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THE APPLICATION OF REFLECTANCE SPECTROSCOPY TO CHERT PROVENANCE OF MISSISSIPPIAN SYMBOLIC WEAPONRY

by

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ABSTRACT

Parish, Ryan Michael. P.h.D. The University of Memphis. August/2013. The Application of Reflectance Spectroscopy to Chert Provenance of Mississippian Symbolic Weaponry. Major Professor(s): Dr. George H. Swihart, Dr. David H. Dye

Determination of the source of chert artifacts ties past peoples to specific locations on the landscape either through direct or indirect procurement strategies allowing researchers to visualize interactions with both resources and people. However, due to inherent variability accurate provenance data often remains elusive. The reliance upon chert provenance data obtained through macroscopic techniques is problematic and emphasizes the importance of continued research and development of analytical methods whose aim is the objective characterization of source for archaeological materials manufactured from chert.

The following thesis is organized around three primary objectives. The first objective is the investigation of the non-destructive provenance application of two reflectance spectroscopy techniques (VNIR, FTIR) in differentiating Dover and Fort Payne chert. The second objective is to test the 'single-source theory' which stipulates that the chert used to manufacture Mississippian sword-form bifaces was solely acquired from deposits of Lower St. Louis "Dover" chert located near the town of Dover, Tennessee. The final objective is to place the sword provenance data into a cultural framework in order to explain the function of the swords within Middle Mississippi Stage polities.

The 'single source' theory has implications for the socio-economic and political reconstruction of Mississippian polities. The presence of 'Dover' chert swords in Mississippian contexts from Oklahoma to Georgia implies long distance procurement, acquisition via exchange networks or political alliances. However, the outcropping of visually similar Fort Payne chert over much of the Southeastern and portions of the Mid-western United States makes the single source hypothesis uncertain.

The results highlight the significant application of reflectance spectroscopy techniques within chert provenance studies. Provenance data for the sample of Mississippian sword-form bifaces refutes the single source theory by showing that variation in resource selection decisions existed. Ethnographic and iconography data clarifies the role that the sword-form bifaces had in Mississippian societies. The provenance data supports the conclusion that the ‘exoticness’ of the material was not an important component in the symbolic cultural meaning of the sword-form bifaces. The results contribute to a growing body of research focusing on the acquisition and use of exotic goods in Mississippian polities.

TABLE OF CONTENTS

LIST OF TABLES

Figure **LIST OF FIGURES** Page

CHAPTER 1

INTRODUCTION

Chert provenance data is primarily gathered through visual identification. Visual identification is problematic due to inaccuracies and a large amount of inter-observer error. The analysis of Middle Mississippian chert "swords" along with a large database of visually similar Dover (Lower St. Louis) and Fort Payne chert samples illustrates the importance of analytical source data and the potential application of reflectance spectroscopy (Visible/Near-infrared [VNIR] and Fourier Transform Infrared [FTIR]) as fast, inexpensive and non-destructive provenance techniques. Researchers are able to gain insight into how prehistoric people lived by studying the mechanisms of resource acquisition, use and eventual discard.

The study of past cultures is important in that it provides a framework within which modern society can be better understood. The story of those who lived on the land before us changes our perception of place, people and posterity. Our explanations of past cultures are heavily influenced by the material record of that particular group at that moment in time. The field of archaeology is dynamic, drawing from a number of different disciplines in order to reconstruct human behavior based upon the material remains generated by people at different spatial and temporal scales. However, the material record is biased to those remains that withstand the weathering environment giving us an incomplete depiction of the total sum of human utilization of natural resources. Stone is one resource that was heavily exploited by people up until present and is more resistant to the weathering environment.

A reliance upon multiple different stone, or lithic, types allowed people to perform a number of different tasks. Chert in particular is one lithic type that, depending on the region and time period, was preferentially selected due to its versatile physical characteristics. Artifacts manufactured from chert survive the weathering environment relative to other components of material culture. Therefore, the archaeological record for a particular group may consist primarily of chert artifacts. The study of lithic artifacts in general, and chert specifically, can inform us about technological organization (Andrefsky 1994), material selection (Steponaitis et al. 2006), inter-group relationships (Koldehoff and Brennan 2010), population movements (Raczek 2011), define culture groups (Burke 2004) and be diagnostic temporal horizon markers (Funk 2004).

Problem Statement

The following study focuses on the provenance, or place of geologic/geographic source, for the chert used to make sword-form bifaces of the Middle-Mississippi Stage (A.D. 1200-1400) through the use of two non-destructive reflectance spectroscopy techniques. The problem is that the existence of multiple outcrops of visually similar chert deposits across a large geographic area complicates qualitative macroscopic identification. Many of the Mississippian sword-form bifaces, defined here as non-utilitarian double tapered elongated bifaces displaying above average skill in manufacture, are visually typed as Dover chert. Consequently, the material used in their production is thought to have been obtained, often from great distances, from prehistoric quarries located along the Cumberland River near the modern town of Dover, Stewart County, Tennessee. Three primary and related secondary objectives of the study include:

1. Testing the application of the VNIR and FTIR reflectance spectroscopy as chert sourcing techniques in terms of level of destructiveness, accuracy, precision, reliability, speed and cost.
    a. The construction of visible, near-infrared and mid-infrared spectral databases from visually similar Dover and Fort Payne chert samples collected from the Mississippian-aged Lower St. Louis and Fort Payne limestone formations, respectively.
    b. The non-destructive spectral analysis of a sample of Mississippian chert sword-form bifaces.
    c. Characterizing the swords to sampled chert deposits at the formational and intra-formational geographic/geologic scales.
2. To use the source data to either confirm or deny the single source hypothesis.
3. Investigate the role that material source had on the cultural function of the sword-form bifaces.
    a. Examine the factor(s) that had the strongest influence on chert procurement decisions for sword manufacture.

The development and application of reflectance spectroscopy techniques within chert provenance studies is the first objective of the study as the techniques potentially provide a non-destructive method for provenance analysis. The accuracy of reflectance spectroscopy at differentiating chert by geologic formation and individual outcrop is tested against a large sample of visually similar Dover 'Lower St. Louis' and Fort Payne chert collected from various deposits/outcrops across the Midwest and Southeastern United States. The provenance data for a sample of Mississippian sword-form bifaces analytically tests the ‘single source hypothesis’ which theorizes that the material for sword manufacture was exclusively obtained from the Dover Quarry sites. Concurrently, provenance data give researchers insight into the function of the non-utilitarian sword-form bifaces. The implications of chert source for the Mississippian sword-form bifaces influence our explanations regarding social complexity, elite control of resources, exchange networks, craft specialization and resource selection for non-utilitarian objects as is discussed in Chapter 4. Objective provenance data provide information regarding the social and ideological function of the swords in Middle Mississippi polities.

Provenance Analysis

Provenance analysis of archaeological materials is not a recent phenomenon, but is a common research objective since the founding of the field of archaeology (Holmes 1919). Provenance or source is defined as the geologic origins or place of procurement for the material utilized to manufacture a particular artifact. Therefore, provenance has dual geologic and spatial characteristics that cannot be divorced from its base definition. Provenience is defined as the ‘find spot’ of the particular artifact at varying spatial resolutions such as the state or county level, specific archaeological site or location within the site. Provenience is fundamentally different from provenance of an artifact in that no geologic origin data are preserved along with the spatial component. The spatial resolution of the provenance data is determined by a number of different variables that are discussed further in Chapter 2. However, it is important to note that the spatial component within provenance data directly influences the anthropologic scale of the research study. Matching the anthropological question to an appropriate provenance spatial resolution is crucial to successfully applying source data to human behavior.

Provenance studies are conducted by many methods and upon a wide range of archaeological materials. These include but are not limited to obsidian, ceramic, amber, metal, paint pigments and various lithic materials including chert. There are as many provenance techniques as there are materials analyzed (Pollard et al. 2007). The wide variety of provenance techniques can be organized into three main categories defined by the type of data being recorded. The three major categories of provenance techniques include those methods that record petrographic, geochemical and macroscopic attributes. The petrographic techniques identify the macro-mineral composition of the sample under study. Characterization of source is performed by analysis of potentially diagnostic quantitative or qualitative mineral data that may be an indicator of the genetic process and following diagenesis. Geochemical methods analyze the chemical composition of the sample recorded by major, minor and trace elements. A quantitative range of these elemental concentrations is the fundamental unit of analysis. Finally, the methods most often applied within chert provenance studies are based upon visual analysis of potentially diagnostic macroscopic characteristics such as luster, texture, fossil inclusions and coloration. Though there exists a wide range of provenance methods employed and data being resolved, one overarching theoretical principle governs the determination of source.

The Provenance Postulate articulated by Weigand et al. (1977) states that the range of variation within a source must be less than the variation outside the source. If these conditions are not met then the material, sample or artifact being analyzed cannot be exclusively sourced to any particular location within the sampling universe. Furthermore, absolute determination of provenance is usually not possible as there exists a range of variation inherit within a particular deposit and within the artifact under analysis. The quantification of the range of variation at different scales and subsequent matching to a source's range of variation is more accurately described as a 'characterization' of source (Harbottle 1982). Artifacts of unknown provenance are sourced to a particular range of variation that may have overlapping characteristics with another source drawing into question the exclusive provenance of the artifact being analyzed.

There are two main problems limiting current chert provenance research. One is that due to the heterogeneity of its visual, chemical and physical characteristics a wide range of variation exists at different spatial scales. The second problem associated with chert provenance research is that a large portion of source data are based solely upon visual characteristics. These two problems are elaborated further in Chapter 2, but it is crucial to identify the limitations of current methodology as they directly influence anthropologic explanative capabilities.

History of Research

Prehistoric quarries. A major topic of earlier archaeological investigations was geologic provenance of archaeological materials. The first lithic provenance studies were undertaken in Europe at the end of the nineteenth century. These early studies focused on surveying and recording prehistoric quarry 'industries'. Researchers linked prehistoric material acquisition evident at the sites with regional distribution of the exploited material. Interest in Neolithic long distance exchange networks further led to the identification of additional quarry sites and material distribution studies. The first mention of raw material procurement was in Greenwell's initial investigation of the Grime's Graves site in England (Greenwell 1870).

Multiple prehistoric quarry sites in Belgium, Britain and France enjoyed early archaeological documentation. At these quarry sites researchers were able to study the location where the direct procurement of lithic resources occurred. Many of these quarry sites were large in scale and became 'type' sites for particular materials. The chert mined at the quarries was often found hundreds of kilometers from the site illustrating the complex distribution of both people and resources. However, archaeological debate shifted at the close of the century, becoming centered upon human antiquity, cave sites and megalithic structures (Smolla 1987). A seminal publication describing the major quarry sites of Western Europe was written by Thomas Wilson in 1899, a curator at the United States National Museum in Washington, D.C. Other North American researchers continued Wilson's work through documenting major quarry sites throughout the United States, Mexico and South America.

The historical development of chert sourcing in North America may be largely attributed to the extensive survey work of one individual. William Henry Holmes at the beginning of the twentieth century visited, described and mapped many of the major prehistoric quarry sites in the western hemisphere (Holmes 1890, 1919). Holmes's research was certainly not the first relating to chert procurement and distribution; however it stands as a landmark study whose focus centered upon major prehistoric quarry sites across the Americas. Contemporaneous to Holmes's work is that of Fowke, Gould, Moorehead, Phillips, Titterington, Thomas and Studer whose investigations of regional sites such as Mill Creek, Crescent, Flint Ridge, 'Spanish Diggings', Indian

Mountain, Flint Hills, Piney Branch and Alibates Quarries provide descriptions of spatial distributions and prehistoric mining techniques and methods. An important side note is that observations of stone tools in various stages of reduction at the quarry sites sparked the theoretical development of the American ‘reduction sequence’ and similarly the *chaîne opératoire* in France.

The sheer size and number of individual quarry pits, coupled with the volume of discarded material observed at the quarry sites, fascinates researchers to this day. The descriptions by early investigators generated debate regarding stone tool production as a continuum in stark contrast to the static typological view that was in use at the time. An additional contribution made by early investigators of prehistoric quarries is that visual descriptions of the stone material procured from the quarry were utilized to type artifacts made from that particular material. This gave archaeologists a mechanism to construct questions regarding resource consumption, acquisition, distribution and use within and between culture groups over time. At first, visual characteristics of particular materials were used to identify artifacts to known quarry/procurement sites. These methods would later give way to analytical techniques designed to determine provenance with quantitative data.

Early geochemical analysis. Chemists of the mid-1800s were the first researchers to state that the composition of artifacts could be used to scientifically identify the source of the material used in their manufacture (Pollard et al. 2007). The work of Austrian chemist Jan Erazim Wocel and French mineralogist Damour were among these who explicitly state the link between geographic source and artifact (Damour 1865, Harbottle 1990). Also, the pioneering research of Estonian chemist C. C. T. C. Gobel in the 1840s, who worked on a large sample of copper artifacts, demonstrated that compositional data could be used to identify culture groups (Pollard et al. 2007). Possibly the most famous early provenance study was conducted by the Polish researcher Otto Helm at the end of the nineteenth century. Helm sought to determine the provenance of 2000 amber beads uncovered by Heinrich Schiemann at Mycenae. Curtis Beck, along with his co-researchers, continued Helm's work and determined that the majority of amber artifacts in Europe originated from sources along the Baltic coastal region, as opposed to other known European deposits (Beck et al. 1964, 1965; Beck 1986).

Trajectory of chert provenance research. Initial chert provenance research is tied to distribution studies of the large prehistoric quarry sites. The studies focused on the prehistoric economy of chert and the broad distribution of the exploited material types (Atwater 1820; Fowke 1894; Hildreth 1838; Holmes 1919; Moorehead 1892; Squier and Davis 1848; Stout 1918). Visual analysis of archaeological materials compared to macroscopic attributes of the particular chert type observed at the quarries was the sole technique utilized by early researchers. The development of significant chemical instrumentation in the 1920s prompted analytical provenance studies. At first, geochemical analysis was performed on metals, ceramics and obsidian. Later geochemical provenance techniques were used to quantify the chemical composition of chert at the macro-, trace and rare elemental resolutions. Specifically, chert provenance research in the 1960s increased significantly. Currently, geochemical methods, including Instrumental Neutron Activation Analysis (INAA), X-ray florescence (XRF) and Inductively Coupled Plasma Mass Spectroscopy (ICP-MS), are a few of the techniques commonly in use. Despite the large amount of chert provenance literature, few researchers are actively involved in chert provenance studies compared to other areas of provenance research. This may be due to the low success rate in analytically differentiating one chert source from another. Presently, a reliance on visual identification of chert types based upon macroscopic criteria prevails as the most practiced approach despite reports of large error rates associated with these methods (Boisvert and Constine 1993; Calogero 1991; Hess 1996; Spielbauer 1984; Price et al. 2012). The current study emphasizes an analytical approach to quantifying variation in chert at a meaningful resolution and its application to the analysis of archaeological materials and the study of human behavior.

Human Behavioral Indicators

The use of chert has spanned most of human history in practically all regions of the world. The geologic distribution of chert resources is discontinuous. Favored deposits were often exploited throughout prehistory, continuing into historic times. Distinct culture groups revisited particular deposits. Therefore, changes in chert use signify culturally significant phenomena. Understanding human behavior in the area of resource use is an important aspect to explain short term changes in the material culture and also to conceptualize broader cultural trends in the social, religious, economic and political realms.

The provenance of chert artifacts allows researchers to test hypotheses regarding resource selection, procurement, use, distribution, technological organization, group mobility, band territories, resource zones, social complexity, craft specialization, prehistoric economies and inter-group relations. These are just some of the multiple lines of inquiry researchers are able to address with chert provenance data. A few excellent bibliographies of chert sourcing studies are Church 1994; Delage 2003; and Hermann and Baumann 2010. Church categorizes the studies by region, technique and material type. The organization of Delage's extensive bibliography is also by region, but also differentiates the body of literature into geological and anthropological studies. He includes information regarding the temporal component of the material culture analyzed. Hermann and Baumann's bibliography is organized alphabetically. The reader is directed to these resources for a more comprehensive list of anthropological applications of chert provenance data. The following provides examples of areas of human behavior that are currently being explored using chert source data. The brief discussion not only illustrates the multi-faceted applications available to the provenance researcher, but more importantly introduces the concept that the research question defines the level of chert data needed to explain the archaeological record. The influence of the research question on the provenance data is discussed in greater detail in the following chapter.

One of the fundamental questions asked by the researcher is; where did prehistoric people obtain chert resources? The question may seem rather simplistic, but in reality it is often an intertangled web of environmental and cultural variables. Resource selection may have been through direct acquisition from a spot(s) on the landscape or indirect methods involving inter-group exchange. The majority of chert source studies attempt to decipher resource selection decisions to construct hypotheses regarding other cultural phenomenon. Often chert artifacts at a particular site are organized into two broad categories, local or exotic. These relatively arbitrary categories are used to arrange chert data into units upon which hypotheses such as group territory or exchange networks can be constructed. An example of an ongoing chert resource selection debate is that regarding the source of ‘jasper’ at the Tomato Springs site, Orange County, California. The classification of jasper as a chert will not be discussed here (see Chapter 2) but the selection decisions of the inhabitants of the Tomato Springs site have implications regarding group mobility and inter-group interactions.

Socio-economic. Explanations regarding the presence of jasper at the Tomato Springs site include exchange with groups to the east (McKinney 1967; Hudson 1969), long distance forays by prehistoric entrepreneurs into the Mohave and Colorado deserts (Cottrell and Del Chario 1984) and local procurement from secondary sources (Koerper et al. 1992). The hypotheses are drastically different. Accepting one hypothesis over the others would not only affect our understanding of the resource selection strategies of inhabitants at the Tomato Spring site, but the regional distribution of jasper in southern California. Broadly speaking, our understanding of the level of socio-economic complexity practiced by the inhabitants is directly influenced by the provenance data. A second case study involving the Uinta Fremont illustrates how chert provenance data provides evidence for resource procurement in the Uinta Mountains previously not thought to have been frequented by Fremont groups.

Group territoriality. Previous research indicates that the Uinta Mountains acted as a natural barrier separating distinct cultural groups (Shimkin 1986; Calaway et al. 1986; Marwitt 1986). Provenance data, along with other lines of evidence, are overturning this model. The high frequency of chert material procured from deposits located within the Uinta Mountains demonstrates that Fremont culture groups inhabiting the Uinta Basin made frequent forays into the mountains up to 70 kilometers distant (Loosle and Johnson 2000). The provenance data redefines previous models of Fremont procurement strategies by providing evidence for resource exploitation in areas not thought to have been visited. A third area in which chert provenance data provides cultural information is that of technological organization.

Technological organization. Chert provenance data assist researchers in understanding stone tool manufacturing. Data obtained by lithic analysts show that the presence and availability of chert sources, along with the quality of those resources, influence technological decisions (Andrefsky 1994). Technological data indicate that if prehistoric inhabitants have access to local chert resources then the amount of expedient and formal tools manufactured from those resources will be equal. Conversely, if groups do not have access to chert resources, then the occurrence of formal tools will be greater than expedient ones as inhabitants will practice resource conservation strategies. The quality of the chert resource is also a variable in technological organization. The poor quality of a local resource will restrict tool production to single use informal tools. In this instance formal tools may be manufactured from distant higher quality resources (Andrefsky 1994). Provenance data provide a means to view the tool assemblage as a product of natural constraints in conjunction with cultural procurement decisions.

Group mobility. A fourth area in which provenance data directly allow researchers to visualize human behavior is the extent of group mobility. Group mobility and group territorial boundaries are a popular topic in the archaeological literature. This is especially true when studying hunter-gatherer groups at the end of the Pleistocene in North America. The lithic procurement strategies of Paleoindian groups is unique in that high quality bedrock outcrops of chert were favored above other sources despite often being located at great distances (Burke 2004). Chert provenance data of Paleoindian site assemblages identify which source(s) were utilized allowing researchers to define group ranges over large geographic areas. Two models are proposed to explain the perceived dependency of hunter-gatherer groups on lithic sources, the logistical forager model and the lithic-centered model (Mullet 2009). Accurate provenance data provide a proxy to study long term resource exploitation decisions. Burke (2004) primarily used chert provenance data from a series of Paleoindian sites in order to map out possible group ranges in the American Northeast. Burke concluded that one to three chert deposits were preferentially selected and that groups moved via north/south axes in the study area (Burke 2004). Mullet's thesis research regarding the use of Upper Mercer and Flint Ridge chert by Paleoindian groups in Ohio tested the validity of the logistical forager and lithic-centered models. Mullet's conclusions demonstrate the large geographic area traversed by Paleoindians. As prehistoric groups became more sedentary in the later stages of the prehistoric record, provenance data are used to identify socio-economic practices including inter-group interactions and craft specialization.

Exchange. An example of inter-group exchange is the presence of non-local chert at Middle Mississippi polities (A. D. 1200 – 1400). Koldehof and Brennan (2010) determined that chert exchange was taking place between Mississippian settlements in the form of finished large bifaces, prepared cobbles and macro-flakes. A preference for local chert resources existed at each site, but non-local materials make up a portion of the artifact assemblages. Furthermore, the researchers suggest that exchange networks were controlled by elites, production at the quarries being conducted by site-based specialists. Similar conclusions were made by Shafer and Hester (1983) and Cackler et al. (1999) following long term excavations at numerous Mayan chert quarry sites in Northern

Belize. The researchers were able to track trends in chert use from 600 B.C. to A.D. 900. Production and distribution of the chert resources were controlled by elites at Colha, a major Mayan polity in the region. Evidence for craft specialization exists in the form of workshop technological continuity and the massive deposits of waste-flake material at the quarry sites (Shafer and Hester 1983:540).

The examples listed above illustrate the range of anthropological inquiry commonly addressed with chert provenance data. Provenance data are used in conjunction with other types of data. The use of multiple lines of evidence bolsters explanations regarding human behavior. The examples also demonstrate the versatility of chert source data. Chert provenance studies are not constrained to particular regions or time periods, but may be applied to any culture group that utilized chert resources. This study focuses on the use of chert resources by Mississippian groups in the manufacture, distribution and use of large sword-form bifaces whose cultural function is not fully understood. The chert provenance data are better understood within a cultural context.

Mississippian Sword-form Bifaces

The Mississippi Period (A.D. 900 – 1700) is characterized in the archaeological record by a cultural explosion of intensified agricultural production, communal architectural projects, social stratification and a rich artistic tradition collectively referred to as chiefdom level societies. The emergence of Mississippian chiefdoms should not be viewed as an enigma, but is more accurately understood as a continuation of lifeways that had its roots in the Woodland Period (1000 B. C. – A.D. 900). What sets Mississippian groups apart from their Woodland progenitors is the relative scale of these activities is unprecedented in North America. Chapter 4 elaborates more on the aspects of

Mississippian culture regarding previous provenance studies. The Mississippian emergence and cultural florescence is discussed in detail by Smith (1990), Williams and Shapiro (1990), Muller (1997), Peregrine (1992), Goldstein and Freeman (1997), Cobb (2003) and Pauketaut (2004, 2007, 2009). Additionally, there are a number of excellent publications detailing investigations of specific sites (Brown 1996; Emerson 1997; Milner 1998; Pauketat 2009; Knight and Steponaitis 1998; and King 2003). The current study focuses on one component of Mississippian material culture, the non-utilitarian sword-form bifaces.

Mississippian symbolic weaponry. Mississippian symbolic weaponry refers to the corpus of stone artifacts manufactured as non-utilitarian items potentially serving a ceremonial function. Various forms include batons, mono-lithic axes, maces, knives, hooks, daggers and swords. Symbolic weaponry exhibits great skill in manufacture and elaborate design elements, but they are considered to be non-functional, at least in a militaristic sense. Malinowski (1934:193) describes these items among New Guinea societies as hypertrophic weaponry. Hypertrophic weaponry refers to non-functional items in weapon form exhibiting a high degree of skill in manufacture. Physical use as striking or stabbing implements would not have been feasible due to the inability to structurally withstand impact though use as cutting implements would have been. Mississippian sword-form bifaces are widely accepted by archaeologists as symbolic items possibly serving a function in Mississippian cosmology. The social, economic, political and cosmological function of Mississippian sword-form bifaces should not be understated. Chapter 4 discusses the possible cultural functions of these items, but it is important to note that this class of Mississippian material culture probably had multiple functions within the particular society.

Whatever their particular function may have been, Mississippian symbolic weaponry is one of the finest examples of Mississippian material culture. The provenance of these items is almost always attributed to exotic ‘non-local’ sources. Currently, researchers are uncovering lines of evidence that aid the construction of hypotheses regarding the cultural role the symbolic weapons had in Mississippian society. The lines of evidence examined are form/style, archaeological context or provenience, Mississippian iconography, ethnographic analogy and provenance. Armed with these data researchers are beginning to address questions regarding social complexity (Helms 1979), exchange (Bell 1947, Brown 1983), social stratification (LeDoux 2009), warfare (Dye 2009, Schultz et al. 2001), cosmology (Marceaux and Dye 2007) and ideology (Marceaux 2003).

Archaeological context. Examples of Mississippian symbolic weaponry are found in archaeological contexts across the Midwestern and Southeastern United States. At least one example of a Mississippian style mace has been located in New York (Giles and Knapp 2012). There is considerable consistency in the form and shape of many of the artifacts despite their occurrence across large geographic distances and across multiple regional culture zones. However, it should be noted that few studies to date have attempted to synthesize the variability in artifact form for the particular types of socio-technic weaponry (Giles and Knapp 2012). The classification scheme by Brown (1996) developed for the socio-technic weapons recovered from the Spiro site is referenced most often when describing the form of a particular class of hypertrophic weaponry. Research examining the form/style for the hypertrophic Mississippian weaponry is needed and might allow researchers to identify particular regional or temporal trends.

The archaeological context of Mississippian symbolic weaponry is divided into three categories; burial, cache deposit or house structure feature. Overwhelmingly, the majority of all Mississippian symbolic weaponry is excavated from one of these three cultural contexts. Of these three contexts symbolic weaponry is predominately excavated from burials either directly associated with human remains within a burial feature or as deposits within a burial mound (Marceaux 2003). Secondary to direct association with burials is the discovery of caches of symbolic weaponry. Usually the caches are not limited to single weaponry forms but contain a number of different types deposited together. Two noted caches of Mississippian symbolic weapons are the Woodlee/McMinnville and the Duck River caches found by farmers in the mid-twentieth century (Vietzen 1956; Knight 1998; Brehm 1981; Peacock 1984). Following burial associations and caches are the symbolic weapons found associated with house structures. An example of this unique context are the sword and mace forms found within a pit in a house platform mound at the Link Farm site (40Hs11) (Nash 1968). It is also worth noting that single deposits of swords have been recovered in isolated locations not associated with any of the three above categories. Proveniences of symbolic weaponry absent of clearly discernible cultural features may be an artifact of missing, inaccurate documentation or post-depositional disturbance. However, the ‘unassociated’ context may have cultural meaning and should be considered as possibly an intentional patterned behavior.

Functional indicators: Iconography. One of the stronger lines of evidence for explaining the cultural function of Mississippian symbolic weaponry is that which comes in the form of images engraved or painted onto pottery, shell gorgets, cave walls, stone palettes, copper plates and other mediums utilized by Mississippian artists. Images depicting shamans, cultural heroes, and/or other-worldly deities wielding weapon forms depict how these implements may have been carried but more importantly what types of associations the artifacts may have had with these figures and stories. A number of researchers have pieced together the rich cosmological and ideological universe of Mississippian people from iconography and other diverse lines of evidence (Reilly and Garber 2007; Langford et al. 2011; King et al. 2007; Townsend 2004). One method utilized by archaeologists is ethnographic analogy.

Functional indicators: Ethnography. Direct application of the ethnographic record to culture groups separated by time, space and degree of social complexity is not ideal and the correlations drawn should be done with caution. However, examples exist where despite the presence of cultural restructuring over a long period of time, there exists continuity in the archaeological record and modern analogs (Binford 1986; Gould 1971; Gould et al. 1971; Hayden 1981; Clark 1989, 1991; Morton 1846; Skertchly 1879; Clarke 1935). Ethnographic studies at the turn of the nineteenth century record cultural practices utilizing symbolic weaponry (Rust 1905; Powers 1877; Goddard 1903). The ethnographic record documents the use and meaning of symbolic weaponry by existing indigenous groups, thus providing researchers insight into possible functions. If no direct comparisons can be applied then the ethnographic record provides a framework upon which hypotheses can be constructed, tested and evaluated. The ethnographies of select

Northern California tribes and the Osage are discussed in Chapter 4, along with some tentative correlations of sword-form biface function.

Functional indicators: Provenance. The final line of evidence discussed here is provenance. Provenance data is not traditionally used to deduce social function of non-utilitarian objects. However, this trend may be shifting (Emerson et al. 2003; Emerson et al. 2013). The relationship between highly skilled manufacture and exotic material selected for symbolic weapons is not a superfluous association (Helms 1993). The provenance of symbolic weaponry is not the end in and of itself, rather the provenance data generated is a proxy to understanding broad cultural concepts such as inter-group interaction, long distance acquisition, craft specialization, elite control of production, resource consumption, political alliance building and social status aggrandizement. One alternative method of utilizing provenance data is to conceptualize geologic source as significant in ideological meaning (Helms 1988, 1993, 1998). Source as a symbol for collective social meaning may have played an important function in the use of the symbolic weapons within Mississippian society. In other words, is material source important to cultural meaning? It is this concept that will be critically examined by testing the single source theory regarding the provenance of Mississippian sword-form bifaces.

Anthropological Problem

In the proceeding sections it is stated that the anthropologic scale of the study is directly influenced by the spatial component of the provenance data. In other words, the ability to address a particular question regarding human behavior is dependent on the accuracy of sourcing chert artifacts back to the geologic and geographic place of procurement. The key variable in the study is the spatial resolution of the provenance dataset. Additionally, the relationship that the anthropological problem has with the provenance data being gathered is of equally crucial importance. The anthropological problem dictates the level of provenance data needed to explain human behavior. The concept is elaborated upon in greater detail in Chapter 2. However, the relationship between the anthropological problem and the provenance data is important to keep in mind during the research design phase of the project.

The fundamental hypothesis being tested is that Mississippian people during the Middle Mississippi Stage manufactured sword-form bifaces primarily from chert procured or acquired from the Dover Quarry sites of north-central Tennessee. Testing the single source hypothesis allows researchers to formulate new hypotheses regarding inter-polity relations, socio-political structures, economy and technological decisions. Future researchers can use provenance data to examine elite control of production and distribution at the Dover Quarries, craft specialization, alliance building, inter-polity exchange and trade. These areas of Mississippian polities are broad categories, each containing numerous variables. The testing of multiple hypotheses places the sword-form bifaces in their cultural context. A multi-field approach utilizing many types of data is needed to more accurately address any one of the above. Therefore, provenance data are not advocated as the conclusive means to explain the function of Mississippian sword-form bifaces in their totality, but it gives researchers one tool to address areas of prehistoric culture. What is important about using provenance data is that it ties a portion of the material culture to a resource on the landscape.

Summary Outline

The following chapter deals with the physical nature of chert and the theoretical and methodological application of chert sourcing. Chapter 3 details the geologic setting of the chert bearing units in the study area with a particular emphasis on the paleo-depositional environment and post-depositional alterations to the Fort Payne and St. Louis limestone formations. An understanding of the geologic setting of the study area is vital to understanding all aspects of chert sourcing and human resource selection, use and redistribution. Chapter 4 places the study in a cultural context by broadly defining Mississippian polities and focuses on previous provenance research regarding other portions of material culture. The temporal and cultural contexts of sword-form bifaces are defined. Case studies illustrate the social importance of material source, political power, cosmology and symbolic expression. Chapter 5 is a technical discussion of the reflectance spectroscopy methods used to gather provenance data. A detailed discussion of the instrumentation used and the theory behind the field of quantum mechanics is not included; however, applicable references are supplied for additional inquiries. The information in Chapter 5 is an introduction to the instrumentation and methods used in the study as the application of reflectance spectroscopy to chert provenance studies is in its developmental stage. The information presented emphasizes instrumentation specifics, the type of data obtained, the nature of variability in the data and variables that affect the collection of reflectance spectral data.

The final five chapters detail the methodology, analysis, results, discussions and conclusions. Chapter 6 discusses the sample collection methodology, instrumentation configuration and design of various pilot studies geared toward quantifying the effect of both natural, anthropogenic and instrument induced variation. Specifically, pilot studies focus on quantifying the affect that heat treatment and weathering has on the spectral response of chert. Chapter 7 addresses sample preparation, analysis of the pilot studies, data processing, analytical treatment and accuracy assessment experiments. Chapter 8 provides the results of the previously discussed pilot studies and quantifies the accuracy of the techniques at the inter- and intra-formational levels. Finally, all of the Mississippian sword-form bifaces analyzed in the study are assigned provenance according to geologic formation and to outcrop/deposit sampled.

Detailed discussions regarding sword-form provenance and the cultural implications of the data are given in Chapter 9. Additionally, material in Chapter 9 discusses chert sourcing theory, problems associated with visual analysis, sampling methodology, results of the pilot studies and utility of the single source theory. The cultural function of Mississippian sword-form bifaces is discussed along with multiple areas for future research. The conclusions of the study are presented in Chapter 10. The application of reflectance spectroscopy techniques to chert provenance research is critically examined in terms of level of destructiveness, cost, accuracy, precision, speed, repeatability, artifact accommodation and database management. A cultural function of Mississippian sword-form bifaces is proposed based upon provenance data, temporal and archaeological contexts, resource availability, ethnographic data and iconography. An appendix provides diagnostic wavelength variables used to differentiate chert types, chert outcrops and assign sword provenance.

CHAPTER 2

CHERT PROVENANCE

History of Provenance Research

Chert provenance research is a dynamic line of study whose goal is to explain human behavior by sourcing artifacts made of chert to the geologic or geographic place of procurement. Presently, chert provenance is performed using numerous techniques. The history of chert provenance research can be traced back to the quarry and distribution studies in Europe and the Americas during the mid to late nineteenth century (Smolla 1987:128). The link between large quarry site surveys conducted by the first geologists/archaeologists cannot be overstated. It is important to recognize the correlation between early prehistoric quarry site surveys and chert provenance studies because it directly influences the research design and conclusions of current provenance studies.

Researchers such as Babbit (1880), Blackman (1903, 1907), Dorsey (1900), Fowke (1892), Gilder (1908, 1909), Harrington (1925, 1926, 1929) and Holmes (1919) produced data that were instrumental for the development of the study of prehistoric quarries and chert provenance in the western hemisphere. Documentation of these “prehistoric industries” gave early researchers information regarding extraction methods, technological organization and material descriptions. The resulting survey data allowed for the construction of regional distribution studies focused on inter-group exchange relationships of indigenous people. The vast size, large piles of discarded waste flakes, quarry pits and sheer amount of material located at the sites made them the ‘type sites’ for chert whose visual attributes matched those materials found at the quarry. The single ‘type site’ location concept became ingrained into the archaeological literature and persists up to the present.

A focus on chert distributions and source sites notably trailed off until the late 1970’s. Some noted exceptions are Ball’s (1941) comprehensive survey and Bryan’s (1950) examination of Holmes’s earlier concepts. Church attributes the increase in chert provenance studies to three events: 1) birth of cultural resource management, 2) the development of the “New Archaeology”, and 3) an increase in sophisticated geochemical instrumentation (Church 1994:2). A discussion regarding the impact that each of these events had on the development of the field of archaeology would require a separate publication in and of itself. The reader is referred to Flannery (2006), Odell (2009), Rapp (2009) and Rice (1985) for more information.

A slight chronological restructuring in the order of Church’s three major events places the development of chemical instrumentation at the forefront. A florescence of instrumentation and methods occurred in the 1940’s, at first related to the war effort, but gaining broad application in the analysis of archaeological materials. Roughly contemporaneous to technological advances, large archaeological surveys were being conducted in many parts of America prior to interstate, dam and reservoir construction. These large scale excavations were conducted in an increasingly systematized manner following the scientific method. The reactionary development of the “New Archaeology” to culture history embraced a scientific approach to archaeological investigation as an attempt to deduce human behavior using “hard” data and ethnographic analogy. The culmination of these three events produced a body of researchers who utilized scientific methods and instrumentation to acquire data used to explain human behavior. Modern chert provenance research is a direct product of the processual archaeology revolution.

Geochemical instrumentation provided an alternative to the traditional visual identification methods. Geochemical provenance of obsidian artifacts began as early as the 1960's and enjoyed a decade of continued research prior to the application of these techniques to chert (Church 1994). Luedtke's (1976, 1978, 1979) corpus of research includes some of the first studies to apply elemental composition data to the provenance of chert. In these studies Luedtke laid the groundwork for sampling, methodology, database construction and statistical analysis as well as articulating key theoretical concepts related to the presence and nature of variation in chert deposits. Prior to Luedtke's research, geochemical chert provenance studies of note are Aspinall and Feather's (1972) and Wright's (1967).

Chert provenance research continued in the 1980's with the organization of large symposia bringing a diversity of researchers together to produce collaborative edited volumes (Butler and May 1984; Vehik 1985). Analytical chert provenance research waned in the last decade of the 20th century as evidenced from journal publications, conference presentations, thesis and dissertation topics and funded grant proposals. Noted exceptions to this are the research of Foradas (1994) and Malyk-Selivanova (1998). Currently, an atmosphere of skepticism exists among archaeologists regarding the success of chert provenance analysis. A reliance on visual identification of source for chert artifacts is the preferred method among many researchers due to time and cost constraints (Bailey 2002; Burke 2004; Dowd 2011; Hurst et al. 2009; Koldehoff and Wagner 2002; Knippenberg 2006; Loosle and Johnson 2000; Mullet 2009; Spivey 2011).

However, a return again to analytical chert provenance research may be occurring with studies utilizing petrographic, geochemical and spectroscopy techniques (Baltrunas et al. 2006; Boulanger et al. 1998, 2005; Brandl 2011; Crandell 2005, 2006, 2007, 2011; Gauthier et al. 2012; Hassler 2011; Loponte et al. 2011; Milne et al. 2009; Parish 2009, 2010, 2012; Speer 2012; Steponaitis et al. 2006).

Current Provenance Research. Current chert provenance methods include visual identification, petrography and geochemical techniques. The data produced by visual analysis includes qualitative attributes regarding color, texture, structure, luster and special characteristics such as fossil inclusions. Visual studies usually rely on a priori knowledge with the aid of a type collection for comparisons. The collection may consist of one or a few samples per chert type collected from a single location. The classification system is usually learned from individuals whose regional experience allows them to be confident in their identifications. The method is cheap, fast and non-destructive, but it can have a large margin of error.

Petrographic studies produce macro-mineral qualitative or quantitative data with the use of a petrographic microscope. The identification of microscopic fossil inclusions may also be studied as a potential diagnostic attribute. Sample preparation for petrographic studies can be expensive depending on the number of samples being made into thin sections. Petrographic methods are also time consuming especially when thin sections are being made by the researcher. Petrography is also destructive. Finally, accuracy of the technique is variable and depends on the presence of diagnostic minerals.

Geochemical analysis is the most commonly applied analytical chert provenance technique. Quantitative macro-, trace, and rare-earth elemental data are obtained through specialized instrumentation. A number of geochemical techniques are available. The selection of an appropriate instrument is dependent upon a number of variables such as cost, speed, elemental resolution, availability and level of destructiveness. Quantitative elemental data is often used effectively in sourcing studies by identifying diagnostic elements, using multi-variant statistical methods and/or the construction of ratio bi-plots. Elemental ratio data are also useful in modeling paleo-environmental conditions (Foradas 1994). Geochemical techniques are usually destructive with the exception of portable X-ray florescence that is gaining popularity in archaeology though the lack of application within chert provenance studies is noted (Gauthier et al. 2012). Geochemical techniques as a whole are expensive, have a long analysis time and produce variable accuracies. A thorough discussion of the various geochemical techniques can be found in Church (1994), Pollard et al. (2007) and Tykot (2004).

Successful chert provenance studies are those that utilize more than one method (Malyk-Selivanova 1998). The various complimentary datasets allow the researcher a broader range of information regarding the nature of the material type in question. Regardless of the method chosen in the provenance study, the technique must be evaluated according to its accuracy, precision, reliability and validity. These four concepts have come to be termed as ‘Hughes four-fold assessment scheme’ (Frahm 2012). The technique chosen to assign provenance should be first evaluated within this framework utilizing a series of controlled studies conducted upon samples of known provenance prior to the analysis of artifacts. Only through these internal tests can the researcher develop an understanding of the strengths and weaknesses of the method(s) selected.

Chert

Definition. Chert is defined in this study as a sedimentary rock exhibiting conchoidal fracture with a Mohs hardness of 7 primarily composed of microcrystalline and cryptocrystalline opal and/or granular quartz. Chert exists as nodules, beds and lenses found within limestone, sandstone, shale or chalk formations. The definition is purposely broad including the varietals flint, agate, jasper, novaculite, chalcedony and hornstone. An argument is occasionally made to differentiate some of these varietals based upon crystalline structure (i.e. chalcedony), formation process (i.e. novaculite) and parent formation (i.e. flint). However, the current study adopts a broad definition of chert including all regional taxonomic forms. A comprehensive discussion of chert and the debate regarding its various forms may be found in Church (1994), Luedtke (1992) and Rapp (2009).

Composition. The primary elemental composition of chert is silicon (Si) and oxygen (O). There are two oxygen atoms for every silicon atom forming the molecule SiO_2 or silica. The silica molecule is linked to other silica molecules forming a tetrahedron structure. Quartz is one member of the silicate mineral group (Luedtke 1992). The mineralogy of chert is composed of 90 – 99 wt. % α quartz. Common impurities found in chert are clays, carbonates, iron or manganese oxides, iron sulfide and organic matter (Eley and von Bitter 1989; Luedtke 1992:38). Impurities may include water, which can make up to 1 wt. % in chert (Luedtke 1992:38). Impurities are also found inside quartz grains and within crystal flaws as elemental substitutions. Most impurities inherent in chert are residual minerals that were present within the paleo-depositional environment. The minerals became encased within the chert as it was originally deposited or were introduced later throughout diagenesis. Understanding the origin of impurities and the process by which they became infused into chert is important as it gives the provenance researcher a proxy for understanding variation in chert. The concept will be articulated more thoroughly in the following chapter discussing the diagenetic process of chert formation.

Properties. The mechanical properties of chert, specifically its hardness and ability to fracture in a predicable manner, made it a preferred resource for manufacturing tools by prehistoric people. The fracture properties of certain chert types are shown to constrain tool design, use and function (Andrefsky 1994; Camilli 1988; Cobb 2000; Gould and Saggers 1985). Chert exhibits a conchoidal fracture, a term adapted from the Latin *concha* or the Greek *cogche* meaning mussel shell (Rapp 2009:69). The term comes from the characteristic scalloped appearance that is left when force is applied in the fracturing process. Each removal is a portion of what in physics is termed a Hertzian cone of force. Force propagates both between and through individual quartz grains along planes of weaknesses. Griffith's hypothesis in the 1920's speculates that there exist microscopic cracks on the surface and inside the material weakening the fracture strength. Chert theoretically contains numerous Griffith cracks. Fracture begins at micro-cracks and propagates through the matrix of small quartz crystals along a line of least resistance (Luedtke 1992:84). The path of least resistance in chert is usually around individual quartz crystals. The Griffith crack hypothesis has implications for an archaeological understanding of 'platform preparation', heat-treatment and patina formation. Prehistoric 'flintknappers' were able to predictably control removals with designed blows. Researchers who are interested in a more complete discussion of prehistoric manufacturing techniques are referred to Crabtree (1971), Waldorf (1979) and Whittaker (1994).

The ‘workability’ or quality of various chert types is related to the grain size of the material (Luedtke 1992). The finer the individual quartz grains are the higher the quality of the material in terms of predictable flaking and edge sharpness. Visually, fine grained high quality cherts will be lustrous and have a smooth texture. Quality can be assessed by striking off a test removal, the pitch produced by tapping with another rock or hammer and observing micro-impacts on the outer surface. The strength of chert is controlled by mineralogy, amount of impurities, grain size, extent of interlocking grains, presence and frequency of cracks and pores and the water content (Luedtke 1992:88).

Color is a highly variable property in chert. Most chert exhibits a color of white, gray or black. However, chert is observed as being various shades of blue, purple, green, red, yellow, brown and various other colors. A few chert types exhibit three major color zones within an individual piece (e.g. Flint Ridge, Mookaite, Horse Creek). The discussion of color in chert is applicable to this study for two main reasons. The first reason is that many chert sourcing studies primarily utilize color properties to assign provenance. The second reason relates to the interaction of light with chert. Visible light is a portion of the electromagnetic radiation which our human eyes can detect. Our eye records the color white if more than 80% of the visible spectrum is reflected from a material (De Grandis 1986:55). Various color combinations are observed due to which portion of the spectrum is absorbed and which portion is reflected. If portions of light we perceive as green or red are absorbed by a material then our human eyes detect the reflected color blue. The mechanisms controlling absorption and reflection are discussed more thoroughly in Chapter 5. The fundamental principle worth noting here is that chert is a compilation of specific chemical, mineral and structural composition that controls which portions and how much of light is absorbed or reflected. This determines the color combinations researchers empirically observe.

Other visual properties of chert include translucency, luster, texture and structure. Translucency is the degree to which light passes through the chert material (Luedtke 1992:68). Factors affecting translucency are electron configuration, grain size, impurities (type of, distribution and amount) and the thickness of the specimen (Luedtke 1992). Luster is the description of light reflected off a chert's surface. Luster is controlled by surface characteristics (e.g. grain size and pitting) and mineralogy (Luedtke 1992:69). Texture does not necessarily refer to surface grain size, but it is more accurately a description of the fracture surface. An uneven fracture surface is termed coarse-grained (Luedtke 1992:70). The structure of a specific chert can also be termed its pattern or fabric (Luedtke 1992:71). Common structures in cherts are striped, banded, mottled or spotted. The structure of chert is primarily a function of chert formation and diagenesis. Chert commonly contains various fossil inclusions. Some of these fossil inclusions are replaced so completely that species identification is possible.

Visual properties of chert are of scientific value. The color of chert gives researchers clues to the type of major mineral impurities. High powered magnification of fracture surfaces allows researchers to observe the fabric and composition of particular specimens. The mineral composition of particular samples helps us understand geochemical data. The microscopic data can be used to construct hypotheses relating to patina formation and prehistoric heat treatment. Observations regarding structure and fossil inclusions can be studied in order to understand chert formation. The study of chert and attempts made to classify particular properties aides our understanding of prehistoric selection decisions based on mechanical and cosmological factors. Quantifying variables such as tensile strength, elasticity and grain size provide a framework to explain technological organization, manufacturing methods and thermal alteration techniques. Finally, studies regarding the atomic and molecular composition and structure of chert provide a mechanism to source artifact to geologic/geographic origins.

