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CHAPTER 8

Archaeometry

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IN RECENT YEARS, southeastern archaeologists have begun to write the history of their intellectual development. This exercise has been caused in part by the golden anniversaries of archaeological societies such as the Society for American Archaeology (Watson, ed. 1985) and more particularly, the Southeastern Archaeological Conference (Knight 1990); by the need to educate younger archaeologists to the nuances of a profession that has been slow to chronicle or to honor the contributions of archaeologists nearing retirement, except through plenary sessions at regional meetings; and by the need to understand the philosophical and political positions that have shaped current interpretations of the archaeological record. Where some writers have turned to substantive themes (Watson 1990), federal sponsorship (Haag 1985; Keel 1988), and biographies (Willey 1988) to illustrate major trends, we review the application of certain archaeometric analyses in southeastern research, principally those involved in materials characterization. An archaeometric analysis simply involves the application of techniques derived from the physical and chemical sciences to characterize archaeological materials. Its distinguishing feature is the scientific objectification of observational data.

We make no attempt to be exhaustive in our coverage of either technique or specific application. General reviews of archaeological applications of techniques may be found in Tite (1972), Aiken (1974), Goffer (1980), Parks (1986), Leute (1987), Mommsen (1986), Bishop et al. (1982, 1990). These general works may be supplemented with issues of *Archaeometry*, the *Journal of Archaeological Science*, and the Archaeological Chemistry series of the American Chemical Society. Our examples are selected

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to exemplify archaeometric activity in the Southeast. The choice of materials that have been analyzed and therefore form the corpus for review is the direct result of the interest of archaeologists working within identifiable research paradigms.

Even though the geographic focus of this article is the Southeast, our comments will necessarily crosscut natural and even cultural boundaries. The natural properties of the materials being characterized set up conditions of study as do the procurement and distribution systems in which the materials circulated. From a cultural standpoint, it appears that, at times, material needs were met wholly within the Southeast, whereas at other times, especially in the quest for sumptuary items needed to reflect heightened social or economic worth, materials were obtained via long-distance interaction, outside the Southeast proper (Steponaitis 1986).

Materials Characterization of Exotics in the Southeast

Materials characterization of an archaeological object is used to answer such questions as, What is it made of? Where did it come from? How do its properties influence its performance? (See also Kingery 1982.) By far the most common questions asked by archaeologists have related to raw material procurement and redistribution systems, especially the long-distance exchange of exotics or sumptuary artifacts. Hopewell "exotic" materials circulating in the Middle Woodland period were among the first objects to undergo characterization studies. The reasons behind their selection and the reasons for a lack of similar studies for other temporal periods, although not explicit, appear to be historical. Certainly, many of these same "exotics" circulated over long distances during the Late Archaic and Mississippian periods (Winters 1968; Ottesen 1979; Johnson 1992), but the models that discuss the possible mechanisms for such exchange have only lately been proposed (e.g., Winters 1968; Marquardt 1985; Brown et al. 1990). In contrast, Hopewell long-distance exchange was modeled in an exchange sphere or interaction sphere with the nodes or sites identified by the presence of nonlocal, raw materials and well-finished artifacts of these same materials in the assemblages (Struever 1964; Struever and Houart 1972).

A certain level of social complexity must exist for materials characterization to lead to supportable inferences about exchange. The description of an exchange sphere by Binford as the "areal (matrix) of regular and institutionally maintained intersocietal articulation" (1965:208) specifies the operational criteria that must be met. The regular maintenance of the flow of goods is a necessary condition for materials characterization studies that attempt to delimit sources of raw materials. These sources must be used repeatedly in order to see patterning beyond randomized, individualized extraction events. Indeed the patterning must be robust enough to compensate for the comparatively few samples that compress hundreds of years.

Archaeologists have relied primarily on the criteria of abundance and fall-off models to identify raw material sources for Hopewell artifacts (see Seeman 1979). For materials that occur under restricted conditions, archaeologists may need only a geologic map to narrow possibilities relative to access. But difficulties arise when more than one equally accessible source exists or when the source implies unexpected levels of complexity in procurement or distribution.

To help overcome these difficulties with the Hopewell exotics, several types of raw material that figured prominently in Hopewell exchange have been the subject of materials characterization. The studies of obsidian, native copper, and galena, which are continental or interregional in terms of source identification, introduce some of the methodological procedures and problems associated with interpretations of multiple-source data.

Obsidian

Trace elemental analysis of Hopewell obsidian artifacts was the first materials characterization study to gain widespread recognition among archaeologists working in the Eastern Woodlands (Gordus et al. 1968). The virtual absence of Hopewell obsidian artifacts outside of Ohio and the observation that the closest obsidian sources were to be found in the western United States, Alaska, and Mexico at once highlighted the possible magnitude of the Hopewell interaction sphere and suggested an alternative to down-the-line exchange. The obsidian project, begun in 1964, was the first of many undertaken at the University of Michigan. At the urging of James Griffin, Adon Gordus, a professor of chemistry, took time away from his study of ancient coins to apply instrumental neutron activation analysis (INAA), which he was using, to obsidian (Gordus 1967; Gordus et al. 1968; Griffin et al. 1969; see also Gordus et al. 1967; Griffin 1976:35). Colleagues were quick to supply obsidian materials to the scientists, and it helped that similar investigations of obsidian were also begun about the same time (e.g., Cann 1968; Renfrew et al. 1968).

The initial screening of samples was carried out using only two elements, sodium and manganese, which limited the possible sources to "Obsidian Cliff in Yellowstone National Park, a source in Idaho, and a source in Mexico" (Gordus et al. 1968:93). The final attribution to Yellowstone was based on five to ten additional elemental determinations. These additional elemental analyses were made possible by instrumentation equipped with a NaI (Tl) scintillation detector, single channel analyzer, printer, and paper tape storage. Although this was a early application of the analytical technique, it was methodologically advanced in the following ways: attention was given to maximizing the analytical precision; standards were used in each irradiation so that elemental determinations could be kept to a constant reference base; and the process was semiautomated to provide for numerous sample throughput. These methodological procedures remain basic, and analytical rigor is dependent upon how well they are followed (Bishop et al. 1990).

