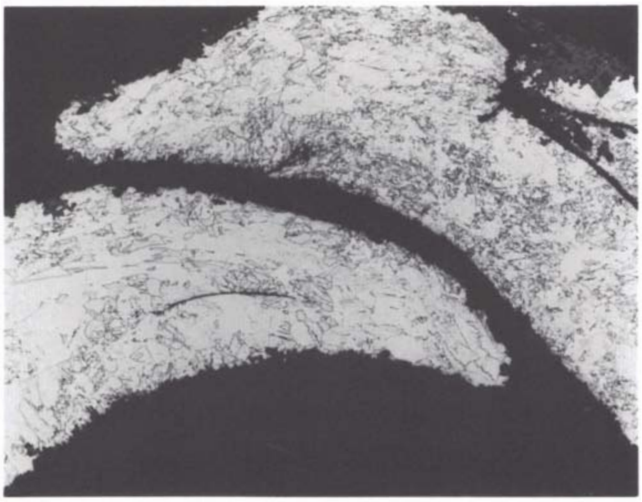
To date, I have performed metallographic analysis on twelve Boucher beads.[6] These were selected to represent the various bead types and sizes, although corrosion and the uniqueness of some objects prevented their analysis. Thus, eleven Type I beads, one Type II bead, and no Type III beads were studied. Six came from burial contexts that have firm dates between approximately 735 and 115 B.C.E.

Figure 6. *Bead from Feature 94A dating to 715 ± 20 B.C.E. Length 6 mm, width 7.5 mm, sheet 1–1.75 mm thick.*

The metallographic evidence indicates that the beads were skillfully made by various combinations of hammering, folding, annealing, hot forging, and cold working. Since different sequences of manufacturing techniques were evident, it is useful to begin with the beads from dated contexts. The two earliest beads, one dating to circa 715 B.C.E. (Fig. 6) and the other to circa 670 B.C.E., were made from strips of copper sheet that varied somewhat in thickness. Some of this variation was due to hammering, but the sheet was also thicker where it had been folded back on itself (Fig. 7). In fact, the practice of folding thin pieces of sheet back onto the main body is repeatedly found and suggests that no extra bit of copper was wasted or cut off. The copper workers also made a concerted effort to focus this folding onto one surface of the sheet. When they rolled a strip of copper, they placed the surface with the folds on the interior of the bead coil (Fig. 8). The only exception in the study group is the oldest bead.

Several other features are present among the early beads. First, care was taken to taper the ends of the strips prior to sequences of annealing and rolling. Second, both beads show a minimal level of cold working that was required to overlap the strip ends (Figs. 7, 8), as well as some residual flow structure from cold hammering prior to the final anneal. The last annealing stage was not taken up either to a sufficiently high temperature or for a long enough period of time to fully recrystallize the grains. A third feature is that neither bead has a yield point indicative of stress

Figure 7. *Overlapping ends of bead from Feature 94A showing where sheet was folded back on itself to make the outer surface. Magnification 17×. Hydrogen peroxide-ammonium hydroxide etch.*



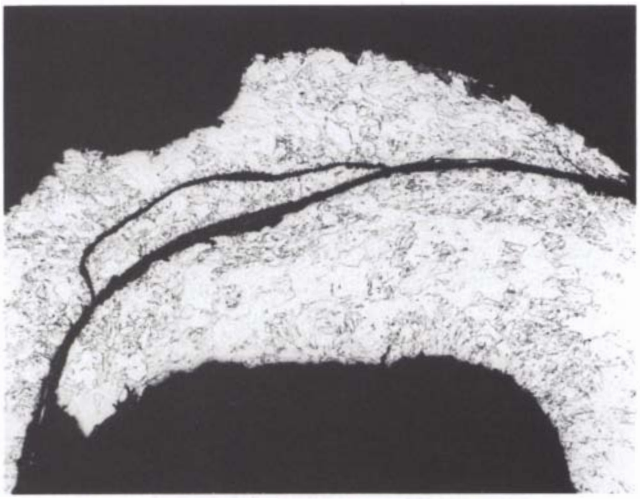


FIGURE 8. *Overlapping ends of bead from Feature 107 dating to 670 ± 95 B.C.E. showing a flap of metal folded onto interior surface of bead. Magnification 17×. Hydrogen peroxide-ammonium hydroxide etch.*

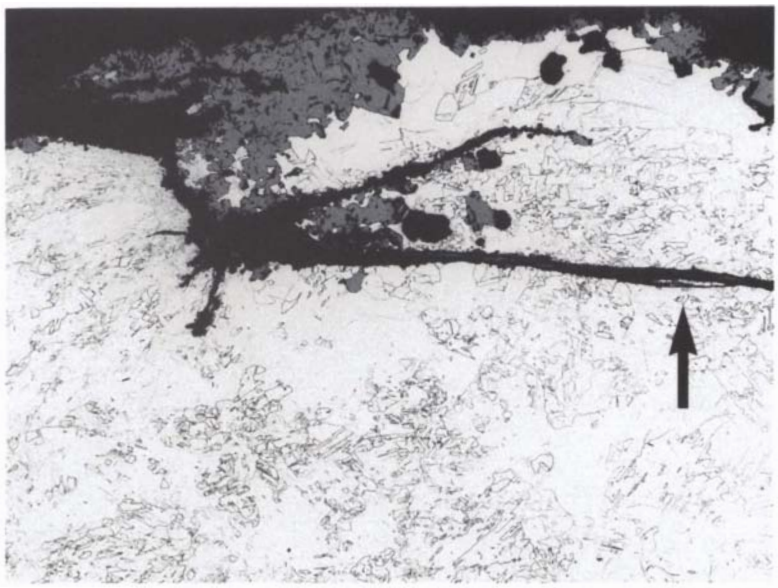


FIGURE 9. *Possible hammer scale (see arrow) lodged in crack between layers of bead from Feature 94A. Magnification 43×. Hydrogen peroxide-ammonium hydroxide etch.*

incurred during bending and rolling. This is interesting since the majority of reported native copper beads have yield points (Smith 1965; Clark and Purdy 1982; Leader 1988). The final feature of these two beads is the presence of possible hammer scale lodged in the fold cracks, although this is best illustrated in a later bead (Fig. 9). These exceptionally thin sheets of copper probably developed as the metal was heated, annealed, reheated, quickly hot forged, and later reannealed. This is based on limited experiments with pressure welding copper (Childs 1991:fig. 8c) and the observations of Clark and Purdy (1982) of the black scale that develops during annealing.

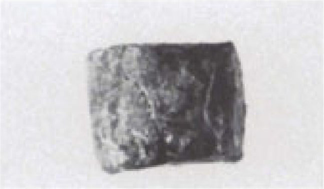


FIGURE 10. *Type I bead from undated Feature 58. Length 3 mm, width 4 mm, sheet 1 mm thick.*

Many of these features are present in the four other dated beads, except for the residual flow structure, which is generally less noticeable. Several undated beads also deserve mention. A Type I (Fig. 10) bead and a portion of a Type II bead were analyzed from the same grave, a composite burial of an interred infant and a cremated young adult. Although it is possible that the large annealed grains in both beads resulted from heat during cremation, the slightly bent annealing twins in both suggests that the sheets were well annealed prior to rolling, which is when some twins were altered. The Type I bead also shows extensive folding and some grain recrystallization over possible pressure weld lines (Fig. 11). One small, thin (0.6 mm) bead was rolled in an entirely cold-worked state (Fig. 12), yet no obvious yield point is evident. Furthermore, despite its thinness, the sheet seems to have been made by repeated folding. This is indicated by some residual grain structure that flows in different directions on either side of a hairline crack or possible pressure weld line (Fig. 13).

The most interesting bead is large, thick, and somewhat irregular in shape (Fig. 14). Visual inspection prior to sectioning revealed two possible seam lines, suggesting that the bead consisted of two pieces of metal. Metallography verified this hypothesis. Each metal piece was heavily folded and layered. The craftsman made the final bead by inserting the somewhat tapered end of the smaller piece into the opened layers of the larger piece (Fig. 15). The flaps of thin sheet were then hammered around the smaller piece. While this was probably done when the metal was hot to maximize the chances of metal fusion or pressure welding between layers, the finishing touches to round the metal into the bead form and to smooth out the exterior surface were done by cold working.

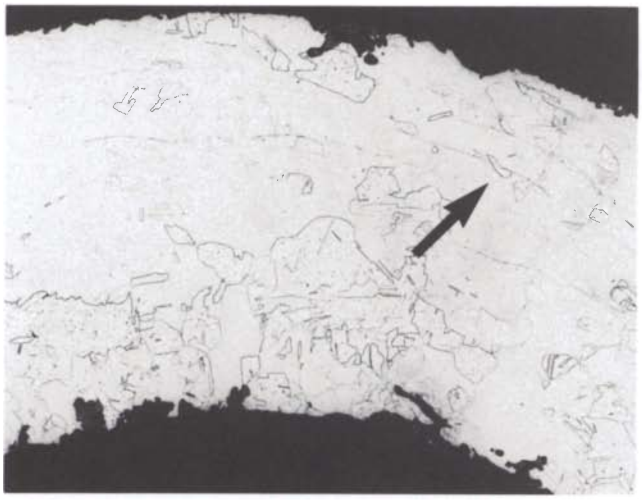


FIGURE 11. *Large annealed grains in bead from Feature 58. Thin, probable pressure weld lines with grain growth across (see arrow). Magnification 36×. Hydrogen peroxide-ammonium hydroxide etch.*

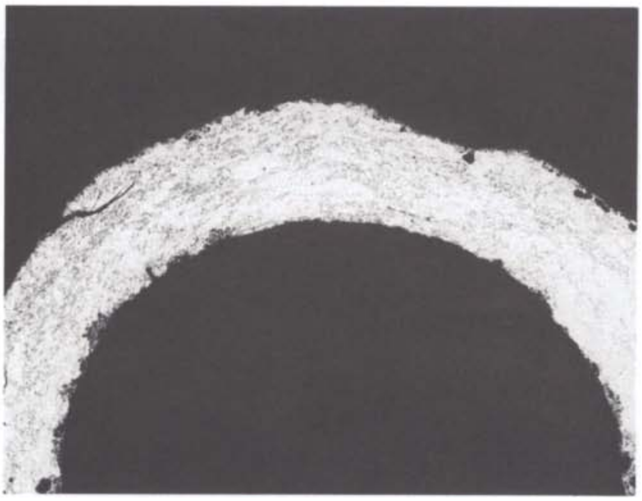


FIGURE 12. *Half of bead from undated Feature 60 showing grain formation in cold-worked state. Magnification 18×. Hydrogen peroxide-ammonium hydroxide etch.*

FIGURE 13. *Close-up of bead microstructure from Feature 60 showing distinct layers demarcated by thin pressure weld lines and grain elongation in different directions. Magnification 88×. Hydrogen peroxide-ammonium hydroxide etch.*

Figure 14. *Large, somewhat irregular bead from undated Feature 64. Length 7.5 mm, width 10 mm, 2–3 mm thick sheet.*

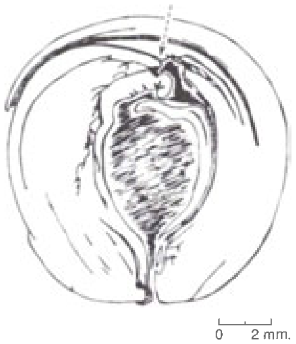


Figure 15. *Cross-sectional sketch of bead from Feature 64 showing where the tapered tip of the smaller piece (see arrow) was positioned between the layers of the larger piece. Length 10 mm across the section.*

The Early Woodland period craftspeople who hammered, folded, hot forged, and annealed these native copper beads were skilled but did not follow a set sequence of methods. The evidence also suggests that this technology may have been adapted to work small pieces of raw native copper. It is now useful to compare these findings with those from other culture areas in order to consider questions of technological variability, localized adaptations, and the spread of the craft.

The study of Franklin and her colleagues, mentioned earlier, is the most comprehensive and suitable one for comparison (Franklin et al. 1981; Franklin 1982). Their research goal was to explore technological variability among copper-using cultures in the western Arctic and Subarctic North America over the last 4,000 years. They note that significant production and use of native copper did not occur until the last millennium[7] when various culture groups exploited local sources of native copper. After subjecting some 350 objects to visual inspection, radiography, chemical analysis, and/or metallography, they find that considerable technological uniformity existed over the area and over time. They characterize the technology as one based on folding and annealing, very similar to that found at the Boucher site. Another similarity is the small size of most of the objects from the two areas.

Franklin's (1982) conclusion that the Arctic and Subarctic cultures developed a "unique" technology needs to be rethought in light of the Boucher data. There is also evidence that folding was a component of native copper working in the Upper Great Lakes region as early as the Old Copper Culture (Vernon 1986) and as recently as the Late Woodland period. Some of the Late Woodland native copper artifacts found at the Juntunen site, located along Lake Huron in Michigan, were made by hammering several individual sheets together or by interlocking two sheets as they were rolled together and hammered (McPherron 1967).[8] All of this evidence, then, suggests that a technology based on folding, annealing, and hot and cold working was used by different populations over a large geographic area and for several millennia. The Boucher beads site probably represents a very early manifestation of this technology which, in contrast to the large objects of the Old Copper Culture, was focused on some of the smallest, most delicate objects studied thus far.

Other metallographic data can be considered to determine the extent of this technology over time and space. Native copper beads have been intermittently found at Early and Middle Woodland period sites along the New England coast. Hunters, fishermen, and foragers who lived in semipermanent settlements possessed beads similar to Type I (Fig. 16) and Type II from Boucher. To date, I have analyzed two beads from Cape Cod in Massachusetts as we commence a regional assessment

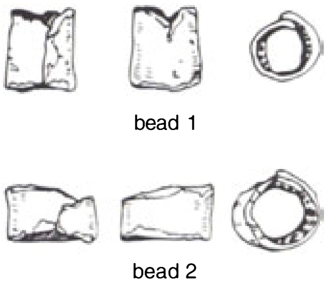


Figure 16. *Type I beads from 19-BN-390 site on Cape Cod found in a context dated to 350 ± 130 C.E. Dimensions of first bead (top row): length 14 mm, width 11 mm. Dimensions of second bead (bottom row): length 9 mm, width 16 mm.*

of native copper production and circulation in coastal New England. In both cases the sheet was hammered out very thinly (0.6–1 mm thick) and the ends were slightly tapered. The large, twinned grains of the sheets reveal that they were well annealed prior to rolling (Fig. 17), although one bead has some residual strain from previous cold work. There is no evidence of extensive folding for either bead, although it is possible that they were subjected to brief episodes of hot working. There is a line of cuprous oxides at the tip of one bead where the metal may have been slightly worked after being overheated. The other bead has a small crack that was partially fused (Fig. 18).

These latter observations suggest that some technological variability existed over time and space in a broad region, particularly in terms of the relationships between certain techniques and certain sizes and types of objects. Although we still do not know who made the various beads at the sites discussed nor their sources of native copper, these data force us to consider why technological variation might have existed. It may reflect different technological styles of production, various types of raw materials used, differing levels of demand for copper, or something about the spread of technological knowledge and/or experts. The data also compel us to analyze the microstructure and chemistry of many more excavated beads from coastal and interior sites to attain a broad regional view of technological variability.

The Iroquois After the Arrival of Columbus

The second case study is significant because it concerns adaptive responses to new influences that were founded on long-standing ideas and technological practices.

At about the time of European Contact, the Iroquois who lived in present-day New York state had established a confederacy that brought together several culturally related groups. These people occupied large, permanent settlements, intensively cultivated maize, fished, exploited numerous local resources, and had well-developed traditions of pottery and pipe making. In contrast to only a generation or two before, they elaborately decorated their vessels, had more visible rituals, and used objects made of exotic materials, such as native copper and shell. The Iroquois groups had had virtually no contact or trade with outside areas from the Late

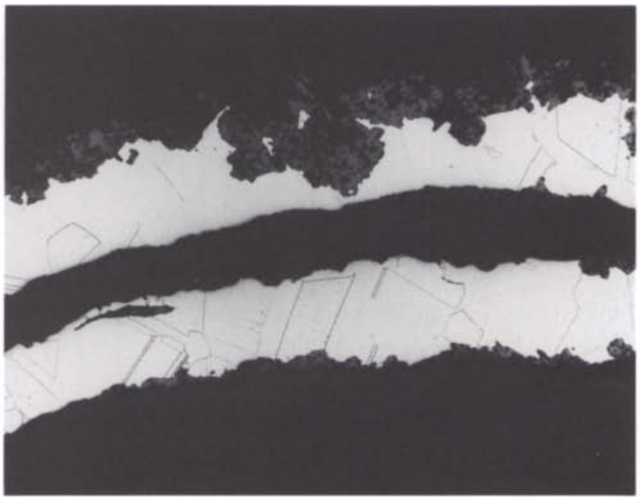


Figure 17. *Large annealed grains in the Type II bead from Boland's Pond site on Cape Cod. Magnification 36×. Hydrogen peroxide-ammonium hydroxide etch.*

Figure 18. *Partial fusion of a crack found in the Type I bead from the 19-BN-390 site in Eastham on Cape Cod. Magnification 72×. Potassium dichromate etch.*

Middle Woodland period, at approximately 1000 C.E., until the mid-fifteenth century. The resurgence of items made of native copper and shell into the material assemblage of the society may reflect shifts in access to power and wealth within the tribally based society (Bradley 1987:42).

By the mid-sixteenth century, more changes in Iroquois lifeways occurred. I concentrate here on the rising incidence of copper in the region and focus on the occurrence of certain copper forms: hoops and spirals. These objects are interesting for several reasons. First, they occur almost exclusively on sixteenth-century Iroquoian sites. Second, they are typically described in the literature as European objects made for trade. Witthoft, for example, described hoops as "metal rings from rigging," while "spiral brass earrings, worn in the left ears of Indian burials represent[ed] a direct transference of the ancient sailor's caste mark . . . against bad eyesight" (Witthoft 1966:204–5). Third, the Iroquois are not well known for metalworking.

The distribution of hoops and spirals are strongly associated with burials located along river drainages occupied by the Susquehannock and Five Nations Iroquois during the sixteenth century (Fig. 19). The objects were carefully

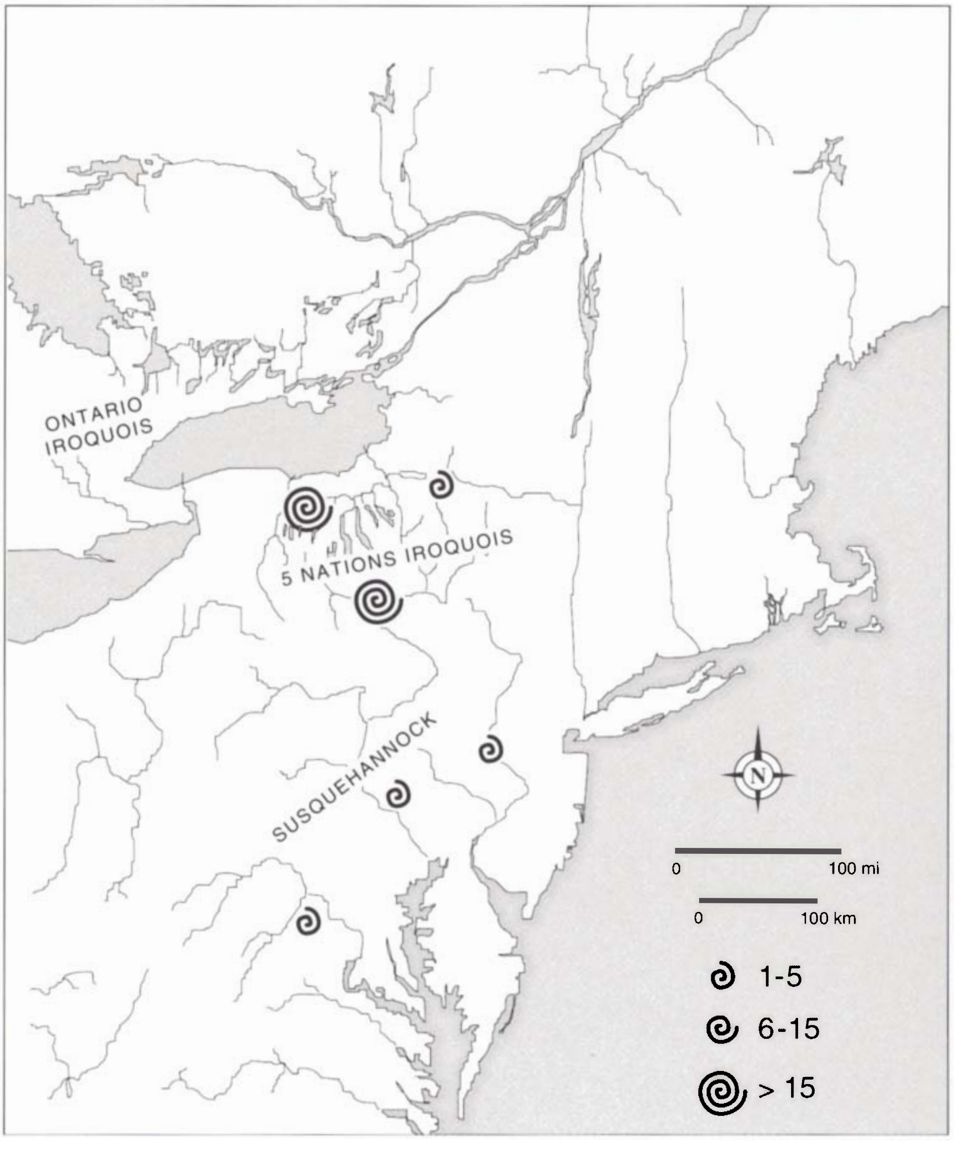


FIGURE 19. *Map of the distribution of spirals and hoops in upper New York State prior to 1575 C.E.*

Figure 20. *Tight spiral from the Dwyer site, New York. Diameter 12.5 mm.*

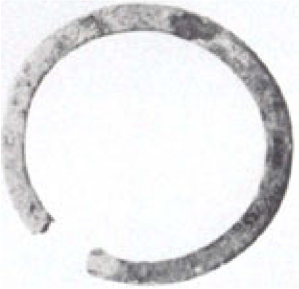


Figure 21. *Hoop from the Adams site, New York. Diameter 82 mm.*

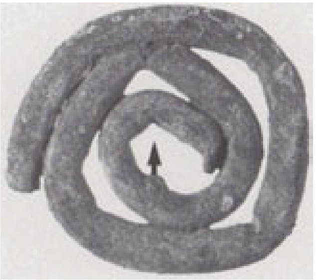


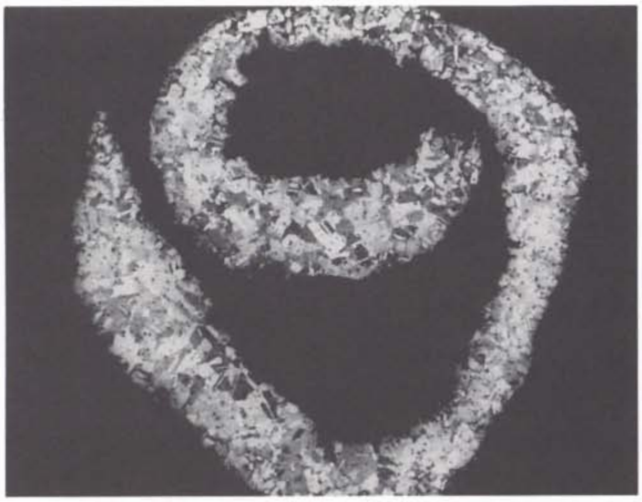
Figure 22. *Spiral from the Adams site, New York, showing several yield points (see arrow) that developed as the rolled tube was spiraled. Widest diameter 20.5 mm.*

positioned in the burials. Spirals were usually placed on or near the temporal bones, thus their designation as "ear rings." It is likely that they were used for hair or ear ornaments as well as pendants. Hoops were most often placed in the neck or chest area. These items occurred in about 5% of the burials with no preference to a person's age. By the early seventeenth century, the frequency of spirals and hoops declined, although their distribution spread to the Ohio River. While the positioning of these objects remained about the same, they appear to be associated with infants and children. They largely disappear from the archaeological record by about 1625, at a time when copper and brass objects of both European and Native manufacture were increasingly common.

The specific temporal and geographical distribution of the copper hoops and spirals and their strong cultural associations to the Iroquois require explanation. Four objects, three spirals (one of which is shown in Fig. 20) and one hoop (Fig. 21), from two late sixteenth-century sites were subjected to visual, metallographic, and chemical analysis to determine how they were made, of what kind of metal(s) they were made, and by whom. In general, the spirals and hoops were made by rolling a rectangular strip of thin sheet into a tube and tapering the ends, although the hoop consists of two sheets of copper rolled together. The tubes were then bent into circles or spirals. One spiral has several yield points indicating that the rolled tube was not sufficiently annealed prior to bending (Fig. 22). Care was taken to finish the objects since the seams were always smoothed out and the entire object was sometimes gently flattened.

Metallography of sections removed from the ends of each object revealed the characteristics of the sheet and the way it was rolled into a tube. The thickness of all the copper sheets varied slightly, undoubtedly produced by hammering. In three of the four objects, the original strip was well annealed prior to rolling since yield points were absent (Fig. 23). The presence of large annealed grains in all the sections suggests that the objects were typically annealed after spiraling or bending into a circle. The finishing touches, such as gently flattening the object or tapping down the seam, sometimes resulted in bent twins or the presence of slip bands.

Metallography and chemistry provided data on the source of the metal. All the objects contained numerous rounded inclusions, indicating that none was made from native copper. In one case I identified cuprous oxides (Fig. 24), often associated with smelted, relatively pure copper, with a polarizer. I analyzed another spiral on a scanning electron microscope and found appreciable amounts of lead in the inclusions. When portions of these objects, plus three other samples (two spirals and a copper kettle fragment), were subjected to atomic absorption analysis, two groups of materials were revealed (Table 1). Most of the objects were made of brass of varying zinc content, while two objects were of high-purity smelted copper. These two groups correspond to two exchange networks that were operating in the area by the middle-late sixteenth century. One was a Basque network that brought "kettles of red copper" (Turgeon 1990:85) from Biscay ports to the Canadian Maritimes. The second network, possibly of Norman sailors, appears to have brought brass to the mid-Atlantic coast.



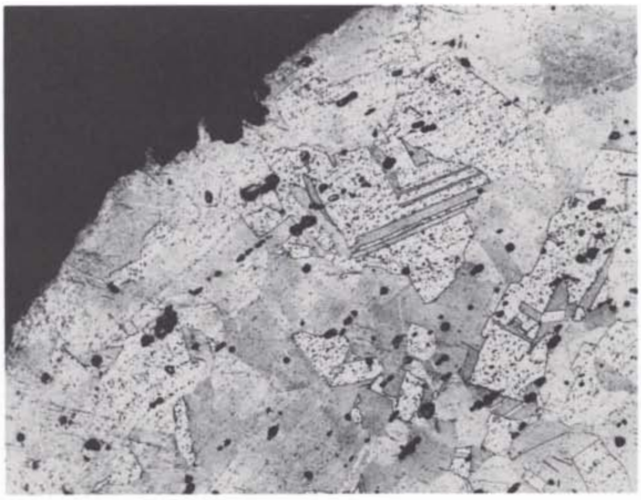


FIGURE 23. *Cross-sectional view of an end of a spiral from the Adams site. Magnification 12×. Potassium dichromate etch.*

FIGURE 24. *Numerous cuprous oxides in the relatively pure copper from the Dwyer site. Magnification 72×. Potassium dichromate etch.*

The evidence suggests that the spirals and hoops were made from European materials and that care was taken in fashioning the objects; but who made them? Three lines of reasoning support Native peoples rather than Europeans. First is the fact that different metals were used to manufacture the same forms at the same site. If the objects were European products, their distribution would be expected to coincide with the spheres of influence of the trading groups. Instead, their distribution seems to reflect the eclectic nature of indigenous networks that drew on many sources. The second line of evidence is that the techniques used—hammering sheet, rolling one or two sheets, and annealing—have been documented among Pre-Contact groups (see Dunbar and Ruhl 1974 for a similar argument). Metal trimmings and partially completed objects have also been found on Iroquoian habitation sites (Bradley 1987). Also, no evidence of metal tools or joining techniques, such as brazing, have been revealed to indicate European manufacture. The final argument for native production is that it helps explain the observed variation in the forming

TABLE 1. *Chemical analysis*[a] *of Iroquoian objects by atomic absorption.*

Sample No.	Cu[b]	Zn	Sn	Ag	Pb	Ni
Seneca						
76/94	73.59	25.14	IS[c]	0.027	0.85	0.24
178/94	81.47	16.73	1.31	0.069	0.25	0.02
526/94	67.86	30.69	0.03	0.027	0.98	0.26
Susquehannock						
LA9/134	81.90	13.59	3.26	0.12	0.68	0.09
LA9/183	88.44	10.98	IS	0.06	0.48	0.04
Onondaga						
DW-1	99.38	0.04	IS	0.08	0.30	0.05
CZA5-3	99.74	0.003	0.003	0.06	0.16	0.03

[a] Weight percentages.

[b] Calculated by subtraction. Value tentative given that insufficient sample was available to determine the weight percentages of all elements tested.

[c] Insufficient sample.

techniques, sizes, and final forms of the hoops and spirals. Greater uniformity in the fabrication techniques and final forms is expected if they were European-made, particularly in contrast to the technical variability commonly found in assemblages of Pre-Columbian native copper objects (for example, the Boucher assemblage presented here).

If the evidence is accepted that spirals and hoops were the product of Native American craftspeople who used materials of European origin, the final question begging an answer is What did they mean to the local society? Researchers have long assumed that these objects were European in both material and concept; their value was deemed to lie in their European origin (Witthoft 1966). The forceful evidence that spirals and hoops were conceived and made by Native Americans suggests that they were traditional forms that drew their meaning and power from long-standing native beliefs and cosmology. Recent studies indicate that the first Europeans to arrive in Iroquois country were seen as returning culture heroes, as man-beings from another world who brought with them a wealth of Under(water) World materials. Native Americans equated copper-based metals and glass, although trinkets to the Europeans, to the traditional substances of life-enhancing and life-restoring power, such as native copper and quartz crystals (Hammell 1987). At Early Contact, then, Native peoples saw Europeans and their exotic material wealth as a part of their own world.

It is possible that the spirals and hoops were a material product of this initial native response, which also involved a revival of copper in healing practices and its traditional guardian, the Underwater Panther. Ethnohistoric descriptions from the eighteenth and nineteenth centuries describe this creature as powerful and catlike; it had horns and a long, spiral tail that was made of or covered with copper scales. Those lucky enough to own a piece of copper from the Panther's tail had a possession of great healing power (R. Phillips 1986:29–30). The presence of spirals and hoops of Native American manufacture in the Early Contact period burials, then, might have been an attempt to invoke the power and protection of the Underwater Panther as new diseases began to impact local populations. The associations after 1575 between these forms and young children, who were least able to protect themselves from disease, are striking.

The hypotheses offered as to who made the spirals and hoops and what they meant to the Iroquois require more testing. The present sample subjected to metallographic and chemical analysis is small and the ethnohistoric data are incomplete. The propositions are stimulating, however, and expose the new directions that scholars can explore if they do not succumb to old assumptions and misconceptions.

Conclusions

While in 1992 many people celebrated the quincentenary of Columbus's arrival in the Americas, the recent efforts to investigate native copper production and use as a dynamic aspect of many Native American cultures for some 6,000 years should also be applauded. It is clear that native copper was significant to the economic, social, political, and ideological systems of many societies in eastern North America for millennia. Various manufacturing techniques were in use and many native copper products were skillfully made. Much later, not only did the copper technology survive Contact, it flourished as Native Americans actively sought out newly available raw materials. Indigenous peoples used traditional fabrication techniques to work European smelted copper and brass in order to create ancient forms with traditional meanings.

These findings are the products of new research directions oriented toward the relationships between technology, culture, and society in North America and the application of more sophisticated laboratory methods to available archaeological materials. Although it is clear that considerably more work needs to be done, the recent efforts synthesized here provide some important contributions toward correcting the injustices and misconceptions that Native Americans have endured since the arrival of Columbus.

Acknowledgments

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Notes

1. Fairly typical of the questions asked is that of Hoy's in 1879: "Did these rude people possess the skill and intelligence requisite to cast articles of pure copper?" (1908:169).
2. For example, Snow recently stated that "Late Archaic makers of copper tools were not practicing true metallurgy" since they merely hammered and annealed native copper nuggets (1980:223).
3. This "culture" dates to 4000–1000 B.C.E. and is associated with the Late Archaic period.
4. Unfortunately, these objects were taken from poorly provenienced surface collections.
5. The following discussion is based on published (Heckenberger, Petersen, and Basa 1990; Heckenberger, Petersen, Basa, Cowie et al. 1990) and unpublished information from the project coordinators, James Petersen and Michael Heckenberger. They also kindly allowed the author to cut up a number of beads toward a more complete history of Native American technology.
6. This is a large sample compared to most metallographic studies accomplished to date on well-provenienced objects. Since this sample size is truly small, it underscores the need for large-scale metallographic projects that can more adequately address questions of technological variation and change.

7. This period of time would be comparable to the Late Woodland in the northeastern United States.
8. This site is one of the few known native copper workstations from the Late Woodland period. It is a significant site because it contains little evidence of copper working prior to approximately 750–1200 C.E., when maize agriculture became important, ossuary burials appeared, settlement patterns changed, and zones of ceramic styles shifted (McPherron 1967).

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Biography

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Chemical Seriation of Northeastern North American Archaeological Sites Using Copper Artifacts

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In the absence of applicable absolute dating techniques, archaeological materials can sometimes be used to help establish a relative chronology. Such an opportunity arises in northeastern North America at the time of contact between the first European explorers, traders, and settlers and the local aboriginal peoples. Archaeological evidence for European contact is usually established with nonindigenous in situ archaeological materials, but this evaluation is often complicated on sites by the nonsurvival of physical evidence in the form of other diagnostic artifacts.

Earlier work by Hancock et al. (1991a, 1991b) on Ontario copper-based materials suggests that a chemical seriation model for copper artifacts may be applied to select northeastern North American archaeological sites. This relative dating method uses elemental chemistry to establish whether an item is made of native copper or is of European origin. The model is based on the principal that the relative abundance of native copper and European smelted copper, brass, or bronze can, when combined with good context and supportive data, provide a chronological indicator. We present limited data from sites in Ontario to substantiate our claim that a model of chemical seriation is a reasonable approach to take in attempting to solve late sixteenth- and seventeenth-century site chronology problems. It is beyond the scope of this paper to address other anthropological issues to which our data may prove contributory. Issues such as trading patterns, cultural preference for particular materials, resistance to the introduction of new products, group identity through jewelry, and burial items are research questions that this paper contributes to but cannot address directly.

Analytical Procedure

Ninety-seven copper-based metal samples from nine different archaeological sites in Ontario (see Table 1) were analyzed by instrumental neutron activation analysis at the SLOWPOKE (Safe Low Power Kritikal Experiment) Reactor Facility at the

Table 1. *Archaeological sites in Ontario from which samples were taken.*

Sample No.	No. of Samples	Site	Borden No.	Period
1–18	18	Farquar Lake, Haliburton District	BgGn-1	Archaic
19–43	25	McCollum, Thunder Bay District	DiJa-1	Archaic
44	1	Farlain Lake, Simcoe County	BeGx-5	15th–16th century
45	1	Waterdown, Hamilton-Wentworth	AiGx-93	16th–17th century
46–54	9	Providence Bay, Manitoulin Island	BkHn-3	1600–1620
55–61	7	MacPherson, Hamilton-Wentworth	AhHa-21	1560–1580
62–68	7	Hanes, Hamilton-Wentworth	AhHa-67	1550–1580
69–85	17	Grimsby, Niagara District	AhGv-1	1615–1650
86–97	12	Old Fort Albany, Moosonee District	FbHj-1	18th century

University of Toronto. Instrumental neutron activation analysis provides chemical data that can be brought directly and unambiguously to bear on research problems associated with trade and provenance but are used here to deal with problems of chronology. These data may be supplemented with other metallographic approaches. Analytical samples ranging in mass between 10 and 400 mg were taken from copper nuggets, knives, projectile points, kettle fragments, needles, staples, beads, fragments of brass and copper trade goods, and funerary and decorative items. Individual samples were stored in clean 1.2 ml polyethylene vials. Samples were analyzed as described by Hancock et al. (1991a, 1991b), with minor modifications to compensate for small sample sizes.

Samples in the mass range of 200–400 mg were first irradiated serially for one minute at a neutron flux of 1.0×10^{11} $n.cm^{-2} \times .s^{-1}$ and assayed for 200 seconds after a delay time of approximately one minute using germanium detector-based gamma-ray spectrometers for copper, vanadium, and aluminum. Elemental concentrations were calculated using the comparator method. Smaller samples were irradiated by increased neutron doses so that suitable quantities of radioactivity were generated. After a delay time of one hour, each sample was reassayed for zinc, manganese, and indium. Medium and long half-life radioisotope producing elements were quantified by batch irradiating eight to ten samples per irradiation container for 16 hours at 2.5×10^{11} $n.cm^{-2} \times .s^{-1}$. After five to eight days, samples were serially assayed for 1000–3000 seconds seeking Sm, Au, La, Cd, As, Sb, and Na. A final counting was made after between ten and fourteen days, at which time the samples were counted for 2–16 hours, depending on sample size, to determine the concentrations of Sn, Se, Hg, Th, Cr, Au, As, Sb, Ag, Ni, Sc, Fe, Zn, Co, and Eu. This procedure produced replicate measurements of enough elements to guarantee no sample mix-ups. Analytical precisions ranged from ±1% to detection limits.

Results and Discussion

Wayman et al. (1985) and Hancock et al. (1991a, 1991b) demonstrated that native copper and smelted European copper-based metals can be differentiated on the basis of relative elemental concentrations. Minor (0.01–0.1%) and trace element (<0.01%)

variations allow one to separate native copper from European copper. Native copper tends to fall into a minimum of three categories: very clean copper, with all trace elements at very low concentrations; iron-rich copper, with possible enrichments of associated elements; and arsenic-rich copper, with associated high antimony and/or silver. European smelted copper has elevated concentrations of Au, As, Sb, Ag, and often Co, Ni, In, Sn, Zn, and so forth, with respect to native copper.

The ninety-seven analyzed samples came from Farquar Lake (eighteen samples), McCollum (twenty-five samples), Farlain Lake (one sample), Waterdown (one sample), Providence Bay (nine samples), MacPherson (seven samples), Hanes (seven samples), Grimsby (seventeen samples), and Old Fort Albany (twelve samples). The archaeological sites are presented in Table 1. Selected analytical data are presented in Table 2 and their significance is discussed below. The various fields with which these data are compared were taken from the original data analyzed by Hancock et al. (1991a, 1991b). Since their data set was not large, these fields should be interpreted as reasonable approximations of the total variability of assorted elemental contents in the copper samples. It should be noted that the left-hand side and bottom of the "native" copper fields for different elements are "defined" by the detection limits calculated for the sample sizes used by Hancock et al. (1991a, 1991b).

Farquar Lake Site

The Farquar Lake copper samples (samples 1–18) contain trace elements, with the exception of Fe, at relatively low concentrations. A scattergram of antimony versus gold (Fig. 1) shows that all eighteen copper samples fit chemically within the native copper field (very low Sb and Au) established by Hancock et al. (1991a, 1991b). Sample 10 had a silver content that was higher than those observed in the samples of Hancock et al. (1991a, 1991b). Although none of the samples was high in arsenic, several samples (7–14, 16–18) contained relatively high iron contents, with sample 11

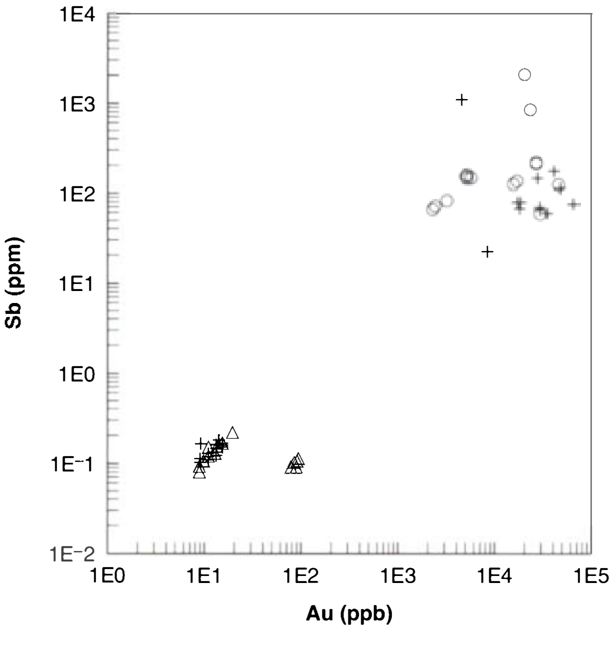

Figure 1. *Scattergram of antimony (Sb) versus gold (Au) for samples from Farquar Lake (+), McCollum (Δ), Grimsby (o), and Old Fort Albany (+). (Note: 1E-1 = 0.1, 1E0 = 1, 1E1 = 10, 1E2 = 100, etc.)*

TABLE 2. *Selected analytical data.*

Site	Sample No.	Fe ppm	Co ppm	Ni ppm	Zn ppm	As ppm	Ag ppm	In ppm	Sn ppm	Sb ppm	Au ppb
Farquar Lake	1	460	2.5	≤16	≤16	≤1.2	197	≤0.5	≤36	≤0.11	≤9
	2	≤160	≤1.7	≤20	≤9	≤1.5	164	≤0.4	≤50	≤0.16	≤9
	3	780	1.7	≤16	≤7	≤1.4	59	≤0.5	≤41	≤0.14	≤14
	4	≤290	2.0	≤36	≤14	≤1.1	251	≤0.4	≤100	≤0.13	≤12
	5	510	1.5	≤19	≤9	≤2.7	121	≤0.9	≤48	≤0.13	≤12
	6	≤190	1.9	≤22	≤10	≤1.5	324	≤0.5	≤48	≤0.16	≤12
	7	2000	2.1	≤54	≤22	≤1.3	243	≤0.4	≤120	≤0.16	≤15
	8	1900	1.8	≤44	≤17	≤1.2	231	≤0.4	≤320	≤0.15	≤14
	9	2500	1.8	≤37	≤16	≤1.3	440	≤0.4	≤160	≤0.17	≤15
	10	2400	1.8	≤35	≤14	≤1.1	605	≤1.0	≤75	≤0.12	≤10
	12	1500	1.6	≤44	≤18	≤1.3	108	≤0.9	≤120	≤0.16	≤15
	13	1500	1.8	≤27	≤13	≤1.6	180	≤0.4	≤70	≤0.18	≤14
	14	1600	2.1	≤30	≤11	≤1.3	233	≤0.7	≤70	≤0.12	≤11
	15	700	2.2	≤18	≤9	≤1.2	292	≤0.8	≤40	≤0.10	≤9
	16	1500	2.4	≤25	≤10	≤1.2	175	≤0.8	210	≤0.13	≤12
	17	1800	2.0	≤34	≤14	≤1.1	213	≤0.5	≤90	≤0.12	≤12
	18	2100	2.2	≤20	≤9	6.2	134	≤0.7	≤50	≤0.15	≤15
McCollum	19	≤150	1.7	≤19	≤10	≤1.2	25	≤0.7	≤50	≤0.12	≤10
	20	≤210	2.1	≤26	≤10	≤1.0	144	≤0.9	≤80	≤0.10	≤10
	21	≤190	1.8	≤24	≤9	≤1.0	113	≤0.7	≤70	≤0.11	≤11
	22	≤140	2.1	≤17	≤10	≤1.0	232	≤0.4	≤32	≤0.10	≤90
	23	≤140	1.7	≤17	≤5	≤1.2	151	≤0.9	≤45	≤0.11	≤93
	24	≤130	2.0	≤14	≤9	≤1.0	148	≤0.7	≤30	≤0.09	≤88
	25	1400	2.9	≤19	≤11	≤1.3	179	≤0.4	≤37	≤0.12	≤10
	26	≤150	1.9	≤18	≤11	6.5	71	≤0.7	≤60	≤0.09	≤80
	27	≤140	1.9	≤14	≤7	7.8	395	≤0.5	≤18	≤0.10	≤87
	28	≤230	2.0	≤27	≤12	36	368	≤0.5	≤57	≤0.16	≤15
	29	≤260	2.1	≤33	≤14	≤0.9	245	≤0.7	≤76	≤0.10	≤93
	30	≤210	2.0	≤28	≤11	2.3	61	≤0.9	≤86	≤0.11	≤19
	31	≤190	1.6	≤22	≤8	29	263	≤0.6	180	≤0.11	≤10
	32	≤70	1.8	≤9	≤3	≤0.9	31	≤0.5	≤26	≤0.08	≤9
	33	≤160	2.4	≤18	≤11	≤1.2	104	≤0.7	≤40	≤0.12	≤10
	34	≤200	2.4	≤24	≤11	≤1.6	121	≤0.7	≤70	≤0.15	≤13
	35	≤200	2.0	≤27	≤10	≤1.7	563	≤0.6	≤40	≤0.15	≤11
	36	≤120	1.7	≤15	≤9	≤1.1	89	≤0.4	≤31	≤0.09	≤9
	37	≤80	2.0	≤10	≤4	≤1.0	43	≤0.5	≤28	≤0.09	≤9
	38	≤150	2.6	≤18	≤8	≤1.6	127	≤0.6	≤60	≤0.12	≤13
	39	≤160	2.1	≤21	≤9	≤1.5	185	≤0.7	≤16	≤0.13	≤12
	40	≤150	2.2	≤17	≤8	≤1.2	182	≤0.4	≤43	≤0.10	≤9
	41	≤180	1.6	≤23	≤9	≤1.1	129	≤1.1	220	≤0.10	≤10
	42	≤700	2.3	≤13	≤5	18	45	≤0.4	≤37	≤0.11	≤10
	43	≤140	2.7	≤17	≤8	≤1.7	160	≤0.4	≤40	≤0.15	≤13
Farlain Lake	44	≤450	≤1.2	≤69	≤60	≤2.0	134	≤0.7	420	≤0.32	94
Waterdown	45	≤1800	≤3.1	≤460	22000	1160	740	3.0	≤470	144	4200
Providence Bay	46	≤300	2.1	≤43	≤17	3.6	120	≤0.4	100	0.82	≤26
	47	1300	3.3	≤65	≤27	13	200	≤0.6	150	≤0.30	≤29
	48	≤440	2.4	≤64	≤28	8.6	66	≤0.8	250	≤0.34	≤30
	49	≤340	3.8	≤35	≤34	≤2.8	280	≤0.6	140	≤0.32	≤21
	50	≤380	2.1	≤52	≤22	≤2.5	120	≤0.7	130	≤0.30	≤30
	51	≤280	1.9	≤43	≤17	≤2.1	130	≤0.6	160	≤0.28	≤24
	52	≤310	2.0	≤50	≤21	≤2.3	110	≤0.7	250	≤0.26	≤27
	53	≤1300	3.1	700	≤73	1370	590	≤0.7	280	2260	10700
	54	≤980	3.2	≤320	280000	750	350	2.1	14000	280	4500

Site	Sample No.	Fe ppm	Co ppm	Ni ppm	Zn ppm	As ppm	Ag ppm	In ppm	Sn ppm	Sb ppm	Au ppb
MacPherson	55	≤480	≤1.5	≤69	≤44	≤2.5	163	≤0.5	310	≤0.56	220
	56	≤630	≤1.9	≤90	≤43	≤2.5	108	≤0.4	400	≤0.60	≤40
	57	≤230	≤2.0	≤33	≤16	≤7.0	106	≤0.5	130	≤0.51	≤25
	58	≤580	≤1.8	≤85	≤40	≤2.8	350	≤0.3	350	≤0.68	330
	59	≤1100	≤3.1	≤450	≤76	800	910	≤0.5	1800	1770	2500
	60	≤2500	≤7.2	≤350	≤190	540	760	≤0.4	870	1990	7400
	61	≤3500	15	≤800	190000	216	460	2.0	27000	60	3000
Hanes	62	≤360	≤1.3	≤67	≤41	≤1.9	106	≤0.7	≤400	≤0.33	≤37
	63	≤470	≤1.8	≤91	≤27	≤2.4	140	≤0.6	620	1.0	≤46
	64	≤270	≤2.3	≤35	≤14	≤11	250	≤0.8	≤230	≤0.51	≤24
	65	≤330	≤1.2	≤64	≤43	≤2.0	140	≤0.6	≤380	≤0.64	78
	66	≤1700	≤5.2	840	≤137	1740	720	≤0.7	≤450	2900	3600
	67	≤1500	≤2.6	≤780	260000	100	61	30	≤430	25	940
	68	≤2000	≤3.8	≤900	340000	100	68	26	≤580	28	940
Grimsby	69	≤1900	53	≤490	280000	450	670	9.5	12100	130	14500
	70	≤1900	8.1	≤570	330000	590	450	3.2	≤410	150	4900
	71	≤2200	8.0	≤610	260000	570	450	3.1	1400	150	5400
	72	≤2200	57	≤610	330000	470	770	9.0	13100	140	15800
	73	≤!800	8.4	≤480	340000	650	460	3.4	≤410	160	5100
	74	≤2200	18	≤640	300000	230	770	17	≤560	63	27900
	75	≤2000	6.9	≤590	310000	620	460	3.9	1200	160	4900
	76	≤2300	7.7	≤700	320000	590	450	4.1	1700	160	5200
	77	≤1800	9.7	≤460	330000	630	480	3.6	960	160	5200
	78	≤920	26	≤140	12000	74	1330	28	≤330	130	43500
	79	≤300	≤3.2	≤800	300000	570	280	2.6	1200	85	3000
	80	≤3900	30	≤1000	320000	310	840	19	2400	210	25100
	81	≤2000	37	≤570	390000	350	800	18	≤390	220	25100
	82	≤2000	121	3500	340000	910	750	12	1300	880	21300
	83	≤2000	≤2.1	1400	330000	500	300	≤0.5	10100	73	2300
	84	≤4000	23	3900	22000	1620	930	3.9	9900	2180	18400
	85	≤1700	≤1.6	1600	310000	480	310	≤0.7	9600	68	2200
Old Fort Albany	86	≤720	20	≤120	≤91	390	1330	18	≤310	180	37900
	87	≤730	28	≤120	≤90	260	1560	31	840	120	44600
	88	≤1100	6.5	≤180	740	9970	1300	6	940	1150	4200
	89	≤920	16	≤140	2300	260	1360	14	≤370	81	61700
	90	≤1700	63	≤490	300000	100	330	12	1100	23	8000
	91	≤2300	15	≤650	330000	240	1080	17	≤520	63	33100
	92	≤2100	29	≤620	310000	280	510	15	1330	71	17100
	93	≤1900	30	≤560	350000	300	480	15	1100	81	16300
	94	≤1900	30	≤650	300000	290	540	14	11900	81	17300
	95	≤2100	17	≤590	310000	390	800	13	4500	150	25900
	96	≤2200	25	≤630	410000	260	890	16	≤430	67	27400
	97	≤1800	24	≤540	400000	260	870	16	≤370	72	27200

reaching 0.78% Fe (samples 1, 2 [adzes]; 3, 5, 6, 13, 17 [needles]; 4, 7 [projectile points]; 12 [hook]; and others [unidentifiable fragments]).

McCollum Site

The twenty-five copper samples from the McCollum Site (samples 19–43) show essentially the same chemical fingerprints as those found in the Farquar Lake material. A scattergram of antimony versus gold (Fig. 1) shows that all copper samples fit chemically within the native copper field together with the Farquar Lake material. Possible anomalies were the high silver content of sample 35 and the low silver contents of samples 19, 32, and 37 (very clean copper). The apparently high gold values shown in these scattergrams are actually high detection limits from very small copper samples. With the exception of sample 25 (and possibly sample 42), the McCollum copper samples are all low in iron as well as in arsenic. All McCollum items are nuggets of native copper.

Farlain Lake Site

The single sample from Farlain Lake site (sample 44) is a "clean," unidentifiable folded sheet of native copper. Figure 2, a scattergram of antimony versus gold, shows that it fits chemically within the native copper field.

Waterdown Site

A single unidentifiable brass sample (sample 45) was analyzed from the Waterdown site. In a scattergram of antimony versus gold (see Fig. 2), this sample, with its high antimony and gold, fits chemically at the low edge of the European copper field established by Hancock et al. (1991a, 1991b).

Providence Bay Site

The nine samples from Providence Bay (samples 46–54) include seven samples of "clean" native copper, one sample of European copper, and one sample of brass. The antimony-versus-gold scattergram of these samples (Fig. 2) shows the expected distribution of these samples between the native copper and European copper fields

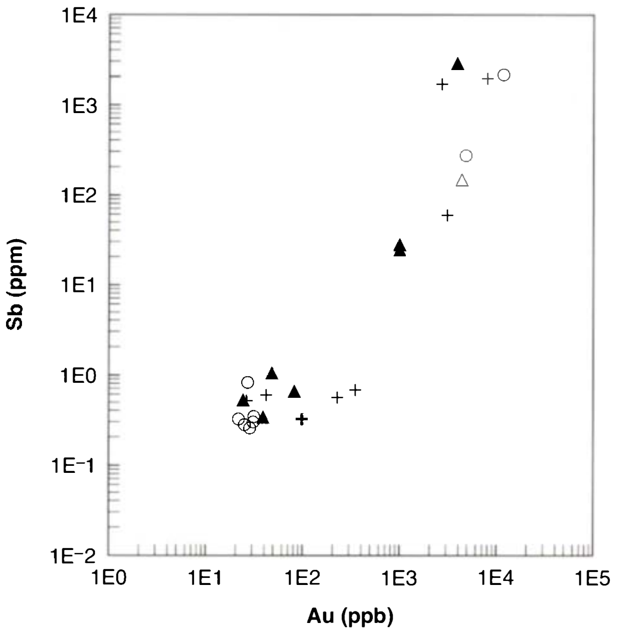

Figure 2. *Scattergram of antimony (Sb) versus gold (Au) for Farlain Lake (+), Waterdown (Δ), Providence Bay (o), MacPherson (+), and Hanes (▲). (Note: 1E-1 = 0.1, 1E0 = 1, 1E1 = 10, 1E2 = 100, etc.)*

(sample 47 [perforated copper artifact]; 48 [copper bangle]; 49 [copper staple in pottery]; 51 [copper ring]; 53 [copper coil, European]; 54 [brass knife]; 46, 50, 52 [copper fragments]).