Provenance Terminology

Chert Type. Prior to a discussion regarding the theory, method and analysis of chert provenance research, commonly used terminology must be defined. In the current study ‘chert type’ refers to the chert that occurs within a specific geologic formation or member of a formation (Eley and von Bitter 1989:34). A second definition is given by Luedtke (1992) as “chert that occurs in a discrete geological deposit and exhibits a restricted range of variation in at least some properties; usually from a single geological formation.” The use of chert type in this manner does not restrict a particular variety to a specific point on a map. The implication for the definition of chert type in this manner is that it includes all possible outcrops, deposits and sources within a single geologic formation available for human exploitation in the past, present and future. The argument is made that chert type should not be limited to a type site locality as this practice potentially limits all archaeological source assignments to a single outcrop/deposit. However, the classification system currently in use in the fields of archaeology and geology is often subjective and regionally dependent (Butler 1984). A body of research exists which examines our classification systems and attempts to structure a more holistic classification approach (Bradley and Edmonds 1993; Burnett 2012; Dunnell 1984; Mason 1970). Awaiting future taxonomic developments that may provide a culturally inclusive system, the current study defines chert type as chert materials found within a geologically defined formation or member within a formation.

Provenance/Source. Provenance and source are used interchangeably and are previously defined. Chert provenance studies can be grouped into either an artifact centered study or a distribution study (Odell 2003). An artifact centered study analyzes suspected sources for a particular artifact or group of artifacts. A distribution study looks at the natural or cultural dispersal of a particular chert type on the landscape. Additionally, it is appropriate to make a distinction between primary source and secondary source. Primary source refers to procurement directly from the parent formation. Primary source in the study also includes procurement from soil residuum directly produced from weathering of the original geologic parent formation. Although the chert residuum in this case is out of its original context, the material still maintains an association with the decomposing or fully decomposed unit and often a close association with its original vertical stratigraphic position. The majority of the largest prehistoric chert quarries are primary sources. Secondary source is the term used for procurement of chert material no longer contained within its original geologic formation or associated with its original residuum. Secondary source materials are transported by ice, water and gravity. Aeolian processes are known to transport and deposit small fragments of chert; however, the use of such deposits by prehistoric people is unknown by the author. Secondary sources of chert are divorced from their original parent formations and transported away from any direct associations with the original soil matrix.

Any artifact being analyzed has only one original geologic place of prehistoric procurement. Another reality is that the particular artifact under analysis may have been chert obtained from the documented process of ‘cultural curation’ or ‘serial use.’ In other words, the provenance of the artifact would have two realities, one associated with the first procurement event from a primary or secondary source, and after discard a recycling event takes place where the material is re-purposed by another prehistoric consumer. This practice is more common in artifact assemblages than commonly realized, though for the provenance researcher only the original geologic source may be determined. This practice is worth noting as the resulting provenance data may lead to inaccurate cultural explanations regarding the artifact assemblage of a particular group (Galup 2007; Masson 2000). Avoidance of such an outcome would be to use multiple lines of research to deduce provenance including debitage and general assemblage morphometric analysis.

The provenance of most artifacts may never be known with complete confidence. The identification and survey of every prehistoric procurement site is incomplete. Many of these sites remain undiscovered or overlooked. Procurement sites are destroyed by modern land use practices and natural weathering. Therefore, even if every chert outcrop/deposit could be adequately sampled and analyzed source locations no longer in existence would prevent a complete representation in the database. Artifacts of unknown provenance are not absolutely sourced to any outcrop, but are rather characterized in terms of overlapping variation (Harbottle 1982:15).

Characterization. The compilation of variation of a specific material type or outcrop/deposit location is referred to as a characterization of the source (Harbottle 1982). Characterization of artifact to source means that the sum range of variation inherent in the chert used to manufacture the artifact most closely matches or overlaps with the sum range of variation in the outcrop or deposit within the sampling database. The definition of characterization of source highlights three main points. The first is that provenance analysis is rarely a comparison between one ‘diagnostic’ attribute of a sampled chert type with one attribute of the artifact of unknown source. The second is that accurately determining provenance is not a perfect matching of traits on the unknown artifact to known traits in a database such as fingerprint identification. The third is that the provenance of an unknown artifact within a database of known samples is best described using statistical probabilities. The analytical method chosen to perform classifications should be one that considers multiple variables and assigns source based upon a set confidence interval or probability. In part, accurate characterization is based upon the representativeness of the chert database within the sampling universe.

Representativeness. Representativeness of the sample refers to the ability of the specimen(s) obtained from specific location(s) on the landscape to collectively embody the full range of variation inherent at that given location(s). The degree to which a chert database is representative of the actual variability in the attributes being measured/observed is intimately related to the amount of variation in those attributes within the location being sampled. The representativeness of the sample may also be dependent on the number of samples obtained from a location. It may be the case that one sample is enough to characterize the entire outcrop/deposit or lateral extent of the sum chert deposits in the formation. However, this is unlikely. It is often the case that multiple samples from a single prehistoric quarry or geologic deposit are necessary to ensure a representative sample. Researchers have developed methods to assess variation and determine the number of desired chert samples necessary to quantify variability at certain confidence levels (Luedtke 1976; Luedtke and Meyers 1984).

Artifact centered studies that classify groups of unknowns based upon similar qualitative or quantitative traits in the absence of a geologic sample database run the risk of not identifying the full range of variation within a particular source. Instead such studies may erroneously identify cluster groups that have no spatial correlate, but are subsumed within one or two outcrop/deposit ranges. The nature and presence of variability will be discussed in the following section, but one issue remains that also dictates the degree of representativeness needed to assign provenance. The factor that controls much of the proceeding discussion is the spatial resolution of the provenance study.

Spatial Resolution. The spatial resolution of the provenance study is the level of geologic/geographic detail needed in the provenance data to explain a question regarding human behavior. In the first chapter this concept is briefly introduced emphasizing the level of spatial resolution needed is primarily dependent on the anthropological problem. High spatial resolution provenance data would be needed to address questions regarding family group control over a specific portion of an individual quarry site as evidenced by the ethnographic record (Clemmer 1990). Mid-level spatial resolution would allow the researcher to construct hypotheses regarding the presence of craft specialists at an individual quarry site within a regional quarry complex such as those in close proximity to the Colha site in Northern Belize (Cackler et al. 1999). Finally, low resolution spatial provenance data would be needed to reconstruct the seasonal round of Paleoindian hunter-gatherers in a lithic poor region (Jennings 2008; Pelletier and Robinson 2005).

The last example illustrates the role that geologic resource availability has on the level of spatial resolution needed to explain human behavior. Putting all of these concepts together allows the researcher to evaluate the dynamic relationship that exists within a provenance study. The structural flow of a provenance study may be conceptualized as the anthropologic problem determining the level of spatial resolution of the provenance study. This in turn dictates the number of outcrops/deposits needed to be represented in the sample database affected by inherent variation and geologic availability. The product is the number of samples needed per individual outcrop/deposit in order to characterize unknown artifacts to source (Figure 1). What is missing from this model is the idea that the cultural selection decisions of prehistoric people almost certainly drove procurement of particular variants; not only for technological concerns, but cosmological motivators (Gould et al. 1971).

Common Chert Provenance Study Weaknesses

There are eight commonly occurring weaknesses found within chert provenance studies. These flaws range from methodological issues to those concerning research design. It is important to identify the areas needing further development so future researchers can build upon the body of existing data and make advances in chert provenance research. Critical analysis of the areas requiring more development also gives researchers perspective on which anthropological questions are appropriate to address using chert provenance data. Our explanations of prehistoric behavior will benefit from confronting these issues, adapting to methodological changes, incorporating new strategies designed to gather provenance data and applying the data to explaining chert resource use, acquisition and distribution among prehistoric people. The eight

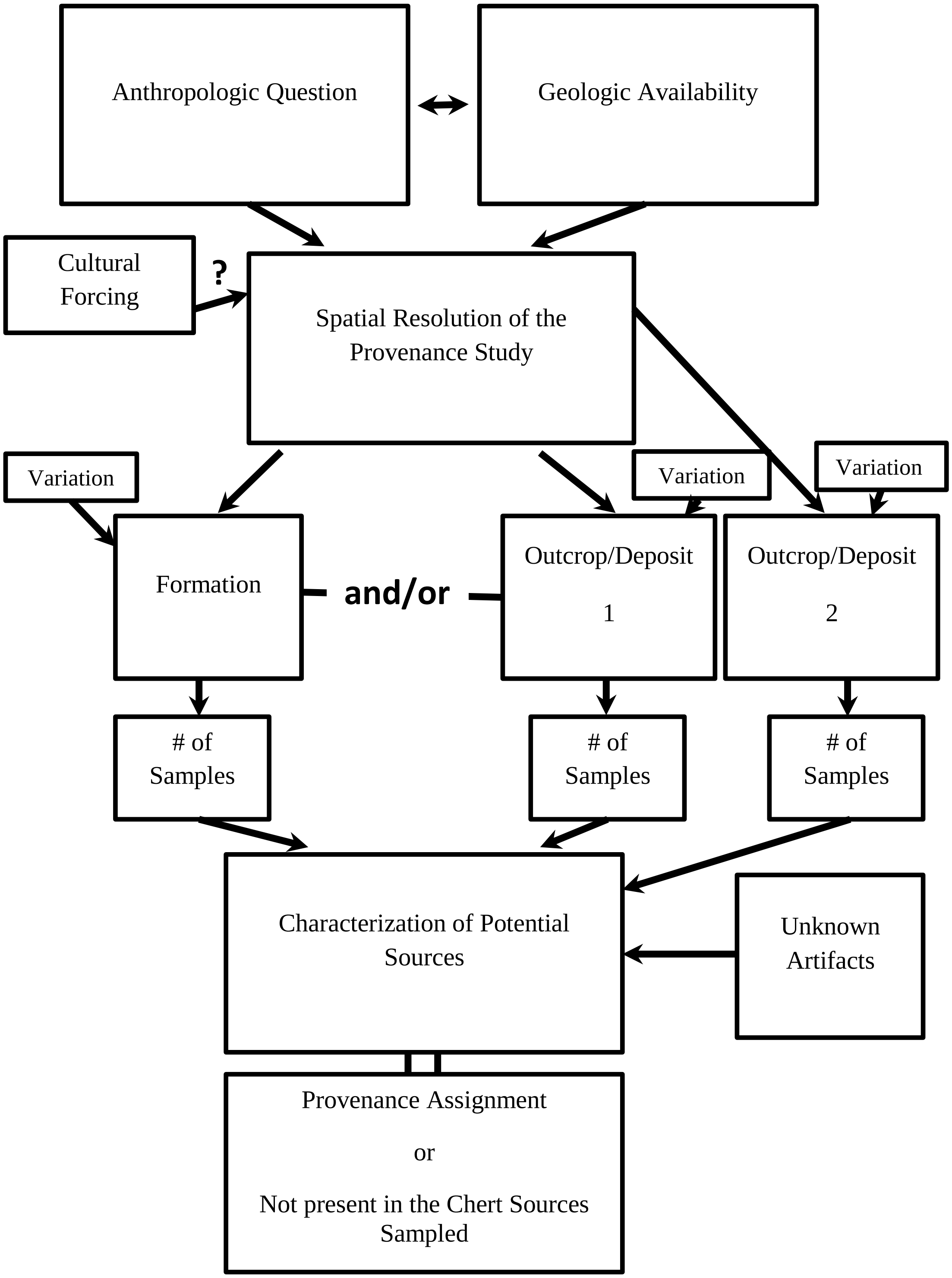

Figure 1. Diagram for structuring a chert provenance study.

flaws identified in previous chert provenance studies are organized into three groups: archaeological provenance paradigms, methodological and theoretical concerns. These issues affecting provenance studies have been voiced by other researchers (Butler 1984; Church 1994; Crandell 2005; Luedtke 1979, 1993; Tykot 2003).

Provenance Paradigms

A paradigm is an established model explaining problems and offering solutions to a body of researchers (Kuhn 1996). There are many paradigms in chert provenance research; three are identified in the current study as problematic. The three paradigms affect the research design of the study, methodology and explanations of the resultant data. The first provenance paradigm is what is termed the "mono-outcrop mindset".

Mono-outcrop Mindset. The origins of the mono-outcrop mindset in chert provenance studies can be traced back to the detailed surveys of large prehistoric quarry sites in Europe and the Americas at the end of the nineteenth century. As previously discussed, one of the results of the quarry studies is that they became material type site locations. The early distribution studies firmly planted the quarry sites in the literature as being the sole source for prehistoric procurement of a particular material. Once the location is placed on the landscape and referenced in the archaeological literature a model is constructed. The mono-outcrop model is potentially inaccurate as it excludes other potential outcrops/deposits along the lateral extent of the geologic formation producing visually similar materials. The list of possible sources for particular artifacts is limited to one of the recorded and studied quarry sites. Secondary sources existing as alluvial deposits are usually the sources that are overlooked most often by the mono-outcrop model. The restrictive nature of the paradigm has serious implications for our explanation of prehistoric chert procurement/acquisition. Usually, artifacts are assigned to ‘exotic’ or non-local sources encouraging explanations including inter-group exchange, trade or long distance direct procurement potentially neglecting the use of local sources.

Unequivocal Sourcing. The second paradigm embedded in chert provenance research relates to the presentation of source results as indisputable. The unequivocal sourcing of artifacts to a point on the landscape is problematic as it discourages the addition of newly discovered resource locations and encourages the dissemination of results often derived from a limited chert sample database. Chert provenance data must be presented with confidence, but also with the understanding that only samples from a limited number of deposits were included in the study. Therefore, results should be presented in terms of statistical probabilities. Chert database development must be dynamic. The flexibility that a dynamic database has allows the addition of newly discovered samples, potentially altering previous results. Since all prehistoric sources cannot be eliminated from the realm of possibilities, probability of source is an important component of a provenance study to report.

Blind Faith in Instrumentation. The instrumentation often used to conduct chert provenance studies is highly technical. Both the methods and mechanics of such instruments are designed for operators trained extensively in physics or chemistry. Therefore, the core assumptions behind the techniques are often elusive for the anthropology trained archaeologist unless they have received additional training outside the usual core coursework. This leads to a blind faith paradigm in the results produced by the provenance instrumentation or the technician operating the instrument. The provenance researcher often relies on others to interpret their data. The problem is that the operator has little or no training in archaeology or anthropology and is presenting the results based upon a geologic, chemical and/or physics background. The archaeologist who wishes to use the provenance data to answer questions regarding human behavior sometimes makes the assumption that data generated by the analysis is free from anthropogenic and instrumental error. Data compatibility issues between labs and instruments are often not expressed as a concern leading to the integration of multiple chert datasets from multiple instruments and labs (Shackley 2010). It is difficult for the archaeologist who does not have a vested interest in the geochemical literature or the mechanics of the particular method chosen to perform the analysis. However, it is necessary to develop a basic understanding of the how's and why's of the instrumentation as well as to conduct multiple pilot studies to test instrument drift or inter-instrument compatibility. Related to the three chert provenance paradigms, additional flaws are those concerning methodology of the study.

Methodological Misconceptions. There exist problems with current methodology that is routinely applied to chert provenance studies. Three main methodological issues involve visual analysis, sampling and quantifying the results of provenance analysis. Refinement in these areas will allow for more detailed studies in terms of spatial resolution and the validity of the archaeological conclusions. Of these three issues, provenance assignment based upon visual analysis alone is the most problematic.

Visual Identification. The identification of source by visual analysis is the most common method currently in use. The method is cost effective and fast. Visual identification of chert type is performed in accordance with other archaeological classification schemes. Lithic artifacts are classified according to type based upon predefined diagnostic attributes. A researcher who has years of regional experience often performs the chert type identifications based upon diagnostic visual characteristics and comparison within a chert type collection. A researcher conducting the visual provenance analysis was taught chert type identifications from another and may never have visited any of the primary or secondary sources in the region. The visual identification of chert type is based upon poorly defined characteristics and in this regard is similar to many of the classification schemes within archaeology.

The process of visually assigning source is arbitrary. The main characteristic of chert used to assign sources is color. Color in chert is shown to have a wide range of variation within the formation, within a particular outcrop and within individual artifacts (Luedtke 1976, 1979). The error rate associated with visual source identification is reported to be between 40 and 70% (Boisvert and Costine 1993; Calogero 1992; Perry 1992; Price et al. 2012). The repeatability of visual chert type identifications between researchers also has large error rates (Price et al. 2012). Compounding these issues are the multiple names in use for a particular chert type. Visual identification of chert type might be best applied to gain a priori knowledge about assemblage variability such as possible number of sources and suspected locations. However, it should not be used as a stand-alone provenance technique.

Grab-bag Sampling. Sampling in the fields of science is crucial to obtain valid, robust results that can be replicated by other researchers. A proper sampling methodology involves having some knowledge about the target population, such as distribution, natural formation and variation. The type, presence and amount of variation within the chert types under analysis are possibly the most important aspects of sampling. It is important to obtain a representative sample of the chert type(s) in question in order to characterize the source. The researcher's goal is to bracket all variability within a known range. Each range then might be diagnostic when compared to other potential sources. Unfortunately, a reliance on 'grab-bag sampling' strategies commonly appears in the chert source literature. Grab-bag sampling is a method where few samples are obtained through random means and are used to represent a potential source. Sometimes only one sample is used in the study to provide a sum of variation for the entire chert outcrop/deposit. Dependent upon the nature of variation at the particular location it is possible, however unlikely, that one or two samples may sufficiently characterize the variation present. Usually, a number of samples obtained from various locations across the extent of the chert deposit are necessary to have a representative sample.

Push-Button Results. Presentation of the provenance data results and conclusions is essential to the study. A common misconception is that assigning source is a simplistic linear procedure involving sample analysis followed by results. An understanding of the analytical procedures and statistical treatment of the data is also necessary before a final provenance assignment can be made. Analysis of the chert sample database cannot be performed by simply feeding data into a device and collecting the results produced. The provenance of an unknown artifact may be known or unknown after the analysis is run depending on the analytical method selected. The provenance is also determined by the representativeness of the samples in the database and the source locations analyzed. Under no circumstances should a researcher expect a provenance determination by simply sending off a few unknown artifacts for analysis. A complex and detailed survey of regional and extra-regional sources provides a comparative database consisting of multiple samples from individual deposits. Internal accuracy of the technique(s) must be assessed prior to assigning source to unknowns.

Theoretical Concerns. The theory behind provenance research in general and chert provenance in particular is lacking in two major areas: geologic framework and an understanding of variation. These two concepts are interrelated; the former being a proxy to explain the latter. However, many provenance studies conducted to date do not contain a section or even a sentence devoted to either. The value of presenting information regarding the geologic setting and a range of observed variation in and between chert types cannot be overstated.

Lack of a Geological Perspective. Chert resources are a direct product of the paleo-depositional and post-depositional environment. An excellent proxy for understanding the natural distribution, occurrence and quantity/quality of chert deposits is to study how the deposits formed and what forces affected them after deposition. Only a few chert provenance studies present an overview of the regional geology. Some studies do not mention the parent formation of the chert source or sources being studied. A brief discussion of the geologic setting lays the foundation for the study and places the selection decisions of prehistoric people within a framework of resource availability. In the absence of a detailed geologic discussion, references should be provided for additional information. Geologic formation names for chert deposits under analysis should be provided at a minimum.

Concept of Variation. Inherent variation in chert deposits can exist in a number of different forms. Variation within a deposit may be evenly spread across both the lateral and vertical portions of the exposure or it can be concentrated in discrete pockets. Luedtke and Meyers (1984) provide a more comprehensive discussion of the types and nature of variation. Understanding variation in the targeted population is often not addressed in chert provenance studies. This is evidenced by small sample sizes and the lack of a sampling strategy. Currently, the concept of variation in chert provenance studies is limited by a focus on singular type locations, visual observations, cost and speed of analysis. Quantification of the range of variation at an anthropologically and geologically appropriate spatial resolution is necessary to obtain useful results.

The eight major weaknesses that repeatedly resurface in the chert provenance literature are those concerning established paradigms, methodologies and theoretical constructs. If chert provenance research is to advance, researchers must address these problems. A lack of chert provenance theory may explain many of these issues. The following discussion attempts to build upon an existing body of chert provenance theory.

Chert Provenance Theory

The fundamental theoretical principle behind all provenance studies is the provenance postulate originally articulated by Weigand et al. (1977) and later refined by Neff and Glowacki (2002). The provenance postulate, as defined previously, deals with space and variation. In the following discussion the nature of variation is expanded upon by looking at variation in chert at different spatial resolutions. The ability of the provenance study to quantify variation at an appropriate anthropological spatial resolution allows the researcher to examine particular human behavioral questions. Four scales of variation are defined and discussed in order of increasing spatial resolution. The four scales of variation are essentially an extrapolation of the provenance postulate along its theoretical projection. The underlying hypothesis is that variation increases with distance. The hypothesis is almost certainly not always the case and it is not argued here that the relationship with variation and distance is a linear one. However, this theoretical principle is worth exploring and is discussed further in the study. The inability of the chert provenance technique or method chosen to differentiate variation at any point would have implications for the types of anthropological questions able to be examined.

Scales of Variation (inter-formation). The primary objective of most chert provenance studies is to differentiate between two or more chert types. Therefore, the researcher is required to quantify and characterize variation between chert types naturally occurring in two or more geologic formations or present in distinct members within a single formation. The term formation is used in the study to describe geologic material containing enough characteristics to distinguish it from adjacent rock. A formation could, but may not have been deposited under similar paleo-climatic regimes. There exists the possibility that a large amount of variation is present within the entire lateral extent of the formation making it necessary to obtain samples from multiple known outcrops. Conversely, the inter-formational variation may be comparably small if the surficial extent of the formation is more restricted.

The size of the parent formation and the relationship it has with the extent of inter-formational variation may not be a reality, but variation at any one chert deposit may not be adequate to characterize the formation’s sum variance. However, an assumption may be made at this point that the sum variance within the chert deposits derived from one geologic formation should theoretically be differentiated from the sum variance of chert from a different geologic formation. It is appropriate to make this assumption based in part upon our geologic classification scheme that differentiates geologic formations according to the nature of their deposition. The determination of chert type provides data that in most cases answers the anthropological problem due to the paradigm of favoring a single outcrop for source. The spatial resolution of the chert provenance study may be low as successful source identification provides data concerning the parent geologic formation.

Scales of Variation (intra-formation). Few chert provenance studies seek to characterize multiple chert deposits within the same geologic formation. The quantification and differentiation of lateral variation at the intra-formational scale is more common in obsidian provenance studies (Ericson and Glascock 2004; Glascock et al. 1998; Glascock et al. 2010; Shackley 1988; Shackley 1992; Shackley 2009). The ability to geochemically differentiate multiple obsidian deposits within a particular flow is attributed to the unique formation of obsidian and its ability to inherit the chemical signature of the surrounding materials (Shackley 1998). Using the provenance postulate as the theoretical base, the researcher can assume that the possibility exists to characterize and differentiate variability between different outcrops within the same geologic formation. The ability to characterize and statistically differentiate individual deposits of the same chert type would increase the spatial resolution of the study, thereby addressing anthropologic questions related to chert use at a smaller scale. The ability to differentiate intra-formational variation would also allow researchers to ask more detailed questions.

Scales of Variation (intra-outcrop). The characterization of intra-outcrop variation represents an extremely high spatial resolution one in which examples are only known from ethnographic analogy (Clemmer 1990; Holmes 1919; Rusco and Raven 1991). Therefore, intra-outcrop variation is essentially a hypothetical study where unknown artifacts are sourced back to portions of the quarry site or procurement location. The ability to study prehistoric resource selection at the intra-outcrop scale would be extremely useful for reconstructing diachronic quarry use, individual household or group control of portions of the quarry and investigating craft specialization. The factors determining the success of a provenance study investigating intra-outcrop resource use are exactly the same as those affecting a provenance study investigating chert type. The difference is that the place of procurement within the quarry is the focus of the provenance study. Another possible difference is that the number of samples needed to characterize portions of the quarry/procurement site may be a significant number to quantify and differentiate the potential presence of lateral and vertical variation.

Scales of Variation (intra-artifact). A provenance study whose aim is to source individual pieces of debitage back to a core or biface would not be an efficient use of time and resources. However, intra-artifact variation in this discussion should not be seen as the end of the variation spectrum. The ability of a provenance study to account for variation at the artifact or sample level is important. Many varieties of chert exhibit heterogeneity at a microscopic scale. It is important to select a bulk analysis technique or account for intra-artifact variation by other methods in order to quantify variation at the artifact or sample level so that individual samples can most accurately characterize the variation at the outcrop/deposit or formation level. A second method to quantify intra-sample variation is to take multiple analyses upon individual specimens. The important point is to account for intra-artifact variation in order to ensure samples obtained from sources are representative of particular chert resources.

The ability to characterize variation at the four scales of variation is directly related to the spatial resolution of the provenance study and the types of anthropologic questions which can be asked and explained by the data. The ability of a provenance study to characterize diagnostic variation at a given spatial resolution is essentially what the provenance postulate articulates. The relationship that geographic/geologic distance has with variation is worth exploring. There are multiple factors that affect chert provenance studies, for further discussions see Church (1994), Foradas (1994), Luedtke (1979, 1992), Malyk-Selivanova (1998a, 1998b) and Neff (1998). The main factors that affect chert sourcing are primarily methodological concerns dealing with artifact analysis, sampling, instrumentation and quantification of resulting data. These four factors are addressed in Chapter 6.

Chert provenance research is a proxy for understanding a wide variety of prehistoric behavior. However, the historic development of the research has imbedded a mono-outcrop paradigm into current studies. Future researchers need to conceptualize chert exploited by prehistoric people as resource pockets potentially accessible along the lateral extent of the parent geologic formation. Researchers must define the spatial resolution of the study by a significant anthropologic question. The spatial resolution of the study will determine the scale of variation needed to be characterized. Other methodological concerns will further structure the provenance study. The constant theoretical principle originally articulated as the provenance postulate directs provenance research. The proxy for understanding variation in chert at different spatial resolutions relies upon an understanding of the paleo-depositional and post-depositional environment. Only through an understanding of chert diagenesis at the regional and local levels can the provenance data be placed in a geologic framework further aiding anthropologic explanations.

CHAPTER 3

GEOLOGY

An understanding of the geologic setting is crucial to a successful chert provenance study. Chert resources should be viewed within a geologic and anthropologic context. A specific chert type is a product of unique natural conditions often existing in pockets over a large geographic area. The combination of original deposition of the parent formation and later changes to these deposits is the formula that produces chert resources. An understanding of the geomorphology of the landscape is also important to a chert provenance study as it allows the researcher to study the availability of the resource as a product of landscape evolution. A geologic perspective defines chert provenance research in two main ways. It provides the researcher with an understanding of lateral continuity of chert sources and a proxy for modeling variation within the chert type and individual deposit. The following discussions expand upon the concepts of lateral continuity and proxy for variation as well as provide a broad overview of chert diagenesis. The geologic and physiographic history of the study area is described with a focus on two formations initially deposited during the Mississippian Period.

Study Area

The study area is defined by the extent of two geologic formations and the occurrence of visually similar chert found within the formations. These two formations are the Fort Payne and the St. Louis limestones, both having surficial expression across the Midwest and the southeastern United States (Figure 2). The surficial extent of the two formations extends south from southern Illinois and central Indiana across much of Kentucky and Tennessee to the northeastern corner of Mississippi, northern Alabama

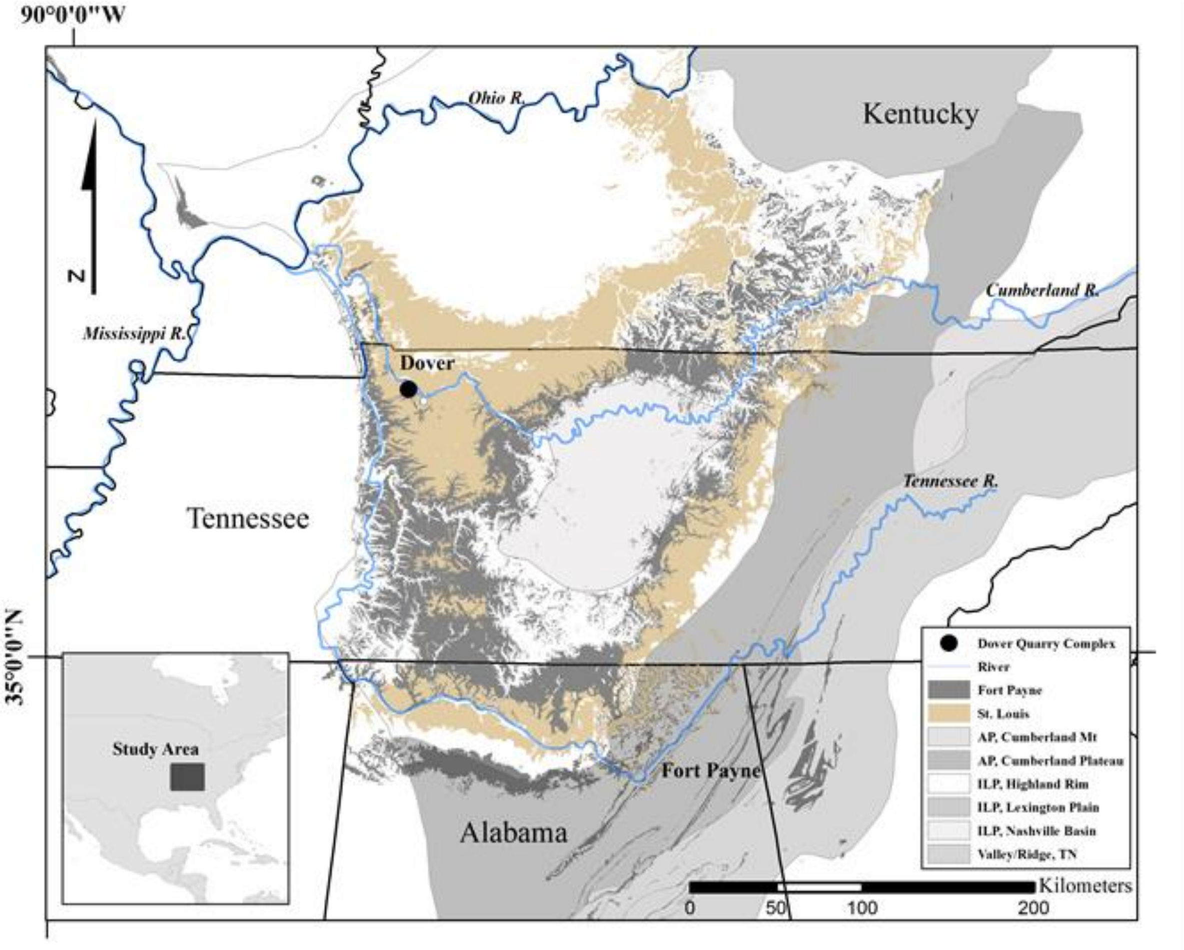

Figure 2. Map of the study area depicting the distribution of the Fort Payne and St. Louis Limestone Formations, the four major drainage basins and the three physiographic regions (Appalachian Plateaus [AP], Interior Low Plateaus [ILP] and Valley and Ridge). Chert type sites and approximate location of the Dover Quarry sites are also depicted.

and the northwestern corner of Georgia. The two formations are incorporated within three physiographic provinces: Interior Low Plateaus, Appalachian Plateaus and the Valley and Ridge. The large study area precludes a detailed discussion concerning each location sampled; however, a broad regional understanding of the Fort Payne and St. Louis formations is possible. Relevant references are provided where applicable for further reading.

The regional geologic history of the two formations provides a backdrop upon which a select few localized studies are used as examples of micro-regional depositional and post-depositional processes. Specific attention is given to the type site locations for ‘Dover’ and Fort Payne chert: Dover, TN and Fort Payne, AL respectively. The geologic history of Tennessee is the primary focus as the majority of chert samples and sword artifacts were obtained from locations within the state’s borders. However, as the study demonstrates, a particular chert type is not confined by state or physiographic boundaries. What does change across arbitrary boundaries is the classification nomenclature causing difficulties in correlating geologic formations and/or units between systems. Despite conflicting typology, a chert provenance study benefits from a review of the geologic literature.

Lateral Continuity

The most basic geologic information that a chert provenance study should report is the parent formation(s) for the chert type(s) under analysis (Crandell 2006). If the geologic formation is not known then further discussion is necessary to describe possible associations and the evidence for inclusion in one formation or another. Reporting the parent geologic formation in a study whose goal it is to assign provenance should be an unconscious act on the part of the researcher. However, it is necessary to explicitly state this as multiple chert provenance studies exist that do not report parent geologic formation (Cackler et al. 1999; Evans et al. 2007; Akridge and Benoit 2001). The identification of the parent formation or possible formation provides information regarding the potential natural distribution of the particular chert resource.

Lateral continuity, in this context, describes the potential for visually similar chert deposits within the parent geologic formation along its geographic spread. Conditions that influenced the deposition of the chalk, dolomite, limestone, sandstone …etc. formation also acted upon the diagenesis of chert. Similar depositional conditions and later stimuli may have produced multiple deposits of chert with similar visual characteristics. Chert resources of sufficient package sizes for prehistoric exploitation are not laterally continuous across the formation but the potential exists for the occurrence of resource pockets. The implication of the lateral continuity concept for studying prehistoric behavior is that multiple procurement locations may exist for a particular chert type. Depending on the surficial extent of the geologic formation, the procurement locations may be located at great distances from one another. A failure to either adopt a previously defined type name or recognize that a deposit is associated with a particular formation leads to many chert type names for material coming from the same geologic formation. Multiple names for chert from the same geologic formation is a correct methodology only if the particular deposit can be differentiated from others based upon some diagnostic attribute(s).

An example of two chert types outcropping in multiple locations over a large geographic area is the Ste. Genevieve and Upper St. Louis. The Ste. Genevieve formation overlies the St. Louis causing confusion regarding the provenience of macroscopically similar chert types. Ste. Genevieve and Upper St. Louis chert are often called Wyandotte, Harrison County, Indiana Hornstone, Kentucky blue, Hopkinsville and Cobden chert. The blue, fine-grained chert occurs in nodules occasionally with concentric banding. The Upper St. Louis chert was heavily exploited prehistorically at numerous deposits in Illinois, Kentucky and Tennessee. The Ste. Genevieve chert was exploited to a large degree by prehistoric people in Indiana and Kentucky. The potential for multiple chert deposits with similar visual, mineral and chemical characteristics along the lateral extent of the geologic parent formation necessitates thorough sampling and differentiation at the intra-formational scale.

Proxy for Variation

The geologic history of the sedimentary deposits containing chert gives clues regarding the nature of variation within and between deposits. Luedtke and Meyers (1984) outline six models describing the nature of geochemical variation in chert deposits. While their study focused on outcroppings of Burlington chert along the lower Illinois River Valley, the models describing potential variation within chert deposits are applicable to any geographic setting. A complete discussion of the six models of variation can be found in Luedtke and Meyers (1984:290-293). The information relevant to the current discussion is that variation within a deposit may be distributed uniformly, randomly, vertically systematic, horizontally systematic, both vertically and horizontally systematic and irregularly.

Variation, whether it is in the form of coloration, mineral content, geochemistry, fossil inclusions and/or texture is correlated with the formation of the parent deposit. Two excellent provenance studies that link the geologic formation of the deposit to diagnostic visual, spectral and geochemical attributes are those conducted by Foradas (2003) and Lyons, Glascock and Mehringer (2003). The geologic history of the study area directly influences the formation of chert and the inclusion of concentrated deposits at particular locations (Pitblado et al. 2012). The geologic history of a particular formation is broadly similar across the lateral extent of the deposit, but may exhibit micro-regional variation due to sea-level transgression/regression events, clastic inputs, tectonics and other influences (Murray et al. 1990; Owen et al. 1997). The reason why one chert deposit may be differentiated from another is related in part to the geologic history. Chert is a product of both primary and secondary regional and local geologic events. Post-depositional processes also directly contribute to variation in chert. Finally, the geomorphology of the landscape allows for exploitation by prehistoric people. However, the geologic history alone may not fully explain cultural selection of particular resources. Other lines of evidence are needed to study preferential prehistoric acquisition of one chert deposit over another.

Chert Diagenesis

The formation of chert continues to be a topic of research for geologists. The formation of chert in a natural setting has not been empirically observed. Geologists did not have a modern analogue for chert formation in Tertiary deposits as late as the 1970's (Lancelot 1973). Currently the existence of a modern analogue is still a controversial topic. The Deep Sea Drilling Project conducted from 1968 to 1983 was a hallmark study for chert research (Luedtke 1992). Though not undertaken specifically to study chert formation, researchers were surprised to find siliceous deposits as precursors of bedded chert in deep ocean deposits worldwide. As the results of the Deep Sea Drilling Project were published, the data revolutionized our understanding of the relationships between sedimentary deposits and chert. The results also encouraged controlled laboratory experiments giving researchers further clues to the formation of chert.

Currently, geologists ask three main questions when studying a chert deposit: 1) what was the source of the silica? 2) what is the timing for the rate of carbonate replacement or the transformation of siliceous ooze to chert? 3) what was the paleo-environment at time of deposition (McBride 1979)? A researcher may also study paleoclimatic variations by recording the oxygen isotope ratios encased in the deposit (Knaugh 1992). The body of geologic chert research demonstrates that the silicification process is extremely complex. What is clear is that chert is a diagenetic product. The fact that there are multiple ways in which a deposit can form is a double edged sword for the provenance researcher. The discouraging aspect of chert diagenesis is there is the potential for a large amount of variation in the composition both between and within formations. The encouraging aspect of chert diagenesis is that if the researcher can quantify the variation, there is a greater likelihood that one deposit will be differentiated from another due to the unique formation processes.

There exist two main theories for the occurrence of chert. The first theory is the biogenetic model where large masses of siliceous ooze accumulate from microscopic organic remains such as diatom skeletons. Through time and temperature changes, the opal-A precipitates are reconstituted into opal-CT. Later changes transform the opal-CT into microcrystalline quartz (Knaugh 1994). The second theory of chert diagenesis is the replacement model. Silica from sponge spicules in shallow sea environments replaced carbonate sediments during early consolidation of the deposits. The mobilized silica directly precipitated as microcrystalline quartz in the form of nodules and thin beds at shallow depths (Knaugh 1992). A detailed discussion of chert diagenesis may be found in Carozzi (1993), Hesse (1990), Knaugh (1992, 1994), McBride (1979) and Siever 1962.

The occurrence of chert in the St. Louis and Fort Payne Limestone formations is hypothesized to have formed via the replacement model (Anderson 1981; Moore 1978). A counter argument is presented by Marcher (1962a, 1962b) for a biogenetic model for the bedded chert in the Fort Payne formation. The deposition processes of the St. Louis and Fort Payne during the Mississippian Period are similar and influence the chert deposits contained within each. A brief examination of the Mississippian Period in the Southeastern United States gives the researcher a broad understanding of the conditions which produced chert deposits over a large geographic area. Examination of a select few micro-regional studies illustrates the variability in the deposition of the St. Louis and Fort Payne across the study area.

Geologic Context

The geologic history of the study area spans the last 1 billion years of Earth's history. To help researchers describe this span of time, it has been broken down into eras that are related to important changes of life on Earth (Miller 1974). The eras displayed in the geologic record of the study area are as follows from oldest to youngest; Precambrian, Paleozoic, Mesozoic, and Cenozoic. These Eras are further subdivided into Periods based once more on changes in life that occurred during the period of time. A Period can be further subdivided into Epochs that are further subdivided into Early, Middle, or Late. The Fort Payne Limestone Formation was deposited during the Early Mississippian Epoch of the Mississippian Period of the Paleozoic Era. The St. Louis Limestone Formation was deposited during the Middle Mississippian Epoch of the same period and era.

The geology of any given region is similarly subdivided within this temporal framework. The composite of all rocks formed during a Period is referred to as a System (Miller 1974). A series are a group of similar rock units equivalent to Epochs, but the basic geologic map unit is the Formation. A number of similar formations described together are referred to as a group. The naming of these formations is based on type locations where the unit was first or best described.

Formations contain distinguishing characteristics that set them apart from overlying and underlying rock units. Some of these characteristics can be the formation's vertical and horizontal position, color, texture, thickness, composition, presence or absence of diagnostic fossils, and lithology. By identifying these characteristics geologists can in turn identify forms of life and reconstruct past depositional environments and post-depositional processes that affected each formation. The current study focuses on carbonate deposits laid down during the Mississippian Period.

Mississippian Period (354-324 mya)

The environment during the Mississippian Period in what is now the southeastern United States was characterized by shallow seas with shifting currents, migrating shorelines, and the deposition of clastic sediment (Figure 3). Much of the land at the periphery of this inland sea was at sea level characterized by tidal flats and the beginnings of swamp forests into which mud washed (Miller 1974). The majority of the Mississippian aged outcrops are exposed along the Highland Rim section of the Interior Low Plateaus province. The Maury shale marks the beginning of the Mississippian aged rocks. By observing the deposition of the Maury shale and underlying Chatanooga formation, geologists can see that no widespread erosion or uplift characterizes the transition from the Late Devonian to the Mississippian Period. However, the large inland sea in the east-central United States during this time deposited a large amount of silty, limy sediment that was replaced in part by silica. This formation is called the Fort Payne and is characterized by limestone and bedded and disseminated chert, shale, siltstone beds, and dolomitic zones (Miller 1974).

Crossbedding in the Fort Payne formation indicates strong wave or current action while other units indicate quiet waters. The depositional environment during the Mississippian Period can be best described as a complex interplay of processes. Clastic deposits of sand and shale in other similarly aged formations suggest deposition by currents or wind action (Miller 1974). An example of this complexity is the Pennington formation in which shale, siltstone, dolomite, and limestone are all present. Thin coal beds deriving from swamps, shale forming from sediment washing in from areas of land, and the dolomite and limestone indicating times when the silt and mud wash were absent, are all represented in the Pennington formation.

The shallow seas and water turbidity provided an environment in which prehistoric life flourished (Figure 3). The most abundant fossils found in the Mississippian System are crinoids, giving this epoch its nickname “The Age of the Crinoids”. Large masses or mounds of them form bioherms and can be found scattered throughout the Mississippian formations. Also, large numbers of foraminifera, single-celled animals with calcium carbonate shells, collected on the sea floor forming significant portions of limestone beds (Miller 1974). The coarse grained limestone deposits are made up of large shell fragments, whereas fine grained limestone consists of

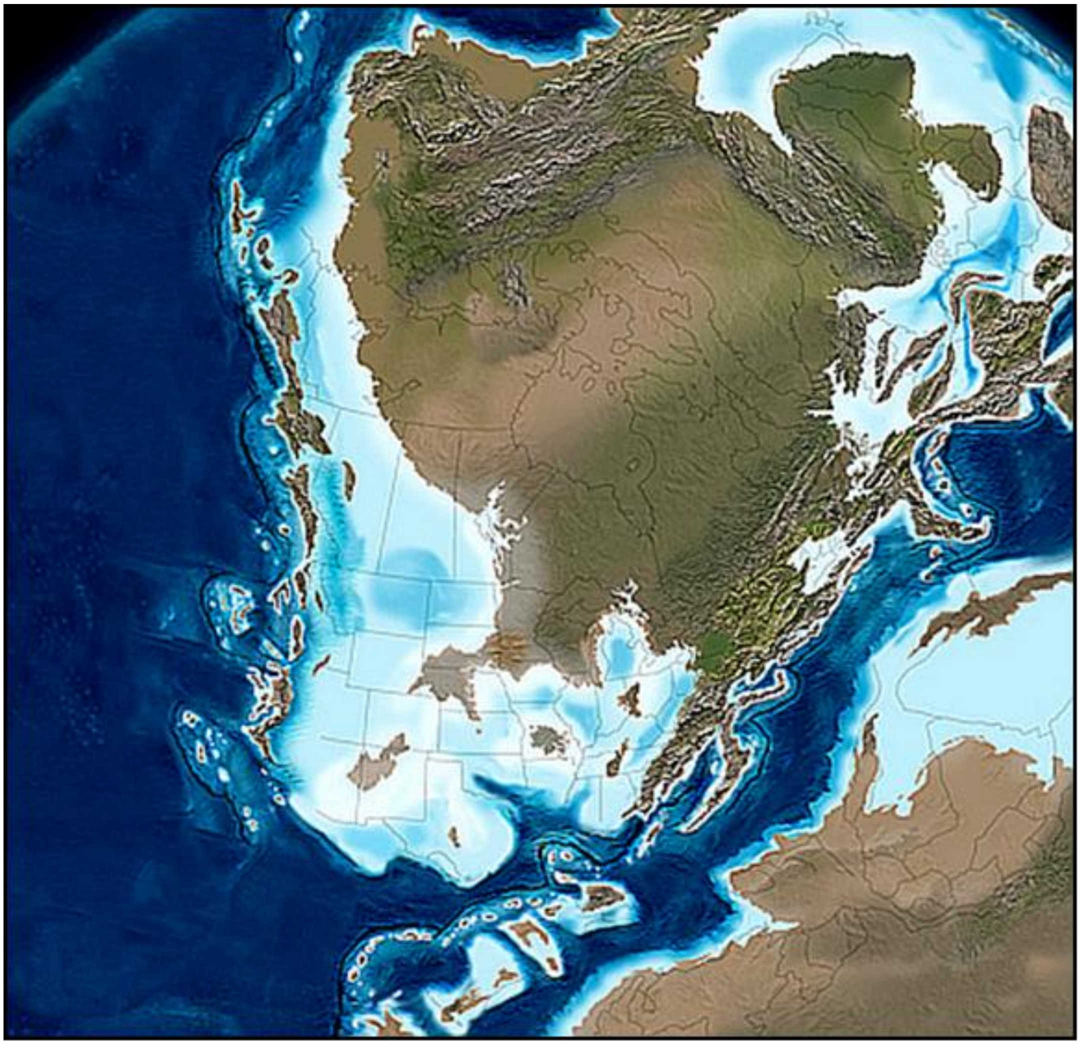

Figure 3. Middle Mississippian Period (345 mya) paleogeography of North America (Blakely 2011).

organically secreted or chemically precipitated lime ooze.