Native Copper

From a methodological perspective, the analytical history of native copper is interesting for it has been the subject of investigation by at least three groups of researchers who used different analytical approaches. While all the native copper studies concentrated on analytic issues, one of the researchers, Sharon Goad, interpreted her results archaeologically. In her dissertation (1978) and subsequent articles (1979, 1980; Goad and Noakes 1978), Goad demonstrated that much of the copper found in the Middle Woodland period was derived from the copper sources of the Great Lakes, particularly from the Keweenaw Peninsula and Isle Royale. Other sources were also identified for the Middle Woodland artifacts, including sources from Wisconsin, and several southeastern ore sources in the Appalachians.

The attribution of southeastern copper artifacts to local southeastern sources supported increasingly regionalized interpretations of Hopewell participation (Brose and Greber 1979). Although copper may be considered an exotic when it came into the Southeast from the Great Lakes, local ores were also available. By demonstrating that local sources were used even sporadically, Goad (1979) was able to suggest alternate exchange patterns. For example, the Southeast panregional exchange centers in the Southeast might have been able to supplement local distribution through the locally manufactured items. This supplementation is thought to have been a late development that culminated in the Mississippian period when procurement focused on the exploitation of sources indigenous to the Southeast with only minor representation from the northern sources (Goad 1978).

Data for Goad's study were produced by optical emission spectroscopy through collaboration with scientists of the U.S. Geological Survey in Denver, Colorado, and Reston, Virginia. In brief, a solution containing the dissolved copper sample was heated to a sufficiently high temperature to cause the elements in the sample to emit unique spectral lines. The lines were recorded on a photographic plate and scanned by a microphotometer for a determination of the wavelength intensity of each line. Following various background subtractions and other spectral analysis, the concentrations were calculated relative to calibration curves.

Results obtained from this mode of analysis were only semiquantitative (Goad 1978:254). Goad acknowledges that the analytical precision of the technique rests on multiple factors, but she does not give a estimate of the error in the data. Given the compromises that are made, for example in sample preparation, use of standards, and equipment errors such as plate fogging, precision with an error rate in the 10–20 percent range would be reasonable for emission spectrographic analysis (Mitteldorf 1965:217; see also Jones 1986: Table 2.2).

Goad proceeded to summarize the analytical data beginning with a cluster analysis followed by a discriminant analysis. Outlier samples were removed and the clusters of sources formed with Ward's method using previously obtained principal component scores. Attribution of the artifactual data to probable source groups was based on a pooling of the source and artifact data, reclustering, and subsequent discriminant analysis. The resultant groups were not exclusive, showing overlap usually with source materials that were geologically adjacent to one another (Goad 1978:63–82).

Hindsight suggests that Goad's research was limited by the choice of an analytical technique that in its earlier form generally suffered from low sensitivity and precision (Harbottle 1982a:21). The use of wavelength intensities, rather than absolute concentrations calculated relative to given standards, further limits the use of the data by others. Finally, the data analysis, while thoughtful, was hardly rigorous with disproportionate reliance being placed on discriminant analysis (see Bishop and Neff 1989). These musings aside, Goad's research represents a valuable contribution to methodological development and to substantive understanding of the archaeological issues she set out to address. She was able to distinguish between the use of northern and southern copper ores, but a more precise technique is necessary to distinguish within source variability.

A limited program of instrumental neutron activation analysis (INAA) was carried out by Goad in collaboration with John Noakes. Although the greater sensitivity of the technique produced a greater number of usable elemental concentration, the interpretative value of their analysis was inconclusive (Goad and Noakes 1978:341). One problem that they cite concerned the masking of the gamma spectra due to the activity of silver. The cause of their problem is unclear because this particular masking effect was not found in a study of native copper conducted by Emil Veakis (1979).

Veakis analyzed native copper source samples from Michigan, Alaska, and Arizona in a effort to assess the extent of intrasource variation through the application of INAA. Copper artifacts were subsequently evaluated as to their agreement with the elemental variability observed in the source materials. A central component of this study revolved about the determination of an optimal program of standards evaluation, analytical sample size, irradiation, cooling, and gamma ray spectroscopy. Several of the samples contained a high silver content. Based on Veakis's study, the "silver" masking effect noted by Goad and Noakes is more likely to have been the result of an insufficient cooling period to permit the activity of the copper isotope to decay with spectrographic problems compounded by Goad and Noakes's use of a detector with less resolution than that used by Veakis. Veakis does not report the resolution of the detector but at that time the detector in use at the Brookhaven Laboratory was on the order of 1.9 keV compared to the 2.3 keV resolution reported by Goad and Noakes (1978:338). Drawing more exact comparisons between the two studies is hampered further because Goad and Noakes do not report the length of counting time.

Since 1966 George Rapp has conducted an extensive program of analysis of native copper from North America, studying in particular the within-source variation in copper from northern Michigan (Rapp et al. 1980; Rapp and Allert 1984; Rapp et al. 1990). Over 1,200 samples have been analyzed in the ensuing 24 years. While the results of these analyses now comprise an impressive data bank, at least in terms of sheer numbers, the utility of these data for further comparative analyses is somewhat questionable.

Rapp and his co-workers have taken what might be called a "rationalizing geological perspective" to the variation that might be found in native copper deposits. Over the years, they made changes in analytical procedure, involving not only the gamma spectrometry but also the use of standards. Rapp and his associates first used emission spectrography, similar to Goad's work, but later abandoned it in favor of the increased precision of INAA. They also changed standards in 1973 and changed again to yet a third set in 1981 (Rapp and Allert 1984:274). Although different standards can be used (see Harbottle 1982b), they report no attempt to normalize the data to a common analytical standard reference base but rather state that their data are "unhomogeneous" (Rapp and Allert 1984:274). Nevertheless, "it is [their] contention that the inherent heterogeneity of the raw materials and the lack of any ancient technology to remove impurities *probably* combine to make measured differences in trace element concentrations of less than one-third of an order of magnitude . . . insignificant in provenance studies of prehistoric copper and bronze artifacts" (Rapp and Allert 1984:274, emphasis added).