MacPherson Site

Seven samples from the MacPherson site (samples 55–61) consisted of four samples of "clean" native copper, two of European copper, and one of brass. Like the Providence Bay material, the MacPherson samples generated an antimony-versus-gold scattergram (Fig. 2) with a distribution between the native copper and European copper fields (samples 55–58 [copper beads, native]; 59, 60 [copper beads, European]; 61 [brass bead]).

Hanes Site

The seven samples from the Hanes site (samples 62–68) consisted of four samples of "clean" native copper, one of European copper, and two of brass. Similar to both the Providence Bay and MacPherson material, the Hanes material generated an antimony-versus-gold scattergram (Fig. 2) in which the samples were distributed between the native copper and European copper fields (samples 62, 64 [copper sheet, native]; 63, 65 [copper beads, native]; 66 [copper bead, European]; 67, 68 [brass sheet fragments]).

Grimsby Site

The analyses of seventeen samples of kettle fragments and rivets (samples 69–85) from the Grimsby site on the Niagara Peninsula showed a mixture of two brassy copper (samples 78 and 84 were both from rivets in brass kettles) and fifteen brass samples with zinc contents between 26 and 39%. A scattergram of antimony versus gold (Fig. 1) shows that all of these samples fit chemically with the European copper field. Although most of the Grimsby samples contain measurable quantities of indium, two samples (83 and 85) do not.

Old Fort Albany Site

From Old Fort Albany, the twelve samples from kettle fragments (samples 86–97) were analyzed. In Figure 1, a scattergram of antimony versus gold, all Old Fort Albany material fits chemically with the European copper field. The zinc contents show that most of these samples are brass with zinc contents of 30–40%. Samples 88 and 89 are slightly brassy copper, leaving only samples 86 and 87 as "clean" smelted copper. Along with their high arsenic, antimony, gold, and silver contents, all of these samples contain measurable amounts of indium and many contain measurable quantities of tin. Their cobalt contents are also much higher than are usually found in native copper.

Chemical Similarities

The data in Table 2 show that several samples analyzed from the Grimsby site are chemically similar. Likewise, several Old Fort Albany samples are rather similar chemically. These observations imply that the analyzed samples of brass from the respective sites came either from a single brass kettle or from a small collection of kettles produced from the same industrial batch. Some representative examples of these chemical similarities are presented in Table 3.

Chronological Implications

This exercise demonstrates that chemical differentiation can be used as a seriational scale, which may have chronological implications (Table 4). Forming the beginning of the seriational scale, the early sites (Farquar Lake and McCollum) produced native copper of various chemical types. The finding of only native copper at a site, together with the absence of other trade goods, implies that the people inhabiting the site had no direct or indirect contact with Europeans. This tends to imply that the site is Pre-Contact (in use prior to the late sixteenth century). But because of

Table 3. *Examples of chemical similarities in brass kettles from Hanes, Grimsby, and Old Fort Albany.*

Site	Sample No.	Fe ppm	Co ppm	Ni ppm	Zn ppm	As ppm	Ag ppm	In ppm	Sn ppm	Sb ppm	Au ppb
Hanes	67	≤1500	≤2.6	≤780	260000	100	61	30	≤430	25	940
	68	≤2000	≤3.8	≤900	340000	100	68	26	≤580	28	940
Grimsby	69	≤1900	53	≤490	280000	450	670	9.5	12100	130	14500
	72	≤2200	57	≤610	330000	470	770	9.0	13100	140	15800
	70	≤1900	8.1	≤570	330000	590	450	3.2	≤410	150	4900
	71	≤2200	8.0	≤610	260000	570	450	3.1	1400	150	5400
	73	≤1800	8.4	≤480	340000	650	460	3.4	≤410	160	5100
	75	≤2000	6.9	≤590	310000	620	460	3.9	1200	160	4900
	76	≤2300	7.7	≤700	320000	590	450	4.1	1700	160	5200
	77	≤1800	9.7	≤460	330000	630	480	3.6	960	160	5200
	80	≤3900	30	≤990	320000	310	840	19	2400	210	25100
	81	≤2000	37	≤570	390000	350	800	18	≤390	220	25100
	83	≤2000	≤2.1	1400	330000	500	300	≤0.5	10100	73	2300
	85	≤1700	≤1.6	1600	310000	480	310	≤0.7	9600	68	2200
Old Fort Albany	92	≤2100	29	≤620	310000	280	510	15	1330	71	17100
	93	≤1900	30	≤560	350000	300	480	15	1100	81	16300
	94	≤1900	30	≤650	300000	290	540	14	11900	81	17300
	96	≤2200	25	≤630	410000	260	890	16	≤430	67	27400
	97	≤1800	24	≤540	400000	260	870	16	≤370	72	27200

Table 4. *Distribution of "copper" by chemistry.*

Site	Native	European	Brassy Cu	Brass
Farquar Lake	18	—	—	—
McCollum	25	—	—	—
Farlain Lake	1	—	—	—
Providence Bay	7	1	—	1
Hanes	4	1	—	2
MacPherson	4	2	—	1
Waterdown	—	—	1	—
Grimsby	—	—	2	15
Old Fort Albany	—	3	1	8

their relative isolation from trade routes, there were probably early Post-Contact period sites that had only native copper and no other European goods. It may not be possible to separate sites in use during the long Pre-European Contact period from isolated sites still in use in the Early Contact period.

At the other end of the seriational scale, Grimsby and Old Fort Albany produced only European copper and brass. In the middle of the scale are Providence Bay, MacPherson, and Hanes, providing different mixtures of native copper, European copper, and brass. The finding of proportionately more native copper at Providence Bay relative to the earlier sites of Hanes and MacPherson either may be a result of the small numbers of samples from each site or may relate to an east-west cline in European metal access by aboriginal peoples.

Some archaeological sites provide isolated single copper samples. So, if one is allowed a little scientific license, differentiating a Pre-Contact site from a Post-Contact site may even be done with a single copper sample from good context. Given that no other trade goods were found, the single piece of native copper from the Farlain site indicates that the site may have been in use prior to the period of trade with Europeans. But, even without other archaeological material evidence, the single brassy copper sample from Waterdown implies that at least one depositional component of the site was active after the arrival of Europeans.

While it is important to establish the presence of Pre-Contact and Post-Contact sites and their geographic distributions, chemical seriation may play only a small part in the overall development of a chronology for the seventeenth-century sites in Ontario. The chemical separation of copper materials will probably never, in a clear and unequivocal manner, be able to place an archaeological site in a firm time frame. But it is hoped that these types of data, in combination with the other kinds available to archaeologists, can narrow the time estimates for site occupation in that important era of early European contact (Ramsden 1975).

Conclusions

We present a chemical seriational model of archaeological copper-based metal samples that allows one to sort the material into three categories: native copper, European copper, and brass. Archaeological sites containing only native copper have a high probability of being Pre-Contact, while sites that contain mixtures of native and European copper have a high probability of dating to the Early Post-Contact period in Ontario history. Those sites containing European copper and brass only are most probably Post-Contact sites.

The determination of time is rarely clear on sites, and without secure context and associated archaeological data unequivocal statements based on this kind of model would be without merit.

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Pre-Columbian Gold Processing at Putushio, South Ecuador: The Archaeometallurgical Evidence

Thilo Rehren and
Mathilde Temme

The metallurgical technology of Central and South America is usually divided into two areas of different processing preferences: Mesoamerica and Colombia, where casting of often copper-rich gold objects is predominant, and Peru, including South Ecuador, where sheet-metal techniques prevailed and noble metal objects contain less copper (Lechtman 1980:271; Hosler 1988; Rovira this volume).

In Ecuador, two regions attracted attention for commercial excavations of Pre-Columbian gold: the northern coast of the province Esmeraldas with the island of La Tolita (Meggers 1966:103; Valdez 1986:81), and the Southern Highland (Uhle 1922b, 1922c:242–44; Saville 1924).

Bergsoe (1937) and Scott and Bray (this volume, Chap. 14) presented the high standard of gold and platinum working among the La Tolita people, commonly attributed to the early Regional Developmental period, that is, to the last centuries B.C.E. (Bouchard 1986; Scott and Doehne 1990). The use of copper and lead was also known (Bergsoe 1938). Much of the La Tolita material, small jewelry and unfinished objects, seems to have originated in a remarkable center of workshops (Farabee 1922; Bergsoe 1937), but due to the total destruction of most of the site by treasure hunters, no actual working place has been identified.

The objects from south Ecuador come mainly from tombs and burials and have been subject to stylistic and technical examinations rather than metallurgical investigations. Several of them indicate some relationship to the later coastal cultures of northern Peru: Chimú and possibly Moche (Saville 1924:illustrations; Meggers 1966:155; Willey 1971:306, fig. 5–66). Gold was beaten, hammered, welded, granulated; the smiths were aware of alloying and gilding, and the art of soldering was highly developed.

During the Integration period, circa 800 C.E. to the Inca conquest, the lost-wax process appeared. Golden objects manufactured in this way were found in the northern highland of Ecuador. In this period, in the Milagro phase on the southern coast and the lower inland to the north as far as to the province Esmeraldas, gold foil and wires of gold, silver, and copper were produced (Meggers 1966; Sutliff 1992).

Recent excavations indicate earlier gold working for Ecuador: A nose ring and other small objects were found in a late Chorrera context at Salango on the coast (P. Norton, pers. comm. 1992), and from Pirincay, Southern Highland, comes a drop of molten gold found in a garbage pit dated to the fifth century B.C.E. (Olsen Bruhns 1988).

The aim of this paper is to investigate some of the relics of ancient gold working in a well-preserved site: Putushio, Province Loja, Ecuador. This Pre-Columbian settlement is located in the upper tributary area of the Rio Jubones, a dry transversal valley in the southern Ecuadorian highland, opened to the Pacific coast. It extends over 400 hectares and comprises a very irregular natural landform pattern with a bold, dominating mount, the "Loma" of Putushio, about 500 m high, and several lower foothills at its base toward the south and inclined plains to the west and north (Fig. 1). The Putushio area is situated only 100 km from the coast and also offers

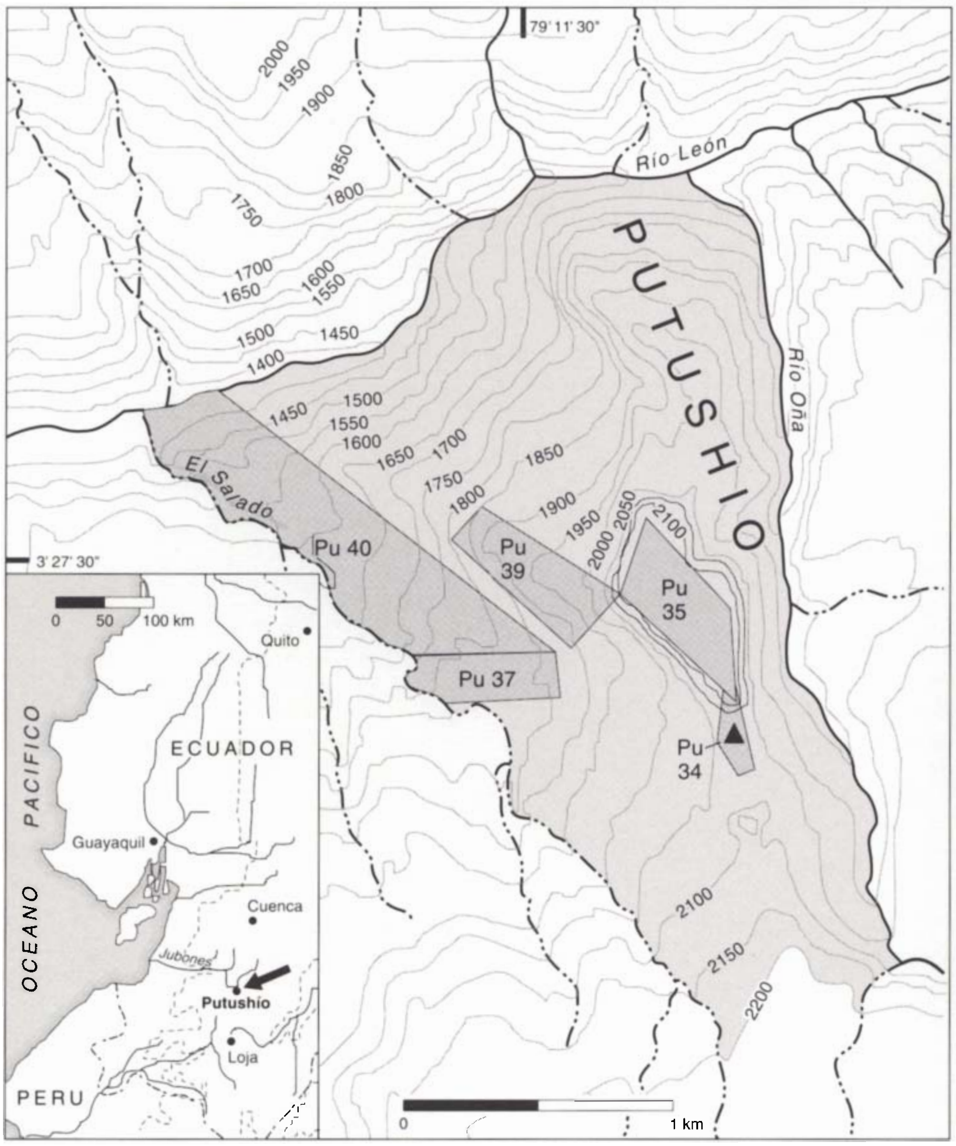


FIGURE 1. *Location of the Putushio site (arrow, inset), indicating areas of survey (dotted pattern) and excavation (solid triangle)*

easy access to the upper gold-bearing tributaries of the Amazon basin. Secondary gold deposits are still exploited at the base of the main hill and downstream in the Leon River.

The settlement activity goes back to the Late Formative period[1] and ends with the invasion of the Incas, probably at the end of the fifteenth or the beginning of the sixteenth century C.E. (Caivallet 1985). Twenty-one radiocarbon dates[2] range from 3420 ± 255 B.P. for the Late Formative period to 435 ± 135 B.P. for the end of occupation.

The excavations on the upper platform and terraces of the Huahua-Putushio were realized during five seasons from 1982 to 1986 as part of a continuing archaeological project in this region by the Museo Antropologico of the Banco Central del Ecuador, Guayaquil. Among many other finds, relicts of twenty-five furnacelike, bowl-shaped installations were uncovered in an area of 120 m^2 from horizons dated from 1770 ± 130 B.P. to 435 ± 135 B.P.

General Cultural Linkages

The prehistoric cultural landscape of Putushio shows an artificial forming of the natural landscape with terraces and several water reservoirs. These structures are reinforced with different classes of stonewalls, indicating that they are of different ages.

The majority of terraces are observable on the main hill and the lower elevations at the southern end (Fig. 2). The Loma of Putushio and the immediate southern foothill, the Huahua-Putushio, as well as some of the smaller elevations, are unirrigationable, while some of the terraces at the slopes and plains at the bottom can receive water.

The dry climate conserves thousands of sherds and many bones in good condition even at the surface; the presence of seashells hints at coastal contact. The

FIGURE 2. *View of the "Loma" of Putushio and the Huahua-Putushio, with an artificial water reservoir in front. Arrow indicates area of excavation.*

agglomeration of archaeological material indicates a high-density, populous index at that time in an environment of very difficult survival based on agriculture. The striking density of architectonic remains over extended areas indicates a nearly urban organization of people, obviously practicing work specialization and supplied from a larger territory than the limited extension of the site of Putushio.

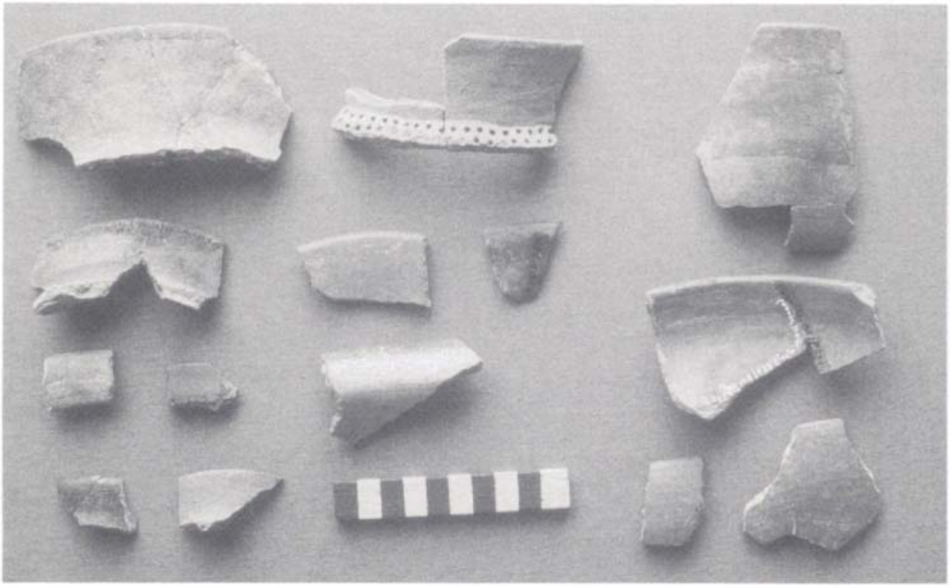
The Late Formative period is marked by a ceramic style related to Cerro Narrio ware (Fig. 3), whose connections are noted by its affinity to Machalilla and Chorrera ware not only to the coast of Ecuador but also to the upper Amazon region, Peru, and as far as Mesoamerica (Uhle 1922a; Collier and Murra 1943:85; Lanning 1963; Meggers 1966; Braun 1982; Bischof 1975b:56; Porras 1978; Guffroy et al. 1987:112).

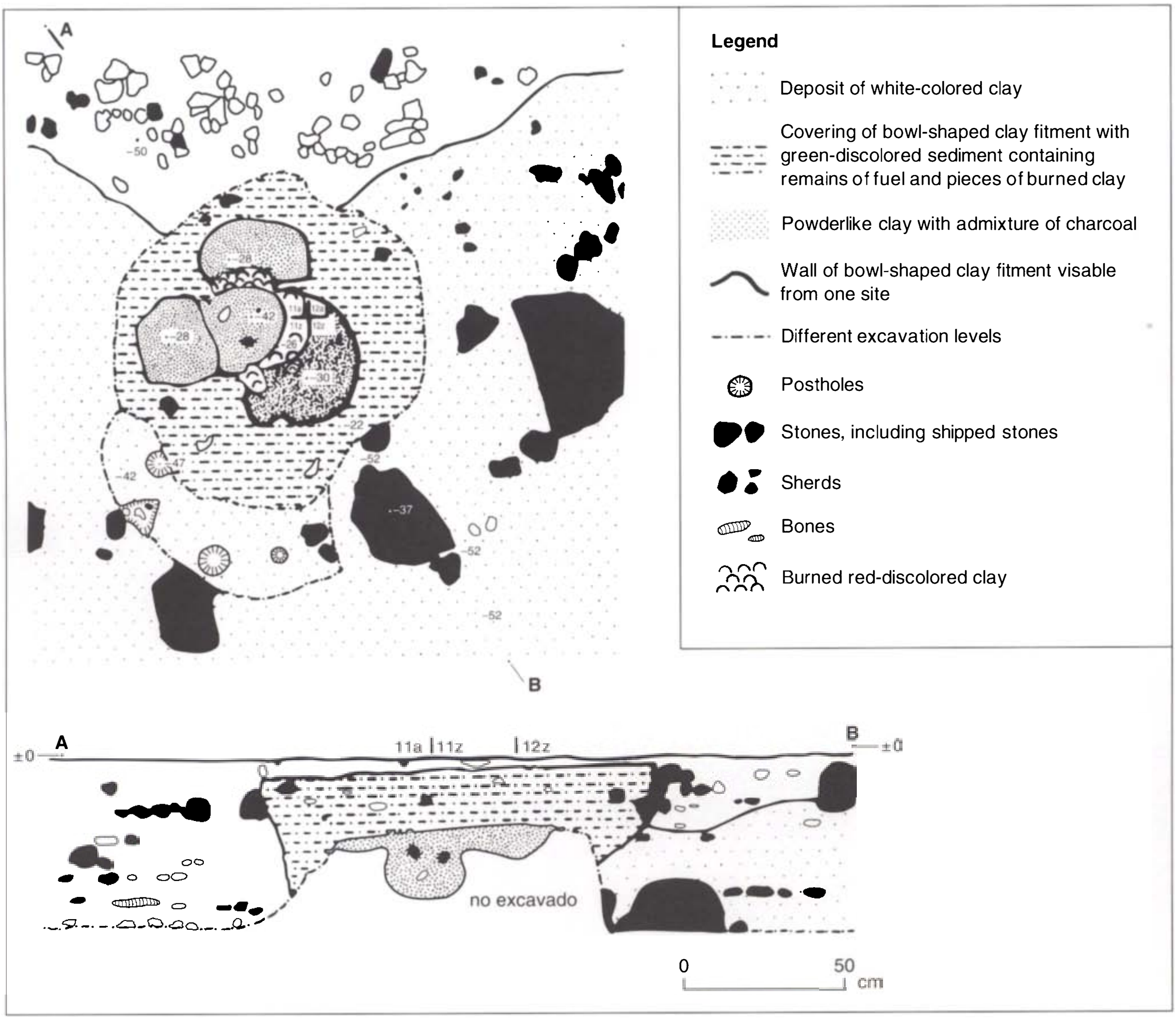
During the Late Regional Developmental period, possible contacts with Peru are supposed by ceramics with negative painting of the Tuncuhuan style (Izumi and Terada 1960:88), whose probable regions of focus are the northern Ecuadorian highland and southern Columbia. Relations with the coast as well as with the northern highland seem to continue during the time after 800 C.E. It demonstrates that Putushio was exposed to different and distant cultural influences (Temme 1988, 1992).

The Evidence of Gold Processing at Putushio

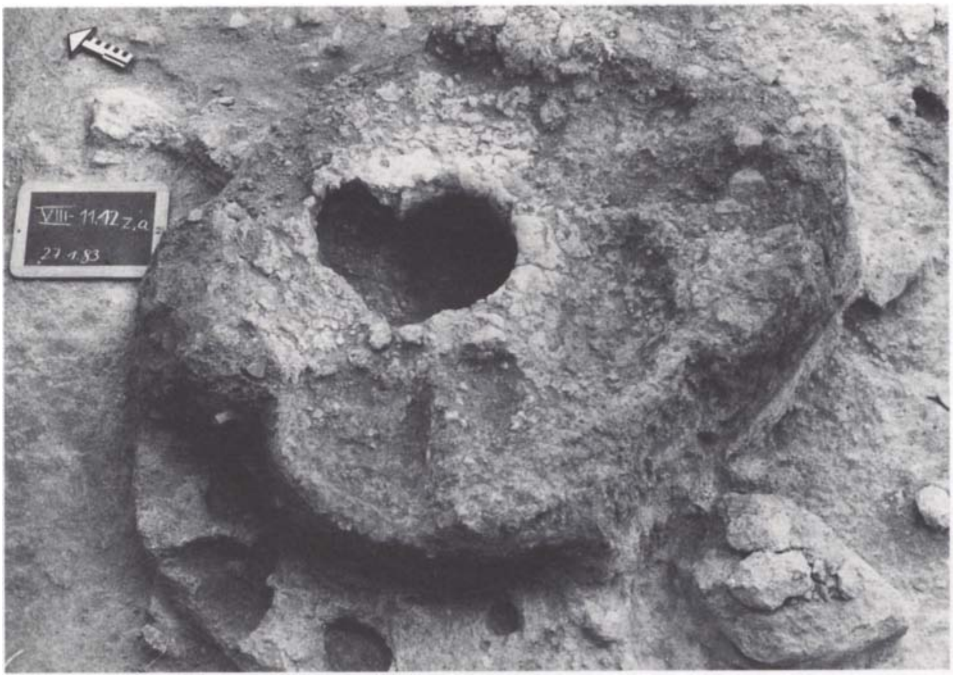
The most obvious evidence for metallurgical activity at the site is numerous installations, excavated at the upper platform and terraces of the Huahua-Putushio and distributed in abundance also at the Loma of Putushio. They consist of clay-lined, bowl-shaped holes, about 30 cm in diameter and 15 cm deep, surrounded by several similar worked depressions of lesser depth, all showing signs of burning. A map and photo of the remains of the installation are shown in Figures 4a and 4b. The holes are filled with a loose powder of high refractory clay and covered by partially

FIGURE 3. *Samples of ceramic of Cerro Narrio ware.*





Figures 4a, b. *Map (a) and photo (b) of the remains of a burned bowl-shaped clay installation for gold processing at Huahua-Putushio, context F 28, dated 840 ± 95 B.P. (Hv 15830).*



burned clay with impressions of grassmatting. According to X-ray diffraction analyses,[3] the powderlike sediment consists of kaolinite, illite, montmorillonite, polyhalite, and quartz and has a considerable admixture of charcoal dust. It corresponds to clays that are still used in the region for lost-mold casting. Apparently this material was recycled, having been found with grinding stones and stored in vessels. Other artifical deposits also related to these installations are white- and green-colored clays. The white clay is very similar to the aforementioned clay powder, but without polyhalite and organic material. It seems to be in a fresh, unused state. The green-colored clay deposits were identified as bearing gismondin, a zeolithe mineral, which appears naturally on the top of the hill of Putushio in its eastern flank and in the upper part of the west side. The green color is caused by a high admixture of garnierite, a nickel silicate. Green colorations, especially on top of the bowl-shaped installations where the clay is less burned, prove that this material, among others, was employed for their construction. Around the fixed installed receptacles, parts of workshop floors were discovered, mingled with charcoal.

Neither slags nor finished gold objects were found in the excavation. Finally, microscopical examination of lithic remains showed traces of gold on some of them. After this, samples of sediments from the inside of the bowl-shaped installations, from the workshop floors around the installations, and from several older cultural layers were panned. All three types of samples, but not all samples of Late Formative cultural layers, yielded tiny particles of gold. They form three morphological groups: molten prills and splashes, artificial foils, and native flakes and micronuggets. From that, it can be assumed that these installations had an important function related to the processing of gold, but that gold working was not confined to them.

The Late Formative layers, found in the upper platform of the Huahua-Putushio, are of different character compared to the later workshop contexts on the terraces: They are associated with house structures, and the quantity of ceramics is considerably higher. Gold working perhaps was not so intensive; the organization of labor and the techniques used might have been different, too.

Scientific Analysis of the Metallic Remains

All three major cultural periods produced traces of gold-working activity, namely pieces of gold foil, prills and splashes of molten gold and gold-alloys, and native gold flakes and micronuggets. A few lithic and ceramic samples are also related to metallurgy due to adhering streaks and drops of gold.

The samples found have been analyzed semiquantitatively by scanning electron microscopy/energy-dispersive spectrometry (SEM-EDS) for gold, silver, and copper.

A selection of twelve samples, representing the whole range of periods and composition known so far from Putushio, was mounted for metallographic and quantitative wavelength-dispersive spectrometry analysis. Elements such as arsenic, bismuth, iron, nickel, and platinum were sought but never detected at levels above 100 ppm; these data are not included here. Details of main element composition, archaeological context, and radiocarbon dates are given in Table 1.

TABLE 1. *Wavelength-dispersive spectrometry analyses of gold samples from Putushio. Analyses normalized to 100%; original values between 98 and 102%, JEOL wavelength-dispersive spectrometer, 25 kV, 10 nA probe current, counting time 40 seconds maximum.*

Sample	Au	Ag	Cu	Period	14-C
W01/1110	52.7	5.7	41.6	RD	1770 ± 130 B.P.
(Prill)	52.1	5.8	42.0		(Hv 15833)
	51.2	13.1	35.6		
	50.9	27.2	21.9		
W03/1552	61.5	10.9	27.6	LF	
(Prill)	61.5	11.6	26.8		
	61.7	10.4	27.9		
	62.3	14.2	23.5		
	60.4	18.8	20.8		
W06/1110	87.6	9.8	2.6	RD	1770 ± 130 B.P.
(Foil)	87.5	9.7	2.8		(Hv 15833)
	87.0	10.3	2.7		
W09/1117	42.0	9.3	22.4	I	1080 ± 175 B.P.
(Splash)	40.6	7.0	52.5		(Hv 15834)
	41.2	6.5	52.3		
	28.5	49.1	22.4		
	31.3	42.0	26.8		
	31.6	39.2	29.2		
W10/1117	84.2	9.2	6.6	I	1080 ± 175 B.P.
(Prill)	84.1	9.3	6.6		(Hv 15834)
	84.3	9.7	6.0		
W11/1117	88.0	10.4	1.6	I	1080 ± 175 B.P.
(Foil)	86.8	9.4	3.9		(Hv 15834)
	88.2	8.7	3.1		
W13/1283	85.4	9.5	5.1	LF	
(Prill)	84.5	10.3	5.2		
	85.6	9.3	5.1		

LF = Late Formative period.
RD = Regional Development period.
I = Integration period.

The Gold Foils

Tiny fragments of thin gold foil make a substantial part of the assemblage in all three periods, and the two or three biggest gold finds from Putushio are foils, several times folded and still 1 mm^2 (Fig. 5).

Two samples, one from the Regional Developmental period (W06/1110) and one from the Integration period (W11/1117), have been analyzed quantitatively and are very similar in composition: 9.5 and 9.9% Ag and 2.9 and 2.7% Cu, the balance being gold.

This composition is less copper-bearing than some other Ecuadorian material labeled as "borderline composition between native gold and gold which has had copper added to it" (Scott and Doehne 1990:189), but contains significantly more copper than the native gold samples from Putushio and the vicinity, as discussed in the following sections. Eluere and Raub (1991:49) conclude on the basis of 3% copper in Late Bronze Age gold foil that "it is practically certain that the L.B.A. goldsmiths had to start from a molten artificial alloy" instead of using unchanged

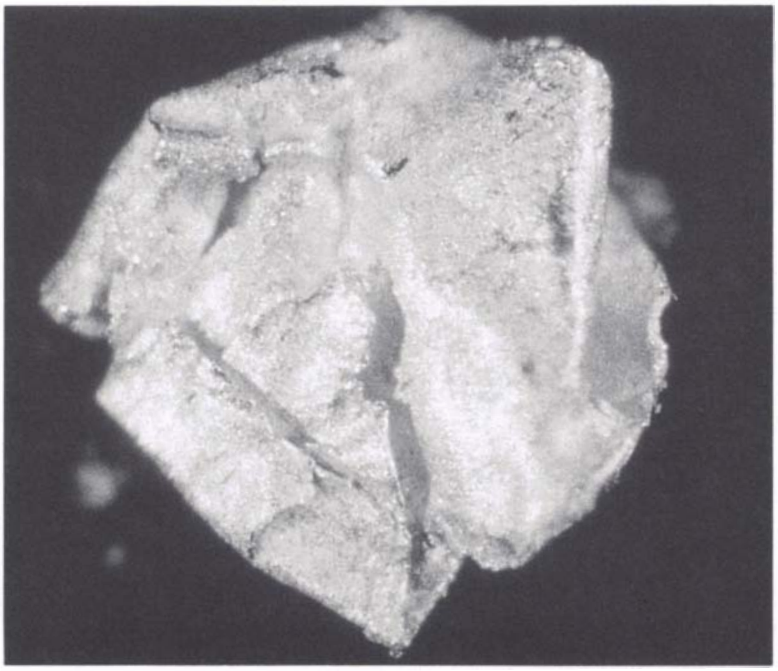


Figure 5. *Gold foil from Putushio, unit F 1580. Late Formative period habitation floor. 2560 ± 85 B.P. (Hv 14707). Object 1 mm in diameter.*

native gold. EDS analyses of several more foil samples gave matching results for all of them.

The Prills and Splashes

The corpus of samples solidified from a melt is the most heterogeneous one in terms of chemical composition, while their size and shape are less so. Spherical prills of 0.02–0.2 mm in diameter are most common, but some pieces are deformed spheres or even amorphous splashes.

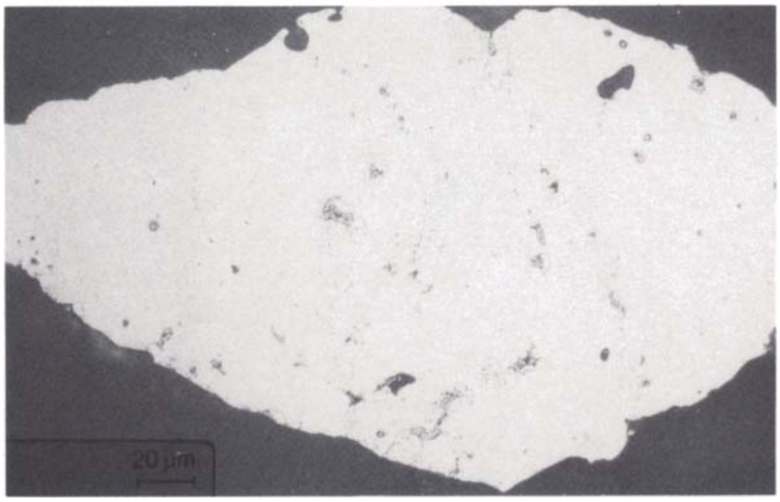
Five samples from all three periods were taken for wavelength-dispersive spectrometry analysis, ranging from 85 to 40% gold and from 5 to 55% copper. Silver variability is more restricted, with silver content typically between 9 and 11% in bulk analyses, but it becomes enriched by a factor of up to three in interstitials and goes beyond 50% in discrete particles within copper-rich prills (Figs. 6, 7). The formation of these particles is due to the miscibility gap between gold-copper and gold-silver alloys; thus, the addition of copper to a gold-silver alloy will force the silver to form a second phase. Energy-dispersive spectrometry analyses of some twenty prills fit well into this frame, showing the less copper-rich samples to be more frequent than the *tumbaga*-like pieces.

Figure 6. *Prill from Putushio, unit F 1110. Regional Developmental period, sediment from bowl-shaped clay installation. 1770 ± 130 B.P. (Hv 15833). Object 0.2 mm in diameter.*

The silver content seems to be directly proportional to the gold content within a given range of silver-to-gold ratios of 0.1 and 0.2 (Fig. 8), while copper behaves independently, suggesting an addition of pure copper to native silver-bearing gold.

The microstructure and homogeneity of the prills depend strongly on their composition. The more copper-rich the samples are, the more developed their tendency is to form gradients in silver content, first as coring in grain structures, and finally as discrete silver-rich phases in a copper-dominated gold alloy. Multiple wavelength-dispersive analyses of five prills are plotted in the diagram in Figure 8,

Figure 7. *Tumbaga splash from Putushio, unit F 1117. Integration period, sediment from workshop floor with destroyed bowl-shaped clay installation. 1080 ± 175 B.P. (Hv 15834). Micrograph from polished sample. See bar for length. Matrix is copper-rich gold alloy, white particles are silver-rich alpha'-(AgAu).*



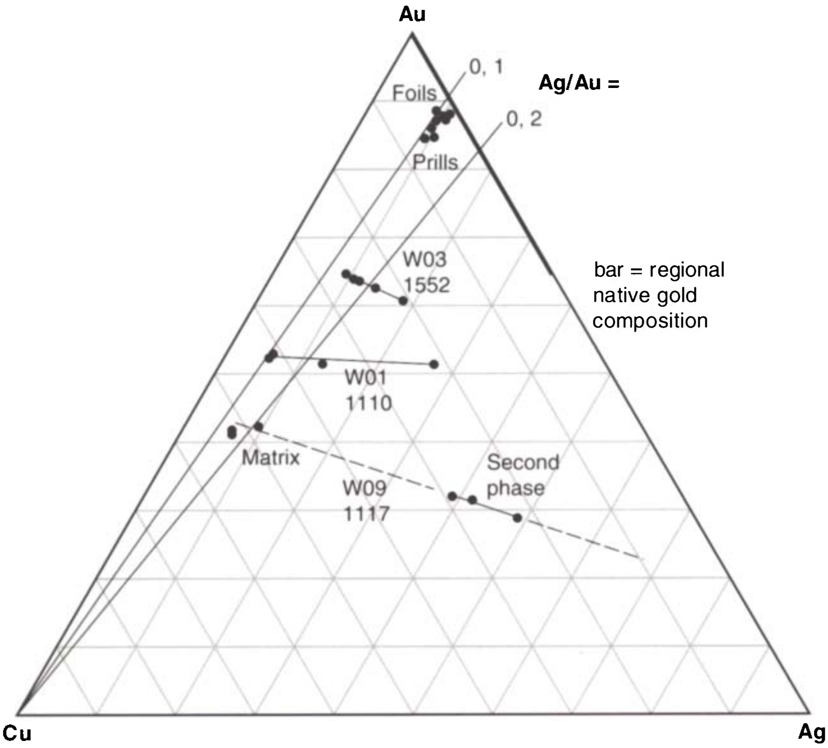
with related sets of values linked by a solid line for continuous gradients and a broken line for second-phase separation.

The most gold-rich cluster is the analysis of gold foils mentioned earlier, and the bold line along the binary gold-silver margin indicates the composition of native gold samples from Putushio, as described in the next section. Lines of silver-to-gold ratios of 0.1 and 0.2 mark the typical area of composition for archaeological samples from Putushio.

The prills analyzed by wavelength-dispersive spectrometry discussed here are in increasing order of copper content (for analytical data see Table 1):

- The two most gold-rich samples close to the foil cluster (W13/1283 and W10/1117) are very homogeneous solid solutions of 10% silver and 6%

Figure 8. *Ternary Au-Ag-Cu plot of wavelength-dispersive spectrometry analyses of gold samples from Putushio. Normalized weight percent, but no other elements above 100 ppm. Solid bar along the binary Au-Ag indicates range of composition of native gold from the excavation and the vicinity. Two straight lines starting at the Cu corner indicate Ag/Au ratios of 0.1 and 0.2. The most gold-rich data cluster is from two gold foils; the cluster with slightly increased copper content indicates composition of two gold-rich prills. Data points connected by lines are from single but inhomogeneous prills.*



copper in gold. Thus, they are quite similar to the gold foils analyzed, but the difference in copper separates the two types sufficiently.

- The next sample (W03/1552), with 11% silver and 25% copper on average, already shows a marked inhomogeneity in its silver distribution ranging from 10% to more than 18%. The silver is enriched in several separate interstitial areas.
- W01/1110, with about 40% copper and 6% silver in the gold matrix, is under the optical microscope still single-phased, but the X-ray silver map (Fig. 9) reveals a strong enrichment of silver in a grain boundary network typical for a cast structure. At its extreme, the silver content (27%) overweighs the copper content (22%), while gold remains at its previous level just above 50%.
- The most copper-rich sample (W09/1117) is a typical tumbaga alloy of more than 50% copper and roughly 10% silver with only 40% gold. Under the optical microscope, it is nearly as red as copper and reveals a second metallic phase (Fig. 7).

This second phase appears as tiny inclusions of bright white color either related to small gas holes or in a eutectic. With a typical diameter of <1 µ, it is too small to be analyzed separately by wavelength-dispersive spectrometry; thus, analyses of this area represent the eutectic rather than the single phase. The exact composition of the second phase can be estimated only by extrapolating the matrix and eutectic analyses toward the silver-rich edge of the miscibility gap given by Rapson (1990). It should be in the range of more than 70% silver with only minute amounts of copper. With the formation of this second phase, the continuous silver gradient[4] of

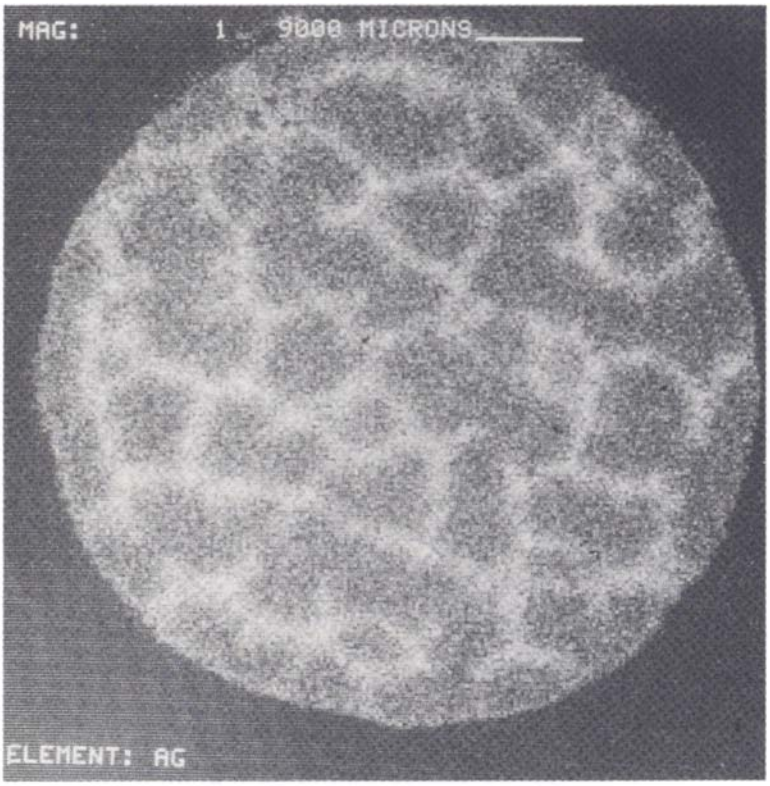


FIGURE 9. *Silver X-ray map of prill from unit F 1110. Regional Developmental period, sediment from bowl-shaped clay installation. 1770 ± 130 B.P. (Hv 15833). Object 0.2 mm in diameter (Note: bar on slide is uncalibrated). Copper-rich gold alloy. Grain boundaries with silver enrichment from 6% silver in grain center to 27% in interstitials. Gold between 51 and 53%, balance copper.*

cored grains present in the less copper-rich samples disappears for the sake of a discontinuous separation, indicated by a broken line (Fig. 8).

Gold Flakes and Micronuggets

The gold flake and micronugget finds are unchanged native samples of gold, obviously from a placer deposit. They are present in many but not all archaeological lots and commonly have a more irregular shape and a less even surface than the artifacts. The flakes are usually flat and oval but much thicker than the gold foil (Fig. 10), while the so-called micronuggets are entirely crude and very individual in shape; some of them may resemble raspberries at best. A set of samples panned from placer gold deposits in the immediate vicinity was included in the analysis for comparison.

Under scanning electron microscopy, the geological samples are equal to their archaeological counterparts in terms of shape irregularity and surface roughness, and wavelength-dispersive and energy-dispersive spectrometry analyses of both groups are indistinguishable: they form a binary gold-silver alloy with zero to more than 35% silver, and only traces of copper not exceeding 1%. No individual data are plotted into the diagram, but the total area present is marked by a bold line along the gold-silver binary. It is worth mentioning that the silver content of the flakes varies more widely within each single pan load than between different deposits. At best, it seems to be shape dependent; the more flattened the flake is, the less silver it contains.

Ceramics and Lithics Related to Metallurgy

Two fragments of a ceramic mold, found in the earliest Late Formative unit F 1470 with adhering gold were mentioned earlier; they are most interesting, as they may shed some light on the tools used by the ancient goldsmiths. The pieces are 2.5 × 2 cm and 1.5 × 1.5 cm, both 1 cm thick (Fig. 11). Their surface is whitish, mostly covered with carbonate sinter, but at least some twenty single droplets of gold stick to the original surface and peer through the coating. For obvious reasons, the

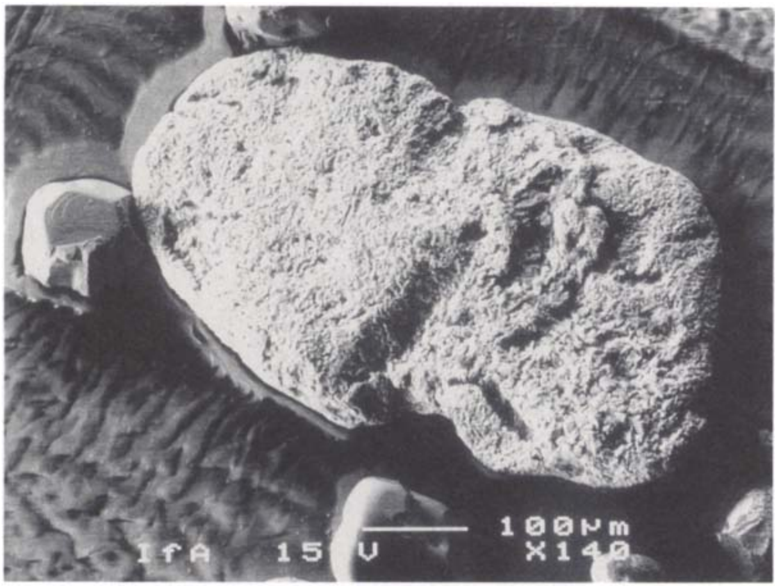
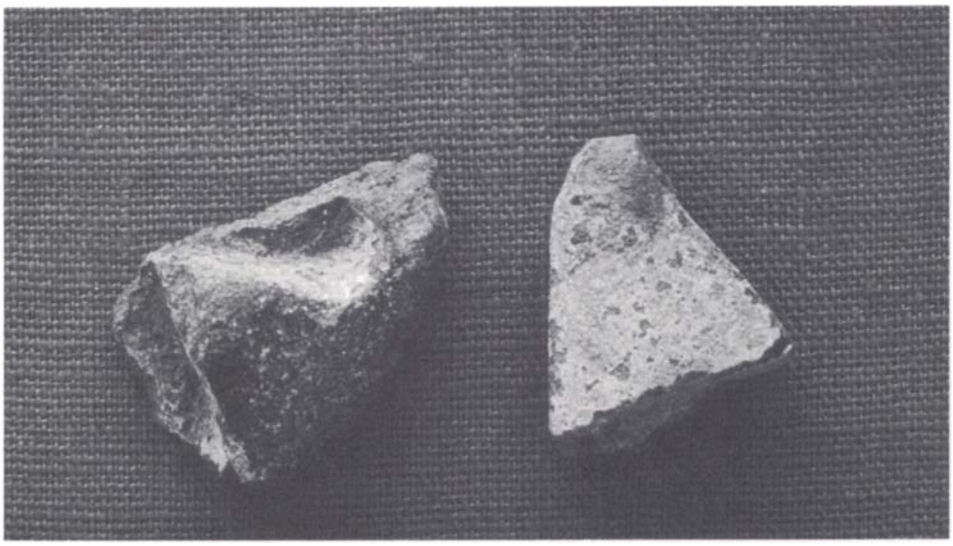


FIGURE 10. *Native gold flake from the vicinity of Putushio. See bar for length of object. Gold-silver alloy, copper below half a percent. Associated with iron-titanium-oxides (panned stream sediment).*

FIGURE 11. *Two fragments of a clay mold with adhering tiny splashes of gold from Putushio, unit F 1470. Late Formative period habitation floor. 3420 ± 255 B.P. (Hv 16798).*



authors did not clean these pieces thoroughly, but all of the gold splashes (except one) are on the very smooth lining in what is thought to be the form of the mold, while the one splash is on top of one of the fragments. Energy-dispersive spectrometry analyses show the metal to be rather pure gold, with about 6% silver and <0.5% copper, making it an unalloyed, natural gold composition, as one would expect from this early time.

Two other pieces related to ancient metallurgical activity are lithics. One is a worked chalcedony of only 1.4 cm in length from unit F 133, a bowl-shaped clay fitment, dated to 435 ± 135 B.P. The oblong and relatively gross form of the artifact seems to be accidental, but the longer edges, dextro- and sinistrolateral, are retouched straight on the two faces. Streaks of gold are on the dorsal face, mainly dextrolateral, and also on the distal end.[5]

The other lithic (Nº 1838) is a fragment of a dark metamorphic rock of elongated triangular form, 2 cm long. It was found in unit F 1117, dated to 1080 ± 170 B.P., a workshop area of about 6 m^2 with some destroyed parts of bowl-shaped installations. The smooth ventral side of the piece has a polished shine of use and shows streaks of gold on the slightly curved distal end. The contact with the metal obviously occurred with some pressure, probably for surface preparation work. Energy-dispersive spectrometry analyses of these streaks gave about 2% silver and 2% copper for the chalcedony sample, and 10% silver with only traces of copper for the dark sample.

The original function of these lithics is not immediately clear. The dark, dense rock, with its smooth surface, may well have been used for thinning gold foil or some other surface preparation work, while the chert sample was probably used as a cutting tool.

Summary and Prospect

Putushio is an archaeological site with a long-lasting settlement over more than three thousand years, from the early fifteenth century B.C.E. up to the end of the fifteenth or beginning of the sixteenth century C.E. The place became abandoned at the time when the Incas entered southern Ecuador. No later settlement took place on the Huahua-Putushio and on the Loma of Putushio.

Ceramic wares and shells indicate far-reaching and continuous relations to the coast of Ecuador and northern Peru. At the end of the Regional Developmental period, these were extended to the north, probably to southern Colombia; contacts to the south and to the eastern slopes of the Andes toward the Amazon basin cannot be denied.

Physical evidence is present for gold working at the site from the Late Formative period up to the Inca conquest. And for the area excavated, the authors can demonstrate a significant increase in metallurgical activity during the Regional Developmental period, marked by the appearance and continuous use of furnacelike installations from about 200 B.C.E. onward.

The position of the workshops in a dry climate, with the advantage of powerful winds (Cieza de Leon 1551; Lechtman 1976:24–32), in an area easy to protect was ideal. The strong linkage of metal workshops to terraces in the excavated area leads the authors to believe that gold working was realized in a nearly industrialized way.

An important source for the gold evidently was the direct vicinity, but its exploitation is also imaginable from the nearby gold-bearing rivers east of the cordillera.

The metallurgical evidence, given in chronological order, presents itself as follows:

1. The earliest relics of metallurgical significance excavated come from the Late Formative floor F 1470. They are two mold fragments, their linings sprinkled with tiny droplets of gold, apparently of natural composition, demonstrating the casting of molten metal into a well-prepared form. The related radiocarbon date is 3420 ± 255 B.P. Several gold foils from other Late Formative period contexts are good evidence for the early production of very thin gold metal.
2. The Regional Developmental period brought the alloying of substantial amounts of copper to the gold, exceeding 40% copper by weight, and the continuous use of more or less unalloyed gold for foil making. In this period falls the introduction of the bowl-shaped installations resembling metallurgical furnaces and the preparation and separate storage of special clays in the activity area. In the area excavated, the installations were built immediately after the construction of the terraces.
3. From the Early Integration period onward, the use of the installations and the appearance of soil deposits related to them increased significantly, at least within the area excavated. The production of tumbaga went on, as did the foil making. One of the stone implements, obviously used as a tool for some type of gold processing (№ 1838), belongs to this period.
4. The microanalytical investigation of the metallic remains shows that all fabricated samples are higher in copper than the native flakes and micronuggets from the excavation and the immediate vicinity. This increase in copper content is small only for the gold foils and some of the prills but becomes more explicit

for some other prills and is overwhelming at the tumbaga splash. The addition of minor amounts of copper to native gold for foil production is not yet possible to prove as an intentional alloying or just the result of using scrap metal; but Shimura (1988) claims for Japanese gold foil 1% copper, an intentionally added amount to enhance color and deformability. Certainly, the tumbaga production at Putushio was a fully deliberate alloying operation to produce a material of major importance for pre-Columbian metalworking.

5. The silver distribution becomes more complex with increasing copper content; the alloys with intermediate copper values are marked by coring with continuous silver gradients from 9 to 27%, while the most copper-rich tumbaga sample develops a eutectic structure with a silver-dominated second metallic phase.

Combining all the evidence given, one certainly can label Putushio the first undisturbed Pre-Columbian gold workshop available for archaeological investigation in all South America. Taking into account the quantity and quality of material from the small area excavated so far, its apparently unbroken gold-working tradition over a very long period of time and its diversity of techniques applied, Putushio may well add significantly to our knowledge of Pre-Columbian metalworking in terms of techniques used and alloys chosen at a given time.

But certainly much more fieldwork and analytical work has to be done to explore the full potential of the site until the cultural concepts and aims behind the methods applied can be fully understood. For the time being, one first has to establish the function and purpose of the furnacelike installations and the soil deposits related to them. Then, a sequence of alloys through time and the origin of the raw materials have to be determined. Finally, the application of different tools and techniques used for the manufacture of objects may be resolved.

Acknowledgments

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Notes

1. Period nominations are to be understood as temporal frames. Corresponding absolute dates for this context are roughly: Late Formative period 1500–300 B.C.E.; Regional Developmental period 300 B.C.E.–800 C.E.; Integration period 800–1500 C.E. (Inca conquest).
2. Radiocarbon dates are from Niedersächsisches Landesamt für Bodenforschung, Hannover, Germany, No. Hv 14702-14708, 15238-15241, 15830-15835, and 16797-16800. Ages given as B.P. are corrected for $\partial^{13}C$, and absolute dates are calibrated against the dendrochronological curve. The youngest date, 435 ± 135,

is from Krueger Enterprise, Cambridge, Mass., Laboratory No. G 10690; no correction and calibration are available for this value.

3. Analyzed by A. Richter, Mineralogisch-Petrographisches Institut und Museum der Universität Kiel, Germany.
4. No detailed TEM study has been done to determine the exact nature of the silver enrichment. Microscopically, there is a continuous gradient that may well be a submicroscopic precipitation of alpha'-(AgAu).
5. The lithics with retouched edges from the later occupation at Putushio are generally very small or are microlithics with less-defined morphological forms compared to lithics of the Late Formative period.