Fort Payne Limestone Formation

The Fort Payne Formation is well-represented in the geologic literature of Tennessee, Illinois, Kentucky, Mississippi, Alabama and Georgia. The formation was named by Eugene A. Smith (1890) after where he observed it outcropping near Fort Payne, De Kalb County, Alabama. Eugene A. Smith placed the Fort Payne Formation between the underlying Chattanooga Shale and the overlying St. Louis Limestone

(Tuscumbia). The base of the Fort Payne is often subdivided into the Maury Shale formation. The overlying Tuscumbia Limestone Formation is correlated with the Warsaw Limestone/St. Louis Formations of Tennessee.

The Fort Payne formation has surficial expression across portions of northern Alabama. Here the limestone is described as a bluish to greenish-gray, fine to coarse grained limestone (Daniel and Hastings 1968). The formation is fossiliferous containing crinoid stems, brachiopods and scattered corals (Ruppel 1971). Thickness of the formation ranges from 31-61 m (Thomas 1967). The Fort Payne formation in northern Alabama contains thick beds and nodules of light gray to black chert. However, chert deposits near the type locality are highly weathered and contain numerous incipient fracture planes. This location is incidentally the southern-most extent of the Fort Payne Formation and is not representative of the entirety of the chert deposits contained within the formation. The boundary with the overlying Tuscumbia Limestone Formation is conformable.

In Tennessee, the Fort Payne Formation was originally named the Tullahoma Formation by Smith and Hayes in 1890. Bassler (1932) was the first to call it the Fort Payne after its type locality (Bassler 1932). The Fort Payne probably represents dark colored highly siliceous deposits that formed further out from the paleo-coastline in the Illinois basin. The maximum thickness of the formation is 136 m, averaging 61 to 76 m thick in the Dover, Tennessee area (Marcher 1962a). Bassler (1932) describes the formation as a massive siliceous to argillaceous limestone that weathers into great quantities of blocky yellow chert. Marcher (1962b) claims that two lithofacies can be discerned, a bedded chert and a ‘scraggy chert’. The bedded lithofacies of uniformly fine grained chert is intercalated with siliceous limestone or siltstone containing siliceous geodes. The ‘scraggy’ chert lithofacies is caused by the weathering of the underlying calcareous layers. The insoluble silica left behind is a pale yellowish brown material contrasting sharply with the darker limestone patches. Marcher (1962) uses the term ‘scraggy’ to describe the chert based upon its blocky appearance caused by small scale folding and faulting after the leaching of soluble sediments.

The Fort Payne Formation contains small carbonate rhombs, cubes and irregular masses of pyrite, and beds of fine grained to coarse grained fossil calcarenite (Marcher 1962b). The occurrence of pyrite is rare as it is often altered to iron oxide. The most abundant fossil type within the Fort Payne is crinoid stems, often located were the unit has been exposed to long periods of erosion. The thinly laminated presence of these crinoid stems and bryozoan fragments indicates quiet waters free from scavengers (Marcher 1962b). The formation of discontinuous beds of fossiliferous calcarenite shows that life was abundant in parts of the inland sea. In the northern portions of the Dover, Tennessee area these beds thicken, indicating a slow subsidence of the depositional basin (Marcher 1962b). In thin section the Fort Payne materials appear as a microcrystalline mosaic of interlocking calcite and silica particles. Crystal boundaries are almost entirely lacking (Figure 4a). Small amounts of fibrous silica and microcrystalline quartz are present along with the crypocrystalline silica (Figure 4b). There is a wide range of particle size, but the uniform texture is attributed to recrystallization of the original lime mud (Marcher 1962b). The upper beds of chert in the Fort Payne can be very similar to the overlying Warsaw Formation and are often hard to delineate in profile. The Warsaw

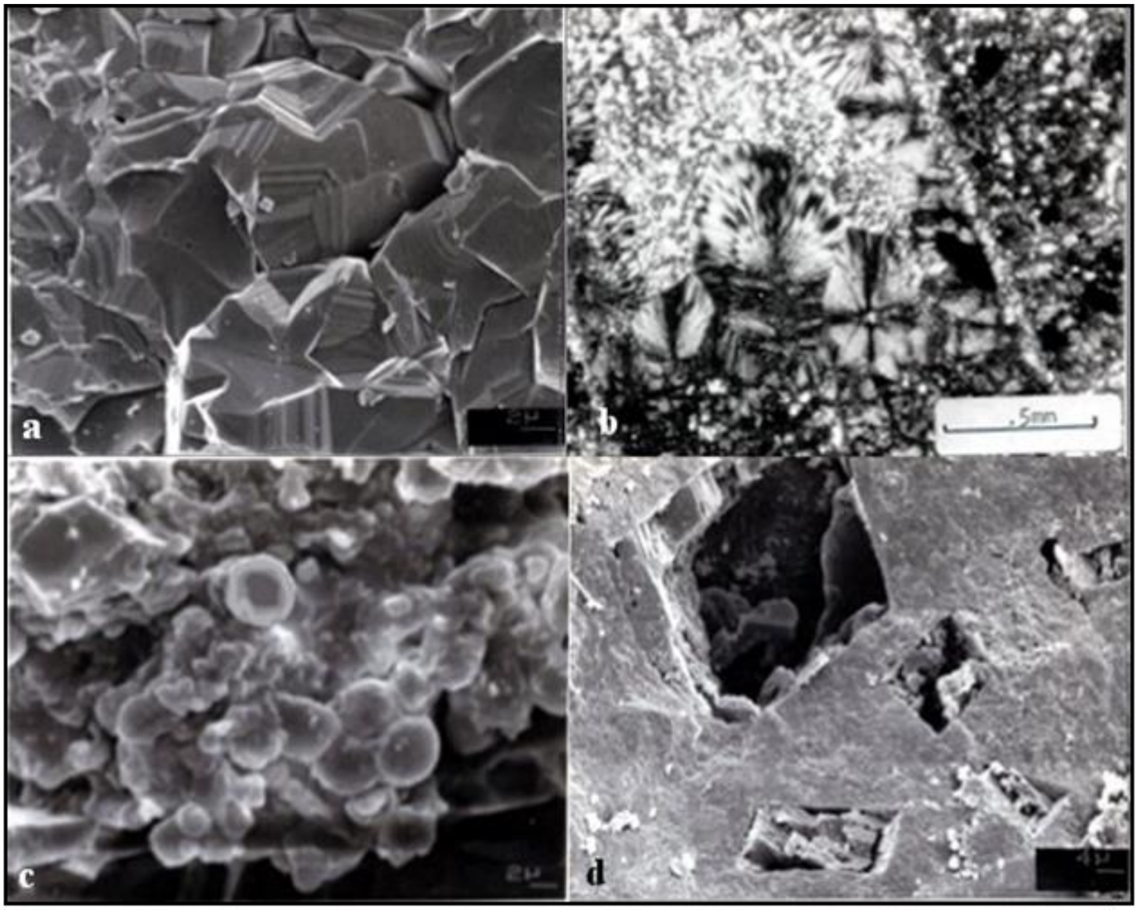

Figure 4. Scanning Electron Microscope images of Fort Payne chert samples depicting microcrystalline structure 4000x (a), fibrous cryptocrystalline chalcedony (b), spherical framboids of pyrite 3000x (c) and rhombic voids from the dissolution of carbonate minerals within a microcrystalline matrix 1500x (d). Adapted from (a, b) Anderson 1981 and (c, d) Moore 1978.

Formation marks a shift to a turbulent well aerated open shelf environment (Anderson 1981:11).

Micro-regional case studies. Previous research of the petrology of the Fort Payne Formation across north-central Tennessee is presented in Lumsden (1988). Petrographic data obtained from four outcrops along the Highland Rim provide lithological data for the formation from west of Nashville to north of Knoxville, Tennessee. The results of this study demonstrate that the Fort Payne formation occurred on a regional high along a passive sea margin isolated from clastic deposits (Lumsden 1988:8). This differs from the deposition of the underlying Chattanooga Shale during the Late Devonian Period as it was laid down initially in a low energy shallow sea (Conant and Swanson 1961). The Fort Payne was deposited at deeper water depths upon a subtidal shelf (Lumsden 1988:10). The marked difference in lithology between the Chattanooga Shale and the Fort Payne is due to sea floor elevation rising into the dysaerobic interval. This sparked an increase in sponges producing silica and carbonate mounds (Lumsden 1988:10). Chert formation occurred as direct replacement of sponge spicules and carbonate fossils. The Fort Payne Formation represents a transitional change in the paleo-environment from the anaerobic deep water conditions of the Chattanooga Shale to the shallow oxygenated marine ramp of the Middle Mississippian carbonate formations (Warsaw, St. Louis and Ste. Genevieve). Major mineral compositions include, dolomitic porcelanite, cherty wackestone/packstone/grainstone, cherty dolostone and chert both bedded and nodular (Lumsden 1988:11).

Petrologic data obtained by Anderson (1981) give more detailed information about the paleo-depostional environment in north-central Tennessee. The base of the Fort Payne Formation is marked by greenish shale containing phosphate nodules that some researchers subdivide into the Maury Shale. The lithology of the Maury Shale marks the first transgressive phase of the Mississippian sea toward the southern tip of the Illinois basin (Anderson 1981:1). At this point what would become the base of the Fort Payne Formation was deposited in a broad intertidal zone characterized by mudflats. Later deposition occurred in a supratidal environment as sea-levels regressed. Final deposition occurred after the area was inundated by rising sea-levels (Anderson 1981:62).

Lateral changes in the lithology suggest multiple shifts between sub-, inter- and supratidal environments. A comparable formation to the Fort Payne in terms of depositional histories is the Monterey Formation of California. A modern analogue to the Fort Payne is the Trucial Coast Embayment in the Persian Gulf (Anderson 1981:50).

Fort Payne Chert

Chert deposits were in place prior to lithification of the surrounding sediments (Anderson 1981). The presence of pyrite spheres is related to the presence of organics and signifies a reducing environment (Anderson 1981:40) (Figure 4c). Additionally, the presence of rhombic and cubic cavities indicates the dissolution of carbonates such as calcite (Figure 4d). Birdseye structures are also present that were originally calcite crystals later replaced by macro-quartz and chalcedony.

Fort Payne chert exists in a wide range of color variations. Munsell Soil Color Chart designations range from black (10YR2/1) to bluish grey (Gley 2 3/10B), dark gray (10YR3/1), greyish brown (10YR3/2, 4/2), yellowish brown (10YR6/4) and white (10YR8/1). Some varieties are mottled with dark silt and sapropelic inclusions, fossil fragments of crinoids, brachiopods and microcrystalline quartz geode “birdseye structures” (Marcher 1962b). Coloration appears to be dependent on a combination of the amount of iron oxides present and the degree of weathering the particular deposit has undergone. Fort Payne chert is found in bedded and nodular form grading from dark black varieties into the other color tones making it the most macroscopically variable chert type in the region. Prehistoric quarry and procurement sites of Fort Payne chert are documented in the northwestern corner of Georgia (Goad 1979), along the Tennessee River (Pickwick Reservoir), Alabama (Johnson and Meeks 1994), the Yellow Creek drainage of northeastern Mississippi (Johnson 1981), and in central Tennessee (Fowke 1928:520-522) and southern Illinois (Lopinot and Butler 1981).

St. Louis Limestone Formation

The St. Louis Limestone Formation, named after exposures in St. Louis, Missouri, makes up the dominant surficial geologic unit across the Highland Rim (Engleman 1847). The St. Louis Limestone Formation was first described by Engleman in 1847. Safford describes St. Louis Limestone as a "gray and blue, thickbedded, fossil bearing limestone, usually with nodules of chert and from 75 to 90 m thick" (Safford 1900). No reef buildups are documented in the St. Louis Formation (Cooper 1979, Cooper and Lumsden 1981). During the initial deposition of the formation sea-water depth was shallow, but gradually increased in depth, adding more wave and current agitation to the deposits (Cooper and Lumsden 1981:91). The lithology of the St. Louis is similar to the Fort Payne, being composed of lime mudstone wackestone, packstone, grainstone, dolostone, chert and shale. The occurrence and distribution of these lithofacies are indicative of shifts among sub-, inter- and supratidal environments. A modern analogue to the St. Louis Formation is the depositional environment of the Great Bahama Bank, particularly west of Andros Island (Cooper and Lumsden 1981:96)

The St. Louis Formation is typically described as the most heterogeneous of the Mississippian aged units composed of fine and coarse grained calcarenite, dolomitic, siliceous and shaly limestone. The occurrence of sapropelic material and pyrite indicates that some areas may have had restrictive circulation resulting in a reducing environment (Marcher 1962a). The lower part of the formation can exhibit foraminiferal dark cherty limestone (Marcher 1962b). Fossils include; brachiopod shells, blastoids, crinoids, echinoid ossicles, bryozoans, fibrous algae, ooliths, and two types of fossil coral (*L. canadense, L. proliferum*). In particular, *Lithostrotion canadense Castlenau* is used as a diagnostic marker for the St. Louis (Figure 5). Thin sections reveal that cryptocrystalline silica, through replacement processes, has destroyed much of the original texture. The matrix consists of feathery quartz, Endothryroid foraminifera, clear crystalline calcite and organic detritus (Marcher 1962b).

Micro-regional case studies. Probably the most cited research regarding the St. Louis Limestone formation is that conducted by Melvin Marcher (1962a, 1962b) in north-central Tennessee. The locations he observed did not include the Dover Quarry sites but his observations in close proximity to them are especially applicable for the current study. The St. Louis Limestone Formation is often divided into an upper and a lower unit in Tennessee. The lower unit is dominated by dolostone and micrite

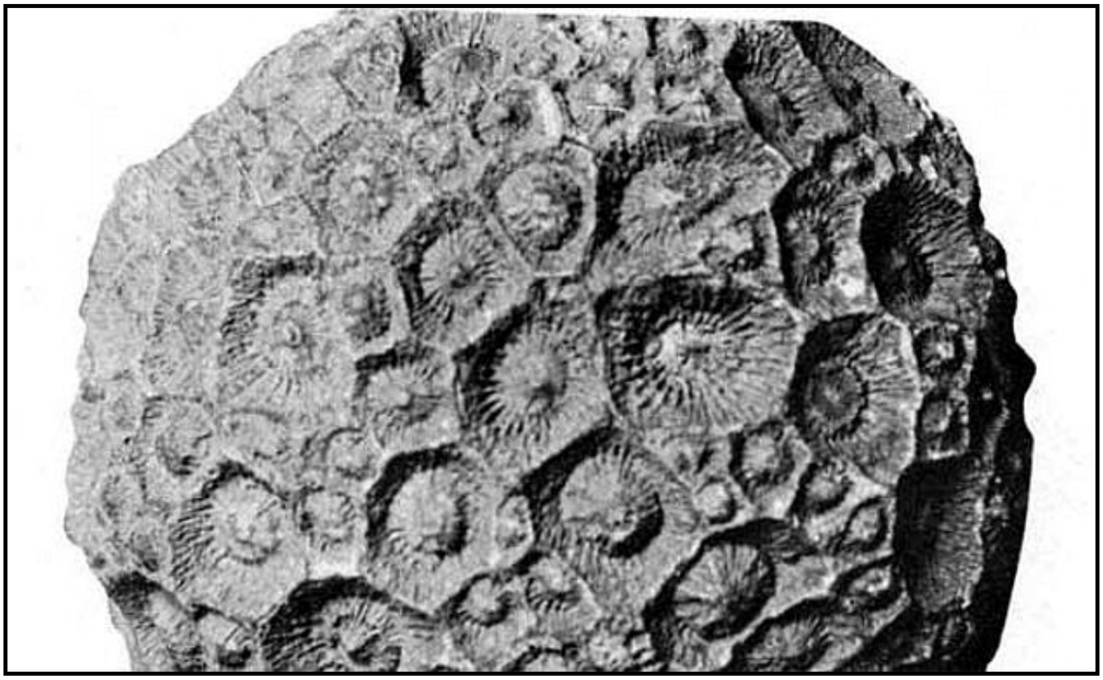

Figure 5. Fossil coral *L. canadense* marker fauna for the St. Louis Formation. Modified from Bassler (1932).

suggesting supratidal environments (Cooper and Lumsden 1981:97). During the deposition of the St. Louis, shoal-like conditions were maintained from earlier Middle Mississippian times. However, the variable character of the formation and an influx of silt and clayey materials reflect increasing instability of the shelf (Marcher 1962a). The depositional environment ranges from deep, quiet water to shallow, agitated water. Weathering of the upper portion of the limestone produces a highly fertile dark red soil containing blocks of yellow angular solid chert (Bassler 1932). The St. Louis Limestone overlies the Warsaw Formation conformably in the Dover area, but may be distinguished by its dark colored beds in contrast to the lighter Warsaw. The predominant hues of the formation are dusky brown, dusky yellowish brown, dark yellowish brown and pale yellowish brown. However, beds near the base of the formation may be much lighter, either light olive grey or yellowish grey making it more difficult to distinguish from the underlying Warsaw (Marcher 1962b).

One distinguishing characteristic of the St. Louis formation is that crossbedding is not as abundant as in the Warsaw Formation. Also the pale to yellowish brown color suggests that the water was neither as turbulent nor as well aerated as it was during the deposition of the Warsaw (Marcher 1962b). The Lower member of the St. Louis Formation is characterized by beds of dense dusky yellowish brown highly siliceous cherty limestone (Marcher 1962a). Thin sections reveal a composition of crystalline calcite and clearly defined fossil edges indicating that the material has not undergone the extensive recrystallization processes common in the Warsaw chert.

St. Louis Chert

Chert deposits were formed by direct replacement of pre-existing dolostone or limestone (Cooper and Lumsden 1981:96). No carbonate host rock has been observed to be draped over the chert nodules. Chert coming from each section differs in appearance; however around the Dover, Tennessee area the presence of the Upper St. Louis formation is not readily observed. The Lower St. Louis "Dover" chert is often described as a dense to vesicular material usually a yellowish brown to dark brown almost black in coloration. The vesicular variety is very similar in texture to the underlying Warsaw chert, but most of the material consists of the denser darker variety (Marcher 1962b). Another distinguishing characteristic of St. Louis chert is that its clear crystalline calcite matrix is the last to be replaced by silicates, unlike the replacement process of the Warsaw chert in which the calcite matrix is replaced first.

Dover chert occurs as a nodular and bedded light brownish grey (10YR6/2) to pale brown (10YR7/3) and black (10YR2/1) mottled material. The dark mottling sometimes combines with white coral (*Lithostrotion canadense, L. proliferum*) fossil fragments to give the chert a wood-grained appearance (Marcher 1962a). Such inclusions may be diagnostic for Dover chert, but are rarely present. In addition to the fossil inclusions, white and/or blue patches of slightly coarser quartz crystals are present either as solid inclusions or in voids lined with small crystals. Under high-powered magnification, St. Louis chert appears very similar to the Fort Payne exhibiting rhombic voids, carbonate minerals and a microcrystalline quartz matrix without clearly defined crystal boundaries (Figure 6).

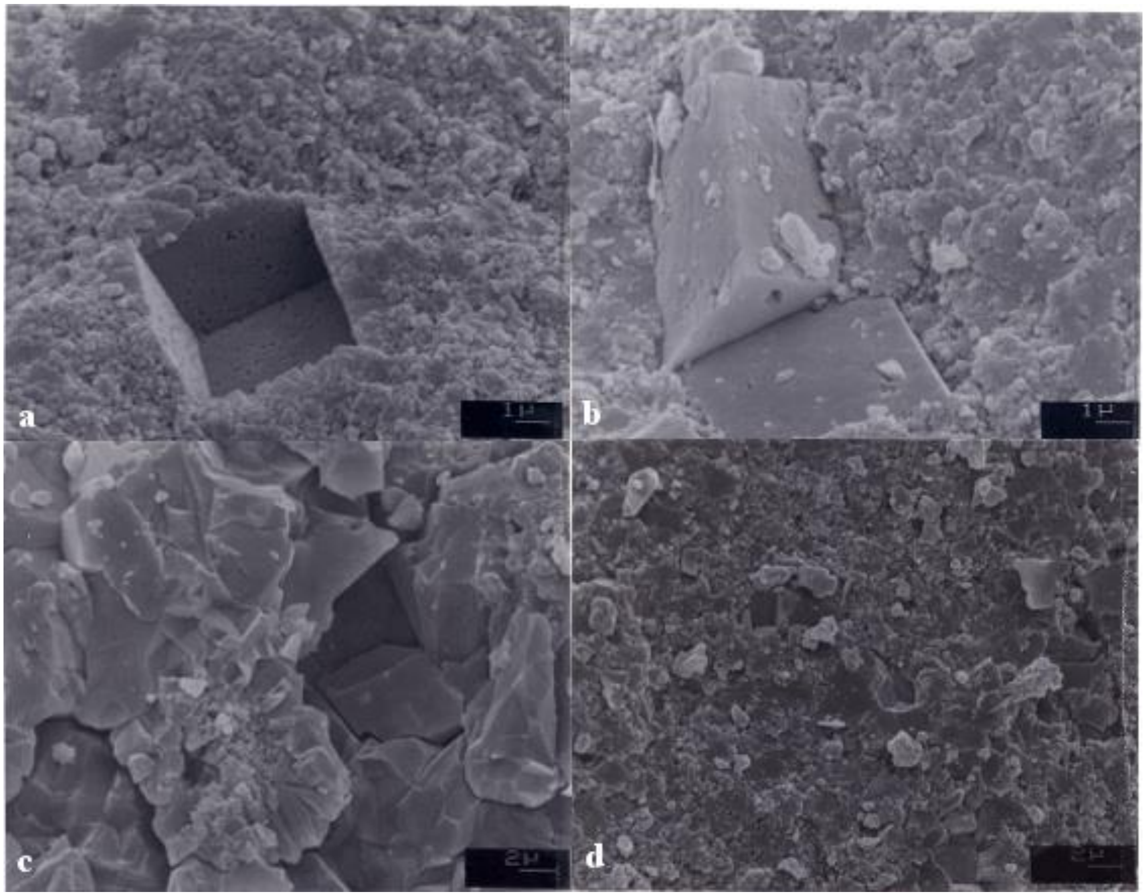

Figure 6. Scanning Electron Microscope images of St. Louis chert illustrating rhombic void 8000x (a), in situ carbonate minerals 8000x (b), microcrystalline quartz matrices 4000x (c) and 4000x (d). Modified from (a, b) Anderson 1981 and (c, d) Moore 1978.

The dark variety of Dover chert is usually found in close association with the parent limestone and relatively protected from weathering. The patina on Dover chert can develop in a geologically short period of time (less than 1,000 years), as evidenced by diagnostic prehistoric artifacts directly associated with the quarry sites. The patina surface is either a light grey or tan color less than 1 mm in thickness. The type locality for Dover chert is a series of prehistoric quarry sites along the lower Cumberland River drainage near the town of Dover, Stewart County, Tennessee (Figure 2). However, evidence for prehistoric exploitation of Dover chert is documented outside the type location (McNutt and Graham 1967). According to Marcher (1962a) "no cherts as discrete masses have been observed in these formations". Instead large 'cannonballs' or chert nodules are the most commonly occurring form of chert found within the formation. These nodules have a thin white tripolitic rind, with an interior of dusky yellowish brown or nearly black fine to medium grained chert. The nodules commonly do not show a radiating internal structure (Marcher 1962a).

Additional Chert Types in the Study Area

There exist a number of other chert types in the study area. Each resource was exploited to varying degrees over time by prehistoric people. The Fort Payne and St. Louis resources were arguably two of the major chert types exploited, but other varieties such as Mill Creek in southern Illinois, Ste. Genevieve in Indiana and Kentucky, and Bangor in Alabama were also highly favored resources. A detailed discussion of these various chert types may be found in Meyers (1970), Koldehoff (1985, 2002) and Ray (2007) for chert resources of Illinois, Cantin (2008) for Indiana, DeRegnaucourt and Georgiady (1998) and Gatus (1979, 1980, 2005) for Kentucky and much of the Midwest, Gramly (1992), Parish (2009), Smith and Moore (1999) for Tennessee, Johnson (1981) for northeast Mississippi, Jones (1939, 1942), Futato (1983) and Jeter and Futato (1990) for northern Alabama and Goad (1979) for Georgia.

Topography

The geomorphology of the study area can be broadly described as dissected hill tops and ridgelines along the Highland Rim Plateau, punctuated at its center by the erosion of the Nashville Dome, currently referred to as the Central Basin section. In the eastern portion of the study area the land is characterized by broad anticline/syncline valleys and narrow elevated ridges, a product of the Appalachian orogeny. Soils in the study area are dominated by Quaternary aged alluvial deposits and colluvium from weathering of the underlying carbonate deposits. The study area is primarily drained by the Ohio, Cumberland and Tennessee Rivers. Numerous tributaries to these major river systems wind through the landscape that provided navigation corridors, broad fertile floodplains and alluvial gravel deposits for prehistoric inhabitants. The underlying carbonate sedimentary rocks undergo significant weathering producing karst topography in central Kentucky and Tennessee. Continued weathering of limestone formations by dissolution of soluble constituents frees the more resistant chert materials from the parent formations (Figure 7). The combined effect of weathering of carbonate formations, tectonic uplift of chert bearing formations and the erosion of saprolitic residuum creates abundant and accessible chert resource deposits.

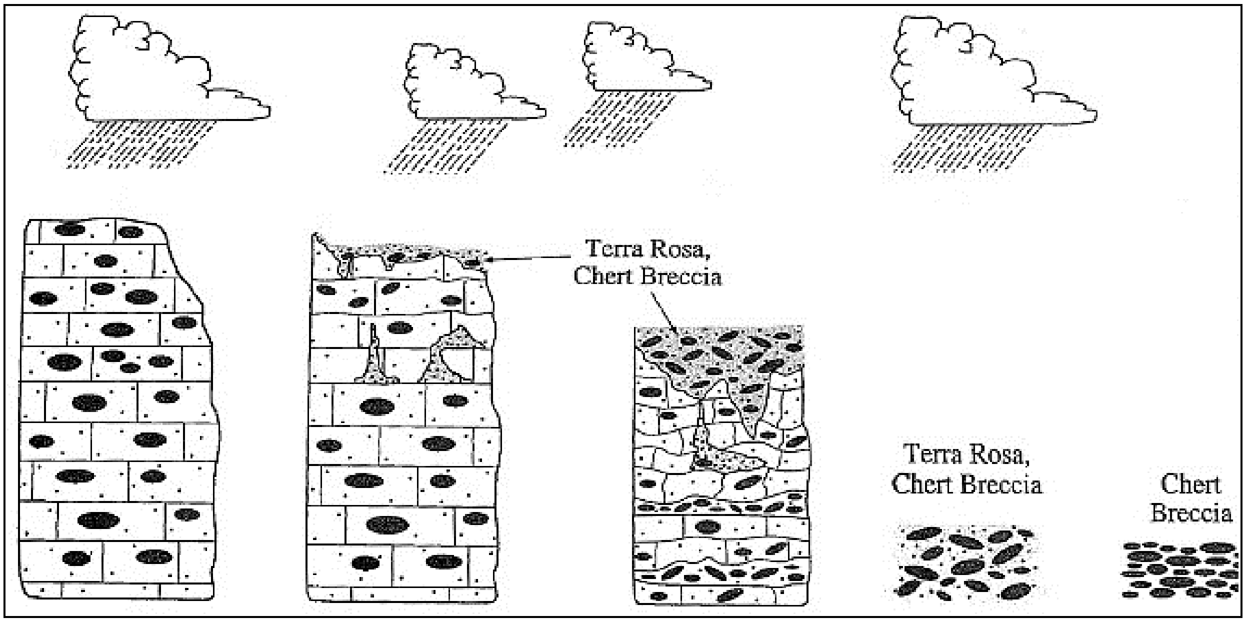

Figure 7. Diagram illustrating the dissolution of carbonate host rock and the concentration of chert resources in residuum. The geologic setting depicted above exists at the Dover Quarry sites and at the majority of large prehistoric quarry sites world-wide. Adapted from Knaugh 1994 (Figure 10).

The availability of chert resources in fluvial gravels, as saprolite deposits and in situ sources within limestone outcrops gave prehistoric people a broad range of procurement options in most regions of the study area. An embedded procurement strategy may have been the preferred method of chert acquisition. However, the craftsmanship of large non-utilitarian objects may have limited the number of procurement options to only a few known deposits. Material constraining variables include package size, quality, degree of protection from the freeze/thaw cycle and availability to prehistoric “miners”. The acquisition of particular materials in order to craft symbolically charged artifacts is well documented in the anthropological literature (Helms 1979, 1988, 1993, 1998). Therefore, acquisition decisions were almost certainly influenced by social, cultural, political and economic forces. A broad understanding of Mississippian polities with a focus on non-utilitarian material culture places the current study in an anthropological context.

CHAPTER 4

CULTURAL CONTEXT

The cultural context is as important as the geologic context in chert sourcing studies. The geologic setting and landscape geomorphology limits lithic resource availability, concentration and distribution. However, the political and social aspects of resource use also constrain the preferred chert type acquired, and where and by what means it is procured. Therefore, discussion regarding the cultural setting of chert resources consumers is necessary and prerequisite. A cultural framework provides context to a chert source study within which selection decisions can be better modeled and understood. Provenance data alone cannot provide researchers with the mechanisms necessary for understanding past human behavior.

The following discussion presents an overview of North American Middle Mississippian culture. Discussion details the appearance of large chert “swords” in the archaeological record termed here sword-form bifaces. The function of these chert swords is discussed here in the context of Mississippian cosmology, iconography, exotic material use, the ethnographic record and anthropological research regarding long distance acquisition and exchange. The addition of provenance data for Mississippian chert swords clarifies possible cultural functions and is presented in Chapter 9.

Mississippian Polities

Mississippian polities are usually characterized as chiefdom level societies (Hudson 1976; Smith 1990). However, not all groups inhabiting the Midwest and Southeast during the Mississippi Period (1000-1600 A.D.) may be classified as chiefdoms. Smaller groups, maintaining kinship ties with larger social units, continued tribal-like organizations.

The term "Mississippian" was coined in the 1930s in reference to prehistoric cultures in the Midwest and Southeast that constructed platform mounds, plazas and used shell-tempered pottery (Snow 2010:200) (Figure 8). The taxonomic classification was employed to delineate these groups from other Eastern Woodland mound building cultures such as Caddo, Plaquemine, and Oneota. The Mississippian was further defined

Figure 8. Approximate distribution of Mississippian culture groups and sword-form bifaces. Mississippian polities mentioned in text are additionally mapped.

in the 1960s to describe socially complex groups that were organized into ranked societies, had institutionalized social stratification, practiced intensified agriculture of tropical cultigens, crafted shell-tempered ceramics, knapped triangular projectile points, constructed platform mounds, plazas and embraced a common cosmology as evidenced by shared iconographic themes.

During the Mississippi Period a religious belief system changed that produced similarities in ritual regalia, iconography, and material goods across a broad geographic region spanning the Southeast and Midwest (Figure 8). Typical cosmological traits, exemplified by non-utilitarian, symbolic artifacts, were once classified into what was then termed the Southeastern Ceremonial Complex (SECC) or Southern Cult (Waring and Holder 1945), though these terms are no longer in use (Knight 2006). Mississippian cultural units are sometimes subdivided into regional variants. For example, groups west of the Mississippi river, centered in eastern Oklahoma and western Arkansas and are referred to as Caddoan. The Oneota inhabited the northern portions of the Mississippi River. Mississippian culture groups identified in the Midcontinent along the Mississippi River are characterized as Middle Mississippian. Groups to the south in Louisiana and Mississippi, along the Lower Mississippi River Valley, are known as Plaquemine. Finally, sites displaying Mississippian traits in Georgia and eastern Tennessee are the South Appalachian variant.

Distinguishing Mississippian characteristics evident in the archaeological record are more than a list of traits, such as agricultural practices, communal architecture, and technological innovations. Woodland groups preceding A.D. 900 also farmed, built monumental earthworks and engaged in inter-regional exchange. However, the level of social complexity evident at Mississippian sites is significantly greater than Woodland groups organized as tribal-like societies and the dependence of farming was of a larger scale.

The level of social, political, and economic complexity that characterizes the Mississippi Period is still debated among researchers. Questions regarding the distribution of goods, centralized control of production, presence of craft specialization, and the nature of prestige goods economy are still ongoing research topics (Brown et al. 1990; Cobb 1989, 2000, 2003; Muller 1984, 1986, 1987; Smith and Moore 1999; Steponaitis et al. 1996; Trubitt 2000; Yerkes 1983, 1986, 1989). What is apparent in the archaeological record is a shift toward greater social stratification and with this, the construction of platform mounds to elevate elite status.

Additionally, the establishment, or possible reestablishment of long distance exchange networks, is evident. The uneven distribution of exotic goods within Mississippian societies, including sharks teeth, marginella shells, copper, mica, crystals, and other non-local lithic materials is confirmation of long distance acquisition of highly prized esoteric materials. Exchange networks of this extent in eastern North American had not been in place since the collapse of the Hopewell Interaction Sphere some five centuries prior to Mississippian exchange systems. Chert types, including Burlington, Dover, Kaolin and Mill Creek also circulated along these networks, spanning the Mississippian socio-geographic world. Research questions are abundant regarding the mechanisms, function and purpose of long distance exchange and exotic goods distribution in Mississippian societies.

Social Status in Ranked Societies

The maintenance of elite social status in complex societies is accomplished through economic, political and cosmological transactions (Reilly and Garber 2007:6). Elites in chiefdom level societies embody a balance between the cosmological and terrestrial realms through military, economic and religious leadership (Helms 1979). An imbalance in any one of these realms would be a direct reflection on the chief who enjoyed an almost culture hero status and who had to demonstrate their spiritual efficacy. Archaeological evidence, including defensive structures, burnt villages, skeletal trauma and town abandonment at many of the larger polities demonstrates the fragile socio-political structure of Middle (A.D. 1200-1400) and Late Mississippian (A.D. 1400-1700) chiefdoms. The cyclic nature of site occupation, abandonment, and re-occupation suggests that internal strife may have been as serious a threat as outside groups (Blitz 1999; King 2007). Thus, the maintenance of elite power is a significant research topic in Mississippian research (Anderson 1990, 1994; Earle 1987; Knight 1986).

Tribal-like local groups during the Woodland Period were organized around kinship ties. Individuals, perhaps ‘Big Man’ or social aggrandizers initially obtained authority by hosting feasts and through ritual performance. The ability to control resources, invoke family obligations, and display wealth, established social bonds among kin participants. A tribal leader’s political authority would be substantiated and maintained through these competitive feasting events. In contrast, chiefdom societies typically have a greater degree of complexity in social and political organization. A small, kin-based community leader responsible for the welfare of the group is in turn led by district chiefs, who are in turn under the control of the paramount chief (Earle 1978).

The pyramidal, ranked social structure is characteristic of the centralized socio-political authority (Blitz 1999). The centralized model dominates Mississippian research, but recently has been criticized for inadequately explaining variability seen at individual sites (Blitz 1999; Cobb 2003; Pauketat 2007).

Staple finance. Ethnographic data demonstrates that chiefly status is conferred by a particular hereditary line, but it also is substantiated by a chief's ability to be an aristocrat and a proven leader. Administration of the community, political negotiations, warfare and public works are means by which a chief substantiates his leadership role. A chief may obtain authority through the accumulation and redistribution of surplus resources. The switch to large scale maize agriculture provides a surplus in good seasons. The administration of the surplus endows the chief with the means to establish obligatory relationships within the community and with other groups outside the polity's immediate control. The generation of surplus is commonly referred to as staple finance and can be used by chiefs to support low or non-producing members of the society such as priests, warriors and craftsmen. Two ethnographic examples of staple finance systems have been documented for the Trobriand Islands and Polynesia.

Malinowski's (1922; Malinowski et al. 1935) and Burton's (1984, 1989) research on the Trobriand islanders of New Guinea provides an example of a simple chiefdom level society. Here, chiefs maintained status not by the accumulation of esoteric exotic goods (wealth finance), but by the redistribution of surplus crops. Intra-regional groups that did not have access to fertile agricultural areas focused on activities such as fishing, basketry, wood carving, lime production and polished stone axe manufacturing. These items circulated via simple down-the-line exchange in return for crops. Production and local exchange of these goods were maintained on an individual basis devoid of central control by elite chiefs, though these relationships were essential for the agricultural economy.

A second ethnographic example is Sahlins's (1958) and Goldman's (1970) research on Polynesian chiefdoms here, elites amassed staple goods and redistributed them as compensation to craft specialists or to establish political alliances. The accumulation of a portion of the staple goods economy substantiated chiefly status claims and leadership roles (Johnson and Earle 2000). Hawaiian chiefdoms were the most politically complex polities in Polynesia (Earle 1978; Goldman 1970; Hommon 1976; Sahlins 1958, 1972) and were characterized by a high degree of social ranking that manifested itself in a hierarchal network of chiefs subordinate to a paramount chief. The political economy was financed by the redistribution of goods in the form of tribute obtained by regional deputies who levied staple goods from commoner labor (Johnson and Earle 2000). The presence of craft specialists demonstrates the role that prestige goods played in reinforcing elite status.

Wealth finance. A second means by which chiefs gained power and maintained control was through the accumulation and redistribution of wealth finance. Wealth finance consists of goods that exhibit a high degree of skill in their manufacture, often made from exotic materials that do not have immediate function as utilitarian implements. The unequal distribution of these goods underscores the idea that elite members of Mississippian societies were primary consumers of non-utilitarian implements. The redistribution of wealth may have insured support among lesser chiefs, solidified political alliances, employed symbolically charged emblems in ceremonies and used as a tangible sign of a chief's right to lead. Mississippian researchers have developed the 'prestige goods economy model' to explain the accumulation and dissemination of highly crafted goods over large areas (Peebles 1970; Plourde 2009). The exchange of prestige goods includes artifacts whose cultural function or importance does not lie in the artifact itself, but rather in the symbolic meaning it invokes in the bearer and to those who witness its exhibition and use.

The prestige goods economy model was constructed in part to explain the presence of wealth goods in many Mississippian polities. The model provides an additional mechanism for paramount chiefs to maintain authority through gift-giving and public displays of wealth. The supply of finely crafted goods, possibly with charged symbolic meaning, would have been important for chiefs in maintaining their status and in supporting followers. Therefore, elucidating crafting in the archaeological record is an important topic among researchers. The presence of specialized crafting funded by ruling elites is often an indication used to define chiefdom level societies. However, the evidence for craft specialization among Mississippian societies is much debated (Muller 1984, 1986; Yerkes 1983, 1986, 1989; Prentice 1987; Welch 1991; Wilson 1999, 2001).

Issues regarding elite control and craft specialization extend beyond non-utilitarian artifacts to include everyday agricultural tools such as the distribution of Mill Creek chert hoes (Brown et al. 1990; Cob 2000). There is a great deal of regional variety in the lithic types used among Mississippian societies; however Burlington, Dover and Mill Creek are the predominant chert types used to manufacture hoes, adzes and picks (Cobb 1989, 2000; Koldehoff 1990). Large quarry complexes located near St. Louis, Missouri, Dover, Tennessee and Mill Creek, Illinois are evidence for intensive direct procurement of large quantities of chert resources. Both Mill Creek and Dover chert have a wide distribution outside the areas surrounding the quarry locations (Cobb 2000; Smith and Moore 1999; Winters 1981).

Agricultural implements made of these two chert types are found in Mississippian archaeological contexts across the Mississippian world. Concentrations of agricultural tools manufactured from the particular chert types are found at large Mississippian centers, however evidence for centralized control of production and redistribution is lacking (Cobb 1989, 2000, 2003; Parish 2009, 2011; Winters 1981). Despite evidence of intensified labor and the extensive distribution of lithic material from quarry sites, ethnographic data suggests that direct control by elites may not have occurred (Burton 1984, 1989; Lass 1991, 1994). The provenance of Mississippian sword-form bifaces as symbolic weaponry adds new data and offers an explanation for the relationship Mississippian elites had with large chert quarries. Up to this juncture, a chief's authority has been defined as coming from economic control, but power may be maintained through other means.

Leverage Authority vs. Representational Authority

One of the defining characteristics of Mississippian societies is what appears to have been a broadly shared cosmology. The Southeastern Ceremonial Complex, as the Mississippian cosmology became known, is believed to have been one of the unifying characteristics of Mississippian societies (Griffin 1952). The chief is the embodiment of the belief system and the primary ceremonial organizer and provider. Once established and passed down through oral traditions and annual ceremonies, Mississippian beliefs would have had a strong unifying force. The community's identity would have been defined by a shared metaphysical understanding of the universe and the polities place in it. The chief assumed the role as mediator between the terrestrial and celestial realms (Emerson 1997).

Leverage authority. Social identity is defined by a number of means such as technological innovation, community architecture, social organization, communal events, and material culture. The ability of a chief to establish and bolster social identity would have been a powerful tool in legitimizing and maintaining authority and political status. The chief would have embodied the collective identity of the polity both in ritual and in day-to-day events. The chief used leverage authority to obtain power through the accumulation and redistribution of staple and wealth finance. Leverage authority is the term used to describe the economic means by which a chief appropriates and maintains authority and power. Giving, taking away, or withholding goods is an effective means to maintain centralized economic authority (Earle 1978). Accessing and maintaining connections with cosmological realms were also important.

Representational authority. The maintenance and performance of institutionalized ceremony solidified cultural identity. Ceremonies, priests, and symbolically charged artifacts projected the collectively shared belief system outwards into the periphery of the chief's direct influence. In this manner, the chief possibly exercised considerable authority in accessing "other-worldly" realms. Representational authority is the ability of an individual to project power as a cultural symbol of a shared belief.

Mississippian research focusing on the cosmological influence as social coercion is only recently gaining momentum (Baltus and Baires 2012; Baires and Baltus 2012).

The maintenance of cosmological balance is a strong motivator for participating in socially sanctioned events such as the forfeiture of surplus food or choice portions, communal building projects, and chiefly warfare. Large-scale architectural projects transformed the landscape into an ordered representation of a celestial realm. The mobilization of labor is fueled by a shared communal cosmology whose ultimate terrestrial representation was the paramount chief.   The representational authority of the ruling elite may have been a greater influence on the society than economic pressures. To maintain this authority, public displays of grandeur that transcended the ordinary were performed to order the universe and root the society, especially ruling elites to culture heroes and honorable ancestors, and project the lineage of the people into the future.

Collective Cosmology. An example of public grandeur on an unprecedented scale is evidenced by the deposits in Mound 72 at the Cahokia site in the American Bottom. In 1967 Melvin Fowler discovered an elaborate central mortuary including two male burials with a 20,000 marine-shell beaded falcon blanket, chunkey stones, and copper covered chunkey poles, mica crystals, and multiple piles of bundled arrows (Fowler et al. 1999). Also associated with the central burial were mass graves of over 50 women and over 40 sacrificial men and women. These deposits are explained as a large funeral ceremony that reenacted portions of Mississippian cosmology (Emerson and Pauketat 2002; Pauketat 2005). A related hypothesis proposed by Brown (2003) is that the deposits in Mound 72 are not an extravagant display of wealth and control of resources but rather is a ‘mythic tableau’ solidifying the cosmology of the collective (Koziol 2010).

The funerary ceremony illustrated by the deposits in Mound 72 was probably not the epicenter for a cultural reawakening, but rather the culmination of a cosmology having its roots in previous generations at multiple locations. The deposits at Mound 72 represent the power of shared belief and a reformation of the society's cosmological order. To perpetuate the community's identity, myths need to be remembered and retold, a link to past culture heroes and their deeds need to be forged and symbolically charged 'relics' representing both are made to illustrate and invoke meaning. Beyond public ceremony, shamans and cults help to strengthen social bonds through fluid cultural practices. Mississippian artifacts that potentially convey these themes are long-nosed god masks, marine shell gorgets, copper repoussé plates, chunkey stones, carved shell cups, Ramey jars, chert eccentrics, maces, and large bifaces. The Mississippian artifacts thought to embody cosmological meaning are classified as prestige goods. However, the prestige goods terminology may be misleading as cultural importance may not have been simply the acquisition of the artifacts to bring status to the individual, but rather to have the right to perform collective ceremonies to gain access to the Above and Beneath Worlds. Mississippian chert sword-form bifaces as symbolic weaponry are thought to have belonged to this body of artifacts.

Provenance of Mississippian Artifacts

The sources for Mississippian non-utilitarian artifacts is important for researchers who focus on inter-group exchange relations and assess the degree of centralized political and economic power in chiefdom societies. The presence of a single obsidian scraper at the Spiro site in Oklahoma is considered evidence for exchange connections with Mesoamerican groups of northern Mexico (Barker et al. 2002). Copper used to make axes, beads, ear-spools, gorgets, and plates found at the larger Mississippian regional centers are thought to have been obtained from sources along the Great Lakes

(Bell 1947; Peebles and Kus 1977; Martin et al. 1947; Sampson and Esarey 1993; Wilson et al. 1997). Shark's teeth, marginella beads and varieties of marine shells are explained as indicators of connections to groups along the Atlantic and Gulf coasts (Bell 1947; Brown 1983; Claassen and Sigmann 1993; Payne and Scarry 1998). Perishable goods such as feathers, textiles, and food items were almost certainly exchanged that originated from distant geographic areas. Unfortunately, these items are rarely preserved in the archaeological record. The few examples researchers have uncovered are feathers and textiles from the Craig Mound at Spiro (Brown 1996; Kuttruff 1993; Rogers et al. 2002) and holly residue from beakers at Cahokia (Crown et al. 2012). The acquisition of exotic goods obtained from great distances was clearly important to Mississippian people. This phenomenon finds its ultimate expression in their association with elite members of Mississippian society.

Early studies of Mississippian culture consistently attributed the provenance of the non-utilitarian artifacts as being manufactured from exotic materials obtained from great distances (Bell 1947). Currently, the long distance hypothesis is being challenged for some artifact types by an increased focus on analytical provenance studies. Research conducted by Emerson et al. on Mississippian flint-clay figurines (Emerson and Hughes 2000; Emerson et al. 2003; Wisseman et al. 2002; Wisseman et al. 2010) and Ehrhart (2009) on copper objects are demonstrating that local resources were exploited, disproving long distance exchange models. Levine's synthesis of copper provenance studies from the Eastern Woodlands illustrates a pattern in archaeological research to assign exotic sources to copper artifacts neglecting local geologic research. Unfortunately, a single geographic source for a particular material becomes entrenched in the literature for decades, thus skewing anthropological explanations of exchange (Levine 2007).