There is no doubt that even though some sources of raw materials—for example, jadeites (Bishop et al. 1992) or turquoise (Garman Harbottle, tle, work in progress)—exhibit a great range of variation, differences among sources can still be determined, partially overcoming analytical error. Accumulated analytical errors, however, can have adverse impacts when attribution to a specific source among related sources is the issue: an analytically induced heterogeneity in the data base will compromise attempts to summarize the data using various statistical programs that draw on interelemental correlation properties (for example, discriminant analysis). Rapp and his associates (1980; Rapp and Allert 1984) formed five groupings of possible native copper source areas in Michigan based on a rank-ordered partitioning of the elemental concentrations, but it is difficult to assess whether these groups are the result of natural or analytical heterogeneity.

For now and in the immediate future, Goad's emission spectroscopic work will provide the analytical and comparative baseline for an interpretation of native copper procurement and distribution. Ultimately, more sensitive and precise techniques can and must be used if the specificity of source attribution is to be improved. Instrumental neutron activation analysis can and has been used, but a data base that reflects close attention to analytical precision and accuracy has yet to be developed to address issues of interest to southeastern archaeology.

Galena

In "an attempt to attack quantitatively the problem of Hopewellian diffusion" Walthall and his collaborators (Walthall et al. 1980:21) engaged in a compositional characterization of galena. Galena samples from several geological sources in the eastern United States were studied along with artifacts from sites representing occupation from the Archaic through Historic periods (Walthall 1981). Early on, the artifacts were analyzed by atomic absorption spectroscopy, but only some of the source samples were so analyzed. The remaining source elemental concentration values were obtained from the literature or from personal communication, and these values were based on emission spectrographic analysis. By 1981 it appears that most of the source samples had been analyzed by atomic absorption, thus bringing the source materials into a more readily comparative level with the artifacts (Walthall 1981).

Walthall, Stow, and Karson (1980) relied on discriminant analysis to attribute artifacts to three "districts." They concluded that rather than exploiting sources in the more immediate area, the occupants of the Middle Woodland Copena Mounds obtained their galena from sources in the Wisconsin-Illinois-Iowa region of the Upper Mississippi Valley. A more extensive analysis using a total of 252 galena samples representing 83 archaeological sites revealed that two of six characterized districts, the Upper Mississippi Valley and Southeastern Missouri I (Bonneterre), were the most heavily exploited sources for Eastern Woodland galena (Walthall 1981:36).

Galena is a naturally occurring material that can form in very different environments and can undergo various stages of alteration yielding secondary minerals. The extent of variation among the elements that were determined in the analyzed galena had to be derived empirically for each district. The wide ranges of elemental concentrations within a given district are not surprising nor are they necessarily larger than that observed for other naturally occurring materials, such as turquoise or jadeite. Indeed, this step of actually determining the elemental abundance in galena is far easier than that of deciding what constitutes a useful characterization.

All samples from a district or a source appear to have been included in the subsequent stage of discriminant analysis (Walthall et al. 1980; Walthall 1981). That is, there was no attempt made to refine a group through the elimination of outliers nor was there an attempt to extend the sampling of some sources to determine whether or not "dirty" galena was present (Walthall et al. 1980:29). We do not know to what extent those galena with extreme values within a district might, in fact, suggest that multiple, "natural" compositional patterns are present within a given formation.

In 1981 Walthall stated that further analyses using atomic absorption supported his previous conclusions, but he did not present the geological source data or the statistical data. Given the potential variation within the formation environment, the often extreme univariate overlap in analytical composition, and reliance on discriminant analysis—a technique that tends to support the grouped data whether they represent separate groups or not—we can only concur with Walthall, Stow, and Karson's (1980:31) earlier statement that "it is surprising that the galena sources can be distinguished as well as they can."

Localized Extraction, Production, and Exchange in the Southeast

The scale of exchange often determines how archaeologists differentiate between exotic/nonlocal and local materials. The success of sourcing long-distance "exotics" raised the possibility that similar studies could be carried out on materials derived from local sources and used locally in the Southeast.

Information about local sources has most often been used to reconstruct settlement-subsistence rounds of activities that link populations to the repetitious use of resources in spatially defined areas. Differential distribution of artifacts produced from materials that are found within a region may also reflect exchange, however, especially if the material is valued for its technological or socioreligious attributes. Distinguishing between intraregional exchange and direct procurement of materials depends not only on the natural distribution of these materials, but upon the organizational complexity of the procurement and redistribution systems as well. Materials characterization can provide data not only on source area, but also on functional and sociotechnical patterns.

Many of the materials characterization studies carried out to date have been primarily methodological, as analysts search for techniques to define the range of natural and cultural variation. The techniques of materials characterization when used to answer questions about localized exchange or localized adaptive strategies require observation and measurement of physicochemical differences on very fine scales. Such refinement or control is particularly difficult to achieve in the Southeast, where materials, particularly those used for subsistence purposes, are uniformly distributed throughout the region.

The Southeast is an old geologic regime that supports a richly diverse biota: rivers flowing through eroded uplands sweep widely over the coastal plains depositing rich alluvium before meandering out to sea. These broad distributary systems transect similar geological zones, and although the effects of incline can be seen in the vegetation, there is a great deal of geophysical homogeneity between distributary systems.

Despite this overall homogeneity, material resources being exploited from mixed riverine alluvial deposits or from residual exposures may be highly localized, and thus may be differentiated. The mapping of microzonal variation in biotic resources has facilitated archaeological reconstruction of the biological resource base and subsistence-related activities. Because similar mapping of the geochemical variation within and across geological outcrops has yet to be realized, the cultural significance of compositional differences in the material assemblages may not be as immediately obvious. To the extent that highly localized resources can be characterized compositionally, material (artifact) attribution may be very specific. The converse, of course, also holds true. Should a compositional profile of a group or class of artifacts fail to match the patterns of the characterized material resource, the archaeologist cannot necessarily conclude that the resource was not used. There may be simply too much variation within the deposit, variation that may not have been sampled, to rule out possible exploitation.

Some biological species, such as shell, which take on the geochemical characteristics of specific drainages, can be difficult to map, as the geochemistry of these microzones changes over time. Materials that are found embedded in a number of different types of geological formations, such as soapstone or chert deposits, are equally difficult to distinguish as the range of variation with a single deposit often dictates the need for an extensive analytical sampling strategy that can overwhelm the limited analytical resources available. Relaxing the parameters that define the variation can have contradictory effects. The concatenation of sparsely sampled regions into a single compositional reference unit may so pertubate the parameters that attributing artifacts to a "source" becomes spurious.