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Biographies

Thilo Rehren began working with the Deutsches Bergbau-Museum in 1985 on Early Bronze Age metallurgy in Iran. Following a six-month training fellowship at the Department of Metallurgy and Science of Materials, Oxford University, he joined the Bergbau-Museum's newly founded Institut für Archäometallurgie in 1990. His main interests are in extractive nonferrous metallurgy, crucible smelting, and melting behavior of ancient metals. He studied economic geology and nonferrous metallurgy at Freiburg and Clausthal universities from 1980 to 1985, and petrology and volcanology as a Ph.D. candidate at Freiburg University from 1986 to 1989.

Mathilde Temme is associate researcher with the Museo Antropológico del Banco Central del Ecuador, where she is studying the archaeology of the southern Ecuadorian highland. In 1968 her doctorate work at the University of Köln took her to South America for the first time. She has lived in Ecuador since 1975 and served as director of the Institute de Investigaciones Económicas of the Universidad Tecnica Particular de Loja before joining the Museo Antropológico. Her work has included the excavation of the preceramic site of Cubilán.

Pre-Hispanic Platinum Alloys: Their Composition and Use in Ecuador and Colombia

David A. Scott and
Warwick Bray

A unique development in metalworking by the ancient Indians of Ecuador and Colombia was the discovery and utilization of native platinum, a material that received very little attention in the Old World and which, in fact, was not recognized in its own right until platinum samples from Colombia reached Europe during the early decades of the eighteenth century.

The early history of platinum and the attempts of many scientists to make use of the new material have been documented by several authors (McDonald 1959, 1960; Chaston 1980). Many difficulties had to be overcome, but in the process, the new elements platinum, palladium, iridium, osmium, ruthenium, and rhodium were discovered and new metallurgical techniques of fabrication developed. The Pre-Hispanic Indians had, of course, no knowledge that the metal they were using was then unknown in Europe, nor that their Spanish conquerors were later to find the dull gray metal a nuisance in their gold-dredging operations. For some time, it was ordered to be thrown back into the rivers as a useless "impurity." The situation is summed up by two of the first scientific travelers to visit Ecuador (Juan and Ulloa 1748:vol. 2:606):

> En el Partido del Chocó, habiendo muchas Minas de Lavadero, como las que se acaban de explicar, se encuentran también algunas, donde por estar disfrazado, y envuelto el oro con otros cuerpos metálicos, jugos, y piedras, necesita para su beneficio del auxilio del Azogue; y tal vez se hallan minerales, donde la platina (piedra de tanta resistencia, que no es fácil romperla, ni desmenuzarla con la fuerza del golpe sobre el yunque de acero) es causa de que se abandonen; porque ni la calcinación la vence, ni hay arbitrio para extraer el metal que encierra, sino a expensas de mucho trabajo, y costo. También se encuentran entre estas minas algunas donde hay mezclado con el oro el metal de tumbaga tan fina, y con las mismas propiededes que la del Oriente—siendo las más singular en ella, el no criar verdín, ni extraerse por medio de los ácidos, como sucede con el cobre ordinario.

> [Several of the mines have been abandoned on account of the Platina; a substance of such resistance that, when it is struck on an anvil of steel, it is not easily separated; nor is it calcinable; so that the metal inclosed within this obdurate metal could not be extracted without infinite labour and charge.]

This state of affairs was later to change, and the Spanish were to achieve notable advances in platinum technology, leading to a period of its use in Spain, especially between 1775 and 1800 (Juan and Ulloa 1748; Chabaneau 1786 [see Chaston 1980]).[1] One of the few examples of the use of platinum in the Old World is that described by Berthelot (1901). A late Egyptian bronze box from Thebes inlaid with silver was also found to be inlaid with a strip of platinum, distinct from silver, for which it was probably mistaken.

The platinum group metals—or platinoids, as they are called—can occur in placer deposits together with gold, and by far the most common occurrence in antiquity is as small, incidental inclusions in gold objects. A recent and comprehensive review of these inclusions in the Old World has recently been published by Ogden (1977). Although very little use of the platinum group metals was made in antiquity, it is difficult to see how the gold workers could have remained unaware of what must have been a troublesome impurity. Gold, in both the New World and the Old, was frequently obtained from placer deposits contaminated with platinoids that possess high melting points (1500 °C upward) and very high hardness values (200–900 on the Vickers DPN scale). Such inclusions will not dissolve appreciably, following cycles of working and annealing, nor in the casting of gold objects; and if their presence is substantial, the surface of the object will be flecked with inclusions. These inclusions may interfere with surface decoration, since incised lines may meet with an inclusion that will act as an effective obstacle. These "impurities" must have been observed by ancient metalworkers; there is, for example, some evidence for believing that Pliny (1962:bk. 37), in writing of minerals which he described as "adamas," included platinoid grains amongst them. He lists six features that quite accurately describe platinoid minerals: (1) they exist as a "knot of gold," (2) they are silvery in color, (3) they are comparable in size to millet or cucumber seed, (4) they "conquer fire," (5) they cannot be worked with the hammer, and (6) they were said to attract iron more readily than a magnet.

Many of these points can be seen as a direct description of the occurrence and nature of platinum metals, while it should be noted that native platinum grains are frequently ferromagnetic and that mechanical deformation of the grains can induce structural changes resulting in enhanced ferromagnetic properties (Crangle 1959). It is remarkable that an awareness, which must surely have existed in both the Old and New worlds, led to the deliberate exploitation of placer platinum deposits only in the New.

The Occurrence of Native Platinum in South America

The source rocks for the platinum minerals in Colombia and Ecuador are thought to be pre-Late Tertiary mafic-ultramafic intrusives (Mertie 1969). Most Tertiary period rocks outcrop along the western cordillera in areas that correlate to some extent with alluvial platiniferous deposits. As can be seen from the map in Figure 1, the most abundant placers are those of the Department of Chocó, in the region of Pacific Colombia, where platinum is found disseminated in ultrabasic rocks such as pyroxene, serpentine, and dunites (Monroy 1978). The Chocó area today produces about 98% of the platinum of Colombia, the other 2% being obtained from the departments of Antioquia and Nariño. A geological examination of worldwide platinum deposits has led to a more detailed understanding of the occurrence of platinum, based on two principal metallogenic regions: (1) Alaskan-type concentrically zoned intrusions, and (2) Alpine-type mafic-ultramafic intrusions.

On the basis of data from the literature, Cabri and Harris (1975) have listed occurrences of these types of deposit. The Tertiary deposits of Colombia are of the Alaskan type (Mertie 1979); the two types being characterized by values of R, where

$$R = \frac{\text{Pt wt\%} \times 100}{\text{Pt wt\%} + \text{Ir wt\%} + \text{Os wt\%}}$$

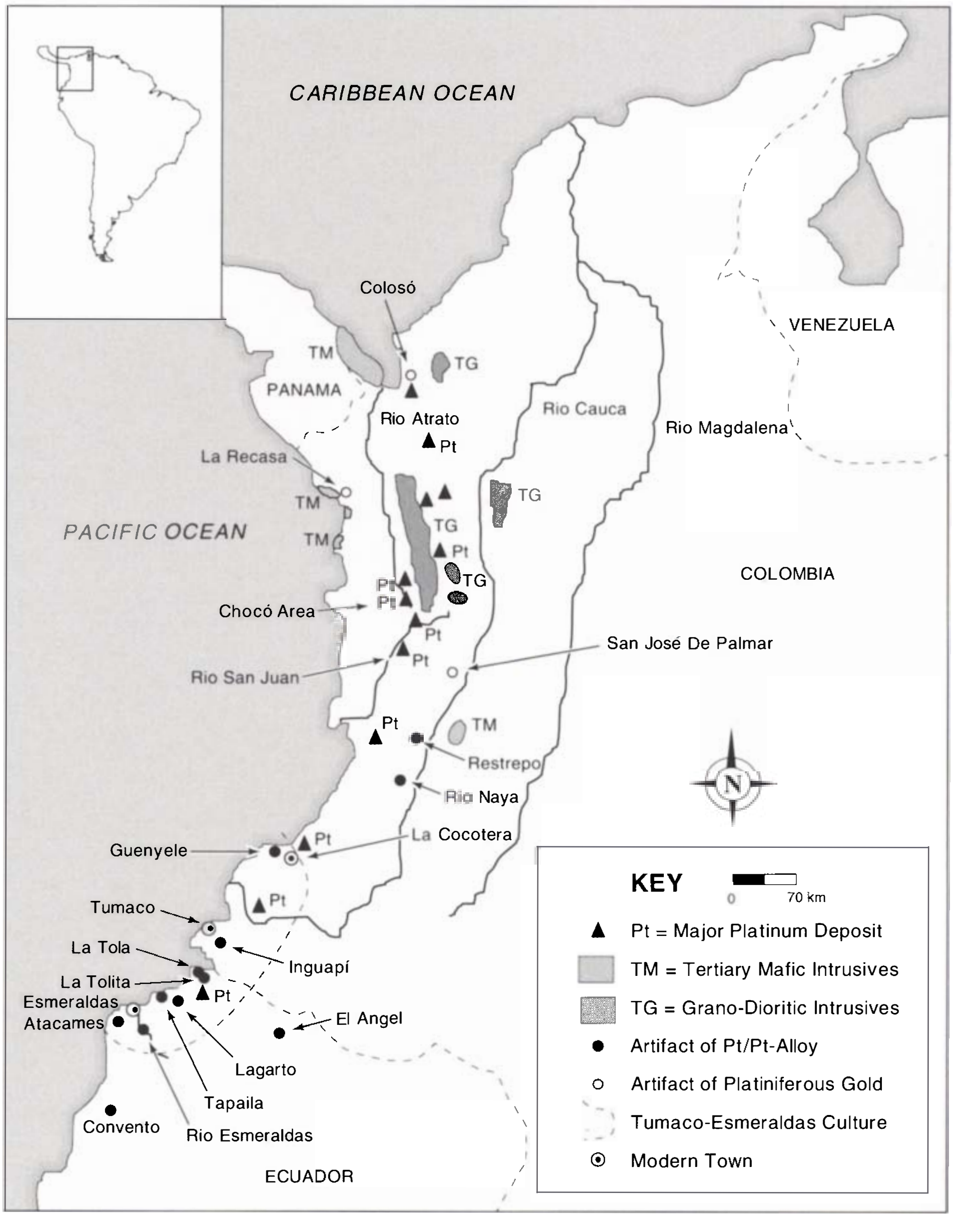


Figure 1. *Map of South American platinum deposits.*

In Alaskan-type intrusions, R has a high value (85) compared with the Alpine-type in which R has a low value (40). Cabri and Harris (1975) have suggested that the Au/Ir ratio may also be of significance. This ratio, as well as R, gives the Colombian and Ecuadorian deposits a particular character in which R has been estimated at about 95 (Mertie 1979:table 27) and the Au/Ir ratio is also high—as is corroborated by examination of ancient gold objects from Colombia (Scott 1982). The very low levels of native iridium-osmium-ruthenium alloys in platinum artifacts from Ecuador and Colombia further substantiate the ratio obtained by Mertie.

The original mafic source-rocks have suffered severe erosion, resulting in alluvial deposits rich in platinum in the Chocó area of Colombia and in the Pacific coastal area on both sides of the Colombian-Ecuadorian border. Alluvial platinum, then, is encountered along the western flanks of the western cordillera. Elsewhere, away from the Pacific lowlands, platinum is rare. Commercial quantities of the metal are in the coastal lands, but small quantities have recently been discovered in the Rio Bravo, a tributary of the Calima above 1000 m (Roe, pers. comm. 1982). It is likely that the upper reaches of many Pacific-draining rivers contain some platinum in the alluvial gold deposits. This would explain the platinum inclusions in a nose ornament from San José de Palmar, Department of Valle. This evidence also helps to explain the relative paucity of platinoid inclusions in the gold work of Colombia, for the gold mineralization belts are found principally along the central cordillera, in parts of the western, and to a minor extent, in the eastern. Any major occurrence of platinoid inclusions in a gold artifact will normally indicate either manufacture somewhere on the Pacific slope, or the import of raw gold from that region.

Unlike platinum metals, the native gold of Colombia is associated with igneous rocks of acid plutonic type, such as granite, granodiorites, and quartz monzonites, which are found in many areas principally along the central cordillera. These deposits occur especially in the departments of Antioquia, Chocó, Caldas, Cauca, and Nariño, where the Indians utilized both placer and vein gold. The quartz veins in the northwest of Antioquia, for instance, were mined to a depth of 20–27 m (White 1884). Apart from the Chocó area (for which there is little archaeological evidence), all the departments mentioned above are known to have been worked extensively in antiquity.

Both the geological and archaeological evidence show that, in most regions, the ancient gold workers had access to deposits that were either free of platinoids or contained very minor quantities of them. Analyses of over 150 gold and *tumbaga* (gold-copper) fragments from various parts of Colombia (Scott 1982) showed that platinoid inclusions were rare, while typical platinum contents were in the parts per million range from 50 to 1000 ppm with low or undetected iridium, osmium, and ruthenium. Mixed gold and platinum placer deposits must have been the source of the platinum that was used in Pre-Hispanic times. Modern methods of gravel dredging operate on a vast scale, compared with Indian methods of mining and gravel-washing by means of the *batea*. Primitive methods, however, would have possessed the virtue of close personal observation of the nature of the sands in which gold and platinum may occur. Castillo found, during investigations in the San Juan valley, that it was possible to tell from the color of the gravel whether it might be gold-bearing or platinum-bearing. The gold gravels were "whitish and reddish in colour, while platinum, owing to the gabbro, has a bluish-black colour. . . . the separation of the gold from the platinum gravel being so sharp that the writer was able to trace the platinum to its source-rock" (Castillo 1909). By panning operations alone, however, it is unlikely that the Indians could separate gold and platinum if these were found together, for the specific gravity of both metals ranges from about 14 to 19; most native gold contains some silver and a little copper, while native platinum may contain varying quantities of iron, copper, rhodium, palladium, and iridium.

Some analyses of native platinum samples from Colombia and Ecuador are given in Table 1. The analytical work of J. J. Berzelius (1828), who examined some platinum from Colombia and Russia, is impressive for its accuracy, even by modern standards, and some of his results are given in the table. Electron microprobe analysis results for Ecuadorian and Colombian platinum show compositional data placing most of the native material in the ferroan platinum–isoferroplatinum region, distinguished from native platinum by the criteria of Cabri and Feather (1975). This platinum-iron alloy appears not to vary greatly within a particular metallogenic region, and this is true of the South American material in which the Fe/Pt ratio was found to fall within the limits of 0.08–0.12. The size of the alluvial grains is similar to that of gold (McDonald 1959), and the separation of mixed deposits would have required hand sorting; although if the native platinum is ferromagnetic, some clumping together of the platinum might be expected on washing in the batea. Larger nuggets of platinum are sometimes encountered; a specimen from the Chocó area now in the Royal Museum of Madrid weighed nearly 700 g (Heuland 1818), and there are archaeological specimens of platinum nuggets from Colombia that have been hammered into simple penannular nose rings. Copper and nickel can

TABLE 1. *Chemical analyses of platinum objects and ores from Colombia and Ecuador. Chemical analyses of native platinum from Colombia and Ecuador and electron microprobe analyses of two fabricated objects.*

Sample	Native Platinum			Sintered Gold-Platinum			Gold-Platinum Block	
Location	Colombia Berzelius 1828	Chocó Monroy 1978	Esmeraldas Wolf 1872	Esmeraldas Different areas of the object shown in Figure 21			La Tolita Different areas of the object	
Reference	(12)	(15)	(13)	1	2	3	1	2
Platinum	81.30	86.16	84.95	85.26	5.68	3.17	83.47	6.37
Palladium	1.06	0.35	4.64	nd[1]	nd	nd	0.68	nd
Rhodium	3.46	2.16		2.11	nd	nd	2.59	nd
Iridium	1.46	1.19	nd	nd	nd	40.23	0.10	nd
Osmium	—	—	—	nd	nd	43.54	nd	nd
Ruthenium	—	—	—	nd	nd	10.16	nd	nd
"Ir/Os"	1.03	1.19	1.54	—	—	—	—	—
Gold	nil	nil	1.12	nd	79.51	nd	0.24	70.17
Silver	nil	nil	tr[2]	nd	8.98	nd	0.13	7.23
Copper	0.74	0.40	tr	0.87	7.52	nd	1.03	7.23
Iron	5.31	8.03	—	7.19	nd	nd	6.37	0.10
Silicon	nil	0.97	0.81	—	—	—	—	—
Total	94.36	100.45	93.06	95.43	101.69	97.10	94.61	91.10

[1] not detected

[2] traces

replace iron in native platinum, leading to a natural series of platinum-copper alloys; there is one example of a platinum-copper nugget being worked to make a small nose ring from Colombia, shown in Figure 5.

Pre-Hispanic Platinum Objects

While undertaking geological exploration in the Ecuadorian department of Esmeraldas, just south of the Colombian border on the Pacific Coast, Wolf (1879: vol. III; 1892) discovered among the alluvial deposits small platinum artifacts that must have been made by the Indians in antiquity. In 1912, Verneau and Rivet described a figurine from El Angel, Carchi, in the Andean highlands, made of sheet gold with one eye of silver and the other of platinum (see Fig. 3).

Further examples of small gold and platinum objects were found at La Tolita in 1912 and published by Farabee in 1921; in this collection (which is now in the University of Pennsylvania Museum) were objects of native platinum, sintered gold-platinum alloys, and gold objects coated with platinum on one side.[2]

Little metallurgical interest was taken in ancient platinum usage until a number of small objects were obtained from Ecuador by Paul Bergsøe. The collection comprises face studs, tweezers, nose ornaments, awls, small ornaments, and other material from La Tolita and various sites in Esmeraldas. The metals used by the Indians of this area were found to be native copper, gold, lead, gold-copper alloys, platinum-gold alloys, gold coated with platinum, and copper plated with gold. There does not seem to be any lost-wax casting in the Esmeraldas-Tumaco area; Bergsøe found no evidence for it, and a recent examination of the material supports Bergsøe's findings. In 1937 and 1938, Bergsøe published two monographs on the metallurgy of the area, the first dealing with gold and platinum and the second concentrating on the gilding method and the metallurgy of copper and lead. The 1937 report gives the first account of the use of sintered gold and platinum alloys in antiquity. Bergsøe described finding, amongst the objects from La Tolita, tiny sintered lumps in which native platinum laths were heated together with gold. These were fused with the blowpipe on charcoal until they were sufficiently sintered to enable them to be beaten out with a hammer. By this simple technique, the Indians were able to make platinum-gold alloys and even achieved such skill in working the sintered alloy that they could coat one side of the small object with platinum, the other remaining gold in color. Bergsøe also conducted a number of analyses of the alloys, some of which proved to be gold (and silver as a constituent of the native gold), platinum, and copper. He carried out experiments on the hardness of the ancient objects, and made some standard comparative alloys in the laboratory. Subsequent investigation has confirmed the accuracy of Bergsøe's findings,[3] and his monographs remain essential reading for an understanding of the metallurgy of the area.

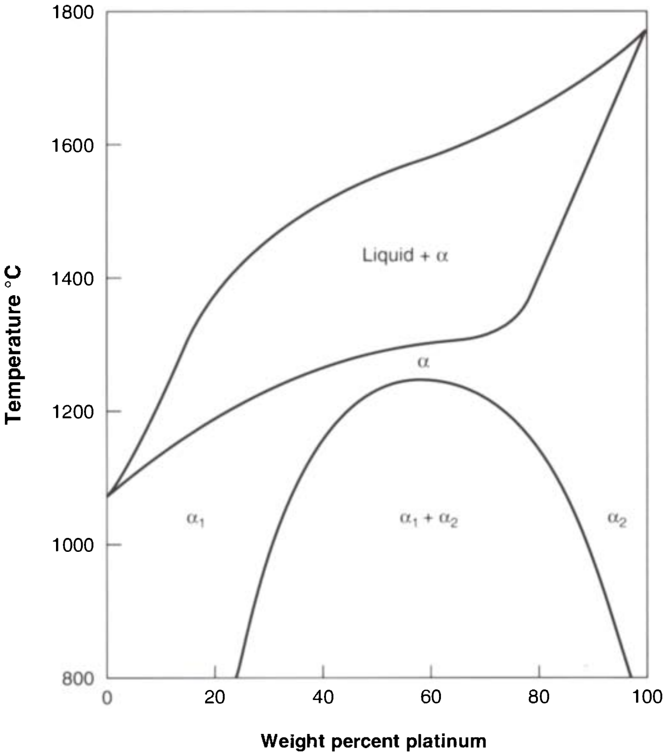
Two later publications derive directly from Bergsøe's work: the study by Reichlen (1942) of all the Esmeraldas metalwork in the Musée de l'Homme and in the Terver Collection,[3] and a note by d'Harcourt (1948), which gives analyses of two platinum objects in the same museum. Some advances have been made since Bergsøe's investigations; in part this is due to the availability of much more sophisticated analytical tools, such as the scanning electron microscope and the electron probe microanalyzer, and in part to a recent resurgence of interest in platinum and platinum metals as a result of geochemical and geological studies (see for example Cabri et al, 1973; Cabri 1974; Cabri and Hey 1974; Cabri and Harris 1975; Cabri and Feather 1975; Cousins 1973; Harris 1974; Harris and Cabri 1973; Mertie 1969; Stumpfl and Clark 1966; Stumpfl and Tarkian 1973).

One of the few omissions in Bergsøe's work was the lack of any analyses for iron in the platinum. He did not seem to be aware that many of the gold and platinum sintered alloys could be picked up with a hand magnet, showing that they are ferromagnetic as a consequence of their platinum-iron content. The analysis of platinoid inclusions was considered by Bergsøe but rejected at that time, since the destruction of many objects would not necessarily have resulted in any worthwhile analytical conclusions. The analyst is more fortunate today, for there are many means by which small inclusions can be analyzed without the wholesale destruction of objects which a bulk analysis would require. Since Bergsøe's time, a number of other platinum or platinum-gold objects have been found in Colombia and Ecuador and a few analyses have been made.

With the generous permission of the Department of Ethnography of the National Museum of Denmark, Copenhagen (where the material examined by Bergsøe is now stored), a number of tiny samples ranging from 1 to 4 mg were taken, mostly from fragmentary objects, for further chemical and metallurgical study at the Institute of Archaeology, London. Opportunity was also taken in Colombia to analyze a few platinum nose rings in the collections of the Museo del Oro, Banco de la República, Bogotá, with the generous permission of the curatorial staff.

Figures 2–22 illustrate a few objects from Ecuador and Colombia in museum or private collections, most of which have received some analytical study.

FIGURE 2. *Gold-platinum phase diagram.*



Archaeological information is also included when any is available. The laboratory number quoted in the descriptions is that of the metallurgical sample number used to track the specimens.

A map of South American platinum deposits is depicted in Figure 1. Figure 2 shows a gold-platinum phase diagram.

Figure 3 shows a figure made from a series of thin sheets of gold held together with the aid of very fine "staples" of gold (Verneau and Rivet 1912–22:323–24, pl. 24, fig. 2). The face and front part of the neck are made in one piece. The skull and back part of the neck are made from a second sheet of gold, fixed to the first by staples passing through two holes on a level with the temples. The left eye is made in silver and also contains a little copper (perhaps a surface enriched copper-silver alloy rather than pure silver). Analysis of the right eye showed Pt 50%, Ag 25%, and Au 25%, with an error range of 5–7%, and ignoring the small quantity of copper and the presence of trace elements (d'Harcourt 1948:325).

Although found in highland Ecuador, the style of this figure is entirely coastal. Verneau and Rivet suggested that it may originally have had two platinum eyes, one of which was lost somewhere in the highlands and was replaced by locally available Andean silver. The age of the piece is difficult to establish. At the time of its discovery, most of the items from Carchi came from shaft tombs that span the period 800 C.E. to the Conquest. These tombs also contain imported seashells and clay figurines of the Tumaco-Esmeraldas type (Francisco 1969; Uribe 1977–78). Jones (1979) compares this figure with one from Frias, in north Peru, which might argue for a date a little before 800.

Figure 4 depicts a gold-alloy mask coated with platinum on the exterior. This fine sheet-metal piece has human features and animal fangs (Schuler-Schömig 1975;

FIGURE 3a, b. *Figure made from a series of thin sheets of gold held together with very fine "staples" of gold. Height 134 mm. From El Angel, Carchi, in the Ecuadorian highlands just south of the Colombian border. Musée de l'Homme No. 45-6-1.*

FIGURE 4. *Gold alloy mask coated with platinum on the exterior. The punched holes suggest that the mask may have been originally pinned to a wooden idol. Dimensions 71 × 52 mm. Believed to come from the Rio Esmeraldas, and obtained in the 1870s by Adolf Bastian, the first Director of the Ethnographical Museum, Berlin. Museum für Völkerkunde, Berlin, Cat. No. Va 2152.*

Scott and Bray 1980:fig. 1). The concave pupils of the eyes are typical of Esmeraldas masks. The punched holes suggest that the mask may have been originally pinned to a wooden idol.

Several nose rings and ornaments are displayed in Figures 5–14. Figure 5 shows a penannular nose ring of circular section (Scott and Bray 1980:fig. 4). The polished surface has a purple-brown patina in which a number of small platinoid inclusions can be seen. Part of the nose ring surface has broken away at one end to reveal a dark brown, powdery interior. The alloy is a platinum-copper-iron nugget and it is weakly ferromagnetic. Figure 6 is a penannular nose ring of circular cross-section made from a native platinum nugget (Scott and Bray 1980:fig. 4).

Figure 7 is a nose ring made in platinum, found in the area of the headwaters of the Rio San Juan, Department of Choco, Colombia (Orchard 1927:118, fig. 41ff). Figure 8 shows a penannular nose ring, elliptical in shape with smooth surfaces of pale silver color (Pérez de Barradas 1954:83, pls. 15, 38, fig. 60; Scott and Bray 1980:fig. 4). Signs of hammering are evident along parts of the length, where pieces of folded-over and burnished metal can be seen. It is made in a sintered platinum-gold alloy. Figure 9 is a small nose ring that, although not analyzed, appears to be made of a sintered gold-platinum alloy (Pérez de Barradas 1954:81, pls. 15, 31, fig. 59).

Figure 10 shows a penannular nose ring of circular cross section, with plain surfaces (Pérez de Barradas 1954:108, 266, pl. 60a, fig. 82). The color, which is yellow-gray, suggests a high platinum content. There are no visible platinoid inclusions. This piece came to the Museo del Oro in Bogotá (with No. 5142) in a lot of forty-seven items, which included two typical pins of the "Yotoco" style (ca. 1–1000 C.E.) from the Calima region of the western cordillera (Bray 1978:63–64; Bray 1991). A similar pin was found at La Tolita (Zevallos Menández 1965–66:fig. 9) and, in the reverse direction, Ecuadorian emeralds have been found with the corresponding style of gold work in the Calima zone (Pérez de Barradas 1954:205). A date older than 1000 C.E. for these platinum items seems likely, though the association cannot be proved.

FIGURE 5. *Penannular nose ring of circular section. Dimensions 25 mm across, 7 mm in diameter. Weight 19.70 g. Specific gravity 12.2. Museo de Oro, Bogotá, no number, Lab. No. M 147.*

FIGURE 6. *Penannular nose ring of circular cross section made from a native platinum nugget. Weight 40.5 g. Specific gravity 14.9. Dimensions 29 mm across, about 7.5 mm diameter. Museo del Oro, no number, Lab No. 74.*

FIGURE 7. *Nose ring made in platinum, found in the area of the headwaters of the Rio San Juan, Department of Chocó, Colombia. The piece is about 26 mm. across. Museum of the American Indian, Heye Foundation No. 5/3948.*

Figure 8. *Penannular nose ring, elliptical in shape with smooth surfaces of pale silver color. Weight 31 g. Dimensions 43 mm × 37.5 mm, 4.66 mm thick. Municipio of Restrepo, Department of Valle del Cauca, Colombia. Museo del Oro, No. 4201. Lab. No. 150.*

Figure 9. *Small nose ring that appears to be made of a sintered gold-platinum alloy. Weight 3.42 g. Dimensions 14 × 15 mm. From the Municipio of Restrepo, Department of Valle del Cauca, Colombia. Museo del Oro, No. 3819.*

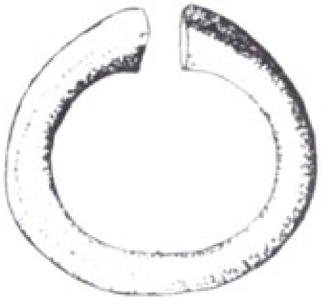


Figure 10. *Penannular nose ring of circular cross section, with plain surfaces. Weight 39.60 g. Dimensions 30 × 33.5 mm. From the Municipio of Restrepo, Department of Valle del Cauca, Colombia. Museo del Oro, No. 5141. Lab. No. 151.*

Figure 11 depicts a small nose ring, rectangular in section with rounded corners (Pérez de Barradas 1954:108, 266, pl. 60a, fig. 82). The surfaces are pale silver in color, which suggests a high platinum content; there are no obvious platinum group metal inclusions. For archaeological background see the previous item.

Figure 12 is a small nose ornament of gold, the surface of which has small specks and dots, some of them so small that they can be seen only with the aid of a microscope (Linné 1929:188, fig. 51F). Linné had a chemical analysis performed, which showed that the inclusions were of platinum. Some of the material from Linné's cemetery can be equated with Phase III of the Cupica sequence established by G. and A. Reichel-Dolmatoff (1961), but most of the pottery clearly belongs within Phase IV. This can be dated, by imported Panamanian wares, to circa 800–1200 C.E.

Figure 13 shows a small crescentic nose ornament of gray-white metal (d'Harcourt 1948:323–24). Analysis of the major constituents (presumably by wet chemical methods) showed the following: Pt 45%, Au 25%, Ag 25%, Cu 5%. These proportions indicate a deliberate, sintered, gold-platinum alloy.

Figure 14 (previously unpublished) is a small sintered gold-platinum nose ring from Colombia, of unknown provenance. An analysis in the Archives of the Museo del Oro showed 22% gold and 75.8% platinum.

A head in gold and platinum (which metal has been used in particular parts of the head is not specified) is shown in Figure 15 (Lapiner 1976:fig. 773). The figure wears a crescentic nose ornament of the same shape as the item just described, and

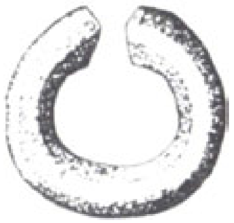


Figure 11. *Small nose ring, rectangular in section with rounded corners. Weight 21.20 g. Dimensions 22 × 22.5 mm. Maximum thickness 5.35 mm. From the Municipio of Restrepo, Department of Valle del Cauca, Colombia. Museo del Oro, No. 5142. Lab. No. 152.*

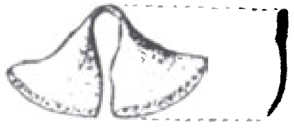


Figure 12. *Small nose ornament of gold, the surface of which has small specks and dots. Original illustration 13 × 22 mm. From Grave 18, La Recasa, Cupica, Department of Chocó, Colombia. Gothenberg Museum, No. 27.21.881. Ecuador, Museo del Banco Central, Quito.*

Figure 13. *Small crescentic nose ornament of gray-white metal. Weight 2.3765 g. Width 13 mm. Musée de l'Homme No. 48.45.1. The Catalogue gives the location as the Hacienda Tapaila, 2 km north of the Rio Mate, and found at the mouth of the Rio Tapaila.*

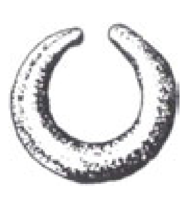


Figure 14. *Small sintered gold-platinum nose ring from Colombia, of unknown provenance. Width 15 mm across. An analysis in the Archives of the Museo del Oro gave 22% gold and 75.8% platinum. Museo del Oro No. 4729.*

Figure 15. *Head in gold and platinum (which metal has been used in particular parts of the head is not specified). From La Tolita, Department of Esmeraldas, Ecuador. Weight 4.0 g. Dimensions 20 × 28 mm. In a private collection in Ecuador.*

earrings in both ears. A sheet diadem is pinned to the head. From the photograph the head appears to be made in a gold-platinum alloy with a gold nose ring.

Figure 16 depicts a composite gold and platinum ornament (Scott and Bray 1980:fig. 2; Lausanne 1991:no. 92). Originally the piece probably had a full complement of platinum alloy spheres around the circumference, numbering forty-three in all, if all the gaps were filled. The braided wire decoration and the circular strip appear to be made in gold with an inset figure that is probably made in a sintered platinum-gold alloy, made in a number of pieces and attached to the central gold disc and to the gold strip running around the circumference. There are signs that the figure is attached to the gold areas by hammer welding, for raised areas of gold strip correspond to the position of the platinum alloy figure, which must continue at the back of the gold strip. The face is made in a hammered platinum-gold alloy.

Four dangle ornaments are shown in Figure 17. At the far left of the illustration is a small circular dangle. The dangle is in native gold plated with platinum on one side. Overall bulk composition is Au 70.23, Pt 12.97, Cu 3.18, Fe 1.17, Ag 2.92; total 90.47 (Bergsøe 1937:pl. 4:70). At the middle left is a small rectangular dangle with repoussé central boss and a small hole pierced toward the midpoint of one edge for attachment (Bergsøe 1937:pl. 4:66). This piece is made in a gold-platinum alloy with pale yellow surfaces on both sides of the dangle. The bulk composition is Au 65.9, Pt 15.3, Cu 6.8, Fe 3.8, Ag 5.9. The composition suggests that a gold-rich tumbaga alloy has been mixed with the platinum to produce the sintered material. At the middle right is a small and carefully made ornament, coated with platinum on the upper surface (Bergsøe 1937:70, pl. 4). A bulk analysis gave Au 73.13, Pt 17.26, Cu 1.24, Fe 3.97, Ag 4.15. The analysis suggests that a native gold was used to make the initial ornament which is plated with platinum.

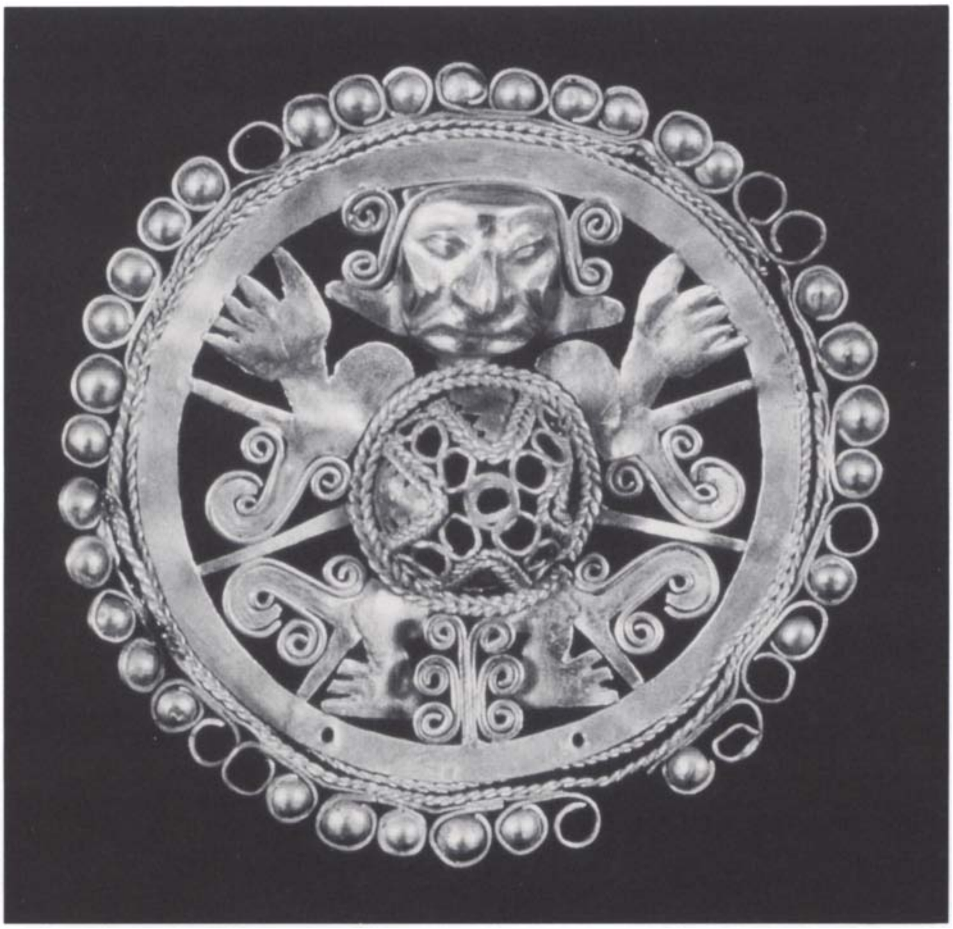


FIGURE 16. *A composite gold and platinum ornament. Approximate diameter 130 mm. Believed to be from the region of La Tolita, Department of Esmeraldas, Banco Central del Ecuador, Quito.*

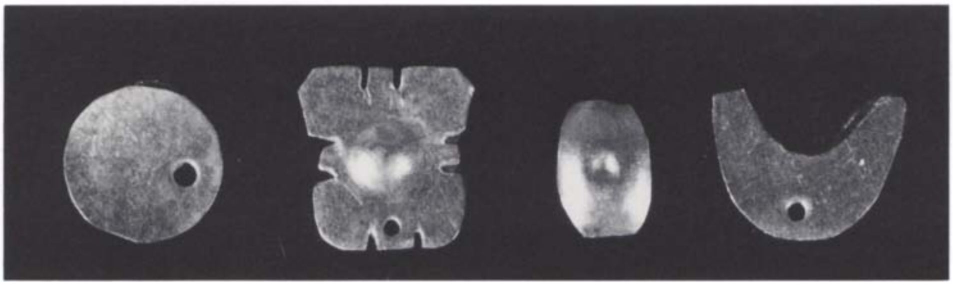


FIGURE 17. *A set of dangle ornaments.* ***Far left:*** *small circular dangle; diameter 7.3 mm, 0.24 mm thick. Museum No. 08274C, Lab No. 162.* ***Middle left:*** *small rectangular dangle with repoussé central boss and a small hole pierced toward the midpoint of one edge for attachment; 11.2 × 9.8 × 0.3 mm. Museum No. 08274D, Lab No. 163.* ***Middle right:*** *small and carefully made ornament; dimensions 5.2 × 3.4 × 0.3 mm. Museum No. 08274B.* ***Far right:*** *dangle with pale golden-colored interior but with silver-gray surfaces on both sides; approximate dimensions 3 × 5.4 × 0.26 mm. Museum No. 08274A, Lab No. 160.*

At the far right of Figure 17 is a dangle (Bergsøe: 1937:Pl. 4:65; Scott and Bray 1980) with a pale golden-colored interior but with silver-gray surfaces on both sides. One side appears to be slightly richer in platinum than the other. A small hole was pierced for attachment and was carefully finished, so there is no indication remaining as to how the hole was made. The dangle is ferromagnetic. A small fragment was removed from the upper left extremity for metallurgical study. The microstructure revealed that this piece had been plated with platinum on both sides of the object. The alloy of the sheet itself is also platinum containing along with occasional platinoid inclusions. The platinum of the interior alloy shows extensive dissolution compared with that of the surface as a result of the cycles of working and annealing the gold to shape the dangle. The platinum grains at the surface were subsequently added and fused with further heating and hammering and the resulting surface was then burnished. Microhardness values for this sheet gave values

Figure 18. *Small gold and platinum insect from La Tolita. Length 5 mm. In the collections of the Museum of the American Indian: Heye Foundation. Collected by Marshall H. Saville.*

ranging from 101 to 165 on the Vickers scale. Energy dispursive X-ray fluorescence analysis was employed to characterize the alloy. The platinum grains were very similar in composition to those shown in Table 1, while the gold-rich matrix was shown to be a native gold with about 10% silver and a trace of copper. Some of the platinoid inclusions were found to be of osmiridium, while one inclusion of native iridium was found. Some small iron-rich inclusions are probably magnetite particles picked up when panning for the platinum. An electron microprobe analysis produced the following data:

No.	Au	Pt	Ag	Ru	Cu	Rh	Os	Ir	Fe	Total
1	78.2	8.4	7.9	nd	4.6	nd	nd	nd	0.4	99.5
2	80.2	5.5	7.9	nd	5.1	nd	nd	nd	nd	98.7
3	3.1	52.0	0.7	nd	1.0	2.5	1.2	24.5	4.8	89.8

Figure 18 (previously unpublished) shows a small gold-and-platinum insect from La Tolita. Two small platinum-gold alloy objects are displayed in Figure 19. The upper object is a nose ornament and the lower a pair of tweezers.

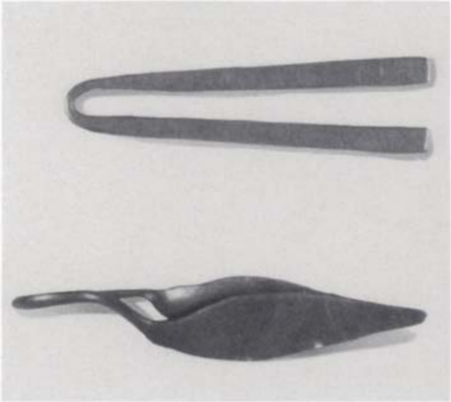


Figure 19. *Two small platinum-gold alloy objects. The upper object is a nose ornament (10 mm across) and the lower a pair of tweezers (length 15 mm). In the collections of the Museum of the American Indian: Heye Foundation. Collected by Marshall H. Saville.*

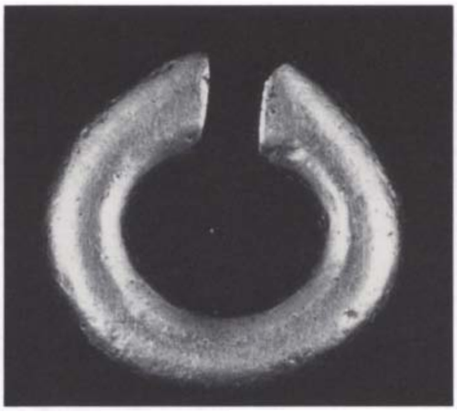


Figure 20. *Platinum-gold alloy penannular nose ring from La Tolita. Width 13 mm across. In the collections of the Museum of the American Indian: Heye Foundation. Collected by Marshall H. Saville.*

Figure 20 is a platinum-gold alloy penannular nose ring from La Tolita. To make sintered alloys into sizable nose rings generally involves a great deal of working, annealing, and interdiffusion and disaggregation of the platinum grains, as shown by the microstructure in Figure 24.

Figure 21 (previously unpublished) shows a gold vase from the Tumaco-Esmeraldas area, made in two pieces and joined around the equator. Half of the outer surface of the gold has been plated with platinum. Figure 22 shows the sintered mass in the early stages of fabrication. Figure 23 depicts a section of the nose ornament illustrated in Figure 8.

A gold-platinum sintered penannular nose ring from Colombia appears in Figure 24. The nose ring has a pale silver-colored surface; it is carefully made with a circular cross section, and the surface is well burnished with no visible platinoid inclusions. The polished and etched section shows a sintered gold-platinum alloy matrix with a considerable number of very small residual platinum globules. The

FIGURE 21. *Gold vase from the Tumaco-Esmeraldas area, made in two pieces and joined around the equator. Diameter 110 mm. Half of the outer surface of the gold has been plated with platinum. In a private collection.*

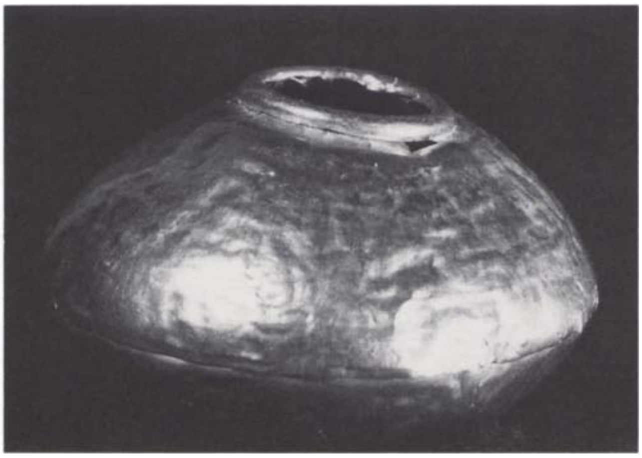


FIGURE 22. *Sintered mass in early stages. Bergsøe collection.*

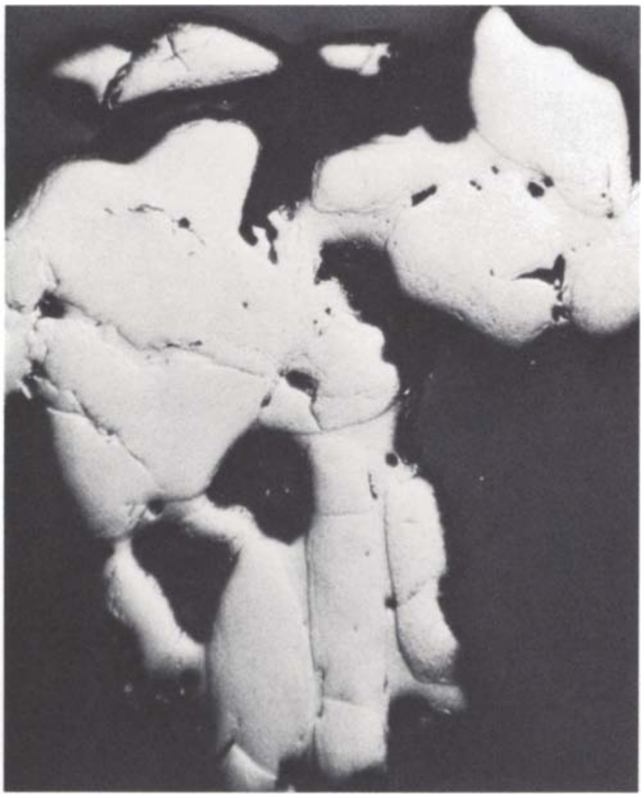
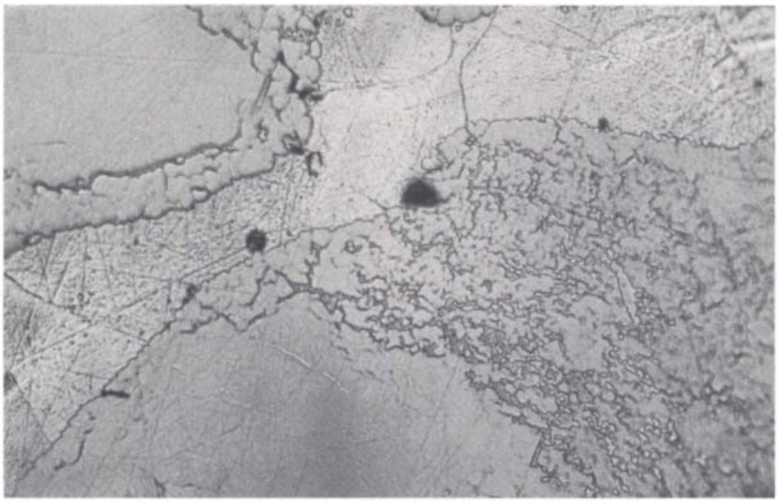
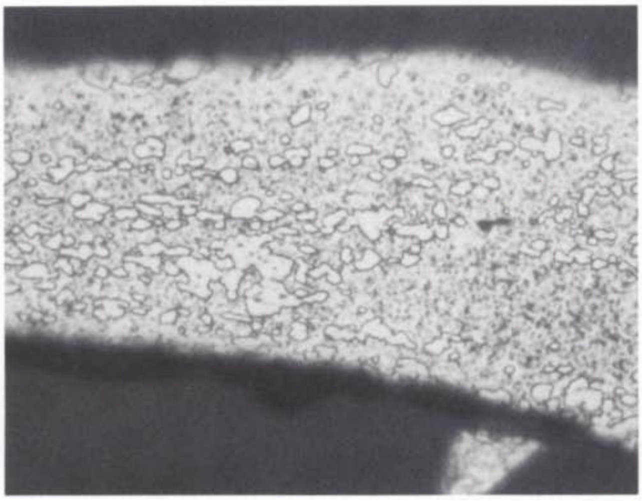


FIGURE 23. *Section of the Colombian nose ornament illustrated in Figure 8.*





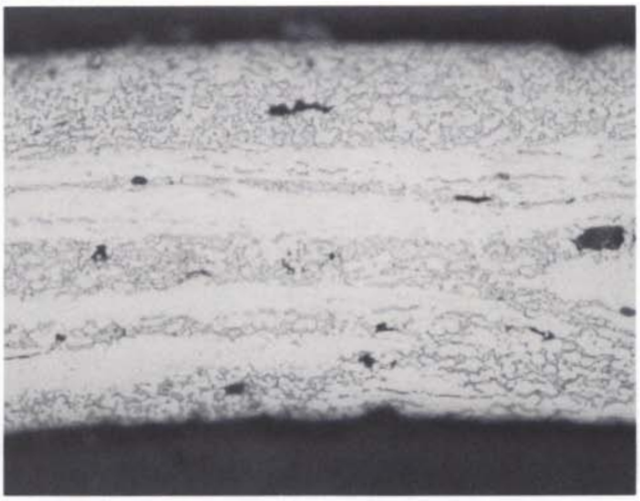


FIGURE 24. *Small fragment of a gold-platinum sintered penannular nose ring from Colombia. Etched in aqua regia. The mounted fragment measures 1.5 × 0.26 × 0.7 mm. Magnification 790×. In the collections of the Museo del Oro, Bogotá, Museum No. 4729.*

FIGURE 25. *Cross section through a fragment of a dangle from the vicinity of Esmeraldas, northern coastal Ecuador. Magnification 126×. In the collections of the National Museum of Denmark, Copenhagen, Museum No. 08275D.*

microstructure suggests that the nose ring contains a substantial amount of platinum and that the ring must have been extensively worked and annealed to shape it and break down the platinum laths to these tiny remnants.

Figure 25 is a cross section through a fragment of a dangle from the vicinity of Esmeraldas, northern coastal Ecuador. The fragment is ferromagnetic. The microstructure of this fragment shows a remarkably platinum-rich matrix with a sintered gold infill. There is a marked directionality to the sheet with elongated platinum stringers continuing along the whole length of the section. The native platinum laths contain many small, creamy gray inclusions that appear to be exsolution features and are rich in iridium. Etching in hot aqua regia tends to dissolve the gold-rich phase without revealing any further structural detail.

Figure 26 shows a cross section of a small dangle from the island of La Tolita, Ecuador. The polished section shows a very fine platinum clad surface on one side consisting of small laths of platinum in a gold matrix. One large platinoid inclusion has sunk through the gold or was already present; analysis shows that it is a platinosmiridium lath containing about 68% iridium, 17% osmium, and 12% platinum. The careful working of this gold sheet has resulted in a platinum-clad surface

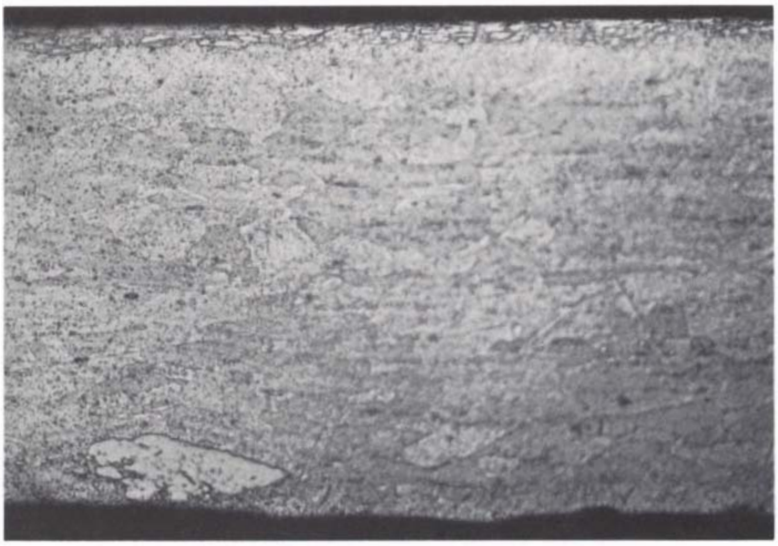


FIGURE 26. *Cross section of a small dangle from the island of La Tolita, Ecuador. Etched in cyanide/persulphate. Magnification 84×. In the collections of the National Museum of Denmark, Copenhagen, Museum No. 08293.*

that is well adhered to the gold by interdiffusion and has kept the color of the platinum content well in the applied surface layer.