Distance and Crafting

Mississippian acquisition of resources obtained from great distances may be viewed as a multi-faceted cultural decision influenced by economic, functional, environmental, cosmological and political motivators. The ethnographic and ethnohistoric record is rich in examples of long distance procurement of exotic materials either by direct or indirect means. Archaeologists typically associate distance in terms of economics using distance decay models and calculating caloric expenditures. These models are useful, but often fall short of explaining the entirety of resource selection decisions. The use of distance decay models to explain chert material obtained for symbolically charged artifacts may be inadequate. The source of procurement is potentially as significant as style and the degree of crafting skill. The geographic setting where the resource is procured signifies associations with a unique landscape or people. Knowledge of place or people may be engrained into selection decisions and therefore have cultural importance. An example of possible cosmologically influenced selection decisions can be drawn from the caches of arrow quivers with distinctive chert points at Mound 72 at the Cahokia site (Pauketat 2005).

Case study. The arrow caches at Mound 72 and in other mound deposits at Cahokia may be significant representations of place and people. Fowler identifies 11 different styles and 18 different subtypes in the arrow point assemblages (Fowler 1973; Fowler et al. 1999). The arrowheads are slightly larger than normal size ranges and exhibit a high degree of skill in their manufacture. Also, many of the arrowheads are organized into clusters by style and material type. Varieties of Burlington, Dover, Fort Payne and Kaolin chert are found in the caches. Both the styles of projectile points and the material type represent relations with groups to the west and south of Cahokia. Given the context of the other deposits at Mound 72, the deposits of distinct clusters by style and material type appear to signify a representation of specific locations and people on the landscape. The materials centrally deposited may symbolically represent the corners of Cahokia's universe and a particular leader's control over these resources. In other words, the entire known terrestrial world is actively represented in the deposit by culturally significant arrowheads made from materials geographically situated at cosmologically defined boundaries.

Social status. A leader's ability to obtain and craft resources acquired from afar is shown as controlling the unknown (Helms 1979, 1988, 1993). An economic perspective suggests that chiefly elites controlled resources and gained authority through exchange, redistribution, and obligatory relationships (Earle 1978; Johnson and Earle 2000; Sahlins 1958; Service 1962). Also of importance is the cosmological reality of long distance acquisition. Mississippian elites who successfully accessed resources over long distances displayed an ability to transcend the boundaries of the known universe. The role of the elite as mediators between the terrestrial and celestial worlds meant they straddled both realms and had access to the resources of both. Material symbols of the dual roles of chiefs would have been important in legitimizing their leadership. The public display of resources not available to the rest of society would have been a powerful symbol and would have strengthened the right of leadership. However, the distance or level of the exotic qualities of the resource is only one component of the non-utilitarian goods.

The level of skill displayed in crafting symbolic items is a significant factor in their cultural function. The term crafting is one that is often misused in the archaeological literature. Crafting includes the production of material goods and other skilled abilities such as dance, oratory prowess, warfare, musical performance and hunting (Helms 1993:5). In the current study crafting and craftsmanship is narrowly defined as the display of above average skill in the transformation of material resources into symbolically charged non-utilitarian objects. The act of crafting may be confined within the household or be supported by the centralized political authority. The presence of specialized craftsmen who do not engage in everyday subsistence activities is a commonly addressed topic in Mississippian archaeology and indicative of emergent state societies. The provenance of Mississippian sword-form bifaces will help researchers address these issues. The evidence for specialized craftsmen is discussed in light of the provenance data in Chapter 9.

Chert Swords

The bi-pointed, elongated bifaces found at Etowah, Link Farm, Spiro and numerous other sites in the Southeast are synonymous with the Middle Mississippi Stage (A.D. 1200-1400). Additionally, contemporaneous iconography depicting falcon warriors wielding the sword-form bifaces indicates that they were employed as symbolic weaponry used to reenact mythological stories and/or to interact with other worldly realms (Marceaux and Dye 2007). Mississippian sword-form bifaces is best studied by considering the provenience, iconography and the ethnographic record.

The corpus of Mississippian symbolic weaponry intrigues researchers who seek to understand the behavioral systems in which these artifacts functioned. Symbolic weaponry is an example of superior craftsmanship. The sword-forms, though possibly not designed to withstand the strain of physical use, certainly had utility in other social realms. The ceremonial chert blades, commonly referred to as “swords” are found in various archaeological contexts, potentially manufactured from exotic materials and are depicted on Mississippian shell gorget iconography (Marceaux 2003; Smith and Moore 1999). The role, or more accurately the roles, that swords had in Mississippian societies is almost certainly complex; however, an examination of the archaeological context, iconography and ethnographic data provides information relevant to deducing sword use in the dynamic behavioral systems of Mississippian chiefdom level societies.

Mississippian sword-form bifaces are found across a large portion of the Mississippian world (Figure 8). Multiple sword-form styles are recovered from the Spiro Site, Oklahoma (Brown 1996; Brown and Rogers 1999). Research by Brown (1996) organizes the sword-form bifaces into three styles, Fulsi-eliptical, Duck River and General. The Fulsi-eliptical and Duck River styles are two forms present in the sample analyzed in the current study. The Fulsi-eliptical sword-form is thin with bi-lateral flaking, parallel sides and symmetrical double tapered ends (Figure 9a). The Duck River style sword-form is described as a long parallel sided biface, some of which are exceptionally thin, with one gently curving convex end and the opposite tip being steeply retouched to a long narrow point (Figure 9b).

The three forms found at Spiro may be a continuum of the chaîne opératoire representing instead various stages of the manufacturing process; however the variation most likely represents multiple types similar to the mace-forms also recovered from the site. Brown identifies five distinct chert types used in the manufacture of the sword-form

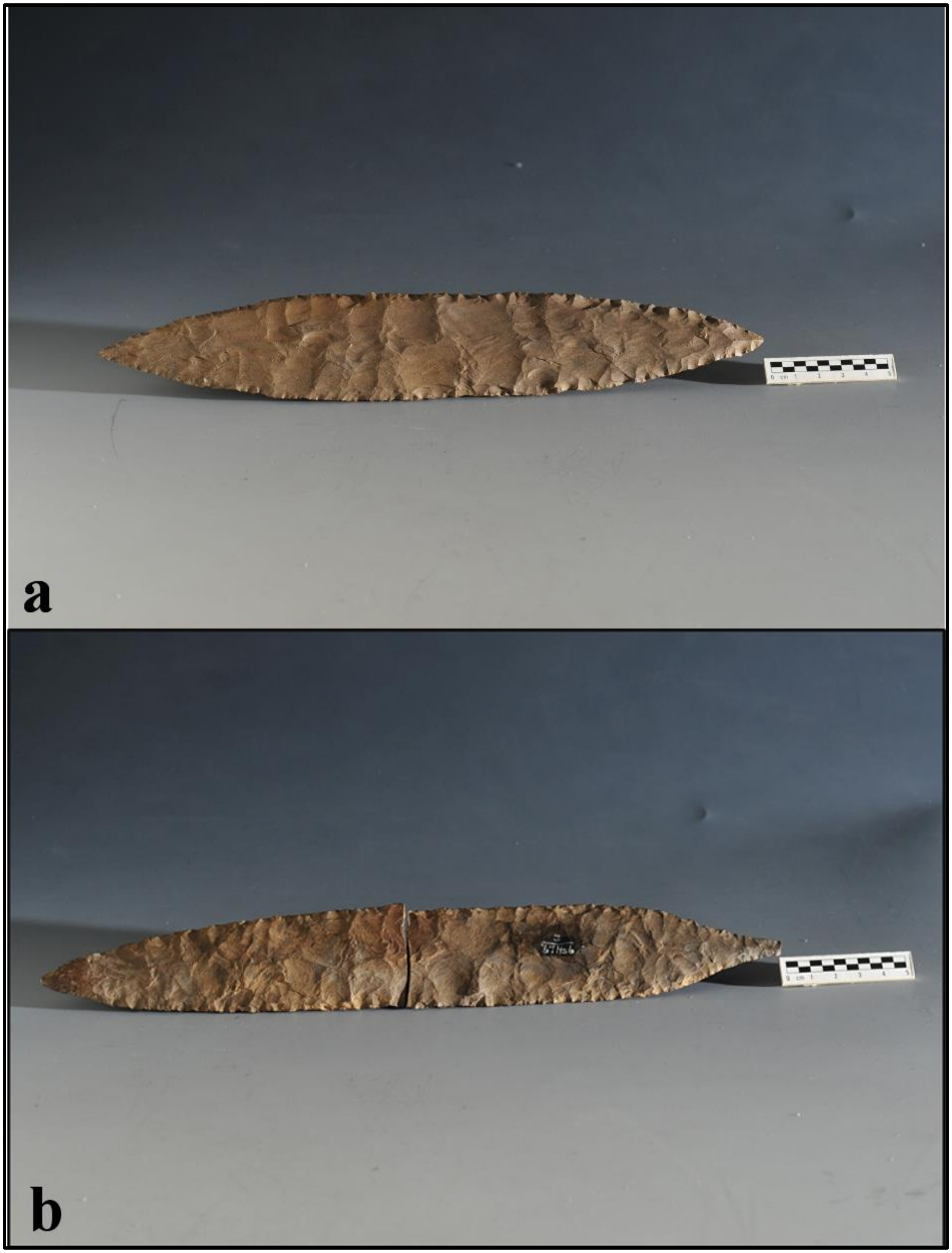

Figure 9. Mississippian Fulsi-eliptical (a) and Duck River style swords (b) (photos courtesy of David Dye).

bifaces including Niobrara Jasper, Kay County, Mill Creek, Fort Payne and Dover (Brown 1983:139, 1996:155). The sword-form bifaces are associated with burials containing other wealth items prompting investigators to refer to the associated human remains as belonging to elite members of the stratified society. Some of the Duck River style bifaces are thought to have been deposited within the Great Mortuary Mound at a later date as secondary internments reflecting a collective three tiered cosmogram (Brown 1996:154; Brown 2010, 2012). The three different sword-form biface styles are dated by association to different cultural phases at Spiro ranging from A.D. 1250 to 1450 (Brown and Rogers 1999). The Duck River style swords are associated with secondary burials dating to later components.

Distribution. Mississippian sword-form bifaces have been recovered from a variety of habitation/ceremonial sites in Tennessee and Kentucky (Figure 8). The Link Farm site (40Hs6) is one of the most famous locations where Mississippian sword-form bifaces have been found. Link Farm is a smaller ceremonial center with habitation and cemetery components in Humphreys County, Tennessee. The Duck River Cache, recovered at Link Farm, is the largest single deposit of Mississippian symbolic weaponry to have been found in Tennessee. The cache was uncovered in the midst of a Mississippian cemetery on top of Link Hill, located over half a mile from the mound complex (Brehm 1981). Underneath the deposit two large stone figurines, one male and one female, were recovered. The figurines are thought to have been manufactured from locally occurring ‘clay stone’, a product of the weathering Fort Payne limestone (Peacock 1954:4). The symbolic weaponry forms found in the cache include maces, bi-lobed daggers, hooks and swords in addition to circular discs and turtle effigies. All of the

Duck River cache swords are visually identified as being manufactured from Dover chert outcropping over 50 kilometers to the northeast though the provenance is questioned by others (Brehm 1981; Parish 2011a). In addition to the Duck River cache, excavations by later investigators recovered six sword-form artifacts from features associated with houses on top of platform mounds and seven from a single burial in the cemetery mound at the site (Nash 1968). The discoveries prompted researchers to tentatively suggest the presence of a specialized craftsman (Nash 1968:33; Peacock 1954, Smith and Moore 1999:105).

A third region where multiple sword-form bifaces have been recovered is the Upper Tennessee and Coosa River Valleys of the Southern Appalachians (Marceaux and Dye 2007). Swords have been recovered from the Ledford Island, Hiwassee Island, Hixon, Toqua and Bennett Place sites in Tennessee (Lewis et al. 1995). In addition, swords have been recovered from the Bell Field, Sixtoe, Little Egypt, King and Etowah sites in Georgia. The sword-form bifaces recovered in Georgia mark the eastern extent of sword-form distribution. The source of the chert used in crafting the swords is not identified in some cases, but some are macroscopically identified as Dover chert (Marceaux 2003:99). The majority of the 24 sword-form bifaces from the Southern Appalachian Mississippian sites are associated with burials, with only five exceptions (Marceaux 2003). The arrangement of burials containing ceremonial bifaces may represent a succession of individuals, one per generation (Marceaux 2003:63).

The three regions and various sites briefly discussed above provide a general cultural context within which some comparisons may be drawn. However, precautions must be taken to avoid broad cross cultural correlations between multiple temporally and spatially defined polities. The social utility of the sword-form bifaces is undoubtedly a complex composite of various unique cultural permeations. Temporally the swords appear in the archaeological record during and slightly post-dating the Middle Mississippi Stage. They are associated with Falcon Warrior iconography and other themes representing the Above Realm and the Morning Star cultural figure or the Hero Twins.

Context. The archaeological context in which the swords are found is in burials of high status males. Though also recovered in caches, middens, house features, as isolated finds, and female burials, the majority of swords are primarily associated with male burials (Brown 1996; Marceaux 2003). The predominant chert type for the swords is Dover chert from north-central Tennessee; however more variability in material source is evident by the swords found at the Spiro site (Brown 1996; Marceaux 2003; Marceaux and Dye 2007; Smith and Moore 1999). The tantalizingly small corpus of evidence reveals few clues regarding the cultural meaning embodied by the swords. Admittedly much of the documentation of Mississippian sword-form bifaces comes from major ceremonial centers such as Spiro and Etowah, but the focus of future research should consider the context of swords found at a diversity of site types. Shifting our focus from context to iconography allows us to study a functional dimension of the ceremonial swords within the belief system and social realm.

Iconography

Mississippian sword iconography is found on Hightower anthropomorphic style marine shell gorgets (Figure 10) (King 2004:158; Knight 2013). The scenes depict a central character with both human and falcon attributes. Two common compositions are

Figure 10. Hightower style shell gorget from the Etowah site, GA.

interpreted as cultural heroes locked in mortal combat or headsman of mythological figures such as Morning Star and the Hero Twins. The anthropomorphic figures are either shown battling monsters of the Below Realm or displaying human heads as trophies. There are multiple important elements in the scenes. One of which is the mythological character wielding a sword gripped at the mid-section above the head in a threatening stance. The legs of the individual are bent showing swift movement (Marceaux and Dye 2007). In the opposite hand the individual either holds a decapitated head or a forked mothra trophy. In some scenes the character's opposite hand holds a hook/claw threatening agnathic decapitation (Brown and Dye 2007). The appearance of the character is neither human nor falcon but a combination of the two in a seamless representation of a transfigured being or the Morning Star figure. The Falcon Warrior, Morning Star or Birdman iconography depicted on the Hightower anthropomorphic style marine shell gorgets is important in a social context in that it links the swords with the above realm figure or cultural hero that provides a balance to the forces of the below realm.

Another interpretation of the images is that the anthropomorphic figure is representative of a human between realms. A human figure in the terrestrial realm possessing/wielding a portal (sword) is evoking the power of the Falcon Warrior in order to defeat his enemy. This interpretation fits within the broader Mississippian cosmology of continuous movement and interconnectivity with all three realms (Knight 2013; Reilly and Garber 2007). The human is at the center of the image showing signs of transfiguration (i.e. feathers, beak and talons) while holding up the symbolic weapon and defeating his enemy in the lower portion of the scene. Mississippian cosmology and the ideological function of the swords can be better understood by studying the ethnographic data from tribes of northern California and the Osage of the Great Plains (Bailey 1995, 2010; La Flesche 1939; Rust 1905).

Ethnography

Large lithic bifaces exhibiting a high degree of skill in their manufacture is noted in multiple assemblages throughout prehistory. The function or social meaning of these implements is variable however their exquisite form, craftsmanship, archaeological context, association with mineral pigments and often the material type selected for their manufacture signifies a symbolic utility. The cultural significance of Mississippian sword-form bifaces can be best viewed from a study of the ethnographic record. Among historic sources, the use of large ceremonial ‘dance swords’ among the Karok, Hupa and Yurok of northern California, though socially organized as complex hunter gatherer groups, may give insight into the purpose for large bifaces. The ethnographic data recorded by Rust (1905) are not directly related to Mississippian culture groups and should not be directly applied however, the examples depicts socio-political and ideological functions of hypertrophic bifaces (Gould and Watson 1982).

Rust in 1898 documents the presence of large obsidian blades in use by the tribes of northern California. The finely made bifaces were 18 to 38 centimeters long and 5 to 10 centimeters wide. Style varieties include parallel sided bi-pointed, bi-pointed with contracting mid-section, pointed on one end with opposing convex end and smaller examples were single pointed with a square opposing end. The first two styles noted are similar to the Fulsi-eliptical type noted by Brown (1996) at the Spiro site. The uni-pointed style is commonly found on the Santa Barbara Island and mainland of southern California and is similar in description to the Duck River Style swords (Rust 1905:694). The smaller bifaces with square ends were hafted onto sticks instead of being held during ceremonies.

The Native people who owned the sword-form bifaces were reluctant to show Rust these items as they were wrapped in bark and hidden away in isolated locations (Rust 1905:688). The bifaces almost always had cloth tied around its mid-section with a loop to fasten over ones wrist to secure it from accidental drops. Notes taken by Kroeber in the same publication identify three color variants, black, red and white. Both the red and black variants are made from obsidian whereas the white is made from chert. Kroeber notes that ‘value’ is attributed by length, the quality of the lithic material, skill of manufacture and most importantly the color. Red bifaces were more valuable than longer black specimens.

The bifaces were passed from father to son as heirlooms but were regarded as communal property (Rust 1905:689). Later, Kroeber clarifies that the swords were almost exclusively property of the individual though they could be used as payment for murder or purchase of a bride (Rust 1905:692). The use of the elongated bifaces was for ceremonial dances as a "badge of distinction, indicating rank and wealth" (Rust 1905:689). The swords were used in the white deerskin dance (Rust 1905:692). The observations documented by Rust and Kroeber describe the role of the bifaces in the white deerskin dance as being prominently displayed, held aloft. They also note the use of red bifaces in some sequences and black in others. The use of matched pairs of bifaces is also worth nothing. The largest bifaces are used during the last song. The ethnographers consider the bifaces sacred but differentiate them from the sacred bundles of the Plains Tribes (Rust 1905:695). Both Rust and Kroeber consider the swords of California tribes to function as status symbols or objects of wealth. The ethnographies of the Osage are different from those of the California Tribes in that the stories and songs connect the swords as symbols of the Falcon Warrior/Morning Star/Red Horn legend.

The Osage at European contact inhabited an area close to the confluence of the Missouri and Mississippi Rivers (Dablon 1959; Yelton 1998). The location and documentation of their cultural traditions links them to Middle Mississippian cultures of the American Bottom, namely Cahokia (Kehoe 2007). Some researchers regard the Osage priestly class as the last existing Mississippian priests (Bailey 1995). The collapse of Cahokia in the thirteenth century meant that at least four centuries elapsed before initial European contact (Kehoe 2007). After their removal to Oklahoma in 1872, La Flesche recorded their cultural traditions and songs at the turn of the nineteenth century.

The oral history of the tribe claims they once inhabited territory along the Ohio River in Kentucky prior to long term conflict with the Iroquois prompting their migration to Missouri, Arkansas and Oklahoma (Burns 2004). The traditions, stories, songs, and practices of the Osage provides an understanding of Mississippian societies with which they may have had strong cultural links (Burns 2004). One story in particular illustrates the connection between the Falcon Warrior, a human supplicant, and a below realm figure (owl). This is the story of the Vision of the War Leader (La Flesche 1939).

La Flesche (1939) records an old story among the Osage recounting the experience of a war leader on a vision quest prior to a raid. In the story a war leader is in the wilderness fasting, seeking a vision which would ensure a successful raid. During the night of the sixth day of his fast he hears two creatures in fierce combat that he later identifies as an owl and a hawk. The owl was winning the fight driving the hawk into hiding under the man's bent knee (La Flesche 1939:10). The hawk promises to reward the man with his powers and courage if he protects him from the owl until the coming dawn. The owl demands the man turn over the hawk to him so that he could kill him. The owl promises the man his powers of night and stealth against his enemy while he sleeps. The man does not deem this to be true courage and does not move. With the first ray of morning the hawk thanks the man and instructs him to take from his left wing the shortest feather and to attach it to his left shoulder before battle to ensure victory. With that the hawk takes flight and swiftly decapitates the owl with his beak. The hawk's final instructions to the man are to remember him before attacking the enemy (La Flesche 1939:10-12).

Variations of the story exist but the major themes maintain a high degree of integrity. At the time when La Flesche recorded the story Osage warriors would carry in their war bundles a dried skin of a hawk prior to conducting a raid (Bailey 1995). The linkages between the hawk, the Morning Star figure, the human supplicant and the powers of the above and below realms are clearly represented by the legend. The role of the man being an intermediary and active participant in the actions of the two realms situates him within the terrestrial realm or the axis mundi between both the above and beneath worlds. Additional examples illustrating the possible function of the sword-form bifaces are found in Osage origin legends and war ceremony.

The origin legend of the Tsi'-zhu Wa-no^{n} gens describes how their people came down from the sky as eagles and decided to make a knife for ceremonial use. The Sho'-ka, or Messenger, went in search of the right type of stone bringing back red, blue, yellow streaked, black and white flint [chert]. The Osage priests rejected each finally accepting a "round-handled-knife" which they in turn took and carved a ceremonial club from the willow tree "the-tree-that-never-dies" (La Flesche 1930:84-85). The knife and club are symbolic references to the two divisions in the Osage tribe the Tsi'-zhu and the Ho^{n}'-ga respectively (La Flesche 1939:15). The two Osage divisions represent cosmological duality of earth and sky. The Tsi'-zhu division represents the sky and the left. The Ho^{n}'-ga represents the earth, water and the right (Bailey 1995).

In the Osage war ceremony the knife is taken in the left hand and the club in the right, referencing the two divisions. The warriors are promised honors at future ceremonies for striking (club) and cutting (knife) deeds in the upcoming conflict (La Flesche 1939:15). Cutting in this instance refers to decapitation of the enemy as depicted in the Hightower shell gorget iconography. Both the Osage origins myth and the war ceremony illustrate how the club and knife are symbolic weapons carrying shared cultural meaning whose bearer can garner honor for personal deeds of valor in conflict. Given the three lines of evidence, archaeological context, iconography and ethonographic record, we can draw some conclusions about the cultural function of Mississippian ceremonial swords.

Ideological Function

The large Mississippian sword-form bifaces are universally deemed non-utilitarian by researchers. Utilitarian in this case is defined as implements that have a practical or functional use upon material objects. Specimens that are uncovered display no macroscopic signs of use such as impact fractures or edge-ware. Broken specimens are classified as ritually "killed" objects (Brown 1996). Other fragmentary specimens examined by the author indicate flaws and subsequent discard during the manufacturing process. Finally, some broken implements show signs of thermal damage such as potlid fracturing and crazing (Brown 1996). Therefore, no damage attributed to use is reported for the Mississippian sword-form bifaces. Additionally, the level of skill exhibited by the thinness, length and flaking upon many of the specimens shows that a great deal of time and expertise was devoted to the manufacture of these items. Physical attributes of the swords also precludes strenuous use especially with the larger specimens. Finally, the context within which the items are found and associations with other regalia artifacts supports a ritual usage. Admittedly, microscopic studies need be conducted to verify a non-utilitarian use and we must hesitate in using broad sweeping functional interpretations, but the evidence to date points to a ritual use.

The provenance of the material used in manufacturing the Mississippian sword-form bifaces is currently ascribed to exotic sources (Bell 1947, Smith and Moore 1999). Visual analysis of the sword types identifies the chert as Dover in the majority of items found in Tennessee. Though researchers have noticed some variety in chert type (Brown 1983, 1996; Parish 2011a), many of the swords are thought to have been manufactured from exotic materials and be the product of long distance exchange or acquisition. The occurrence of multiple outcrops of visually similar chert types to Dover throughout the Southeast calls into question the single source theory (Parish 2011a; Smith and Broster 1993). In turn, the existence of the large bifaces at mound centers may indicate that the swords were part of the prestige goods economic model. However, this is unlikely as the items are found at a diversity of sites both in proximity to the procurement site and abroad. Therefore if the items were in fact used in ritual contexts, what was the nature of their involvement and symbolic meaning?

The evidence for the ceremonial function of the swords can be evaluated from iconography. The anthropomorphic figures wielding the swords may illustrate common stories that the handling and display of the swords may have invoked in the collective knowledge of the populace. The depictions of the Morning Star character and the Hero Twins on other mediums and in contexts other than burial settings demonstrate that these images were known across social and cultural boundaries. The swords may have been used as ideologically charged objects during times when reenacting cosmological events to access dawn time powers (Dye 2013). The retelling of these myths may have been a way to ensure victory in combat or invite the power of the Falcon Warrior/Morning Star to embody an individual or group. Another theory is that the ceremonial swords were held by certain individuals as insignia for distinction in battle. The combat scenes depicted in the iconography are testimony to the connection between violence (whether ritual or mundane/existent), the warrior, the above realm figure and the symbolic weapon. Additionally the archaeological examples of these items in burials demonstrate that the object or icon was connected to a specific clan or individual.

From these various theories and lines of evidence (context, iconography and ethnography) common elements become apparent. The Mississippian sword-form bifaces are linked to combat, the connection with the Falcon Warrior or Morning Star figure, the above realm and to particular individuals, cults or more broadly to specific polities. Therefore, a hypothesis that unites these common elements is one that suggests the swords are a symbolic connection between a warrior supplicant and the Falcon Warrior/Morning Star figure. In the Hightower shell gorget iconography the swords are held overhead in the left hand not in a threatening manner (Marceaux and Dye 2007) but as a conduit or portal of direct access to the Above Realm. In this manner the Above Realm figure embodies the human supplicant transfiguring the individual into the Falcon Warrior. La Flesche's (1939) ethnography of the Osage records the meaning of the ceremonial knife held in the left hand as symbolic of the Above Realm. A direct reference to the Vision of the War Leader recounts the hawk making a covenant with the human by promising him speed and power to overcome his enemy through decapitation, by remembering the hawk and by displaying the feather on/above the left shoulder prior to battle (La Flesche 1939). The ability of the war leader to access the power of the Falcon Warrior ensured the individual success in battle and the bestowal of war honors that were essential for sanctioned violence, political and social advancement. The sword was the link between the celestial and the terrestrial realms.

The shell gorget iconography of the Hightower tradition shares common elements to Osage ethnography. The common elements include the hawk as a symbol of Morning Star and the Above Realm, reference to the left side, bent knee posture, combat, decapitation via hook or beak, and a below realm adversary. Of these the bent knee posture of the anthropomorphic figure in the image is of particular interest. In the Osage story the hawk seeks sanctuary under the bent knee of the war leader. The war leader does not deny the hawk this protection despite the demands and enticement of the owl. The bent knee represents a vessel within which the hawk may dwell. Therefore the shell gorget iconography may not be depicting swift movement but rather a posturing of the human supplicant inviting the powers of Morning Star to enter in. Though the similarities of the iconography and the ethnographies may be compelling we must take caution at literal interpretations. However, by taking one more cautious, though precarious, step out further onto the interpretive limb we are able to hypothesize about the curious form of the Duck River Style.

The Duck River Style is named after the type of ceremonial swords found within the Duck River or “Link Farm cache” (Brown 1996). In the shell gorget scenes the sword is gripped in the left hand at the midsection above the left shoulder. In the story the hawk instructs the war leader to take the shortest feather from the left wing and attach it to his left shoulder prior to battle. When viewed in this context the unique style of the Duck River Style looks similar to a feather, the rounded end being the tip of the feather while the narrow point represents the quill. The possible depiction of a falcon’s feather by Mississippian manufacturers is similar, though not directly associated, to Aztec depictions of Quetzalcoatl where feathers of the serpent/bird are represented by long chert knives (Nicholson 2000:147-156). Additionally, the possible association of the swords with a falcon feather may also explain the preferential selection of a mottled brown chert type.

The chert types of the Southeast are plentiful and diverse. A few chert types that may be procured in large enough package sizes necessary to craft a sword-form biface include the Upper St. Louis, Burlington, Mill Creek, Kaolin, Fort Payne and Dover. Of these types the brown mottled varieties of Dover and possibly the Fort Payne are preferentially selected though examples of Mill Creek and other types exist. There are multiple reasons which would explain the selection of particular chert type(s); however with certainty the light tones of the Burlington and blues of the Upper St. Louis do not appear consistently in the assemblages. This is an interesting point as the mottled brown colors of Dover and Fort Payne are closest visually to that of a falcon's feather. Apart from these attribute debates a broader understanding of the cultural role of Mississippian sword-form bifaces is gained apart from base form.

Regardless of whether the Duck River sword-form literally represents a falcon's feather or not, they are emblematic of Mississippian cosmology. The interment of the swords within a burial context demonstrates a link between particular individuals or sodalities. Clues from Mississippian iconography illustrate the association of the swords with the Falcon Warrior or Morning Star character. Finally, the ethnography of the Osage gives us insight into human interactions with the above and below realms. Additionally, the story recounts a way in which a war leader can ensure victory and longevity through one’s ancestors by remembering the hawk and displaying the symbol of his power.

The cultural function of the sword-form bifaces almost certainly had a variety of socially defined significance. However, it is hypothesized that the swords were insignia of combat and warfare and were symbolic of the bearer’s ability to access the power of Morning Star/Falcon Warrior and in so doing become transfigured or a vessel of the Above Realm in order to defeat his enemy and ensure longevity through ancestors or the appropriation of life forces (Dye 2013; Parish 2011c). The hypothesis is constructed from three main lines of evidence: archaeological context, Mississippian iconography and the ethnographic record. The ethnographic data recorded from tribes of northern California and the Osage offer tentative explanations regarding linkages between context and iconography. Through the story of the War Leader’s vision recorded by La Flesche (1939) much of the iconography is transformed from inanimate imagery to a dynamic interplay between the human world and other realms and beings. The references to the left side, bent knee, trophy taking (decapitation) and the covenant between the hawk and the human are common elements in the Osage stories of creation, the war leader and the descriptions of the war ceremony. The analysis of these lines of evidence provides a greater understanding of the role of the ceremonial swords within Mississippian societies and cosmology.

CHAPTER 5

REFLECTANCE SPECTROSCOPY

Reflectance spectroscopy techniques potentially provide a low-cost, fast, accurate and non-destructive analytical chert provenance method. No chert sourcing technique to date provides all of these desirable characteristics. Two complimentary reflectance spectroscopy techniques are utilized in the current study. However, the strengths and weaknesses must be identified prior to full-scale adoption and broad application of reflectance spectroscopy as a chert sourcing technique. Specifically, Visible/Near-Infrared (VNIR) and Fourier Transform Infrared (FTIR) reflectance spectroscopy are used to analyze geologic chert samples and Mississippian sword-form artifacts. The following discussion details the methodology, technical mechanics and previous archaeological applications of VNIR and FTIR spectroscopy.

Electromagnetic Radiation

The scientific study of light and the propagation of light enjoy considerable notoriety within the fields of chemistry and physics, but also in popular culture. Such names as Aristotle, Sir Isaac Newton, Albert Einstein and topics including the theory of relativity and quantum mechanics stimulate interest among a broad audience. The nature of light is a subject that sparked debate among seventeenth century naturalists and continues to this day. The theory that light travels through a luminiferous aether was first proposed by Boyle in the late seventeenth century (Birch 1672). Newton explained light as consisting of numerous small particles but had trouble explaining refraction and diffraction. The stumbling block for many of the early theorists is that light was envisioned as a longitudinal wave needing a medium for propagation. The finding that light is a transverse wave made up of two components revolutionized the study of light. However, the theory of a mysterious aether persisted until the late nineteenth century. The Michelson-Morley experiment demonstrated that an aether did not exist (Michelson et al. 1887). The foundation of physics was shaken and led to Einstein's discovery of special relativity (Smith 1996:5).

The two components of light are electric and magnetic. Light is only one portion of a spectrum of radiation. Newton's use of a glass prism demonstrated the different portions of light radiation from violet to red that our eyes can observe. Radiation is composed of small packets of energy called photons (Hollas 2002:9). Photons can behave like particles at smaller scales and have characteristics similar to waves at larger scales. Radiation waves have an electric field of strength and a magnetic field of strength. Both the electric and magnetic fields oscillate in-phase, on a single plane and are perpendicular to one another (Stuart 2004:3). Therefore, the term electromagnetic radiation refers to these dual components of radiation.

Electromagnetic radiation is characterized by the size of the wavelength (λ) or frequency (v) along a spectrum. Different types of radiation have different wavelengths. The electromagnetic spectrum consists of gamma (γ) rays, X-rays, ultraviolet, visible, infrared, microwave and radio-frequency components listed here from short to longer wavelengths. A particular frequency or wavelength of radiation is determined by the length from adjacent wave peak to wave peak or adjacent trough to trough in sub-units relative to the meter. Common units encountered in spectroscopy are the angstrom (Å) equal to 10^{-10} m, the nanometer (nm) equal to 10^{-9} m and the micrometer (μm) equal to 10^{-6} m. Another common unit in spectroscopy is the wavenumber (cm^{-1}) referring to the number of wavelengths along a one centimeter segment in the direction of wavelength propagation. By studying the interaction of electromagnetic radiation with matter, researchers are able to record chemical, structural and mineral data.

Spectroscopy

The experiments conducted by Sir Isaac Newton on the dispersion of white light in 1667 demonstrated that light was composed of different color components. Newton's experiments led to the discovery that radiation consisted of different segments according to particular wavelengths. By observing how specific wavelengths interacted with certain types of matter, researchers gained the ability to use dispersed radiation as a chemical analytical tool. Spectroscopy is the study of experimentally obtained spectra (Hollas 2002:5). A spectrum refers to the recorded observable interactions of a portion of radiation with matter. There are four main radiation/matter interactions. The two general types recorded in spectroscopy are absorption and emission. Radiation can also be reflected and/or transmitted when it encounters matter. A spectrometer is an instrument that records the relative intensity of these interactions as a function of wavelength (Hollas 2002:4). Our human eye is an excellent example of a spectrometer. The sky is blue at mid-day due to solar radiation (light) interacting with the atmosphere. Long wavelength radiation (red) is transmitted through the atmosphere while the shorter wavelength (blue) light is scattered. Therefore when looking at the sky our eyes see more blue than red. The photons travelling at 'blue' wavelengths electrically stimulate the retina.

All four radiation/matter interactions usually occur to some degree. Recording the observations of radiation/matter interactions illustrates where and to what extent certain wavelength portions or specific wavelengths are absorbed or reflected.

Absorption is dictated by the unique atomic structure, molecular configuration and chemical composition of the material. Spectral analysis is very versatile having the capacity to analyze solids, liquids, gases and films. The current study applies reflectance spectroscopy to chert whose mineral and crystalline structure influences the reflectance and absorbance of radiation. Therefore, the proceeding discussion focuses on the interactions of radiation with crystalline solids.

Absorption. A discussion regarding the interaction between chert and electromagnetic radiation begins with the incident photons striking the surface of chert. Some of the photons are immediately reflected away from the surface of individual microcrystalline quartz grains. Some photons are reflected toward other grains where they can be transmitted through the grain, absorbed, transmitted or reflected again. Photons may also be emitted from the surface of chert as all objects above absolute zero emit photons (Clarke 1999:3). The arrangement of the quartz grain matrix and the absorbed photons are key components in understanding a chert sample's spectrum.

Electronic processes. The absorption of photons traveling with specific wavelengths is what allows researchers to collect mineral and chemical information. A variety of processes determine the absorption of particular portions of radiation. However, two main principles control the absorption of radiation in minerals. These are electronic and vibrational processes (Burns 1993; Farmer 1974). Electronic absorption processes occur due to shifts in the discrete electronic energy state of a particular atom or ion (Clarke 1999). Absorption of photons by an atom, molecule or ion bumps it up to a higher energy state which may result in emission of a photon. Absorption of photons occurs at specific wavelengths. In minerals, the most common electronic processes are caused by crystal field effects and charge transfers.

Crystal field effects occur due to vacancies in the outer electron shell of transition elements (Ni, Co, Fe . . . etc.) (Clark 1999). Atoms of transition elements split their outer electron shell creating vacancies when located within a crystalline matrix. The vacancies allow incoming photons at appropriate wavelengths to elevate the atom into a higher energy state. The initial energy state of the atom is determined by a number of different factors such as coordination number, symmetry of its placement in the crystalline matrix, type of ligands formed and metal-ligand interatomic distance (Burns 1993). Since the crystal field varies between minerals a particular ion may absorb photons at different wavelengths providing a proxy for mineral identification using spectroscopy. Also, chemical compositional changes in the mineral will shift absorption wavelengths of the same ion.

Charge transfers occur when the absorption of photons at particular wavelengths causes an electron to move from one ion or ligand to another. Charge transfer absorptions are more intense than crystal field effects and are diagnostic of mineralogy (Clark 1999). Incidentally, the red color of hematite and other iron oxides are a result of charge transfers. Other common characteristics causing absorption in minerals are the presence of conduction bands and color centers (Clark 1999). Conduction bands describe a higher energy level where electrons move freely separate from the lower valence levels. The space between these energy levels is called the band gap and absorbs portions of radiation that are diagnostic for some minerals. Color centers are caused by crystal defects which may signify impurities and act as a trap for electrons. Incident photons are needed to knock electrons into the trap. The photon induced movement of electrons into the color centers is signified by diagnostic absorption of particular wavelengths.

Vibrational processes. The second main process by which incident radiation is absorbed occurs due to the vibration of molecules. These vibrations are wavelength dependent meaning certain molecules will only be stimulated by certain wavelengths causing absorption at that particular location in the mineral's spectrum. The bonds of an individual molecule or a series of molecules in a crystal lattice are like springs. When a particular wavelength stimulates the molecule(s) vibration of the lattice occurs (Clark 1999). The wavelength that vibrates the system is determined by the strength of the molecule's bond and it's mass.

There can be more than one wavelength dependent vibration for each molecule. The multiple vibrational modes are called fundamentals and are labeled ν_1, ν_2, ν_3, etc. Molecules may have a stretching fundamental, a bending fundamental or display both. Atoms in a diatomic molecule that pull-apart in opposing directions are exhibiting a stretching fundamental. Atoms in a polyatomic molecule that bend around a central point are vibrating in the bending fundamental. A third type of fundamental a molecule may have is a rotational one. Rotational fundamentals occur at low energy frequencies (far infrared and microwave regions) and do not produce a strong absorption. Rotational fundamentals are not discussed further here as they occur beyond the spectral range of the instruments currently used in the study.

The non-linear polyatomic water molecule, H_2O, is an example of a molecule that has three vibration fundamentals, one bending (ν_2) and two stretching modes (ν_1, ν_3) (Figure 11). The two O-H bonds in a water molecule stretch and contract either

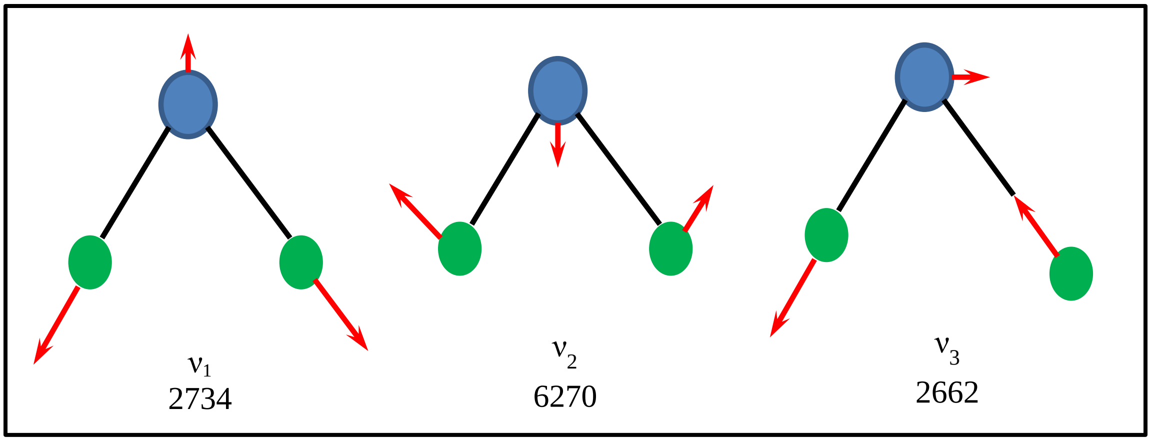

Figure 11. The three fundamental vibration modes of H_2O, ν_1 symmetric stretch, ν_2 bend and ν_3 asymmetric stretch (redrawn from Hollas 2002).

symmetrically (in-phase [ν_1]) or asymmetrically (out-of-phase [ν_3]) (Hollas 2002:82). The number of fundamental vibrations for any molecule can be calculated for a linear molecule using the equation 3N-5 where N equals the number of atoms in the molecule. A non-linear molecule has 3N-6 number of fundamental vibrations (Hollas 2002:82). Vibrations may also occur as overtones of an original fundamental. Overtone vibrations create absorptions at wavelengths which are roughly multiples of the original fundamental vibration. Overtone vibrations are likened to the harmonic oscillations of a musical note (Wisseman et al. 2002:693). Overtone vibrations from different fundamentals may combine together when they overlap. However, overtone absorptions are weaker than their fundamentals. Reflectance spectroscopy is extremely sensitive and can often detect 2nd and 3rd overtones and combinations (Clark 1999).

Reflectance. The amount of electromagnetic radiation that is reflected from a mineral is primarily dictated by the amount and frequency of incident radiation, the chemical composition, the physical structure of the mineral's surface, grain size, grain spacing, the presence and amount of absorbers and the amount of radiation that is transmitted by the mineral. Reflectance on a spectrograph is measured on a relative percentage scale from 0 (no reflectance) to 1 (100% reflectance). Shorter wavelengths are more easily reflected than longer wavelengths. Incident radiation interactions with surfaces are described primarily as four interactions. Ideal specular reaction occurs when all of the incident radiation is reflected from a surface. Near-specular reflection is similar to ideal however, a small portion of the incident radiation is scattered and absorbed. Both ideal and near-specular reflection is described as ‘mirror-like’ reflection. Near-diffuse and ideal-diffuse reflectance are defined as the scattering of nearly all and all of the incident light from the surface, some of which is absorbed.

It is important to note that the collection of reflected radiation from a mineral’s surface contains potentially diagnostic information. Additionally, the interaction of radiation with a mineral is not always a surficial phenomenon. The internal scattering of incident radiation to some depth and diffuse reflection is an important attribute of reflectance spectroscopy. Both characteristics have implications for analysis of a weathered surface and the identification of subtle absorption features.

The relationship between grain size and reflection is best described as an inverse one (Clark and Roush 1984). The larger the grain size the less reflection of incident radiation will occur but this is wavelength dependent. Large grains create a longer path length for incoming photons to be absorbed. Smaller grain sizes create more surface area and more opportunities for reflection. In other words the surface to volume ratio is a function of grain size (Clark 1999). At longer wavelengths this trend may be reversed as surface reflection dominates (Clark 1999). Grains which are packed closely together present a uniform surface whereas grains spaced further apart increase scattering. The reflection of photons from the surfaces of mineral grains is not linear but randomly oriented. The random path of photons on an uneven surface enhances weak absorptions that are not readily detected by other techniques (Clark 1999). Another factor determining reflection is mineral color.

Chemical composition controls reflection for wavelength frequencies in the visible portion of the electromagnetic spectrum. Light grains of quartz reflect nearly all wavelengths of visible radiation whereas dark colored grains of magnetite absorb a large amount of photons. Those photons that escape reflection from a grain of magnetite are absorbed at a high percentage when interacting with an adjacent grain. Dark colored minerals do not have a large amount of reflected visible radiation. It is the absence of reflectance that is indicative of sample mineralogy and chemical composition.

A sample’s spectrum consists of multiple reflectance values with their corresponding wavelength positions. Graphical representation of a spectrum consists of Gaussian and Lorentzian curves (Figure 12). Spectral features diagnostic of chemical and mineral composition are displayed as troughs or pinnacles. Both spectral troughs and pinnacles are referred to as absorption peaks. The spectral resolution refers to the smallest peak that can be resolved. The spectral bandwidth is a similar term referring to the sampling interval between consecutive reflectance values. A spectroscopic technique recording a number of contiguously spaced bandwidths has good spectral resolution. High spectral resolution may record a reflectance value every 2 nm or less whereas a low spectral resolution records reflectance values every 20 nm or more.

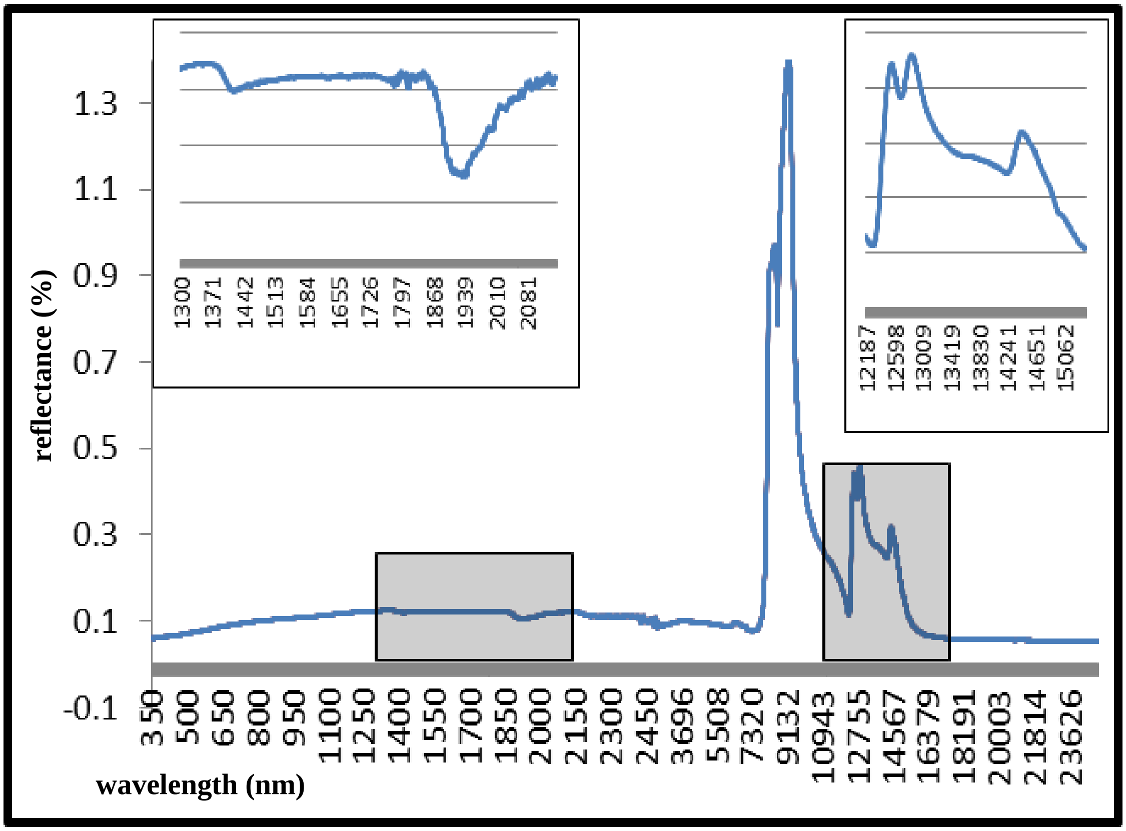

Figure 12. Typical chert spectrum spanning the visible through the mid-infrared (350-25,000 nm) with highlighted spectral features.