The observed range of variation that is due to sampling is only one of the factors contributing to the total range of variation that has to be filtered before exploitative patterns become apparent. In addition to the natural variation in the materials and the analytical variation imposed by instrumentation and sampling, the compositional profile of the artifacts is also the result of cultural variation. That is, there is variation beyond that related to idiosyncratic extraction activities. In most cases, the cultural variation relative to material resources pertains to selective criteria, which is the exploitation pattern being sought, but in other cases, especially in ceramics, this variation pertains to the modification and admixture of materials collected in their natural state.

Although the cultural variation contributes to sourcing problems, this variation also becomes a focus of study in materials characterization analyses that attempt to determine the performance or functionality of the artifact, such as ceramic performance. The modification of materials is usually intentional, and further analysis may lead to an understanding of how technological developments improve adaptive responses. Depending on the scale of the study, some modifications may be correlated with technical knowledge or conventions that differ between production units. In such cases, the organization of production is also being monitored.

Shell

The use of marine shell artifacts dates from the Early Archaic but was particularly extensive and widespread in the southeastern United States during Middle Woodland and Mississippian times (Ottesen 1979). Shell was involved in diverse social contexts, as inferred by its use as utilitarian items by coastal peoples and as religious objects or as symbols of status among inland groups (e.g., Peebles 1971; Peebles and Kus 1977). Recent attention has been called to the possibility that among Mississippian societies, marine shell, usually in the form of beads, was used as a form of wealth (Prentice 1987), as *wampum* was in postcontact times. Trade is inferred when the shell is found in an inland archaeological context, away from possible marine source areas. As for other "exotic" materials, the attribution of shell to its source area(s) would serve to focus, more sharply, directionality in trade. When certain shell artifacts retain sufficient identifying characteristics to ascribe the shell to a particular species (e.g., Goad 1979), an attribution to a broadly defined source might be possible, although the range of species habitats along the southeastern coast can be extensive. With many smaller artifacts, attribution to any particular region is far more speculative.

Common sense tells us that sources for marine shell lie along the Gulf and Atlantic shores and in the mouths of tidal rivers. In an attempt to impart more locational specificity, Katherine Miller (1980) investigated the extent of chemical variation among quahog or hard-shell clams (*M. mercenaria*). Under the guidance of members of the Chemistry Department at Brookhaven National Laboratory, Miller carried out instrumental neutron activation analysis (INAA) and atomic absorption spectrometry on specimens from along the Atlantic seaboard: Maine, Massachusetts, Long Island, and Georgia. INAA was an important choice for analysis as the small sample size necessarily meant that, if successful, the technique could be extended to include small objects or small samples taken from large but elaborately carved objects. Atomic absorption, although necessitating an appreciably larger sample, nonetheless affords an opportunity to obtain data on additional elements, including those that are important in influencing the calcite to aragonite ratio of the shell.

Since the chemical makeup of the shell for a given species is influenced by the immediate conditions of temperature, salinity, and ions available from the drained geological environment, it was reasoned that chemically distinct zones along the Atlantic shore might be identifiable. Ten elemental concentrations with acceptable levels of analytical precision were quantified; six of these were determined to be useful for differentiating among the sampled regions.

Although Miller's preliminary findings indicated that it was possible to differentiate among shells of *M. mercenaria* at an interregional level, other findings, such as an inability to compare, in a meaningful manner, archaeological and modern shell and the need to measure more fully the chemical variation within the shell, have limited the rush of others toward chemical investigation of this material. A notable exception, however, is the work by Cheryl Claassen (1985b, 1987, 1988; also Coughlin and Claassen 1982) who has continued to pursue chemical characterization of marine shell within a single region (that is, *M. mercenaria* from North Carolina) using atomic absorption. The findings from her studies demonstrate that chemical elements which were absorbed by the marine shellfish resulted in compositionally specific signatures among North Carolina's watersheds (Coughlin and Claassen 1982; Claassen 1988).

Claassen (1988) also has reported on the analysis of three *Busycon* shells by X-ray fluorescence. In addition, David Brose (Claassen 1988) has submitted archaeological and modern *Busycon* shell for analysis by inductively coupled plasma emission spectroscopy (ICP). To our knowledge, however, the results of the latter study have not appeared.

Miller's initial study and the more recent investigations by Claassen serve to illustrate the inherent difficulty encountered in attempts to characterize marine shell. At the present time, the studies remain exploratory, primarily methodological refinements of technique as well as identification of sources of variation. Atomic absorption or ICP requires substantially larger samples for analysis than INAA, large enough, in fact, to probably exclude the sampling of small beads or elaborately carved artifacts. Without fast adherence to secondary standards or "comparators" and careful attention paid to analytical precision, the chemical data produced by one technique may not be relatable to that obtained by others, leading to noncomparable data sets. Additionally, providing that a given technique can provide data of requisite sensitivity and precision, the basic notion of what constitutes a "source" will require modification. Unlike the sources for many other types of raw materials found in the archaeological record, the marine shell "source area" is one that might move location over time, depending on species, and would therefore be influenced chemically by new environments. It is clear that efforts to determine the source locations for marine shell have a long way to evolve before substantive interpretations can be made.

Soapstone

The analytical sourcing of soapstone has received more "archaeometric" than "archaeological" attention. In a series of articles, chemist Ralph Allen and various associates discuss a neutron activation program for soapstone analysis (Allen et al. 1975; Luckenbach et al. 1975; Allen and Pennel 1978; Allen et al. 1982). Similar methodological approaches have also been applied to an investigation of soapstones in Labrador (Rogers et al. 1983). Geochemical considerations of variable parent materials evaluated with principals of ionic substitution caused the researchers to place primary reliance on patterns found for the rare earth elements when normalized to chondrite abundances. A source area is represented by an average chondrite-normalized profile whose distribution curve is then compared to the curves for other sources.