The following items are not illustrated here, but the information is included to show the range of some of the surviving gold-platinum alloy objects:

- A small ornament made in a gold-rich alloy with a surface coated with platinum from the island of La Tolita, Department of Esmeraldas, northern coastal Ecuador (Bergsøe 1937:pl. 4, fig. 70). Dimensions: about 11 mm wide; thickness varies from 0.13 to 0.11 mm. The surface has a characteristically fused appearance as a consequence of the incomplete fusion of the platinum. Two small holes have been punched through and the edges finished to remove burrs. There is a split extending from the edge to the center. National Museum of Denmark: 08274. Lab. No. 177.
- A sintered platinum-gold alloy eye with a pupil of green stone which is not from the same site as the sintered eye from the La Tolita region, Department of Esmeraldas. (Bray 1978:Cat. No. 38) Dimensions: 31 mm wide; 0.14 mm thick. The alloy is weakly ferromagnetic. This piece was exhibited in the London El Dorado exhibition at the Royal Academy in 1978–79 and is currently in a private collection in Bogotá.
- A nose ornament shaped like a link from a chain, half gold and half platinum, threaded through a stone bead from Rio Inguapí, Tumaco region (Plazas and Falchetti 1986:fig. 1b; Bray 1991:fig. 102). Width: 2.8 cm. Museo del Oro, Bogotá, No. 22.765.
- A birdlike ornament made in gold, with an eye reported to be of platinum from the island of La Tolita, Department of Esmeraldas (Zevallos Menández 1965–66:pl. 2, fig. 5). Scale not given on original plate where length is 100 mm. Museo de la Casa de la Cultura, Nucleo de Guayas, Guayaquil.
- A miniature sheet gold mask, with eyes and teeth of platinum believed to be from the La Tolita region (Bushnell 1974:pl. 292a; Lausanne 1991:No. 95). Height: 9 cm. Age unknown. Museo del Banco Central, Quito, Ecuador, No. 3804.2.60.
- A large crescentic nose ornament, on which can be seen some platinoid inclusions. Found at San José de Palmar, Department of Valle, Colombia, adjacent to the Chocó area at an altitude of approximately 2000 m on the Pacific slope of the western cordillera (Scott and Bray 1980:fig. 5).Weight: 29.70 g. Width: 92 mm. In a private collection in Bogotá.
- Ear ornament in the shape of a condor head, made of repoussé gold sheet with a platinum beak from the Tumaco region (?) (Plazas and Falchetti 1985:fig. 1). Museo del Oro, Bogotá.
- Small items in Tolita-Tumaco style, including items of tumbaga clad with platinum from La Cocotera, Department Cauca, Colombia (Patiño Castaño 1988). (Discussed in the following section.)
- Pectoral representing the side view of a feline with a long tongue and human feet from La Tolita, Department of Esmeraldas (Tesori dell'Ecuador

1973:No. 332; Lausanne 1991:No. 93). Height: 5 cm. The main part of the animal is in "platinum" sheet, with trimmings of gold wire. Museo del Banco Central, Quito, No. 56.80.70.

- Feline face with elongated canines from La Tolita, Department of Esmeraldas (Tesori dell'Ecuador 1973:no. 323). Height: 8 cm. Described as "gold and platinum." Museo del Banco Central, Quito, No. 59.89.70.
- Lizard pendant of sheet gold from the La Tolita area, Department of Esmeraldas (Lausanne 1991:No. 87). Attached to the back feet are "platinum" danglers identical to the one illustrated in Figure 4. Museo del Banco Central, Quito, No. 2.29.79.
- Small items in Tolita style similar to those examined by Bergsøe from La Tolita (Scott and Bouchard 1988). (Discussed in the following section.)

An Examination of Some Platinum Objects

The illustrations cover the range of known platinum artifact types that can be grouped into five metallurgical categories:

1. **Native platinum**
   a. Native platinum-iron nuggets
   Sizable platinum nuggets are uncommon, and the known examples of their use are very few. Figures 6 and 7 illustrate two examples, one of which, as might be expected, is from the Department of Chocó. There are no detailed quantitative analyses available for these objects since destructive sampling has not been possible.
   b. Platinum-copper-iron alloy
   There is only one known example of this alloy being used in antiquity, and that is the nose ring shown in Figure 5. A previous report of the existence of geological specimens of these alloys has been made by Monroy (1978).
2. **Sintered platinum-gold alloys**
   This group is by far the most numerous, with several examples of nose rings from Colombia (Figs. 4, 8, 9, 10, and 11); most examples of this alloy originate from the Esmeraldas area, some being made into small tools, while the majority are small decorative objects. That limitation in size was not a concomitant of the use of these platinum-gold alloys is shown by the mask in Figure 4. Outside of the Esmeraldas-Tumaco area, no examples of sheet metal made in sintered platinum-gold alloys have yet been reported.
3. **Platinum-clad alloys**
   All known examples are from the Esmeraldas area. It is interesting to note that there are no examples of platinum-clad copper, and that all the pieces examined have proved to be gold-based with a platinum coat on one side or on both sides. If an object proves to be platinum-rich on both sides, it is only possible

by laboratory examination to confirm that it is clad with platinum, rather than consisting of a sintered mixture. Bergsøe (1937:38) suggests that cladding was employed in order to conserve platinum, which would always have been in short supply relative to gold. In the case of danglers coated on one side only, the aim may also have been to provide color-contrast. Examples are illustrated by Figures 17, 21, and 26.

4. **Bimetallic objects**

   Where an object is made in parts, consisting of different alloys, it can be described as bimetallic. None of these pieces has yet been examined in the laboratory, and whatever information exists concerning them has been derived from descriptions and from the photographs themselves. A very elaborate example is shown in Figure 16.

5. **Objects with incidental platinoid inclusions**

   In the brief account of the geology of the platinum deposits of Colombia, it was mentioned that few gold objects have been found to contain visible platinoid inclusions. There are, no doubt, Colombian objects in museum collections that may have incidental inclusions that have not yet been reported. Laboratory examination, however, indicates their comparative rarity in Colombian gold alloys. This may be surprising to specialists working in the Old World, where many examples of platinoid inclusions have been found in a variety of gold artifacts (Lucas 1962; Ogden 1976, 1977; Young 1972; Whitmore and Young 1973; Meeks and Tite 1980). Some of the reasons for this scarcity have been outlined previously. The gold workers of Esmeraldas appear to have taken some trouble to remove platinum metals both in copper-gold alloys and in native gold objects, where the presence of platinum was not required. Since placer deposits in the Esmeraldas area were utilized, and these contain both gold and platinum (Wolf 1879, 1892), careful sorting must have been carried out to ensure that, where a golden color was required, it was not obscured by the presence of unwanted platinum. Gold used to "fusion-gild" copper objects from Esmeraldas shows no evidence of any platinoid content upon either surface or metallurgical examination. The same is true for gold-copper alloys from the area; only occasional and very small inclusions are found.

   The presence of platinoid inclusions in ancient gold work is often adduced as evidence for the exploitation of placer deposits, as opposed to vein gold. This criterion, however, may not be sufficient without an examination of the geological nature of the deposits in a particular area. For example, Stumpfl and Clark (1966) reported the existence of gold-platinum intergrowths in concentrates from Southeast Borneo, while iridium apparently occurs together with gold in some of the South African gold veins (Hunt,[5] pers. comm. 1982). Both of these deposits are geologically different from the Alaskan-type Colombian deposits, which, as was discussed previously, have very high Au/Ir and Pt/Pt + Ir + Os ratios.

These five categories cover all known occurrences of platinum in artifacts from South America. Detailed analyses are available for some of these, and the results of work carried out so far are discussed in the next section.

Analytical and Metallurgical Studies

Category 1: Native platinum. With the generous permission of the staff of the Museo del Oro, Bogotá, some X-ray fluorescence analyses were allowed. The objects examined are shown in Figures 5, 6, and 8, the first two of which proved to be of native platinum. The following elements were found:

Element	Figure 5	Figure 6
Platinum	a major constituent	a major constituent
Gold	not detected	not detected
Copper	appreciable amount	not detected
Iron	appreciable amount	minor constituent
Iridium	minor constituent	minor constituent
Palladium	minor constituent	very small amount
Osmium	not detected	minor constituent
Ruthenium	not detected	not detected

In addition, the surface of the nose ring shown in Figure 5 contains a few visible platinoid inclusions of silver-gray color.

The analyses represent, in semiquantitative terms, typical compositions of the naturally occurring materials. The shaping of native nuggets would require a considerable amount of working and annealing; the material is much more difficult to work than a typical tumbaga alloy. Some laboratory experiments were carried out on a 6 wt % iron and 94 wt % platinum alloy, which was made under inert conditions in an induction furnace. The hardness of the cast ingot was found to be 90 on the Vickers DPN scale using a 50 g loading. The bead was alternately cold worked in a percussion mortar and annealed at 900 °C for 15 to 20 minutes. A deformation of 50% was thereby produced, after which the small strip had a hardness of 130 on the Vickers scale (H_v). The native nuggets are probably harder than the laboratory alloy would indicate; indeed, signs that some difficulty was experienced in the working of these alloys can be seen in the surface finish of the nose ring shown in Figure 6. A number of cracks appear in the surface and these are particularly noticeable at the slightly flattened ends where severe working has taken place.

Ramdohr (1969) reports that naturally occurring placer platinum is appreciably harder than laboratory alloys of the same composition. This was attributed by Zemczuzny (1920) to cold working during fluvial transport. The range of microhardness values published in the literature for native platinum (Cabri et al. 1973; Stumpfl and Tarkian 1973) shows variations between 401 and 633 H_v. Yushko-Zakharova et al. (1970) found that their minerals gave values from 187 to 451 H_v, although there has been some confusion in the literature with regard to the variation in microhardness with composition (see Uytenbogaardt and Burke 1971).

It was not possible to destructively sample the existing objects, so further data concerning the working process cannot, as yet, be established by laboratory examination.

Category 2: Sintered platinum-gold alloys. Many sintered platinum-gold alloys have been examined in the laboratory. Paul Bergsøe conducted some analyses, which are given in Table 2, while some recent electron-microprobe analyses for some of the material is presented in Table 3. The gold-platinum equilibrium diagram of Figure 2 (after Darling et al. 1952) enables a better understanding of the microstructure of sintered gold and platinum alloys to be made. The diagram shows a wide separation between the liquidus and solidus curves over a considerable range of composition. There is also a large gap between the melting points of the pure components, gold at 1064.4 °C and platinum at 1772 °C (Weast 1978), a difference of 708 °C. Of course, the native gold will contain some silver and the native platinum some iron, both of which will lower the melting point. The platinum-iron system has recently been investigated by Cabri and Feather (1975); the Colombian platinum falling in the compositional range from isoferroplatinum to ferroan platinum. Samples of native gold from Esmeraldas analyzed at the Institute of Archaeology contained silver, but only in the range from about 5 to 12%. This silver will carry over into any artifact or alloy made from the gold, and accounts for the silver content of the items analyzed in Table 2.

The usual metallurgical apparatus of Colombia and Ecuador was a charcoal fire and blowpipe, with hammering being carried out using polished stone hammers, held in the hand.[6] There are examples of stone hammer and anvil sets from Colombia (Plazas de Nieto 1975:fig. 11; Bray 1978:no. 43, fig. 15). With a charcoal fire and blowpipe it is not normally possible to attain temperatures higher than 1400 °C,

TABLE 2. *Analysis of sintered platinum-gold alloys (after Bergsøe 1937:26). The results show that tumbaga alloys have very low platinum levels compared with the prepared Au-Pt alloys. Method of analysis: wet chemical. Hardness values quoted are on the Brinell scale.*

Object	Location	Au	Ag	Pt	Cu	Total	H_BWorked	H_BAnnealed
Asintered lump	La Tolita	16.0	3.0	72.0	nd	91.0		
Piece of a sheet	La Tolita	38.0	4.0	57.0	nd	99.0	259	134
Piece of a sheet	La Tolita	36.0	5.0	55.0	4.0	100.0	201	168
A forged object	La Tolita	64.0	9.0	26.0	1.0	100.0	206	149
Platinum nose ring	La Tolita	40.0	15.0	40.0	3.0	98.0	225	174
Forged ingot	La Tolita	55.0	6.0	2.0	34.0	97.0	279	201
Small star	Atacames	58.0	23.0	0.5	17.0	98.5	235	185
Circular plate	Atacames	53.5	10.5	1.2	35.4	100.6	250	165
Sewing needle	La Tolita	36.0	4.0	2.0	50.0	92.0	201	120
Ear ornament	La Tolita	81.6	16.3	0.3	1.6	99.5		
Face stud	La Tolita	47.4	6.0	1.6	44.2	99.2		
Pendant	La Tolita	75.8	22.0	0.3	2.9	101.0		
Hook in pendant	La Tolita	71.9	10.9	12.3	1.8	96.9		
Bead	La Tolita	79.7	17.9	0.8	0.5	98.9		
Nose ring	Atacames	62.1	5.3	2.8	26.0	96.2		
Nose ring	Atacames	65.2	13.0	1.2	20.3	99.7		
Nose ring	Atacames	55.8	5.5	2.8	38.0	102.1		

while a more usual temperature would be expected to be in the range from 1000 to 1200 °C. In the equilibrium diagram a wide, two-phase field can be seen to exist between 25 and 97 wt % platinum. This area of spinodal decomposition, in which a homogeneous solid solution breaks down into two alternating phases, $\alpha' + \alpha''$, cannot be intersected with a line drawn from the liquidus curve until a temperature of about 1500 °C is reached. With a lower working temperature, the platinum that enters into solution with the gold can only decompose from the liquidus to give single-phase solid solutions toward the left-hand side of the equilibrium diagram. It can be seen, therefore, why some platinum, which enters into solution with the gold as a result of solid state diffusion, will do so at temperatures below the melting point of the metal, and why the gold-platinum matrix will be single-phased. In a recent study, Handwerker et al. (1991) examined the evidence for the actual working temperatures attained during the sintering process of gold and platinum. The work carried out showed that the microstructure was consistent with the gold remaining as a solid phase during sintering. This seems perfectly logical, for many small objects made with platinum and gold would be ruined during manufacture if the gold melted during working and annealing to shape. When the original mixture is first made, however, it would be reasonable to place the gold and platinum on a charcoal depression and heat the mixture until the gold melted and fused the platinum grains

TABLE 3. *Electron microprobe analysis of platinum alloy objects. The results show that tumbaga alloys have very low platinum levels compared with the prepared Au-Pt alloys. Method of analysis: wet chemical. Hardness values quoted are on the Brinell scale.*

Object	Location	Au	Ag	Pt	Cu	Ru	Rh	Os	Ir	Fe	Total
Small dangle, Fig. 17:A (no. 162)	Esmeraldas	70.23	12.97	72.00	3.18	1.17	2.92	nd[1]	nd	nd	90.47
Small dangle, Fig. 17:B (no. 163)	Esmeraldas	65.90	15.30	6.80	3.80	5.90	nd	nd	nd	nd	97.70
Small dangle, Fig. 17:D (no. 160)	La Tolita	78.20	8.40	7.90	4.60	nd	nd	nd	nd	0.40	99.50
Dangle, Fig. 17:D: gold-rich phase		80.20	5.50	7.90	5.10	nd	nd	nd	nd	nd	98.70
Dangle, Fig. 17:D: platinum grain		3.10	52.00	0.70	nd	1.00	2.50	1.20	24.50	4.80	89.80
Sintered platinum lump	La Tolita	nd	nd	85.30	0.90	nd	2.10	2.00	nd	7.20	97.50
Sintered lump: gold area		69.20	8.30	13.80	6.40	nd	nd	nd	nd	0.70	98.40
Sintered lump: platinoid inclusion		nd	nd	3.20	nd	9.20	nd	46.50	38.90	nd	97.80
Nose ring (no. 83)	unknown	81.20	nd	6.40	12.00	nd	nd	nd	nd	nd	99.60
Nose ring: platinum-rich area		13.60	69.50	2.30	nd	nd	1.20	nd	nd	6.90	93.50
Nose ring: gold-rich area		77.30	11.80	6.10	nd	nd	nd	nd	nd	0.30	95.50
Nose ring: mixed area		57.10	8.20	31.80	nd	0.70	nd	nd	nd	2.90	100.70
Sintered platinum sheet (no. 167)	Esmeraldas	5.30	0.80	79.20	nd	nd	3.10	nd	nd	7.90	96.30
Sintered sheet: gold-rich area		78.30	10.60	7.10	nd	nd	nd	nd	nd	0.70	96.70
Sintered sheet: mixed area		35.10	4.10	48.50	nd	nd	nd	nd	2.10	4.70	94.50
Sintered sheet: platinoid inclusion		nd	nd	11.80	nd	1.10	2.60	11.60	69.80	0.60	97.50
Platinum coated dangle (no. 176)	Esmeraldas	79.60	8.60	1.40	10.10	nd	nd	nd	nd	nd	99.70
Platinum coated dangle: platinum coating		18.40	2.10	63.40	1.60	nd	nd	nd	0.90	7.50	93.90

[1] not detected

together so that the gold could effectively coat the platinum grains. It may be that the gold was molten for only a few seconds, but it appears the most likely possibility, at least for the starting material.

The starting materials for the fabrication of sintered platinum-gold alloys are small lumps of platinum grains fused together with gold. An analysis is given in Table 3. The microstructure illustrated in Figures 22 and 23 shows part of the section removed from one edge of the object. The section consists of about twelve large platinum laths, the longest of which measures 0.5 mm, in a gold matrix. The composition of the gold is about 12.6% silver, 2% copper, and 85% gold, placing it within the range of a native alloy. The largest of the platinum laths shows the presence of some inclusions that were found to be of native osmium and of iridosmine. At higher magnification (Fig. 23), the perimeter of the platinum laths can be seen to be slowly breaking up as a consequence of sintering and interdiffusion. The iron content of the platinum laths does not vary greatly and averages 0.098 as an Fe/Pt ratio. The hardness of the platinum laths was found to vary between 209 and 232 H_v.

The sintered mass in the initial stage is lumpy, porous, and difficult to work without breaking off small pieces of alloy in the process. Successive working and annealing produces a microstructure typified by a matrix consisting of gold containing some platinum, with elongated platinum stringers running along the length of the section as a result of the working of the alloy. An examination of the platinum eye mentioned above shows that it has been beaten out from thin sheet and is only 0.14 mm thick around the base, from which a small fragment was taken for analysis. It was thought at first that the eye had been clad with platinum on the outer surface, for the interior appears pale gold compared with the silver-gray surface. However, metallographic examination showed that it is a sintered alloy throughout, with a greater concentration of platinum toward the outer surface. Electron microprobe examination of the eye shows the greater concentration of platinum laths toward the outer surface as well as a few inclusions of magnetite, which must have been picked up with the platinum at the panning stage.

The microstructure shown in Figure 24 is taken from a fragment measuring 1.5 × 0.26 × 0.7 mm, which was sampled from a sintered platinum-gold nose ring in the Museo del Oro, Bogotá (Museo del Oro 4729). The piece is of unknown provenance, and a bulk analysis in the archives of the Museo del Oro gave 22% gold and 75.8% platinum (illustrated in Fig. 14). Some microprobe analysis results are given in Table 3. The structure shown in Figure 24 gives some idea of the very fine nature of the sintered alloy. The nose ring has a finer distribution of platinum than most of the examples from Esmeraldas, and must have been heavily worked and annealed to break up the platinum laths so extensively.

Of the objects examined from the Esmeraldas area, only a small awl and a small, heavily worked block show a very finely dispersed platinum component. This is significant, for to ensure that the awl would have good working properties and hardness, the alloy would not be able to possess the porosity and large platinum remnants that are typical of much of the small sheet items such as the eye. Even with such intractable material, the metalsmith was able to exercise control over the nature of the alloy.

Category 3: Platinum-clad alloys. If fine platinum laths are placed over a strip of gold and heated at 800–1000 °C, then some dissolution takes place and the platinum will tend to sink through the gold, some of it becoming broken down to fine globules. This was carried out in a laboratory experiment using pure gold and filings of a 96 wt % platinum and 4 wt % iron alloy. Similarly, if the unalloyed laths are forced onto the surface of the gold with a hammer, they tend to be driven into the surface and to be covered with the softer gold matrix. However, a platinum-coated surface was produced by the Indians. What process could have been employed? Bergsøe (1937:27) suggests the following method:

> It is extremely easy with a hammer and anvil to make a piece of platinum plated gold. A small piece of the hammered-out plate made of artificially produced (sintered) alloy is placed above a little bead of gold alloy, heated until coherence takes place and then hammered out with a few intervals for annealing. When the two metals have attained the same degree of hardness they are hammered out together, and we now have a gold plate with a thin coating of platinum alloy.

Metallurgical examination of some small objects shows that, in some cases, extremely thin platinum-clad surfaces have been produced, consisting of gold with a single layer of small platinum laths; very little sintering has occurred and the platinum could not have been applied as a sintered mixture subsequently fused to a gold base.

The method of manufacture can probably be reconstructed as follows: First, a gold alloy has been hammered out approximately to shape, followed by the addition of fine platinum particles to one side. With careful heating, these platinum additions will just fuse with the gold at the surface. When this alloy is hammered out, the platinum surface cannot be driven into the gold to the same extent as unalloyed inclusions, and they will tend to flatten out along the surface of the gold as both are deformed. Since the platinum will still be appreciably harder than the gold matrix, some embedding of the platinum would be expected with severe working. But if the process is repeated, then a substantial coating of platinum can be built up which will give a smooth silver-gray surface on burnishing. A thin coating of platinum can be seen in Figure 26. Working of this kind illustrates the fine metalworking skills of the La Tolita gold workers. A laboratory experiment was performed on a gold bead coated with filings of the 96% platinum and 4% iron alloy. The initial color of the filings was silver, but after heating under charcoal in a muffle surface to about 900 °C for 15 minutes, the sintered surface of the platinum assumed a dull gray-silver color. As the platinum enters into solution with gold, the color of the resulting alloy changes from gold to gray-yellow to gray-white as the platinum content increases. The change in color on the outer surfaces of the platinum here, however, is due to some oxidation of the iron component. If the platinum-iron alloy filings are heated in a blow torch with a blue oxidizing flame, the filings are rapidly covered in a thin layer of iron oxides that interfere with the sintering process. The Indians, with a charcoal fire and blowpipe, had the means of avoiding this excessive oxidation, since the atmosphere in a charcoal fire will not usually be an oxidizing environment. The laboratory alloy was lightly hammered and annealed at bright-red heat; further cycles produced a flat sheet with gold on one side and platinum on the other. A little of the platinum broke up and sank through the gold by gravity separation; the major part remained on the surface to produce the desired result.

Category 4: Bimetallic objects. None of these has been available for laboratory examination; the joining techniques that may have been used, therefore, have not been studied. One of the most spectacular pieces is that shown in Figure 16, a composite gold-and-platinum ornament. All known objects of bimetallic construction originate from the Esmeraldas-Tumaco area.

Category 5: Objects with incidental platinoid inclusions. Gold free of platinum (as well as gold containing platinum as a deliberate alloying addition) may contain inclusions of other platinum metals. The nature of these inclusions can be characterized on an elemental basis:

a. Inclusions of Pt-Fe alloys
b. Inclusions of Ir-Os-Ru alloys
c. Inclusions of Ir-Pt-Os alloys
d. Inclusions of native Ir or native Os
e. Other inclusions such as quartz, calcite, pyrites, platinum sulphides, cassiterite, iron oxides, and other gangue minerals

Electron microprobe analysis of polished metallurgical sections of small fragments and ornaments from the Esmeraldas area has revealed a number of platinoid inclusions. The most numerous group was found to be composed of rutheniridosmine.[7] Several examples of iridosmine and osmiridium were found as well as a few inclusions of native iridium, native osmium, and ruthenos-miridium. The least common were inclusions of platiniridium and platinosmiridium; zoning was not a significant factor in the composition and very few intergrowths were observed. Some platiniridium was found as exsolution features in platinum laths.

The ruthenium concentration in all the inclusions analyzed proved to be quite low (less than 20 atomic %); most inclusions could be plotted in the Ir-Os-Ru ternary system with ruthenium often less than 10 wt %.

Whitmore and Young (1973) reported the existence of platiniridium inclusions from some Lydian coins, the only previous instance in which this group has been reported in ancient gold work.

The analytical data came from the Esmeraldas-Tumaco area, but there is no reason to suppose that the Colombian material would be at all different in nature. Indeed, Harris and Cabri (1973) include in their analyses a few Colombian inclusions that fall into the low ruthenium side of the Os-Ir-Ru ternary diagram. It is not clear from the literature whether the object found by Linné at La Recasa, on the Pacific coast of Colombia (Fig. 12), was flecked entirely with platinum or whether there could have been other platinoid grains; until laboratory examination can be carried out there is no way of knowing. An interesting geological point is the outcrop of the tertiary ultramafic rocks exactly at Cupica, which is where the site of La Recasa is situated. As was noted before, these rocks are source rocks for the Colombian platinum. Gold-bearing sands in this area would therefore be expected to be highly platiniferous after erosion of the source material. The occurrence of a gold nose ornament with many platinum inclusions suggests that the craftsmen were using locally available metals, and that the artifact was not an import from another area. The style of the piece, too, suggests a local origin, since the form has no exact parallel elsewhere.

The same kind of geological argument applies to the nose ornament from San José de Palmar and to the nose-ring described by Orchard from the headwaters of the Rio San Juan in the Department of Chocó (Fig. 7). In the same category is the previously unreported nose-ring examined in the Museo del Oro (No. 19460), with indications of platinoid inclusions in the surface. The color is also a rather light gold, which may indicate some platinum content. The ring weighs 1.75 g and is a simple penannular shape. It was found in the Municipio of Colosó, Department of Sucre. In the *Atlas de Colombia* (1969:99), a source of platinum is marked in precisely this area, though Colosó falls outside the main gold-producing area. The two metals do, however, occur together a little distance further south. With the continued examination of new and existing finds from Colombia and Ecuador, and the characterization of gold and any inclusions that it may contain, further information on gold sources and trade will undoubtedly be forthcoming.

The Archaeological Context of Platinum Metallurgy

True platinum metallurgy, as opposed to the use of gold with accidental platinum inclusions, is confined to the Tumaco-Esmeraldas region, on either side of the Colombia-Ecuador frontier (Fig. 1).[8] In this area, the raw material is readily available and archaeological finds of "platinum" objects are not uncommon. Outside this limited region (e.g., at Convento, El Angel, and in the Colombian cordillera), the few platinum objects are almost certainly trade pieces.

The chronology of this metalwork still presents certain difficulties; few platinum items have come from controlled excavations, and documented specimens of any kind are rare. At the moment, the oldest evidence for metallurgy in the region comes from Inguapí, near the port of Tumaco, where hammered gold wire was recovered from a stratum with clay figurines of Tolita style (Bouchard 1979; Scott and Bouchard 1988). This site gave a radiocarbon determination (uncalibrated) of 325 ± 85 B.C.E. (Ny-642). Soon after this date there is direct evidence for platinum metallurgy from the site of La Cocotera, at the mouth of the Rio Bubuey on the Colombian coast, with a radiocarbon date around 100 C.E. (Patiño Castaño 1988:24). The metal items from this excavation are in pure Tumaco style and include objects made of tumbaga, tumbaga clad with platinum, and gold-platinum fragments containing a little silver with traces of iron and copper. By the early centuries of the Christian era, sophisticated metalwork in gold, copper, silver, and various alloys had become widespread throughout Pacific Ecuador (Alcina Franch 1979; Meggers 1966).

The critical site for discussion is La Tolita, which—if information from treasure hunters can be believed—has yielded more platinum artifacts than any other locality. Unfortunately, the site has been continuously looted from 1600 C.E. to the present day (Ferdon 1940; Alcina Franch 1979; Valdez 1987:44–48), and most of the metal objects come from alluvial deposits that seem to be the result of redeposition of material from eroded and washed-out archaeological zones. In practical terms, these specimens are undated and undatable. The general consensus is that the Classic Tolita style of pottery, and the associated metalwork, had emerged by approximately 300 B.C.E. at the latest (Valdez 1987; Scott and Bouchard 1988). The oldest documented metalwork comes from Bouchard's excavation in the Cancha sector of the site, where he found items of platiniferous gold, tumbaga, and gold-platinum alloy. The radiocarbon date for Cancha is 90 ± 60 C.E. (GIF-6815) (Scott and Bouchard 1988).

The end of this metallurgical tradition is more difficult to fix with any precision. La Tolita itself seems to have been abandoned during the fourth century C.E. (Valdez 1987), but other sites, with rather different styles of pottery, carry the story of the Colombia-Ecuador frontier zone up to and beyond the time of European contact. Excavations at these more recent sites have yielded little metalwork and no platinum artifacts (Scott and Bouchard 1988), but some of the undocumented finds may well belong to these late periods, and the liking for miniature ornaments persists into the historical era. Confirmation for this view comes from sixteenth-century Spanish accounts of the Ecuadorian coast at the time of first European contact. Francisco Lopez de Gomara commented that the Indians of the Catamez (i.e., Atacames) region in 1552 "los de allí llevaban sembraddas las caras de muchos clavos de oro, pues se horadan por muchos lugares, y meten un grano o clavo de oro por cada agujero, y muchos meten turquesas y finas esmeraldas" [the people wear many gold studs in their faces. They pierce the flesh in many places, and in each hole they put a grain or stud of gold, and many of them put turquoises and fine emeralds] (López de Gómara [1552]1965:I:194).

Little studs and tiny ornaments of just this kind are the most common category in archaeological collections and are abundantly represented on the clay figurines, many of which go back to the early centuries of the Christian era. Some of the little platinum dangles in the Bergsøe collection can be directly matched among the ear ornaments of these figurines (compare Scott and Bray 1980:fig. 3 with Raddatz 1977:abb. 7, 8, 30). This typical "Tolita" jewelry was still being worn in 1552, when Adrián Sánchez Galque painted a portrait of the leaders of the "Mulatos" of Esmeraldas (Bray 1979:fig. 1), while historical documents prove that the local metallurgical tradition was still vigorous in the 1590s (Alcina Franch and de la Peña 1976:63, 84). It should also be emphasized that both Bergsøe (1937:figs. 1–4) and Reichlen (1942) recognized European-influenced pieces and European alloys in the collections they studied.

In summary, then, Tumaco-Esmeraldas metalwork spans more than fifteen hundred years. Presumably the "platinum problem" was recognized as soon as craftsmen began to exploit the placer deposits of the region, and circumstantial evidence suggests that platinum technology was fully developed during the early centuries C.E. and probably first emerged around 500–300 B.C.E. In its broader context, this metalwork constitutes a regional variant within the North Andean tradition of Lechtman (1979:2), and is defined by a series of technological and stylistic traits that stretch along the Pacific Coast from northern Peru to Tumaco. In many respects this "Pacific tradition" is quite distinct from that of the Andes and Colombia. Technologically it is characterized by a preference for sheet metal and pieces assembled by means of soldering, welding, "granulation," or filigree. Lost-wax casting is uncommon in North Peru and virtually absent from the Ecuadorian industries. Jewelry may incorporate colored stone or shell, and bimetallism is popular, with its contrast of silver-colored and gold surfaces (Becker-Donner et al. 1977:nos. 185, 194; Tushingham et al. 1976:nos. 34, 42, 234, 245).

Certain fairly specific traits are spread throughout the region. Face studs, tooth inlays, and spiral ornaments of rolled wire or strips are distributed along the coast to the Gulf of Guayaquil, and are particularly common from the area of the Milagro-Quevedo culture, dating from 500 C.E. to the Conquest (Estrada 1954, 1957, 1962; Ubelaker 1981; Meggers 1966:figs. 39, 40).[9] Double spirals also occur, albeit rarely, in northern Peru (Tushingham et al. 1976:no. 208). Discs and other ornaments with globular elements fused to their edges, or clasped within S-shaped loops of wire, are frequently found in the Moche and Vicus styles of northern Peru, and one particular form of nose ornament from La Tolita (Bray 1978:no. 510; Bray 1991:fig. 102) has an exact parallel in a Mochica collection from Peru (Becker-Donner et al. 1977:nos. 136, 137). As Zevallos Menández (1965–66) and Jones (1979) have already pointed out, relations are especially strong between the Esmeraldas material and the Vicus and Frias metalwork of northernmost Peru, close to the Ecuadorian frontier. These styles have close links with Moche, and the few radiocarbon dates from the Vicus area fall within the first millennium C.E.—a figure that is quite consistent with the evidence from Esmeraldas.[10] Particularly striking are the similarities between the masks and sheet-metal figures from Tumaco-Esmeraldas and those of Frias. The general technique of manufacture, the beading around the eye, the depressed pupil, and the head deformation all link Figure 2 with other examples from Esmeraldas (Fig. 21) (Zevallos Menández 1965–66:fig. 7; Jones 1979:fig. 30) and with the well-known figure from Frias (Jones 1979:fig. 29). Another sheet-metal figure of this general type (now in a private collection) closely resembles the Ecuadorian clay statuettes and is said to be from Tumaco (Scott and Bouchard 1988:2). In this broader setting, we can begin to see how, and why, platinum metallurgy developed.

Conclusions

Three categories of "platinum" artifacts have been distinguished: (a) items containing only a small percentage of platinum as an accidental inclusion; (b) items made wholly or partly of sintered gold-platinum alloy, of fairly homogeneous composition, gray or silver-colored to a variable degree; and (c) items plated or clad with platinum over a base of gold or tumbaga.

Objects in the first category are presumably nonintentional and result from poor sorting. They may be expected to occur from the time when the Chocó placer deposits were first exploited as a source of raw material. The other two techniques, sintering and cladding, are obviously purposeful, and require considerable skill and inventiveness.

This prompts the question: What for? Why did jewelers trouble with a recalcitrant material like platinum? What advantages does it offer over other metals? What had the craftsmen of Esmeraldas in mind when they developed a platinum technology?

Looking at the range of objects for which platinum was employed, it becomes clear that they were mainly decorative and ornamental. Tools (fish hooks, needles, awls, axes, etc.), for which the increased hardness of platinum would be beneficial, were rarely made from this material. Instead, great virtuosity was devoted to making small, and sometimes unspectacular, ornaments. Since it is more difficult to work than the other metals or their alloys, and no advantage was taken of its extra hardness, it appears that the platinum was appreciated more for its aesthetic qualities than its technological ones. Of these, the significant factor seems to be color—as shown by the trouble taken to give gold and gold-rich tumbaga danglers a platinum surface (sometimes on one face only), and by the relative abundance of bimetallic items. Some of the finest artifacts are the figurines and miniature masks of gold or tumbaga with platinum eyes.

As we have already demonstrated, this liking for bimetallism is characteristic of Pacific Coast jewelry in general. Zevallos Menández, for instance, reports a Peruvian figurine of gold with silver eyes, precisely on the Esmeraldas model (Zevallos Menández 1965–66:78). If we examine the distribution of platinum and silver artifacts within this total area, the result is striking. Outside Tumaco-Esmeraldas, silver and its alloys predominate along the coast and also in the Andean regions (Meggers 1966:52, 133–38, 152, 163). Platinum artifacts are absent, apart from a very few trade pieces. In contrast, platinum objects are common in Esmeraldas, but only one silver item has been published from this area (Zevallos Menández 1965–66:fig. 16). Significantly, this is a gold mask with silver eyes. The distribution of the two metals is complementary. If we are right in believing that, in Esmeraldas, platinum was prized for its color (in a region that has no silver deposits), we see also that platinum takes over the role occupied by silver in neighboring cultures. This, in turn, raises an intriguing set of speculations. Lechtman (1979), in her search for "the idea behind the artifact," suggests that Andean alloys cannot be understood in terms of technology alone, in isolation from the cognitive and symbolic beliefs of their makers and users (Lechtman 1979:32):

> The basis of Andean enrichment systems is the incorporation of the essential ingredient into the very body of the object. The essence of the object, that which appears superficially to be true of it (i.e., its visual appearance), must also be inside it. The object is not that object unless it contains within it the essential quality, even if this essence is only minimally present.

If, then, silver and platinum were interchangeable, as it seems they were, does this imply that the two metals were equivalent also at the symbolic and "essential" level? If so (and this cannot, of course, be proved), it raises the possibility that, in aboriginal South America, metals were classified in terms of their appearance (color value) and symbolic qualities rather than in terms of their chemistry and their technological properties. This line of investigation must, for the moment, be left to the anthropologists and ethnohistorians.

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Notes

1. Chaston (1980) gives 1786 as the most likely date for the production of malleable platinum by Chabaneau. Much of Chaston's article describes Chabaneau's early work in the subject of the purification and working of platinum obtained from South America.
2. Platinum is recorded as an impurity (0.18% and 0.24%) in two simple copper rings excavated at the Maya site of Tonina, Chiapas, Mexico, in a burial dated approximately 900–1200 C.E. (de Grinberg and Franco 1982; and de Grinberg, personal communication 1983). This is the only record from Mesoamerica, and the source of platinum remains unknown. Platinum is also recorded as a trace element, generally below 0.1% in metal artifacts from Costa Rica. No major source of platinum has been found in the republic, though "microscopic grains" are reported from a single ultrabasic intrusion at Cebadilla (province of Alajuela) (Durando 1961:19).
3. Some doubt has arisen since Bergsøe's time as to whether the objects that he describes as being "fusion gilded" have, in fact, been depletion gilded (Lechtman 1971, 1973) instead. A recent reexamination of the material confirmed Bergsøe's findings in broad outline. The underlying alloy is often copper containing a little gold (3–6%), covered with a tumbaga alloy which is sometimes enriched as a result of copper oxidation (Scott 1986).

4. In the 1940s the Terver collection was a private collection in Paris. The authors have received no further information as to its present whereabouts.
5. The late Dr. Leslie Hunt, formerly head, Research Laboratory, Johnson Matthey and Co. Ltd., Hatton Garden, London.
6. There is also an Esmeraldas pottery figurine, thought to be from the fourth to seventh century C.E., which shows a seated figure holding a rectangular block (Emmerich 1956:Fig. 200). Resting on the block are a nose ring and a bead. Spanish cronista accounts are given of metalsmiths using stone blocks, carefully smoothed, with which to hammer out gold and tumbaga, using shaped stone hammers (Bray 1971:28).
7. For an explanation of the nomenclature of the alloys of iridium, osmium, and ruthenium, see Harris and Cabri (1973:105–12).
8. A newspaper article (*El Espectador*, 20 May 1981) describes the discovery of gold, platinum, and bimetallic objects at Guenyele, on the Rio Guapi. These items are not illustrated, and their precise context is unclear. The authors are indebted to Luisa Turbay for the reference.
9. This excludes objects in which silver (sometimes in quite high percentages) is an unintentional constituent, deriving from impurities present in the gold sources.
10. There is one exception to this generalization. Platinum is unsuitable for making large objects of sheet metal, such as the headdresses and vessels that are so prominent in Peruvian silver work.

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Biographies

David A. Scott is currently head of Museum Services for the Getty Conservation Institute. His principal interests revolve around the examination of museum objects, the study of Chumash Indian rock art pigments, and the metallurgy of ancient Ecuador, Colombia, and Costa Rica. Before joining the Getty Conservation Institute in 1987, he lectured in conservation at University College London. He is a fellow of the International Institute for Conservation and a fellow of the Royal Society of Chemistry.

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Pre-Hispanic Goldwork from the Museo de América, Madrid: A New Set of Analyses

SALVADOR ROVIRA

Following the important synthesis carried out by Rivet and Arsandaux (1946), in which almost all the analytical information published at that time was compiled, and the Peruvian metalwork analyses performed by Root (1949), a rather small number of new quantitative analyses of Pre-Hispanic goldwork have been made to date, though a long list of articles with short contributions could be reported. During the last few decades it seems that research interest has been focused toward punctual studies on metallurgical technology, which has increased our knowledge of Pre-Columbian metallurgy, particularly with regard to gold-working techniques (Bray 1972; Lechtman 1973, 1979; Bouchard 1979; Scott and Bray 1980; Lechtman et al. 1982; Scott 1983a). In the last few years we have systematically analyzed the collection of metal objects at the Museo de América, Madrid, and part of the results will be discussed here.

Method of Analysis

Quantitative analysis has been performed with the aid of an X-ray fluorescence (energy dispersive) multichannel spectrometer (Kevex Mod. 7000). Primary excitation beam is provided by a ^{241}Am source with an X-ray intensity of 20 mCi. The solid-state detector Si(Li) has a beryllium window 0.025 mm thick and the detector area measures 80 mm^2. The working conditions have been established in 500 seconds acquiring time, in the spectrum range of 40 keV, measuring the following spectral lines: Fe(Ka), Ni(Kα), Cu(Kα), Zn(Kα), As(Kß), Ag(Kα), Sn(Kß), Sb(Kα), Au (Lß), Pb(Lß).

The EXACT program of QUANTEX was run for mathematical treatment, using in each case the calibration constants of a standard alloy whose composition is as close as possible to the unknown alloy. The best standard has been automatically selected through a matching-up routine, also provided by the QUANTEX software package.

Owing to the method employed, a few analytical results must be considered only as indicative, especially those of some Colombian objects made of *tumbaga*, if the surface is gold enriched in a very thick layer by depletion gilding. This circumstance does not affect the Peruvian objects studied here.

No modern method of chemical analysis is capable of exactly resolving the unknown quantity of the original composition of an archaeological metal object, approaching a more or less satisfactory manner to the present composition, which is expected to be affected by corrosion processes over time.

Surface analysis by X-ray fluorescence techniques applied to archaeological metals has limitations that we see fit to recall, even though these limitations were already made clear by Hall (1961:63): (a) The fall-off of fluorescent yield with depth is very sharp; (b) this fall-off will vary depending on the element being analyzed as well as the elements in the matrix alloy itself, but in no instance are we analyzing layers more than 200 μ below the surface; and (c) due to the complicated nature of the problem, accurate estimates of composition of alloy where considerable surface enrichment has occurred are probably impossible by X-ray fluorescence techniques.

Many works have been carried out to establish the reliability of this method in relation to other techniques. Schweizer and Friedman (1972:106) concluded that the degree of agreement between carefully cleaned area results and wet chemical analyses is very good when analyzing the amount of silver and gold in silver coins. On his part, Oddy (1972:114–15) claimed that the agreement between milliprobe and specific gravity, or neutron activation analysis of gold content in coins, is not good for the earlier series but better in the recent ones. It seems that gold contents found by milliprobe are slightly higher than those calculated by a chemical method of analysis. A more recent comparative study of aurichalcum analyses made by seven methods also concludes that X-ray fluorescence provides precise and useful results when specimens are prepared very carefully (Carter et al. 1983:212).

It has been reported that repeated cleaning and measuring can be used effectively to overcome any surface effects such as surface enrichment of silver or surface gilding (Schweizer and Friedman 1972:106). The enriched layer of a gilt surface in Pre-Columbian metals did not use to measure more than 20–50 μ thick, as indicated by electron microbeam probe traces of gold, silver, and copper concentrations across the cross section of the metal (Lechtman 1973:41, 43, 45; Scott 1983a:104–6). Surface cleaning and large-area analysis allows a good approximation to the composition of bulk metal using this nondestructive method. However, almost all the objects in the collection are very well preserved, with no signs of corrosion, and are large enough to provide a suitable area for investigation without causing visible damage.

The principal problem of accuracy does not derive from the method itself but from the set of available standards, which must match the unknown alloy as closely as possible. We have no gold standards with more than 30% Cu and 30% Ag. Then, some deviations in the results from "true" values may be expected, generally by defect, when copper or silver in the sample pass 30%. In any case, the results fit much better than when a semiquantitative routine is used (also provided by QUANTEX).

Central Andean Region

The Andes mountain range dominates the western region of South America, from northern Colombia to Tierra del Fuego at the southern end of Chile. The central region includes Ecuador, Peru, most parts of Bolivia, northwest Argentina, and northern Chile. But for the purpose of this discussion, only ancient Peru is considered because it is the country of origin of the artifacts.

Analytical Results

The results can be seen in the appendix to this chapter. The most ancient materials in the Museo de América are two masks and a nose ornament from the Mochica culture, which were made in an Au-Ag-Cu ternary alloy, with copper oscillating between 1.5 and 4.0% (2.9% Cu average) and silver between 16.6 and 21.1% (18.2% Ag average).

Having the same antiquity as Mochica but originating in the Peruvian south coast, four Nazca objects have been analyzed. They consist of a nose ornament and three sheets, whose compositions show a copper content of 1.6–7.7% (4.2% Cu average) and a silver content of 6.6–11.9% (8.7% Ag average).

From the Middle Horizon, Huari culture, we have a repoussé bracelet and a ceremonial vessel. The metals contain between 0.5 and 3.9% of copper (2.28% Cu average) and between 9.7 and 18.5% of silver (13.5% Ag average).

The Late Intermediate period was an epoch of great splendor for Peruvian metallurgy, detaching from the Chimú culture works. We contribute with six analyses belonging to a mask, a scepter, a crown, a pin, and two decorated sheets. Copper content oscillates between 1.6 and 2.6% (1.9% Cu average) and silver between 9.81 and 20.9% (15.6% Ag average).

Finally, from the Inca period we present fifty-two new analyses performed on pins, pendants, rings, figurines, tweezers, and sheets. The copper content varies between 0.2 and 10.5% (3.8% Cu average) and the silver between 2.7 and 42.4% (27.1% Ag average).

Comparative Study

Except for the Inca period, too few objects from other cultures have now been analyzed to attempt a complete study of Peruvian alloying technology. By taking into account the analytical information introduced by bibliography and adding it to our set, some conclusions can be drawn. Table 1 resumes the number of analyses used for this purpose.

Information about Chavín objects was published by Lothrop (1951:238) and Lechtman (1984:274). The mean values of copper and silver are 2.9 and 20.7%, but it is convenient to detach the finds of a nose-pendant wing with 40% Ag and a pin shaft with 74% Ag (Lothrop 1951:238), which are without a doubt two artificially made alloys. It can be concluded that intentional gold-silver alloying practice could have started in the Early Horizon. The ternary diagram in Figure 1 shows how the dots spread along the Au-Ag axis.

Table 1. *Number of analyses conducted in the comparative study of the Central Andean region.*

Culture	Museum	Bibliography	Total
Chavín	—	10	10
Paracas	—	8	8
Mochica	4	7	11
Nazca	4	7	11
Huari	3	—	3
Chimú	6	10	16
Chancay	—	16	16
Ica-Chincha	—	17	17
Inca	52	11	63

In the Peruvian south coast, Paracas goldsmiths worked sheets and wires during the Late Early Horizon. We know of eight analyses performed by Root (1949:13). Mean values of copper and silver are 2.0% and 6.0%. See ternary diagram in Figure 2.

The literature provides analyses of three bracelets or rims of ear-stud disks (Kroeber 1944:132) and four small jaguar figurines (Lechtman et al. 1975:17) from Late Mochica time. The figurines were first dated proto-Mochica or Early Vicús (Lechtman et al. 1975:12); they were later dated in the Middle Horizon (Lechtman 1980:328). These objects are now believed to be from the end of the Early Intermediate period or the beginning of the Middle Horizon (Lechtman 1988:365).

There is an appreciable difference in the copper mean values between the sets of Mochica artifacts in the bibliography and in the Museo de América: The former offers a higher cipher (5.7% Cu). Silver content is nevertheless similar in both series. This does not take into account a small ingot of 62.9% Cu, 9.3% Ag, and 27.64% Au (Kroeber 1954:161) and a bracelet of 4.1% Cu, 77.4% Ag, and 18.3% Au (Baessler 1906:12) for the present unusual alloys in the Central Andes, though they are comparable in some aspects to the soldering mixture detected in one of the jaguar figurines mentioned above (Lechtman et al. 1975:39) and to other tumbaga ornaments found at Virú (Lechtman 1973:39), whose alloys have not been computed here. These compositions indicate that not only native gold but intentional

Figure 1. *Ternary diagram of Chavín gold alloys. Data from bibliography.*

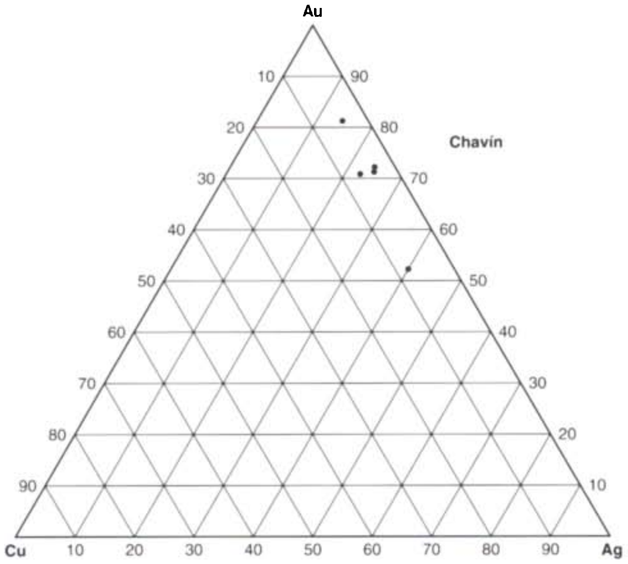
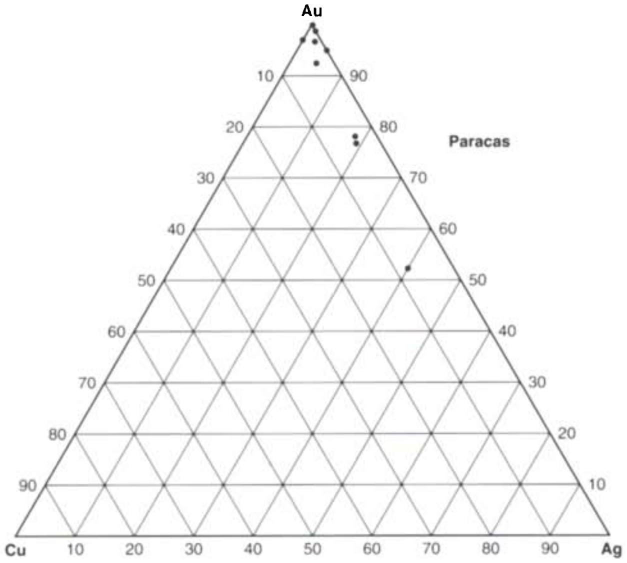


Figure 2. *Ternary diagram of Paracas gold alloys. Data from bibliography.*



alloys of gold-copper and gold-silver were used and can be dated within this period (Lechtman 1988:355). A ternary diagram is shown in Figure 3.

Root (1949:13) performed analyses on seven Nazca ornaments, giving a copper average similar to that calculated with the analyses reported here (3.7 and 4.2%, respectively), but the latter set results were richer in silver (4.28% vs. 8.72%), as shown in the diagram in Figure 4.

There is no comparative series for Huari gold work in the literature, and the Museo de América does not preserve metal objects to compare with those of Chancay (Baessler 1906:13; Rivet and Arsandaux 1946:102; Lechtman 1976:33) and Ica-Chincha collections (Root 1949:17–30). With such scarce analytical information, almost nothing can be said about Huari gold metallurgy, except that the three objects seem to be made of native gold. That is not the case of Chancay and Ica-Chincha, Post-Middle Horizon cultures developed in central Peru and the south coast of Peru. The novelty is a large-scale use of gold-silver alloy, as was pointed out by Root (1949:17) and shown in the ternary diagrams in Figures 5–7.

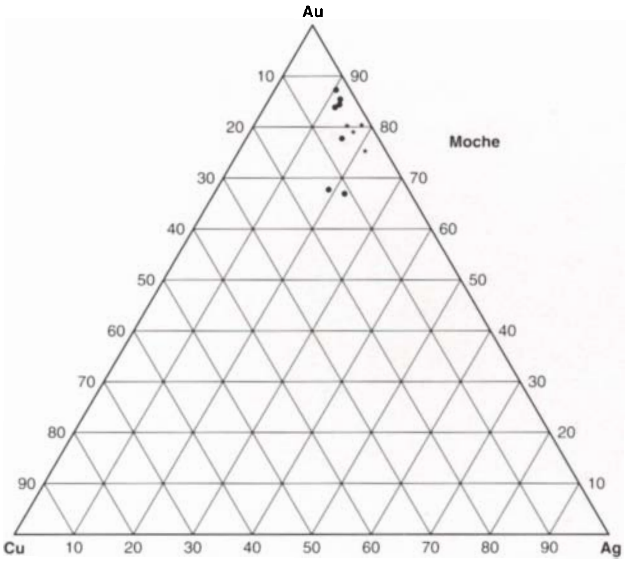


Figure 3. *Ternary diagram of Mochica gold alloys. Data from bibliography (dots) and Museo de América (stars).*

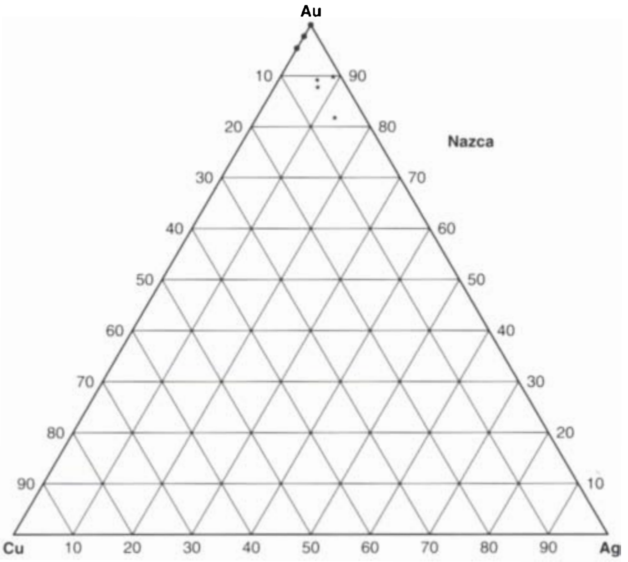
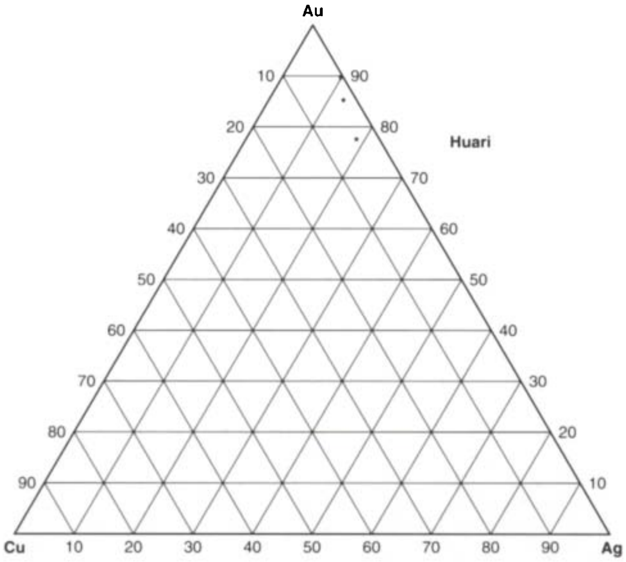


Figure 4. *Nazca gold alloys. Data from bibliography (dots) and Museo de América (stars).*



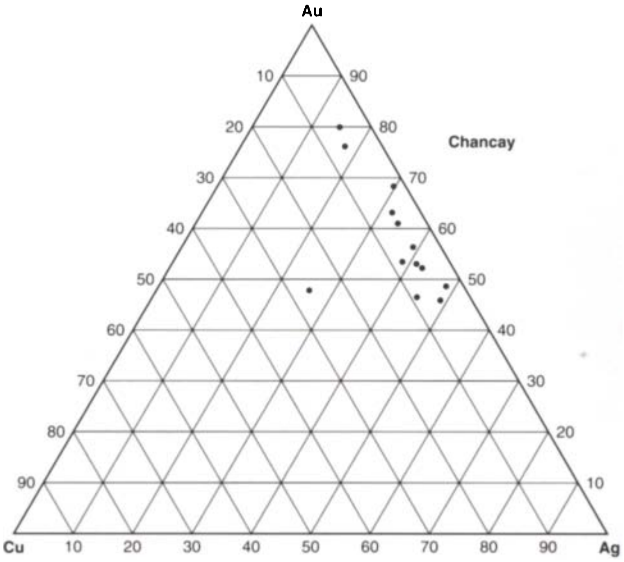
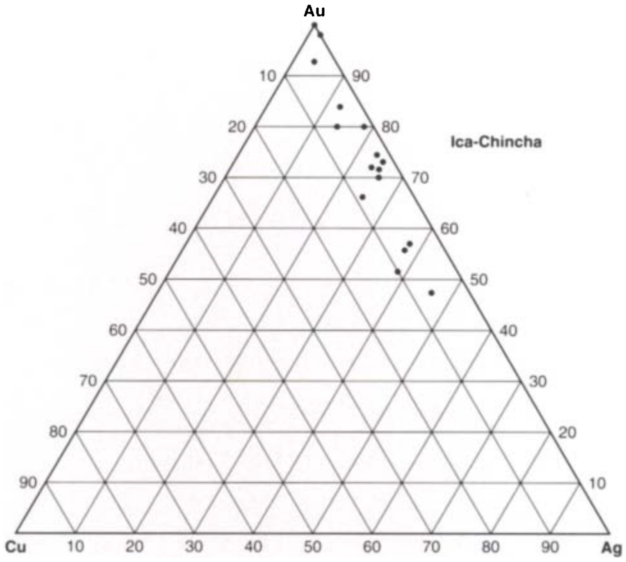


FIGURE 5. *Ternary diagram (above left) of Huari gold alloys. Data from Museo de América.*

FIGURE 6. *Ternary diagram (above right) of Chancay gold alloys. Data from bibliography.*

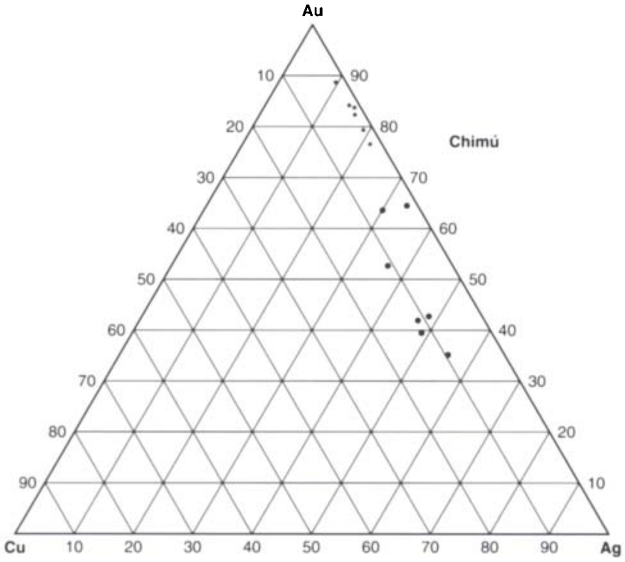
FIGURE 7. *Ternary diagram (near right) of Ica-Chincha gold alloys. Data from bibliography.*



The compositions of Chimú alloys in the set discussed here are quite different from those introduced by Reichlen (1941:130), Rivet and Arsandaux (1946:102), and Lechtman (1973:39), as they show copper and silver averages (1.97% vs. 8.09% Cu, 15.66% vs. 38.48% Ag). But, far from producing any disquietude, the finding enriches the panorama of this important metallurgical culture, filling a part of our knowledge that was lacking and modifying the ideas on quality and types of Chimú metals. At the same time, the provisional nature of any conclusion based on present data processing is emphasized. A ternary diagram is represented in Figure 8.