The spectral range is the total portion or wavelength segment that can be detected in the spectrum. Therefore, a visible spectroscopic technique might have a spectral range in the visible region (350-750 nm) at a resolution of 4 nm intervals. It is important to have a priori spectral knowledge about the materials under analysis regarding where the diagnostic absorptions occur and their width. Selection of a proper instrument having an appropriate resolution and range is necessary.

Instrumentation. A spectrometer or spectrophotometer is a device that records radiation/matter interactions as a function of wavelength. Early spectrometers utilized prisms to disperse light into its various components. Later, the development of dispersal gratings increased spectral resolution and range of the instrument. Current spectrometers have the ability to record radiation at multiple wavelengths quickly. However, many variables affect the ability of a spectrometer to accurately gather spectral data. Variables affecting the collection of spectral data include, spectral range, spectral bandwidth, spectral sampling, signal-to-noise ratio (S/N) and viewing geometry (Clark 1999:3). The first three variables were discussed previously but the S/N ratio and the viewing geometry need to be considered.

The S/N ratio is dependent on the detector's sensitivity, the spectral bandwidth and the intensity of the incident radiation (Clark 1999). Noise in a spectrum may not affect larger spectral features and a small S/N value is acceptable. However, small spectral features may not be resolved due to noise interference in the spectrum. A large S/N ratio value is necessary to accurately record smaller spectral features. The viewing geometry of the incident radiation, sample surface and detector control the overall intensity of the spectrum. Alterations of the viewing geometry during multiple analyses may cause unwanted changes to the spectral intensity. This should not be a major concern. The position of individual spectral features will not change making minor changes in viewing geometry less of a concern. An example which Clark (1999) gives for alterations in viewing geometry is how the eye's perception of the color of a leaf does not change while moving in the wind. Simple post analysis processing of the spectrum can correct for slight changes in viewing geometry.

Variables affecting chert source application. The current application of reflectance spectroscopy to chert sourcing introduces a few more variables needing careful consideration. The technological practice of heating chert in order to alter its physical characteristics is well documented in the ethnographic record (Hester 1972) and through experimentation (Ahler 1983; Crabtree and Butler 1966; Purdy 1981; Purdy and Brooks 1971). Therefore, researchers who wish to analyze chert artifacts must consider heat-treatment effects on the sample's spectrum. The alteration of both the mineral and chemical composition of chert during heat-treatment cannot exceed the natural range of variation for a specific chert type or within a deposit in order to obtain accurate source data.

The non-destructive analysis of cultural materials manufactured from chert requires collecting data from the surface of an artifact. The outer layer of chert is subject to both mechanical and chemical weathering. Archaeologists refer to the weathering of the outer surface of chert as patina formation. The depth of patina is often measured in microns. The leaching of soluble materials or conversely the addition of organics or secondary minerals may significantly impact the spectral signature of artifacts having undergone taphonomic processes for thousands of years. Both the effects of heat-treatment and weathering are examined in the following chapters.

Application. The application of reflectance spectroscopy is variable. Reflectance spectroscopy is currently used to gather remote sensing data from space, direct material analysis from distant planets, study land-use and climate change, quality control in industry, analyze coatings in chemistry and identify cancer cells. One of the first applications of remote sensing in archaeology was conducted by the National Aeronautics and Space Administration (NASA) on the Chaco Canyon site in the American southwest. They discovered a roadway system possibly linking other major ancestral Pueblo sites (Server and Wagner 1991). Reflectance spectroscopy is also used in geology to identify unknown mineral samples. Mineral identification is aided by large spectral libraries of spectra recorded from pure mineral samples. Multiple spectral libraries exist, some of which have digitized their archives online.

The use of reflectance spectroscopy also varies with scale. The use of reflectance spectroscopy ranges from analysis of the structure of an individual cell to the composition of entire planets. A commonly stated disadvantage of reflectance spectroscopy is that it is too sensitive to slight chemical and structural changes (Clark 1999). Continuing research is uncovering the causes of spectral shifts and natural variation allowing for the increasingly detailed analysis of chemical variability. The analysis of chert benefits from extreme analytical sensitivity as the mineral, chemical and structural differences are often minor.

VNIR Spectroscopy

Visible Near-Infrared spectroscopy records electromagnetic radiation in the visible (350-750 nm) and near-infrared (750-2,500 nm) regions. The spectral data recorded are qualitative in nature meaning that the presence of diagnostic absorption features indicates presence in the material being studied. VNIR spectral data can be processed in a way to obtain quantitative data however this is rarely performed (Clark 1999). Spectral data in the visible and near-infrared regions record absorptions caused by both electronic and vibrational processes. Specifically, wavelengths in the visible region are affected by electronic processes (see discussion above). In mineral identification applications, absorption of photons due to electronic processes gives information regarding the presence and nature of a particular ion and its environment, adjacent ions and defects in the crystal lattice (Hunt 1982:296). Absorption features in the near-infrared region are due to vibrational processes of specific molecules. Near-infrared spectral data give information regarding chemical composition, neighboring atoms or molecules, how they are bonded and their arrangement (Hunt 1982; Wisseman 2002). Diagnostic features of carbonates, clay minerals and iron oxides are commonly recorded in sedimentary rocks by VNIR spectroscopy (Hunt 1982).

Disadvantages of VNIR spectroscopy include large datasets consisting of raw reflectance values, the need for multiple analyses per sample and the extreme sensitivity to subtle structural and chemical changes. Large datasets present a problem with compiling, searching, processing, storing, organizing and updating. Thousands of reflectance values are recorded per reading depending on the spectral resolution setting. Multiple readings per sample to account for intra-sample variation along with multiple samples create an unmanageable dataset in a short period of time. Some basic computer programming skills are necessary to handle spectral datasets. Simple visual analysis of graphed spectra is not realistic. Visual pattern recognition among thousands of reflectance values is impossible. Spectral analysis of multiple samples necessitates the use of higher order statistical treatments. Finally, the instrument sensitivity may lead to multiple overlapping spectral features that can be masked by a dominant absorption feature.

Advantages of VNIR spectroscopy include its speed, low operating cost, replicable data collection, sample size accommodation, gentle learning curve and non-destructiveness. The instrument used in the current study records spectra continuously once a reference sample is recorded and the instrument is optimized. Therefore, once a sample is placed under the detector a spectrum is almost instantaneously generated. Saving the recorded spectrum takes a matter of seconds. Operation cost of most VNIR instruments includes the purchase of a light source. Quartz halogen bulbs can be obtained from suppliers at $25 each. A bulb may last for approximately 2,000 hours. However, instrument cost is significant. Spectral data obtained consecutively is reported to have only a 0.02% deviation (Hatchel 1999). Instrument drift over the course of 30 minutes is shown to introduce a 0.2% variance from the original spectrum (Hatchel 1999). These two reports demonstrate the replicable abilities of the technique. The instrument configuration does not restrict artifact size. A basic knowledge of instrument operation can be learned in less than a day allowing for the operation by multiple new users. Many VNIR spectrometers are portable and can be taken out into the field or to collections without complicated instrument set-up. Finally, the non-destructive nature of VNIR reflectance spectroscopy is potentially the most desirable attribute. Non-destructive analysis balances conservation, preservation and cultural concerns with scientific research. These characteristics make the technique attractive to archaeological applications.

Archaeological applications. VNIR and NIR spectroscopy in recent years are becoming widely used to analyze various archaeological materials and associated remains. Materials including nephrite, amber, soil, soapstone, paint, flint-clay, various masonry stones and chert are currently analyzed from an archaeological research perspective. The first application of VNIR/NIR spectroscopy was conducted by Beck in order to provenance amber artifacts from western Europe (Beck 1986). Notable other studies include those conducted by Hubbard on chert types of Ohio and his thesis on soapstone sourcing (Hubbard et al. 2005; Hubbard 2006). Recently, researchers affiliated with the program on Ancient Technologies and Archaeological Materials (ATAM) at the

University of Illinois have been using NIR data to source Hopewell pipes and Mississippian figurines (Emerson et al. 2013; Wisseman et al. 2002). The ATAM studies and subsequent results are frequently referenced throughout the current study. Additionally, the work of the author shows the potential application of VNIR spectroscopy to chert provenance (Parish 2009). Morin's dissertation research using NIR spectra in sourcing nephrite celts of the Pacific Northwest coast demonstrates the potential of these datasets in provenance applications (Morin 2012). A more extensive list of archaeological applications of VNIR data may be found in Morin (2012:194).

FTIR Spectroscopy

Fourier Transform Infrared (FTIR) spectroscopy records spectral data in the mid-infrared (2,500-25,000 nm) region of the electromagnetic spectrum. The mid-infrared region is composed of wavelengths not visible to the unaided human eye. Infrared radiation is also called heat. Absorbed short wavelength radiation is emitted in the form of infrared radiation. Absorption features are indicative of vibrational processes. Absorption due to electronic processes is not recorded in the mid-infrared. The presence of dipole moment change in the vibration of material is necessary for the absorption of infrared radiation (Hollas 2002). The wavelength position of a particular absorption feature is diagnostic of a certain molecule. The intensity and frequency at which absorption features occur reveal information regarding bulk compositional data about the material under analysis. Mid-infrared spectral data is qualitative but can show relative constituent amounts.

The development of FTIR spectroscopy would not have been possible without the interferometer, computer and the Fourier transform algorithm. The interferometer combines wavelengths that have been split by a beam-splitter and after being recombined studies the constructive (in phase) or destructive (out of phase) interference. The difference is potentially diagnostic for anything that disrupted the original incident radiation. In order to obtain a spectrum, complex calculations are needed to transform the interferogram (Hariharan 2007). The development of the Fourier transform algorithm coupled with fast computer calculations makes the transformation of the interferometer signal to a wavelength dependent spectrum possible (Smith 1996).

Disadvantages of FTIR spectroscopy include those already mentioned for VNIR spectroscopy, namely large datasets. Additionally, instrument and atmospheric introduced noise may obscure subtle features. The single largest disadvantage of FTIR is that it cannot record electronic vibrational processes related to atomic and monatomic ions, symmetrical homonuclear diatomic molecules and noble gases (Smith 1996). Therefore, elemental compositions will go undetected unless they are part of a dipole chemical bond. Other techniques such as Raman spectroscopy can be used in conjunction with FTIR to record these chemical compositions. Complications also arise when examining the spectra of complicated mixtures. The presence of multiple overlapping absorption peaks might obscure other diagnostic features indicative of minor mineral groups. Also, samples containing high water content may mask diagnostic features in IR spectroscopy. However, the use of Raman spectroscopy avoids major influences due to sample water content. Finally, FTIR spectroscopy is a single-beam technique meaning that unwanted instrument and atmospheric contributions to the spectrum are measured separately at a different time than sample analysis and have to be corrected post hoc (Smith 1996).

Advantages of FTIR spectroscopy are that it is fast, has a low operating cost, accommodates large artifact sizes, is replicable and non-destructive (in reflectance mode). The speed of analysis is dictated by the user specific instrument settings. Increasing either the spectral resolution or the number of scans also increases the time needed to record a single spectrum. At a spectral resolution of 4 cm^{-1} and 64 continuous scans, the time it takes to record a single spectrum is just over a minute. Operation cost of an FTIR reflectance micro-spectroscope involves replenishment of the liquid nitrogen coolant. The use of liquid nitrogen to cool the detector is instrument specific and is necessary for sensitive and consistent spectral collection in the FTIR used in the current study. An additional expense is the replacement of the mid-infrared laser source. The cost of a mid-infrared laser is approximately $900 but lasts for 1,000's of hours of use. The configuration of the FTIR instrument used in the current study is able to accommodate large artifact sizes in reflectance mode. Artifact thickness is constrained by the adjustable stage and swivel detector. Uncomplicated instrument adjustments can increase the height of the optical attachments and detector allowing for the analysis of thicker specimens. A spectrum is a product of multiple continuous scans eliminating subtle instrument variations. Multiple scans on a single spot of chert show that spectral variance over time is minimal (Hassler 2012). Finally, the non-destructive characteristic of FTIR reflectance spectroscopy makes it a valuable tool for archaeological applications.

Archaeological applications. Archaeologists have utilized FTIR spectroscopy in provenance studies of amber (Beck 1986) and chert patina formation (Purdy 1981). Recent archaeological applications of FTIR reflectance and FTIR transmission spectroscopy include residue analysis (Ribechini et al. 2007; Shillito et al. 2009b), thermal alteration of chert (McCutcheon 1997; McCutcheon & Kuehner 1997; Berna & Goldberg 2008), soil chemistry (Dibble et al. 2009; Shillito et al. 2009a; Goldberg & Berna 2010), artifact composition (Helwig 1998; Watts et al. 1999; Manoharan et al. 2007) and provenance studies (Angellini and Bellintani 2005; Hassler et al. 2013; Hawkins et al. 2008; Long et al. 2000; Sathya and Velraj 2011; Vasilache et al. 2011).

Directly relevant to the current study is the research of Hawkins et al. (2008), Long et al. (2000) and Hassler et al. (2013). Both Hawkins et al. (2008) and Long et al. (2000) are members of the same research group out of Laurentian University, Toronto, Ontario. They used transmission FTIR spectroscopy to study Lower Paleozoic chert types from southern Ontario. FTIR transmission spectroscopy is a destructive method in which the sample is ground and the powder formed into a thin pellet. The incident radiation beam passes through the pellet and is recorded. FTIR transmission spectroscopy provides a stronger overall reflectance signal due to less loss of the incident radiation. The Laurentian University research group found a series of potentially diagnostic absorption features between chert samples taken from different geologic formations. Hassler et al.'s (2013) study is part of the current research group at the University of Memphis, Tennessee. Hassler's research utilized FTIR reflectance spectroscopy in order to distinguish between visually similar chert types. Data obtained from X-ray Diffraction (XRD) and petrographic analysis aided the identification of minerals within the chert samples. It is evident from these publications that the application of FTIR spectroscopy within archaeological research is becoming more common. Three previously published studies, only one of which utilizes a non-destructive reflectance approach, illustrates that the technique is in its developmental phase.

The application of reflectance spectroscopy to provenance studies is a potentially useful approach to the non-destructive analysis of archaeological chert materials. However, both VNIR and FTIR reflectance spectroscopy require careful a priori testing in order to assess the strengths and weaknesses of the techniques. The analysis of a large sample of Lower St. Louis “Dover” and Fort Payne chert collected from multiple deposits along both the vertical and horizontal distribution of the formations provides a test case examining both inter- and intra-formation accuracy. The non-destructive analysis of a sample of Mississippian sword-form bifaces provides a case study for future archaeological application. The provenance data gathered from the Mississippian sword-form bifaces tests the single source theory and aides our explanations regarding the ideological function of Mississippian symbolic weaponry.

CHAPTER 6

METHODOLOGY

The research design of a chert provenance study is crucial. Areas needing careful consideration include the geology of the formations bearing chert deposits in the study area, cultural background of those groups consuming chert resources, instrumentation used for analysis, analytical treatment used to assign source and the sampling strategy of both chert reference materials and artifact specimens. The following discussion details methods used in obtaining samples, creating a chert database, selecting a sample of Mississippian sword-form bifaces, choosing reflectance spectroscopy and a statistical analysis technique. Variables possibly affecting the accurate collection of spectral data are discussed in greater detail. Small independent pilot studies are outlined in order to assess the variables potentially influencing spectral data collection.

Sampling

Sampling is an essential component within any study whose objective is to make observations about a population. Samples must be representative of the target population (Orton 2000). Samples should provide comprehensive coverage of the phenomena at the appropriate spatial scale defined by the research question. Samples need to be obtained using a planned approach whether random, systematic or judgmental. However, certain aspects of the target population must be known prior to sampling. One aspect of the target population that must be known prior to sampling is size. Population size is potentially related to variation. The study should have some knowledge regarding how much variation is in the characteristic(s) being measured in the population. Investigators concerned with spatial relationships must also know something about the distribution of the population in the sampling universe. Finally, a researcher designing a sampling strategy must incorporate knowledge of variables affecting the frequency of distribution in the population.

In the context of a chert provenance study, samples must accurately represent the resources suspected as the source or the resources distributed within the study area. As previously discussed, the ability to obtain a representative sample may not be possible due to the destruction of primary sources, reburial of secondary sources by natural processes and/or the complete exploitation by prehistoric people. These are very real possibilities. Observations by the author indicate that modern logging of quarry sites completely destroys almost all evidence of prehistoric quarrying. Also, the composition of present day secondary chert sources is not constant throughout time due to shifting erosional and depositional regimes. Finally, prehistoric exploitation of specific chert varieties may have led to the complete exploitation of the resource. However, the last scenario can be accounted for by sampling debitage at the procurement location.

Sample locations. Selecting sample locations is important in order to ensure that the chert samples accurately represent the resource prehistoric people utilized. Chert provenance studies have traditionally selected samples from three locations: modern exposures, prehistoric quarry/procurement sites and secondary sources. Locations should be ranked in terms of priority to sample. Chert specimens should be obtained first from prehistoric quarry/procurement sites regardless of temporal context. It is difficult to date quarry sites due to the lack of organic material and diagnostic artifacts. Temporal context is usually assigned based upon off site diagnostic artifacts visually sourced to the quarry site. Therefore, the assumption should not be made that because the quarry is thought to have been heavily exploited during the Late Woodland Period that it was not available or known by Paleoindian groups 10,000 years prior.

Samples obtained from prehistoric quarry/procurement sites should be from in situ deposits, but also from associated debitage. There exist cautions in the archaeological literature discouraging researchers from obtaining samples of debitage due to the practice of tool-kit rejuvenation at quarry sites (Church 1994; Luedtke 1992). One must be aware of the discard of non-local materials at quarry sites but this can be easily avoided by excluding curated tools from the sample. There is no known example of prehistoric people manufacturing non-local material at the quarry site. Non-local material is strictly in the form of bifaces or other tools at the end of their use life (Funk 2004; Gramly 1980, 1984). Restricting samples to primary and secondary debitage produced by cobble testing and initial trimming prior to transport to workshop areas will exclude the possibility of contamination.

The second ranked sample location based on priority is modern chert deposit exposures such as road-cuts, historic quarry sites and other deposits possibly not available in prehistory. Samples obtained from modern exposures will almost certainly not be representative of the actual spot of prehistoric procurement. However, sourcing the unknown artifact(s) back to the original deposit may not be the desired spatial resolution needed to answer the anthropologic problem. In this case the identification of the material's presence at the modern exposure may assist the quantification of variation at the formational level. Also, it is important to incorporate modern exposures into a sampling strategy as these sources might closely represent prehistoric quarry/procurement locations in close proximity that remain undocumented or are no longer in existence. The provenance researcher’s goal is to characterize the source. The sampling of modern exposures is essential to achieving characterization of source.

Finally, the sampling of secondary sources is ranked third on the priority list of locations targeted for sampling by a chert provenance study. Despite being ranked third, secondary sources provided viable and in some cases the only materials for prehistoric procurement (Hurst et al. 2009). In lithic rich areas secondary sources provided an excellent source for expedient tools. The effects of water action sort out certain package sizes and also remove undesirable areas weakened by frost fracturing. Secondary sources should not be excluded from a sampling strategy. The geologic provenance of these sources is unknown and multiple chert types are often present at these sources. An understanding of the surrounding geology coupled with the principle that gravels do not move up-gradient may allow the researcher to bracket the general location where the chert entered the alluvial transport system. The strategy also encourages the discovery of primary source areas. The inclusion of secondary sources into the provenance study gives the researcher a more accurate view of resource availability in the region. The presence of these resources may force researchers to question conventional hypotheses regarding long distance acquisition from primary sources (Koerper et al. 1987; Meltzer 1984; Shackley 1987, 1992). The representativeness of the sample is linked to the appropriate scale of variation needed to answer the anthropologic problem.

The amount, type, presence and distribution of variation in the targeted chert resource(s) should be known in order to ensure representativeness. The appropriate number of samples needed to obtain representativeness is determined by the variation present (Luedtke and Meyers 1984). In the example provided by Luedtke and Meyers

(1984), the number of samples needed to represent the chert deposit quickly escalates depending on the confidence interval desired. A set sample number of 30 is considered an appropriate size for large populations based upon student t coefficients (Drennan 2010). The location of where on the deposit samples are obtained is another important aspect.

Sample selection at the chert deposit. A single prehistoric quarry or procurement site may cover multiple square kilometers horizontally and multiple meters vertically. In order to obtain a representative sample, the sampling strategy must quantify variation across the entire horizontal and vertical distribution. Therefore, a detailed survey of the site is necessary prior to sampling. Surveys of prehistoric quarry sites are essential so that samples can be obtained across the expanse. A random sampling strategy is ideal so that valid statistical comparisons can be implemented. Systematic sampling at specific intervals across the quarry is another strategy. Judgmental sampling entails the selection of samples based upon justifications made by the researcher such as assessing the intensity of quarrying activity. Multiple combinations of the three sampling strategies exist. The most important aspect of a sampling strategy is coverage that captures any variation present both laterally and perpendicular to bedding within a stratum. Coverage here refers to a distribution of samples across the entire breadth of the site. Samples obtained from one quarry site may not be representative of the entire chert type. Gathering 30 samples from one corner of the prehistoric quarry site may not adequately represent the entire range of variation present within the material procured at the location. Surveying and sampling of the chert outcrop/deposit are practices that should be conducted in concert.

Chert database. An important aspect of a chert sourcing study is the creation of a sample database. The chert database is often called a 'chert type collection'. Traditionally provenance studies are organized into two categories based on the order of sample analysis. The first group of sourcing studies begins with the collection and analysis of geologic samples and later compares artifacts with unknown provenance to the spatially referenced database. This is the traditional structuring of a provenance study. However, a second group of sourcing studies begins with the analysis of archaeological materials with unknown provenance in order to gain an idea of how many populations or sources are represented in the assemblage. Post hoc attempts are then made to tie the artifact source groups to existing geologic resources on the landscape.

Provenance analysis of artifacts of unknown source is not a tenable method. Source groups or "floating" groups that do not have a spatial component may not be an accurate proxy for identifying number of sources. Geologic variation can manifest itself as two or more distinct populations within a single spatially confined source. Therefore, a baseline of samples representative of geologic formation and deposit is needed as a reference collection within which unknown artifacts can be compared. The importance of quantifying variation within potential resource pockets is deemed more methodologically sound than speculating about the possible number of sources in the artifact sample.

Design of Chert Sampling Strategy

In order to provide a baseline comparison for Mississippian swords, a reference collection consisting of 1,050 chert samples was constructed (Table 1). The chert

Table 1. Descriptions for all sampling locations.

Sampled Locations	Description	N	Sample	Geologic Formation
Prehistoric Quarries Sites				
Brigham Site, TN	Prehistoric Quarry	30	64-#	Lower St. Louis
Cross Creek Site, TN	Prehistoric Quarry	30	66-#	Lower St. Louis
Thompson Hollow Site, TN	Prehistoric Quarry	30	67-#	Lower St. Louis
Commissary Ridge Site, TN	Prehistoric Quarry	30	80-#	Lower St. Louis
Prehistoric Procurement Sites				
40Ho51	Procurement	30	Ho51	Fort Payne
40Ho54	Procurement	30	Ho54	Fort Payne
40Ho55	Procurement	30	Ho55	Fort Payne
40Ho57	Procurement	30	Ho57	Fort Payne
40Hs327	Procurement	30	Hs327	Fort Payne
40Hy136	Procurement	30	Hy136	Fort Payne
Geologic Outcrops/Deposits				
Al 1	Outcrop/Gravels	30	Al 1-#	Fort Payne
St. Florentine, AL	Prehistoric Quarry	30	Fl-#	Fort Payne
Elco, IL	Outcrop	30	D1-#	Fort Payne
Elco, IL	Outcrop	30	D2-#	Fort Payne
Elco, IL	Outcrop	30	D8-#	Fort Payne
Lake Barkley1, KY	Outcrop	30	B-#	Lower St. Louis
Lake Barkley 2, KY	Outcrop	30	B-10#	Lower St. Louis
Dry Branch, KY	Outcrop	30	DB-#	Fort Payne
McCormick Creek, KY	Outcrop	30	MC-#	Fort Payne
Pickwick, MS	Alluvial Gravels	30	P1-#	Fort Payne
Pickwick, MS	Alluvial Gravels	30	P2-#	Fort Payne
Cumberland City, TN	Alluvial Gravels	30	T-#	Lower St. Louis
Link Farm, TN	Outcrop	30	L1-#	Fort Payne
Wells Creek, TN	Alluvial Gravels	30	Wells-#	Fort Payne
Erin, TN	Outcrop	30	Er-#	Fort Payne
Humphreys Co., TN	Outcrop	30	Hy-#	Fort Payne
Bucksnort, TN	Outcrop	30	B-#	Fort Payne
Beaver Dam Creek, TN	Outcrop	30	BDC-#	Fort Payne
Beaver Dam Creek 2, TN	Outcrop	30	BDC2-#	Fort Payne
Lobelsville, TN	Alluvial Gravels	30	Lobel-#	Fort Payne
Crazy Horse Canoe, TN	Alluvial Gravels	30	Crazy 1-#	Fort Payne
Waynesboro, TN	Alluvial Gravels	30	Wayne 1-#	Fort Payne
Natural Bridge, TN	Alluvial Gravels	30	NatBr 1-#	Fort Payne
Berry College, GA	Outcrop	30	GA3-#	Fort Payne
GA 4, GA	Outcrop	30	GA4-#	Fort Payne
Total (n)		1,050		

database is composed of Lower St. Louis “Dover” and Fort Payne chert samples gathered from 35 deposits (Figure 13). The term deposit is used here to describe concentrations of chert in alluvium, colluvium and contained within the parent geologic formation. A total of 30 samples were collected from each of the 35 deposits. The selection of chert deposits and collection of samples from each deposit are controlled by the study’s sampling methodology.

Sample locations. The location of chert deposits sampled is dictated primarily by the surficial extent of the Fort Payne and St. Louis limestone formations (Figure 2). Other major chert bearing formations are located within the study area but the study is

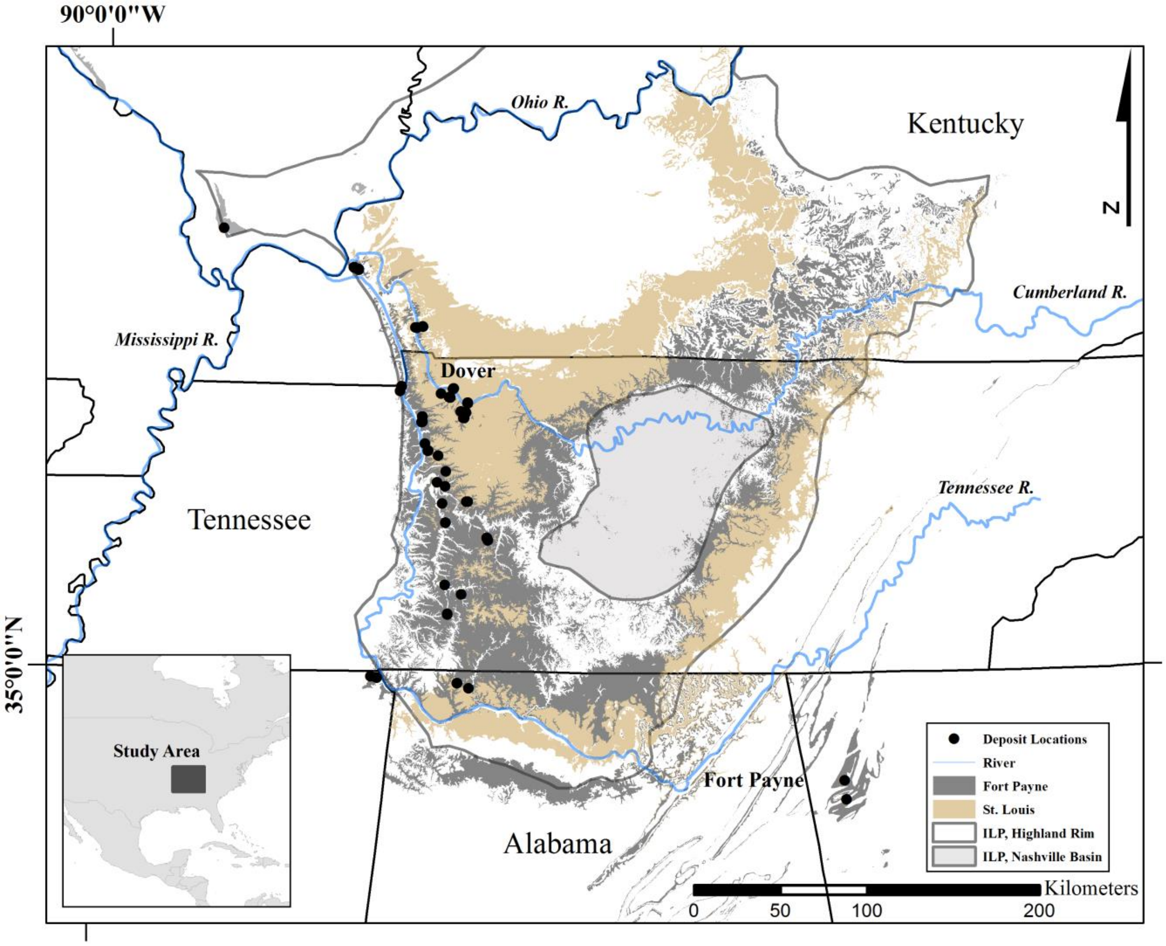

Figure 13. Location of all 35 chert deposits sampled. Sample locations are mapped with respect to geologic formation and physiographic province.

designed to examine only the Lower St. Louis “Dover” and Fort Payne look-alike chert types. Specific sampling locations within each formation are controlled by the type of deposit. Additional sample location information is presented in Table 1. As outlined above, prehistoric quarry/procurement sites are the highest ranked sample locations. In situ deposits exposed by modern road-cuts, waterways and historic limestone quarry sites are a secondary sampling location. Finally, chert deposits within fluvial gravel bars provided a third sampling location.

Rivers and smaller tributaries primarily bisecting either the Lower St. Louis or Fort Payne formations were sampled. Gravel bars along waterways with steep gradients bisecting multiple chert bearing formations were not targeted due to the possibility of multiple chert type contributions. Prehistorically fluvial deposits of chert were an excellent resource but it is likely that the package size demands for production of large hypertrophic bifaces would have discouraged the acquisition of material from gravel bars. However, a characterization of secondary chert resources can be indicative of variability in upstream deposits. Through sampling and characterization of fluvial chert deposits, the researcher gains an awareness of deposits within the particular drainage.

The majority of sampled chert deposits are located along the Western Highland Rim section of Tennessee (Figure 13). However, less concentrated sampling of deposits occurred at the margins of the Fort Payne and St. Louis Limestone formations. The northern extent of sampled deposits is in Illinois and Kentucky. The southern extent of sampling was from deposits in Mississippi, Alabama and Georgia. The 35 sampled deposits provide a spread of intra-formation variability across the surficial expression of the two formations. The samples analyzed in the study may not be representative of the entire population across this large geographic area. Continued sampling can potentially refine our model of variation within Lower St. Louis and Fort Payne chert.

Specimen collection. The collection method of 30 chert specimens from each of the 35 locations is described as judgmental random. When a sample location was initially located, the entire exposed chert deposit was surveyed along its entire lateral and vertical extent. A typical survey consisted of beginning at one of the end margins of the deposit and pacing transects perpendicular to the horizontal plane of the exposed material. A new transect was started in an alternate direction approximately five meters beyond the initial one when the vertical margin of the deposit was reached. The survey strategy gave the researcher the opportunity to walk over the entire deposit noting concentrations and resource distribution. Prehistoric quarry/procurement activity was recorded spatially as the utility of this strategy in deciphering prehistoric use is shown in Parish (2009). The deposit was spatially referenced with the aid of a handheld Global Positioning System (GPS). Coordinates were obtained along the length and width of the deposit.

The collection of 30 chert specimens began upon completion of the deposit survey. Specific sample locations were determined judgmentally by selection of a spread of samples from across both the lateral and vertical extent of the deposit. Each sample location was recorded with the GPS. Specimens were not obtained from singular locations within the deposit. Variables affecting specimen selection are location within the deposit, concentration of material, evidence of prehistoric use, lithic quality and spatial distance from a previously collected specimen. Therefore, the specimen selection strategy was not purely systematic nor was it purely random. The strategy was certainly biased toward empirical observations but the collection of specimens across the entire area of the deposit was deemed more important than introduced sampling bias. The sampling strategy is appropriate for the spatial resolution of the chert source study that is defined as sourcing at the intra-formation level. A sourcing study whose spatial resolution is set at the intra-deposit level might benefit more from a random sampling strategy.

Specimen preparation. Chert samples consist of nodules, angular blocks from bedded horizons, platter shaped lenses and cobbles. Some specimens have a thick outer cortex while others had frost fractured planes. Each chert specimen has different degrees of weathering and organic growth on its outer surface varying in intensity between and within deposits. Therefore, each specimen was broken using direct percussion with a quartzite hammerstone in order to expose its interior surface. Between seven to ten fractured fragments for each specimen were placed into a four mil plastic bag. Provenience information for each specimen was written upon the bag including deposit location and sample number. Larger (3-6 cm in diameter) fragments with relatively flat interior surfaces were retained rather than small angular pieces. Additionally, a single piece of the specimen containing at least one weathered surface was retained to be incorporated into a pilot study. The weathered specimen retained is not a cortical fragment but a portion of a frost fractured or prehistorically induced breakage surface.

Each specimen contained varying amounts of non-molecular bonded water. Prior to analysis, the chert specimen was given sufficient time to dry. Specimens were not washed or cleaned with any substance. A lens tissue was used to wipe off any dust particles upon the freshly fractured surface. Care was taken in handling the analysis surface so as not to place oils or unwanted residues onto the specimen. Artifact preparation was entirely non-destructive and sensitive to potential archaeologically important residues. A lens tissue was used to gently wipe the surface of the artifact prior to analysis. This constitutes the only surface treatment performed on the Mississippian sword-form biface specimens.

Design of Artifact Sampling Strategy

A total of 30 Mississippian swords were analyzed in the study (Table 2). The selection of the sword sample was influenced by collection accessibility, temporal context and visually assigned chert type. The style of the biface played a small role in selection as well. The Duck River Style (n=17) was the desired sword-form in the sample however, a total of 13 were of the Fulsi-elliptical type defined by Brown (1996). Archaeological context, high resolution temporal context and artifact provenience were not factors that affected the inclusion of Mississippian swords in the sample. These factors would be included in designing future studies focusing on the identification of specific spatial, temporal and cultural patterns. The anthropologic problem addressing resource selection from a single, often long-distance, source is the primary research question. Once the primary research question is addressed future studies can be designed to investigate additional cultural, spatial and temporal patterns.

The accessibility of the collections was the primary determining factor for inclusion in the sample. The analysis of the artifacts required their loan for a period of time in order to transport them to the University of Memphis. The period of time needed for analysis was two days for all 30 specimens, however the collection loan period was approximately one month. The extra time facilitated photographic documentation and

Table 2. Mississippian sword-form bifaces analyzed.

Catalogue #	Site Type*	Context	Age**	Style	(l, w, t) cm
Mississippian Sword					
40Su14	PM	House Feature	M	Duck River	10.5,5.3,1.4
6614/16By13	OH	House	W, LM	Fusi-elliptical	27.8,4.1,1.3
4893/16By13	OH	Plowzone	W, LM	Fusi-elliptical	20.5,6.0,1.3
15/3Sw1	BM	Burial?	M	Fusi-elliptical	36.0,6.4,1.0
217/30Sw20	SG	Burial?	M	Duck River	28.4,4.4,1.2
129-B56/30Sw20	SG	Burial?	M	Duck River	21.2,4.8,1.1
B213/30Sw20	SG	Burial?	M	Fusi-elliptical	25.6,4.3,1.6
40Hs6	BM	Mound Fill	M	Duck River	5.6, 3.8,1.4
3/68Hs6	OH	House Feature	M	Duck River	19.2,3.9,1.1
3/67Hs6	BM	Burial/Cache	M	Duck River	30.3,3.2,1.3
4/67Hs6	BM	Burial Cache	M	Fusi-elliptical	23.8,4.1,.5
6/67Hs6	BM	Burial Cache	M	Duck River	25.3,4.2,1.1
7/67Hs6	BM	Burial Cache	M	Duck River	23.5,4.1,1.0
20/70Hs12	PM,OH	Fill	LW,M	Fusi-elliptical	17.8,4.5,1.4
5-1/71Hs12	PM	Burial	LW,M	Duck River	22.1,3.9,.9
B-96(2)/40Mr7	PM,OH	Burial	M	Fusi-elliptical	25.9,6.4,2.6
660(1)/1Ha3	PM,OH	Burial	W,M	Duck River	9.9,3.4,1.0
660(2)/1Ha3	PM,OH	Burial	W,M	Duck River	23.2,4.0,1.1
1221(1)/1Hy1	OH	Level 2	M	Duck River	24.7,4.6,1.2
1221(2)/1Hy1	OH	Level 2	M	Duck River	22.4,4.2,1.4
475/7Hy5	OH	Level 2	LW,M	Duck River	21.4,4.0,1.3
1047/7Hy5	OH	Plowzone	LW, M	Duck River	13.5,4.2,1.3
1104(1)/7Hy5	OH	House Feature	LW, M	Fusi-elliptical	16.5,4.3,2.9
1514/7Hy5	OH	Level 1	LW, M	Fusi-elliptical	18.7,3.3,1.2
1841/7Hy5	OH	Level 1	LW, M	Duck River	17.8,3.9,.8
2763/7Hy5	OH	Level 10	LW, M	Fusi-elliptical	10.4,3.6,1.2
3194/7Hy5	OH	-	LW, M	Duck River	18.9,3.9,.8
3526/7Hy5	OH	-	LW, M	Fusi-elliptical	18.0,4.1,1.3
3563/7Hy5	OH	-	LW, M	Fusi-elliptical	16.9,4.8,1.6
467/3Re12	PM, OH	Burial	W, M	Fusi-elliptical	19.1,5.1,.9

*Burial Mound (BM), Open Habitation (OH), Platform Mound (PM), Single Grave (SG)
** Woodland (W), Late Woodland (LW), Mississippian (M), Late Mississippian (LM)

general artifact analysis. The FTIR spectrometer is not portable necessitating collection loans. The VNIR spectrometer is portable and can be easily configured in any artifact repository. The decision was made to only analyze artifacts which were able to be loaned for a period of a few weeks in order to facilitate analysis with both instruments.

The majority (n=31) of the artifact specimens came from collections curated by the McClung Museum at the University of Tennessee, Knoxville. Two of the bifaces came from earlier Archaic contexts and were later removed from analysis. A single sword was analyzed from the Castalian Springs Site (40Su14) located in Sumner County, Tennessee. The samples from the McClung Museum were recovered by excavations conducted from 1936-1942 by Tennessee Valley Administration (TVA) and Works Progress Administration (WPA) workers. Temporal components for the sites are primarily derived by relative dating methods and diagnostic artifact associations. No carbon-14 dates are reported. Table 2 details the temporal and archaeological context, when available, for each of the swords analyzed. Both the temporal and archaeological context is important for constructing explanations of chert resource selection. Therefore, a more detailed discussion of the temporal and archaeological context of the swords is provided in Chapter 9.

Influencing variables. Two variables potentially affecting the identification of source to artifacts of unknown provenance are the natural weathering of an artifact's exterior and the documented practice of prehistoric thermal alteration. Both topics enjoy a large amount of discussion in the archaeological literature too numerous to list in their entirety here (Ahler 1983; Bordes 1969; Collins and Fenwick 1974; Crabtree and Butler 1964; Flennicken and Garrison 1975; Griffiths et al. 1987; Hurst and Kelly 1961;

Mandeville 1973; Purdy 1981; Purdy and Brooks 1971, 1981; Purdy and Clark 1979). A brief discussion of surface weathering and thermal alteration is necessary as the effects of these processes on chert artifacts are important to consider prior to analysis. Specific variables related to the use of reflectance spectroscopy are discussed below.

Thermal Alteration. The thermal alteration of chert refers to the technology where controlled heating is used to alter chert. Thermal alteration also refers to natural firing of the chert due to grass or forest fires. The thermal alteration of chert is a process that changes the mechanical properties of the material. There are a number of theories as to what the process of heat treating does to the microcrystalline structure of chert. The leading theory is the Griffith crack theory which hypothesizes that heating creates numerous micro-cracks in the quartz crystal allowing for fractures to propagate through the crystals instead of around them (Luedtke 1992:83). Additional alterations to chert may include the oxidation of various iron minerals giving a pink or red hue to the artifact that many archaeologists use as an indicator or heat treatment. A provenance study must consider the effects of thermal alteration to the potentially diagnostic properties being used to source the artifact. The accurate determination of chert provenance may be compromised if the alteration of micro-mineral groups, trace elements or other inherent traits is affected beyond the natural range of variation occurring at the original deposit.

Patina. Patina is a term used to describe a variety of visible alterations to the surficial aspects of chert and should not be used interchangeably with cortex. Cortex is a transition zone that forms at the same time as chert diagenesis progresses (Luedtke 1992). Cortex may also be a product of weathering over a considerable period of (geologic) time. Patina is used in the current study to describe the “thin [commonly] light-colored outer layer produced by weathering (Dictionary of Geologic Terms 1962)" including "the surface layer consisting of compositional gradients and optical properties that are different from the interior (Purdy 1981; Purdy and Clark 1987:215)." Purdy (1981) identifies two weathering layers upon a chert's surface/near-surface. The first layer is severely roughened by the static weathering process. The second layer, located under the first, is affected by dynamic weathering processes of selective removal of ionic species (Purdy 1981:129). What can be inferred from these definitions is that patina formation is a visually distinct change in the exterior of chert and is a function of weathering over a relatively short period of (geologic) time.

The degree of artifact patination is commonly used as a relative age indicator (Sheppard and Pavlish 1993). However, patina formation is almost certainly due to a number of variables deterring simple age calculation models. The degree of patina formation even within a single archaeological site does not appear to be uniform as shown by mended projectile points. What is important to note at this point is that patina formation is a surface/near-surface alteration of the artifact(s) in the provenance study. Therefore, analysis on the outer surface of an artifact or sample may not give an accurate measurement of intra-artifact/sample variation (Luedtke 1978). The outer weathered surface of artifacts should be accounted for in the methodology and analysis sections of a provenance study. Two experiments discussed below were designed to document the effect of patina on the current study.

Pilot Studies

Two pilot studies were designed to investigate the potential affect that thermal alteration and weathering has on the spectral signature of chert and the ability to accurately source samples of unknown provenance. Both pilot studies are small in scope but highlight the need to address weathering of and heating of cultural materials in a provenance study. The results of each study are presented in Chapter 8 followed by a discussion in Chapter 9. The methodology and outline for each study is detailed below.

Heat treatment study. A controlled heat treatment experiment analyzed the spectral effects upon six chert types. The pilot study consisted of thermally altered samples of Dover, Horse Creek, Camden, Fort Payne, Flint Ridge and Mill Creek chert types. The results of heat treatment upon Dover and Fort Payne chert directly pertain to the provenance study. However, the analysis of Horse Creek, Camden, Flint Ridge and Mill Creek varieties demonstrate trends in the data that substantiate those noticed in the Dover and Fort Payne samples.

Types. Horse Creek chert is a highly variable tri-colored chert type ranging in color from blood red at its center, to yellow, and black/grey on the exterior. The unique coloration may be due to the presence of hematite or other ferrous mineral inclusions. Horse Creek chert is associated with the Eutaw Formation of Decatur and Hardin Counties. The material exists as chert residuum in a sand and gravel matrix and may be observed as alluvial deposits along the Hardin, Indian, and Horse Creeks near Savannah, Tennessee. The Horse Creek sample was collected from an abandoned chert gravel mine in Decator County, Tennessee.

Camden chert is a white to light grey coarse grained material located in the Ross Formation, Lower Devonian, of western Tennessee. Camden chert has a localized distribution in archaeological assemblages along the Western Highland Rim of Tennessee. Thick bedded planes of Camden chert were observed underlying the Eutaw gravel formation. Camden chert was sampled where it was exposed in the abandoned chert gravel quarry in Decator County.

Mill Creek chert is a white to grey speckled material occurring in platter shaped nodules. It has a large archaeological distribution across the Midwest and Southeastern United States. Mill Creek chert occurs in the Ullin Limestone Formation of Illinois. The use of Mill Creek chert reached a climax during the Mississippi Period. Samples were collected by Brian Butler from the prehistoric quarry complex in Union County, Illinois. Mill Creek chert has been used in other heat treatment experiments (Dunnell and McCutcheon 1994; McCutcheon 1997; McCutcheon and Kuehner 1997).

Flint Ridge chert refers to a number of varieties of chert occurring throughout mid-state Ohio. Flint Ridge chert occurs in the Vanport Limestone Formation. Samples of Flint Ridge chert were obtained from modern chert quarry pits in close association with prehistoric ones in central Ohio. Flint Ridge chert was widely distributed among prehistoric groups in the Northeast.

Dover chert samples were obtained from the Thompson Hollow Quarry site (40Sw67). Fort Payne samples were collected from a steep bluff near the Link Farm Site in Humphrey's County, Tennessee. One nodule or block of each of the five chert types was broken into five specimens. In this manner, intra-outcrop variability is reduced by preparing samples from a single nodule. Though some inconsistency may exist due to intra-nodule variation, it is likely that this would be to a lesser extent than if multiple nodules were included in the analysis. All specimens were approximately equal in size. Therefore, a total of 30 chert specimens, five of each type, were used in the heat treatment experiment.

The 30 samples were organized into six groups of five samples each. One specimen of each type was included per group. The first trial group acted as a control. The subsequent four additional groups were subjected to controlled heating in an electric furnace at 100-400˚C. The analysis and results of the experiment are discussed in the following chapters.