Analyzed soapstone artifacts that are considered to be matches for a characterized source profile are used to suggest extraction-distribution patterns. The choice of data summarization, based on the normalized distribution curves, presents little opportunity to consider the extent of variation among the characterized sources or within a given source. To date, the reconstruction of soapstone procurement and distribution "routes" is seemingly based on a very limited number of artifact analyses.

As mentioned above, the soapstone program has been predicated upon expected elemental behavior given certain assumptions about soapstone formation processes. These assumptions made by Allen and his coworkers have recently been called into question by data presented by Moffat and Buttler (1986) in their study of rare earth distribution patterns in Shetland soapstone sources. Moffat and Buttler conclude that it is unlikely to expect that steatites found within a given complex will have a similar rare earth profile throughout the complex given the nature of the formation process and involvement of different parent materials; unrelated sources may have a *similar* rare earth compositional profile as a result of the formation process; and from a consideration of fractionation, there is no reason to believe that rare earth elements will be evenly distributed in steatite minerals (1986:113). It seems obvious that more than just average normalized profiles must be reported before we can assess the extent of inter- and intrasource variation let alone the extent of artifact correspondence.

Chert

The sheer quantity of chert artifacts recovered from southeastern sites would suggest that an adequate program to relate artifacts to sources would provide data on extractive and redistributive activities. Traditionally, chert sources have been classified and attributed to regional sources on the basis of visual properties, that is, luster, inclusions, texture, and particularly color (Futato 1983b; Prothero and Lavin 1990). That chert receives different varietal names based on its color and impurities suggests that petrographic analysis would be a useful approach to its characterization. At the same time, it is an indication of the potential variation that can be encountered in a chemical analysis. Analytical difficulties arise because chert forms in a sedimentary environment, most frequently derived as a replacement product in a carbonate host rock (usually limestone) or as a product from ephemeral silica-rich alkaline lake environments. Other than macroscopic impressions, however, chemical analysis of chert appears to be the preferred approach to source identification of southeastern cherts, but the material has been recalcitrant.

Depending upon the amount of impurities such as clay, hematite, or calcite (each of which have their own variable trace elemental pattern), the degree of chemical variation within a source can be large, and thus extensive analyses of sources and artifacts would be necessary for a characterization project—or, if the variation is too great, the observable variation could easily preclude a chemically based investigation. Furthermore, trying to classify varieties can be extremely difficult because at a given level of analysis macroscopic differences, such as color, might not correspond to chemical differences.

In a study of Fort Payne chert from Mississippi (Futato 1983b), the elemental concentrations of K, Ca, Fe, and Na were found to occur at the trace level (below 100 parts per million) and to be fairly homogeneous across different color zones in a ca. nine by eight meter exposure. In another study carried out by Hoffman (1981), a combination of petrographic, structural, and chemical analysis was used to locate sources of chert recovered in a survey area within Tishomingo County, Mississippi. Qualitative and semiquantitative chemical analyses were obtained by emission spectrometry and quantitative data by atomic absorption spectrometry. X-ray diffraction confirmed the predominant quartz component of the chert. Hoffman's results also revealed that in spite of color differences, the chemical analyses demonstrated considerable homogeneity, indicating that specific sources could not be inferred for chert found in the study area.

In the case of chert, as well as other types of materials, questions surround the extent of localization of an analyzed source—whether or not the "homogeneity" viewed by a subset of attributes by one analytical technique is useful for discriminating among nearby or more distant sources. The most extensive investigations of trace element characterization of chert have been carried out by Barbara Luedtke (1978, 1979; Luedtke and Meyers 1984; see also Ives 1984, 1985). Like other studies that use trace elemental characterization to differentiate among the products of different sources, the study was predicated on the assumption that a material source can be considered to be compositionally similar and relatively dissimilar to other characterized sources. Luedtke's investigation of compositional variation in American midwestern chert clearly revealed that a single source can be extremely variable, which would appear to vitiate the use of a trace elemental approach for chert (Luedtke 1978; Luedtke and Meyers 1984). Nevertheless, Luedtke's careful sampling and attention to the variation within a source area permitted her to reach archaeologically useful conclusions.

Outside of the United States similar conclusions were reached by Mark Tobey (1986; see also Tobey et al. 1986). Focusing on the variation within the chert-bearing region about the site of Colha in Belize, Tobey and his co-workers concluded that compositional separation into several relatively homogeneous groups was possible despite the apparent variation within the source area. Unfortunately, the Colha program of trace elemental analysis has not included chert sources outside of the Colha chert area. Therefore, it is not surprising that the researchers parsimoniously concluded that the extensive chert source area in immediate proximity to the site of Colha was the source for the Colha chert!

Where, then, do these studies leave the Southeast? Certainly, the work of Luedtke and Meyers (1984) within the Burlington formation offers hope that a trace element investigation of chert sources and artifacts might be successfully carried out in the Southeast. Such a chemically based investigation will need to be extensive in order to sample multiple source areas within a region and to analyze a sufficient number of artifacts so that the artifactual variation can be meaningfully compared to the sources.

Ceramics

A few years ago, Jerry Milanich, commenting on PIXE ceramic analyses, wondered if "Twinklebell [*sic*]" would be next (1985:177). If, as he implied, PIXE applications were being treated as something magical, a technique that could stave off laborious rites of passage in the quest for analytical data, there is indeed a flirtation with Twinklebell.

Proton induced X-ray emission spectroscopy (PIXE) is a technique of microanalysis that is capable of obtaining major and minor concentrations of elemental data at a greater sensitivity than X-ray fluorescence (Kullerud et al. 1979). Glen Doran (1984, 1985) has investigated the use of PIXE as a relatively quick and very inexpensive means of obtaining analytical data on pottery. He cites the vast disparity in cost between neutron activation analysis at the commercial rate of $450 per sample and PIXE at approximately $10 per sample (1984:115; 1985:104). In reality, of course, no archaeological program could afford INAA at such a commercial rate, and thus the comparison is rather spurious.

Doran proposes a further cost-saving technique of using a scraped sample rather than preparing the more usual pelletized one, realizing a savings in time of approximately 80 percent. More cost cutting is achieved by not employing analytical standards, relying instead upon the proportional intensities of the emitted X-ray spectrum. Determinations on 13 elements are obtained routinely, but these determinations are ratios of the amount of silicon and aluminum. Doran has thus gained time and saved money, but at what cost?