Finally, the fifty-two analyses of Inca objects fit without difficulty the well-known group published by Root (1949:31–33), with neighboring copper and silver averages in both sets (3.89% vs. 6.54% Cu, 27.17% vs. 24.63% Ag), as indicated in Figure 9.

By unifying data, some trends begin to be appreciated, and the following is an attempt to validate them. First, it appears licit to talk of change that has occurred since the Huari political and territorial unification, but for more chronological and geographical concretion we must await new metal analyses dated into the now



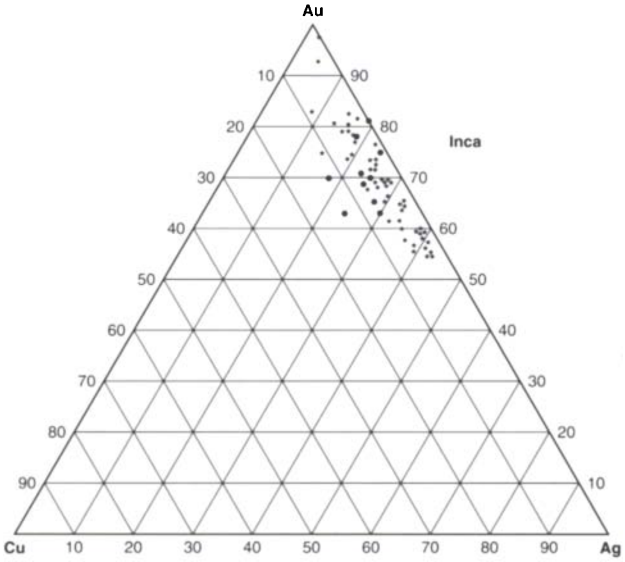


FIGURE 8. *Ternary diagram (above left) of Chimú gold alloys. Data from bibliography (dots) and Museo de América (stars).*

FIGURE 9. *Ternary diagram (above right) of Inca gold alloys. Data from bibliography (dots) and Museo de América (stars).*

poorly represented Middle Horizon. This notwithstanding, it is evident that gold alloy technology was different before and after the Middle Horizon (Fig. 10): Chimú, Chancay, Ica-Chincha, and Inca pieces present silver averages significantly higher than the ones from precedent cultures. Copper contents are instead maintained at low rates with few significant variations. It appears that gold-silver alloying, which commenced during the Early Horizon, became frequently used in the Late Intermediate period and spread throughout the coastal cultures in Peru.

Though knowledge about gold-mining areas worked by the Peruvian Indians during the Early Horizon and the Early Intermediate periods is scarce, analytical data suggest different provenances of gold supply for northern and southern Peruvian cultures, the source of the first ones having been richer in silver. One may observe the contrast between Chavín and Paracas in Figure 10, a contrast that is maintained with few changes in the Early Intermediate period between Mochica and Nazca. About twenty native gold analyses in classic literature (Raimondi 1878; Wolf 1892; Créqui-Montfort et al. 1919; Rivet and Arsandaux 1946; Petersen 1970) already insinuate the existence of groups in function of silver and copper rates.

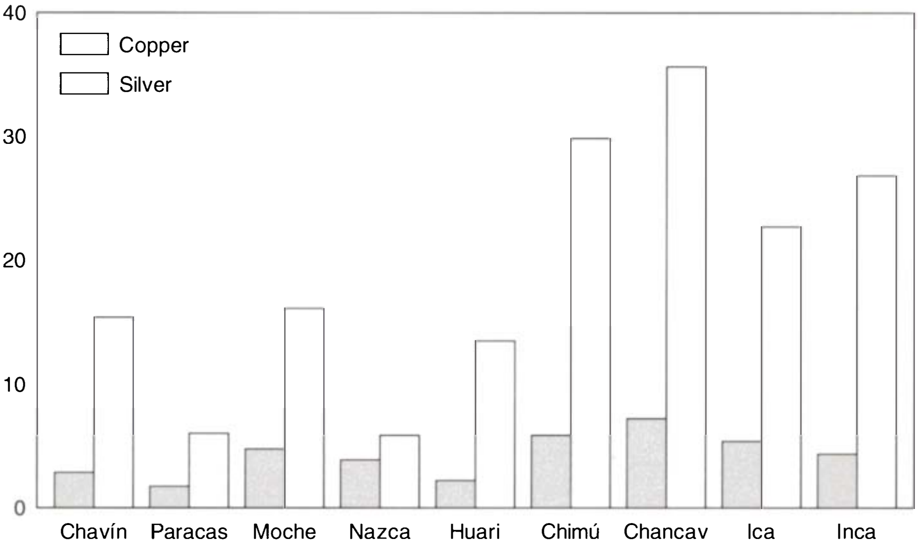


FIGURE 10. *Global copper and silver averages of Peruvian gold work.*

Thus, raw gold from the Sandía and Carabaya districts (Peruvian Highland, Carabaya Mountains) present a low-to-medium silver amount (1.7–14.8% Ag) and no copper (Petersen 1970:51). The same can be said for the placers located on the Chuquiaguillo River (near La Paz, Bolivia) (Rivet and Arsandaux 1946:34). The Yungas gold (Cajones River, High Plateau) is silver-rich (20.1–21.3% Ag) but without copper (Rivet and Arsandaux 1946:34). The gold from Ancash (Ninamahua and Pallasca, Department of Ancash, Peruvian Central Coast) has a moderate silver amount (4.8–8.4% Ag) and a relatively high copper content (6.5–7.6% Cu) (Raimondi 1878:75). In the northwest, the Tumbes River carries away raw gold at Zaruma containing 26.34% Ag and 0.73% Cu (Wolf 1892:318). Finally, many tributaries of the Amazonas in northern Peru have gold placers, probably with high silver rates judging from the analyses from Ucayali and Chínchipe (Petersen 1970:51). There are many other gold districts, but the author does not know if quantitative analyses have been attained.

Thus, a higher silver average in Chavín and Mochica works may be indicative of gold supplies like those in northern placers, while a lower silver average in Paracas and Nazca works may refer (but not exclusively) to gold like the one in the Carabaya and Sandía mines. Native gold from Ancash seems to have been used by northern and southern goldsmiths.

In relation to copper impurities, only the raw gold from Ancash contains more than 1% Cu, but it is reasonable to think that Ancash is not the only district that can provide this kind of native gold. Much more analytical (and archaeological) information is needed to outline an accurate panorama of the nature of resources and trade routes.

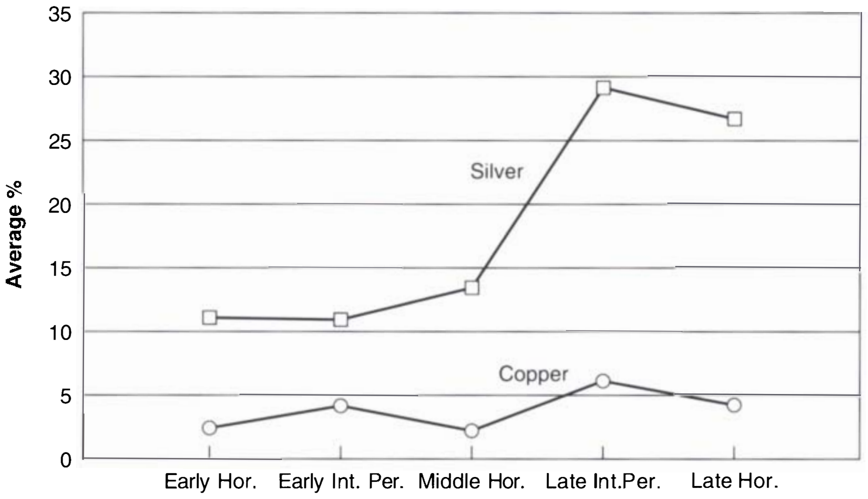
However, it is this author's opinion that the metal technology forms a substratum, with many common attributes reflected in all the Peruvian cultures, and its progress is linked to the general advance of the society (Rovira 1990:788–91). For example, the difference between Mochica and Nazca alloys could be expounded by supposing distinct provenances of native gold, a matter that has no relation to technology but is related to trade or territorial control. The style to work metal is in fact the same in both cultures. Much more striking are the coincidences between Chimú, Chancay, and Ica-Chincha (Fig. 10). In other words, cultural personality does not necessarily imply technological differences as a whole.

Bearing these ideas in mind, and in spite of the limited information, it does not appear too risky to assert that the rise of silver mean values observed after the Middle Horizon was due to the common intentional practice of alloying native gold and silver (Fig. 11). For its part, the copper amount tends to grow during the vast period between the Early and Late Horizon.

Before proceeding further it is necessary to determine the general criterion that allows one to distinguish between raw gold and intentional alloyed gold. Such a criterion has to be subjective because of the rather small number of analyses and their regional variability. Table 2 shows the range of main components of native gold as calculated from analyses in the works mentioned above.

As has been previously discussed, gold containing silver at high concentrations is not unusual in northern Peru and could easily represent a natural alloy (Lechtman

Figure 11. *Tendencies of copper and silver averages over time in Peruvian gold work.*



et al. 1982:7). Raw gold analysis supports this argument. Several ancient objects from the south coast (Paracas and Nazca) are also silver-rich (about 20% Ag) (Root 1949:13), and there is no reason to think that they were made of an artificial alloy. Therefore, the cipher of 25% Ag may be established as the upper limit from which intentional gold-silver alloying can be assured. This does not mean that some other metals with lower silver rates could not be artificial as well, but it is very difficult to determine so.

To establish the limit of natural copper impurities is a much more complicated task. At least two aspects are involved: First, most old analyses (but not all, fortunately) show that Peruvian raw gold is copper-free, a quality remarked on by Caley (1977). As such, it is highly probable that many objects containing more than 1–2% Cu could be made of an artificial gold-copper alloy. Second, it is well known that the addition of a small quantity of copper to the gold reduces significantly the melting point, as can be seen in the phase diagram of these metals. The matter is to elucidate whether the Early Horizon goldsmiths knew this or not, because almost the half of the objects in this period contain more than 2% Cu.

The presence of copper in native gold, therefore, must be more frequent than the analyses show (the present sample is not significant). Moreover, the effect of reducing the melting point is noticed by the skillful ancient metallurgists when the copper amount is 5% and above; I suspect that lower concentrations have some effect on the physical and external properties, which were probably imperceptible at the technological level that metal was worked in the Early Horizon. Gold economy or melting loss also may be invoked to explain small copper amounts as a deliberate addition, but more evidence is needed to prove this. Resting on these a priori reasons, one can suggest a range below 5% Cu for nonintentional gold-copper alloy.

Table 2. *Range of main components of native gold.*

Element	Minimum	Maximum	Average
Copper (%)	0.0	7.6	0.93
Silver (%)	1.7	26.34	8.38
Gold (%)	72.95	98.50	90.19

Some ancient objects are dramatically interesting in relation to the beginning of artificial alloying. A bimetallic pin from Chongoyape revealed a composition of 26.0% Au, 74.0% Ag, and 0.0% Cu (Lothrop 1951:238); a bracelet from Virú was made of 18.27% Au, 77.41% Ag, and 4.15% Cu (Baessler 1906:12); a small ingot found in a grave in the Huaca of the Moon at Moche is a copper-gold alloy of 27.64% Au, 9.30% Ag, and 62.90% Cu (Kroeber 1944:161); and a ternary alloy of copper (45.3%), silver (43.7%), and gold (7.5%) is the metal of a bangle, also Mochica (Lechtman 1973:39, Table 1). Thus, we see that the debut of artificial gold-silver alloy could be situated in an until-now nonconcrete moment within the Chavín epoch, while the copper-gold and copper-silver-gold alloys could start in the Mochica epoch (Lechtman 1973:50, 1980:292–93). The Ag/Au ratio can be useful to distinguish these alloys.

The importance of each type of gold alloy in Peruvian metallurgy was very different if one judges by what has been seen in the metal analyses. Gold-silver alloy was employed more and more (Fig. 12), while gold-copper (or copper-gold) alloy, the true tumbaga, remains poorly represented up to the present. The third type, Au-Ag-Cu, seems to have a definite utility to prepare the base metal of objects gilt by a depletion method, somewhat frequent in Chimú works (Lechtman 1973:39, Table 1) but assayed much earlier. However, it is important to note that these gilt objects were made of true ternary alloys prepared by melting together gold, silver, and copper (Lechtman 1973:39).

Figure 12 is not to be understood as an exact behavioral pattern of the evolution of gold alloys because its design is based on a criterion that only considers an intentional alloy when the composition surpasses the limits of 25% Ag and/or 5% Cu. It is, in a certain manner, a model of minimum numbers but indicative enough of how gold-alloying practice grew.

Figure 11 exposes a fact that is convenient to explain. When silver content rises following the Late Intermediate period, copper rises as well when, logically, it must diminish as gold does (if we accept that copper is a natural impurity of raw gold). One explanation for this apparent contradiction comes at the hand of the Ag-Cu alloy progress at the same time, as the author has demonstrated in other work

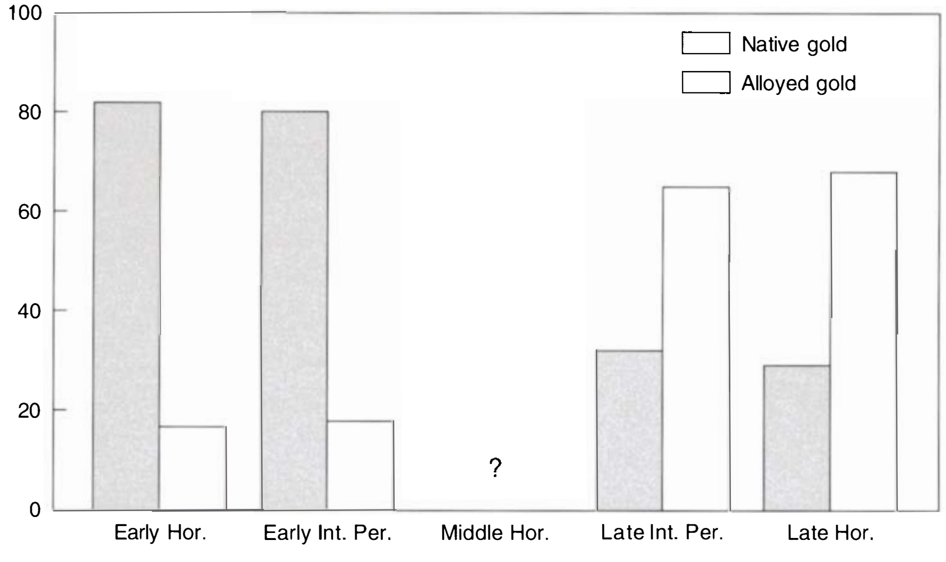


Figure 12. *Relative frequency of gold alloys in Peruvian gold work.*

(Rovira 1990:791). Therefore, the frequent use of Ag-Cu alloy to reduce gold carats is responsible for the elevation of the copper average, putting silver and gold work in a close relation. In this case, being higher than before, the Ag/Au and Cu/Au ratios will change and can be detected by comparison with raw-gold compositions. Another explanation can be drawn if we consider the opportunity of alloying natural Au-Ag with copper. The Ag/Au ratio will remain unchanged, being now affected by the Cu/Au ratio. But if we take a quick look at the set of analyses we will see that the first explanation is sounder than the second when the gold amount is over 30%, that is, for the objects considered here as gold-made within the Peruvian area. Gold recycling may also play a role in the subject of copper content as it occurred, for instance, in Europe during prehistory (Montero and Rovira 1991:12–13), where hoards of broken pieces have been found, ready to be reused in the goldsmith workshop; however, at the moment there is no method to establish what important recycling metal was in Peru.

The Intermediate Area

The Intermediate area consists of the countries of the Isthmus of Panama and northern Andes that gravitate under cultural influences from Mesoamerica and the Central Andes.

Colombia

Analytical results. The present situation of Colombian archaeology does not allow us an approximation to the metallurgical phenomenon in the same way the Central Andes does. The main problem is the difficulty in assigning a precise chronology to the objects studied. Pre-Columbian cultures, or "styles," form a mosaic of regions that developed over long periods of time. It is likely that successive sequences within or among cultures will be calibrated in the future, making it possible to outline the evolutionary trends of metal technology. In the meantime, the present situation only allows a rough approximation, attributing to the same culture some objects that are perhaps distant in time.

The Museo de América holds a significant collection of Colombian gold work, including the unicum known as the Quimbaya's Treasure, catalogued by Cuesta and Rovira (1982). A small part of this treasure has been analyzed, and the results are shown in the appendix to this chapter.

The period between the third and fourth centuries C.E. marked a splendid time for Calima jewelry, attributed to a people who lived in western Colombia, between the coast and the Cauca River. None of the objects analyzed has the grandeur of the big masks and pectorals of the Yotoco phase; our Calima collection is comprised of numerous but modest personal-use items such as nose and ear ornaments, necklaces, and pendants. The forty-nine analyses presented here fall into two different groups of gold alloys, one with a copper content of less than 5%, the other with a high copper content of more than 20%.

Similarities can be seen in the thirty-three analyses of Quimbaya castings; for example, tumbaga alloy has a copper content of more than 30%. The Quimbaya territory spreads over the middle basin of the Cauca River, and gold work appears to reach its peak before 1000 C.E.

In about the year 750 C.E. new chiefdoms seem to emerge. Some of these grew in the Nariño region in the interior highland of southwest Colombia. A single object from this culture, a disk-shaped pendant made of native gold (1.62% Cu, 7.3% Ag), is kept in the Museo de América collection.

The basin of the Sinú River was occupied by chiefdoms of the same name. Two objects belong to the Sinú style: an anthropomorphic pendant and a nose ornament. The first seems to be made of native gold (3.23% Cu, 7.7% Ag), the second is a tumbaga alloy (52.25% Cu, 4.91% Ag).

Ten analyses of anthropomorphic figurines (tunjos) from the Muisca cultural complex have been performed. All of them show metals with low gold content (7.3–34.9%). The most interesting finding has been the detection of alloys containing four metals, tin being the fourth. Such is the case with analyses Nos. 7336 and 7349M. The surprise existence of true tin-bronze in Muisca metalwork has been discussed in other work (Rovira 1990:875). Tin-bronze technology may have been introduced in Colombia after Spanish contact with Indian metalsmiths and used during the period in which local traditions survived under the Colonial regime.

Finally, twelve Tairona objects have been analyzed. They show ternary alloys with high copper content.

Comparative study. The cultural provenance of the material used in the comparative study is represented in Table 3. Some previous analyses with a poor adjustment were rejected for calculation. The data have not been used with the group of qualitative determinations collected by Plazas (1975) except for contrasting certain qualitative aspects.

Statistic central trends are irrelevant owing to, on one hand, the dramatic variability of the copper content of alloys, and on the other hand, the insignificant role silver plays in Colombian gold work. General tendencies are already known and evident: Goldsmiths used Au-Cu-Ag ternary alloys frequently. Silver is a natural component of the native gold, ranging between 2.0 and 36.6% Ag, in accord with previous analyses (Rivet and Arsandaux 1946:34–37). Colombian raw gold is considered to be copper-free. As a consequence of the aforementioned copper variability, it was reasonable to expect a notable contrast between the analytical results discussed

TABLE 3. *Number of analyses conducted in the comparative study of the Colombian region.*

Culture	Museum	Bibliography	Total
Tumaco	—	7	7
Calima	49	—	49
Quimbaya	33	20	53
Nariño	1	12	13
Sinú	2	—	2
Tairona	12	2	14
Muisca	10	76	86

here and those introduced by bibliography. This does not deter one from making use of both sets when the aim is not to get an exact quantitative image of the alloying practice (which is always problematic) but to determine particular tendencies.

Although San Agustín and Tierradentro seem to be the earliest cultures to provide gold objects, the chronology is doubtful. In fact, the earliest date for a grave with gold ornaments is the year 40 B.C.E. (Plazas and Falchetti 1985:51), but there is no analysis of the metals.

The first well-dated analyses come from Tumaco (Bouchard 1979:23, 1984:81) and are represented in the ternary diagram in Figure 13. Despite the small sample size, the two common metals of Colombian gold work are distinguishable: native gold and tumbaga objects.

For the Calima gold work we have only the contribution of the Museo de América. The metal distribution falls again into a double grouping: native gold close to the Au-Ag axis and tumbaga close to the Au-Cu axis (Fig. 14). It does not appear that a preferred or more frequent alloying interval could be established; however, it

FIGURE 13. *Ternary diagram of Tumaco gold alloys. Data from bibliography.*

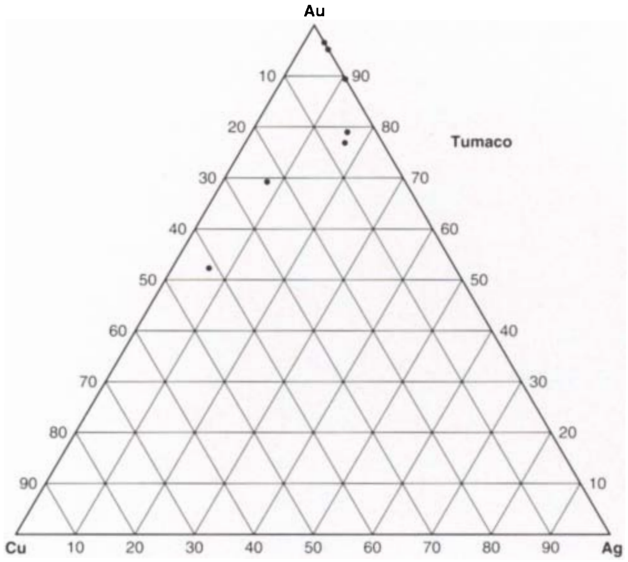
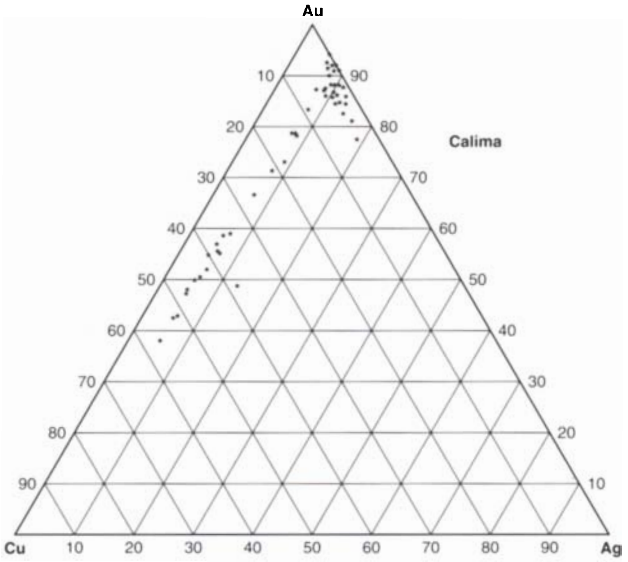


FIGURE 14. *Ternary diagram of Calima gold alloys. Data from Museo de América.*



is probable that alloys situated in the range of 10–20% Cu could be due to the melting together of recycled tumbaga and raw gold.

In the distribution of the Quimbaya analysis represented in the ternary diagram in Figure 15, we can verify how the sets in the literature (Rivet and Arsandaux 1946:40–41, 49–54) and the Museo de América share the same region. Once more we must discuss native gold and tumbaga objects, the latter being clearly predominant. Nevertheless, some peculiarities may be noted. First, the use of different alloys to cast parts of an artifact for a chromatic effect has been confirmed, as in the head of pin no. 7051, decorated with a richly dressed anthropomorphic figurine; lost-wax casting and casting-on techniques reached an astonishing level in Quimbaya time. Second, a very rare alloy has been detected in a zoomorphic bead of a necklace from the Quimbaya's Treasure. The bead was found to contain 17.1% lead (analysis no. 17467). The phase diagram of gold-lead alloy presents a melting point at 820 °C for a lead concentration of 17% in weight, and a peritectic reaction at 418 °C. Thus, lead facilitates casting much better than copper. As far as we know by the archaeological finds, however, lead was unknown at the time. A research program involving electron microscopy is under way to investigate this singular object, which is morphologically similar to the rest of the beads of the necklace.

The Nariño alloys are known owing to the research by Scott (1983a:104, 1983b:196). The set is shown in Figure 16. A single object from this region, a disk-shaped pendant made of raw gold, is in the collection of the Museo de América. Two aboriginal traditions have been established by Plazas (1977–78), one using high-carat gold (Capuli style) and the other using tumbaga (Piartal-Tuza style), although we do not know the analytical framework for this assertion. Nevertheless, the small number of analyses seems to point to a double metallurgical tradition, as Plazas claims.

The scarce information available about Sinú metalwork makes any approximation nonviable other than recording the existence of objects made in native gold and tumbaga, as suggested by the composition of two objects, a pendant and a nose ornament from the Museo de América.

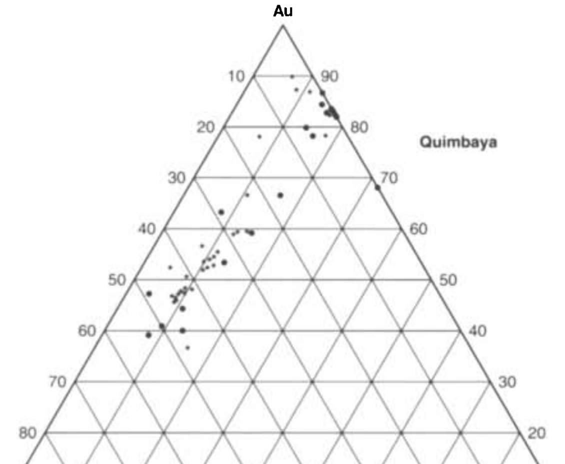


FIGURE 15. *Ternary diagram (below left) of Quimbaya gold alloys. Data from bibliography (dots) and Museo de América (stars).*

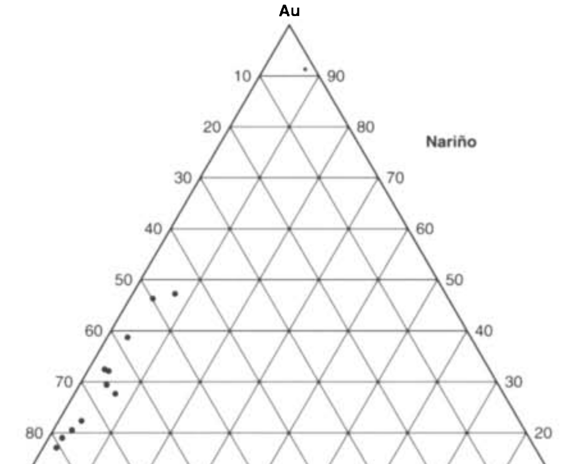
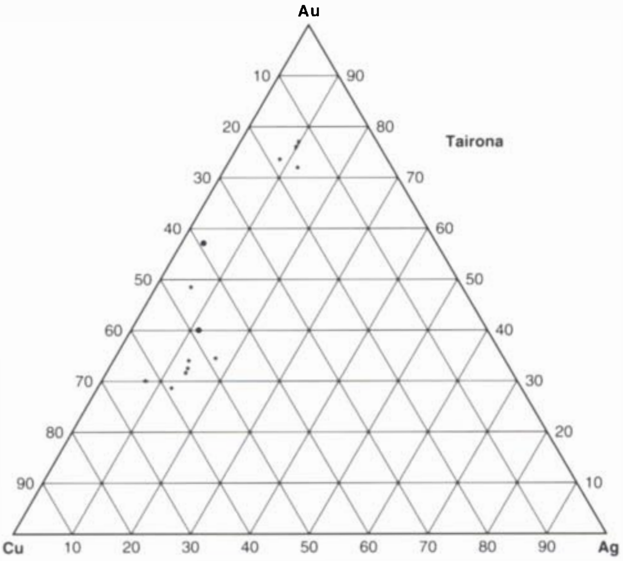


FIGURE 16. *Ternary diagram (below right) of Nariño gold alloys. Data from bibliography (dots) and Museo de América (stars).*



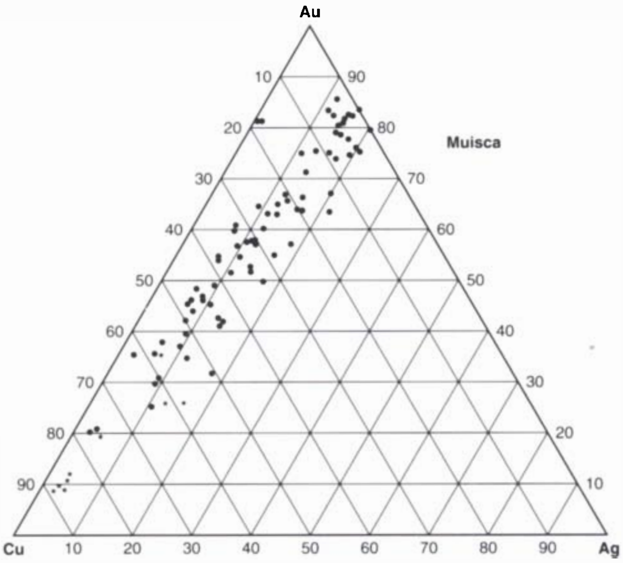


FIGURE 17. *Ternary diagram (above left) of Tairona gold alloys. Data from bibliography (dots) and Museo de América (stars).*

FIGURE 18. *Ternary diagram (above right) of Muisca gold alloys. Data from bibliography (dots) and Museo de América (stars).*

The Tairona goldsmiths used basically copper-rich alloys, as shown in Figure 17. The analysis of some objects containing copper between 10 and 20% in weight, perhaps produced by melting recycled tumbaga and raw gold, leads us to suspect that some high-carat items may exist.

The Muisca gold work is the best known from the point of view of metal composition (Fig. 18). Many analyses were collected by Rivet and Arsandaux (1946:41–43, 49–54). Some objects are made of native gold but the majority show a ternary alloy rich in copper. In particular, the *tunjos* from the Museo de América are cast in low-gold alloys, indicating surface coloring by a depletion gilding method even though there is no evidence that the treatment was applied. The detection of tin-bronze-gold alloy used for casting several of these figurines (7336, 7349) is an attractive novelty.

In examining the entirety of Colombian metals as depicted by ternary diagrams (there is a lack of findings for the Tolima culture), one can say that many metallurgical attributes are common to a great extent. The differences, however, are more qualitative than quantitative and probably strongly conditioned by our incomplete understanding of Colombian prehistory, a situation that will not change until field archaeology and laboratory research provide us with a complete analytical data set.

At present, considering the average values of copper and silver (Fig. 19), Nariño gold work stands out as having the lowest in carats (60.4% Cu, 3.6% Ag), but this seems to have brought about improved surface embellishing techniques in the precious-metal economy (Scott 1983a). Quimbaya (27.1% Cu, 11.8% Ag), Tairona (31.3% Cu, 12.0% Ag), Muisca (34.2% Cu, 11.3% Ag), and Sinú (27.7% Cu, 6.3% Ag) form close groups according to the mean values, but these ensembles are not so close if we take into account the dispersion of extreme values. Finally, Calima (16.8% Cu, 8.7% Ag) and Tumaco (10.0% Cu, 8.8% Ag) are the regions where high-carat artifacts often may be expected.

Perhaps it would be more instructive and conclusive to depict graphically how common the use of native gold was (Fig. 20). The Tumaco and Calima groups have

Figure 19. *Copper and silver averages in Colombian cultures.*

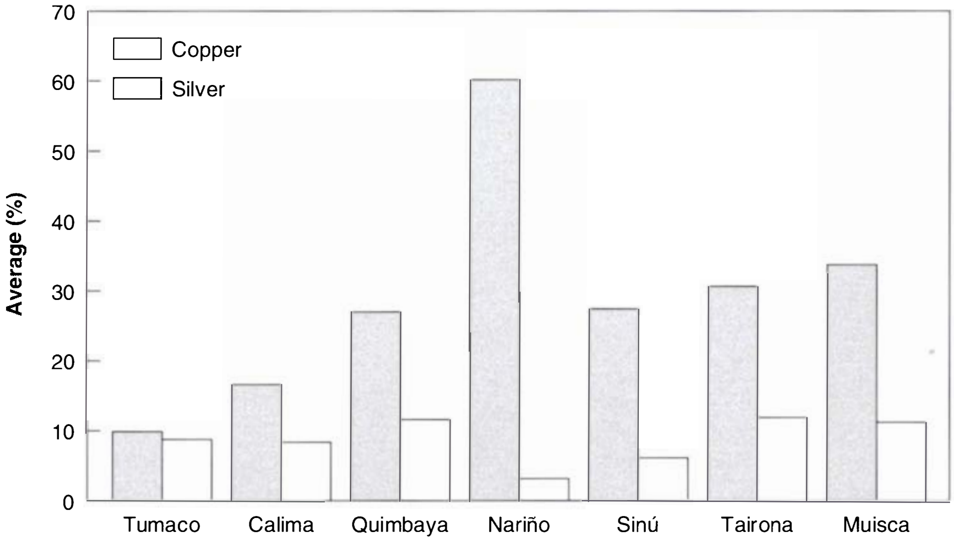
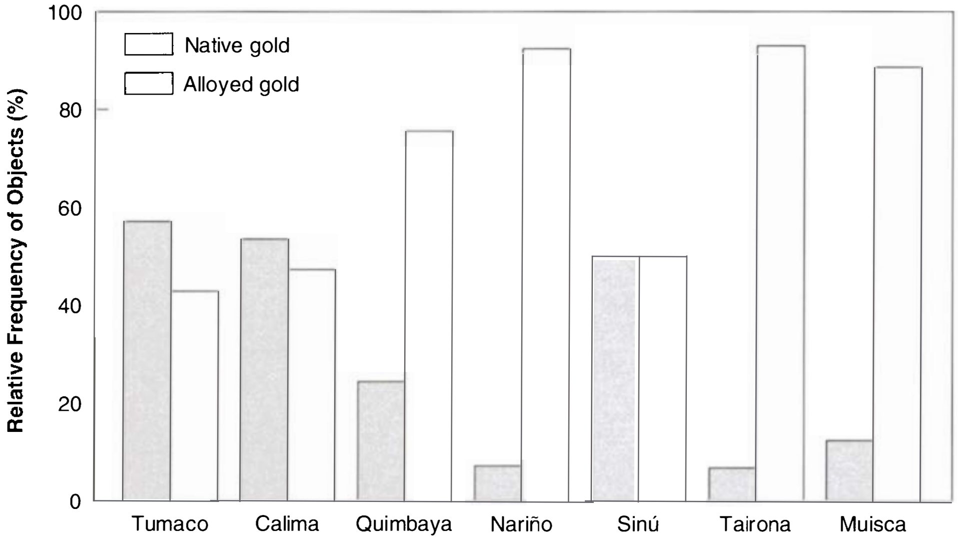


Figure 20. *Relative frequency or artificial gold alloys in Colombian metalwork.*



the largest percentages of objects made of raw gold. Quimbaya attains an intermediate level, while Muisca, Tairona, and Nariño have gold work made predominantly of artificial gold-copper alloy (Sinú has not been considered because only two analyses are available). If we leave aside some determining factors such as nearness to gold sources and metal and item circulation—the influence of which is evident but difficult to value—an increasing development in the use of tumbaga seems perceptible over time. Therefore, in the Phase of Regional Cultures, the earliest to work gold, one finds that the Tumaco, Calima, and Quimbaya groups that flourished before the tenth century C.E. frequently used native gold. After that date, during the Phase of Regional States, tumbaga dominates the Colombian metallurgical landscape.

Previous research (Créqui-Montfort et al. 1919:553; Rivet and Arsandaux 1946:35–36) compiled more than fifty quantitative analyses of native gold from Colombia. No copper was detected, and the range of silver oscillates between 2 and 36.6%. Given that the Ag/Au ratio does not affect the alloy because no addition of silver can be expected (silver is a rare metal in Colombia), the distribution of these ratios may be indicative of patterns in supply areas, though the information is not complete enough to study a concrete location. Calima and Nariño offer a very similar distribution, accumulating many objects in the range 0.0–0.2 Ag/Au ratio, perhaps indicating a common gold source or, at least, gold sources of similar characteristics. The Quimbaya used a raw gold richer in silver; many works were made with a kind of metal like that which the Calima used, but it is common to find objects with an Ag/Au ratio of about 0.2–0.3. The Tumaco and Muisca occupy an intermediate level between the Quimbaya and Calima. Finally, the Tairona gold, drawing a bimodal distribution, seems to originate from two different sources, partially used by the Muisca and Quimbaya as well.

The meaning of this model in relation to the realities of history is not to be exaggerated. The idea is surely in everybody's mind that changes in the Ag/Au ratio can occur when different kinds of gold are mixed or recycled. Nevertheless, and partially owing to the small size of the analytical sample, some perceptible contrasts agree with certain archaeological readings and encourage us to continue our research. Archaeological finds often suggest the existence of trade routes connecting distant points within Colombia, a claim that could be attested to by the Spanish chroniclers who lived during the last years of the aboriginal world.

Costa Rica

Typological and technological aspects of gold work from the Isthmus of Panama have been treated well (Bray 1981; Snarskis 1985; Cook and Bray 1985). For Costa Rica, however, there was no analysis of metal composition except for the figurine in Rivet and Arsandaux (1946:58). The forty-two analyses presented here (see appendix) attempt to correct this. The collection has been assigned to Late Diquis style (Cabello 1980) and consists of pendants of different shapes.

Central tendencies can be assumed by the following mean values: 11.51% of copper and 3.08% of silver. More illustrative is the ternary diagram in Figure 21, which reflects two kinds of gold, one being a copper-rich alloy and the other probably native gold. About half of the alloys contain less than 5% Cu, and it can be assumed that these objects were made of native gold.

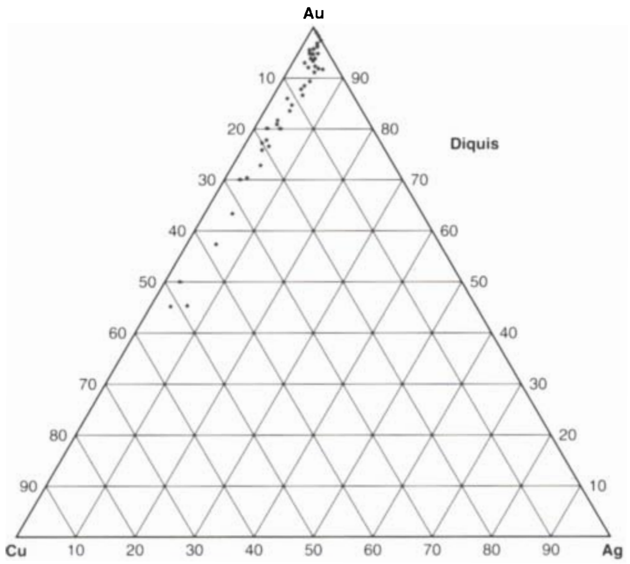


Figure 21. *Ternary diagram of Diquis gold alloys. Data from bibliography (dots) and Museo de América (stars).*

The metal composition of raw gold from Costa Rica has not been introduced, but it seems reasonable that gold from placers at the Isthmus contain small amounts of silver. Indirect proof of this assessment is that the analyses discussed here are in agreement with those of Panamanian objects made by Rivet and Arsandaux (1946:41–43, 49–54), coinciding with the distributions in a ternary diagram (Rovira 1990:908).

Thus, we can see that gold metallurgy in the Isthmus of Panama and Colombia presents coincident features to such an extent that the first can be considered the northern region of a large territory of goldsmiths that spreads from northwest Ecuador as far as Nicaragua.

Conclusions

A few years ago I sought an explanatory model applied to Pre-Columbian metallurgy that went beyond the commonly accepted theories of diffusion (Rovira 1990:921–37). I did not believe ancient Peru to be the sole region where one must search to find the origin of metallurgy in America. Like the Old World, where evidence of several invention points is growing stronger, the New World seems to be moving in the same direction.

American metallurgy, like archaeology to a great extent, seems to constitute a series of nonlinked cells. Punctual (the item itself) or microregional research has produced unbalanced knowledge because archaeometallurgy always follows field archaeology, and the latter has developed with unequal fortune.

From a metallurgical standpoint, the best-studied region is, without a doubt, Peru. Although absolute chronology of Peruvian finds related to gold work and metallurgy in general seems to be the earliest, the commonly accepted theory says: Metallurgy is a technological phenomenon that originated in Peru and spread slowly north. This theory has simplicity as its one great virtue, but it is ambiguous and does not define which components of metallurgy spread away (metals, alloys, technology?) and, therefore, does not explain why some components spread and others did not spread at all.

Gold metallurgy appears to verify the theory. The earliest gold work in Peru (Waywaka site) is much more ancient than the gold work in Colombia (Tumaco-Tolita, San Agustín). But when one analyzes acutely the attributes of these metallurgies (alloying practice is one among many other attributes), one observes such irreconcilable differences that there is no way to support the notion that gold metallurgy in Colombia must be understood as a consequence of a diffusion process from Peru. This is one of several reasons that led me to think of a theory of cultural blocks with semipervious borders as an alternative to diffusion (Rovira 1990:928–37).

Gold work in the Peruvian Block is characterized by: (a) invention of a gold proto-metallurgy before 1500 B.C.E.; (b) essay of Au-Ag alloy at the middle of the first millennium B.C.E. (the use of this alloy grew to become the preferred method of goldsmiths); (c) detection of a few objects made of a Cu-Au alloy, probably starting in Mochica time, and application of depletion gilding methods (both technologies, which probably arrived from the Colombian Block via Ecuador, were rooted in

Peru as a secondary activity of gold working); and (d) clear predominance of sheet-metal objects over castings, even in Inca times.

The Colombian Block is characterized by: (a) invention of a gold proto-metallurgy in a nondated moment but anterior to 500 B.C.E., in La Tolita-Tumaco, if the existence of gold sheets within the Chorreroid Horizon can be confirmed; (b) essay of Au-Cu alloy early in Christian time and becoming a frequently used alloy (several surface coloring techniques, mainly depletion gilding, were developed at the same time); (c) invention of lost-wax casting process about 100–300 C.E., which would become the basic method utilized to cast the beautiful and very complicated designs of the Intermediate area jewelry (this method reaches the north of Peru after 1000 C.E.; and (d) since 500 C.E. cast items predominate over sheet-made ones, though some regional differences have been reported.