Patina studies: Cross section. Two experiments document the effects that patina has on the spectral response of chert. The first is a small scale experiment designed to analyze sample cross-sections incrementally from the outside inward. The second study provides spectral data from 105 weathered surfaces of samples included within the chert sample database. Data from the first experiment provide detailed information and direct the processing of spectral data recorded from Mississippian sword-form bifaces. Information from the second experiment identifies any decrease in overall provenance assignment accuracy at the formational and outcrop levels.

In order to test the effects that patina has on the spectral reflectance response, a total of ten geologic samples were taken from a limestone outcrop at the Cross Creek Quarry (40Sw66) site. All ten chert samples were taken from a vertical section of the limestone bluff approximately 7.7 m^2 in extent (Figure 14). A number of Dover chert nodules were visible along the exposure, each of which was split due to a combination of mass wasting of the valley wall, frost fracturing and anthropogenic alteration.

The cortex of the Dover chert ranges from a few millimeters to centimeters thick and consists of a white to brown coarse rind. The color variation present in the material can be directly attributed to varying degrees of silicate replacement processes and weathering to which the individual nodule or piece has been

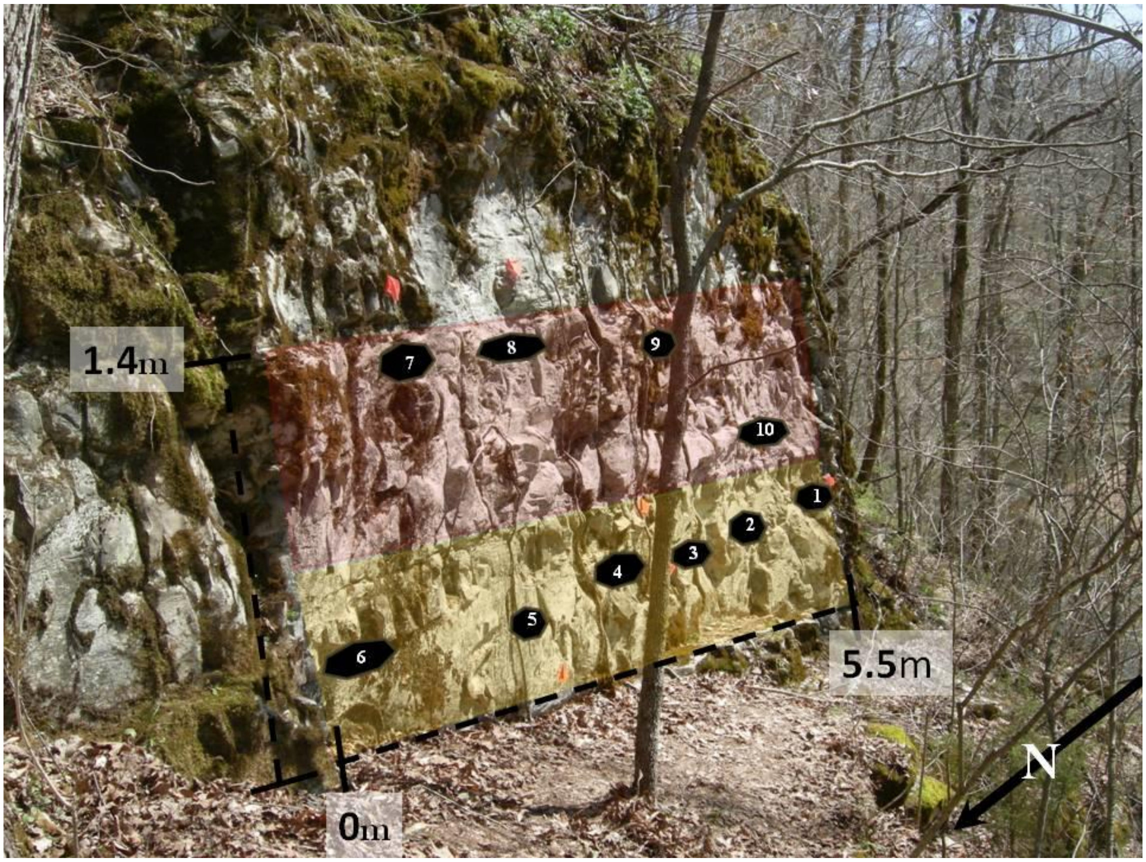

Figure 14. Location of all ten in situ samples used in the patina cross-section experiment. Outcrop located at the Cross Creek Quarry Site (40Sw66).

subjected (Marcher 1962). Prehistoric debitage on the ground surface appears grey to light brown.

The geologic positioning of the chert nodules within the limestone bedrock is situated within two horizons of the limestone formation. These horizons appear to be parallel or sub-parallel to the geologic strata. A stratified judgmental sampling method was implemented to obtain ten chert samples from individual nodules selected within the two horizons (Figure 14). Samples were chosen to be representative of the entire lateral and vertical extent of both horizons. The provenience of each sample was recorded and maintained throughout analysis. The samples were flint knapped exposing the interior surface. The resulting cross sections of the ten samples displayed the degree to which patina formation had progressed upon the outside facet of each nodule that was exposed on the cliff face. The finer grained samples exhibited a thin patina less than a millimeter in thickness while others were in excess of three millimeters. Finally, samples were washed and allowed to dry prior to analysis.

Patina studies: Subset sample. The second study utilizes the chert specimens exhibiting at least one patina surface originally retained within the chert sample collection. A sample of 105 patina chert specimens were randomly selected from the chert database containing 1,050 samples. The provenience of the patina samples was maintained throughout the experiment. However, they were treated as having unknown provenience. The patina surface of all specimens was wiped with a dry lens tissue prior to analysis by both reflectance spectroscopy techniques. The objective of the second experiment was to assess the accuracy of provenance determination at the formational and outcrop levels when analyzing the patina rather than analyzing a fresh interior surface.

Instrumentation

The selection of a provenance method must be done with careful consideration given to eight main desirable attributes. The eight attributes include the accuracy, precision, reliability, level of destructiveness, speed, cost, database management and artifact accommodation of the method chosen. There is not a method in existence, nor may there ever be, that fully satisfies all of these requirements. It may be deemed feasible to use a combination of methods to enhance the provenance study in certain areas. It is important to select a provenance technique(s) according to the eight criteria listed. The desirability of any one of the eight attributes is dependent upon the research design and ultimately the anthropological question.

Accuracy/Precision. Accuracy refers to the ability of the instrument/method to produce results which most closely match the true value (Pollard et al. 2007:313). In a provenance study, accuracy would be the ability of the instrument/method to quantify the true variation at a particular scale of variation. Accuracy is also the ability of the provenance study (instrument/method and analytical method) to source artifacts to their true source of prehistoric procurement. Accuracy should be tested upon artifacts of known provenance. Precision on the other hand is different. Precision is the degree of reproducibility over the course of repeated measurements on the same sample (Pollard et al. 2007:313). Frahm (2012:168) argues that the term repeatability should replace precision emphasizing measurements taken within a discrete study under controlled conditions. Similar to accuracy, precision has multiple facets to its meaning within a chert provenance study.   Precision of the instrument/method in the context of a chert provenance study is the ability to quantify or qualify the variation of a sample over repeated measurements. Precision could be the consistent description of color for a sample during repeated observations or the standard deviation between multiple measurements of a single trace element within a sample standard. Instrument ‘drift’ would be a factor affecting precision. The accuracy and precision of the provenance instrument or method chosen are arguably the most important aspects of the study.

Reliability. Reliability deals with precision of repeated measurements over the course of time, between different observers and/or different experiments upon the same samples. Reproducibility is an analogous term for reliability (Frahm 2012:169).

Reliability within a chert provenance study is an evaluation of measurements over time on the same chert samples by the same method. A provenance study utilizing visual identification may contain a high rate of inter-observer error. A provenance analytical method using the same instrumentation in different labs may involve concerns regarding reliability despite using the same standards and procedures. Reliability is an important aspect in the creation of large chert databases over time. The addition of new elemental or qualitative data between observers or instruments is potentially problematic as a degree of error is introduced contributing to inaccurate provenance assignments.

Level of Destructiveness/Artifact Accommodation. The degree to which artifacts or samples are destroyed or damaged is an aspect of a provenance technique demanding careful consideration. Destructive analysis is defined as those techniques that cut, grind, ablate, break, irradiate or pulverize an archaeological artifact prior to or during analysis. Artifacts of significant social, cultural and historic value are often those that would provide valuable provenance data. Due to the value of such artifacts, destructive provenance analysis is not an option. However, destructive analysis of debitage or other materials whose scientific or cultural value is deemed less might be a valid option for researchers. A related concern is the size of the sample chamber of the instrument, in this study termed ‘artifact accommodation’. The provenance method chosen to collect data may be completely non-destructive however the sample chamber restricts the size of the artifact necessitating destructive preparation. The level of destructiveness may prevent the provenance study from addressing particular aspects of the anthropological problem. Damage to the artifact being analyzed must be considered when selecting a provenance technique.

Speed/Cost. Due to the need for large sample sizes for the characterization of variation in provenance studies, the speed and cost of analysis is a factor when selecting a technique. The speed of analysis for visual identifications is on the order of minutes whereas the collection of elemental data via neutron bombardment may be weeks. The speed of analysis is important if decisions regarding site preservation need to be made. However, speed also relates to cost as a study that can generate pilot data quickly is able to rapidly structure a research design and proceed with other aspects of the study. Speed may also limit the design of large provenance studies. The increase in number of samples also increases the amount of time involved in analysis effectively producing small, possibly non-representative, chert databases. The main controlling factor of project size is cost of analysis. Sample preparation and analysis costs usually range from approximately $20 to $125 per sample. As discussed previously, large sample sizes are potentially necessary to characterize variation. The cost of the provenance study can easily grow even prior to artifact analysis.

Database Management. Database management refers to the accumulation of potentially diagnostic data from the chert samples analyzed. Traditionally, chert provenance research has generated three major types of data for the archaeological community. Data exist in the form of chert samples usually combined to form comparative collections or reference libraries, provenience information attached to each sample and provenance information in the form of mineralogy, trace elemental chemistry, coloration, fossil content and other potentially diagnostic traits. The accessibility of chert provenance data may be restricted by publication limitations and the overwhelming quantity of information needed to characterize a material type or outcrop location. The digital environment alleviates most of these issues by providing a forum in which dynamic chert databases may be accessed, updated, and utilized by other researchers. Examples of chert databases are the Jack Holland type collection and the MURR Archaeometry Laboratory Database. A chert database must be applicable to other researchers and at the same time maintain a level of security for preservation and conservation concerns.

Instrumentation utilized. The reflectance spectroscopy instruments used in the chert provenance study are hyperspectral spectroradiometers. Both instruments are considered to be hyperspectral due to their ability to record radiation/matter interactions at extremely high resolutions. A large amount of reflectance data is gathered with every spectrum recorded. Due to their high spectral resolution, the spectrometers are commonly used to ground-truth remote sensing data gathered from sensors mounted on satellite platforms.

VNIR. Spectral data measured in the visible and near-infrared regions of the electromagnetic spectrum are recorded by two instruments manufactured by Analytical Spectral Devices Inc. (ASD). The first VNIR spectrometer is the ASD FieldSpec ® portable spectrometer. The spectral range of the device is 350-2500 nm. The spectral resolution is 4 nm from 350-1000 nm and 10 nm from 1000-2500 nm. A reflectance value is recorded every 2 nm producing 2,150 reflectance values (bands). The detector is encased in a hard plastic shell ergonomically designed for easy transport and protection. A fiber optic cable runs from the detector to an interchangeable handheld pistol grip. The fiber optic cable consists of three spectrometer probes. The first probe is called the VNIR (visible near-infrared) recording spectral data from 350-1000 nm. The second probe is the SWIR 1 (shortwave infrared) recording data from 1001-1775 nm. The final probe is the SWIR 2 recording reflectance data from 1776-2500 nm. An entire spectrum is recorded in less than 0.1 seconds. The ASD FieldSpec ® portable spectrometer is housed at Murray State University, Kentucky. The FieldSpec ® was used to analyze all of the Mississippian swords and a portion of the chert samples.

A second ASD spectrometer was used in conjunction with the FieldSpec ®. The FieldSpec ® 4 portable spectrometer is a newer model but has comparable specifications. The spectral range is 350-2,500 nm. Spectral resolution is slightly improved being 3 nm from 350-700 nm and 8 nm from 701-2,500 nm. The sampling interval of the FieldSpec ® 4 is 1.4 nm from 350-1000 nm and 2 nm from 1,001-2,500 nm. The total number of reflectance values recorded per reading is 2,151. Instrument configuration is identical to the FieldSpec ® both of which have optional detector probe handheld accessories. The ranges for the VNIR, SWIR 1 and SWIR 2 probes are the same. The use of interchangeable fore-optic attachments provides varying field-of-view diameters. The time elapsed for recording an entire spectrum is 100 milliseconds. The use of the ASD FieldSpec ® 4 spectrometer was courtesy of a one month instrument loan through the Alexander Goetz Instrument Support Program (AGISP) offered by ASD Inc. The FieldSpec ® 4 was used to analyze all 1,050 chert samples within the chert database. The use of two VNIR reflectance spectrometers provides a case study to investigate inter-instrument reliability. Both the FieldSpec ® and FieldSpec ® 4 instruments were used to analyze 240 chert samples taken from four deposits of Dover and four deposits of Fort Payne chert. The results of the inter-instrument experiment show that the standard deviations between reflectance measurements did not exceed approximately 0.1 reflectance units.

FTIR. All middle-infrared reflectance data was recorded by a BioRad FTS-40 infrared spectrometer. The device is capable of recording in transmission mode (destructive) and reflectance mode (non-destructive). All samples were analyzed in reflectance mode. The FTS-40 includes a single beam He-Ne laser, a water-cooled ceramic infrared source and a liquid nitrogen cooled Mercury Cadmium Telluride (MCT) external detector. The FTS-40 requires a constant supply of water to cool the ceramic infrared source and dry air to reduce or eliminate water vapor, pulse the interferometer and keep the optics in working order. In reflectance mode the sample is placed under the binocular microscope objective. Magnification power of the viewing objective is 4X. The viewing objective aids the selection of a particular spot on the sample surface. Once focused the IR objective is set in place for analysis. Both the viewing objective and the IR objective are conveniently located on a swivel mount. The magnification of the IR objective is 32X. An adjustable 2” x 3” stage accommodates focusing and sample repositioning.

The spectral range of the FTS-40 is 2,500-25,000 nm. The spectral resolution is adjustable. The current study utilizes a spectral resolution of 4 cm^{-1} which was found by previous experiments to provide the best compromise between noise and resolution (Hassler 2011). The resulting sampling interval is 12 nm giving a total of 1,867 reflectance values. However, detector limitations excluded potentially useful spectral data collection in the 16,000-25,000 nm range. Therefore all infrared analysis was performed on data collected from 2,500-16,000 nm. The BioRad FTS-40 infrared spectrometer is housed in the Chemistry Department at the University of Memphis. All artifact and chert samples were analyzed using the spectrometer.

Selection of Instrumentation. The choice to use the ASD Inc. FieldSpec ® devices and the BioRad FTS-40 reflectance spectrometers was controlled by the research design of the study itself as testing these techniques is the primary objective of the study. Reflectance spectroscopy in general and the instrumentation used specifically in the study provides a method that is precise, reliable, non-destructive, accommodating to artifact size, fast, low-cost, database friendly and potentially accurate. Precision of the VNIR spectrometers is reported to 0.1 nm between spectral readings over the course of 30 minutes. Instrument drift occurs and is minimized in the study by recalibrating the background reflectance and collecting a white reference spectrum every 10 minutes. Precision of the FTIR spectrometer is reported as 0.1 nm over the course of two hours of analysis. At approximately two hours the liquid nitrogen supply in the MCT detector dewar becomes low causing increasing instrumental drift.

Through consistent replacement of the liquid nitrogen supply and background correction for both the BioRad and ASD spectrometers, reliable reproducible measurements are obtained. In reflectance mode both instruments provide non-destructive analysis of samples. Furthermore, both techniques are able to accommodate a wide range of artifact/sample sizes without complicated instrument reconfiguration. The speed at which the spectrometers record reflectance data is also conducive to a chert sourcing study. Approximate analysis time of 30 chert samples with the VNIR spectrometers was one hour, recording three spectra per sample. Time needed to analyze 30 chert samples (3 spectra per sample) with the FTIR spectrometer was approximately three hours. The operation cost of the VNIR spectrometers is solely attributed to replacing the relatively inexpensive quartz-halogen bulbs (1 replacement during the current study). Operation cost for the FTIR spectrometer includes supply of laboratory grade liquid nitrogen ranging from thirty cents to one dollar and fifty cents per liter and replacement of the He-Ne laser (not needed in the current study). Also, the resulting reflectance data are numerical values organized into rows and columns easily digitized, exported, compiled, searched and stored. Finally, the accuracy in identifying chert by formation and by deposit within the formation is evaluated in greater detail in the following chapters.

Quantitative Analysis

Two prerequisites that Tykot (2003:63) states are needed for a lithic provenance study are: “measurable, statistically valid differences between sources must exist for one or a combination of these [properties] parameters; and they must be measurable using analytical methods appropriate for archaeological artifacts.” There exist as many source assigning methods as there are provenance techniques. Qualitative methods identify potentially diagnostic attributes and match these up to samples from known sources. Quantitative methods utilize a range of methods from simple bi-plot diagrams to multivariate statistical analysis. Once analysis of the artifact is performed the researcher is left with data upon some measured attribute(s). Matching the attribute(s) of the artifact to representative chert samples in the database is not a simple process. The identification and selection of diagnostic attributes is the first step.

Typically the data are studied by the researcher prior to performing statistical techniques. The human eye is incredibly good at picking out patterns; however this ability is limited to three variable datasets (Beebe et al. 1998). Next, the researcher should perform some initial exploratory data analysis to assess the amount of variability in the dataset. Common exploratory data analysis techniques are to look at the measurements within the chert database and find differences that may differentiate one group of samples from another. Bi-plots are often generated as graphic depictions of these differences. In the case of trace element data, the bi-plot is generated with two or a ratio of four elemental concentrations. Sometimes multiple combinations of data producing numerous graphs are needed before the best result is chosen. The resulting graph plots the geologic samples into cluster groups which overlap or are distinguished to some degree. The unknown artifact is then assigned provenance by plotting within the graph depicting the best cluster differentiation or using a distance to cluster center calculation.

The means of assigning provenance in a petrographic study are similar to those in a visual analysis. In both, the identification of diagnostic attributes such as fossil inclusions and macro or micro-mineral groups are used to differentiate geologic chert samples and match artifacts with unknown provenance. As previously discussed, there often exists significant inter-observer error with visual analysis. In petrographic studies the presence of diagnostic fossils or minerals could be a rare occurrence. The chance of small artifacts containing these special inclusions may be slim. Therefore, analytical techniques capable of assessing multiple measured variables are potentially a more robust method. However, high order statistical treatments are not infallible (Thomas 1978).

Essentially, provenance researchers using statistical methods are performing a cluster analysis. The goal is to organize geologic chert samples at the formational and/or outcrop spatial scale and to classify the unknowns into one of these cluster groupings. A parallel goal is to reduce the large dataset into smaller components. Data reduction is particularly useful for trace element data gathered for upwards of 70 elements. Data reduction is extremely useful in the current study where 4,000 potentially diagnostic reflectance values are produced upon a single chert sample/artifact. Statistical techniques commonly used to group samples are organized into unsupervised and supervised methods. An unsupervised method is one that does not utilize a priori group membership data. Principle Component Analysis (PCA) is a common unsupervised statistical method. The unsupervised statistical method analyzes each measured variable and generates a result which is a reduced form of the original measurements. Conversely, supervised techniques utilize existing knowledge regarding group membership. The group membership information is integrated into the classification. Artifact provenance is assigned based upon similarity to one of the predefined groups (Morin 2012). An example of a supervised classification technique is discriminate function analysis.

How the measured data generated by the provenance technique is handled to assign source is crucial and may produce alternate interpretations of the data. An understanding of the basic principles of statistics is necessary so that faulty assumptions regarding the data will not be made. Various publications are devoted to addressing these concerns with the use of statistics in archaeology (Baxter 2003; Christenson and Read 1977; Drennan 2010; Thomas 1978; VanPool and Leonard 2011).

Statistical methods utilized. The amount of visible, near-infrared and middle-infrared reflectance data generated by the study is immense. The total number of reflectance values in the chert spectral database exceeds four million. Each value is potentially diagnostic of a particular deposit or formation. Evaluation of spectral variation by simple pattern recognition without the aid of data reduction techniques is impossible. Through the course of this study and two previous studies (Parish 2011b; Parish et al. 2013), a large amount of exploratory data analysis was conducted in the form of comparison of two dimensional spectral graph plots. Visual identification of diagnostic spectral features upon the spectral line graphs was difficult as overlaying as many as 10 spectra cluttered visibility. Therefore, an average spectrum per sample deposit group of 30 was generated. The sample group spectral averages aided inter-group comparisons but masked intra-group variance. Therefore, minimum and maximum spectra were generated per sample group to bracket the range of spectral variation exhibited by the 30 chert samples at a particular location. However, none of these visual techniques identified clear consistent spectral features which were diagnostic at the formation or intra-formation levels. Visual analysis of the spectra was useful in that it identified segments of the spectrum that were the most variable both between and within formations.

The size of the reflectance datasets is one factor that defines reflectance methods from previous geochemical chert provenance studies. Another factor is that sample spectra qualify variation by the shape and presence of absorption features. Mineral identification is performed but mineral quantification is not a common objective with reflectance spectroscopy methods. Therefore, the generations of bi-plots of diagnostic spectral feature measurements or ratios of these measurements was not deemed to be a productive methodology. Preliminary exploratory data analysis identified the need for higher order statistical methods in analysis of the large spectral datasets.

The branch of statistical analysis describing the analysis of large amounts of data is chemometrics (Bokobza 1998). Chemometrics is the entire process of extracting information from data used in decision making (Beebe 1998:1). The analysis of large spectral datasets often falls under the chemometric branch of statistics. The use of the Pearson's correlation coefficient has been applied to reflectance spectral data (Hassler 2011; Hassler et al. 2013; Parish 2009; Parish 2011a). Correlation coefficients are calculated based upon overlays of sample vectors. A perfect overlay score would be 1. Identification of unknown chert samples within a database of known provenance generates a series of correlation scores ranging from -1 to 1. A source match is determined by the absolute highest correlation score of the unknown sample/artifact. A benefit of using correlation matrices is that it factors wavelength position along with reflectance intensity value.

The most common group of statistical methods employed in chemometrics is multivariate techniques including PCA and discriminant function analysis. Multivariate methods are desirable due to their data reduction techniques. The large amount of reflectance data per sample is reduced to components of variation. The two major advantages of these techniques are that they allow the researcher to examine patterns in the data set and highlight the similarities and dissimilarities seen.

Application of PCA to reflectance data first subtracts the means of the x and y dimensions. The x dimension in reflectance data is the wavelength position at which the reflectance value is recorded or extrapolated. The y dimension is the reflectance value measured in relative percent reflectance. Next, a covariance matrix is generated allowing the calculation of both the eigenvalues and eigenvectors. The eigenvector with the highest eigenvalue is the principle component of the dataset. The data matrix is reduced to a number of principle components. Usually the first five components describe nearly 100% of the patterning in the dataset. Therefore, very little data is lost by not including components beyond five. PCA transforms data into patterns in relation to relationships between samples. Application of PCA to chert reflectance data allows the researcher to potentially differentiate chert samples by deposit and by formation (Parish et al. 2013).

Discriminant function analysis is a high-order multivariate statistical technique with similar attributes to PCA. The technique builds a predictive model for group membership based upon a training sample dataset. The training sample dataset contains known membership information. The creation of a predictive model is facilitated by the calculation of primary functions based upon selected diagnostic variables per sample group. Another powerful function of discriminant analysis is that a stepwise method can be employed to assess the inclusion of each variable in the dataset. Unwanted discriminatory variables are discarded. Necessary statistical assumptions include independent cases, normal distribution of variables, within group variance and covariance matrices should be equal, group membership is mutually exclusive and all cases are members of a group. Validation of the discriminant function models can be performed by reclassifying a percentage of your training samples as test samples. Samples with unknown group membership are compared to the resulting established groups by calculation of the Mahalanobis distance between group centroids.

The analytical method used in the present study is canonical discriminant function analysis. The choice of this method is based upon its ability to reduce data by stepwise selection of the most diagnostic variables and adjustable significance levels. These attributes are valuable when handling large amounts of reflectance data. Also, the ability to perform internal validation assessments is a desirable characteristic of discriminant analysis. Finally, the primary anthropologic question regarding whether the chert type utilized to manufacture the Mississippian sword-form bifaces is Dover or Fort Payne is addressed. Type assignment is given based upon the Mahalanobis distance calculations. Chert type or formation provenance is assigned. An unknown assignment is not given which in this case is a desirable trait. The details of variable selection and user specific settings are discussed in the following chapter.

There are many variables to consider when designing a chert sourcing study. The sampling of geologic and archaeological specimens, database construction, controlled pilot studies investigating cultural and natural phenomena, instrumentation selection and analytical treatment methodologies are all areas needing careful evaluation. The research design of the current study is a direct product of the capabilities of the reflectance spectroscopy techniques utilized. However, accurate source assignment of the Mississippian sword-form bifaces is quantified by the internal validation tests of each technique and controlling variables potentially affecting the ability to assign source. The advancement of future provenance studies benefits from the recording of specific analytical steps taken during the study. The next section details these steps in order to encourage reproducible experimentation between labs by multiple researchers.

CHAPTER 7

ANALYSIS

The following section discusses specifics for experiments conducted throughout the course of the study. The first portion of the chapter focuses on the procedural steps regarding the instrumental analysis of the chert sample database and the Mississippian sword-form bifaces. The analyses of the heat treatment and patina studies are included in order to contextualize the subsequent results and contribute to future research. The second portion of the chapter documents the processing of the raw reflectance data. Pre-treatment procedures used on the spectral data are explained according to their application prior to statistical analysis. The statistical methods employed to differentiate chert by inter-formational and intra-formational variation are listed. Finally, the selection of different portions of the chert spectral database for internal accuracy assessment tests is discussed. The analytical procedures used in the study are reported in detail as the reflectance spectroscopy techniques have never been applied to chert provenance research at the current scale.

Sample Analysis

Chert sample. Each of the 1,050 chert samples collected was processed according to the procedures outlined in the previous chapter. A total of 6 to 10 specimens per sample were retained in 4 mil plastic bags with associated provenience information. One specimen was selected for analysis. Selection of the specimen is based on size and the presence of a relatively flat interior unweathered (less weathered) surface. Thick angular specimens do not fit easily upon the adjustable stage of the FTIR spectrometer. Also, a relatively flat conchoidal surface allows for a more perpendicular probe to sample surface angle. The perpendicular probe to sample surface angle is desirable as more of the reflected signal is detected. This is also true for the VNIR spectrometer though specimen size is less of a concern.

The same specimen was analyzed both with the VNIR and FTIR spectrometers. A sample was positioned on either a glass microscope slide or wooden disc with the relatively flat interior surface of the sample facing up. The sample was mounted on the slide/disc with a small amount of Silly Puddy ®. The Silly Puddy ® provides a malleable slightly adhesive substance which form-fits the micro-surface of the sample's underside. The Silly Puddy ® temporarily held the sample to the slide/disc. The use of Silly Puddy ® also allowed uncomplicated minor sample adjustment when placed beneath the detector probe. However, care had to be taken when leaving samples mounted for long periods (> 5 minutes) of analysis as heavier samples would depress the Silly Puddy ®. It was also noted that in laboratory conditions with slightly higher relative humidity the viscosity of the Silly Puddy ® would decrease providing a less stable mount. The ease at which Silly Puddy ® could be applied and removed without leaving noticeable residues or adhering particles made it a superior mounting and stabilizing substance.

The mounted sample was placed under the detector probe and the resulting spectrum recorded. A total of three spectra were recorded per sample by slight sample readjustment after each reading. The three resulting spectra per sample provided a range of intra-sample measurements. The goal of this methodology is to avoid analysis upon a single macro-mineral. Preliminary studies demonstrate that the amount of intra-sample variation for Dover and Fort Payne chert was minimal (Hassler et al. 2013). Intra-sample variation was not a major concern in the study. Later processing of the spectra involved averaging the three intra-sample readings into one representative spectrum. Analyzed samples were placed into a separate 4 mil plastic bag along with a portion of the original patina surface for later analysis. In this manner all chert samples were analyzed.

Artifact sample. The non-destructive analysis of the 30 Mississippian swords followed the procedures of the chert sample. No portions of the artifacts were removed. The surficial analysis of museum curated sword artifacts presented challenges not encountered with the geologic chert specimens. The first of these methodological challenges involves artifact size. The collection of spectral data in the visible and near-infrared is in no way constrained by artifact size. Artifact size did make FTIR analysis complicated due to instrument and stage configuration. However, the length of the particular artifact in no instance prevented analysis. Slightly longer setup time was required to ensure artifact stability and analysis of the desired spot location. The second analytical challenge was caused by the presence of various residues on the surface of the artifact. Some of these residues are prehistoric such as the presence of possible graphite around the mid-section of sample B-96(2)/40Mr7. Most of the residue encountered is modern substances such as glue and reconstruction paste.

Areas were chosen for analysis based upon the lack of noticeable residues and flatness of the surface. Typically, desirable areas for analysis occurred on large flake scars. If residues were accidently analyzed the resulting spectrum would clearly show a major deviation from the typical spectrum of chert. A total of 10 different analysis spot locations were analyzed per artifact. Five spectra were recorded upon each side of the artifact. Later processing of the spectra averaged the 10 readings into a representative composite spectrum. The averaged spectrum minimized any potential influences of accidental residue analysis. The 10 readings per sample also minimized any effect of analysis upon a particularly altered portion of the artifact. Provenience information was maintained for each sword throughout analysis.

Instrument Setup

VNIR spectrometer. Both the FieldSpec ® and FieldSpec ® 4 instruments required a warm-up period of approximately 30 minutes to 1 hour prior to use. These instruments are designed to operate either in the field utilizing solar radiation or in a laboratory setup using an artificial light source. The following descriptions are procedures for use in a controlled laboratory setting. The lab designated for spectral analysis should be free of both artificial and natural light and have atmospheric controls to keep water vapor at a minimum. Atmospheric variables affect the collection of spectral data, however the procedures used in the study included steps to subtract these influences.

The laboratory setup for the FieldSpec ® instruments are nearly identical with the portable spectroradiometer placed on a lab table, attached to a laptop computer via an interface cable and plugged into an external power source. The fiber optic cable containing the three detectors ran from the spectroradiometer into a pistol grip detector mount equipped with a bubble level. The bubble level assured the perpendicular downward aim of the detectors' probe tip. The pistol grip detector cable mount was in turn fixed to a metal stand with elongated arm clamp. The suspended level detector probe was held at a constant sample to probe distance of 5 cm.

The probe to sample distance influences atmospheric contribution and the field of view of the detector on the sample's surface. A longer sample to probe path length means that the reflected radiation has to travel through more atmosphere potentially scattering or absorbing important spectral data. However, a shorter probe to sample distance may create a shadow obscuring reflection data. Optional fore-optic attachments are available that increase the probe's field of view on the sample's surface. No fore-optic attachments are used as the bare probe at 5 cm above the sample provided an approximate 2 cm field of view. The recording of three spectral readings per sample also allowed for adequate surface coverage.

A wooden sample tray lay underneath the detector probe containing a second smaller wooden platform. The sample, mounted to a small wooden disc, was placed onto the inset wooden sample platform within the larger tray. The setup allowed for the horizontal movement of the sample without readjustment of the detector arm. Also, by placing or removing sheets of paper underneath the inset wooden platform, the vertical sample to probe distance of 5 cm was maintained. The quartz halogen light fixture was mounted on a second metal stand and arm clamp slightly angled above the detector mount at 38 cm above the sample surface. The angle of the incident light is important as this could over saturate the detector or result in variations in spectrum intensity between samples. Therefore, the position and angle of the light source was held constant being overhead at an acute angle aimed at the spot underneath of the detector probe. All mounting equipment and sample trays are spray painted a flat black to prevent unwanted potential background scattering and interference (Figure 15).

Once the instrument was set up and given the opportunity to warm up, the operating software system was opened up on the accompanying laptop computer. The operating package accompanying the VNIR spectrometers is the RS_3^{TM} software produced by ASD Inc. The RS_3^{TM} software is available for free download from the ASD website. The first step in calibrating the spectroradiometer signal is to place a white reference sample under the detector probe. Spectralon ® is the white reference standard used for all reference spectra. Spectralon ® provides nearly 100% reflectance but also assists in recording subtle atmospheric interferences. The white reference must be placed in the same sample to probe geometry as the sample. In other words, the white reference should not be angled unless the sample to be analyzed is angled.

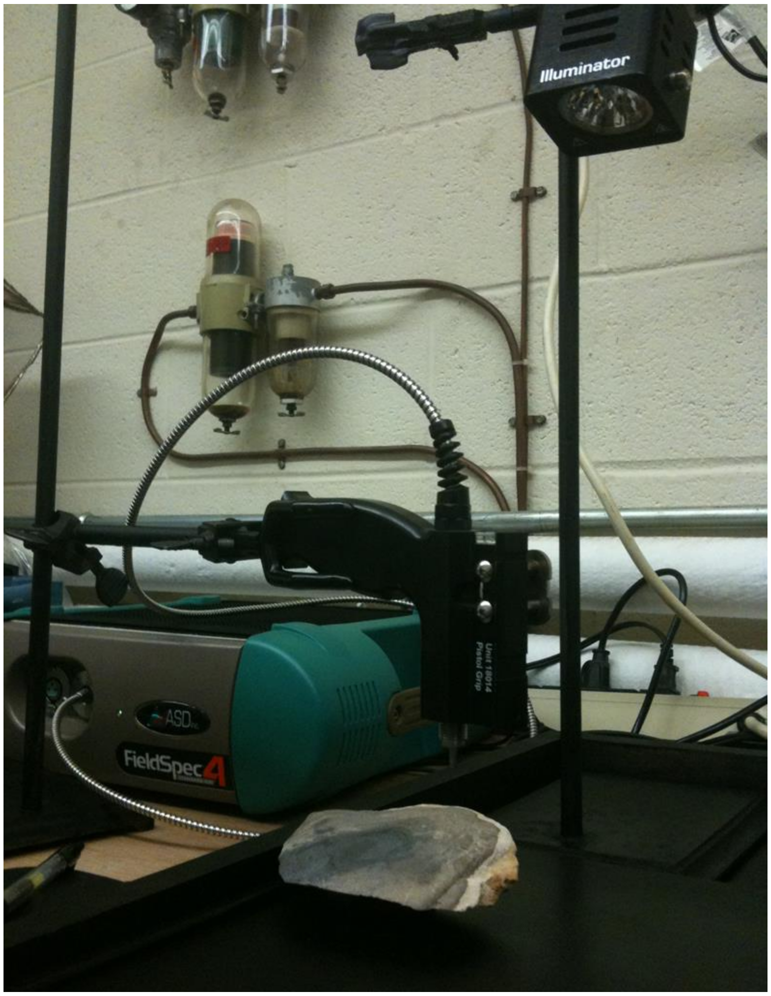

Figure 15. The ASD inc. FieldSpec ® 4 in a laboratory configuration.

Next, the spectrometer was optimized using the operating software. Optimization assures the proper light settings for the light source used to collect data. Re-optimization is not necessary through the course of analysis unless over saturation occurs or the light source intensity diminishes. However, optimization was conducted in conjunction with white reference measurements every 10 samples analyzed (approximately every 20 minutes). After the signal was optimized, the white reference measurement was recorded. A white reference measurement standardizes all subsequent measurements allowing the RS_3^{TM} software to compute the reflectance signal for the sample.

Sample analysis began after the white reference spectrum was taken. Each sample, mounted on a small wooden disc, was placed directly under the detector probe. Care was taken so that no Silly Putty ® or portions of the wooden disc stuck out from underneath the sample. The positioning of the sample was such that the detector probe's field of view was entirely on the sample surface. The angle of the sample surface to probe was slightly adjusted until it was as close to perpendicular as possible. As previously mentioned, the measurement of spectra is a continuous repetitive process as soon as optimization occurs. The resulting reflectance spectrum is graphically generated automatically on the computer display screen. A spectrum's reflectance values are plotted as intensity vs. frequency. The analyst can wait as multiple scans, one every 3 seconds, are gathered but after the first two scans there is no noticeable difference. The spectrum is then saved as an ASD file. The file format can be easily opened, processed, manipulated and exported as a text file using the companion software package ViewSpec Pro produced by ASD inc.

FTIR spectrometer. The Bio-Rad FTS 40 spectrometer collected all of the mid-infrared data used in the study (Figure 16). The instrument is housed in a climate controlled environment in the Chemistry Department at the University of Memphis. The device, including all of its components, weighs approximately 180 lbs. The FTIR

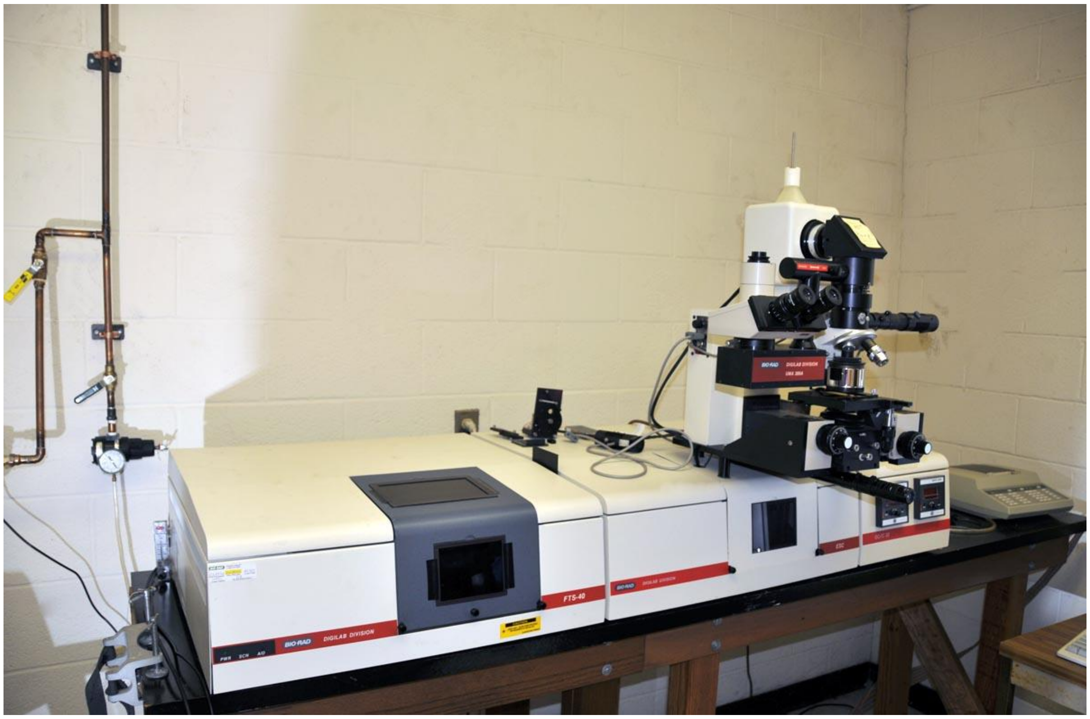

Figure 16. Bio-Rad FTS 40 middle-infrared spectrometer.

spectrometer is attached to an external water source and a gas purging system to prevent overheating and to protect the optical components. The device is also attached to a desktop computer upon which the Win-IR operating software is loaded for data collection and data processing.

Prior to analysis the instrument was turned on and allowed to warm-up for approximately 30 minutes. Next liquid nitrogen (approximately 24 oz) was poured into the MCT detector dewar. The dewar is refilled with liquid nitrogen every 3 hours. An additional 15 minutes was allowed to cool down the detector before the system electronics were calibrated. The mirror inside the microscope was manually adjusted to optimize the signal. Calibration was performed by focusing the IR beam onto a gold standard and selecting the calibration function in the Win-IR software. The spectrometer gain range amplification system was calibrated. Next a background measurement was recorded upon the gold standard. The background measurement provides a relative scale for absorption intensity (Thermo Nicolet 2001). The background measurement is later subtracted from the collected spectra essentially canceling out instrumental and atmospheric influences. A background measurement was collected once every analysis session, approximately every 3 hours.

The parameters for spectra collection can be changed to fit the needs of the particular study. Preliminary experimentation determined the settings used as providing optimal signal to noise ratios and analysis speed. The number of continuous scans was set at 64 meaning that the resulting spectrum is a product of 64 analyses. The spectral resolution was set at 4 cm^{-1}. At higher resolution noise is introduced into the spectrum and at lower resolution small absorption features are not resolved. Artifact samples were initially analyzed at 2 cm^{-1}, however the presence of noise necessitated the interpolation of the original spectra to the 4 cm^{-1} spectral resolution. Once the instrument parameters were set, the analysis of chert samples began.

Each sample was given a base name reflecting its provenience within a deposit. Samples were consecutively numbered 1 through 30 during collection in the field. The sample number was maintained during analysis as future studies might focus on intra-deposit variation requiring sample point provenience spatial data. The three spectra recorded per sample were in turn labeled a, b and c. Each recorded mid-infrared spectrum was automatically saved in SPC file format. The SPC format can be opened by the WinIR software and exported as text files.

Heat Treatment Study

The 30 chert samples were first allowed to air dry for one week to drive off any surficial moisture. The FTIR spectrometer was used to analyze the middle-infrared reflectance spectra of each of the 30 chert samples prior to heat treating. The location that was analyzed on each specimen was marked in order to provide a consistent sampling location. Additionally, multiple spectral readings were recorded on one chert sample from each type. This was done in an attempt to account for intra-sample variation. Next, a series of staged heating trials prepared the samples for further analysis. One sample of each of the six chert types was left unaltered while the remaining second, third, fourth, and fifth samples were subjected to four heating trials ranging from 100 to 400°C at 100° increments. The heating trials each consisted of placing a single sample of Dover, Fort Payne, Mill Creek, Flint Ridge, Horse Creek and Camden chert inside a sand bath within a metal tray. The samples were insulated by 2-3 cm of sand throughout the duration of heating to prevent thermal shock. A thermocouple sensor was placed inside the sand bath to measure the internal temperature during each heating trial.

The metal tray and sand bath containing one sample of each chert type was placed inside an IsoTemp Muffle Furnace. The furnace was set to the desired maximum temperature and then the samples gradually increased in temperature at a slower rate than the ambient internal temperature of the furnace. The insulating effect of the sand bath resulted in the samples being heated at a rate between 1° to 2° per minute. The time it took to achieve the desired sample temperature varied from one to eight hours. The chert samples were left for one hour at the designated temperature before they were allowed to gradually cool to 100°C. Once cooled the samples were removed from the furnace and placed into a dessicator. These steps were followed for the four groups of six samples, one group at each of the desired maximum temperatures of 100, 200, 300 and 400°C. The procedure produced a total of 24 heat treated chert samples each heated to one of the four temperature stages and an additional six unaltered control samples. All heated samples were stored in a dessicator to inhibit rehydration. It is important to note that only the Dover sample heated at 400°C showed signs of thermal shock as it was reduced to fragments of various sizes. The characteristic red coloration typically used as an indication of heat treatment by analysts was noted on the Camden, Fort Payne and Mill Creek samples heated to 400°C.

Patina Studies

Cross section study (VNIR). Each of the ten chert samples obtained from an in situ deposit at the Cross Creek Quarry site (Figure 14) was analyzed with the VNIR reflectance spectroscopy technique. The relatively large diameter of the spot analyzed on a sample's surface precluded micro-profiling of the sample's cross section. Therefore, two measurements were recorded per sample. The first measurement recorded the VNIR spectrum upon the outer weathered surface. The second measurement was taken upon the sample's less weathered interior surface. The two spectral measurements were compared visually in order to note any differences between the spectra obtained from the sample. This procedure was repeated for all 10 of the samples.

Cross section study (FTIR). The 10 weathered chert samples were positioned under the FTIR microscope objective lens with the conchoidal interior surface oriented up. A series of spectral measurements were taken upon each sample from the outer edge inward. The area of the specimen analyzed during a single reading by the detector is approximately 0.02 -0.2 mm in diameter facilitating precise measurements from the edge of the sample into the interior. Spectra were obtained upon each of the ten samples at 0.1 mm, 1.0 mm, 2.0 mm, 3.0 mm, and for some specimens at greater depths from the outer edge depending on the degree of weathering. A cluster of three spectral measurements were taken at each of the locations to include potential intra-sample variation. The resulting dataset provided spectral information representative of the sample's cross section. The goal of these procedures was to obtain spectral data from the patinated outer surface to the relatively unweathered inner core. The results of the small scale study are presented in the following chapter.

Analysis of the patina subset sample. In another test 105 randomly selected patina samples from the chert sample database were analyzed with both the VNIR and FTIR reflectance spectroscopy techniques. All analysis in this test was performed on the unaltered patina surface. Three spectra were recorded per sample and later averaged. The corresponding spectra recorded from the interior surface of the 105 samples were removed from the original 1,050 sample database to eliminate bias. The patina subset samples were treated as specimens of unknown geologic and geographic provenience. The unknown samples were then analytically characterized within the remaining 945 sample chert database by geologic formation and by specific deposit. The provenance accuracy was studied to quantify the effect that analysis on a weathered surface has on source assignment. Additionally, the results stimulated the design of a series of small experiments to compare the degree of weathering observed upon the Mississippian sword-form artifacts.

Spectral Data Processing

The spectral reflectance data recorded from the geologic chert and artifact samples were exported as text files and compiled into spreadsheets. One spreadsheet contained the VNIR chert spectral database and another contained the FTIR chert sample spectra. A third spreadsheet contained all spectral data recorded on the sword artifacts. The spreadsheet data were transposed so that each row contained the reflectance values of a sample and columns matched wavelength positions. In this way, an individual cell contains a reflectance value recorded at a specific wavelength for a particular sample. The formatting of the spreadsheets in this manner allowed for direct upload into other software packages used in the study for more sophisticated manipulation.

Three software packages were used to process the spectral data. The first is the GRAMS manufactured by Thermo Scientific. GRAMS is a multifunctional software package designed specifically for handling spectral data. GRAMS was used to background correct each of the middle-infrared spectra, convert from wavenumbers to nanometers and calculate an average spectrum from the multiple spot analyses recorded per sample/artifact. Finally, the spectra were exported as text files. The visible and near-infrared spectra needed no post hoc background correction or unit conversion and were exported as text files by the ViewSpec Pro software. Both the GRAMS and ViewSpec Pro packages have many other processing functions facilitating both analysis and display needs; however, the use of Unscrambler X 10.2 allowed for rapid processing, manipulation and analysis.