One problem pertains to the extent to which a single analysis of scraped ceramic paste is representative of a sampled sherd. With microanalytical techniques only a small amount of variation is measured at any one point. Therefore, multiple analyses are usually made at each of several locations and then averaged in order to assure representativeness (see De Atley et al. 1982; Swann 1982a,1982b).

Assuming an adequately representative analysis, the program described by Doran would appear to be well suited for extensive archaeological use *except* for the lack of analytical standards (see Bishop et al. 1990). While the greatest abundance of silicon or aluminum in pottery probably occurs in the base clay fraction, these elements may also enter the ceramic sample from other sources. The same ratio expression can arise from additives in the clay rather than the clay itself. Ratio data cannot discriminate among different components nor can they be subjected to statistical procedures based on normal distribution curves (Bishop et al. 1982:300).

An even more fundamental problem, however, is that spectral intensities are instrumentally specific. The energy spectra are influenced by the size of the detector and thus the ratios among the isolated peaks will differ from one detector to another. Internal consistency within a program may be maintained over time, but results are highly likely to differ among laboratories. This project-specific aspect places severe limitations on an attempt to generate a data base that will be used by other investigators. With alternative analytical resources available, through collaborative programs or through purchase, we see no reason why analytical time should be spent on a less than fully quantitative analysis.

Doran raised the possibility that PIXE could function in a "screening" mode, and should the level of discrimination not be sufficient, a more sensitive technique could be used. A similar use of PIXE was advocated by Fishbeck et al. (1989) for a study of pottery from the Arkansas basin and Ozark highlands of eastern Oklahoma. In the latter investigation, the PIXE generated major elemental data was used to eliminate clays that obviously did not correlate with the pottery. The clays that did show chemical similarity to the pottery could then be, but were not in this case, evaluated using a more sensitive method of analysis (e.g., INAA).

This is not an unreasonable approach yet a certain level of cynicism causes us to wonder how often the multiple step process will be employed to move beyond the instrumental findings of the PIXE "exploration" approach.

Although already mentioned as having greater sensitivity for elemental analysis, instrumental neutron activation has received little attention in the Southeast. Indeed, relative to more than three decades of application in the Old World and in Mesoamerica, INAA analysis in North America has been largely ignored. Prudence Rice, a mesoamerican scholar, carried out a limited INAA investigation of Weeden Island pottery (Rice 1980). This effort was largely exploratory, resulting in the description of paste variability among 49 ceramic samples and their relationship to the variation observed in 12 analyzed clay samples. This preliminary study served to highlight the need for greater sampling of ceramic resources and better temporal control of the pottery while revealing that the Weeden Island assemblage was constituted from pottery made locally and pottery imported from several unlocated production areas (see also Rice and Cordell 1986).

Twenty-five specimens of Mississippian pottery from sites in the northern Mississippi valley (Mero, Armstrong, Aztalan) and in the central Mississippi and Ohio valleys (Cahokia and Angel) were also subjected to neutron activation analysis as part of a program of technological and compositional analysis "[begun] in an attempt to explain not only the role of shell tempering, but also why such an innovation was so widely accepted" (Stimmell et al. 1982:220–221). The chemical analysis pointed out the general similarity of the pottery under study. In all the samples, the elemental concentrations were inversely correlated with the abundance of calcium, most likely resulting from the shell temper. The mineralogical and textual analyses were used to estimate the firing temperature. Although the INAA data failed to support the authors' hypothesis, they nonetheless suggest that NaCl was added to the pottery to promote sintering (Stimmell et al. 1982:226–227).

The Mississippian pottery study was expanded, again as a methodological statement, to include ceramic specimens from Northern Ontario and Hokkaido, Japan (Stimmell et al. 1986). The study concludes with a cautionary warning about the potential complexity of the ceramic system and how INAA data obtained from coarse-tempered pottery might be difficult to interpret (compare Neff et al. 1988, 1989).

The authors also failed to observe the level of homogeneity they expected to find in the analyzed clays of the Mississippi valley. With their limited sampling of the clays and pottery, however, they were unable to look for possible geographic and chemically derived paste compositional covariation that could form a basis for differentiating production loci along the Mississippi drainage.

In marked contrast to the ceramic studies referred to above, the mineralogical and technological investigations of Floridian pottery by Ann Cordell represent a model of systematic research. Beginning with the study of Weeden Island pottery (Cordell 1980, 1983, 1984; see also Milanich et al. 1984) and more recently with pottery from southwest Florida (Cordell 1989, 1992; see also Marquardt 1986), Cordell has focused on standardizing observations of ceramic compositional and technological features in order to document systematically the temporal and spatial variation within a target region. Obviously aware of the limiting effects of small samples, she uses the binocular microscope as a primary device for differentiating among what is mostly undecorated pottery; her sampling is extensive.

Cordell's binocular-based paste classifications are augmented as necessary through the use of petrographic examination. The compositional attributes of the ceramic pastes are supplemented by information about paste color, hardness, rim form, rim thickness, and vessel form. Additional information, such as refired paste color, is obtained from samples that are selected judgmatically. She has been able to find covariation among the different attributes, which enables her to differentiate imported from locally produced pottery, and she is also able to apply the sensitivity of compositional and technological features toward refining the regional chronology. Her efforts to demonstrate a direct relationship between ceramic composition and specific occurrences of clay deposits have been somewhat less successful. In spite of this limitation, the characterization of the ceramics informed by the "Criterion of Abundance" can be used to approximate production loci (Bishop et al. 1982:301). The systematic nature of Cordell's investigations tends to build in a regional manner so that lacunae in the data of today are likely to be filled in by future efforts.

In the above studies, we have reviewed only part of what is subsumed under ceramic technology, that is, compositional studies. Ceramic technology as a related group of activities or techniques includes, for example, consideration of materials preparation, choice of temper, drying and firing practices, decoration, and finish. Although observations about these features have been made for over a century (e.g., Powell 1886:lx; Nordenskiöld 1893), what has changed is our ability to achieve greater resolution of the effects of these features through better technology.