Appendix

Culture	Type of object	Fe	Ni	Cu	Ag	Sn	Sb	Au	Pb	Ag/Au	Number
Calima	Cylindrical bead	0.01	—[1]	2.6	12.4	nd[2]	0.02	86.7	nd	0.14	3173D
Calima	Cylindrical bead	0.01	—	2.4	10.1	nd	0.01	87.3	nd	0.13	3173K
Calima	Cylindrical bead (solder)	0.01	—	2.8	11.2	nd	0.01	85.8	nd	0.13	3173L
Calima	Disk	0.02	—	26.1	7.4	nd	nd	66.1	nd	0.11	18004B
Calima	Disk bead	0.01	—	3.0	16.2	nd	nd	80.6	nd	0.20	3173A
Calima	Disk bead	0.01	—	2.9	13.5	nd	nd	83.3	nd	0.16	3173B
Calima	Disk bead	0.01	—	2.6	11.8	nd	nd	85.5	nd	0.14	3173F
Calima	Disk bead	0.01	—	2.1	9.8	nd	nd	88.0	nd	0.11	3173I
Calima	Ear disk	0.01	—	0.3	6.0	nd	nd	93.4	nd	0.06	3137
Calima	Ear disk	0.01	—	2.4	7.5	nd	0.02	89.9	nd	0.08	3138
Calima	Ear disk	0.01	—	5.3	7.1	nd	0.01	87.3	nd	0.08	3139
Calima	Ear disk	0.01	—	1.3	6.8	nd	nd	91.6	nd	0.07	3140
Calima	Ear disk	0.01	—	1.3	11.2	nd	0.01	87.3	nd	0.13	3141
Calima	Ear disk	0.02	—	1.3	6.4	nd	0.01	92.0	nd	0.07	3142
Calima	Ear disk	0.01	—	0.8	11.9	0.01	0.01	87.1	nd	0.14	3143
Calima	Hemispherical bead	0.01	—	2.2	8.8	nd	0.02	88.8	nd	0.10	3173E
Calima	Hemispherical bead	0.01	—	3.4	9.3	nd	0.02	87.0	nd	0.11	3173J
Calima	Nose ornament	0.01	—	38.2	6.2	nd	0.01	55.5	nd	0.11	7470
Calima	Nose ring	0.01	—	13.8	8.5	nd	nd	77.6	nd	0.11	3123
Calima	Nose ring	0.02	—	14.4	7.3	nd	0.03	78.1	nd	0.09	3124
Calima	Nose ring	0.03	—	13.7	8.6	nd	nd	77.6	nd	0.11	3125
Calima	Nose ring	0.02	—	1.2	7.6	nd	nd	90.8	nd	0.08	3126
Calima	Nose ring	0.02	—	21.0	7.8	nd	nd	71.0	nd	0.11	3127
Calima	Nose ring	0.07	—	4.3	8.2	nd	0.05	87.0	nd	0.09	3128
Calima	Nose ring	0.02	—	0.1	6.9	nd	nd	91.3	nd	0.07	3129
Calima	Nose ring	0.02	—	38.8	12.5	nd	0.09	48.5	nd	0.26	3130
Calima	Nose ring	0.01	—	41.5	6.2	0.24	0.02	51.7	nd	0.12	3131
Calima	Nose ring	0.04	—	2.0	9.6	0.40	0.06	87.5	nd	0.11	3132

Culture	Type of object	Fe	Ni	Cu	Ag	Sn	Sb	Au	Pb	Ag/Au	Number
Calima	Nose ring	0.01	—	38.7	6.2	nd	nd	54.9	nd	0.11	3133
Calima	Nose ring	0.02	—	1.5	11.3	0.10	nd	86.9	nd	0.13	3136
Calima	Nose ring	0.01	—	38.3	5.3	nd	nd	56.2	nd	0.09	3146
Calima	Nose ring	0.01	—	34.2	6.9	0.10	nd	58.7	nd	0.12	3147
Calima	Nose ring	0.02	—	56.7	4.8	nd	nd	38.4	nd	0.12	3148
Calima	Nose ring	0.03	—	51.1	6.3	nd	nd	42.4	nd	0.15	3149
Calima	Nose ring	0.02	—	18.5	9.1	nd	nd	71.9	nd	0.13	3150
Calima	Nose ring	0.01	—	44.8	5.3	0.05	nd	49.7	nd	0.11	3151
Calima	Nose ring	0.01	—	36.4	5.2	0.08	0.02	58.1	nd	0.09	3152
Calima	Nose ring	0.03	—	43.2	6.4	nd	nd	50.2	nd	0.13	3153
Calima	Nose ring	0.02	—	40.1	4.9	nd	nd	54.8	nd	0.09	3154
Calima	Nose ring	0.02	—	51.9	5.1	0.07	nd	42.5	nd	0.12	3155
Calima	Nose ring	0.02	—	1.1	7.6	nd	0.02	90.9	nd	0.08	3156
Calima	Nose ring	0.04	—	9.4	7.3	0.06	0.03	82.9	nd	0.09	3157
Calima	Nose ring	0.01	—	46.8	5.6	0.04	0.02	47.4	nd	0.12	3159
Calima	Ring	0.01	—	47.6	4.7	nd	0.01	47.5	nd	0.10	18004A
Calima	Sheet pendant	tr[3]	—	3.4	8.4	nd	0.01	88.1	nd	0.09	7465
Calima	Sheet pendant	0.01	—	0.2	8.8	nd	0.01	90.8	nd	0.10	7489
Calima	Spherical bead	0.01	—	2.2	12.2	nd	nd	85.3	nd	0.14	3173C
Calima	Spherical bead	0.01	—	3.2	20.2	nd	nd	76.4	nd	0.26	3173G
Calima	Spherical bead (solder)	0.01	—	3.8	18.2	nd	nd	77.8	nd	0.23	3173H
Chimu	Decorated sheet	0.02	—	1.6	14.9	0.02	0.02	83.3	nd	0.18	7441
Chimu	Mask	0.01	—	1.7	18.6	nd	nd	79.5	nd	0.23	18003
Chimu	Pin	0.01	—	1.9	9.8	nd	nd	88.2	nd	0.11	7439
Chimu	Sceptre	0.01	—	2.6	13.8	0.01	nd	83.4	nd	0.16	7474
Chimu	Small sheet	0.02	—	1.8	15.8	nd	nd	82.2	nd	0.19	18007
Chimu-Inca	Crown	0.01	—	2.0	20.9	nd	nd	76.9	nd	0.27	7477
Huari	Bracelet	tr	—	0.5	9.7	nd	0.01	89.7	nd	0.11	7476
Huari	Vessel (body)	tr	—	2.3	12.5	nd	nd	85.2	nd	0.15	7473A
Huari	Vessel (soldered tube)	0.01	—	3.9	18.5	nd	nd	77.4	nd	0.24	7473B
Inca	Anthropomorphic figurine	0.02	—	29.0	59.2	1.96	0.25	8.9	0.53	6.65	7025
Inca	Anthropomorphic figurine	0.02	—	2.6	4.6	nd	nd	92.4	nd	0.05	7459
Inca	Anthropomorphic figurine	0.01	—	3.8	26.5	nd	nd	69.5	nd	0.38	7460
Inca	Anthropomorphic figurine	0.02	—	4.8	34.9	nd	nd	60.1	nd	0.58	7461
Inca	Anthropomorphic figurine	0.01	—	2.2	37.8	nd	nd	59.9	nd	0.63	7498
Inca	Anthropomorphic pendant	0.06	—	10.5	13.9	0.08	0.01	75.3	nd	0.18	7458
Inca	Bracelet	0.02	—	0.2	2.7	0.03	0.01	96.8	nd	0.03	7450
Inca	Bracelet	0.01	—	3.9	34.0	nd	nd	61.3	nd	0.55	7462
Inca	Bracelet	0.01	—	4.0	27.2	nd	nd	68.6	nd	0.40	18001-02

Culture	Type of object	Fe	Ni	Cu	Ag	Sn	Sb	Au	Pb	Ag/Au	Number
Inca	Bracelet	0.01	—	3.7	27.1	nd	nd	69.0	nd	0.39	18001-02
Inca	Bracelet	tr	—	6.7	19.3	nd	nd	73.8	nd	0.26	18006
Inca	Decorated sheet	0.01	—	3.6	24.4	nd	nd	71.8	nd	0.34	7453
Inca	Decorated sheet	0.01	—	5.4	19.3	nd	nd	74.4	nd	0.26	7478
Inca	Decorated sheet	0.02	—	3.3	18.1	0.03	nd	78.3	nd	0.23	7499
Inca	Diadem sling shaped	nd	—	3.4	27.7	0.02	nd	68.7	nd	0.40	7037
Inca	Disk	nd	—	1.7	16.7	0.05	nd	81.3	nd	0.21	7343
Inca	Disk pendant	0.01	—	5.5	15.2	0.04	nd	79.1	nd	0.19	7454
Inca	Ear-ring	tr	—	3.0	32.0	nd	nd	64.9	nd	0.49	7491
Inca	Necklace	nd	—	4.7	39.4	0.05	nd	55.6	nd	0.71	7443A
Inca	Necklace	nd	—	1.7	32.0	0.02	0.02	66.1	nd	0.48	7443B
Inca	Ornitomorphic pendant	0.01	—	3.0	28.1	0.18	nd	68.7	nd	0.41	18005
Inca	Pin	0.01	—	1.3	21.9	0.01	nd	76.7	nd	0.29	7442
Inca	Pin	0.01	—	2.4	21.3	nd	nd	76.2	nd	0.28	7444
Inca	Pin	0.01	—	3.8	29.7	nd	nd	66.3	nd	0.45	7445
Inca	Pin	0.02	—	8.9	8.4	0.19	0.02	82.2	nd	0.10	7446A
Inca	Pin	0.01	—	5.4	25.2	0.03	nd	69.2	nd	0.36	7457
Inca	Ring	0.04	—	5.9	26.4	0.01	nd	67.5	nd	0.39	7394(M)
Inca	Ring	0.02	—	6.4	31.8	nd	nd	61.4	nd	0.52	7414
Inca	Ring	0.01	—	7.0	25.0	nd	nd	67.9	nd	0.37	7447
Inca	Sheet	0.03	—	4.1	23.1	nd	nd	72.7	nd	0.32	7448(M)
Inca	Sheet	0.02	—	3.8	16.6	0.02	nd	79.3	nd	0.21	7449(M)
Inca	Sheet	0.01	—	3.0	23.5	nd	nd	73.4	nd	0.32	7480
Inca	Sheet	0.01	—	3.1	15.0	nd	nd	81.9	nd	0.18	7481
Inca	Sheet (frag.)	0.01	—	6.1	36.8	nd	nd	57.0	nd	0.64	7492
Inca	Sheet (frag.)	0.02	—	2.5	32.5	0.03	nd	64.8	nd	0.50	S/N-001
Inca	Sheet (frag.)	0.01	—	2.7	32.7	0.02	nd	64.4	nd	0.51	S/N-002
Inca	Sheet (frag.)	0.01	—	2.8	32.0	0.03	nd	65.0	nd	0.49	S/N-003
Inca	Sheet (frag.)	0.01	—	1.9	41.2	0.04	nd	56.7	nd	0.73	S/N-004
Inca	Sheet (frag.)	0.01	—	4.8	29.4	nd	nd	65.6	nd	0.45	S/N-005
Inca	Sheet (frag.)	0.01	—	2.1	38.2	0.08	nd	59.4	nd	0.64	S/N-006
Inca	Sheet (frag.)	0.01	nd	2.1	38.5	0.07	nd	59.2	nd	0.65	S/N-007
Inca	Sheet (frag.)	0.02	—	2.8	39.5	0.08	nd	57.4	nd	0.69	S/N-008
Inca	Sheet (frag.)	0.02	—	2.8	37.4	0.03	0.02	59.6	nd	0.63	S/N-009
Inca	Sheet (frag.)	0.02	—	3.5	24.1	0.04	0.01	72.2	nd	0.33	S/N-010
Inca	Sheet (frag.)	0.02	—	4.1	23.7	tr	nd	72.0	nd	0.33	S/N-011
Inca	Sheet (frag.)	0.01	—	2.6	41.0	0.09	nd	56.2	nd	0.73	S/N-012
Inca	Sheet (frag.)	0.03	—	2.6	42.5	nd	nd	54.7	nd	0.78	S/N-013(M)
Inca	Sheet (frag.)	0.03	—	2.6	42.2	0.04	nd	54.7	nd	0.77	S/N-014(M)
Inca	Tuft	0.01	—	3.7	18.5	0.02	0.01	77.6	nd	0.24	7440
Inca	Tweezers	0.01	—	3.6	16.2	nd	nd	80.1	nd	0.20	7455
Inca	Tweezers	0.01	—	5.8	13.5	nd	nd	80.6	nd	0.17	7469
Inca	Zoomorphic figurine	0.02	—	4.5	39.3	nd	nd	56.1	nd	0.70	7399

Culture	Type of object	Fe	Ni	Cu	Ag	Sn	Sb	Au	Pb	Ag/Au	Number
Inca	Zoomorphic figurine	0.02	—	4.2	42.4	nd	nd	53.3	nd	0.79	7404
Late Diquis	Anthropomorphic pendant	0.01	—	17.6	2.2	nd	nd	80.1	nd	0.03	512 bis
Late Diquis	Anthropomorphic pendant	0.02	—	1.4	2.4	nd	0.01	95.7	nd	0.02	671
Late Diquis	Anthropomorphic pendant	0.01	—	15.5	4.3	nd	0.01	80.1	nd	0.04	672
Late Diquis	Anthropomorphic pendant	0.01	—	20.6	2.5	nd	0.02	76.7	nd	0.03	673
Late Diquis	Anthropomorphic pendant	0.01	—	19.0	3.5	nd	nd	77.3	nd	0.04	674
Late Diquis	Anthropomorphic pendant	0.03	—	2.7	2.1	nd	0.02	94.7	nd	0.02	675
Late Diquis	Anthropomorphic pendant	0.02	—	2.7	3.2	nd	0.02	93.8	nd	0.03	682
Late Diquis	Anthropomorphic pendant	0.03	—	4.0	2.9	nd	0.03	92.7	nd	0.03	688
Late Diquis	Anthropomorphic pendant	0.06	—	3.2	5.0	nd	nd	91.4	nd	0.05	693
Late Diquis	Anthropomorphic pendant	0.01	—	19.0	2.4	0.01	0.01	78.5	nd	0.03	694
Late Diquis	Anthropomorphic pendant	0.02	—	0.7	2.4	nd	0.01	96.8	nd	0.02	701
Late Diquis	Bell	0.01	—	2.6	1.9	nd	nd	95.4	nd	0.02	683
Late Diquis	Chain of three links	0.01	—	48.3	5.9	nd	0.01	45.7	nd	0.13	3172
Late Diquis	Disk pendant	0.01	—	1.9	2.3	nd	0.01	95.6	nd	0.02	3162
Late Diquis	Disk pendant	0.02	—	3.1	2.8	nd	0.02	93.8	nd	0.03	3163
Late Diquis	Disk pendant	0.03	—	0.2	2.9	nd	0.02	96.8	nd	0.03	3164
Late Diquis	Disk pendant	0.01	—	3.6	2.3	nd	nd	93.8	nd	0.02	3165
Late Diquis	Disk pendant	0.02	—	0.7	2.3	nd	0.02	96.8	nd	0.02	3166
Late Diquis	Disk pendant	0.01	—	2.4	2.1	nd	0.02	95.3	nd	0.02	3167
Late Diquis	Disk pendant	0.02	—	6.5	3.7	nd	0.02	89.5	nd	0.04	3168
Late Diquis	Disk pendant	0.01	—	2.7	3.5	nd	0.01	93.6	nd	0.04	3169
Late Diquis	Disk pendant	0.02	—	0.1	1.9	nd	0.02	97.8	nd	0.02	3170
Late Diquis	Disk pendant	0.02	—	2.7	2.3	nd	0.02	91.9	nd	0.02	7490
Late Diquis	Ornitomorphic pendant	0.01	—	22.9	4.6	nd	0.01	72.3	nd	0.06	684
Late Diquis	Ornitomorphic pendant	0.03	—	3.3	4.8	nd	0.01	91.7	nd	0.05	685(M)
Late Diquis	Ornitomorphic pendant	0.01	—	11.9	3.9	nd	0.01	84.0	nd	0.04	676
Late Diquis	Ornitomorphic pendant	0.01	—	47.2	2.8	nd	0.01	49.8	nd	0.05	678
Late Diquis	Ornitomorphic pendant	0.01	—	50.8	2.9	nd	0.01	46.1	nd	0.06	679
Late Diquis	Ornitomorphic pendant	0.01	—	0.1	2.2	nd	0.03	97.5	nd	0.02	680
Late Diquis	Ornitomorphic pendant	0.01	—	11.0	3.7	nd	0.01	85.2	nd	0.04	689
Late Diquis	Ornitomorphic pendant	0.03	—	11.3	2.4	nd	0.01	86.3	nd	0.03	690
Late Diquis	Ornitomorphic pendant	0.01	—	20.1	2.6	nd	0.02	77.2	nd	0.03	692
Late Diquis	Ornitomorphic pendant	0.01	—	8.5	4.0	nd	0.01	87.3	nd	0.04	695
Late Diquis	Ornitomorphic pendant	0.02	—	4.9	2.1	nd	0.03	92.6	nd	0.02	696

Culture	Type of object	Fe	Ni	Cu	Ag	Sn	Sb	Au	Pb	Ag/Au	Number
Late Diquis	Ornitomorphic pendant	0.02	—	7.8	3.6	nd	nd	88.2	nd	0.04	697
Late Diquis	Sheet pendant	0.02	—	7.3	3.8	nd	0.02	88.7	nd	0.04	3171
Late Diquis	Zoomorphic pendant	0.03	—	3.5	3.8	0.02	0.02	92.5	nd	0.04	677
Late Diquis	Zoomorphic pendant	0.03	—	32.1	4.3	nd	0.01	63.3	nd	0.07	681
Late Diquis	Zoomorphic pendant	0.02	—	15.6	2.3	nd	nd	82.0	nd	0.03	686
Late Diquis	Zoomorphic pendant	0.01	—	16.0	2.5	nd	nd	81.3	nd	0.03	687
Late Diquis	Zoomorphic pendant	nd	—	0.1	2.0	nd	nd	97.5	nd	0.02	691
Late Diquis	Zoomorphic pendant	0.02	—	26.3	2.9	nd	0.01	70.6	nd	0.04	698
Mochica	Mask	0.01	—	3.1	16.6	nd	nd	80.1	nd	0.21	7467
Mochica	Mask	0.01	—	4.0	16.9	nd	0.01	78.9	nd	0.21	7468
Mochica	Nose ornament	tr	—	1.5	18.1	0.03	nd	80.2	nd	0.23	7472A
Mochica	Nose ornament	0.01	—	3.2	21.1	0.02	nd	75.5	nd	0.28	7472B
Muisca	Anthropomorphic figurine	0.01	0.16	87.6	2.6	nd	0.01	9.5	nd	0.27	7077(M)
Muisca	Anthropomorphic figurine	0.05	0.26	58.8	5.8	0.07	0.01	34.9	nd	0.17	7334
Muisca	Anthropomorphic figurine	0.01	0.14	85.4	3.1	3.25	0.03	7.9	nd	0.40	7336
Muisca	Anthropomorphic figurine	0.01	0.09	76.6	3.8	nd	0.01	19.3	nd	0.20	7340
Muisca	Anthropomorphic figurine	0.01	0.10	84.7	3.2	nd	nd	11.8	nd	0.28	7341(M)
Muisca	Anthropomorphic figurine	0.02	0.13	61.0	13.5	1.08	0.07	22.4	1.66	0.60	7345
Muisca	Anthropomorphic figurine	0.01	0.20	89.5	2.0	0.09	nd	8.1	nd	0.25	7346
Muisca	Anthropomorphic figurine	0.01	0.10	86.4	3.1	2.99	0.03	7.3	nd	0.43	7348A
Muisca	Anthropomorphic figurine	0.01	0.07	85.5	3.2	3.07	0.03	8.0	nd	0.41	7349(M)
Muisca	Anthropomorphic figurine	0.03	0.28	58.2	14.8	1.19	0.07	23.2	1.14	0.64	7351
Nariño-Carchi	Disk pendant	0.01	—	1.6	7.3	nd	0.01	91.1	nd	0.08	3144
Nazca	Decorated sheet	0.01	—	1.6	8.8	nd	0.01	89.4	nd	0.10	7479
Nazca	Nose ornament	0.03	—	5.7	11.9	0.04	0.01	82.1	nd	0.14	7500
Nazca	Sheet pendant	0.01	—	5.2	7.4	nd	0.01	87.2	nd	0.08	7451
Nazca	Sheet pendant	tr	—	4.2	6.6	nd	0.02	89.1	nd	0.07	7452
Quimbaya	Disk pendant	0.01	—	41.0	8.2	nd	0.01	50.7	nd	0.16	7160(M)
Quimbaya	Helmet	0.10	—	42.4	4.7	nd	0.01	52.6	nd	0.09	17432(M)
Quimbaya	Nose ornament	0.02	—	1.9	11.1	nd	nd	86.7	nd	0.13	17464
Quimbaya	Nose ornament	0.06	—	22.6	10.4	nd	0.10	66.7	nd	0.16	17466
Quimbaya	Nose ornament	0.03	—	3.0	6.9	0.13	0.02	89.6	nd	0.08	81/4/93
Quimbaya	Pin head	0.01	—	47.9	15.6	nd	nd	36.2	nd	0.43	7051A
Quimbaya	Pin head	0.01	—	4.2	17.6	nd	nd	78.0	nd	0.23	7051B
Quimbaya	Pin head	0.02	—	4.3	8.6	nd	0.01	86.8	nd	0.10	7051C

Culture	Type of object	Fe	Ni	Cu	Ag	Sn	Sb	Au	Pb	Ag/Au	Number
Quimbaya	Pin head	0.02	—	0.9	16.5	nd	nd	82.3	nd	0.20	7051D
Quimbaya	Stopple of a vessel	0.02	—	14.9	7.4	0.01	0.01	77.6	nd	0.09	17465
Quimbaya	Zoomorphic bead	0.02	—	44.3	8.8	nd	nd	46.8	nd	0.19	17469
Quimbaya	Zoomorphic bead	0.02	—	44.0	9.1	nd	nd	46.8	nd	0.19	17470
Quimbaya	Zoomorphic bead	0.02	—	45.7	8.9	nd	nd	45.3	nd	0.20	17471
Quimbaya	Zoomorphic bead	0.07	—	29.2	11.7	nd	nd	58.9	nd	0.20	17472
Quimbaya	Zoomorphic bead	0.02	—	43.8	9.2	nd	0.02	46.8	nd	0.20	17473
Quimbaya	Zoomorphic bead	0.05	—	36.6	11.3	nd	0.02	51.9	nd	0.22	17474
Quimbaya	Zoomorphic bead	0.01	—	26.6	14.1	0.04	nd	59.2	nd	0.24	17475
Quimbaya	Zoomorphic bead	0.02	—	36.0	9.7	nd	nd	54.1	nd	0.18	17476
Quimbaya	Zoomorphic bead	0.05	—	45.1	9.1	nd	nd	45.5	nd	0.20	17477
Quimbaya	Zoomorphic bead	0.03	—	42.5	9.4	nd	nd	48.0	nd	0.20	17478
Quimbaya	Zoomorphic bead	0.03	—	34.2	10.4	nd	nd	55.3	nd	0.19	17479
Quimbaya	Zoomorphic bead	0.02	—	44.9	8.6	nd	nd	46.3	nd	0.19	17480
Quimbaya	Zoomorphic bead	0.04	—	45.4	8.7	nd	nd	45.7	nd	0.19	17481
Quimbaya	Zoomorphic bead	0.02	—	33.4	11.2	nd	0.02	55.3	nd	0.20	17482
Quimbaya	Zoomorphic bead	0.01	—	40.4	9.7	nd	nd	49.8	nd	0.19	17483
Quimbaya	Zoomorphic bead	0.06	—	35.5	10.5	nd	nd	53.8	nd	0.19	17484
Quimbaya	Zoomorphic bead	0.02	—	33.9	10.9	nd	nd	55.0	nd	0.20	17485
Quimbaya	Zoomorphic bead	0.04	—	41.5	10.1	nd	0.03	48.2	nd	0.21	17486
Quimbaya	Zoomorphic bead	0.03	—	43.1	9.6	nd	nd	47.1	nd	0.20	17487
Quimbaya	Zoomorphic bead	0.02	—	34.8	11.8	nd	0.02	53.2	nd	0.22	17488
Quimbaya	Zoomorphic bead	0.03	—	37.5	10.2	nd	nd	52.1	nd	0.20	17489
Quimbaya	Zoomorphic bead	0.02	—	35.7	8.0	nd	0.02	39.1	17.1	0.20	17467
Quimbaya	Zoomorphic bead	0.07	—	28.5	12.5	nd	0.02	58.8	nd	0.21	17468
Sinu	Anthropomorphic pendant	0.02	—	3.2	7.7	nd	nd	88.9	nd	0.09	3145
Sinu	Nose ornament	0.04	—	52.2	4.9	0.05	nd	42.7	nd	0.11	82/2/15
Tairona	Anthropomorphic pendant	0.03	—	62.5	7.2	nd	0.01	30.1	nd	0.24	82/3/1
Tairona	Ear ring	0.01	—	18.2	8.5	nd	nd	72.7	nd	0.11	82/2/9
Tairona	Ear ring	0.02	—	45.2	6.3	nd	0.04	48.3	nd	0.13	82/2/10
Tairona	Ear ring	0.01	—	13.2	9.8	nd	nd	76.9	nd	0.13	82/2/12
Tairona	Ear ring	0.02	—	13.8	9.9	nd	nd	76.2	nd	0.13	82/2/13
Tairona	Nose ring	0.01	—	16.2	12.4	nd	nd	71.2	nd	0.17	3158
Tairona	Ornitomorphic pendant	—	—	0.0	30.9	—	—	68.5	—	0.45	82/3/2B
Tairona	Zoomorphic pendant	0.01	—	58.9	12.4	nd	nd	28.5	nd	0.43	82/2/17
Tairona	Zoomorphic pendant	0.02	—	52.7	12.4	nd	nd	34.7	nd	0.36	82/2/18
Tairona	Zoomorphic pendant	0.03	—	53.7	13.7	nd	nd	32.5	nd	0.43	82/2/19
Tairona	Zoomorphic pendant	0.07	—	49.1	16.1	nd	nd	34.6	nd	0.46	82/2/20
Tairona	Zoomorphic pendant	0.01	—	54.8	13.4	nd	0.01	31.6	nd	0.43	82/2/26

[1]— = not searched

[2]nd = not detected

[3]tr = traces, usually below 0.01%

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Biography

Salvador Rovira is head curator of the Conservation Department (including the research laboratory) of the Museo de América, Madrid. He specializes in archaeometallurgy and the preservation of metals. Since 1982 he has participated in a national research project investigating the origins and evolution of metallurgy in the Iberian Peninsula.

Archaeological Sites and Dating

A Methodology for the Study of Buried Archaeological Sites

Luis Barba

The theoretical basis of a methodology for the study of archaeological sites is that any individual archaeometrical indicator is just one facet of the original total. As can be seen in Figure 1, the original cultural material existed only in the systemic context because, after the abandonment of the site, the most vulnerable materials quickly disappeared (Chenhall 1975). Other materials remained longer, and the speed of decay depended upon the characteristics of the original material and the context in which it was buried. Chemically stable materials such as ceramics are the most common archaeological remains, but again, they represent only a very small portion of the original systemic whole.

There are two ways of addressing this problem. One would be to take a single prospecting technique to its limit, but the Archaeological Prospecting Laboratory chose a second option. This approach involves the application of many different prospecting techniques simultaneously to obtain a more comprehensive picture of the whole by interpreting a wide range of information. It is also an attempt to fill the gap between traditional archaeological excavation, which deals with areas in the order of 10^1–10^2 m^2, and the archaeological survey, which usually studies areas around 10^5–10^6 m^2.

There are several theoretical and methodological problems to solve. The laboratory has chosen an empirical approach to try to solve these problems. Because each of the geophysical, chemical, photographic, and archaeological techniques deals with just a small part of the archaeological information, all of them complement one another (Fig. 2). Therefore, if one applies all the available techniques and interprets them in a synoptic way, a clearer understanding of an archaeological site can be obtained from the surface.

Logic demands that these techniques be applied in an ordered and efficient way. Initially, the simpler techniques are applied over a wide area of the site, and the more time-consuming ones are restricted to small areas and performed later (Barba 1984). Attempts to confirm results take place at every step. A wide variety of aerial images are assembled up front, followed by common-use geophysical techniques to

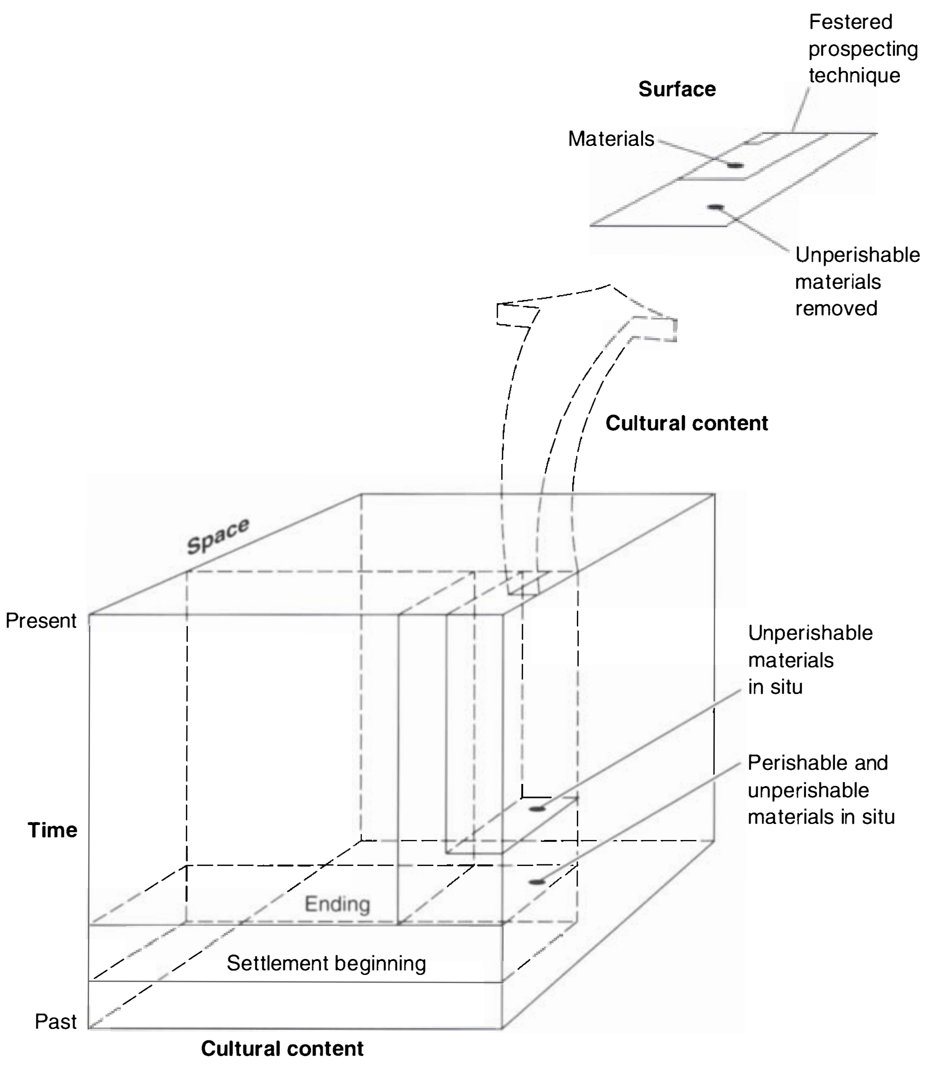
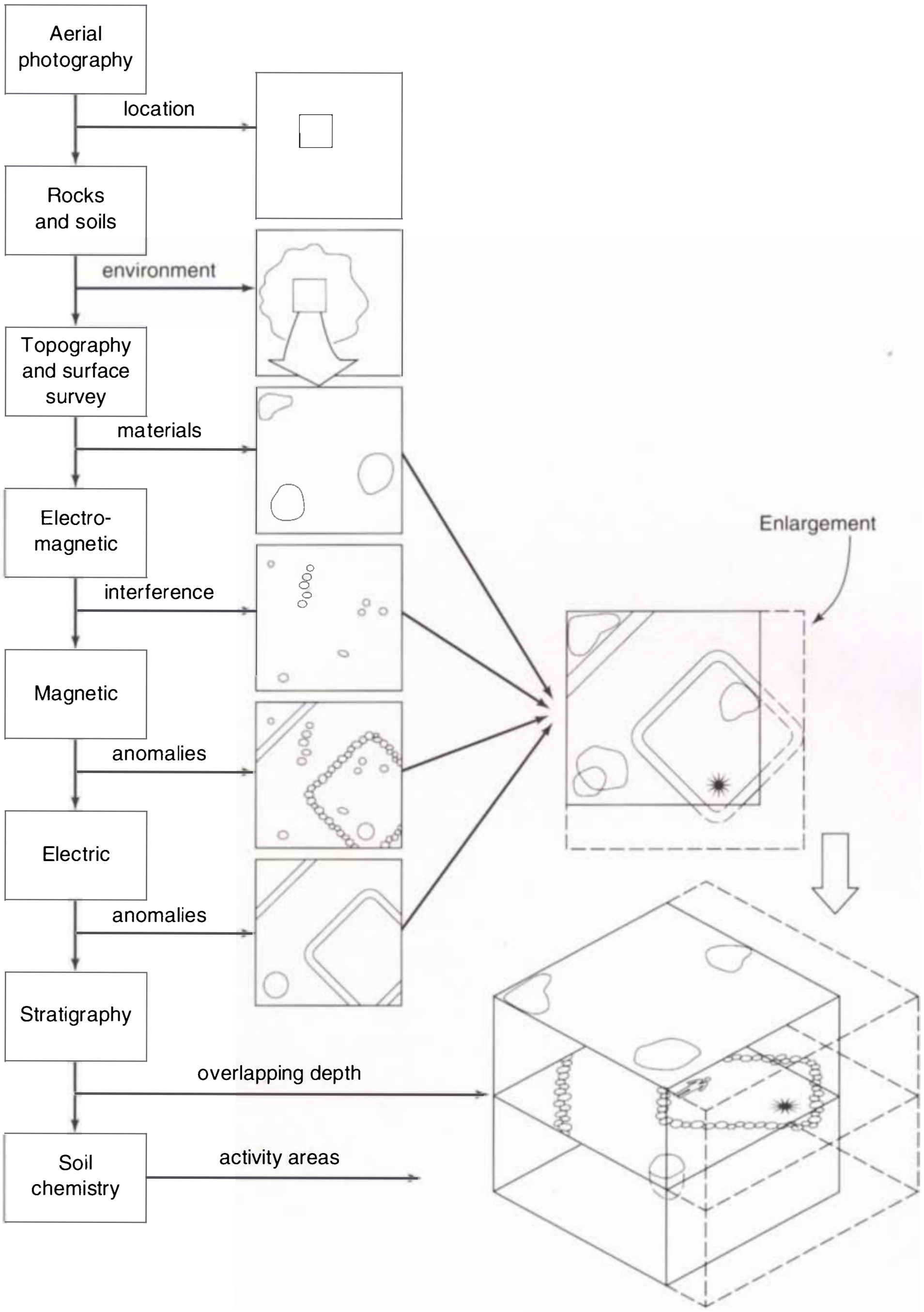


FIGURE 1. *Limited information provided by the application of one isolated technique (modified after Chenhall 1975).*

locate buried structures. In order to obtain reliable information about the depth of archaeological remains, it is necessary to take cores and analyze soil samples to confirm previous indicators. Further sampling in specific areas and at specific depths provides information about areas of activity. It is then possible to go a step further in interpretation and take into consideration archaeological material scattered on the surface in conjunction with the results of the above-mentioned prospecting techniques to identify some of the activities performed by the ancient users of the sites.

This methodology emphasizes the intrinsic information of the soil more than that of the actual archaeological material. Most of the information recovered comes from the soil samples and from the comparison of soil properties with the remaining archaeological materials. The soil matrix is therefore recognized as an important source of information that has scarcely been used before. This approach supports the tendency to consider the information provided by prospecting techniques as valid in itself and not in need of being validated by excavation. The methodology permits confirmation at every step, and at the end of the process enough evidence will have been accumulated to support a solid interpretation independent of excavation. Archaeological excavation will provide more detailed information and may confirm or reject the interpretation and even support extrapolations, but it is not necessarily required to validate data.

Figure 2. *Flow diagram indicating the procedure for the application of prospecting techniques (Barba 1984).*



Description of the Methodology

In Figure 2, the first box indicates the information provided by satellite imagery and aerial and balloon photography. Latest developments in image digital processing and improvements in the resolution of satellite photography are making this information more useful to archaeology. Balloon photography provides detailed information through low-altitude photographs. The results, interpreted in conjunction with available cartography and environmental data, provide the basis for further research.

In addition, it is necessary to determine where to perform later studies. It has been proven that a detailed topography of the area allows the detection of slight differences, which suggests a first hypothesis about buried structures. Archaeological remains scattered on the surface are then registered and collected. At this stage it is important to obtain all the available information concerning the distribution of the archaeological material. Using standard collecting techniques over 100% of the surface area, distribution maps may be produced of every selected material. Most of the fragments of building materials correspond to topographic elevations, whereas the distribution of pot sherds and other artifacts may surround them. From this point on, geophysical techniques will be focused on the more promising areas to confirm the presence of buried structures.

A magnetic survey is the next technique used to study extensive areas. In some cases, a metal detector is used to check for interferences produced by modern metallic waste. The resulting maps should be interpreted in conjunction with the previous information to confirm the presence of structures. Not all areas will produce magnetic anomalies, but most will show close correlation with building materials and high topographic values. Additional confirmation can be obtained using measurements of electrical resistance. Again, the majority of buried structures will show an increase in electrical-resistance readings, but some will not. Small differences between electrical and magnetic properties distinguish different types of structures. A formal structure made of stone with a stucco finish will provide very different readings compared to a structure made of adobe with an earthen floor. Interpretation of their characteristics can be done using this approach.

Further steps are designed to obtain a third dimension. All the previous techniques mainly provide information about the distribution of data on the surface. Even geophysical techniques that penetrate the surface can give only a general idea of the depth of the origin of the anomalies. For this reason it is necessary to employ coring techniques that would allow the reconstruction of the archaeological stratigraphy. Due to expected difficulties in the identification of differences in soil strata, it is important to perform chemical field tests.

Previous experience in chemical prospecting in archaeology suggests that the use of chemistry to locate archaeological sites and structures is inefficient. Consequently, this technique has been included as the last step in the sequence to obtain information about soil stratigraphy and the chemical content of soil samples. Extensive application of chemical analysis of soil samples shows a dramatic increase of certain compounds around structures. Using relatively simple chemical tests, it is possible to obtain important information concerning the use of the structures and identify certain areas of activity, especially those related to fire.

One of the main goals in designing this methodology was to obtain results during fieldwork to define the excavation strategy and perform the excavation immediately after prospecting studies had been finished. The only way to achieve this was to take laboratory facilities to the field. A mobile laboratory was designed and built. The truck provided easy transportation of equipment, the space and facilities to perform chemical analysis of soil samples, and the necessary computing power to process numerical data in the field (Litvak et al. 1990). These facilities have allowed the application of the proposed methodology at various archaeological sites over the last ten years.

There has been a gradual move toward the integration of prospecting techniques. In the fifties, the Lerici Foundation was a pioneer in the multiple application of techniques (Lerici n.d.). During the seventies, two or more techniques were applied simultaneously. Chemical and geophysical techniques were later used together, but very few projects of this type were published; it was not until the eighties that these techniques became more common. Nevertheless, the simultaneous application of different techniques still is not considered an established methodology, but it is moving in that direction.

Multiple application is not the most economic approach, but it is reliable. Usually, two or more of the indicators overlap, and this helps to confirm individual interpretations. Compared with the cost of many archaeological projects, however, this is a very good option.

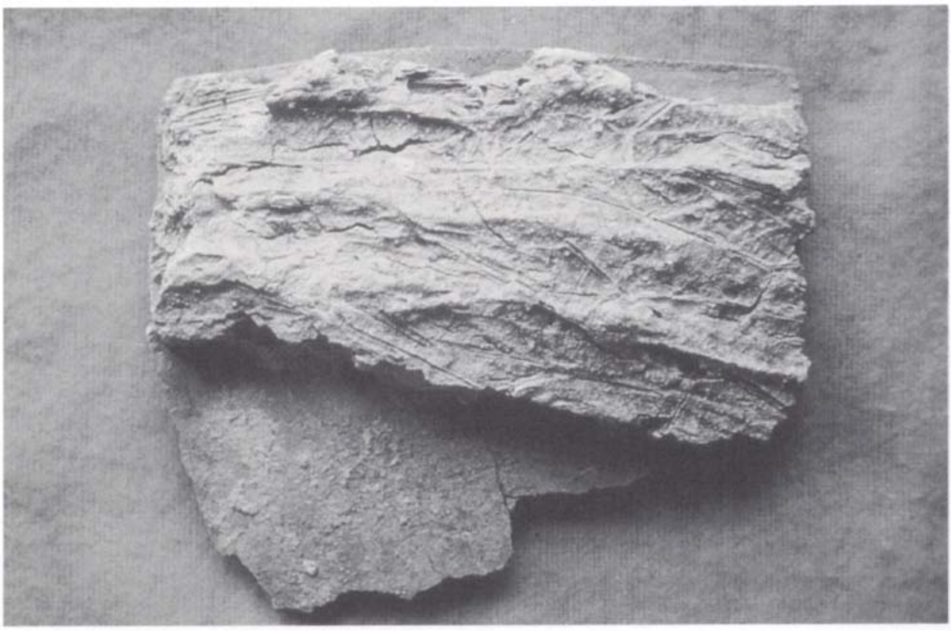
Two Case Studies

In order to illustrate the interpretative possibilities of the methodology in solving an archaeological problem, the cases of San Jose Ixtapa and Oztoyahualco, Teotihuacan, in Mexico are discussed in the following sections.

San Jose Ixtapa

The archaeological site of San Jose Ixtapa was located by Limon and Barba (1981) through the photointerpretation of black-and-white vertical pictures (1:25,000). This site was identified as whitish spots on a dark terrain. From an archaeological point of view, the site selected did not show any surface structures. When one walked on the surface, the only archaeological feature seen was the concentration of archaeological material on the cornfield. Most of these materials are pot sherds and stones. There are 200 sites like this in the valley, and most of them are close to the Lerma River. The downslope movement of sediments has covered most of these sites. Selection of the site by Limon was done on the basis of three important characteristics. First, the surface survey showed it was the only site containing archaeological evidence related to Tula and Teotenango, two important Post-Classic sites. This relationship indicated that this small village had some kind of exchange with two of the most important contemporary cities. The second characteristic was the presence of conspicuous quantities of pot sherds, in various states of firing, covered with an exterior layer of mud mixed with vegetable fiber (Fig. 3). The production of large amounts of this pottery, the intentional mixture of mud and grass over the exterior of the pot, the firing of the outside mud layer, and finally the deliberate destruction of these pots imply a conspicuous activity that may be considered part of the technoeconomic sphere. The third feature considered for selection of the site was the lack of structures on the surface. The sediment seemed to be quite homogeneous, which was advantageous in the application of the chosen prospecting techniques and in the interpretation of the results.

FIGURE 3. *Mud-coated pottery sherd from San Jose Ixtapa.*



The site of San Jose Ixtapa is at the edge of the Lerma River and close to the Tepuxtepec Dam. Because the last occupation of this site has been dated as Post-Classic (1100–1200 C.E.), the site has been abandoned for 700 years. This is a relatively short period of time for significant weathering, and one would not expect to find important displacements or thickness of sediments. Also, the time is too short for chemical action to have caused serious deterioration of archaeological materials.

The first task was a general survey of the terrain. This was done by walking over the entire area, 8000 m^2, following the furrows plowed in the field.

The principal surface items recorded included the following:

- faced stone, probably architectural
- large rocks and stones, probably to serve architectural functions (size is greater than 50 cm)
- mud-coated pottery
- fired adobe
- other pot sherds
- metates or flat stones
- obsidian

The next step was to perform a topographical survey of the site to produce a general topographic map (Fig. 4). As has been described previously, the sequence also includes three geophysical techniques and at least two steps of soil sampling.

Analyses were performed at the mobile laboratory (Fig. 5). Carbonate testing was based upon a reference table that takes into consideration the effervescence of carbonates when reacted with hydrochloric acid (Dent and Young 1981; Barba and Córdoba 1988). Phosphate analysis was done using the method developed by Eidt (1973) and Eidt and Woods (1974), with modification by Eidt (1977). This method consists of chemical reaction with molybdates to produce a blue coloration on filter paper. Determination of pH was done by using a combined reference-glass elec-

Figure 4. *Topographic map of the site at San Jose Ixtapa.*

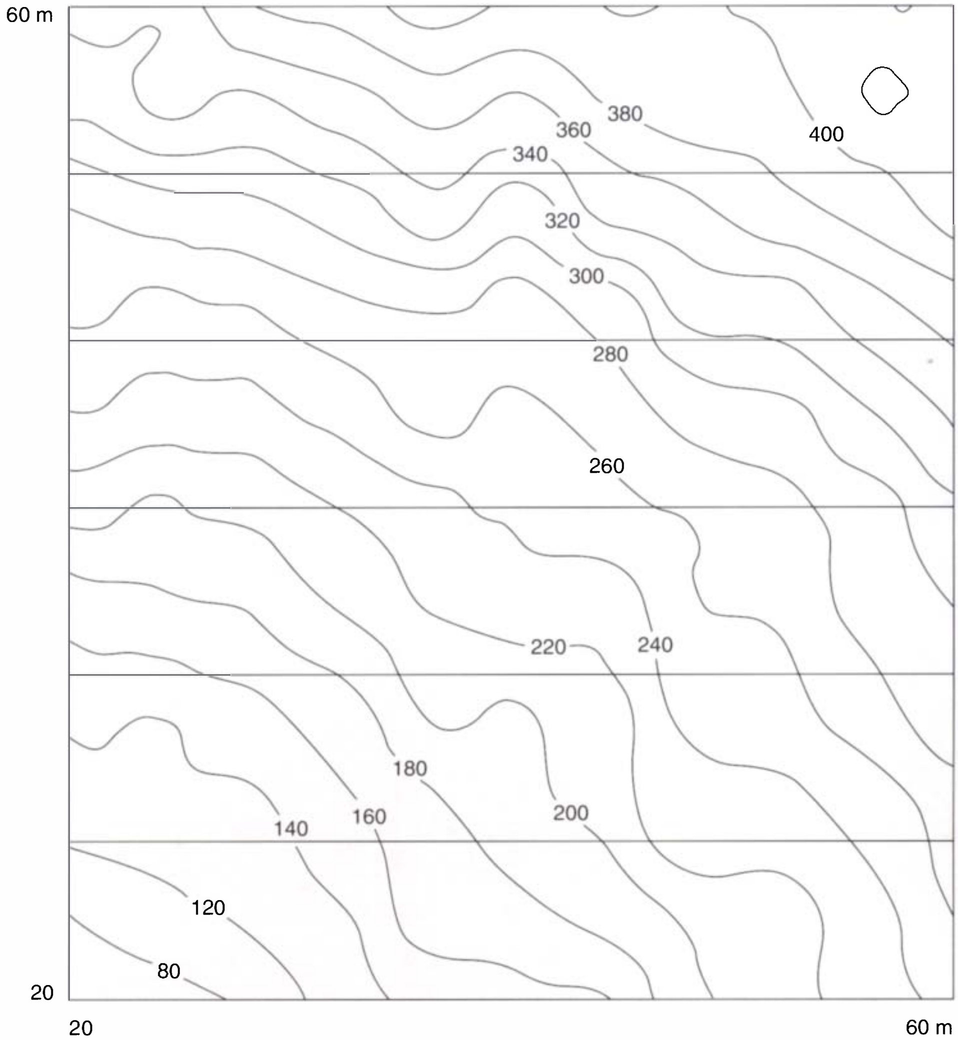


Figure 5. *Soil analysis being performed inside the mobile laboratory.*

trode with a Beckman pH meter (Barba and Córdoba 1993). Color was determined using a Munsell Soil Color Chart. The numerical conversion was proposed by Hurst (1977) and modified by Barba (1989).

Microscopic examination of soil samples was performed with a binocular stereoscopic microscope at 10x magnification. In this case, soil samples were selected on the basis of pH. This is because high pH has been related to fire. There was a conspicuous area in the center of one of the grids where high values of pH (>8.5) were concentrated. The preliminary general examination of a variety of samples revealed crystals with a red-orange color, a rod form, faces, and adamantine luster. Description of other microscopic material included characteristics of ceramic and charcoal particles. White particles were described as light cream–colored, rounded, and porous fragments. Red-gray nodules were described as rounded fragments with red and gray veins and adamantine luster.

These items may be considered to be cultural indicators. Ceramic particles are produced by continuous fragmentation of pots and pot sherds. The white particles came from deterioration of plasters and mortars used as building materials. Charcoal is the remnant of the combustion of wood; also, ashes and rounded particles interpreted as scoria may be produced by transformation activities related to fire. These materials confirmed the hypothesis that this was a productive area related to cinnabar and mercury (Barba and Herrera 1988).

The mobile laboratory played an important role in the processing of samples and their analyses. During fieldwork it was possible to process 600 soil samples. With this information, plus the distribution of materials and the electrical and magnetic anomalies, it was possible to have almost up-to-the-minute results at every step of the sequence.

The computer and the mapping program played another important role. Thanks to magnetic maps, it was possible to search for specific anomalies and confirm their presence (Barba et al. 1987). Distribution maps of materials on the surface permitted a preliminary association between the structures and human activities. As a result, the outstanding inferred activity was the production of mercury. Through an ethnoarchaeological approach that involved reconstruction of the pots, the mud-coated fragments were recognized as a by-product of the mercury production process (Fig. 6). Firing areas and some of the structures were located and some related activities were interpreted.

Oztoyahualco, Teotihuacan

The application performed at Oztoyahualco, Teotihuacan, in collaboration with Linda Manzanilla involved two main steps. The first dealt with prospecting techniques applied before excavation to locate the most promising areas to perform it. The second step used the results to extrapolate information to the rest of the studied area, making the interpretation more accurate and the study very cost effective.

The Oztoyahualco area is located about 2 km northwest of the Pyramid of the Moon, and the study area was chosen between two plazas, each with three temples. The study area was about 5000 m^2 and was divided into five modules (Fig. 7). The techniques applied in the modules were aerial photography, topographical mapping, magnetic survey, electrical resistance, soil sampling with chemical analyses, and the registration of archaeological materials, such as pottery sherds, obsidian, and building materials, on a grid composed of 2 × 2 m squares (Barba and Manzanilla 1988).

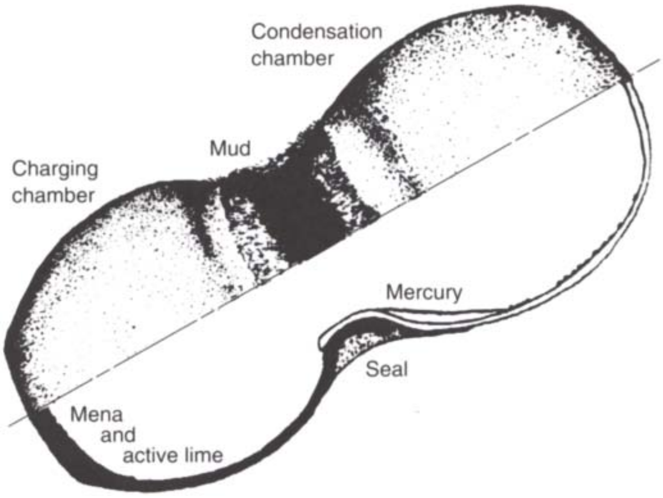


Figure 6. *Hypothetical reconstruction of two pots joined with mud for mercury production (Barba and Herrera 1988).*

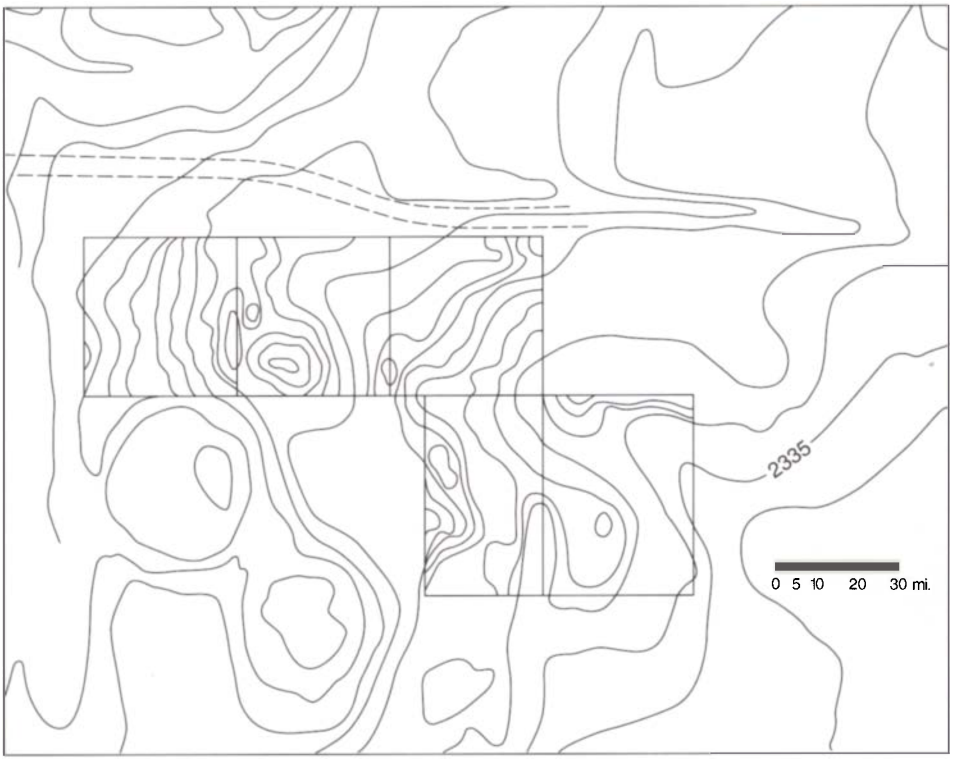


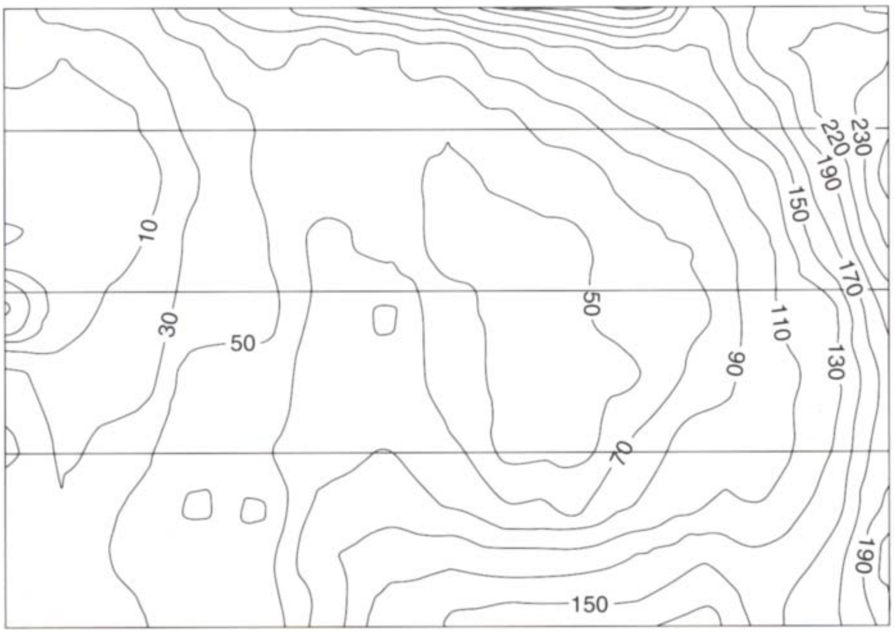
Figure 7. *Topographic map from Oztoyahualco showing the study area divided into five modules (modified after Millon 1973). The bottom row shows modules D and E.*

This methodology considered the interpretation of buried structures as the first step. Therefore, the following techniques were interpreted together: the white spots indicated in aerial photography (Fig. 8), the topography (a detail of which is shown in Fig. 9), the magnetic and electrical anomalies, and the distribution of building materials. Later, indicators such as the distribution of soil characteristics and archaeological material were included with the objective of inferring certain activities and uses of the located structures.

Vertical aerial photography was undertaken by using a tethered balloon that revealed white spots on the surface. The relationship between the photography and subsequent studies was obtained using reference signals at the corner of each module.

Figure 8. *Aerial photograph showing the white spots at Oztoyahualco (height 50 m).*

FIGURE 9. *Detailed topographic map of modules D and E at Oztoyahualco.*



With the information provided by the excavated residential unit, it was also possible to draw conclusions about some of the archaeological material found on the surface. For example, it was clear that a special kind of flag stone called *ixtapaltepetl* was used to support a panel, or *tablero*, that projected out from the wall. Therefore, the presence of this flag stone implies construction using this specific architectural feature. When the distribution of this stone on the surface was taken into account, it was concluded that the two residential units and the *banqueta* used these architectural elements (Fig. 10).

Concerning building materials, excavation confirmed the information that walls were built using tuff and pyroclastic blocks, and their inner and outer surfaces were finished with thick stuccos. This explained the origin of most of the calcium carbon-

FIGURE 10. *Map showing distribution of flag stones (*ixtapaltepetl*) on surface.*

ate found on the surface (Fig. 11): Collapsed walls yielded small particles of stucco, which were then dispersed by plow into the soil matrix, resulting in the white spots indicated in aerial photographs as well as high values in the soil color (Fig. 12) and carbonates.

The close relationship between topography, the distribution of building materials, and white spots suggests that displacement is in fact negligible. This supports the reliability of the information provided by the distribution of archaeological material on the surface. After the application of this methodology, it was possible to

Figure 11. *Map showing distribution of calcium carbonate (maximum values).*

Figure 12. *Map showing location of white spots registered from aerial photography.*

interpret the whole area using the data provided by the techniques applied on the surface and the results from the reduced excavated area (Fig. 13).

There were two clearly differentiated residential units (HU1 and HU2) with common architectural features such as building stones, stucco, and tableros, but there were two other, smaller residential structures (S1 and S3) characterized by the same features. Because of the obsidian and pot sherds found here, one can conclude that they were also of domestic character.

The only nondomestic, isolated feature is the banqueta (S2), constructed of the same materials and having the same architectural features as the other structures. The banqueta is depicted at the right in Figure 14.

The rest of the structures (S4, S6, S7, and S8) form a very interesting group. All of them have small carbonate impregnated pyroclasts (*tezontle*). S4, S7, and S8 present high electrical-resistance values and magnetic dipoles. High pH values from ashes are to the north and south of S7, so it is possible to have a fire-related activity, especially in this structure. S6 has pottery sherds and has been interpreted to be related to domestic activities. Furthermore, it seems to be the only one of these structures built with stones but without stucco or tableros. Finally, the last structure, S8, is the only one without building materials; it has only geophysical anomalies related with pyroclasts and carbonates, which suggests a productive area.

S4, S6, S7, and S8 most probably represent areas devoted to a specific task. Due to the overlapping of concentrations of impregnated pyroclasts, carbonates, electrical and magnetic anomalies, and high pH values, these structures are interpreted as being areas of lime production where the firing and turning off of the limestones were done. The soil matrix is becoming an important source of information and must be used.

FIGURE 13. *Interpretation of the entire area based on excavation and surface information.*

Figure 14. *Oblique aerial photography after excavation. The white area at right, indicated by an arrow, is the* banqueta. *The excavated area is shown at left.*

It is clear that the application of this methodology facilitates the location of buried structures and the interpretation of their architectonic characteristics and use. In addition, productive areas can be reconstructed using ethnoarchaeological data. By using the proposed methodology, it is possible to reach a more comprehensive interpretation of the cultural complexity of an archaeological site.

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Biography

Luis Barba is head of the Archaeological Prospecting Laboratory at Instituto de Investigaciones Antropológicas, Universidad Nacional Autonoma de México. His fields of research are remote sensing geophysical techniques and chemical analysis for the study of human activity. He holds a B.S. in chemical engineering, an M.S. in archaeological geology, and a Ph.D. in anthropology. He has authored two books and forty-five articles.

Exceptional Molecular Preservation in the Fossil Record: The Archaeological, Conservation, and Scientific Challenge

Noreen Tuross and
Marilyn L. Fogel

A special challenge to archaeologists and conservators is found at well-preserved sites where organic materials dominate the excavated assemblage. Although wet sites are known as likely origins of materials that require special handling (Purdy 1988), friable organic materials may be found in a variety of environments. Two excavations in the recent past, Windover in Florida and Monte Verde in southern Chile, have produced new types of information from archaeological materials, and in the recent parlance of the paleontological field, Windover and Monte Verde are sites of "exceptional fossils" (Briggs 1991). In these excavations the usual materials by which one defines a culture are missing or represented by a very small sample, and both Windover and Monte Verde consist of friable organic matter from animals, plants, and sediments.

The purpose of this chapter is to discuss the impact that certain archaeological and conservation practices had on postexcavation isotopic and biochemical analysis, in particular stable isotope measurements for paleodietary interpretations from calcified tissue at Windover, and ancient DNA analysis from mastodon bone at Monte Verde. Further, when illustrative comparative data on conservation treatments exist for other archaeological collections that have been analyzed in our laboratories, they have been included in this discussion.