Unscrambler X version 10.2 manufactured by CAMO Software Inc. was used to perform additional spectral data handling. First, each file was uploaded into the software package with an onscreen spreadsheet display. Next, both the VNIR and FTIR reflectance data were transformed into absorption spectra by application of a spectroscopic transform function. The resulting spectra represent the absorbed incident radiation at specific wavelengths. A normalization function was then used to standardize differences in absorption peak heights. Normalization is performed by dividing all absorbance peaks by the intensity value of the largest feature, a value between 0 and 1. Therefore, if the intensity of the largest absorbance feature is .7 then all other features are divided by .7. Normalization minimizes spectral differences inherent between measurements obtained under slightly different conditions (e.g. viewing geometry) (Smith 1996:77).

Finally, the first derivative for each spectrum was calculated using the GAP algorithm with a moving kernel value of 1. Selection of a GAP value of one is a compromise between noise and spectral resolution. The use of a derivative algorithm on spectral data is an established technique in spectral analysis (Kemper and Luchetta 2003; Smith 1996). A derivative is a plot of the slope of a function versus its X axis values (Smith 1996:184). The GAP algorithm with a value of 1 calculates the slope difference between every other reflectance value. A derivative algorithm is useful in spectral analysis as it removes any multiplicative effects while highlighting absorbance features (Kemper and Luchetta 2003).

In a first derivative transformed spectrum the point at which the spectrum crosses the X axis at zero reflectance directly corresponds to the wavelength of peak absorbance in the original spectrum. Derivative transforms are used to aid peak matching of unknown spectra within a spectral library. A derivative transform is useful in the current study as it highlights subtle slope changes due to electronic and molecular influences within a particular chert type at a particular geographic location. Slope changes are important as the major absorption features of chert are relatively homogenous. The first derivative transform also highlights smaller features with the elimination of noise using the derivative GAP value.

Spectra collected from artifacts were processed in the same manner as the spectra collected upon the chert reference samples. Transform upon the reflectance values produced absorption spectra and normalization standardized the absorption features between measurements. Additionally, a Gaussian Filter smoothing algorithm with kernel size 7 was applied to the visible and near-infrared portions of the artifact spectra in order to minimize surficial weathering affects. The use of a smoothing filter was chosen due to the need for non-destructive analysis on the weathered outer surface of the curated specimens. The analytical methodology was based upon the results of the independent weathering studies which are discussed in detail in the next chapter.

Each pre-treated spectrum was then exported as a text file for statistical analysis. The visible and near-infrared data were stored as a single text file while the middle-infrared data were stored as a separate text file. A third file contained all of the spectra collected from the Mississippian swords. The creation of three separate files allowed for independent analysis on the data collected by the VNIR and FTIR techniques. Later the datasets were combined providing a complete assessment of the complimentary reflectance spectroscopy techniques.

Statistical Analysis

All statistical analysis of the spectra was performed using the Statistical Package for the Social Sciences (SPSS) manufactured by IBM. Both the VNIR and FTIR chert spectral database spreadsheets were individually uploaded into SPSS. The X-axis wavelength positions were coded as individual integer variables and positioned as column headings. Chert sample names were positioned as the row headings. Individual cells contained the first derivative transformed reflectance values at corresponding wavelength position. A grouping variable was created in the first column in order to designate sample classes. The grouping variable was an integer ranging in value from 1 to 2. The grouping variable designated chert samples coming from either the Lower St. Louis “Dover” (1) or Fort Payne (2) formations. In a later analysis the grouping values were changed to 1 through 35 representing groups of 30 samples from each of the 35 sample locations.

A canonical discriminant analysis was conducted on portions of the VNIR and FTIR spectral datasets. The determination of which portions of the dataset to analyze was controlled by a priori explorative data analysis and software limitations. Preliminary examination of spectra identified portions of noise. Usually, areas dominated by noise are located at the shortest wavelength ends of both the VNIR and FTIR datasets. Also, the longest wavelength end of the spectral datasets contained higher noise due to low detector sensitivity. Therefore, the 350-399 nm and 2,495-2,500 nm sections were excluded from analysis in the visible and near-infrared dataset. The noise dominated region of 2,500-2,577 nm and 14,399-25,000 nm was not analyzed in the middle-infrared dataset. The potentially diagnostic regions in the VNIR data include most of the visible and a portion of the near-infrared sections. Exploratory data analysis and previous research by Hassler (2011) and Hassler et al. (2013) identified the 2,600 to 7,500 nm region of the middle-infrared spectral data as containing potentially diagnostic information. Specific diagnostic wavelength positions are reported in Parish et al. (2013). The middle-infrared range includes numerous smaller features located at shorter wavelength positions before the spectra are dominated by the large quartz reststrahlen band fundamentals. Most of the diagnostic variables used in the study were selected from the 2,600 to 7,500 nm region; however, additional portions of the middle-infrared signal were also included.

Accuracy assessment tests. In order to assess the accuracy of the reflectance spectroscopy techniques, a series of tests were conducted at different levels. The initial test assigned a grouping value of 1 to all samples obtained from the Lower St. Louis formation and a value of 2 to all samples derived from the Fort Payne formation. Stepwise discriminant analysis was performed first on the VNIR dataset then separately on the FTIR dataset. One of the optional outputs of the discriminant analysis model is predicted group membership. The predicted membership output is used to assess the accuracy of group assignment. The accuracy of the predicative model was noted for both techniques prior to continued analysis. Next, a 10% random sample within the chert database was selected. The 10% subset sample is treated as a test sample of unknown provenience by deleting the group identifier value. The discriminant analysis model was re-run and the resulting group assignment of the test sample recorded. The grouping value was restored to the initial test sample and a 20% random sample was selected as a second test case. Group assignments were recorded and a final 30% random sample was used to create a third test group. The accuracy tests provide a means to quantify the internal accuracy of the discriminant model in differentiating Dover from Fort Payne chert.

A second series of tests were conducted to assess the accuracy of the reflectance spectroscopy methods and canonical discriminant analysis in differentiating chert by individual deposits. The grouping variable range of values was increased to 35. Each sample was labeled with a value ranging from 1 to 35 depending on its deposit provenience. Therefore, the grouping variable effectively organized the chert database into 35 groups each group consisting of 30 samples. A stepwise discriminant analysis model was run which created multi-dimensional functions to separate all 35 group classes. The accuracy of the model was recorded, based upon the predicted group membership output. Finally, a series of randomly selected samples were assigned an unknown group provenience. The 10%, 20% and 30% subset groups from the previous tests were used again to assess the accuracy of provenance assignment at the intra-formation scale.

Both the inter- and intra-formation accuracy tests at the 10%, 20% and 30% iterations were conducted on the combined visible, near-infrared and middle-infrared datasets. The accuracy of the expanded spectral dataset method in differentiating variation between the Lower St. Louis and Fort Payne formations and between outcrops within the Lower St. Louis and Fort Payne were recorded. Additional patterns, differences and observations between the previous accuracy tests were noted.

The accuracy tests at the formation and intra-formation level were conducted prior to inclusion of the Mississippian sword data. It is important to quantify the reliability of the provenance technique(s) and analytical method(s) before inclusion of artifacts with unknown provenance. By conducting internal tests within the chert database of known provenance, the accuracy of source assignment at different levels is assessed. Conducting internal tests also helps the construction of appropriate anthropological questions. These anthropological questions are tailored to the ability of the source technique to quantify and differentiate variation at various spatial scales.

Artifact provenance determinations. The final step in analysis was the determination of chert source for the Mississippian sword-form bifaces analyzed. The spectra from all 30 of the swords was copied and pasted into the VNIR dataset, the FTIR dataset and the combined VNIR/FTIR dataset. No grouping values were assigned to the sword specimens. The artifact spectra with missing group value numbers are treated by the discriminant model as having unknown provenance. Predicted group assignment was calculated based on the Mahalanobis distance calculation to the nearest chert sample group centroid.

The first discriminant analysis model explored the fundamental provenance question as to whether the material used in Mississippian sword-form biface manufacture is from Lower St. Louis “Dover” chert or Fort Payne. The group assignment variable was limited to a 1 or 2. Discriminant analysis calculated the predicted group assignment for the swords and displayed these in terms of group assignment probabilities. Based upon the results of the formation provenance, the determination of source at the deposit scale was calculated by rerunning the discriminant model with only those swords and samples which were assigned to the same formation. In this manner Dover chert swords were compared with the six Dover chert sample groups and the swords assigned to the

Fort Payne formation were compared with the 29 Fort Payne chert sample groups. The results of both discriminant analyses were recorded.

Summary. It is necessary to record the steps taken in analysis of a large chert sample database and the assignment of provenance to archaeological materials. The analysis process of 1,050 chert samples and a sample of 30 artifacts with the VNIR and FTIR reflectance spectroscopy techniques encountered variables potentially influencing the end provenance results. The variables identified in the study include intra-sample variation, anthropogenic heat treatment and patina formation within the natural weathering environment. The variables influence the analysis of samples and artifacts. The variables also prompted the design of smaller pilot studies to investigate the effects of each upon the provenance assignment. Additionally, canonical discriminant analysis was selected for a multi-variant classification technique.

The accuracy of the reflectance spectroscopy data were assessed according to technique and the scale of provenance determination. The results of the heat treatment and patina studies were examined in order to study the effect upon accurate provenance determination. The results of the accuracy assessment tests inform the application of reflectance spectroscopy within chert sourcing studies. Finally, the provenance of the Mississippian sword-form bifaces gives researchers insight into resource selection decisions.

CHAPTER 8

RESULTS

The results of the study are organized into three main components. The focus of the first two components is defining the accuracy of the VNIR and FTIR reflectance spectroscopy techniques and the statistical methods used to characterize and differentiate variation within the chert sample database. The third component presents the provenance results of the Mississippian chert sword-form bifaces. Organization of the results in this mode is necessary as the application of reflectance spectroscopy to chert provenance studies is in its developmental phase. Testing the application of VNIR and FTIR reflectance spectroscopy to sourcing chert is one of the primary objectives of the study. Once the accuracy of the techniques and statistical methods are defined, the provenance of the chert swords is best presented.

The results of the inter- and intra-formation accuracy tests at 10%, 20% and 30% iterations are listed by technique. All wavelength variables selected by the discriminant function models are reported in the Appendix. The heat-treatment and patina studies direct the treatment of the sword spectral data. Therefore, the results of the heat-treatment and patina studies are reported prior to the provenance data for the swords. The format of the results are spreadsheets based upon SPSS output reporting classification assignments and group probability percentages for each of the 1,050 samples and 30 artifacts analyzed. Sample group classification and chert sword provenance data are reported in tables.

Due to the volume of data generated, only the wavelength variables selected by the discriminant function analysis models are reported in the Appendix. All spreadsheets generated in the study may be downloaded in their entirety from the Digital Archaeology Record (tDAR) website (http://core.tdar.org) with the project name: *The application of reflectance spectroscopy to chert provenance of Mississippian symbolic weaponry*. Results are also illustrated in the form of discriminant function bi-plots. However, the two-dimensional bi-plots are inadequate representations of sample cluster groups whose classification is based upon one to 35 calculated functions. Despite the graphical limitations, the bi-plots display spatial relationships between sample groups.

Inter-formation Accuracy Test

The inter-formation accuracy test examined the ability of the reflectance spectroscopy technique in differentiating Dover chert occurring within the Lower St. Louis limestone formation in Fort Payne chert from the Fort Payne limestone formation. Therefore, all samples were initially assigned a grouping variable of 1 for Dover or a 2 for Fort Payne. A total of 180 Dover samples comprised group 1 whereas the remaining 870 samples were classified as Fort Payne in group 2. A stepwise canonical discriminant function analysis evaluates each wavelength variable and enters or removes it from the model depending on its probability of F value. An entry value of 0.5 and a removal value of 1.0 are used to independently assess the significance level of each variable's F value. Only the most discriminatory variables (reflectances/wavelengths) falling between the entry and removal value are used to construct the model. Additionally, the groups were weighted to account for differences in group size.

The analysis of the VNIR spectral data in the wavelength region 400 – 2,494 nm correctly classified 1,045 (99.5%) of the samples into their prospective formation (Table

Table 3. VNIR inter-formation accuracy assessment experiments: base model, 10% unk., 20% unk. and 30% unk. Correct classifications reported by group.

Sample Group	**N**	**Base Model**	**n**	**10%**	**n**	**20%**	**n**	**30%**
		correct		*correct*		*correct*		*correc*
Brigham Site, TN	30	30	3	3	8	8	9	9
Cross Creek Site, TN	30	29	2	2	9	8	11	9
Thompson Hollow Site, TN	30	30	3	3	5	5	7	6
Commissary Ridge Site, TN	30	30	2	2	5	5	10	8
40Ho51	30	30	3	3	5	5	8	8
40Ho54	30	30	2	2	6	6	8	7
40Ho55	30	30	4	4	7	7	7	7
40Ho57	30	30	3	3	9	9	10	10
40Hs327	30	30	3	3	5	5	8	8
40Hy136	30	30	5	5	9	9	12	12
Al 1	30	30	3	3	8	8	3	3
St. Florentine, AL	30	30	2	2	2	2	13	13
Elco, IL D.1	30	30	4	4	5	5	10	10
Elco, IL D.2	30	30	3	3	4	4	10	10
Elco, IL D.8	30	30	2	2	4	4	11	11
Lake Barkley1, KY	30	30	3	3	4	4	8	7
Lake Barkley 2, KY	30	27	2	1	4	3	10	8
Dry Branch, KY	30	30	2	2	7	7	9	9
McCormick Creek, KY	30	30	7	7	4	4	13	13
Pickwick, MS P.1	30	30	1	1	5	4	5	4
Pickwick, MS P.3	30	30	3	3	5	5	9	9
Cumberland City, TN	30	30	4	4	3	3	10	9
Link Farm, TN	30	30	2	2	7	7	11	11
Wells Creek, TN	30	30	-	-	8	8	10	9
Erin, TN	30	30	4	4	5	5	7	6
Humphreys Co., TN	30	30	4	4	5	5	6	6
Bucksnort, TN	30	30	3	3	9	9	9	9
Beaver Dam Creek, TN	30	30	4	4	6	6	8	8
Beaver Dam Creek 2, TN	30	30	2	2	7	7	7	7
Lobelsville, TN	30	30	4	4	4	4	9	9
Crazy Horse Canoe, TN	30	30	3	3	9	9	7	6
Waynesboro, TN	30	30	3	3	4	4	9	8
Natural Bridge, TN	30	30	5	5	7	6	11	10
Berry College, GA	30	29	-	-	8	8	11	11
GA 4, GA	30	30	5	5	8	8	9	9
Total	1,050	1,045 (99.5%)	105	104 (99%)	210	206 (98%)	315	300 (95%)

3). The stepwise discriminant function model retained 105 wavelength variables in the construction of the base model (Appendix). Next, the model was rerun treating a 10% (n=105) random sample as unknown by deletion of their grouping variable. A total of 104 (99%) samples were correctly classified by parent geologic formation. The discriminant function model selected 83 variables (Appendix). A second random 20% (n=210) sample resulted in 206 (98%) correct classifications. The stepwise discriminant model selected 65 variables to construct the classification functions (Appendix). Finally, a 30% (n=315) random sample resulted in 300 (95%) correctly assigned to their respective formation. The discriminant model utilized 57 wavelength variables to construct group classifications (Appendix). In summary, the discriminant function model rerun four times resulted in a classification accuracy ranging from 95% to 99.5%.

The middle-infrared spectra collected with the FTIR spectrometer produced comparable results. The wavelength region of 2,578 - 14,398 nm was used to compute all discriminant functions. The initial base model correctly classified 1,011 (96%) of the samples with known formational provenance (Table 4). A total of 38 wavelength variables were selected by the base model (Appendix). The treatment of 105 (10%) of the samples as having unknown provenance resulted in 98 (93%) correctly classified. Thirty-seven variables were used to construct the classification groupings (Appendix). Next, the 20% test demonstrated that the discriminant model identified 202 (96%) ungrouped samples to their correct formations. The discriminant function model selected 33 variables for inclusion (Appendix). The discriminant function model on the 30% unknown test used 34 wavelengths to build the discriminant functions (Appendix). The 30% unknown model correctly classified 282 out of 315 (90%) randomly selected

Table 4. FTIR inter-formation accuracy assessment experiments: base model, 10% unk., 20% unk. and 30% unk. Correct classifications reported by group.

Sample Group	**N**	**Base Model**	**n**	**10%**	**n**	**20%**	**n**	**30%**
		correct		*correct*		*correct*		*correct*
Brigham Site, TN	30	24	3	3	8	7	9	8
Cross Creek Site, TN	30	28	2	1	9	9	11	10
Thompson Hollow Site, TN	30	26	3	3	5	5	7	6
Commissary Ridge Site, TN	30	29	2	2	5	5	10	9
40Ho51	30	28	3	2	5	5	8	8
40Ho54	30	29	2	2	6	6	8	6
40Ho55	30	30	4	4	7	7	7	7
40Ho57	30	30	3	3	9	9	10	10
40Hs327	30	30	3	3	5	5	8	8
40Hy136	30	30	5	5	9	9	12	12
Al 1	30	30	3	3	8	8	3	3
St. Florentine, AL	30	30	2	2	2	2	13	12
Elco, IL D.1	30	29	4	2	5	5	10	9
Elco, IL D.2	30	30	3	3	4	3	10	9
Elco, IL D.8	30	27	2	2	4	3	11	8
Lake Barkley1, KY	30	29	3	3	4	3	8	6
Lake Barkley 2, KY	30	14	2	1	4	1	10	5
Dry Branch, KY	30	30	2	2	7	7	9	9
McCormick Creek, KY	30	29	7	5	4	4	13	12
Pickwick, MS P.1	30	30	1	1	5	5	5	5
Pickwick, MS P.3	30	30	3	3	5	5	9	8
Cumberland City, TN	30	30	4	4	3	3	10	10
Link Farm, TN	30	30	2	2	7	7	11	11
Wells Creek, TN	30	29	-	-	8	7	10	8
Erin, TN	30	28	4	4	5	5	7	7
Humphreys Co., TN	30	30	4	4	5	5	6	6
Bucksnort, TN	30	29	3	3	9	9	9	9
Beaver Dam Creek, TN	30	30	4	4	6	6	8	8
Beaver Dam Creek 2, TN	30	30	2	2	7	7	7	7
Lobelsville, TN	30	30	4	4	4	4	9	9
Crazy Horse Canoe, TN	30	30	3	3	9	9	7	7
Waynesboro, TN	30	30	3	3	4	4	9	8
Natural Bridge, TN	30	30	5	5	7	7	11	11
Berry College, GA	30	30	-	-	8	8	11	11
GA 4, GA	30	30	5	5	8	8	9	9
Total	1,050	1,011 (96%)	105	98 (93%)	210	202 (96%)	315	282 (90%)

samples by formation. The discriminant function model applied to the FTIR spectral database resulted in an inter-formation accuracy between 90% and 96%.

Intra-formation Accuracy Test

The intra-formation accuracy test examined the ability of the two reflectance spectroscopy techniques and discriminant function analysis in differentiating variation at each of the 35 sample locations within both the Lower St. Louis and Fort Payne limestone formations. Therefore, each sample was assigned a grouping value of 1 to 35. Each group initially contained 30 samples. The organization of the results in Tables 5 and 6 mirror that of the inter-formation accuracy test in the previous section.

The results of the VNIR spectral data were presented first. All discriminant function models are constructed from 215 wavelength variables from the 400 – 2,494 nm interval. The discriminant function base model correctly identified 1,049 (99.9%) samples by their sampled location (Table 5). The discriminant function retained 198 variables in the analysis (Appendix). A random 10% sample was treated as having unknown deposit provenance. The discriminant model calculated functions based upon the input of 194 variables (Appendix). The resulting model correctly identified 97 (92%) by group within the 10% random sample. For the 20% samples treated as having unknown intra-formation provenance the model correctly assigned 199 (95%) to their deposits. The discriminant function retained 187 variables in the analysis (Appendix). Lastly, the model result using 30% as unknowns was 290 (92%) sourced to their procurement deposit. The discriminant model used 183 variables in the analysis (Appendix). Samples were correctly assigned to their deposit locations between 92% and 99.9% of the time.

Table 5. VNIR intra-formation accuracy assessment experiments: base model, 10% unk., 20% unk. and 30% unk. Correct classifications reported by group.

Sample Group	**N**	**Base Model**	**n**	**10%**	**n**	**20%**	**n**	**30%**
		correct		*correct*		*correct*		*correct*
Brigham Site, TN	30	30	3	3	8	8	9	9
Cross Creek Site, TN	30	30	2	1	9	8	11	9
Thompson Hollow Site, TN	30	30	3	3	5	5	7	7
Commissary Ridge Site, TN	30	30	2	2	5	4	10	5
40Ho51	30	30	3	3	5	4	8	8
40Ho54	30	30	2	2	6	5	8	7
40Ho55	30	30	4	4	7	7	7	7
40Ho57	30	30	3	3	9	9	10	10
40Hs327	30	30	3	2	5	5	8	7
40Hy136	30	29	5	5	9	9	12	11
Al 1	30	30	3	2	8	8	3	3
St. Florentine, AL	30	30	2	2	2	2	13	9
Elco, IL D.1	30	30	3	3	5	5	10	8
Elco, IL D.2	30	30	3	2	4	4	10	9
Elco, IL D.8	30	30	2	1	4	4	11	9
Lake Barkley1, KY	30	30	3	3	4	4	8	8
Lake Barkley 2, KY	30	30	2	2	4	4	10	10
Dry Branch, KY	30	30	2	1	7	6	9	9
McCormick Creek, KY	30	30	7	7	4	4	13	13
Pickwick, MS P.1	30	30	1	1	5	5	5	5
Pickwick, MS P.3	30	30	3	3	5	4	9	8
Cumberland City, TN	30	30	4	4	3	3	10	10
Link Farm, TN	30	30	2	2	7	7	11	11
Wells Creek, TN	30	30	-	-	8	6	10	8
Erin, TN	30	30	4	4	5	5	7	6
Humphreys Co., TN	30	30	4	4	5	5	6	6
Bucksnort, TN	30	30	3	3	9	9	9	9
Beaver Dam Creek, TN	30	30	4	4	6	5	8	8
Beaver Dam Creek 2, TN	30	30	2	2	7	7	7	7
Lobelsville, TN	30	30	4	4	4	4	9	9
Crazy Horse Canoe, TN	30	30	3	3	9	8	7	6
Waynesboro, TN	30	30	3	3	4	4	9	9
Natural Bridge, TN	30	30	5	4	7	6	11	11
Berry College, GA	30	30	-	-	8	8	11	11
GA 4, GA	30	30	5	4	8	8	9	8
Total (n)	1,050	1,049 (99.9%)	105	97 (92%)	210	199 (95%)	315	290 (92%)

Intra-formation accuracy tests performed upon the FTIR middle-infrared data also report high degrees of accuracy (Table 6). The initial base model resulted in 991 (94%) correct group assignments. The discriminant function model selected 82 discriminant variables (Appendix). Accuracy was 85% (n=89) with the random 10% unknown sample test. A total of 74 wavelength variables were used to compute the discriminant functions (Appendix). The results of the discriminant model rerun upon the random 20% samples was 180 (86%) correct group classification using 69 variables (Appendix). The last discriminant model, examining the entire database with 315 (30%) selected samples as unknown intra-formation provenance, resulted in 253 (80%) correctly assigned provenance. Eighty-three variables were selected by the discriminant function model to compute group assignments (Appendix). Samples were correctly assigned to their deposit locations between 80% and 94% of the time. The results of the accuracy tests at the inter- and intra-formation levels illustrate important findings and observed trends both of which are discussed in the next chapter.

Mississippian Sword Provenance

Heat treatment results: VNIR. The visible/near-infrared spectra obtained on the six heat treated chert sample types produced spectra that upon initial visual comparison are similar. The spectrum is dominated by three vibrational absorption features centered at 1,400, 1,900 and 2,400 nm (Figure 12). The features are caused by hydroxyl (OH) bonding in water molecules. The presence of both surface and inter-granular water produces the distinctive hydroxyl absorption features. Two main patterns are observed when comparing unheated samples to those heated at 400˚C. The first pattern is that a decrease in overall reflectance intensity at 1,400, 1,900 and 2,400 nm is indicative of both

Table 6. FTIR intra-formation accuracy assessment experiments: base model, 10% unk., 20% unk. and 30% unk. Correct classifications reported by group.

Sample Group	**n**	**Base Model**	**n**	**10%**	**n**	**20%**	**n**	**30%**
		correct		*correct*		*correct*		*correct*
Brigham Site, TN	30	27	3	3	8	6	9	4
Cross Creek Site, TN	30	23	2	1	9	8	11	7
Thompson Hollow Site, TN	30	28	3	3	5	5	7	6
Commissary Ridge Site, TN	30	30	2	2	5	5	10	7
40Ho51	30	28	3	3	5	5	8	7
40Ho54	30	30	2	2	6	6	8	7
40Ho55	30	30	4	4	7	6	7	6
40Ho57	30	30	3	2	9	6	10	8
40Hs327	30	30	3	3	5	3	8	6
40Hy136	30	29	5	5	9	9	12	7
Al 1	30	26	3	3	8	8	3	2
St. Florentine, AL	30	28	2	0	2	1	13	10
Elco, IL D.1	30	28	3	3	5	3	10	7
Elco, IL D.2	30	30	3	1	4	4	10	10
Elco, IL D.8	30	28	2	1	4	3	11	8
Lake Barkley1, KY	30	30	3	3	4	4	8	7
Lake Barkley 2, KY	30	30	2	2	4	4	10	8
Dry Branch, KY	30	30	2	2	7	6	9	8
McCormick Creek, KY	30	29	7	5	4	4	13	9
Pickwick, MS P.1	30	28	1	1	5	5	5	5
Pickwick, MS P.3	30	27	3	3	5	3	9	7
Cumberland City, TN	30	30	4	4	3	2	10	8
Link Farm, TN	30	30	2	2	7	6	11	11
Wells Creek, TN	30	24	-	-	8	5	10	7
Erin, TN	30	30	4	4	5	5	7	7
Humphreys Co., TN	30	28	4	3	5	4	6	5
Bucksnort, TN	30	24	3	2	9	5	9	5
Beaver Dam Creek, TN	30	29	4	4	6	6	8	8
Beaver Dam Creek 2, TN	30	30	2	2	7	6	7	7
Lobelsville, TN	30	30	4	3	4	4	9	7
Crazy Horse Canoe, TN	30	24	3	2	9	6	7	6
Waynesboro, TN	30	28	3	3	4	4	9	7
Natural Bridge, TN	30	25	5	3	7	6	11	9
Berry College, GA	30	30	-	-	8	8	11	11
GA 4, GA	30	30	5	4	8	8	9	9
Total (n)	1,050	991 (94%)	105	89 (85%)	210	180 (86%)	315	253 (80%)

surface and inter-granular water loss with prolonged heating. The observation is further supported by a decrease in sample weight in excess of 1 wt%. Water loss is observed in all six chert types.

The second observation is the presence of a broad absorption peak between 630 and 730 nm for some samples heated at 300˚C and 400˚C. Specifically, the Camden, Fort Payne and Mill Creek samples exhibited the addition of the spectral feature upon heating the sample at higher temperatures. The 650-750 nm segment of the electromagnetic spectrum is the red region of the visible spectrum. The samples of Camden, Fort Payne and Mill Creek heated to higher temperatures exhibit an observable reddening discoloration. A red discoloration is likely caused by the oxidation of iron mineral inclusions. The presence of the absorption peak is not observed in the Dover, Flint Ridge or Horse Creek samples.

Heat treatment results: FTIR. The middle-infrared spectra of the Camden, Dover, Flint Ridge, Fort Payne and Horse Creek chert samples are dominated by two absorption features that are characteristic of quartz. These two features are the Si-O-Si asymmetric stretch fundamental centered between 8,000-9,500 nm and the O-Si-O bending mode occurring between 12,000-13,000 nm. Both are caused by vibrations in the molecular bonding of a silica crystal lattice (Clark 1999:27). No trend with heating in the quartz stretch and bend absorption features is observed in any of the six sample types.

Water bearing minerals have H-O-H bending and OH stretching features at various locations along a sample's spectrum. The first of these features seen in the middle-infrared spectra of chert is located at approximately 2,670-3,450 nm. The OH stretching mode interval, observed as a valley within this bandwidth, contains other spectral features associated with water that may be obscured to some degree by the larger OH stretching mode. At longer wavelengths two H-O-H bending features can be observed at 6,079 nm and 6,270 nm respectively signifying the presence of water. In a similar study, McCutcheon (1997:72) noticed a trend of decreasing reflectance in these portions of the middle-infrared with progressive heating. In the present study, no distinctive pattern of decreasing spectral reflectance at these bandwidths was observed despite the loss of water due to prolonged exposure to heat.

The presence of the mineral calcite is detected in the Dover chert samples by diagnostic absorption peaks located approximately at 6,300-7,000 nm and 11,200 nm. The two spectral features diagnostic of calcite are not observed in the other chert samples. No noticeable changes in the spectral features of calcite were observed for untreated versus heat treated Dover specimens. Small differences in peak intensity and shape are attributed to noise as opposed to significant changes due to the heating process.

In addition to calcite, a second mineral is observed in the spectral reflectance data of the chert samples. The presence of hematite is indicated by an absorption peak centered between 15,000 and 15,330 nm. Hematite is observed in five of the six chert types analyzed. Camden chert is the only sample group where the diagnostic hematite feature is not seen. Additionally, the Flint Ridge, Fort Payne and Horse Creek samples show increasing spectral intensity with increasing heating. The spectral feature may indicate the oxidation of other iron minerals into hematite.

Weathering test results: Cross section study. The results of the VNIR study on the 10 samples collected from in situ deposits at the Cross Creek Quarry site show that measurements taken upon the exterior surface exhibit significant spectral alterations when compared to interior readings. The spectral region with the most differences is in the visible portion of the electromagnetic spectrum (350-750 nm). There is a general increase in reflectance intensity in all ten samples. In all but one sample, the introduction of a broad spectral feature between 500-600 nm and a more pronounced feature centered at 690 nm is present on the outer weathered surface in contrast to the corresponding interior measurement. However, the near-infrared portion of the spectra (900-2500 nm) is relatively free of major discrepancies between exterior and interior measurements.

The results of the FTIR cross section experiment are broken down into four main observations: SiO_2 reststrahlen band intensities, spectral feature contrasts, presence/absence of absorption features, and calcite/dolomite feature alteration. The four observations are individually discussed in reference to how each changed depending on the depth to which intra-sample spectral measurements were taken. Additionally, the results are based on the assumption that patina formation is predominately a surficial phenomenon progressing in a non-linear manner into the interior of the chert specimen. A Spearman's correlation (r) coefficient score is reported for each observed trend. The selection of the Spearman's correlation coefficient is used to quantify the non-parametric relationship between the four observations.

The first trend observed in the spectral data relates to the reflectance peak intensities of the alpha quartz reststrahlen bands. These spectral features are located at 7,800-11,000 nm and 12,500-13,000 nm (Figure 12). The reststrahlen bands are the dominant middle-infrared spectral features in chert. Reststrahlen bands occur in silicate minerals due to "mirror-like" reflection from smooth cleavage surfaces, or in the case of chert, conchoidal fracture (Salisbury 1993:80). The height or intensity of these reflectance peaks is the result of specular reflection with very little to no intra-granular penetration. Data from the experiment showed that in all but two instances the reststrahlen band intensities were the lowest in spectra recorded at or near the weathered surfaces (0.1 mm). The tendency observed for the middle-infrared spectra is that with increased depth (1.0 mm, 2.0 mm, 3.0 mm, and >3.0 mm) the reststrahlen band intensities increased (r=0.94). The trend is possibly a function of decreasing inter-granular scattering from the porous outer surface to the solid interior. The next observation looks at an increase in spectral contrast in another section of the middle-infrared spectrum.

The same inter-granular scattering that likely decreases reststrahlen band intensity with proximity to the weathered surface, increases spectral contrast in the shorter wavelength regions of the middle-infrared signal (2,500-7,000 nm). Throughout the shorter wavelength section of the middle-infrared spectrum, numerous small features are present. Often these are hard to distinguish from background noise, but the spectra obtained from near surface measurements (0.1 mm) are characterized by well-defined absorption bands each one representing a unique molecular vibration. As measurement depth increases (1.0 mm, 2.0 mm and 3.0 mm) differences between the heights of reflectance features and the depths of absorption bands generally decrease (r=0.95). In some chert samples almost all spectral contrast in the 2,500-7,000 nm region vanishes when spectral measurements are taken upon the interior unweathered surfaces.

If patina formation is caused by the addition of some material then potentially its unique spectral signature should display marked differences between measurements taken on the altered surface to those taken at interior depths. This is not the case in the majority (n=7) of the chert samples analyzed. As stated previously the intensities of the spectral features in the shorter wavelength region did decrease with depth but all feature positions remained consistent. Samples W7, W8, and W9 on the other hand displayed the presence of spectral features at the surface not noticed in intra-sample measurements at greater depths. One final observation is the alteration of the reflectance features centered at 6,300-7,200 nm and 11,100-11,500 nm.

The spectral features at 6,300-7,200 nm and 11,100-11,500 nm consist of a series of small absorption peaks. The features are present in all ten samples analyzed and show variation in intensity depending on what depth the intra-sample measurement was taken. The trend observed in the spectral data is that measurements taken at the surface of the specimen had low reflectance intensity at 6,300-7,200 nm and 11,100-11,500 nm but with increased depth of measurement, the features gained reflectance intensity (r=0.94). There are exceptions to this trend but predominantly the pattern of increasing feature intensity with increasing measurement depth is observed in the dataset. The features at this location are interpreted as being related to fundamental vibrations of the carbonate molecule in calcite or dolomite.

Weathering test results: Patina subset sample group provenance. VNIR analysis on the 10 percent (n=105) patina subset sample group produced absorption features that are altered from the corresponding interior surface measurements. The reflectance values in the visible region of the spectrum displayed an increase in intensity as is observed in the cross-section experiment. No major addition or subtraction of features is noted in any of the samples analyzed. However, when the spectra were converted to absorption and transformed into first derivatives, subtle differences became apparent. The spectral differences mainly include intensity differences as spectral features and feature locations remained constant. A few locations displayed the addition or subtraction of features. In order to attempt to alleviate the differences between interior and exterior measurements a Gaussian Filter transform was applied to the patina subset spectra. The smoothing transform consisted of a moving kernel which removed noise in the spectrum by sequentially recalculating the spectrum as a Gaussian function. What the transform does is to minimize intensity differences between the spectra obtained from interior measurements and spectra obtained from the weathered outer surface.

VNIR inter-formation accuracy was first tested with the patina subset sample treated as unknown and the corresponding spectral interior measurements removed from the original dataset. The discriminant function model resulted in 84 (80%) correctly classified (Table 7). Twelve Lower St. Louis chert samples were included in the patina subset sample, of these seven were correctly classified as belonging to the Lower St. Louis sample group. The intra-formation accuracy test resulted in 4 (4%) patina samples correctly identified by their deposit location. The FTIR patina subset sample experiment produced similar results.

The FTIR analysis of the 105 samples in the patina subset confirmed trends initially recorded in the cross-section study. These trends include an overall increase in reflectance values in the 2,500-7,500 nm region, and decrease in quartz reststrahlen band intensity and spectral features indicative of carbonate minerals such as dolomite and/or calcite with proximity to the weathering surface. The 105 patina spectra were not assigned a grouping value and the corresponding interior measurements were removed from the database prior to rerunning the discriminant function model. Inter-formation accuracy was reported as having correctly classified 70 (67%) by parent formation (Table

Table 7. Patina subset sample inter- and intra-formation provenance results. Correct classifications reported.

Weathered Sample	Provenance	n	VNIR Inter-	VNIR Intra-	FTIR Inter-	FTIR Intra-
Brigham Site, TN	St. Louis	-	-	-	-	-
Cross Creek Site, TN	St. Louis	-	-	-	-	-
Thompson Hollow Site, TN	St. Louis	4	3	0	4	0
Commissary Ridge Site, TN	St. Louis	2	1	0	2	0
40Ho51	Fort Payne	4	4	0	2	0
40Ho54	Fort Payne	3	3	0	0	0
40Ho55	Fort Payne	4	4	0	4	0
40Ho57	Fort Payne	3	2	0	2	0
40Hs327	Fort Payne	8	7	0	5	0
40Hy136	Fort Payne	4	4	0	4	0
Al 1	Fort Payne	2	2	0	2	0
St. Florentine, AL	Fort Payne	4	3	1	2	0
Elco, IL D-1	Fort Payne	-	-	-	-	-
Elco, IL D-2	Fort Payne	1	1	0	1	0
Elco, IL D-8	Fort Payne	4	4	0	2	0
Lake Barkley1, KY	St. Louis	4	2	1	0	0
Lake Barkley 2, KY	St. Louis	2	1	0	1	0
Dry Branch, KY	Fort Payne	2	2	0	2	0
McCormick Creek, KY	Fort Payne	2	2	0	2	0
Pickwick 1, MS	Fort Payne	5	3	1	3	3
Pickwick 3, MS	Fort Payne	3	2	1	3	0
Cumberland City, TN	Fort Payne	6	4	0	5	0
Link Farm, TN	Fort Payne	3	2	0	2	0
Wells Creek, TN	Fort Payne	3	2	0	3	0
Erin, TN	Fort Payne	2	2	0	0	0
Humphreys Co., TN	Fort Payne	3	3	0	1	0
Bucksnort, TN	Fort Payne	4	4	0	4	0
Beaver Dam Creek, TN	Fort Payne	4	3	0	2	0
Beaver Dam Creek 2, TN	Fort Payne	1	1	0	1	0
Lobelsville, TN	Fort Payne	1	1	0	1	0
Crazy Horse Canoe, TN	Fort Payne	2	2	0	0	0
Waynesboro, TN	Fort Payne	4	1	0	1	0
Natural Bridge, TN	Fort Payne	4	4	0	0	0
Berry College, GA	Fort Payne	6	5	0	6	0
GA 4, GA	Fort Payne	1	0	0	0	0
Total		105	84 (80%)	4(4%)	70 (67%)	3 (3%)

7). Seven of the twelve Dover samples were correctly identified as coming from the Lower St. Louis formation. A total of 3 (3%) patina samples were assigned to their correct deposit in the intra-formation accuracy test. The patina subset sample results for both techniques prompted an experiment designed to test whether the swords exhibited a similar degree of patina formation as that present on the 105 weathered samples analyzed.

Degree of weathering test. In order to test the degree to which the sword artifacts are weathered, the spectra from the 105 patina samples were assigned to a single group. The spectra gathered from the interior of the same 105 samples were organized into a second group. A discriminant function model was run to differentiate the two groups, weathered vs. un-weathered. The results from the initial base model demonstrated that no samples were miss-classified. Next, spectra from all 30 of the sword samples were run in the discriminant model. The grouping variable for the swords was left as unknown in order to evaluate if the swords spectral measurement is a closer match to the weathered or un-weathered group. The test results for the VNIR dataset showed that 17 of the 30 swords had greater affinity to the un-weathered sample group. The effects of weathering in the visible region of the spectrum were partially mitigated by the use of the Gaussian Filter smoothing pretreatment. The use of the smoothing pretreatment improved the VNIR test results such that 26 of the 30 swords were classified to the un-weathered sample group in the discriminant function model. The test results for the FTIR dataset showed that 29 of the 30 swords are closely related to the un-weathered sample group.

Weathered Quarry artifacts. A final test designed to control for surficial patina development analyzed four artifacts recovered as surface finds at the mouth of Caney Hollow near the Brigham Dover Quarry site. Three of the artifacts are large secondary flakes and the fourth is a hoe preform snapped during manufacture. The interpretation is made that these four artifacts are made from Dover chert specifically that obtained from the nearby Brigham Quarry site. The artifacts are not curated tools and show no signs of use. The observation further supports the hypothesis that they are manufactured from the local Dover chert source.

Both the VNIR and FTIR spectra were collected from the four artifacts. The wavelength regions selected for analysis were consistent with those used throughout the study (400 – 2,494; 2,578 - 14,398 nm). The VNIR artifact spectra were pretreated using a Gaussian Filter smoothing algorithm. The artifacts were treated as having unknown provenance by not assigning them a grouping variable. Three out of the four artifacts were correctly classified to the Lower St. Louis formation using the VNIR technique. All four of the artifacts were correctly assigned to the Lower St. Louis formation with the FTIR technique.

Sword Provenance: Inter-formation. The provenance of the 30 Mississippian swords is presented first by formation then by deposit. The analysis of the VNIR spectra resulted in a total of 9 swords being classified as Lower St. Louis "Dover" chert (Table 8). A total of 81 wavelength variables were selected by the stepwise discriminant function model from the spectral range of (400-2,494 nm) (Appendix). The group probability percentages show that only one of the swords (1514/7Hy5) had less than a 95% group probability percentage. The results of the discriminant function model on the FTIR spectra classified 17 swords as being manufactured from Lower St. Louis "Dover" chert (Table 8). The discriminant model used 42 variables to build the functions (Appendix).

Table 8. Inter-formation provenance results for the Mississippian swords.

Catalogue #	VNIR	FTIR	Combined VNIR/FTIR
Mississippian Sword			
40Su14	Fort Payne	Fort Payne	Dover
6614/16By13	Dover	Dover	Fort Payne
4893/16By13	Dover	Dover	Fort Payne
15/3Sw1	Fort Payne	Dover	Fort Payne
217/30Sw20	Fort Payne	Dover	Fort Payne
129-B56/30Sw20	Fort Payne	Dover	Fort Payne
B213/30Sw20	Fort Payne	Dover	Fort Payne
478/41Sw26	Fort Payne	Fort Payne	Fort Payne
3/68Hs6	Fort Payne	Dover	Fort Payne
3/67Hs6	Fort Payne	Fort Payne	Fort Payne
4/67Hs6	Dover	Dover	Fort Payne
6/67Hs6	Dover	Dover	Fort Payne
7/67Hs6	Fort Payne	Dover	Fort Payne
20/70Hs12	Fort Payne	Fort Payne	Fort Payne
5-1/71Hs12	Dover	Fort Payne	Dover
B-96(2)/40Mr7	Fort Payne	Dover	Dover
660(1)/1Ha3	Dover	Dover	Fort Payne
660(2)/1Ha3	Dover	Dover	Dover
1221(1)/1Hy1	Fort Payne	Fort Payne	Fort Payne
1221(2)/1Hy1	Fort Payne	Fort Payne	Dover
475/7Hy5	Dover	Dover	Dover
1047/7Hy5	Fort Payne	Dover	Fort Payne
1104(1)/7Hy5	Fort Payne	Fort Payne	Dover
1514/7Hy5	Dover	Fort Payne	Fort Payne
1841/7Hy5	Fort Payne	Dover	Fort Payne
2763/7Hy5	Fort Payne	Fort Payne	Fort Payne
3194/7Hy5	Fort Payne	Fort Payne	Fort Payne
3526/7Hy5	Fort Payne	Fort Payne	Fort Payne
3563/7Hy5	Fort Payne	Fort Payne	Fort Payne
467/3Re12	Fort Payne	Dover	Fort Payne

A total of 8 swords had source probability percentages under 95%. The two techniques produced a total of 12 discrepancies in the inter-formational source assignment. Four of the 12 miss-matched specimens had group probabilities below 95%.

VNIR/FTIR combined provenance results. In order to resolve the conflicting source assignments, the visible/near-infrared and middle-infrared (400-14,398 nm) diagnostic wavelength variables were used together to re-classify the 30 Mississippian swords by formation. The combined spectral database displays a high degree of accuracy. The initial discriminant function base model, where all samples are assigned either to the Lower St. Louis or Fort Payne formations, produced a total of 1,047 (99.7%) correctly identified samples. Randomly selecting a 10% sample and treating these as unknown resulted in a classification of 99% accuracy. The results are the same for the 20% unknown sample test. Finally, seven misidentified samples are present for the 30% unknown test for an accuracy of 99%.

The 30 swords were placed within the combined spectral chert database and the resulting discriminant function model selected 96 variables for group classification (Appendix). A total of seven swords were classified as being manufactured from Lower St. Louis "Dover" chert (Table 8). All resulting classifications were between 99 and 100% probability for group measurement. All three inter-formation provenance assignments are presented in Table 8. The combined VNIR and FTIR dataset produces the most accurate results for the 1,050 samples of known origin. All references to Mississippian sword-form bifaces provenance in ensuing discussions refer to the results of the combined spectral dataset.

Sword Provenance: Intra-formation. The sample of Mississippian sword-form bifaces is organized into two groups. The Dover group contains the seven swords typed as material originating from the Lower St. Louis formation. The Fort Payne group consists of the 23 swords spectrally sourced to deposits within or associated with the Fort Payne formation. The seven swords classified as Dover chert from the Lower St. Louis limestone formation were evaluated within the combined spectral database in order to determine intra-formation provenance assignment. The intra-formation spectral database consists of 180 Dover chert samples taken from six deposits (Table 1). Therefore, all 180 samples were assigned a grouping value of 1 to 6. The seven swords were included in the database but were not assigned a grouping value. The discriminant function model selected 70 wavelength variables in the construction of six discriminant functions (Appendix). The resulting intra-formation classifications report that six of the seven swords are manufactured from material acquired from the Brigham Quarry site (Figure 17). Sword 660(2)/Ha3 is classified to the Lower St. Louis chert deposit located along Lake Barkley (Lake Barkley 2) (Table 9).