In her discussion of ceramic technology, with particular emphasis on the American Southwest, Suzanne De Atley outlines three reasons for the study of ceramic technology, the first two of which are modified from Shepard (1936:389): tracing the history of the ceramic craft; using ceramic technology as an applied science to derive social or cultural inferences; and using "technological behavior" to articulate production techniques and artifact use requirements with other aspects of the cultural system (De Atley 1991).

Various applications of ceramic technology have appeared in the southeastern literature. Influential studies that have been applied to pottery similar to that of the Southeast, especially Woodland and Mississippian pottery, include those of David Braun (1983, 1985), Klemptner and Johnson (1983), and especially Vincas Steponaitis (1983). If the significance of a work is judged by the number of times that it is cited, then the ceramic technological studies carried out by Vincas Steponaitis (1981b, 1983) are phenomenally important.

Steponaitis borrowed techniques from the field of materials engineering to describe ceramic attributes. His studies provide a glimpse into the history of the ceramic craft as practiced at Moundville. Although his experiments and observations were based on but a few samples, a weakness he readily acknowledges (1983:45), he attempted to elevate the use of description to a higher level of interpretation, suggesting that the "potters maintained the distinction between coarse and fine wares for reasons that were fundamentally technological, rather than purely aesthetic" (1983:45).

Several of Steponaitis's conclusions rest heavily upon the acceptance of many assumptions that are made: that the sampling, however limited, was adequate; that the lack of kaolin detected in the fired pottery was a function of firing temperature; that the "black-filmed" wares of Moundville were produced by postoxidization firing smudging; that observations drawn from thermal shock experiments carried out on sherds can be extrapolated directly to whole vessels. By pointing to these assumptions we are not suggesting that any of them are necessarily wrong, but they have yet to be tested.

For example, shell heated to 650°C–900°C is generally presumed to expand in volume during an irreversible alteration from aragonite to calcite—a presumption that still has to be verified in the laboratory (Klemptner and Johnson 1983:104). Following from this assumption, if crushed and sintered shell were to be added to pottery as a temper, it would strengthen the ceramic body, avoiding expansion that could lead to spalling when heated and providing resistance to thermal shock. Given the disclaimer that Steponaitis made about his conclusions, it is unfortunate that his work has been taken beyond his intent, when, for example, David Hally accepts the Moundville study and infers that shell temper in pottery is used to minimize thermal shock (Hally 1986:278).

Specifics aside, Steponaitis joined more traditional archaeological approaches with insights and methods derived from the recently emerging field of materials science. Investigators approaching the ceramic record in this manner seek to understand the "performance" of a ceramic by examining the stages of fabrication (mining, mixing, forming, firing, and finishing) as they relate to characteristics of composition and texture and how all of these factors affect thermal expansion and conductivity and mechanical strength (Klemptner and Johnson 1983: Fig. 1; see also Bronitsky 1986; Bronitsky and Hamer 1986; for a geological approach to similar issues, see Gertjejansen et al. 1983).

Discussion Points

With certain significant exceptions, materials characterization, upon which our review is based, is not routinely practiced in the Southeast. Reflecting over the totality of the analyses in the Southeast, we can appreciate only clusters of intensive research performed in isolation. Such an evaluation, however, can only be made from a perspective that somehow stands in contrast. Certainly, archaeology as a whole is not benefiting from the full potential that can be achieved with physical and chemical scientific techniques (Crown 1991; De Atley and Bishop 1991; Bishop 1992).

Beginning in the late 1960s and throughout the 1970s interest in processual archaeology led archaeologists to believe that if sources of materials could be identified, more specificity could be ascribed to the processes of procurement and distribution. Scientific techniques could be used to test hypotheses about extraction, distinctive processing techniques, or directionality of exchange. "For a while it seemed that with sufficient ingenuity, an emphasis on deductive inference, and use of new-fangled equipment and techniques . . . we could say something interesting, significant, and true about any part of the archaeological record" (Watson 1986:440). Even if Dunnell's (1990) contention that southeastern archaeologists avoided most of the excesses of the new archaeology is true, the complexity of the archaeological record in the Southeast involving long-distance trade and the evolving complexity of indigenous societies caused them, like others, to look to the promises of new technology for baseline, if essentially descriptive, data.

How have these data contributed to models of southeastern developments? Recent reviews of the state of southeastern archaeology do little more than mention the fact that such studies have been undertaken (Steponaitis 1986; Johnson 1992b). The large amount of effort necessary to characterize the materials is distilled into one or two archaeologically relevant statements that are then cited over and over in the literature. Instead of raising new or more refined questions, the results gain unquestioned acceptance but limited application as archaeologists acquire new data and begin to refine previous models. The variable impact of these studies on the development of new interpretive models, while due in part to the difficulty of assessing techniques and methods falling outside the traditional boundaries of archaeology, is also due to the research matrix in which such studies take place.

There is no overgeneralization intended in the statement that archaeological investigations into the properties and sources of artifactual materials have greatest utility when they are carried out in the theoretical and substantive context of wider investigations. Decisions about what properties to study or the extent to which compositional groups must be refined are contextual; there must be feedback between archaeological information and analytical data. The theoretical umbrella provides the transformational bridge between the raw data (information) and systematized knowledge.

Although not conceived in these terms, this need for context and linkage between analysis and knowledge may have been behind Alfred Kidder's and J. O. Brew's warning to Anna Shepard that she avoid working in the Southeast. In the late 1940s, under urging from the director of the Carnegie Institution of Washington, Vannevar Bush, Shepard was seeking a new region in which to conduct ceramic technological research. In spite of the recognition of a new crop of "young archaeologists"—Gordon Willey, James Ford, Philip Phillips, and James Griffin—they cautioned her that it would be many years before enough was understood of the region's prehistory to make her work worthwhile. She would be better served, Brew suggested, to continue to work in the American Southwest or to look toward the classic cultures of the Mediterranean (letters from J. O. Brew to Anna O. Shepard, 28 November 1947, and A. V. Kidder to Anna O. Shepard, 28 October 1947).

The role of linkages has been well illustrated in the recent work on obsidian (Hatch et al. 1990). Not only do the researchers refine the source locations, but they do so in order to use the information in another application, hydration dating. The hydration rates, which are used to calculate the date of obsidian artifacts, are specific as to the source area. With information on the dates of acquisition and the number of sources used, the researchers have begun to formulate more specific questions about the complexity of Hopewell exchange in terms of size and magnitude.