The Windover site in east-central Florida dates to approximately 7,500 years B.P. and is a human burial ground. It was excavated in the mid-1980s by Glen Doran and co-workers of Florida State University. One hundred and sixty-eight individuals were excavated from the site, and the human and faunal remains are stored at the same university (Doran and Dickel 1988b). Many of the skeletons are complete or nearly so, and ninety human brains were found during the excavation. William Hauswirth of the University of Florida was contacted when the first brain tissue was found, and he took responsibility for the postexcavation treatment of the neural tissue. The treatment consisted of immediate retrieval of the human brains from the site and transporting the tissue in an inert atmosphere to –80 °C storage, where they remain today. The Windover excavation produced a large faunal and floral assemblage

(Doran et al. 1990) and eighty-seven specimens of preserved textiles (Figs. 1a, 1b). In contrast, the nonorganic remains consisted of a lithic assemblage of a total of five bifaces.

Monte Verde, excavated by Tom Dillehay at the University of Kentucky, is believed to be a human habitation site whose major cultural layer dates, by multiple radiocarbon analyses, to 12,000–13,000 years B.P. (Dillehay 1984, 1989; Dillehay and Collins 1988). Unlike Windover, there are no human remains at the site, but the excavated material from Monte Verde is also dominated by organic remains: remnant wooden-hut structures, bone and ivory, skin (presumably mastodon, still adhering to the wooden structures and pieces of bone), and the soil of the cultural layer that was full of small pieces of bone and skin (Fig. 2). The lithic artifacts, although larger in number than those at Windover, are not a "classic" set with defined stylistic traits but a small, diverse collection of multishaped tools from a wide variety of source material.

It is helpful to come to an understanding as to how the two sites were preserved for thousands of years. Again, there are similarities between the two deposits, but also major differences. Windover is a more classic case, where submersion burial in a peat bog meant that the human skeletons were underwater in a neutral, anoxic peat.

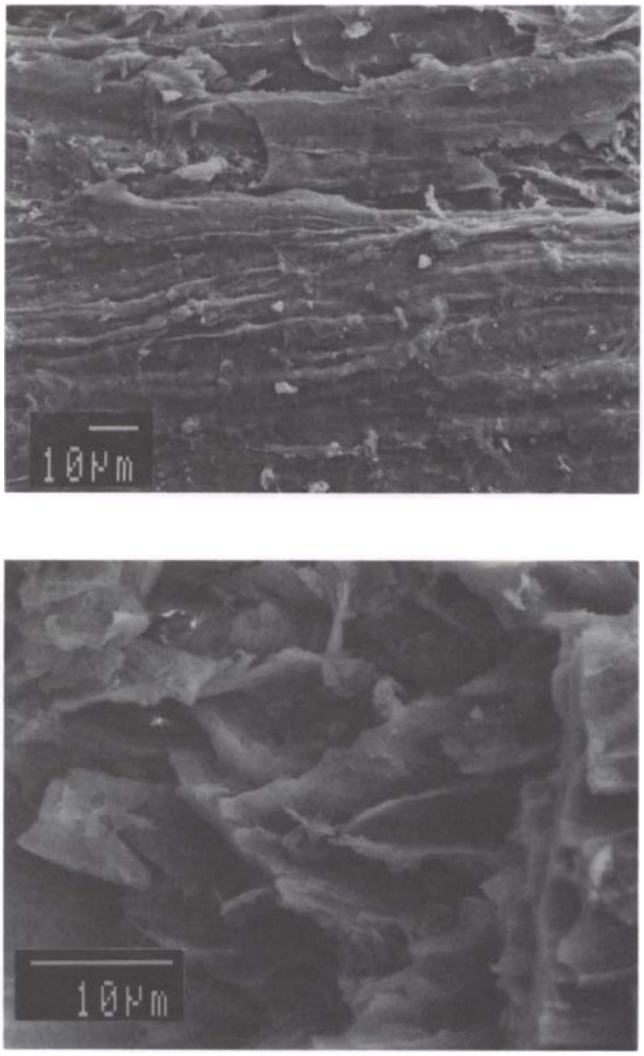


FIGURE 1a, b. *Scanning electron micrographs of the external fiber, at right (a), and cross section below (b), of remnant fabric pieces excavated at the 7,000–8,000 B.P. archaeological site, Windover. Fabric pieces were freeze-dried prior to gold-palladium coating for scanning electron microscopy (SEM) imaging.*

FIGURE 2. *Decalcified (0.5M EDTA, pH 7.2, 4 °C) mastodon bone collagen from Monte Verde. The collagen fibrils still are a pale yellow color and held in fibrillar register after approximately 13,000 years.*

There is a wide range of preservation of organic material at Windover, including the human bone, especially at the pond margins, indicating that perhaps the burial ground alternated between wet and dry periods. The center of the pond, where the human brain material was concentrated, seems more likely to have been persistently wet for the bulk of the 7,000 years.

The organic preservation at Monte Verde has been much harder to understand, largely because this type of site has not been previously observed in the Americas. The Monte Verde habitational layer was also covered by peat that at its base was not terribly acidic, approximately pH 6. The peat cover at Monte Verde, however, was not the surface layer and was a very woody, immature peat. In addition, the substratum of Monte Verde was not soil at all, but a gravellike material that underlies the habitational layer with a minimum depth of 8.2 m. One of the major constituents of this gravel is silica gel (Tuross and Dillehay n.d.), as determined by its hygroscopic characteristics, energy-dispersive analysis by X ray, and Fourier-transform infrared spectrometry. The silica gel-rich gravel underlying the site would pull water away from the habitational layer and the peat above. The organic remains at Monte Verde persisted through time because it was a deposition that went and stayed anoxic fairly quickly at a slightly acidic pH; it was under desiccation by silica gel, and in the amino acid composition of a mastodon bone fragment, the presence of methionine (an easily oxidized amino acid) indicates that a reducing environment was likely (Tuross and Dillehay n.d.). When the depositional environment is coupled with a fairly low mean annual temperature in southern Chile (about 12 °C), organic preservation at Monte Verde is more comprehensible.

One pronounced effect of these different depositional environments is the better preserved vertebrate calcified tissue at Monte Verde compared to Windover in terms of tensile strength, integrity, protein content, and humic contamination (Tuross and Dillehay n.d.). The mastodon bone from Monte Verde is easily decalcified (Fig. 2) to produce a pale yellow replica with intact collagen fibrils. In contrast, the faunal and human bone excavated at Windover was deeply impregnated with peat, as were the brains (Doran et al. 1986). Decalcification and the production of pure collagen from the Windover bone samples proved to be a difficult and time-consuming process (Tuross, Fogel, Newsom, and Doran n.d.). Windover and Monte Verde have produced some of the earliest evidence for lifeways in the Americas, and extreme care was taken to maximize the information potential in the excavated materials (Doran and Dickel 1988a). From the postexcavation analysis of these assemblages, it is clear that in addition to morphology integrity, excellent atomic and molecular preservation is also found at these sites. The impact of excavation and conservation practices utilized at sites such as Windover and Monte Verde is discussed in a comparative setting and assessed in relation to light-stable isotope analyses and ancient DNA extractions.

Stable Isotopes ($\delta^{13}C$ and $\delta^{15}N$) in Collagen: The Effect of Preservatives

Stable isotopic studies of bone collagen and apatite for paleodietary purposes have grown in number and complexity during the last decade (for introduction see DeNiro 1987; for recent review see Schwartz and Schoeninger 1991). The human and faunal bones from Windover were analyzed for stable carbon and nitrogen isotopic values in bone collagen for the purpose of assessing the trophic level at which humans ate in the Florida archaic and to determine the relative contribution of marine food sources in the diet. In the course of paleodietary investigations (Tuross and Fogel n.d.; Tuross, Fogel, and Owsley n.d.; Tuross, Fogel, Newsom, and Doran n.d.), we have observed the effect of two stabilizers, polyvinyl acetate and the acrylic Rhoplex on adult human collagen stable carbon and nitrogen values. Three populations were compared: (1) the archaic Eva, Cherry, and Ledbetter human bone (ribs) were provided preservative free (Tuross, Fogel, and Owsley n.d.), (2) the protohistoric Plains Sully site human bone (ribs) had been surface coated with polyvinyl acetate (Tuross and Fogel n.d.), and (3) the archaic Windover human and faunal bones had been treated with Rhoplex (Stone et al. 1990) with the exception of six human rib specimens that were free of any stabilizing agent (Tuross, Fogel, Newsom, and Doran n.d.). The source of the polyvinyl acetate used on the Sully site samples is unknown. The alkaline Rhoplex was obtained from Rohm and Haas.

The $\delta^{15}N$ bone collagen values were not altered by the addition of either preservative among the adults in the three archaeological samples (Table 1). The range of $\delta^{15}N$ values from 1.2 to 3.3 °/oo can be ascribed both to within population variation and to differences in the temporal span of the deposits which result in climatic and dietary alterations that are reflected in the human collagen stable isotope values. In addition, there is no elemental nitrogen in either polyvinyl acetate or Rhoplex.

The $\delta^{13}C$ bone collagen values from adult and subadult were altered by the application of Rhoplex, but not by the application of polyvinyl acetate (Tables 2, 3). The ability to remove polyvinyl acetate from bone and produce biologically faithful isotope data has been previously reported (Moore et al. 1989). Collagen $\delta^{13}C$ values ranged 2.5 °/oo in the untreated archaic bone samples and 5.2 °/oo in the Post-Contact coalescent bones. The difference in the absolute $\delta^{13}C$ values in the archaic

TABLE 1. *Effect of consolidation on stable nitrogen isotopic values ($\delta^{15}N$) °/oo per mil. The average values differ among the three samples due to base dietary differences. The standard deviations and coefficient of variations are similar in the three samples. The Florida archaic group includes both the Rhoplex-treated and untreated individuals.*

	% ± S.D.	N[1]	V[2]
Tennessee Archaic (Untreated)	8.5 ± 0.5	13	6
Florida Archaic (Rhoplex treated)	11.7 ± 0.9	21	8
Plains Post-Contact (PVA treated)	11.1 ± 0.5	8	5

[1] Number of adult individuals
[2] Coefficient of variation

TABLE 2. *Effect of consolidation on stable carbon isotopic values. Stable carbon isotopic values in two samples that span approximately 5,000 years in time. The difference in the mean $\delta^{13}C$ is due to variation in the amount of C–3 and C–4 plants in the diets of the humans.*

	% ± S.D.	N[1]	V[2]
Tennessee Archaic (Eva, Cherry and Ledbetter-untreated)	−20.7 ± 0.5	36	2
Plains Post-Contact (Sully-PVA treated)	−12.7 ± 1.2	17	9

[1] Number of adult individuals
[2] Coefficient of variation

TABLE 3. *Effect of consolidation on stable carbon isotopic values in the Florida archaic. Windover adult bone collagen values in one group that was not treated with any preservative and one group that was treated with Rhoplex.*

	% ± S.D.	N[1]	V[2]
Untreated	−15.6 ± 0.8	6	5
Rhoplex treated	−21.0 ± 3.0	15	14

[1] Number of adult individuals
[2] Coefficient of variation

and Plains samples reflects the variability in the amounts of C–3 and C–4 foods in the diets of these humans.

The range in Windover human stable carbon isotopic values is shown for the six untreated samples and the fifteen Rhoplex-treated bones (Table 3). In the Rhoplex-treated human bone samples from the Windover site, the range in $\delta^{13}C$ was –16.2 °/oo, slightly larger than the total range of stable carbon isotopic values observed in all ancient human bone collagen measured to date. In addition, the mean of $\delta^{13}C$ values differed in the Rhoplex as compared to the untreated adult bone samples (Table 3). The magnitude of the difference of the means (5.4 °/oo) between the treated (–21.0 °/oo) and untreated (–15.6 °/oo) samples is sufficient to result in a different and erroneous interpretation of paleodiet in the Rhoplex-treated samples.

It was not possible to remove the Rhoplex completely and still produce clean collagen (Tuross et al. 1988), so all of the stable carbon isotopic data from the Windover human bone with the exception of the six untreated samples were rejected. Rhoplex removal was attempted by decalcification with both halide acid (1N HCl) and a calcium chelator (0.5M EDTA), and by extraction with a basic (1M NaOH) and an organic (ethanol) solution. Furthermore, gelatinization (Longin 1970) was attempted. For the purposes of stable isotopic analysis, none of the procedures successfully removed all of the Rhoplex preservative that formed a tight coating against the hydroxyapatite, precipitating in the interstices of the bone (Figs. 3a, 3b). It is clear from the scanning electron micrographs (Fig. 3b) that the Rhoplex stabilizer had invaded the bone cortex through the Haversian canals, and this preservative was not a surface coating that could be mechanically removed. The collagen in the Windover bone was quite soluble in all solutions, thus cumulative losses were observed when additional extraction procedures were applied.

It should be noted that the archaeologically recovered bone most likely in need of stabilization from the standpoint of morphological preservation will also be bone in which the remaining macromolecules, including collagen, are fragmented and soluble. Any postexcavation application of stabilizers that requires additional chemical treatments prior to stable isotopic analysis will result in lower collagen yields and, at a minimum, will result in the destruction of larger sample sizes of original calcified tissue.

Because nitrogen stable isotopes (δ^{15}N) were not affected by the Rhoplex treatments, we were able to document that in children under four years of age the δ^{15}N from bone collagen was significantly higher than in the adult population (Figure 4). This led us to formulate hypotheses regarding the etiology of this effect, which was subsequently tested on a group of contemporary mothers and their breast-fed infants (Tuross, Fogel, and Owsley n.d.). The working hypothesis, subsequently confirmed (Fogel et al. 1989; Tuross, Fogel, and Owsley n.d.) was that the enrichment in ^{15}N in infant bone collagen was from breast milk.

The success and failure of the isotopic analyses of the Windover bone collagen illustrate the impact that excavation and conservation decisions can have on these types of investigations. Although specific goals and paleodietary hypotheses were formulated prior to the isotopic analysis, the complications of Rhoplex stabilization compromised the experimental design. Far fewer human samples were analyzed for δ^{13}C than was optimal, and the time investment in the project increased. In contrast, the enrichment of ^{15}N in infant bone collagen relative to the adults in the sample

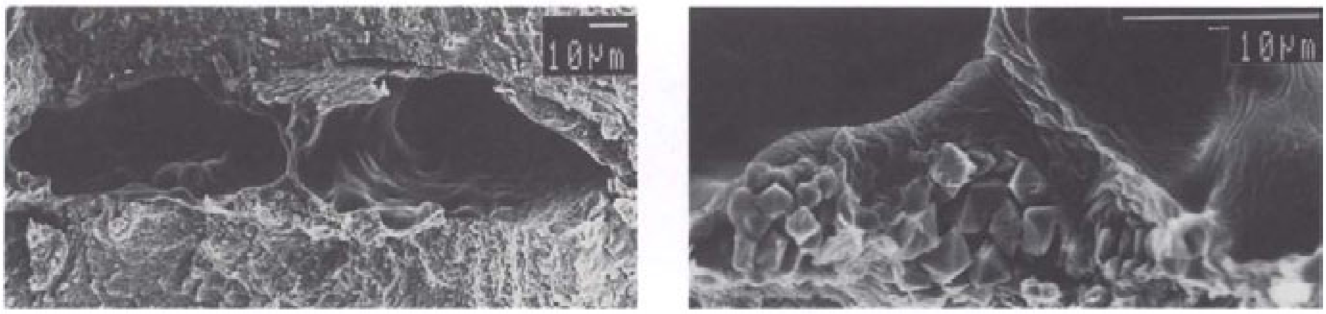


FIGURE 3a, b. *Fresh fracture of adult femur from Windover that had been treated with Rhoplex. The Rhoplex can be seen coating the surface of the twin Haversian canals in the compact bone, below left (a). A higher magnification scanning electron micrograph, below right (b), illustrates the smooth surface of the Rhoplex-covered bone and the precipitation of the stabilizer in a nest of crystals.*

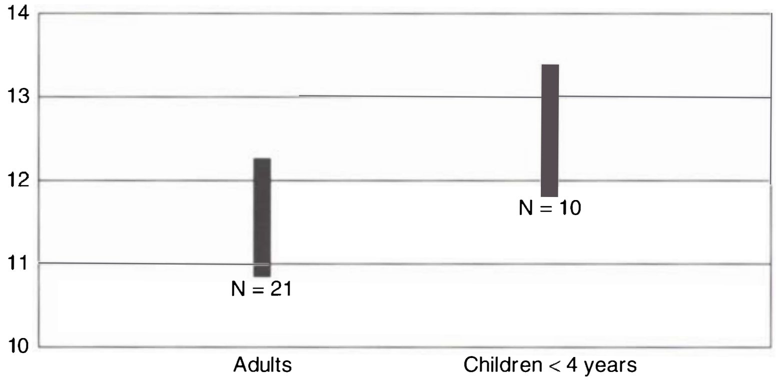


FIGURE 4. *Difference in the total range of $\delta^{15}N$ in the adult bone collagen compared to the values in children under four years of age. The increase in the bone collagen ^{15}N is a result of breast feeding during infancy.*

was an observation born of the ability to follow preliminary data by enlarging the sample size with a directed strategy.

It is quite straightforward, based on these data, to suggest that Rhoplex or any untested consolidant be avoided if isotopic analysis of archaeological materials is desired. It is less clear how to subsample a large skeletal collection for isotopic analysis if consolidation on the bulk of the material is felt to be necessary on morphological grounds. Some of the unknowns include the optimal number of analyses in a true population, the best sampling strategies for a diachronic sample, the possible range of isotopic values in various skeletal elements, and the full impact of ontogenetic effects.

Ancient DNA

The brain tissue that was excavated at Windover has proven to be one of the most exciting sources of ancient DNA to date (Doran et al. 1986; Lawlor et al. 1991; Hauswirth et al., 1991), and both mitochondrial and nuclear sequences have been derived from this material. There is also a growing appreciation that archaeologically recovered bone also may be a source of ancient DNA (Hegelberg et al. 1989; Horai et al. 1989).

The binding of DNA to hydroxyapatite under proper conditions is a well-known phenomenon that can be utilized to purify this genetic material. The mineral phase of vertebrate calcified tissues, bone, dentin, and enamel is imperfectly crystalline hydroxyapatite (Eanes and Posner 1970) and could be expected in some environments to retain and even absorb DNA from postmortem cellular degradation.

In an effort to extend the applications of ancient DNA to vertebrate calcified tissue, a bone perfusion method for the nondestructive removal of this genetic material from human skeletal remains has been developed. The strategy in the development of this protocol was threefold: (1) minimize the amount of bone that is destroyed in the analysis, (2) maximize the amount of DNA removed per individual, and (3) assess the quality of DNA retrieved as compared to more destructive procedures.

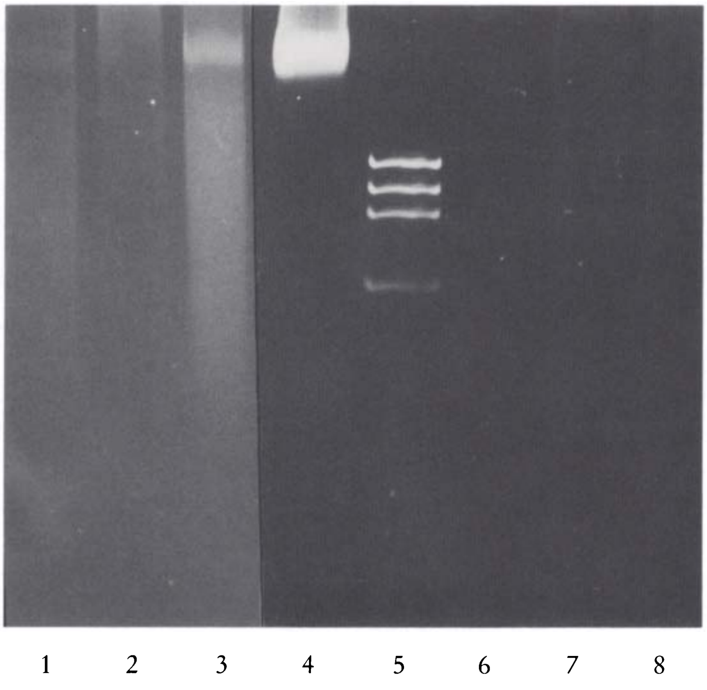
Skeletal material is a precious resource, and the widespread use of genetic analysis to address anthropological issues will involve large numbers of individuals. With these concerns in mind, the perfusion protocol was developed in order to be able to cope with substantial sample sizes without the necessity of large-scale destructive analysis. Another goal was to develop procedures that would allow for multiple analyses of the genetic material from a single individual in order to circumvent the need for repeated sampling of a skeleton. Because much of the available skeletal material has been treated with consolidants, one aspect of this study compared the DNA retrieved from untreated and preservative-treated long bones.

To remove the DNA from the intact femurs, a small hole (1 cm in diameter) was made with a muffled drill bit in some of the samples to allow the perfusing solution to be introduced into the midshaft cavity. Other samples had slight but sufficient erosion of the femoral head so that solution could be introduced through these lesions. A small polyethylene tube was also inserted into the foramen to provide an exit route for the major blood vessel in the femur. Perfusing solution could also be inserted through this tube using a syringe, although the procedure was more time-consuming.

All perfusions were done in a HEPA-filtered (high-efficiency particulate air) cleanroom with the additional protection of an exhaust hood. The left and right femurs of three individuals from a historic New Orleans cemetery were compared. Consolidation by polyvinyl acetate was thought to be necessary, because this collection was quite friable and had to be shipped from New Orleans to Washington, D.C. The right femur of each of these three individuals had been treated with polyvinyl acetate, while the left femur was left untreated. After the skeletal material had been washed thoroughly with water and air dried, the designated bones were dipped in polyvinyl acetate (VINAC B–25). This solution was made by dissolving one part polyvinyl acetate in three parts ethanol. The bones were totally immersed for two to five minutes and then allowed to air dry for four to six days on wire racks (Owsley et al. 1990).

The effect of polyvinyl acetate consolidation on DNA removal by perfusion is shown in Figure 5.[1] The increase in the amount of the DNA extracted by perfusion of the untreated femur as compared to the treated femurs is apparent to the eye in

FIGURE 5. *Gel electrophoresis of DNA extracted from the left and right human femora of three individuals. Lanes 1, 2, and 3 are the untreated bone; lanes 6, 7, and 8 are the polyvinyl-acetate-treated bone. Lane 4 is a cellular DNA standard, and lane 5 is a PhiX174-HaeIII digest standard in which the band nearest the top of the gel is 1,353 bp.*



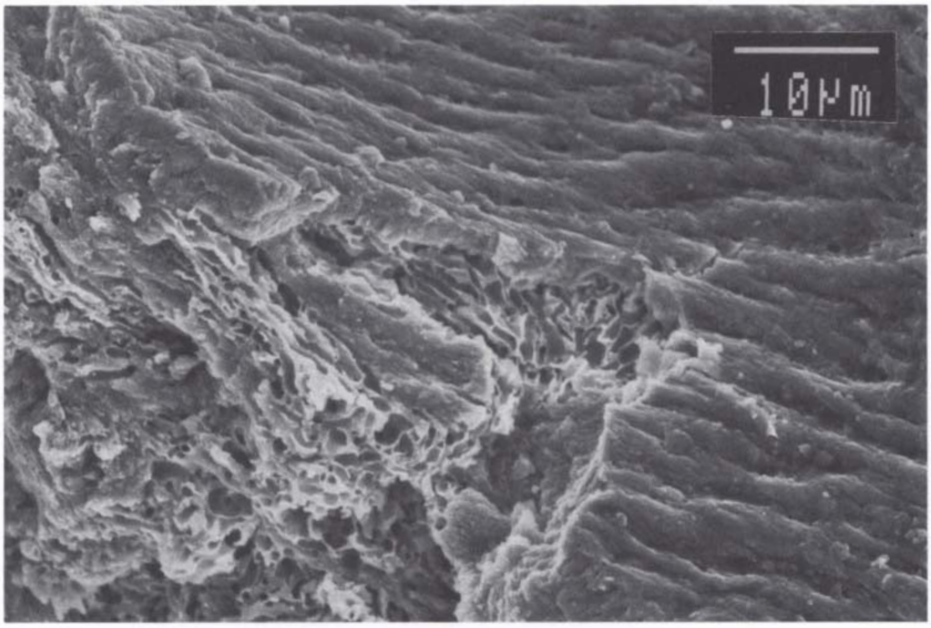


FIGURE 6. *Scanning electron micrograph of polyvinyl-acetate-treated bone from the historic New Orleans cemetery, Cypress Grove. Variability in bone quality can be seen with the interstices of the compact bone full of honeycomblike erosion. It is not clear if the applied polyvinyl acetate gives a smooth appearance to the surface of the bone.*

each case. It is not known whether the mineral associated with DNA was removed or degraded by the immersion of the bones in solvent during the application of polyvinyl acetate. However, the coating of accessible mineral surfaces (Figure 6) with polymers does, at a minimum, inhibit the removal of DNA from human long bone. It is possible that destructive sampling, followed by complete decalcification, could release any DNA remaining in the bone. It is unlikely that nondestructive methods of DNA extraction will be useful with archaeological bone that has been stabilized with plasticizers.

The temporal depth of ancient DNA preservation is unknown. However, the bulk of the vertebrate fossil record is calcified tissue, bones, and teeth, and the presence of ancient DNA in these tissues will greatly enlarge the question that can be posed. We have examined the well-preserved bone from Monte Verde for the presence of DNA. A small piece (16 g) of mastodon bone was decalcified with 0.5M EDTA/4M guanidine HCl, and the solution concentrated by Amicon filtration (YM30). After exchanging the extract into proteinase K buffer and digestion with proteinase K, the mastodon extract was electrophoresed and stained with ethidium bromide. High molecular weight (>1.3 kb), ethidium bromide positive material that can be digested with DNAase, was observed. It should be stressed that the apparent high molecular weight of putative DNA may be a function of crosslinks that formed postmortem, and that sequence will be required to unambiguously prove that this DNA is of proboscidean origin. However, these data demonstrate that DNA can be extracted easily from well-preserved, untreated archaeological bone of an extinct animal that is 12,000–13,000 years old.

Conclusions

It may be that optimal treatments for morphological preservation are incompatible with many types of molecular analysis. Historically, both excavation and conservation techniques have emphasized maintaining the shape of excavated materials. The development of fields such as isotopic paleodietary analysis and ancient DNA studies suggests a future in which the principle excavator, the archaeologist, will be required to balance the need for morphological integrity with the information content accessible at atomic and molecular levels.

Once in the museum environment, excavated materials remain at risk to conservation treatments that could render a collection useless for comparative molecular analysis. Although some excavation suggestions such as the use of gloves, Teflon instruments, storage in sterile containers, and conservation treatments such as long-term low-temperature (–80 °C) may seem extreme, in cases of unusual molecular preservation the effort will be justified. There is the common but mistaken notion that if molecules have lasted thousands of years in the ground, no unusual measures need be taken during excavation or processing. The organic materials excavated from the sites of Windover and Monte Verde illustrate that these depositional environments were extraordinarily protective. Maintaining an equivalent level of protection postexcavation can be quite difficult, and it seems prudent to treat organic remains as biological specimens, not archaeological artifacts.

Optimizing the retrieval and maintenance of information contained in a complex archaeological site such as Windover or Monte Verde is a challenge likely to evolve over the next decade. The studies of stable isotopic values and ancient DNA extractions indicate that both excavation techniques and postexcavation conservation can impact subsequent laboratory-based analysis. Our experience with the biomaterials from Monte Verde and Windover suggests that the applications of established experimental paradigms and new developments are most likely to derive from unconsolidated remains whose molecular potential is recognized at the point of excavation.

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Note

1. The samples were first washed with 100 ml 4M guanidine HCl, 100 mm TRIS, pH 7.2 on all external surfaces. This solution was retained at –80 °C. The femurs were propped on sterile glass supports at each end, with a plastic tray under the sample to catch the perfusion solution. Two 50 ml aliquots of 0.5M EDTA, 4M guanidine HCl, 100 mm TRIS, pH 7.2 were introduced into the midshaft cavity of the femurs and allowed to diffuse out through the compact bone. The same solution was removed from the tray by syringe and reintroduced into the bone

every 20 minutes to 1 hour for 6–8 hours. The covered bone samples were allowed to sit overnight, and the next morning the perfusing solution had generally solidified into a gelatinous mass in the tray. Fifty to 100 ml of distilled, deionized water were introduced into the bone and allowed to collect in the trays. The bone was then soaked in large volumes of water to remove chemicals and allowed to air dry.

The supernatant or perfusing solution was filtered through 0.45 µ filters and concentrated by Amicon filtration (YM30) in a stirred cell. This filter will retain all molecules of approximately 30,000 daltons or larger. Because these stirred cells are not disposable or easily sterilized, special thoroughness was instituted in the cleaning of the cells, and a control solution consisting of 50 ml of perfusing solution was added to the cell and concentrated to less than 1 ml before each bone sample. The concentrated control solution would then serve as the blank in any subsequent experiments. The bone extracts were reduced to 1–2 ml and stored at –80 °C until use.

One milliliter of each of the concentrated samples was put in freshly prepared dialysis tubing and rapidly exchanged against prechilled distilled, deionized water at 4 °C (three times in 24 hours). The dialysis tubes were then moved directly into proteinase K buffer and exchanged for 6 hours at room temperature. The samples in proteinase K buffer were transferred to tubes that had been preloaded with proteinase K (Sigma) and allowed to digest at 50 °C overnight.

After digestion with proteinase K, the samples were concentrated by Centricon 30 filtration to a minimum volume (usually 50–300 µl). Thirty microliters of this concentrated solution were visualized by gel electrophoresis on 6% acrylamide gels (100 V/gel; TBE buffer) and stained with ethidium bromide.

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Biographies

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Marilyn L. Fogel is an isotopic geochemist at the Geophysical Laboratory of the Carnegie Institution of Washington. Her Ph.D. was awarded by the University of Texas at Austin. Recent studies include isotopic biomarkers in the Eocene and nitrogen cycling during acid rain deposition.

Stratigraphic Dating and Cultural Sequences of Pre-Hispanic Northern South America

Thomas van der Hammen

Stratigraphy is a way of measuring the past: recognizing sequences of strata that correspond to time intervals, or time slices, and that may be related to cultural sequences. A stratigraphic sequence may contain charcoal fragments or other organic materials that enable us to place the stratigraphic sequence in a time scale in 14C years B.P. that, for the last 8,000 years or so, may be converted into an approximate time scale in calendar years. Besides the radiocarbon dating, there are other ways of "absolute" or relative dating, such as thermoluminescence, fission tracks, fluorine, and potassium-argon, that may help whenever the necessary materials are present and according to the length of time to be studied. But the stratigraphy as such, determined by the changes in lithology in the widest sense, contains information that may help us to measure the past, including time, aspects of the physical and living world, and the environment.

The information contained in the stratigraphy is, so to speak, coded. To decode it, we need different specialized techniques and sedimentological, pedological, and Quaternary geological knowledge. And, as soon as humans enter the scene and exercise direct or indirect influence on the stratigraphy, archaeological knowledge is needed. In any archaeological excavation, one has to deal with stratigraphy, which is sometimes simple and often complex. This chapter discusses a number of more important aspects of stratigraphy in South America related to dating and environment that provide tools for measuring the past.

Natural Stratigraphy

In excavations, both in rock shelters and in the open, "natural" stratigraphy may be relatively important and even dominant, especially when longer time intervals are studied. Principally, two factors are involved: sedimentation and soil formation.

Sedimentation of gravel, sand, soil, or clay may take place by running water and/or river inundation, colluviation, or solifluction; sedimentation of stones may take place by rockfalls or exfoliation; and, eventually, sand and silt may be carried and sedimented by the wind (aeolian sedimentation). The way of sedimentation may be deduced by the form of the sedimentary body, by the sedimentary structures, and by lithological analysis such as grain-size analysis.

A special type of sedimentation, of considerable importance in the Andes, is the deposition of volcanic materials, especially via the air: volcanic ash, sand, or lapilli.

Soil-forming processes start anywhere a surface is exposed to air, soil water movements, and vegetation. When vegetation is present on the exposed surface, different forms of humus may accumulate on the surface or be deposited, infiltrated, or otherwise mixed with the sedimentary material directly below the surface. The type of humus and the humus profile and the type of soil profile depend on the type of sediment, the climate, the local hydrological conditions, and the vegetation type. A layer of superficial, raw humus is formed, for example, when the subsoil is poor in nutrients and the pH is low. A special type of organic material accumulation is peat formation in certain marshy conditions. Under natural circumstances one, several, or all these aspects or agents may be recognized and used for the measurement of time, the environment, and environmental change.

Both sediments and soils, besides the direct information on sedimentary environment *(facies)* or soil-forming environment they may provide, may contain other vital information on the general environment, on vegetation (and fauna), that may give clues to the estimation of temperature and rainfall. Sometimes organic and inorganic chemistry and the analysis of isotopes may equally contribute important data. One of the most effective methods is pollen analysis (or palynology) of sediments and soils, if suitable; it is a most important universal archaeometric tool.

Human Influence on Stratigraphy

In some cases stratigraphy may be purely anthropogenic, as in the case of shell middens or superposed cities in earth mounds, but very often both in rock shelters and in open sites there is human influence, strong or feeble, on the natural stratigraphy and sedimentary processes.

Simple examples are the visible density of sherds, artifacts, flakes and animal bones, house floors or earth works, hearths or extensive stratified accumulations of ash and charcoal. But in addition, there is often a secondary effect of the active presence of a group of humans on the local environment by destruction of the local (or regional) vegetation, leading to local soil erosion, sheet erosion, and local increase of colluvial (or other) types of sedimentation. As we will see, in rock shelters and on slopes, for example, all this may lead to a rapid increase in the rate of sedimentation-accumulation related to human presence, and a return to very slow accumulation rates during periods of human absence.

Dating and Dating Problems of Stratigraphic and Cultural Sequences

Radiocarbon analysis is no doubt one of the more effective ways of so-called absolute dating of strata and cultures. There is, of course, a difference between radiocarbon and calendar years, but that aspect has been extensively treated and more or less solved for approximately the last 8,000 years. For older dates, the age in radiocarbon years may be wrong, and it may be possible only to compare and correlate strata. First, statistically, one out of somewhat more than ten may be beyond the indicated limits of error. Second, there may be contamination by younger materials such as rootlets, humus infiltration from above, animal burrowing, or any other form of intrusion or redeposition; and third, there may be a natural mixture of older and younger organic material in sediments and soils. Because of this, in order to build a trustworthy time scale for a stratigraphic-cultural sequence, a good number of 14C dates are needed, and every date needs to be evaluated in relation to the whole series and in relation to the stratigraphic sequence (including indirect stratigraphic dating by correlation); a date should be rejected if it is definitely inconsistent with the rest of the data set.

Most of this is rather obvious, but some aspects may need more discussion, such as the aspect of natural mixture of organic material. There are mostly two fractions of organic material in a sediment that may be separated and dated individually, or the whole organic content may be dated. There is the *alkali-soluble* fraction and the organic residue. The first one may eventually infiltrate more easily from a more recent level into lower-lying older material; the second one is more resistant as particles and may be redeposited as part of a recent river sediment or colluvium, for example. A total analysis of the sample may therefore result in too young or too old as compared to its stratigraphical chronological position, but the separate dating of the two fractions may clarify what happened and what should be the most trustworthy date.

Besides direct dating of a sequence, there are a number of methods that may help in correlation and interpolation, and in refining the time scale internally. If the sequence contains many animal bones or bone fragments, fluorine analysis of vertically, closely spaced samples may create a relative time scale that may be converted into a more absolute scale with the aid of the available 14C dates, permitting interpolation.

When pollen grains are present in a good state of preservation in the sediments and there is no reason to suppose large differences in pollen influx during the interval studied, indirect pollen density dating may be used for constructing a more refined time scale, permitting interpolation of dates (Middeldorp 1982). The method is based on the fact that average pollen influx per square centimeter per year under normal circumstances is a rather constant cipher; it may change somewhat when the vegetation changes fundamentally, but if there are sufficient 14C dates of the sequence, this is no problem. The number of sum pollen grains of regional origin per cubic centimeter is established by adding a known number of pollen grains of a known foreign species to a known volume of sediment, preparing the sample in the ordinary way for pollen analysis, and counting a slide of the prepared sample under the microscope. If every cubic centimeter of the stratigraphic sequence is analyzed in this way, it is possible to construct a curve of the relation of pollen density to depth and, with the available 14C dates, a curve of the relation of cumulative pollen density to time. This shows the pollen influx values and eventual variations, per square centimeter per year over the entire interval studied, and permit the establishment of a calculated age for any level of the sequence. Pollen influx values are often in the order of 2,000–6,000 grains per cm^2 per year, but lower and higher values may occur. Although it is not possible to calculate the error of the method, there is no doubt that the method gives often excellent, trustworthy results, and in most cases gives a better approximation than linear interpolation. The method depends on (and also gives information on) the rate of sedimentation: when sedimentation becomes twice as fast, pollen density decreases to half.

Natural stratigraphy may provide important clues for correlation and indirect dating by means of regionally recognizable and dated guide horizons. The lithological changes that determine these guide horizons are often determined directly or indirectly by climatic change, or they are related to other regional phenomena such as volcanic events. To use this stratigraphic information in the right way, a thorough knowledge of the Quaternary geology of the area is required. This knowledge is especially important when a regional search for promising sites is undertaken, as it may enable one to know very soon what time intervals are represented in a site, before any 14C date is available.

Examples from Northern South America

After these more theoretical considerations on stratigraphic dating, the following examples from northern South America illustrate the use of combined stratigraphic data and absolute or relative dating as a way of measuring time of the past. First, some natural stratigraphic sequences are discussed, followed by some examples of combined stratigraphical and cultural sequences.

Tephrostratigraphy and Tephrochronology

Tephrochronology is a well-known and locally used method in volcanic regions. It is based on the fact that a volcanic eruption that takes place at a certain moment in time may leave a clear sign in the form of an ash, sand, or lapilli layer in a very wide area in sediments and soils. Such a layer may even be recognized and differentiated from others by mineralogical and chemical characteristics. It allows one to recognize a certain moment in time in the sedimentary and soil sequences of a wide area. Many tephra will permit the recognition of many such time horizons. Once the tephra have been dated by radiocarbon analysis (e.g., of associated charcoal) or other absolute dating methods, tephrochronology provides the basis for absolute dating of many stratigraphic-sedimentary and soil sequences.

In the central cordillera of the northern Andes there is a long north-south zone of volcanoes that have spread their ashes over a very wide area, often reaching not only the central cordillera but also the eastern and western cordilleras, and locally even the western Llanos and western Amazonia. A detailed study of the Andosols, lake sediments, and moraines of the central cordillera, allowed the development of a very detailed tephrostratigraphic chronology that is more detailed near the volcanic centers, where minor eruptions are also recorded (Thouret and van der Hammen 1983; Thouret et al. 1994). A rather complete sequence of soils and tephra has been established for approximately the last 50,000 years, and further detailed for the last 15,000 years. As the Andosols and lake sediments are also excellent material for pollen analysis, the tephrostratigraphic chronology may be directly associated with vegetational and climatic environmental history, and whenever cultural materials are present in these sequences, human prehistory may be associated directly with environmental history and chronology.

Climate in Stratigraphy and Chronology

Climate in the Andes during the last 50,000 years has changed drastically. During the Middle Pleniglacial (approximately 60,000–26,000 B.P.) the climate was cool to relatively cold and relatively humid; during the Upper Pleniglacial (approximately 26,000–14,000 B.P.) the climate became very cold; and from 21,000 B.P. on the climate was very dry. During the Late Glacial (ca. 14,000–10,000) the climate became warmer and more humid, while during the Holocene (10,000 to the present) the climate became more like the present, relatively warm and moderately humid. Each of the periods mentioned, however, shows variations of climate of minor order; there are interstadials and stadials in the period between 60,000 and 10,000 B.P., and variations of temperature and especially humidity during the Holocene.

Around 30,000 B.P. there is the Santuario interstadial; during the earlier Upper Pleniglacial there are the Suta and Saravita intervals; and during the Late Glacial there are the Susacá and Guantiva interstadials, especially the relatively cold El Abra stadial (ca. 11,000–10,000 B.P.). During the Middle Holocene the climate was slightly warmer than it is today (1–2 °C), and there were quite a number of drier or wetter intervals. All these climatic changes and intervals are well known and well dated (van Geel and van der Hammen 1973; van der Hammen 1974).

Changes of climate (temperature and rainfall) may result in important or minor changes in vegetation in respect to plant cover; together these factors may change geomorphological processes considerably, including erosion and sedimentation and also pedogenic processes, and consequently have influence on the stratigraphy. The major changes took place during the Upper Pleniglacial, when average annual temperatures were up to 8 °C lower than they are today and rainfall may have been less than half of the present-day values, but the Late Glacial climate changes (Guantiva interstadial–El Abra stadial), for example, were also considerable. The upper forest limit during the Upper Pleniglacial was locally lowered from approximately 3,500 m to less than 2,000 m altitude. Because of this, the warmer and relatively wet intervals are often represented by intervals with a higher organic content; cold and relatively dry intervals are often represented by more minerogene stratigraphic intervals and a low content of organic material. But this is only one aspect. During the Holocene, for example, periods of lower rainfall in series of lake sediments may lead to the intercalation of peaty layers, and cold-wet climatic intervals may lead to stratigraphic intervals with fluvioglacial sand or even gravel. Cold climate in rock shelters may lead to strata with rockfall or rich in stones because of exfoliation of the rock ceiling. These are only a few examples of the rich variety of effects of climatic change or stratigraphy in the Andes that are also directly related to chronology.

Climate in tropical lowlands also changed fundamentally and showed many variations during the last 50,000 years. Rainfall changed fundamentally and temperatures during the Pleniglacial may have been 2–6 °C lower than they are today. River sediments were relatively coarse during the wet and colder periods (when much more sediment was transported from the Andes downward). During the dry and relatively cold Upper Pleniglacial, when sea level was moreover very low, the rivers incised their valley into their earlier sediments (van der Hammen et al. 1991a). In the wetter Late Glacial sedimentation started again in the valleys, and after a probable minor erosion phase during the El Abra stadial, the present inundation plains were formed (sedimentation during seasonal inundation). In the present-day savanna areas of the Colombian and Venezuelan llanos, during the later part of the Upper Pleniglacial and Late Glacial, a virtual desert was formed, with extensive sand-dune formation on top of humic soils of an earlier, more humid period (Roa Morales 1979). Another interesting example of the relation of climate, time, and sedimentation is the stratigraphic sequence in the lakes and marshes of Carajas (Absy et al. 1991), representing the last approximately 60,000 years. Dry periods of extension of savanna vegetation, approximately 60,000, 40,000, and 20,000–11,000 years B.P., correspond to layers of minerogene sideritic sandy material, while the more humid periods in between correspond to organic clay.

In Amazonian inundation plains (called *varzeas* in Brazil), as for example in the lower valleys and inundation areas of the Magdalena, Cauca, and San Jorge rivers, there is a clear relation between Holocene sedimentation and climate. During periods of low rainfall and low levels of inundation there is a general extension of zones with formation of peaty organic sediments, while during the periods of higher rainfall and high levels of inundation, minerogene sedimentation (clay, silt) may extend widely. This results locally in the stratigraphy as an alternation of organic (peaty) layers and clay-silt layers that is related to climatic change and hence to chronology. Important drier intervals in the Late Holocene are dated 2700–2000 B.P., 1500–1300 B.P., 650–750 B.P., and so forth (Absy 1979; van der Hammen 1986; van der Hammen et al. 1991b). It is most probable that these phenomena are related to the climatic condition known as El Niño.

Stratigraphy, Environment, Chronology, and Cultural Sequences

From the foregoing it will be clear that there is a close relationship between environment (in respect to environmental variation and climatic change) and stratigraphy. As climatic change is often contemporaneous over large areas, once the relation is established with the stratigraphic sequences and placed in the chronological sequence by 14C and/or other ways of dating, stratigraphic sequences may provide important indirect dating and information on the human environment of those groups that left cultural remains in a stratigraphic sequence.

As an example, we may refer to the stratigraphic and cultural sequences of the Late Quaternary in the high plain of Bogotá, where human influence on the stratigraphy is sometimes added to the environmental influence (Hurt et al. 1976; van der

Hammen 1978; Schreve-Brinkman 1978; van der Hammen and Correal Urrego 1978; Correal Urrego and van der Hammen 1977; Correal Urrego 1981, 1990).

The excavations in the rock shelters of El Abra, Tequendama, and others, unless there were local differences, revealed stratigraphic sequences that are comparable (Fig. 1). On a "basement" of old clay sediments related to the large former Sabana Lake, there is a gray to dark humic soil including recognizable thin layers of volcano ash, dated approximately between 30,000 and 21,000 years B.P., representing the very end of the Middle Pleniglacial and the first part of the Upper Pleniglacial. The top of this layer, known also as the lower soil of the high plain outside the rock shelters, often shows deep cracks apparently caused by former drying out of the surface. This darker humic layer is covered with a yellowish silty layer (the same material fills the cracks); this layer can be dated between ca. 21,000 and 13,000 B.P. It is a very characteristic stratigraphic level in the entire area, separating the two superposed soils of the high plain of Bogotá and is also recognizable in a wide area in the mountains of the eastern cordillera. The material seems to be of aeolic origin, partly volcanic ash, deposited during the very dry and cold upper part of the Upper Pleniglacial. The dry climate is probably the cause of the fact that no organic material was deposited or conserved in this layer. The earliest human artifacts (a few choppers and flakes) were found in this layer. We know that the environment was open paramo (without trees) above 2,000 m, and there was probably dry open vegetation in the tropical Upper Magdalena valley and locally up to 2,000 m; there was an abundant population of Mastodon in these open areas. The next layer in the rock shelters is a mostly darker one with little stone fragments, followed upward by an often somewhat lighter layer with abundant stone fragments from exfoliation. This is the very characteristic Late Glacial sequence, when the climate became wetter and warmer. The high plain of Bogotá was covered with high Andean forest during the time of deposition of the first layer, dated between ca. 12,500 and 11,000 B.P., and corresponds to the Guantiva interstadial. The upper layer mentioned was dated between 11,000 and ca. 10,150 B.P. and corresponds to the colder El Abra stadial. These Late Glacial layers contain abundant remnants of human occupation: lithic artifacts and animal bones, with the first clear signs of the influence of man on the stratigraphy, visible especially in the accumulation of ash from fireplaces.

In the Tequendama site, the limit of Late Glacial and Holocene is marked by a yellowish silty layer that seems to represent colluvial material that was washed in from an opening in the back of the shelter and was related to the sudden climatic change. The accumulation of sediments and the stratigraphy of the Holocene seem to be strongly influenced by the human occupation of the shelters. Outside the shelters the Holocene is represented by a dark-colored andic soil of some 75 cm; inside the shelters the accumulation was fast during occupation, with the inclusion of ash, bones, and lithic material and possibly some colluvial material. Visible stratigraphical features such as bone layers and ash accumulation are of human origin, while the differences in the color because of additions of humus (from vegetation) indicate phases of relatively continuous occupation (little humus; fast rate of sedimentation) and discontinuous, little, or nonoccupation (higher humus content; low rate of sedimentation). In both shelters the change of rate of sedimentation related to density of human occupation is clearly illustrated by the series of 14C dates or charcoal. After 6,000 B.P. there is no or only little occupation, and the sedimentation rate drops almost to zero (Fig. 1).

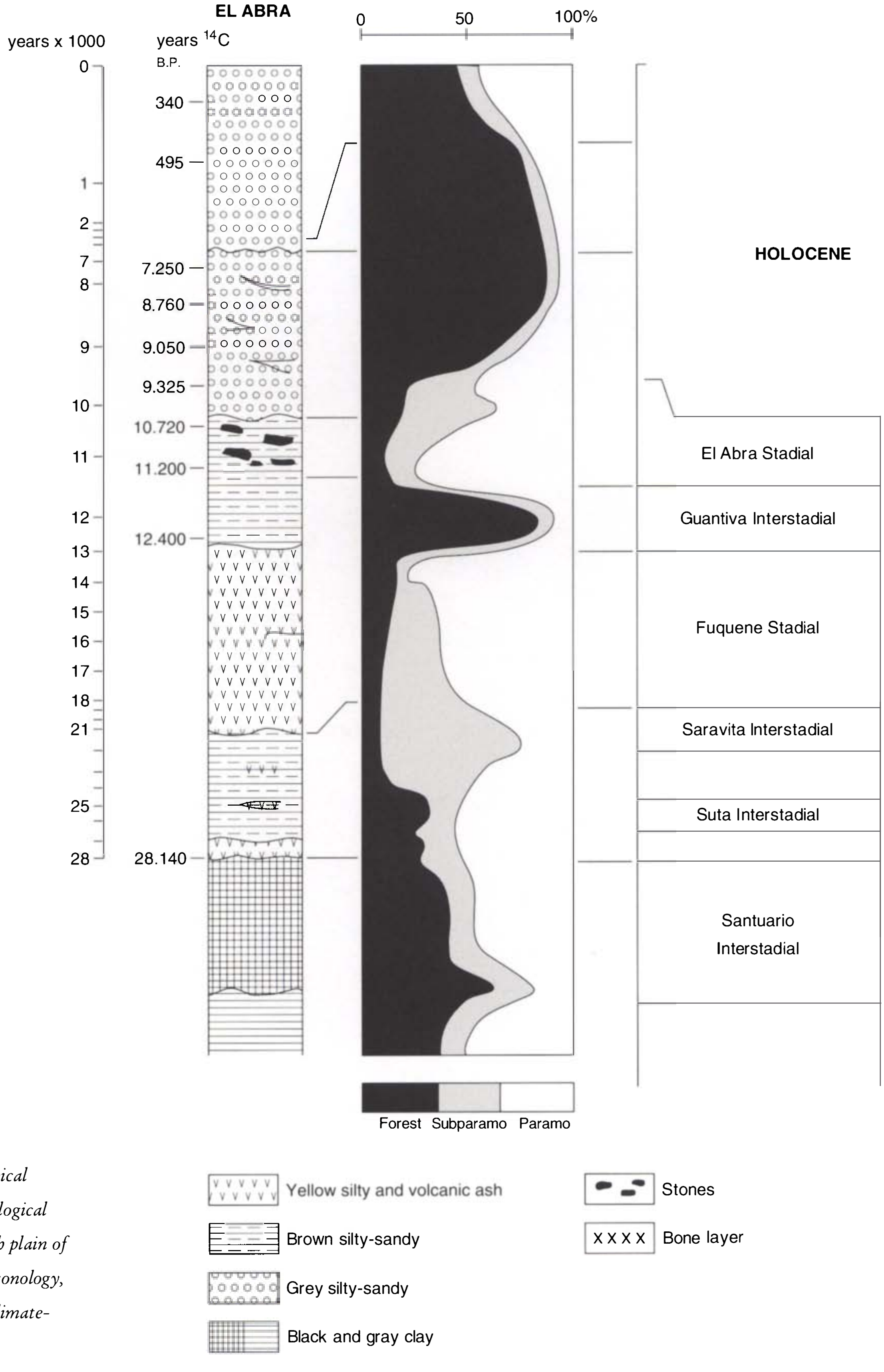
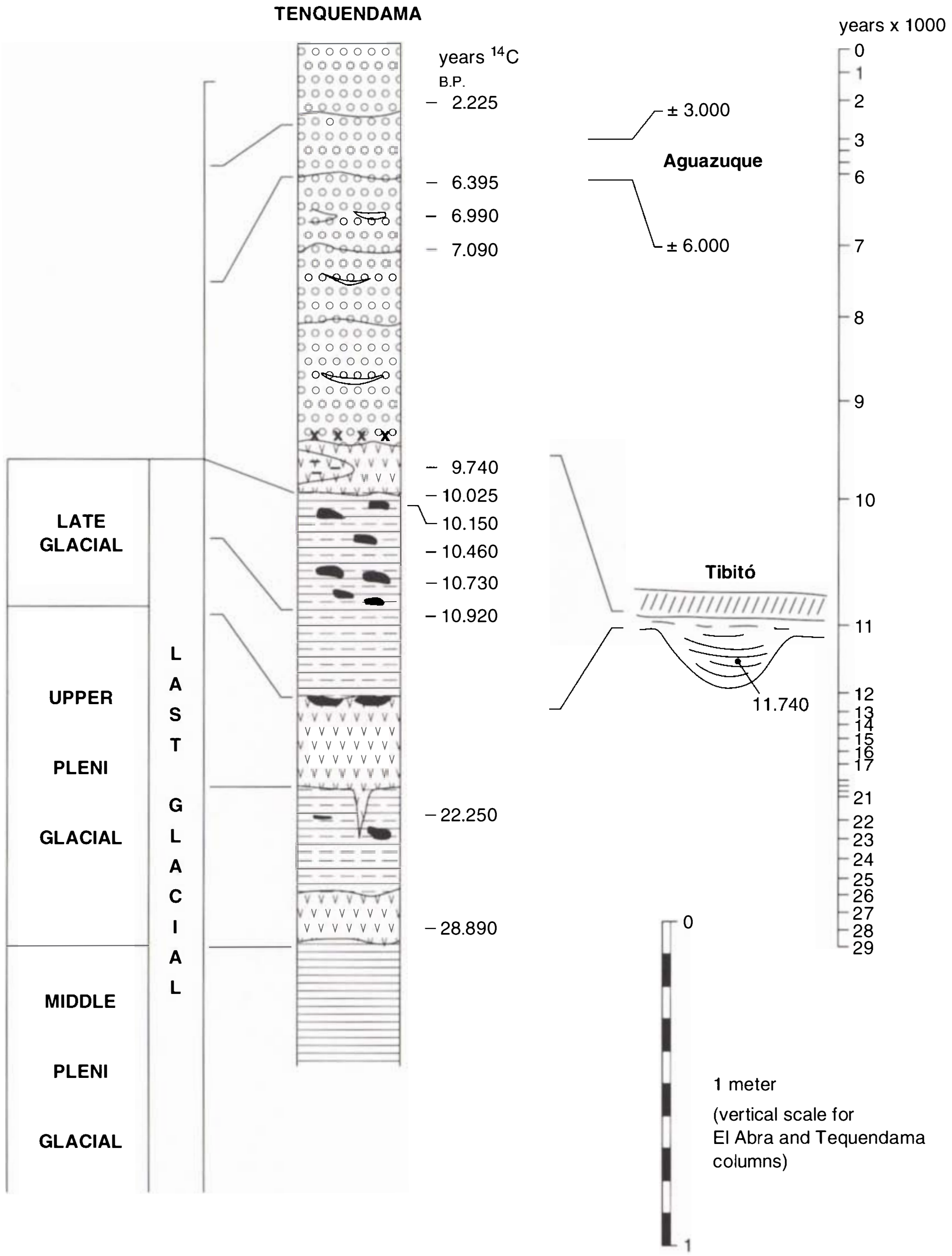


FIGURE 1. *Stratigraphical columns from archaeological excavations in the high plain of Bogotá; 14C dates/chronology, pollen diagram, and climate-stratigraphical units.*

Sedimentation starts again in the Ceramic period approximately from 3000 B.P. on. The result is that the 6000–3000 B.P. period may be represented by a relatively thin and darker layer. This period is now well represented outside the rock shelters, as was demonstrated by the excavations in Aguazuque (Correal Urrego 1990).