This study stands in sharp contrast to the majority of materials characterization studies, which stop with the identification of the source. Long-distance trade or exchange figures prominently in attempts to monitor ideological, political, social, or economic contact external to a social group. Materials or objects of obsidian, copper, galena, and shell have been identified as items susceptible to movement over long distances, from the point of raw materials procurement to the final (archaeological) recovery locale. Obsidian from site X can be related to the flows of Yellowstone Park; copper can be attributed to the characterized sources of the Great Lakes area or to the more proximal southeastern sources. The commodity, at least in its material sense, has been identified as having a single vector extending from source to site. Even broad changes over time, such as the shift indicated between the early use of northern copper sources to later use of those of the Southeast, are discernable.

Source and directionality, however, represent only two out of several characteristics of exchange networks that have been identified by Fred Plog (1977:128–129). For example, what was being exchanged: finished product or raw material? We may not be sure of which is the actual commodity that is being exchanged from source location to final receptor. The context of the exchanged material often is illusive.

Materials characterization studies are usually too limited in scope, sometimes requiring long periods of methodological testing before archaeologically significant results are forthcoming. Without specifically defined problems with specifically defined parameters, the results of the analyses are vague, indicating little about the magnitude, symmetry, or complexity of the exchange system. Seeman's (1979) model of Hopewellian exchange anticipates just such difficulties.

Although Seeman's analysis did not benefit from the later analyses of galena or native copper, he was able to identify potential source areas that have been subsequently supported by the analyses. Yet Seeman's model and the analytical data both overlook a significant aspect of the exchange. Seeman suggests that the occurrence of costly acquired (distant) items could not support the continuous operation and maintenance of an exchange system (1979:304). But he does not clearly distinguish between local materials used in stylistic copying and the importation and brokerage of distant (costly) preferred raw materials. That is, he does not consider fully the distribution of finished goods with regard to composition, a deficiency which calls into question his evaluation of important commodities in the exchange network when he equates range and frequency with cost and access (Canouts 1986:78–79).

Goad's (1979) finding that southern sources of copper were used for

Hopewell artifacts is significant. Her suggestion that such use would affect exchange patterns has been expanded upon by Bender (1985), who suggests that the continued growth of Hopewell phenomena in the South meant that southerners were siphoning off exotic goods before these goods could reach their northern neighbors. Both the stylistic copying model and this expanding economy model depend on different conditions of production that would be effected through more localized extraction and processing. Unfortunately, if materials characterization studies are to go beyond just identifying far-removed sources and acknowledging that the Southeast, as a region, did not exist in a cultural vacuum, more refined compositional studies must be undertaken.

The labor and time needed to conduct intraregional characterization studies, particularly ones involving ceramics, are costly. To be successful, they are also strongly dependent upon either the extent of variation in the natural environment or upon the degree of standardization during the stages of raw material processing and production. Some "signal" must stand out above the "background"—be it natural or cultural. The broad geological, geomorphological similarities of many regions of the Southeast place severe limitations on our ability to discern "sufficiently" discrete subregional patterns among similar materials that can be translated into useful cultural differences.

We stated initially that materials characterization was not routinely practiced. Part of the problem relates to the social and technical matrix in which research is conducted. There is a social dimension involved in the conduct of archaeometric investigation and it is one, that by virtue of the need for access to instrumentation, places an archaeologist in a client-patron relationship with physical scientists. Use of facilities or recourse to the scientists' expertise is obtained through their goodwill. Those areas of the world that have been the beneficiaries of intensive and extensive programs of archaeometric investigation have been the focus of laboratories that had both the necessary resources and scientists dedicated to physical methods of analysis. Long-term programs in Mesoamerica were established by the efforts of Edward Sayre and Garman Harbottle at Brookhaven National Laboratory and programs in Greece and the Mediterranean by scientists at McGill University, Canada, the British School in Athens, the Research Laboratory for Archaeology at Oxford, and at the Lawrence Berkeley Laboratory.

One of us (Bishop) recalls the time that he discussed the possibility of taking a postdoctoral study with a noted geochemist only to be advised that nothing so serious could be undertaken—to the effect, "when we work with archaeology, you have to realize that we are bored and want to have some fun!" This is a singularly stark recognition that what we do must have appeal for the collaborating scientist. With such recognition, it is probably no accident that the geographical areas referred to above are those whose histories of development have witnessed exceptional achievements in the arts that are expressed in lithics, ceramics, and other classes of artifacts.

We have caricatured the above role of the scientists to draw attention to the potential volatility of the cross-disciplinary interaction required for most archaeometric research. With the possible exception of the Ceramic Laboratory of the Florida Natural History Museum, no group endeavor resembling the above cross-disciplinary studies exists for the Southeast. In contrast, the southeastern archaeological investigations that employ techniques of the physical sciences have been exceptionally individualist and of limited duration, usually not extending beyond that necessary to satisfy dissertation research requirements.

Before closing our discussion, we wish to draw attention to the type of individuals who are needed to assemble the data bases that are necessary for materials characterization analyses. Few investigators engaged in archaeometric activities would claim to be "archaeometrists," preferring to be recognized according to their primary fields of expertise (physical chemists, organic chemists, physicists, archaeologists, etc.). Part of the reason may derive from the training that directs the research orientation and the interpretation of the results of the analysis. Part of the reason undoubtedly relates to the perception of how science is conducted.

While we are not opposed to a scientific archaeology, we believe that archaeologists do not conduct investigations in the same manner as do laboratory scientists. It has been pointed out elsewhere that archaeology does not have trained laboratory technicians (Kelley and Hanen 1988:150), but the distinction between a technician and scientist or researcher is unwarranted in this case. Scientists for the most part recognize the need for routine analyses in applied research. They are far more apt to work in teams. In contrast, archaeologists still operate in a field where single authorship is the standard and where innovative research, whether or not significant applications are forthcoming, is rewarded (see also Kelley and Hanen 1988:136–137, 152–159). In order to produce a body of data large enough to monitor variation, several investigators working on common problems within a cooperative matrix must become the norm rather than the exception.