People lived in houses in the open, and the simple stratigraphy of a dark andosol or andic soil of 75 cm was complicated, and accumulation was faster because of addition of cultural materials and waste to almost 200 cm. It is interesting to compare also the rock-shelter sequence of earlier time with that of an occupied site in the open. The example is from Tibito (Correal Urrego 1981) in the western part of the Sabana of Bogotá. There we find that the original surface of the clays of the Middle Pleniglacial large lake of the high plain of Bogotá was eroded, probably during the upper and still relatively humid part of the Upper Pleniglacial. During the very cold and dry upper part of the Pleniglacial, small valleys and gulleys were dry, around 12,000 B.P. Mastodon and horse hunters lived on the bottom, leaving their artifacts and the bones of the animals they slaughtered. Soon rainfall increased, and the valleys and gulleys were quickly filled up with fluvial to colluvial sediments that covered the archaeological occupation level and made the valleys inhabitable. The infill took place during the Guantiva interstadial and El Abra stadial; when the original relief had disappeared, a Holocene dark humic soil formed on top, covering everything.

Another example is from the last 3,000 years in the lower San Jorge area, part of the large inundable lower Magdalena-Cauca-San Jorge area. The stratigraphy is determined by river sedimentation that takes place principally during the months of inundation. We have seen that dry and wet periods are registered in the stratigraphy by alternating peaty or strongly humic layers and clayey-silty river deposits (van der Hammen 1986). During the last 3,000 years or so, the area was inhabited by Indians who constructed extensive canal and ditch systems to dominate and regulate the annual inundations in favor of the cultivation of crops in raised fields. Extensive investigations in this area (Plazas et al. 1988) show a close relationship between stratigraphic chronology, environmental changes, and cultural sequence and activities. The construction and utilization of canal systems could be dated to the wet periods, while the stress of dry periods and sometimes of the wet ones seem to have a considerable influence on the human communities and the cultural sequence; the Zenu culture and hydraulic management disappear at the beginning of the 750–650 B.P. (1200–1300 C.E.) dry period, and the Malibu culture begins afterward, without hydraulic management.

Conclusions

These few examples, I hope, have illustrated, for northern South America, the relation of stratigraphy, dating, environment, and cultural sequences. They seem to enable us to draw some general conclusions:

- Natural stratigraphy is determined by the local conditions of the site that largely depend on the regional environment and environmental change.
- Climate is a very important component of the environment that may be quantified (Centigrade; millimeters of rainfall).
- As climatic change proves to be often contemporaneous over a large area such as northern South America or even worldwide, climate-determined

stratigraphic features also contain chronological information: climate-stratigraphy = chrono-stratigraphy.

- Regional study and absolute dating of Late Quaternary climate-stratigraphical and tephrostratigraphical sequences may lead to the recognition of important dated time-stratigraphic horizons. These, by stratigraphic correlation, may be recognized in archaeologically important stratigraphic sequences. Every (14C) date should always be evaluated in light of stratigraphic and lithological-environmental evidence. Once a good agreement between local and regional stratigraphy and chronology is reached, we may safely use the known quantitative paleoenvironmental data together with the archaeological ones for ecological prehistoric, or archaeoecologic, reconstruction: the dynamic relation of humans and their material culture with the changing environment, and with a reliable chronology.

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Biography

Thomas van der Hammen is a geologist and biologist whose scientific work focuses on paleoecology in South America and Europe. He has been closely connected with archaeological and archaeoecological research, especially in South America. For many years a professor of palynology and paleoecology at the University of Amsterdam, he is now retired and lives in Colombia, where he continues his investigations in the Andes and in Amazonia.

Coloration in Etowah Textiles from Burial Nº 57

LUCY R. SIBLEY AND
KATHRYN A. JAKES

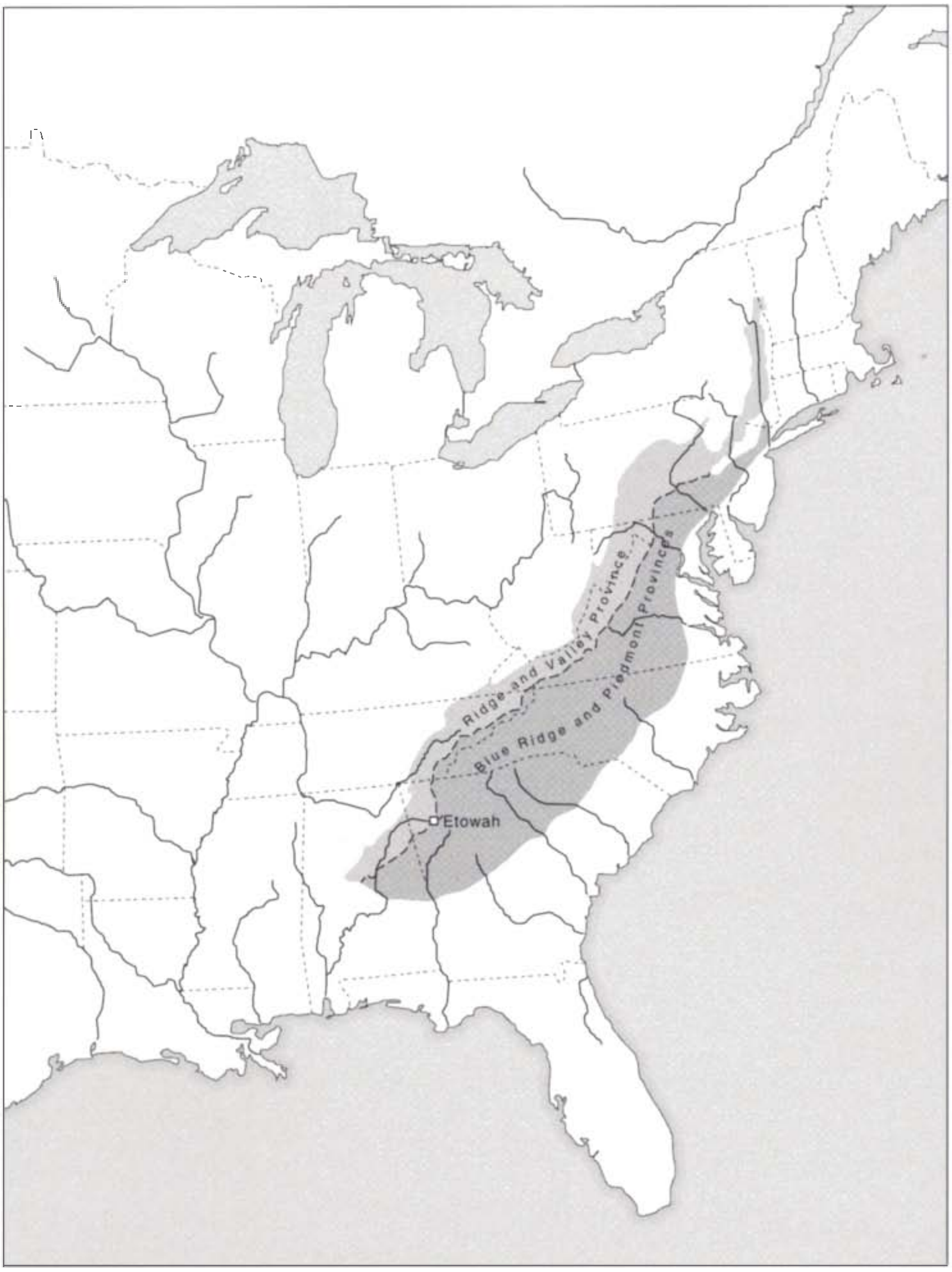
Some 300 years prior to the sixteenth-century Spanish exploration of southeastern North America, prehistoric people living in the region placed fabrics made of various materials in a log tomb burial of an adult male. The burial was prepared just prior to the last construction phase of a large Mississippian ceremonial mound of the Etowah Mound Site; the burial has been designated as Nº 57 while the mound is known as Mound C. The site itself is located on the floodplain of the Etowah River in present-day Northwest Georgia, U.S.A. (Fig. 1). Considered a rich burial, Nº 57 contained, in addition to the fabrics, such high-status grave goods as copper axes, engraved copper plates, pearls, and conch shell bowls. Two of the fabrics from Burial Nº 57 are the focus of the ensuing efforts to identify and explore the use of coloration in Etowah textiles from Burial Nº 57.

One would not be surprised to discover evidence of coloration in the Etowah textiles, since traces of red ocher were recovered at the Etowah site although not in association with textiles (Larson 1989). Red, white, and black were employed by other Mississippian groups of the Late Mississippian (1350–1550 C.E.) and the Protohistoric (1550–1650 C.E.) periods to ornament their pottery (Dye and Wharey 1989). Ocher could well have been used as a pigment, perhaps suspended in grease, to produce a topical coloration or painting of textiles.

The use of coloration in the sixteenth century was reported by Europeans as they recorded their impressions of encounters in "Florida." Among the accounts of the De Soto exploration of southeastern North America is one that describes the discovery of feather shawls in white, gray, red, and yellow (Lewis 1907:174). The entry by the Gentleman of Elvas is not the only reference to colors observed in blankets and garments worn by people encountered by the members of the expedition. Not only were skin garments decorated in black, red, and yellow, but fabric mantles also received similar treatments (Robertson 1933:2, 76; Lewis 1907:166).

Despite the other archaeological and ethnohistorical evidence, the two Burial Nº 57 fragments from Etowah, which are the focus of the research reported here, did not appear to have had color added to their structures. The visual appearance of

FIGURE 1. *Map of southeastern North America indicating the Etowah Mound Site and physiographic provinces.*



one, an intricately twined fabric (Catalog 840, known hereafter as EMC 840), did not exhibit any evidence of the addition of color in the form of dyes or pigments. The red and yellow colors in a second fragment appeared to be the original colors of its feather components from which the fabric was constructed (Catalog Andover 842, known hereafter as EMC A842) rather than the result of any addition of a colorant. The question of additional coloration for the two had to be reserved for a later effort when microanalytic techniques were available and more was known or understood about the fabrics. The current investigation is part of ongoing research devoted to study of the textile remains from Mound C, Etowah.

Etowah Textile Research

The Etowah textile research project has focused primarily on investigations of textile fragments from Burial Nº 57, where survival of the organic textile remains is the result of a mineral replacement process in which copper ions impregnate textiles, replacing them with mineral entities that assume the original shapes of fibers (Jakes and Howard 1986; Jakes and Sibley 1986; Sibley and Jakes 1982). While Schreffler (1989) explored status differentiation as indicated by the textile and copper evidence in the outer-ring burials of Mound C, Sibley et al. (forthcoming) examined the feather evidence in Burials № 103 and № 110.

EMC 840. Identification and characterization of the fragment have proceeded at the fiber and fabric levels of the structure. It is composed of nettle (*Urticaceae sp.*) fibers and displays four different areas of twined pattern variation that have been replicated (Jakes and Sibley 1986; Sibley and Jakes 1986; Sibley et al. 1989; Sibley et al. 1990). As a cultural object, the fragment has been used to explore technology (Sibley and Jakes 1986) and to propose a model for inference that plotted the use of textile evidence to examine culture (Sibley and Jakes 1989).

EMC A842. Most recently, the second fabric, EMC A842, has been the subject of research that examined its raw materials and their availability and use by Mississippians at Etowah (Sibley et al. 1992). The feather fabric consists of alternating layers of red and yellow downy barbules of the *Anseriformes* order, (ducks, geese, and swans), anchored by bast yarns (Fig. 2). Although there is evidence that feather material is wrapped around the bast yarns, not enough remains to determine the method of fastening. The feather-faced fabric does have the characteristic ridges that give evidence of its hidden fabric structure (Fig. 3). Using the proposed model for inference, the investigators studied the implications of the feather fabric evidence.

Method

Two parallel lines of investigation were employed in the research. One followed a set of chemical analytical procedures designed to identify any coloration and the method of application, while the other inquiry studied the ethnohistoric, ethnographic, and archaeological evidence concerning the use of color in the Mississippian period. Findings from both strands of analysis were examined and compared using the components of the proposed model for inference as a means to organize the discussion.

FIGURE 2. *Alternating layers of feathers and bast fibers in EMC A842, magnification 9×.*

FIGURE 3. *Ridged surface structure in EMC A842, magnification 8×.*

Experimental Procedures

Microscopy

The objects were examined and photographed employing a Bausch and Lomb stereomacroscope at magnification levels of 3.18× to 21.6× and using Ektachrome 160 tungsten film (e.g., Fig. 2). One piece of EMC A842 was carefully raised and supported so the edge could be examined and photographed as well (Fig. 2). The view from the edge gave evidence of the layers of fabric and fibers present in the piece.

A Zeiss Axioplan research microscope was employed for the microscopic examination of the fiber samples. Techniques of brightfield, darkfield, phase contrast, polarized light, and differential interference contrast were used in the study of each of the specimens at magnification levels of 31.25× to 312.5×. Micrographs were taken using Ektachrome 64 tungsten film.

Scanning Electron Microscopy and X-ray Microanalysis

Small samples of each of the fibrous materials were selected, mounted on carbon planchettes with carbon paint, carbon coated, and examined by scanning electron microscopy using a JEOL JSM 820 scanning electron microscope. The same samples were subjected to X-ray microanalysis using a Link Analytical eXL energy-dispersive X-ray spectrometer. Each sample of fibers was examined along its length. Then the stage was tilted to allow observation and analysis of fiber interiors. Samples of dirt and wood obtained from the collapsed tomb of Burial Nº 57 were also examined, as were particles of dirt found on the surface of EMC 840 and particles found near the EMC A842 fragment. One of the dirt samples from EMC A842 was located near the fragment in the Riker box, but it could not be assured that it came from that particular fragment. The other sample was located directly beneath the section of EMC A842 raised on end for examination. This second particle was more clearly associated with EMC A842.

Infrared and Visible Microspectroscopy

A third small sample of red and gold material from EMC A842 and a sample from EMC 840 were selected for microspectroscopic examination by an Analect AQS-20M infrared microspectrometer system consisting of an Analect fX-6260 FTIR and an Analect fXA-515 infrared microscope utilizing a 15× Cassegrain objective. The same system was employed in a previous study (Jakes et al. 1990) and some details of the methods are reported therein. Further developments in techniques are projected for a future publication (Martoglio et al. 1992). For visible microspectroscopy, a modified Instruments SA, Inc., Ramanor U-1000 system was employed (Sommer et al. 1990).

In addition to the fibrous materials, three dyeplant materials and one animal dye were studied:

1. *Galium aparine*, common in North America, collected in Ohio.
2. *Galium corymbosium*, previously classified as *Relbunium* but recently reclassified as belonging to the genus *Galium* (Dempster 1990), native to South America, collected by K. Antunez de Mayolo in Peru.
3. *Rubia tinctorium or cordifolia*, European or Indian madder, obtained from the Alliance Import Company, Sacramento.
4. *Dactylopus coccus*, cochineal, obtained from the Alliance Import Company.

Extracts of the dyes were examined as well as alum mordanted woolen skeins, which were dyed with the dye materials. By means of infrared and visible spectroscopy, dye extract solutions, dyed single fibers, and undyed single fibers were examined to establish comparative data.

This work stems from the exploration of infrared and visible techniques to identify whether dyes can be recognized on single fibers without the extraction or solution procedures that are commonly used. Early stages of this work have been reported in Martoglio et al. (1990) and Jakes et al. (1990). Further work on dye identification by these microtechniques is described elsewhere (Martoglio 1992; Martoglio et al. in press). Included in those reports are the examination of the infrared and visible spectra of alizarin, carminic acid, and purpurin, of single fibers dyed with those agents, and spectral subtraction techniques applied to them. Having explored relbunium, cochineal, and madder dyes in the earlier work on Paracas textiles, this work added a *Galium* dyeplant to the spectral library for the purpose of cursory examination and discernment of any differences between the different anthraquinone-based materials. There was no attempt in this preliminary investigation to obtain spectra of all of the dyeplant possibilities available to North American natives. In addition, it should not be inferred that the North American natives had access to either of the madder or relbunium dyeplants employed. Rather, it is one of the recommendations of this report that a dyeplant collection be established that is representative of the materials used by prehistoric Native Americans.

Upon establishing the method for the infrared and visible examination of single fibers, the researchers obtained spectra of the single fibers from the Etowah materials described above. Instrumental reproducibility was verified for these and other single-fiber samples by a series of repeated collections of the spectra for the same fiber location. Due to the inhomogeneous nature of fibers and to uneven dyeing, reproducibility of fiber sample spectra could not be determined. With a larger population of sample fibers to be examined, some statistical approach to allocation of spectral variation to the component due to sample inhomogeneity and the component due to the technique itself possibly could be accomplished, particularly with synthetic fibers. The sample sizes employed in this exploratory study, however, were very limited, and therefore the assumption is made that the spectra are true representations of the compositions examined.

Subtraction techniques developed involved scaling the two spectra to be subtracted so that a single selected peak on each is of equal height. Subtraction then yielded a spectrum of the difference between the two if the concentrations were equal with respect to the chosen peak. This method was repeated for other selected peaks throughout the spectra. Subtraction aberrations were thereby limited.

Results and Discussion

The microscopic structure displayed by the fibers of EMC 840 was described previously (Jakes and Sibley 1986). Although the overall color of the fabric is brown to the eye, on magnification the fibers display lighter brown and green coloration in some areas as well. The EMC 840 fibers show a surface structure of encrusted bast-type fiber bundles. Earlier work in examination of examples of the EMC 840 fibers showed fibrillating, cracked fiber bundles with some surface folds (Jakes and Angel, unpublished research). Cross-sectional views of the fibers show that they are solidly filled with material (Jakes and Sibley 1986). The lumen is not apparent in the cross-sectional views of these fibers.

Microscopic examination of the red and yellow material from EMC A842 shows the characteristic structure of downy barbules of feathers of the order *Anseriformes*. The red feather barbules are colored throughout, with a more intense coloration apparent in the area of the nodes. When examined by electron microscopy, the yellow feathers appeared cleaner and smoother than the red feathers, which displayed an encrustation along their surfaces. A small yarn fragment removed from the underlying fabric structure of EMC A842 appeared to be bast, but no further identification has been made.

Results of X-ray microanalysis of these materials provided further data, which are reported in Table 1. Yellow feather surfaces yielded a spectrum containing significant quantities of copper, sulfur, phosphorous, and calcium and small quantities of aluminum, silicon, and iron. Surface contamination by aluminosilicates from the soil is likely. The internal composition of these feathers contains copper, sulfur, and calcium. Lack of aluminum, silicon, and iron within the fibers supports the theory that the surfaces are contaminated with soil particulates. The red feathers yielded a composition of copper, sulfur, and calcium with a small amount of aluminum, silicon, and phosphorous.

Bast fibers of EMC A842 display small amounts of silicon, phosphorous, and sulfur with large amounts of copper and calcium. Sodium is sometimes present in the spectra as well. Fiber interiors examined contain copper, sulfur, and calcium with the occasional presence of sodium.

The surfaces of bast fibers from EMC 840 display copper, aluminum, phosphorous, sulfur, and calcium. In these spectra, silicon and iron are present in small amounts. Once again, surface contamination by aluminosilicates and other types of soil is indicated. Fiber interiors contain copper, aluminum, phosphorous, sulfur, and calcium with small amounts of silicon and iron, indicating that the fiber cross sections might not be clean. The EMC A842 fibers differ from the EMC 840 fibers in two respects: They occasionally contain sodium, and the quantity of phosphorous exhibited is minimal in comparison to that noted in EMC 840 fibers.

Soil particles removed from the wood recovered from the burial contain aluminum, silicon, potassium, calcium, and iron. Some spots examined displayed titanium and magnesium as well. These data are consistent with electron microprobe data reported previously (Jakes and Sibley 1986). A particle of high calcium content was found in the dirt sample, indicating the presence of a calcium carbonate or oxide of some sort in the soil. The soil particles from EMC A842 contained aluminum, silicon, potassium, calcium, and traces of iron. The particle from EMC 840 contained copper, aluminum, silicon, phosphorus, sulfur, potassium, and calcium; the presence of the sulfur, copper, and phosphorous is indicative of the lack of purity of the sample and the possible mixture of this dirt with associated fibers.

Although the coloration of the feathers might lead the observer to consider that they were colored with ocher pigments, the elemental composition of the encrustations does not corroborate this hypothesis. The lack of iron in the encrustations eliminates this possibility of pigmentation with ocher. X-ray microanalysis of areas of the gold feather show very small amounts of iron always associated with aluminum and silicon, which are present in varying but small amounts within the spectra. Thus the iron that is present is too small in quantity to be related to the source of coloration; rather, the little that is apparent is associated with soil contamination of the feather fabric. In addition, the pigmenting of feathers is not suggested by the clean-looking surface of the gold feathers.

The red feathers, although encrusted with material, also do not give evidence of iron oxide pigmentation. One particle on the surface of a red feather was found that displayed a high iron content, but further exploration found no other such particles.

TABLE 1. *Elemental composition of fibers and feathers and related materials.*

Description	Site	Cu	Na	Mg	Al	Si	P	K	S	Cl	Ca	Ti	Mn	Fe
842 gold feather	surface particle	L[2]			L	L					S			
	surface particle		S[3]		S	S	S	S	S	S	S			
	feather surface [1]	L			S	S	L/S		L		L			S
	feather interior [1]	L							L		L			
842 red feather	feather surface [1]	L			S	S	S		L		L			
	feather interior [1]	L							L		L			
	surface particle	L		S	L	L	S	L	S		L			L
	surface particle	L			S	S	S		L		L			
840 bast fiber	fiber interior [1]	L			L	S	L		L		L			S
	fiber surface [1]	L			L	S/L	L		S		L			L
	surface particle [1]	S			L	L		S			S			
842 bast fiber	fiber interior [1]	L							L		L			
	fiber surface [1]	L	S		L/S	L/S		S	S		L			
	associated soil particles [1]	S			L	L		S			S			
wood from tomb					L	L					L/S			
soil associated with wood from tomb [1]					L	L		S			L/S	S	S	L/S

[1] Multiple surface and interior spectra were collected, the data reported are summative.

[2] L, peak height is large.

[3] S, peak height is small.

In fact, the predominant characteristic of the red feather is the conspicuous absence of iron despite the surface encrustations.

Both red and gold feather surfaces and interiors display significant quantities of calcium, copper, and sulfur. The sulfur can be attributed to the protein composition of the feathers. The copper is present because the materials that have been retrieved from this burial are preserved by impregnation of copper ions coming from corroding copper objects in the same burial zone. The calcium content of the feathers can be attributed to an ion-transport phenomenon similar to that of copper. The soil samples examined displayed significant quantities of calcium, and some crystalline-looking particles contained calcium alone, thus indicating the presence of mineral oxides or carbonates. The solution of calcium minerals in rainwater as it penetrates the burial zone is likely (Garrels and Christ 1965). Infiltration of the feathers by the water permeating the site will result in deposition of calcium in a manner comparable to deposition of copper.

Although the encrusted surface of the EMC 840 bast fibers might suggest pigmentation, the composition of the encrustation displays evidence of soil contamination plus copper, phosphorous, and a small amount of sulfur. Most notable in the elemental spectra of the EMC 840 fibers is the predominance of the calcium peaks in these fibers as well as the presence of sulfur and phosphorous, which are present in fiber interiors as well as on fiber surfaces. The EMC A842 bast fiber samples similarly display significant amounts of calcium as well as some sulfur, but do not display phosphorous. In addition to calcium enhancement due to permeation and deposition in burial, some additional sources for the calcium content of these fibers is possible. This calcium also could be attributable to the formation of calcium oxalate crystal phytoliths within the fiber as it grew, a characteristic typical of the nettles.

While sulfur is expected within the protein structure of the feathers, sulfur is not a typical component of cellulosic fibers. Contamination of the fibers with sulfur from the soil is not indicated, since no soil particle examined contained sulfur. One exception is a particle removed from the surface of EMC 840 that could well have been contaminated with fibrous material. The absence of sulfur-containing material in the soil and the absence of sulfur in the wood obtained from the burial tomb lead one to assume that the sulfur content of the EMC 840 fibers was present prior to burial and is due to some sort of fiber treatment.

The phosphorous content of the EMC 840 bast fibers distinguishes them from the EMC A842 bast fibers. Once again it is indicated that the phosphorous is a particular characteristic of the fiber rather than a consequence of the burial conditions, since there is no phosphorous in any of the soil samples studied nor in the wood.

Infrared microspectroscopic spectra of the gold feathers yielded a spectrum of protein. Some red-brown particles removed from their surfaces yielded a spectrum that revealed some composition in addition to feather protein. Spectral subtraction techniques yielded a spectrum that contained peaks similar to those derived from a *Galium aparine* extract and to a comparable subtraction of standard wool dyed with *Galium aparine*. Subtraction of the visible spectrum of undyed protein from the spectrum of the colored feathers yielded a visible spectrum comparable to the visible spectrum of *Galium aparine.* Whether these spectra are definitive for *aparine* species only is not known; it is known, however, that the spectra are distinct from those of the South American *Galium* (commonly termed *Relbunium*) and the European *Rubia* dyeplants spectra examined. Although the three belong to the family *Rubiaceae*, there are some distinct differences in their color chemistry, which are reflected in their infrared and visible spectra.

Prior to spectral subtraction, it is apparent that the infrared spectra of the red feathers show some bands that are not due to its proteinaceous composition. These bands could be attributed to colorant comparable to that derived from *Galium aparine*, and this identification was confirmed by the visible spectra. Surface encrustation of the red feathers yielded similar results, although some particles gave a spectrum that appeared similar to that of cochineal as well.

Martoglio's dissertation (1992) describes the appearance of bands attributable to cochineal in the spectra of at least one of the surface particles on the red feathers. It is not known if the spectra observed can be uniquely attributed to cochineal or if some other material could have been the source of the coloring components examined. It is assumed that this material contained carminic acid as well as other anthraquinones. Further work is required to ascertain the prevalence of this composition in the colored particles on the surface of the Etowah materials.

Infrared spectra of the EMC 840 fibers revealed cellulose spectra with some additional bands as well. Small areas and surface particles that were green in color yielded the spectra of malachite; the fibers apparently are replaced with the copper mineral in these areas. Other areas yielded spectra which, after spectral subtraction, are comparable to the *Galium aparine* extract (Martoglio 1992; Martoglio et al. 1992). Figure 4 displays the results of the spectral subtraction and a comparison to the *Galium* extract spectrum. The similarities to *Galium aparine* extract do not imply that the fibers could only have been dyed with *Galium aparine*, but that the coloring composition of the Etowah materials is comparable to that of the *Galium* extract.

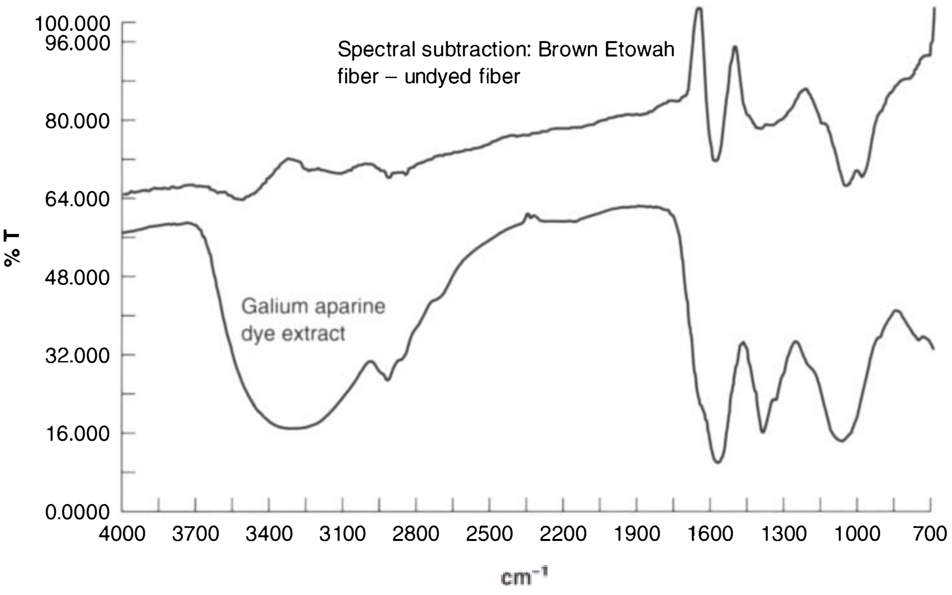


FIGURE 4. *Infrared spectrum of undyed fiber subtracted from EMC 840 fiber compared to infrared spectrum of Galium aparine extract.*

Implications

The proposed model for inference incorporates burial and site data as well as data from physicochemical and fabrication analyses to examine the textile complex of a culture. It is represented algebraically as:

$$C = f(T_1 + T_2 + B + O)$$

where C = Cultural context, T_1 = physicochemical data, T_2 = textile fabrication data, B = burial and site data, and O = other parameters. The model proposes that cultures affect the biologic stage of plant and animal life cycles through collecting or cultivating activities as well as an archaeological stage where discard behaviors shape the diagenetic activity that occurs after burial and/or discard. It is evident that decisions made by the Etowah population led to the preparation of Burial № 57 and the placement of certain special grave goods within its log tomb. That coloration was added to both fabrics is evident, but the decisions and the reasons for the subsequent decisions remain to be examined.

Biologic Stage

Larson (1971, 1989) notes that the Etowah population exploited the resources of two physiographic zones, the Ridge and Valley province and the Piedmont province. A variety of *Galium* species would have been available in either or both, as were many other dyeplant materials (Tables 2, 3). Collecting plants capable of yielding red dye as well as other dyes would have been part of the cultural store of knowledge or certainly of those responsible for producing textiles. Larson also reports the availability of red ocher locally, as noted above. It could have been used

Table 2. *Citation of yellow dyeplants and their geographic location.*

Common Names	Genus species	Citation	Geographic Location	Color	Colorant Composition
Bloodroot	*Sanguineria Canadensis*	Gilmore, Densmore	GA, OH	Red/Yellow	
Curly Dock	*Rumex Crispus L.*	Brunello	GA, OH	Yellow	
Barberry roots	*Berberis Vulgaris L.*	Color Index, DeGraaf	OH only Extirpated	Yellow	Berberine
Goldthread	*Coptis Trifolia*	Densmore	OH only	Bright Yellow	
Alder	*Alnus Incana, Alnus Rugosa*	Densmore	GA, OH	Yellow	
Sumac	*Rhus Glabra L.*	Densmore, Brunello, DeGraaf	GA, OH	Yellow	Gallotannin
Bloodroot and Wild plum	*Sanguineria Canadensis* and *Prunus Americana*	Densmore	GA, OH GA, OH	Dark Yellow	
American Quercitron oak	*Quercus Tinctoria L.* or *Quercus Velutina Lam.*	DeGraaf, Schweppe	GA, OH[1]	Yellow	Quercitin

[1] Present but not native

for textile coloration as a pigment, but it apparently was not used on the Burial Nº 57 textiles. The fact that *Galium* species could have been used to color both the red and yellow downy barbules and the structurally patterned nettle fabric suggests that the Etowah population had access to a wide variety of plants. The choice of one raw material rather than another was a cultural decision because both were available.

The dyeplant examples studied are not considered all-inclusive. Rather, the microspectroscopic data are reported herein to show that the examination of a single fiber can be useful in determining that fiber's composition, including the dye or other component present in small concentration. In this work a distinction could be seen between the coloring constituents of three dyeplants of the same family, that is, *Rubiaceae.* Schweppe (1989) states that of the twenty-three different hydroxyanthraquinones in madder roots (*Rubia tinctorium*), the presence of alizarin, purpurin, and pseudopurpurin may be sufficient for the identification of madder; Foster and Moran (1989) state that the presence of alizarin was sufficient for identification of madder in pigments. Because alizarin is the primary coloring constituent in madder, its predominance may be sufficient to identify the presence of madder in a fiber. The South American *Galium* species has been noted to be composed primarily of purpurin and pseudopurpurin (Hofenk de Graaff 1969) with little alizarin. Thus the infrared and visible spectra of the two will be distinctly different. Thomson (1987) identifies some of the anthraquinone components of *Galium* species, including *Galium tinctorium.* Some of the anthraquinones are the same as those found in *Rubia tinctorium*. Since the spectra obtained are representative of the composition as a whole and no attempt was made to separate the individual components of the colorants, the source of the differences between the three *Rubiaceae* studied is not known. It can be surmised, however, that the differences reflect different anthraquinone composition and/or relative differences in anthraquinone concentration.

TABLE 3. *Citation of red dyeplants and their geographic location.*

Common Names	Genus species	Citation	Geographic Location	Color	Colorant Composition
Eastern Hemlock (bark)	*Tsuga Canadensis*	Densmore	GA, OH	Red	
Bloodroot	*Sanguinaria Canadensis*	Gilmore, Densmore	OH	Red/Yellow	
Dodder, Love vine	*Cuscuta Paradoxa Raf.*	Gilmore	GA, OH	Red/Orange	
	Galium Tinctorium and *Rhus Glabra L.*	Brunello	GA, OH	Red	Alizarin, Purpurin
	Galium Pilosum	King & Gardner, Brunello	GA, OH	Red	
	Galium Sp.	Color Index	GA, OH	Red (on alum mordant	
Puccoon	*Lithospermum Caroliniense*	Densmore	OH	Red	
Red cedar (bark)	*Juniperus Virginiana*	Densmore	OH only	Red	
Red-Osier Dogwood and Alder	*Cornus Stolonifera* and *Alnus Incana*	Densmore	GA, OH	Red	

Many more dyeplant examples need to be considered. In fact, many native plants could have been used to color textiles red or yellow, and there are many coloring constituents, not just the anthraquinones. A list of dyeplants cited either in the ethnohistoric literature as having been used by Native Americans in what is now Georgia or Ohio in eastern North America, or in the literature as it has developed on natural dyes as dyeplants of the geographic region. It is divided into yellow dyeplants (Table 2) and red dyeplants (Table 3). Ethnographic reports such as that of Gilmore (1911–12) describing the people of the Missouri River region, and that of Densmore ([1928]1974) describing the Chippewa of Minnesota and Wisconsin detail the use of dyeplants by these populations. Use of these materials by prehistoric cultures is suggested by their historic use by subsequent population groups. Similarly, references made by Brunello (1973) to the use of dyeplants by historic eastern North American groups are considered indicative of the possibility of their use in earlier periods.

Examination of the tables shows that not only are the *Rubiaceae* family represented in the *Galium* species noted, but other plant roots and bark are also listed. The chemical composition of the coloring components of each of these materials is known in only a few cases. It is necessary therefore to collect examples of native dyeplants from the area in a manner similar to the collection of dyeplants native to Peru gathered by Saltzman (1978).

Du Pratz ([1774]1975, 1758) reports that the eighteenth-century Natchez of Louisiana collected the roots of the *achechy* plant to use for dye. He describes the plant as growing 6–7 in. high in shaded areas of woods. Its roots consist of "a great many sprigs a line in diameter, full of red juice like chickens blood" (1975:252). His description of the plant corresponds to *Sanguineria canadensis*, or bloodroot, which grows in the present state of Georgia where Etowah is located. Bartram (Harper 1958) in his eighteenth-century travels notes the presence of the same plant at Rabun Gap in northeastern Georgia. It is also known as red root. If *achechy* is bloodroot, then it would have been collected in the early spring when the flower would have been visible in wooded areas and stored until the fiber-producing plants were collected in mid- to late summer.

Collecting and storing plants for dyes and fibers were not the only methods to obtain color in the textiles. Certainly an exchange system for other raw materials as well as finished goods was operating in the early thirteenth century during the period of the Southern Cult stage of the Mississippian period (Mullen 1989; Brown et al. 1990). Research investigating the availability of certain raw materials in the physiographic provinces utilized by Etowah would add much to the understanding of how the exchange worked. What is evident is that the materials for coloration were available. Whether they were used to produce the Etowah textiles is another question.

Systemic/Cultural Stage

Production. Ultimately, the production of textiles by a cultural group is controlled by the decisions made by the corporate group, since the textile product is produced to meet a need or needs (Sibley and Jakes 1989). One cannot discount entirely experimentation and the idiosyncratic use of colorants in the production of fabrics, but these activities are less likely to be the case for objects placed in such elite burials as Etowah Burial Nº 57. More probable is the presence of a long-standing tradition of coloring fabrics by employing certain dyes to achieve specific colors. The end use of the colored textile controls the decision concerning production. Also necessary to the successful development of textiles are (1) the availability of desired raw materials, whether obtained locally or through exchange networks, and (2) the availability of people with technical knowledge and skill capable of utilizing the raw materials.

Coloration of the textile adds another dimension to the traditional steps of fiber, yarn, and fabric production, and the actual addition of color may occur at any one of the steps in the process. Color may also be added to form patterns with motifs placed in special locations to achieve a particular effect, or color may be added through the use of a single color. Much depends on the purpose or function of the textile.

While the data provide evidence for the dyeing of the fibers and feathers of Etowah with colorant available from species of the *Galium* genus, the method by which the fibers or feathers were dyed is unknown. Since it has been shown that the fibers and feathers of Etowah display evidence of dyeing with colorant possibly derived from *Galium* plants, the method for dyeing with anthraquinones must be established. The ability of the prehistoric Native Americans to obtain boiling water has been questioned, but a boiling dyebath is not necessarily required in dyeing. In fact, allowing a dyebath of madder type dyes (anthraquinones comparable to the *Galium* genera) to boil will result in brown or dull colors (Hofenk de Graaff 1969).

Natural dyes display poor washfastness and lightfastness properties if they are dyed onto unmordanted fibers (Schweppe 1989; Hofenk de Graaff 1969). In general, the mordant is assumed to be one of a number of metals that form chelate lakes between the fiber and the dye (Diehl 1972; Hofenk de Graaff 1969). The fact that there is no evidence of heavy metal composition within the Etowah fibers and feathers examined could be problematic except that other routes to dyeing with madder type dyes are indicated in the literature as well. A handbook on natural dyes and dyeing notes that although the mordants most frequently used are metallic salts of alum, chrome, iron, and tin, other agents, namely acetic acid, ammonia, copper sulfate, sodium hydroxide, lime, tannin, and tartaric acid can be employed as well (Schetky 1984).

Farris (1979) states that protein fibers can be dyed from a single dyebath of madder with sulfuric acid, but the properties of the dyeing are not as fast as those produced on a mordant. He recommends the use of hard water or the addition of lime to the dyebath to improve fastness properties. Thus the addition of calcium may be sufficient to bind anthraquinone to fibers, possibly in a mechanism similar to that of chelation of heavy metals. Perhaps the high calcium content of both the Etowah feathers and fibers is indicative of the mordanting of the dye with calcium.

Schweppe (1980) indicates that an orange color can be achieved with madder and ammonia. The addition of urine to dyebaths or after dyeing would have provided a source of ammonia that would mordant the dye to the fiber. This practice has been noted in many prehistoric cultures. The Dakotas dyed porcupine quills by boiling the quills with various lichens and adding urine (Brunello 1973:26).

Tannins may also provide the mordant in the dyeing of fibers. The coloration of porcupine quills with *Galium tinctorium* and sumac berries has been attributed to North American natives (Brunello 1973). Sumac branches and leaves also contain tannins and could act as mordants as well as provide coloration on their own (Densmore [1928]1974; Brunello 1973).

Although the literature uses the term "mordant" in describing the use of acid or base to dye fibers with anthraquinones derived from madder, the mechanism may in fact be one comparable to the dyeing of fibers with vat dyes (Peters 1975). Treatment of anthraquinones with acid or base will reduce the carbonyl moieties, producing a more soluble *leuco* form of dye. Once the dye has entered the fiber, it can be readily oxidized to form the more stable, less soluble anthraquinone structure.

It is evident from the discussion of the dyeing process that EMC 840 and EMC A842 represent very different decision-making processes with respect to their coloration. The nettle fabric has a structural pattern achieved through variation in twining. It is doubtful that patterns in color were superimposed on an already complex structure, although it is not impossible. The textile evidence does suggest that the fabric was of one color.

Different decisions prevail with the feather-faced fabric. Since both the red and yellow downy barbules display evidence of colorant possibly derived from species of the *Galium* genus, production of the feather fabric would have required considerable planning and foresight. The final result would have been a fabric with areas of different color or a color-patterned fabric. Each color area would have required a separate treatment and probably coloring at the fiber or yarn stage rather than the fabric. An alternative explanation must not be discounted. It is possible that the fragment is actually the remains of two separate fabrics somehow folded together during the archaeological stage. The present layered condition of the feather-faced fabric is probably a result of the diagenetic action and not the original shape of the fabrics.

Du Pratz describes the dyeing of feathers in the following manner: "Having first dyed their feathers or hair yellow or a beautiful citron colour with the *ayac* wood, they boil the roots of the *achechy* in water, then squeeze them with all their force, and the expressed liquor serves for red dye. That which was naturally white before it was dyed yellow, takes a beautiful scarlet; that which was brown, such as buffalo's hair, which is of a chesnut colour, becomes a reddish brown" ([1774]1975: 252). Whether the feathers were boiled in the dyebath is not clear. His description of historic Natchez practices may or may not have been used by the earlier Etowah population. Nonetheless, it is interesting to observe that white feathers could have been dyed yellow with dye from the ayac tree, and scarlet or red feathers could be obtained by a second dyeing, this time with the achechy root dye. One is reminded that the red downy barbules from EMC A842 do display particulate matter of colorant along the surface of the shaft while the yellow barbules do not.

When reviewing the steps in dyeing, it seems obvious that to paint pigment on the surface of a fabric would require fewer decisions than to dye fabric materials.

There is evidence of patterns obtained through resist-coloring textiles recovered by the Morehead excavation in the late 1920s. One fragment displays a circle with crosses motif in a regular pattern (Morehead 1932:64).

The knowledge and skill needed to produce fabrics with coloration suggest that certain members of the corporate group acted as craft specialists, at the very least as part-time specialists (Yerkes 1989). Whether the fabrics are evidence of a prestige goods economy with consequent implications for trade remains to be seen (Brown et al. 1990). Although the evidence points to ready accessibility of nettle and dye, the availability of downy barbules of ducks, geese, and swans is less certain, particularly if white down were necessary for obtaining the red and yellow feather fabrics.

Certainly the relation between craft specialists who produced special objects and members of the elite who used the objects continues to be discussed within the context of Mississippian research. The development of objects with increasingly complex forms of production suggests the work of a craft specialist and the presence of a ranked society. Both the Etowah textiles exhibit evidence of sophisticated knowledge of raw materials and the ability to transform the raw materials into textiles of color and pattern.

Utilization. The material objects associated with the Mound C burials are considered those which represent the elite. They act as "badges of status" (Galloway 1989). Counted among the Burial № 57 grave goods are such sociotechnic objects as copper axes. Whether made of exotic raw materials or those available locally, the Burial № 57 grave goods represent the full range of goods that display control of resources (Larson 1989). The question that has perplexed the investigators is, Did the textiles serve a sociotechnic function as well, or did the Etowah people place utilitarian textiles in the graves alongside items displaying prestige? The results of the analyses conducted to date tend to support the high-status nature of the textiles. Coloration in the two textiles adds yet another layer of decision making to already complicated fabric structures. So, the presence of colorants in both textiles simply confirms them as symbols of status.

At the same time the occurrence of red and yellow in the feather fabric and either red or yellow in the twined nettle fabric suggest the possibility that red and yellow have value as symbolic colors. In particular, the juxtaposition of red with yellow raises questions about the importance of the two taken together.

Larson (1971, 1989) proposes that the Mound C burials are those of an elite or dominant clan because both males and females are buried in the mound, and diversity in age is also present. Whether red and yellow represent clan affiliation is unknown, but it is possible. Certainly the historic Creek and Cherokee of the same area employed color to distinguish clans. Red was used to refer to villages of the Red clan while white was also used to indicate the White clan (Swanton 1928; Hudson 1976). Also, specific colors were associated with the points of the compass in the cosmology of the Creek and Cherokee. For example, Swanton (1928) reports that, among the historic Creeks, red and yellow referred to north; blue denoted south; black indicated west; and white symbolized east. Green was used to indicate north or west. For the Cherokee, red indicated east; black referred to west; blue reflected north; and white, south. Yellow meant trouble. The use of red to denote hostility was practiced. Its opposite was white, which was used to indicate a peaceful intent. The selection of the coloration in the Burial Nº 57 textiles was in all probability a deliberate choice to define affiliation with clan, to express part of a belief system, or perhaps both. And the juxtaposition of red and yellow in the same fabric or related fabrics was not a matter of color preference but rather a result of cultural values.

Untroubled by any meaning attached to color in the textiles of the Indians, members of De Soto's expedition reported seeing red and black on carefully prepared skins, red (and black?) on blankets of nettle, and feather blankets of "branca, verdes, vermelhas, & amarellos" (Robertson 1933:1, iv) or white, green, red, and yellow. Both the blankets of the barks of trees and the feather blankets were discovered in an abandoned "barbacoa," or raised houselike structure (Robertson 1933; Lewis 1907).[1] The importance placed on the colors represented in the feather fabrics is unknown, although it is interesting to find reported fabrics with colors to which the Creek attribute directions of the world. Nor did the Gentleman of Elvas indicate whether more than one color was present in each blanket. One further comment is pertinent. The blanket is described as a covering to the body somewhat like a shawl that was draped over the shoulders.

Also important to De Soto's expedition was an encounter reported by Ranjel, De Soto's secretary. Ranjel described the dress of a "cacique," or chief, as including a feather mantle that hung from his shoulders to the ground. In this case the feather mantle, or "pelote," was serving as a high-status garment and symbol of rank and authority. Ranjel's comment (translated into English by Bourne) is "very imposing" (1904:120). The Burial Nº 57 feather fragment may well be the remains of a feather mantle worn by a leader.

Archaeological Stage

The placement of the adult male in a log tomb burial accoutered with copper, shell beads, conch shell bowls, and textiles of variety and color was the final acknowledgment of the male's status in the Etowah society. As a select burial, it included the trappings of his authority as part of the interment, not as a ritual offering (Larson 1989). The subsequent changes that occurred are the result of the interaction of the buried artifacts with the surrounding environment. Initially resting in an open area in a log tomb, the textiles were compressed by the later collapse of the tomb. A shifting of artifact location is also likely. Surrounded by soil and permeated by rainwater, the textiles would have been infiltrated with soluble soil elements and soluble products of corrosion and degradation of other artifacts in the burial site. The further impregnation and/or replacement of the fiber's organic composition with copper compounds would have led to the inhibition of biodeterioration and preservation of fiber morphology.

Summary

Two textile fragments from Burial Nº 57, Mound C, Etowah Site (EMC 840 and A842) were examined for evidence of coloration added during their fabrication.

Chemical and physical analyses show that, despite the depth of color observed in red and yellow *Anseriformes* downy barbules, there is no evidence of the presence of pigmentation. Although red ocher was available in the region where Etowah is located, it was not used to add color to the feathers. Nor was it used to add pigment to the bast fibers that served to anchor the red and yellow feathers of EMC A842 and the nettle fibers of EMC 840.

Infrared and visible microspectroscopic analyses reveal that the feathers and fibers contain a composition that is similar to the colorant composition of *Galium aparine.* Of the three plants of the *Rubiaceae* family that were evaluated, the spectrum of *Galium aparine* alone was reflected in the spectra of the feathers and fibers that were examined.

X-ray microanalysis spectra display characteristics of the fibers that indicate the biological differences between them as well as reflect the contamination from the soil in the archaeological context. Further, there is no evidence of the presence of a metal mordant, although the high calcium content of the fibers suggests the possible use of a calcium mordant for the anthraquinones of the colorant discovered in the red and yellow *Anseriformes* downy barbules of EMC A842 and the nettle fibers of EMC 840.

A second line of investigation analyzed the use of coloration in the archaeological, ethnohistoric, and ethnographic records. The results of this inquiry provided a context for the chemical and physical analytic results. Using the three stages of the proposed model (biologic, systemic/cultural, and diagenetic), the investigators examined the implications of the evidence.

Biologic stage. It is evident that the Etowah population collected plants of the *Rubiaceae* family, probably species of the *Galium* genus to use in coloring two different types of textiles. The discovery of no heavy metal and the presence of calcium mean that the population made decisions concerning which raw materials to collect and use as a mordant.

There are numerous possible additional sources for dyes reported in the ethnohistoric record. The establishment of a comparative collection of material and its examination will result in a significant contribution to knowledge of prehistoric people.

Systemic/Cultural stage. Decisions by the Etowah population also affected processing and the addition of dye and mordant to the textile fibers and feathers. Based on other evidence, the investigators propose that EMC 840 was originally dyed one color, either a red or a yellow. EMC A842 would have required additional planning since addition of each dye would have to have been done at the fibrous mat of downy barbules stage of production. What is evident is that there is an apparent tradition of using red and yellow coloration in societies in southeastern North America. Although meaning of the coloration tends to vary somewhat, both colors are used during the 500-year period from 1200 through 1730 C.E. The use is not limited to textiles but appears in other material objects. At least for the Etowah textiles and the textiles viewed by De Soto's expedition, the colors were applied to bast fiber blankets as well as to feather mantles and appear to be linked to clan affiliation and/or high status.

Archaeological stage. The archaeological context for the Etowah textiles is that of a high-status burial of an adult male in a log tomb. The amplitude and quality of the other grave goods underscore the elite position occupied by the male in Etowah society and accompanying him in the grave. The subsequent changes that occurred led to the collapse of the log tomb and the compression of its contents. Whether the feather-faced fabric was one or two is uncertain. What is certain is that the Etowah people placed a colorful feather-faced fabric in the tomb along with an equally colored nettle blanket.

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Note

1. The Portuguese terms for the colors are from a facsimile of the sixteenth-century Portuguese (Robertson 1933:vol. 1, iv), but Robertson (1933:vol. 2, 76) and Lewis (1907:166) translate the passage as white, gray, vermillion, and yellow. It is curious that the translators of the Portuguese used the term gray instead of green for *verdes.* Written originally in Portuguese, the account has been translated using vermillion for *vermelha* (red) (Robertson 1933:vol. 1, iv; Lewis 1907).

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Radiocarbon Dates of Teponaztlis from Mexico

REINER PROTSCH VON ZIETEN
AND RAINER BERGER

Teponaztlis are horizontal, cylindrical wooden drums with slotted tongues that were struck by tongs. They are known from museum collections such as those of the Museum of the American Indian, Heye Foundation (16/3373), and stem from Aztec times. In 1946 a teponaztli was given to the Lowie Museum, University of California, Berkeley, as part of the Inez Mejia collection (Fig. 1). It was radiocarbon-dated as UCLA-1482. Another teponaztli from a private Southwestern collector was also analyzed by the same technique as UCLA-2848. In both cases the rationale for testing was the question of whether these drums were of Pre-Columbian origin.

For sampling purposes, the Lowie specimen was drilled into, and 7.6 g of wood shavings were removed. The location of the drill hole was close to the central tree rings to avoid damage to the carvings on the outside of the drum. Between the central tree rings and the outside of the drum there were at most about twenty rings. The other drum was sampled from the bottom edges near the outer perimeter of the drum, and 6.5 g of wood chips were collected.

For chemical pretreatment purposes, the wood chips obtained were extracted continuously in a Soxhlet with ether until the extract contained no more solute.

FIGURE 1. *Teponaztli from the Lowie Museum (UCLA-1482).*

Thereafter the samples were treated in succession with diluted 2N hydrochloric acid and 0.1N sodium hydroxide. After washing with distilled water, both samples were dried at 110 °C. The samples were then converted to pure CO_2 gas and assayed in the proportional counting system of the Archaeometry and Isotope Laboratory at the University of California, Los Angeles with the following results (Stuiver and Pearson 1986):

Sample	14C-age b.p.	Calibrated age
Lowie teponaztli (UCLA-1482)	330 ± 40	1474–1642 C.E.
Southwestern teponaztli (UCLA-2848)	<300	max. 1700 C.E.

Thus the Lowie teponaztli belongs in either the Late Post-Classic period or the Early Colonial period. Yet due to its temporal placement at the transition from the last purely native to early colonial times, it is likely that the motifs used in its decoration reflect the original Pre-Columbian techniques and style. The Southwestern piece belongs clearly in the Colonial period or could be even a modern adaptation made as recently as the twentieth century. While its motifs may resemble the original native ones, they can at best be a carryover.

In summary, Aztec motifs carried over into recent times do not by themselves necessarily offer reliable criteria for correct chronological placement necessary to establish cultural veracity. Independent radiocarbon tests can be helpful in age dating, unless it can be shown conclusively that old wood was used in recent times to create a forgery.

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