The 23 Fort Payne swords were placed within a spectral database consisting of only those chert samples obtained from or associated with the Fort Payne formation. The total number of chert samples in the Fort Payne spectral database is 870 representing 29 groups of 30 samples each. The swords classified as Fort Payne were treated as having unknown intra-formation provenience by leaving their grouping variable blank. The discriminant function model selected 235 variables in constructing 29 functions (Appendix). All 23 swords are classified to one of seven deposits (Table 9) (Figure 18). The largest number of the swords (n=8) are sourced to in situ outcrops along McCormick

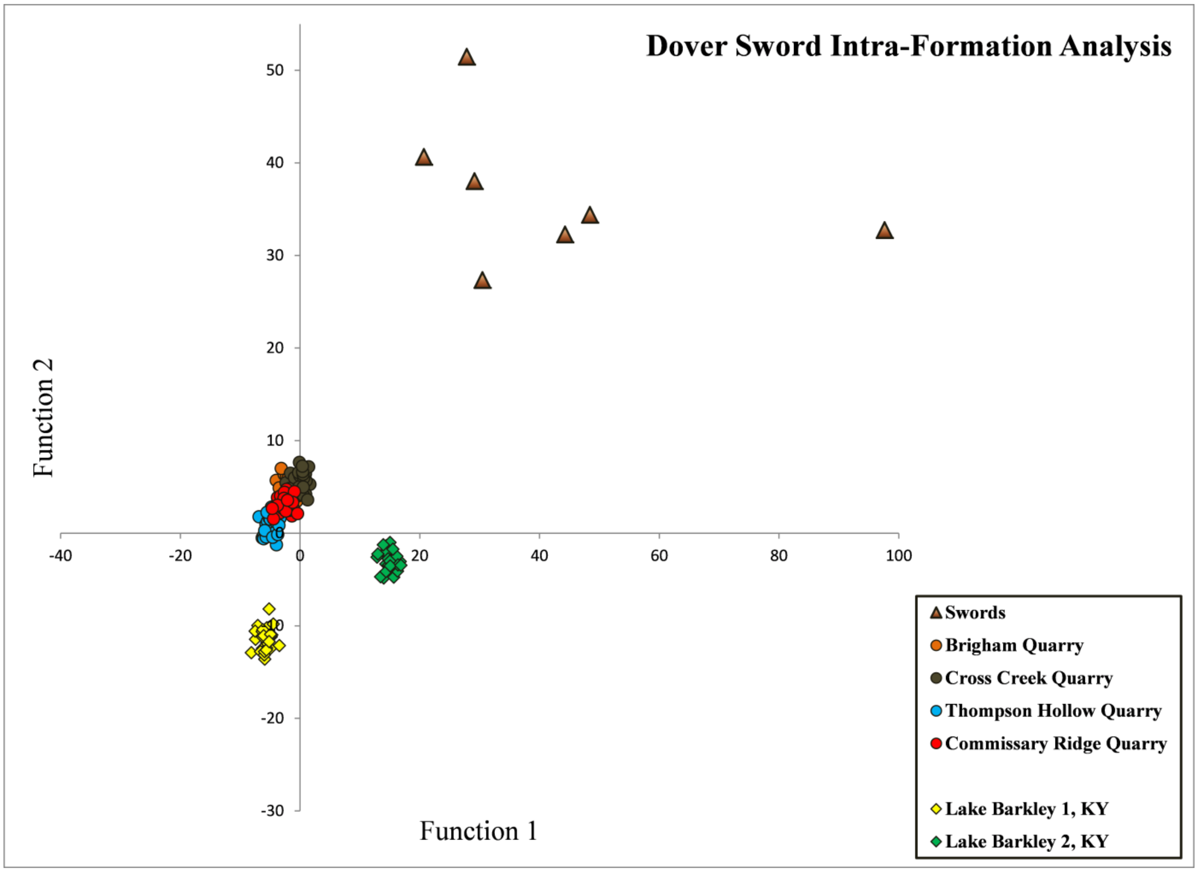

Figure 17. Intra-formation bi-plot for the swords classified as being manufactured from Dover chert. Note the group separation for the Lake Barkley samples in comparison to the four Dover Quarry sites. Cluster group separation limited by two dimensional graphical constraints.

Creek, Kentucky. Additional outcrops of Fort Payne chert along nearby Dry Branch, Kentucky are determined to be the source for two of the swords. Five of the swords are classified to an outcrop of Fort Payne chert in the Northwestern corner of Georgia (GA 4). Four of the swords are sourced to a prehistoric quarry site in Houston County, Tennessee (40Ho54). A second prehistoric quarry located in Henry County, TN (40Hy136) is found to be the source for two of the swords. A single sword is sourced to outcrops of Fort Payne chert at the Link Farm site in Humphreys County, Tennessee. Finally, one sword is classified with material obtained from Bucksnort, also in

Table 9. Intra-formation provenance results for the Mississippian swords.

Catalogue #	Parent Formation	Intra-formation Provenance
Mississippian Sword		
40Su14	Lower St. Louis	Brigham Site, TN
6614/16By13	Fort Payne	Bucksnort, TN
4893/16By13	Fort Payne	40Ho54, TN
15/3Sw1	Fort Payne	McCormick Creek, KY
217/30Sw20	Fort Payne	McCormick Creek, KY
129-B56/30Sw20	Fort Payne	GA 4, GA
B213/30Sw20	Fort Payne	Dry Branch, KY
478/41Sw26	Fort Payne	40Ho54, TN
3/68Hs6	Fort Payne	McCormick Creek, KY
3/67Hs6	Fort Payne	McCormick Creek, KY
4/67Hs6	Fort Payne	GA 4, GA
6/67Hs6	Fort Payne	McCormick Creek, KY
7/67Hs6	Fort Payne	GA 4, GA
20/70Hs12	Fort Payne	McCormick Creek, KY
5-1/71Hs12	Lower St. Louis	Brigham Site, TN
B-96(2)/40Mr7	Lower St. Louis	Brigham Site, TN
660(1)/1Ha3	Fort Payne	40Ho54, TN
660(2)/1Ha3	Lower St. Louis	Lake Barkley 2, KY
1221(1)/1Hy1	Fort Payne	GA 4, GA
1221(2)/1Hy1	Lower St. Louis	Brigham Site, TN
475/7Hy5	Lower St. Louis	Brigham Site, TN
1047/7Hy5	Fort Payne	GA 4, GA
1104(1)/7Hy5	Lower St. Louis	Brigham Site, TN
1514/7Hy5	Fort Payne	40Ho54, TN
1841/7Hy5	Fort Payne	40Hy136, TN
2763/7Hy5	Fort Payne	Link Farm, TN
3194/7Hy5	Fort Payne	McCormick Creek, KY
3526/7Hy5	Fort Payne	Dry Branch, KY
3563/7Hy5	Fort Payne	McCormick Creek, KY
467/3Re12	Fort Payne	40Hy136, TN

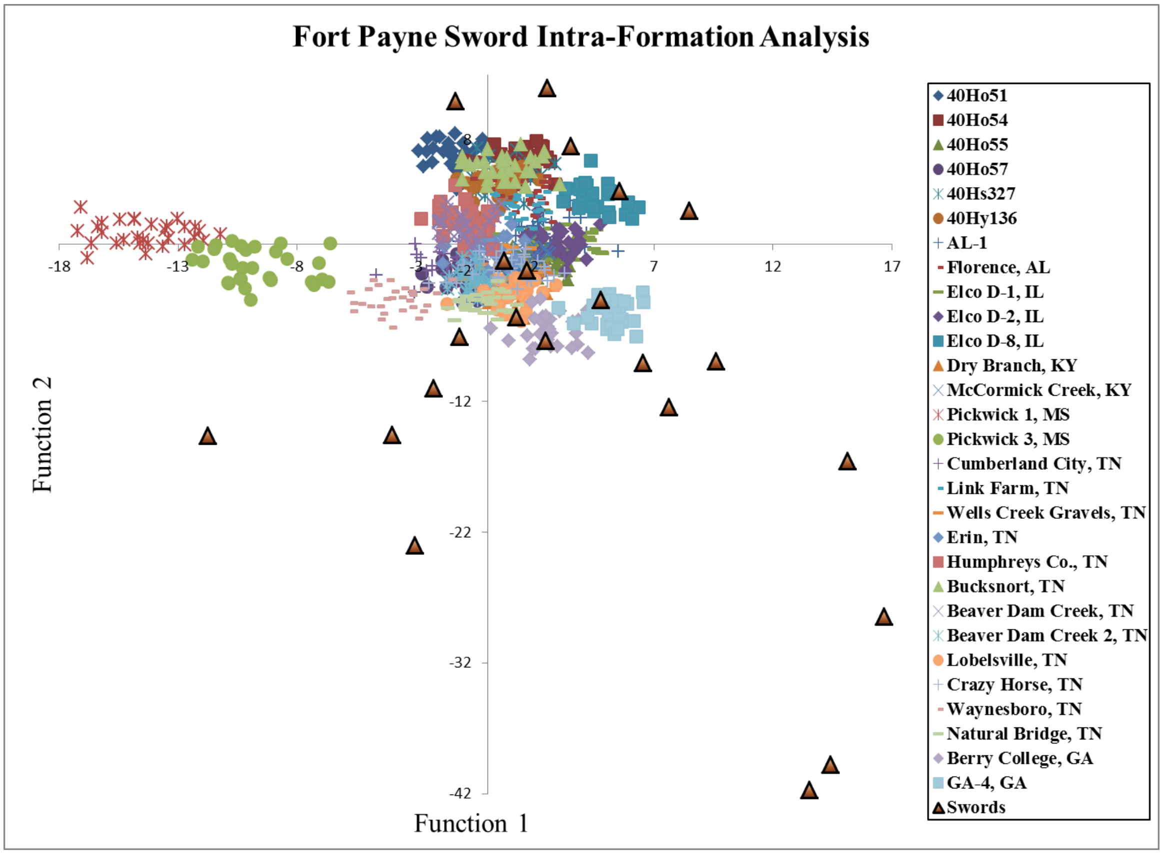

Figure 18. Intra-formation bi-plot for the swords classified as being manufactured from Fort Payne chert. Cluster group separation limited by two dimensional graphical constraints.

Humphreys County. All classifications are between 99 and 100% probability for group membership.

Summary. A high degree of accuracy was shown through a series of tests for both VNIR and FTIR reflectance spectroscopy analyses conducted on interior surfaces. The high accuracies were reported for both chert provenance determinations between formations and within a single formation. Additionally, the effects of heat treating were explored with some noted spectral alterations. The analysis upon the outer surface of chert displaying different degrees of weathering showed that significant differences exist and affect accurate provenance classification. Finally, inter-formation provenance results reported that the majority of the Mississippian sword-form bifaces are manufactured from

Fort Payne chert. The results of the intra-formation analysis showed that Dover chert from the Brigham Quarry site is the primary source for Lower St. Louis chert used for the sword-form bifaces in the sample. The intra-formation provenance of the swords manufactured from Fort Payne chert is variable between seven deposits from primary sources located in Kentucky, Tennessee and Georgia. The technical significance and cultural implications of the results gives researchers information regarding both archaeological application and cultural reconstruction.

CHAPTER 9

DISCUSSION

The results directly address the first two primary objectives of the study, namely testing the application of VNIR and FTIR reflectance spectroscopy as a chert sourcing technique and examining the single source theory for the Mississippian sword-form bifaces. However, prior to offering explanations for the provenance results, the research question of the study, design, methodology, analytical technique(s) and sampling strategy must first be considered. Therefore, the first half of the chapter discusses the results of the internal accuracy tests carried out within the chert database of known provenience and known provenance. The effects that cultural and natural phenomena have on the samples and artifacts under analysis must also be carefully considered.

The development of any provenance technique is an ongoing research objective and often cannot be addressed in full by a single study. Despite the reality of lengthy research projects, a provenance researcher must design internal tests and set controls for variables potentially influencing source assignments. The two main variables affecting provenance determinations of chert cultural material are thermal alteration, both cultural and natural, and weathering. The results of the thermal alteration and patina tests are first steps in both qualifying and quantifying the changes occurring in the spectral reflectance values of chert in the visible, near-infrared and middle-infrared portions of the electromagnetic spectrum.

Additionally, the large sampling methodology and resulting internal source classifications reveal potentially meaningful data regarding the nature of variation between and within chert bearing formations. The inherent variability in Dover and Fort

Payne chert has a spatial relationship. The discussion of the potential geologic relationship between intra-formational distance and variation refines the provenance postulate. The spectral data collected from a large number of chert samples with known spatial components provides an illustration of the distance/variation relationship.

In the context of the a posteriori internal accuracy testing, the provenance of the Mississippian sword-form bifaces is best presented. The second objective of the study is determining the formation source or chert type for the 30 swords in the sample. Because both the Lower St. Louis and the Fort Payne formations have surficial expression over a large geographic area, the inter-formation characterization matches the spatial scale needed to test the single source theory. The sourcing of the Mississippian sword-form bifaces to specific deposits allows for a higher spatial level of examining selection decisions. Future studies focusing on provenance patterns at specific sites or regionally defined interaction zones, may provide a spatially restricted framework within which intra-formation provenance data contributes to localized patterns of resource procurement and use. However, the current provenance data allow us to hypothesize about the relationship that resource selection has with social meaning. The provenance data should not be over interpreted, but patterns within the Mississippian sword-form biface sources are thought to have correlations to Middle Mississippi Stage polities.

Chert Sourcing Methodology

The sampling methodology of the study results in two main findings that may provide direction to future chert provenance studies. The current methodology shows that a great deal of visual similarity exists between and within chert deposits of the Lower St. Louis and Fort Payne formations separated by hundreds of kilometers. Also, the results of the internal accuracy tests indicate that the use of small potentially unrepresentative sample sizes may not adequately characterize the deposit or the chert type. The significant overlap of macroscopic characteristics and the need for large sample sizes are thought to directly apply to other chert provenance studies.

Visual identification. Visual 'type' classifications for chert are inaccurate and dependent upon the observer (Price et al. 2012). The results are rarely repeatable between observers. In a survey among archaeologists Price et al. (2012) recorded an average visual chert type identification score of 18.3%. No participant in the survey scored higher than a 53% in identifying a sample collection of multiple chert/obsidian types from a large geographic area. Chert type classifications are taught by experienced researchers and/or the use of chert type collections. There is a great deal of merit in accumulated empirical experience and the consultation of regional lithic analysis experts as well as local flintknappers and rock hounds is recommended. The information provided by local experts is invaluable and provides an excellent first step in familiarizing oneself with the materials commonly present in site assemblages. However, the experience of the current researcher reveals that many knowledgeable individuals have not visited prehistoric quarry sites or observed in situ deposits with geologic quadrangle reference maps. Instead, chert type classifications are learned through repeated observation with an experienced researcher or are based upon chert type collections containing only one or two samples by type. The limited type collections potentially mask the wide range of variability in macroscopic attributes.

Secondly, many of the chert artifacts under analysis are small debitage specimens from prehistoric manufacturing waste debris. The small artifact size may not include diagnostic visual attributes such as fossil inclusions, mottling or texture differences. Additionally, visual analysis is performed on cultural material subjected to the weathering environment for multiple years. Patina formation can obscure original attributes such as texture, luster and color. The scattering effect of visible light on the coarse outer surface produces the characteristic cloudy or white patina observed on artifacts of supposed great antiquity. The effect of weathering is readily detected when studying modern artifact damage such as plow nicks. The recent damage reveals the interior surface and potentially the original macroscopic characteristics of the particular artifact. Finally, the practice of classifying chert types by type site locations instead of by geologic formation may mask prehistoric reliance on local deposits outside of the material type locality.

Grab-bag sampling. Sample size is a critical component in a chert sourcing study. An appropriate number of samples are needed in order to represent a population of variability at the desired spatial resolution. The number of samples needed relies upon the nature and distribution of variation in the deposit or formation (Luedtke 1976; Luedtke and Meyers 1984). It may be possible that a single chert sample contains all of the variability present in the material type. However, from what is known about the formation of chert the probability that a single sample is representative of the entire population is extremely low. Therefore, chert provenance studies whose comparisons are between two samples from one location and five from another are almost certainly inadequate representations of the deposit, the formation and the material procured prehistorically. The internal accuracy tests for the VNIR and FTIR techniques provide a case study to examine the effects of diminished sample sizes upon classification accuracy.

Grab bag sampling case study. The internal accuracy tests show that a trend of diminishing source accuracy occurs with the removal of progressively more samples from within the database (Tables 4-7). The range of samples removed in the series of internal accuracy tests per deposit is from 0-7 for the 10% unknown test and from 3-13 for the 30% unknown test. Accuracy decreased with removal of an increasing number of samples in all but one instance (VNIR intra-formation test) (Table 5). Specifically, accuracy decreases as much as 5% between the 10% unknown test and the 30% unknown test. The nature of variability within individual deposits is revealed in the data by comparison of the number of samples removed to the number of samples correctly classified per deposit. The comparisons demonstrate that some sample groups can maintain accurate classification with the removal of many specimens (i.e. Berry College, GA and Link Farm, TN). Conversely, other sample groups (i.e. Cross Creek Quarry site, TN) have a relatively higher number of miss-classifications with sample removal. The results illustrate the nature of variability within the sampled deposits. The results are also a warning against small sample sizes when the objective is to differentiate one deposit from another.

Internal Accuracy Assessments

VNIR and FTIR reflectance spectroscopy. The results of the internal accuracy assessment experiments prove that both reflectance spectroscopy techniques have great potential application to chert sourcing. The baseline comparison tests in which no samples were treated as having unknown provenience reports an accuracy range of 94%

to 99.9% for the inter- and intra-formation experiments. The high accuracies indicate that there are enough discriminating reflectance intensity values at diagnostic wavelengths to differentiate Lower St. Louis chert from Fort Payne and differentiate individual deposits within the formations. If diagnostic variables were not present then group assignment would show significant overlap classifications and produce low accuracies.

The high degree of classification accuracy is maintained throughout the 10%, 20% and 30% unknown tests. There exists a slight decrease in classification accuracy due to the removal of samples containing representative variability but even the lowest classification accuracy of 80% for the FTIR intra-formation experiment is very high in comparison to accuracies reported for visual identification (Calogero 1991; Price et al. 2012). It should also be noted that intra-formation analysis is rarely an objective of a chert sourcing study. The objective of the majority of chert sourcing studies conducted to date is the differentiation of material between formations not the characterization of individual deposits. Obsidian provenance studies are commonly conducted at the intra-formation spatial scale. The use of reflectance spectroscopy as a chert sourcing technique demonstrates a new direction in chert provenance research. In this context, the scope and results of the current study are unprecedented.

Chert Thermal Alteration

The analysis of the visible, near-infrared and middle-infrared reflectance data obtained from the Camden, Dover, Flint Ridge, Fort Payne, Horse Creek and Mill Creek chert samples is revealing. The data indicates that in fact there is not much change in the middle-infrared reflectance data of heat treated versus untreated chert samples.

Admittedly, the limited number of chert types and sample specimens analyzed makes conclusive determinations tentative. However, the spectral signatures of the heated and untreated specimens do not show marked differences. Both the VNIR and the FTIR reflectance spectroscopy techniques may be best suited to analyze the water loss or dehydration of the chert sample throughout the heat treating process as observed by McCutcheon (1997) and McCutcheon and Kuehner (1997) in their application of FTIR spectroscopy. The use of spectral data to detect prehistoric heat treatment would not be warranted as rehydration of the artifact in question would rapidly occur even prior to deposition.

Additionally, the observations that both the calcite and hematite spectral features did not alter dramatically with increased heating demonstrate that the presence and quantity of certain impurities in the cryptocrystalline matrix of chert does not change. The detection of goethite, rutile and pyrite prior to heat treatment and later re-analysis of spectral features diagnostic of iron oxide might be a reliable indication of thermal alteration. However, post alteration analysis would only provide qualitative and relative quantitative data. The researcher would not be able to conclusively detect heating without baseline data. These findings support those of Luedtke (1992:105) as she observed that the trace elemental data of chert are not altered through the heat treatment process.

Despite the lack of clear evidence for heat treatment in the visible, near-infrared and middle-infrared reflectance data, a significant observation can be drawn regarding the potential application of the device in provenance studies. It is encouraging to note that the prolonged heat treatment of the six chert types did not obscure or obliterate their unique and potentially diagnostic spectral signatures. Though four of the chert types are macroscopically dissimilar, the reflectance spectra of each sample retained its particular distinguishing traits. The preservation of potentially diagnostic spectral features indicates that the application of VNIR and FTIR reflectance spectroscopy techniques to sourcing thermally altered chert cultural material may not be detrimentally affected. Macroscopic identification of color, luster and texture change is not a suitable method for detecting the heat treatment of various chert types as the Dover, Flint Ridge and Horse Creek samples showed no visible alterations. The VNIR and FTIR spectroscopy techniques proved to be unsuited for identifying heat treatment in chert types. However, the potential application of reflectance spectroscopy for studying water loss as a function of heat alteration may give researchers insight into the thermodynamic characteristics produced by the prehistoric heat treatment of chert.

Chert Surface Weathering

Cross-section experiment. The visible, near-infrared and middle-infrared reflectance data obtained through reflectance spectroscopic analysis of the ten Dover chert samples allow the researcher to make interpretations about the formation of patina and how it affects the spectral response of chert. The observations demonstrate how the combined weathering processes of diffusion-controlled and matrix dissolution alter the surface and near-surface aspects of chert specimens. Specifically, the surface of chert is altered by the chemical leaching of soluble constituents leaving behind the more resistant quartz grains. Dissolution creates inter-granular voids and a porous surface. The increase in reflectance intensities in the visible portion of the spectrum obtained from the weathered surfaces indicates that more diffusely reflected portions of visible light are being reflected back to the detector as opposed to being absorbed by the dark interior chert samples. The increasing SiO_2 reststrahlen peak intensities in the middle-infrared data with depth into the interior of the sample are evidence supporting the existence of a more uniform microcrystalline surface causing specular reflection.

Additionally, the increased reflectance and absorbance feature contrast in the shorter middle-infrared wavelength region on the exterior of the chert samples gives further evidence for a coarse surface. The middle-infrared data show that the reflectance and absorption peaks indicative of molecular bonding, chemical composition and mineralogy remain relatively consistent in wavelength position for analyses from the outer edge into the interior of the sample. Overall, the similarity of spectral features in this study demonstrates that patina formation is not an additive process. However, other researchers using other techniques have noted barium enrichment in the outer surface of chert (Gauthier et al. 2012). Finally, the increasing size of the calcite/dolomite spectral features with increasing measurement depth illustrates that these soluble minerals are being depleted from the surficial margins of Dover chert.

Researchers conducting chert provenance studies should be familiar with the mechanisms that contribute to patina formation and should structure their research design accordingly. An excellent example of one such study is Gauthier et al. 2012 who designed multiple tests to qualify and quantify the application of energy dispersive X-ray fluorescence (ED-XRF). Particular consideration must be given to chert provenance techniques that primarily analyze the surficial aspects of cultural material as the chemical leaching of soluble particles may lead to inaccurate datasets or provenance determinations. This is the case with Gauthier et al.'s studies in which surficial analysis is found to compromise provenance characterization (Gauthier and Burke 2011; Gauthier et al. 2012). The non-destructive application of VNIR and FTIR reflectance spectroscopy within chert provenance studies is a technique that has potential to provide researchers with accurate chert type identification and outcrop differentiation (Hassler et al. 2013, Hubbard et al. 2005; Parish 2009, 2011b, 2013). Additional research needs to be conducted to demonstrate the reliability and precision of reflectance spectroscopy techniques to other chert types and how anthropogenic and natural alteration of chert affect the spectral response.

The visible, near-infrared and middle-infrared spectral data obtained using both VNIR and FTIR reflectance spectroscopy support the hypothesis that patina on Dover and Fort Payne chert is a direct result of chemical leaching of soluble materials and the subsequent mechanical dissolution of the quartz matrix. Though these processes have implications for chert provenance analysis, they are not deemed detrimental to the potential application of VNIR and FTIR reflectance spectroscopy to artifacts. However, comparison of the ability of the techniques to accurately provenance materials using a weathered spectral dataset versus a dataset obtained from fresh interior surfaces indicates that there are significant disadvantages in surface analysis of significantly weathered samples.

Patina subset sample group. The analysis of the outer weathered surface of the randomly selected 10% patina subset sample group (n=105) provides a means to study the effects of weathering upon accurate source determinations. The experimental result is a significant decrease in inter-formation accuracy by over 20% for both the VNIR and FTIR techniques. The intra-formation test demonstrates that outer surface analysis on a developed patina reduces accuracy to single digits. However, the nature of the patina surfaces analyzed should be discussed in greater detail.

The 105 weathered samples in the analysis are retained portions of the exterior surfaces of corresponding samples whose interiors were analyzed. The patina subset sample group does not contain pieces of cortex but are fragments of exteriors that were originally exposed due to prehistoric knapping, natural frost fracturing or mass-wasting events. The exposure times and micro-regional weathering environments represented by the samples are variable. The patina upon the samples formed from prolonged exposure on the surface where they were subject to bleaching by ultra-violet radiation, carbonic acid dissolution, repeated freeze/thaw cycles and organic inter-granular growth.

Two weathering processes affect the chemical, visual, textural, mechanical, and mineralogical properties of chert artifacts. Mechanical weathering is the reducing of chert by abrasion, the freeze-thaw cycle, thermal shock, or pressure from overlying sediments (Foradas 1994:5). However, the natural process that is primarily responsible for the development of patina is chemical weathering. Chemical weathering is “any alteration that occurs to the surface of [chert] as a consequence of chemical interactions with its atmospheric, aquatic, or soil environment (Purdy and Clark 1987:211).” Therefore, weathering, both mechanical and chemical, is a natural response to the atmosphere, temperature, pressure, organic and compositional environment (Luedtke 1992).

Patina formation is a combination of both mechanical and chemical processes described as matrix dissolution and diffusion-controlled. Matrix dissolution occurs when the inter-granular bonds are destroyed and individual quartz grains are lost (Purdy 1981;

Purdy and Clark 1987:229). The diffusion-controlled process is the selective leaching of ions when exposed to acidic environments (Purdy 1981; Purdy and Clark 1987:229). Diffusion takes place first along grain boundaries weakening silica bonds and may lead to matrix dissolution of quartz minerals. Both the matrix dissolution and diffusion-controlled weathering processes directly contribute to the exterior appearance of chert.

The hydrated or oxidized iron creates a cream, brown, red, or black patina that is visible on outer surfaces. The resulting porosity of the outer surfaces creates a coarser texture increasing the scattering of light. The scattering effect gives the material a white cloudy hue (Hurst and Kelly 1961:254). Additionally, the white patina may be stained by humic soils developing darker colorations (Luedtke 1992:109). Other variables affecting the visual exterior appearance of chert are grain size, texture, type of impurities, and color centers (Hurst and Kelly 1961). All of these factors may be altered by the diffusion-controlled and matrix dissolution processes and help explain variation in patina types.

The different degree of patina formation upon artifacts with a variety of depositional histories is an ongoing research objective. Researchers continue attempts to quantify patina formation as an age estimator (Frederick et al. 1994; Sheppard and Pavlish 1993). Also, randomly included in the patina subset sample are samples obtained from fluvial gravel deposits whose outer surfaces developed a tan to dark grey patina.

Fluvial patina formation on chert. Fluvial environments almost certainly represent a radically different weathering environment. The periodic abrasion by various grain size particles and ion exchange with the dissolved load in a river system probably create an exterior surface which varies from that of terrestrial chert materials. The total number of fluvial gravel samples randomly included in the patina subset sample group is 32 (Table 1 and 7). The results presented for the patina subset sample provenance in Table 7 demonstrate that the inter-formation source accuracies for the fluvial chert gravels in both the VNIR and FTIR techniques is 11% less than the accuracy reported for patina source analysis on samples obtained from bedrock and residual sources. The removal of the 32 fluvial chert samples from the patina subset sample group improves the VNIR accuracy by 5% and the FTIR accuracy by 8%. The findings show that the sourcing of artifacts whose depositional environment is within a fluvial setting is negatively affected to a greater extent than sourcing artifacts from other weathering environments. Additional testing on a larger sample database is needed to either confirm or refute this finding. The relatively poor accuracy results discussed above led to additional testing to determine if the degree of patina formation on the Mississippian sword-form bifaces is more closely associated with the reflectance spectroscopy measurements taken upon the interior or exterior surfaces.

Degree of weathering test. The results of the comparison between the surface spectral measurements taken upon the Mississippian sword-form bifaces with the weathered vs. un-weathered groups demonstrates that the patina on the artifacts more closely matches interior surface measurements. Therefore, relating the results of the patina subset sample test to expected non-destructive provenance accuracy of the swords may be an inaccurate comparison. The degree of patina formation upon the samples comprising the chert database is obtained from specimens exposed upon the ground surface for prolonged periods of time. All of the artifacts with known provenience (n=27) were recovered from buried contexts (Table 2). Of these, 19 were found in burial contexts explained as demonstrating intentional internment. The swords would have been relatively protected from the same degree of weathering that altered the surface of the patina subset sample group. The analysis of the four artifacts recovered in close proximity to the Brigham Quarry site provides additional evidence to support the claim that the sword spectra may not be affected to the same degree as the patina subset samples.

Chert Variation and Lateral Distance Relationship

The results of the intra-formation provenance experiments conducted on the chert spectral database suggest that a relationship exists between variation and lateral distance within a chert bearing formation. The hypothesis is that with increasing lateral distance within a formation, variation also increases relative to a central location. The relationship is almost certainly not a simple linear one to one correlation due to involvement of different paleo-depositional basins and varying post depositional processes. However, the results of the intra-formation accuracy test suggest the presence of greater chert variability the further out from a starting position samples are collected within the formation (Figure 17). Stratigraphic position within a formation is not accounted for in the observation and may also have an effect on the presence of variation within a chert deposit and chert bearing formation.

An excellent example of the variation/distance hypothesis is the intra-formation bi-plot of the Lower St. Louis samples (Figure 17). The four Dover Quarry sites are located within an approximately 4 km radius of one another. Therefore, the Dover chert deposits may have formed under very similar diagenetic conditions. The assumption may not be entirely infallible as demonstrated by Luedtke and Meyers’s (1984) geochemical study of Burlington chert outcrops along the Illinois River. The intra-formation bi-plot of Dover chert samples depicts the 120 quarry samples as being closely associated in vector space in comparison to samples obtained along Lake Barkley 40 kilometers to the north. In contrast, the two Lake Barkley sample groups are not closely related in vector space despite being only 0.4 km apart.

A simple linear regression model was developed to explore the variation/distance hypothesis. The linear regression model was constructed for the six Lower St. Louis deposits sampled in the study. The Brigham Quarry site was chosen as the arbitrary datum point and distances to each of the five deposits were measured using a geographic information system (GIS). Once the distance measurements were recorded, the diagnostic reflectance values at corresponding frequencies were averaged for each of the six deposits. Next, the standard deviation was calculated for each of the diagnostic reflectance values at corresponding wavelength positions. An example of this step is that the standard deviation between the Brigham reflectance value and Thompson Hollow reflectance value at frequency position 400 nm is calculated. Next, the standard deviation between the Brigham reflectance value and the Cross Creek value at 400 nm was calculated. The step was performed for the wavelength value at 400 nm for the Commissary Ridge, Lake Barkley 1 and Lake Barkley 2 deposits. The formula was then populated across the entire length of the spectrum to calculate standard deviations at each frequency position across the combined visible to middle-infrared wavelengths (400-14,398 nm). Finally, the sum of the standard deviations by deposit was calculated. These six standard deviation values, one for each of the six deposits, are used as the x-axis values. The y-axis values are the horizontal distance in kilometers from the Brigham

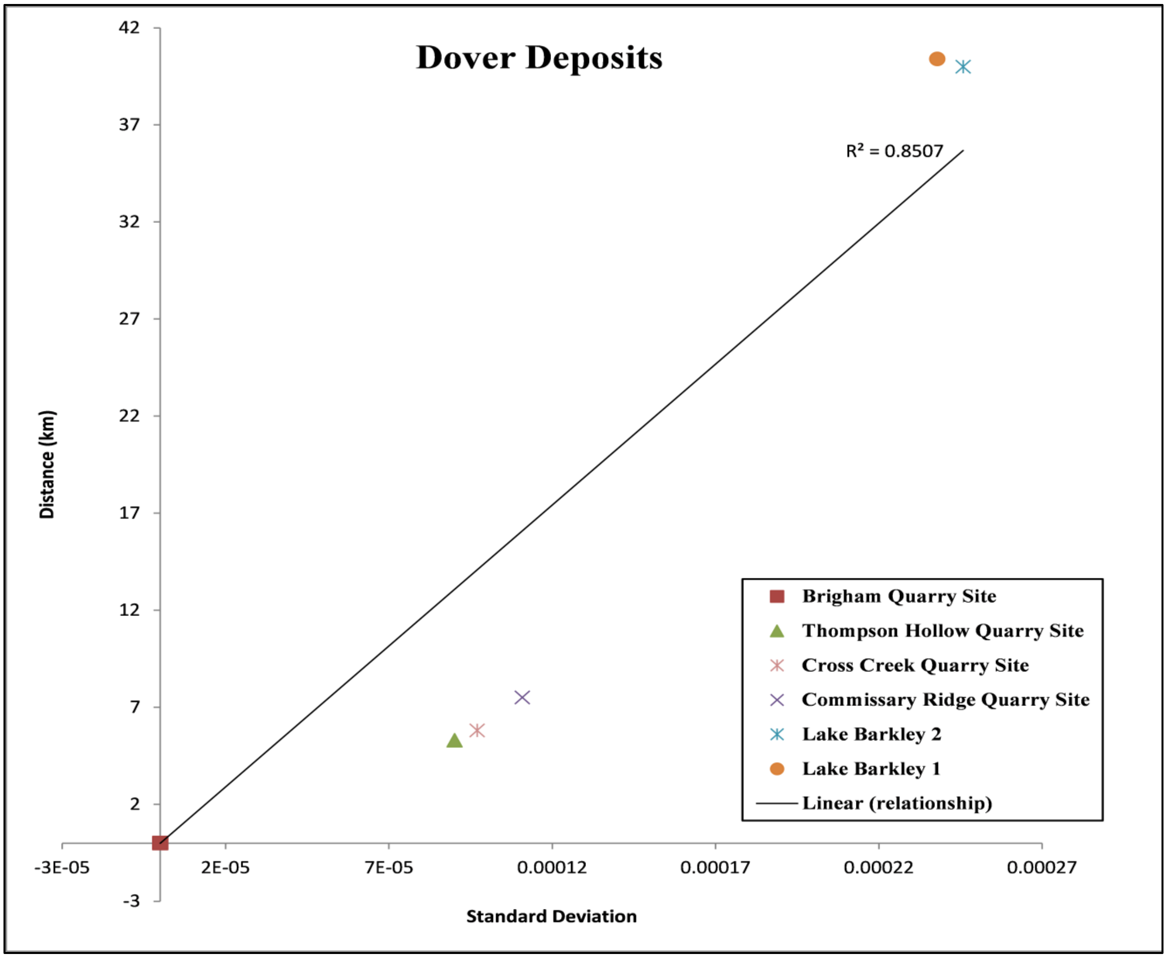

Figure 19. The linear correlation between spectral variation and distance for the six deposits of Dover chert sampled in the study.

Quarry site (Figure 19). The datum is the Brigham Quarry site whose standard deviation with itself is zero and whose distance from itself is also zero.

The insertion of a trend line with y-intercept set at the Brigham Quarry site shows a positive significant ($R^2 = 0.8507$) linear relationship. The model tentatively supports the hypothesis that variation increases with geologic/geographic distance for the Lower St. Louis deposits sampled in the study. Further testing is needed along with rigid statistical analyses to test for violations in assumptions. The results are important for chert provenance studies that seek to source artifacts to non-sampled or non-existent deposits. It is impossible to have complete confidence in provenance assignments as not all possible sources can be sampled (Luedtke 1992). However, each source characterization may give the researcher a localized regional proximity to the original prehistoric source if variation within the formation has a spatial relationship.

Anthropological Implications

The provenance data for the sample of Mississippian sword-form bifaces provide significant cultural information pertaining to the selection, acquisition and/or direct procurement of chert resources utilized to manufacture this class of symbolic weaponry. The provenance data are best contextualized in a cultural framework built from archaeological provenience evidence, Mississippian iconography and the ethnographic record. The source for the socio-technic weaponry should not be conceptualized in economic terms. The economic cost or acquisition/procurement of material that is readily available and in use by the greater populace in the form of agricultural implements is not a useful model to explain the social function of Mississippian sword-form bifaces. Traditional cost-distance calculations might quantify the effort exerted for direct procurement from a favored resource but such information almost certainly does not explain the cultural function or role of the swords in Mississippian societies. A more holistic framework is necessary to evaluate the sword-form bifaces. Provenance data for the swords find their ultimate expression within this multi-faceted model.

Cultural distance. Greater geographic distance does not always equate to cost. The distance and cost relationship is viewed as an inadequate means to explain the provenance data for Mississippian sword-form bifaces. Distance as measured in linear kilometers is also an inadequate proxy for explaining the selection decisions of the individuals who acquired chert material for crafting a sword-form biface. Cultural distance is a more precise view of the relationship a society has with the distribution of people and place on the landscape. Cultural distance is here defined as the socially perceived space within or outside of the known landscape, resources and people of a particular society. The boundaries of the social landscape may have been thought of as an 'alien' or a transcendent space in which intermingling between the borders of the cosmological above and below realms occurred (Dye 2013). Alien people and resources brought back from such places would have imbued prestige to the transcendent individual. Helms presents the idea that crafting of 'exotic' resources is a cosmological transformation of both the exotic or ordinary resource into a symbolically charged item (Helms 1993).

The gathering of both local and exotic craft goods establishes the collective body of a people as the center or axis mundi of the universe. The rituals, myths, regalia and songs solidify the collective populace and create a position for the society within an ordered cosmological space. The collective body of social knowledge, symbolic items and rituals are the 'soul' of chiefdom level societies. The desecration of the temple by allied tribes fighting with Desoto's conquistadors essentially erased the social identity of the populace. These acts were not only demoralizing to the inhabitants but symbolically killed their identity and place in the world as they defined it. A people without a soul would have been little better than shadows in the cultural sense not grounded centrally to one world or the other.

The concept can also be viewed analogously in modern society, albeit to a lesser extent, by accounts of flag capturing or rescuing during the American Civil War. The flag is not viewed by the soldiers as a wealth item being crafted from Italian silk, gilded with Peruvian silver or an emblem of the governing administrative body but rather the flag symbolized the identity of the company of men fighting under it. The flag was their collective honor and how they distinguished themselves from other companies or divisions. The loss of the flag was considered a disgrace and would haunt the men until they redeemed themselves by other means. Therefore, it is probable that the Mississippian sword-form bifaces were firmly established in the cosmology and collective identify of the people. Distance as measured by kilometers in resource acquisition may not have held much importance to a participant in a ceremony or an engaged observer especially if the material is from a source that was readily available to the populace.

Resource selection decisions. Resources represent a place on the landscape or a people. Again the deposits of arrow quiver bundles at Cahokia grouped according to arrowhead material type and style is used as an example when viewing cache deposits in centralized locations. The decision to acquire distant resources might have had political, social or economic motivators but certainly had cosmological meaning. The control and redistribution of resources is one avenue by which high status individuals garnered and maintained power. However, another is by being representatives of cosmological realities. Authority is awarded through ritual, dance, storytelling and regalia by linking oneself to the ancestors and projecting longevity through descendants.

Resource selection decisions by high status individuals plays a role in authority by bringing together both materials and crafted goods normally outside of society’s utilitarian consumption. Physical and natural constraints apply to chert resources selected for sword manufacture. The extent to which these physical constraints influenced Mississippian selection decisions for sword manufacture is qualified by the provenance results.

The provenance results indicate that multiple source locations were exploited for chert material. The presence of both Lower St. Louis and Fort Payne chert in the sample suggest that no single deposit was favored over other possible closer sources. The favoring of particular deposits on a case by case or regional basis almost certainly occurred due to the physical material demands needed to craft a sword-form biface. Chert material of the desired length, quality and accessibility could not have been obtained from fluvial gravel bars. It is suggested that favored sources existed such as the deposits at the Dover Quarry sites and the multiple outcroppings of Fort Payne in and around the Link Farm site in Humphreys County, Tennessee. At both locations the necessary factors of length, quality and accessibility are observed. Additional chert provenance studies investigating intra-formation variation are required to make these assertions at a finer spatial and anthropologic scale than what is presented here. However, the intra-formation results reveal potential relationships between chert deposits and Mississippian polities.

Crafting. Crafting and craftsmanship are commonly explored themes in complex societies. The macroscopic examination of the 30 Mississippian swords shows varying degrees of skill represented in the samples. The largest specimen (15/3Sw1) measures 36 cm and exhibits exceptional proficiency in technique that would not have been a universal skillset. Other swords are more clumsily executed (20/70Hs12) and may be a stage along the manufacturing process or simply functioned in a less formal way. It is probable that only a few individuals per group would have had the ability to consistently craft a Mississippian sword-form biface. The discovery of flintknapping tool kits as burial goods associated with specific individuals at the King Site, Georgia indicates the presence of members of society with unique skillsets (Cobb and Pope 1998).

One way of visualizing the presence of a craftsman in the archaeological record is by stylistic and technical analysis of the flaking scar removal patterns on swords obtained from a single site or those found in a localized region. Also, the provenance data might indicate a shared source for all swords thought to have been manufactured by an individual. The archaeological context of sword-form bifaces found as burial goods with individuals thought to have had high social status might be used to indicate commissioning of craftsman by elites. The discovery of two maces and a thin blade by Nash (1968) in association with a house platform mound at the Link Farm site is evidence that suggests the presence of a craftsman. The Link Farm site in particular is a good location to examine sword production and possible material procurement as evidenced by the large number of symbolic weaponry finds and the site’s close proximity to the Dover Quarry sites and to multiple thick bedded outcrops of Fort Payne chert.

Cosmological associations. The ethnographic record of the Osage and the tribes of Northern California combined with Mississippian iconography provide strong evidence that the sword-form bifaces are objects with cosmological associations. Shell gorgets of the Hightower tradition depicting transfigured anthropomorphic figures holding aloft sword-form bifaces are evidence supporting symbolic relation. The ethnographic accounts of ceremonial use and social value of sword-form bifaces among the Karok, Hupa and Yurok of California and the Osage of the High Plains provide a framework for examining ideological function and worth.

A direct comparison between the tribes of Northern California and Mississippian societies should not be made but the importance given to size, color, chert/obsidian type and the cultural worth attributed to the bearer of the sword-form bifaces cannot be lightly discarded either. The social context provided by ethnographic data from the Osage is a more reliable and direct comparison among the descendants of a Mississippian society. The importance of chert type to the Osage priest class in their creation myth and bestowing the knife by deities from the above realm solidify the position of the sword as a symbol within Osage cosmology. Additionally, the story of the War Leader, the hawk and bent knee posture are connected to the sword-form bifaces by shell gorget iconography and possibly the unique style of the swords.

The falcon imagery, posturing, left hand associations and style demonstrate a cosmological link to the Morning Star deity, sanctioned violence, renewal of life forces and eternal life through descendants. The bent knee posture with upraised sword in the left hand symbolizes the right of an individual to evoke and embody the power of Morning Star to overcome the forces of the Below Realm, perform the appropriate rights prior to conflict and ensure immortality for himself and those who follow. The brown dark mottled variety of Dover and Fort Payne chert coupled with the Duck River Style may be an intentional association with the color and shape of the feather of a falcon. Crafting a sword in the Duck River Style shows intentionality in design. A total of 17 swords in the sample display typical characteristics of the Duck River Style. The Fulsi-eliptical type is not radically different stylistically having both the convex end and pointed tip; however, the accentuation at the tip is not present. The style of the sword would have had cultural meaning. The coloration of the material used to craft the item may or may not have shared the same cultural importance but as evidenced by the ethnographic record of the Karok, Hupa and Yurok, coloration is a factor in cultural meaning.

Inter-formation Sword Provenance

The sample of 30 Mississippian sword-form bifaces is herein categorized into two geographic groups with the exception of one outlier. The majority of the swords (n=23) are recovered from sites located in Benton, Henry, Humphreys and Stewart Counties, Tennessee (Table 2) (Figure 20). The 23 swords from these counties are collectively referred to as the Lower Tennessee River group. The six swords located in Bradley, Monroe, Hamilton and Roanne Counties, Tennessee are organized into the Appalachian group (Table 2) (Figure 20). One sword is recovered from Summer County, Tennessee.

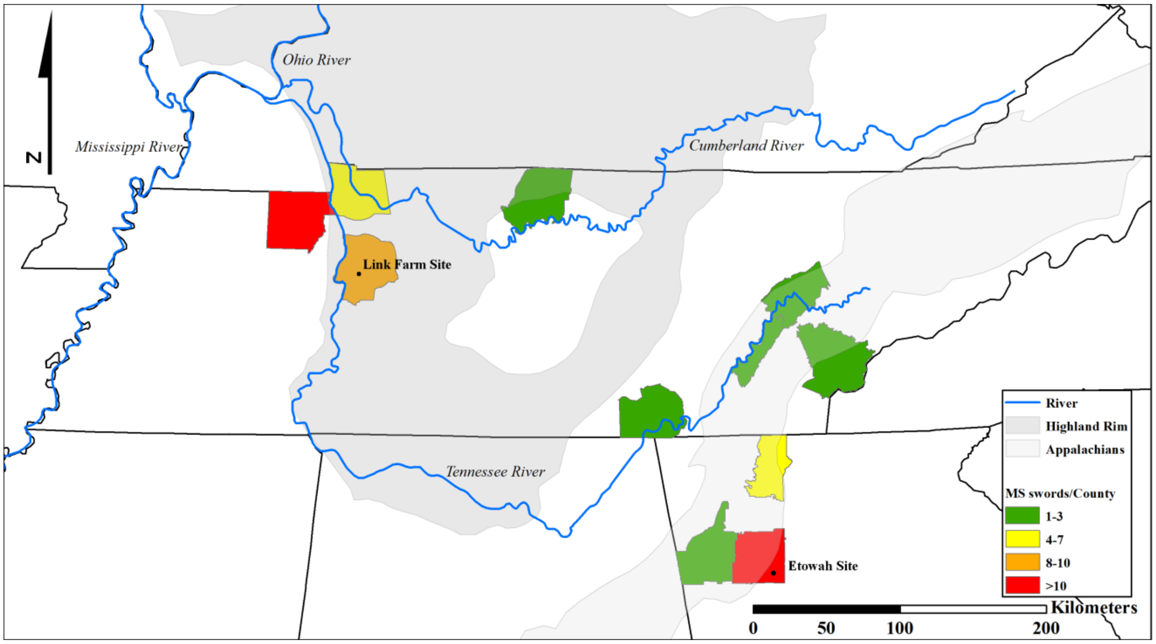

Figure 20. Distribution of Mississippian sword-form bifaces by county along the Tennessee River Drainage Basin from the current study (n=30) and Marceaux (2003) (n=24).

The provenience of a larger sample of swords is needed to confirm the distribution noted in the current study.

Whether the two distribution groups have culturally relevant meaning remains to be seen; however, the proximity of the Appalachian group to the Etowah site, Georgia and the similar distribution of both swords and shell gorgets depicting sword iconography noted by Marceaux (2003) is evidence supporting the distribution pattern (Figure 20). The location of the Link Farm site within the Lower Tennessee River group is also of note especially given that the largest concentrations of Mississippian sword-form bifaces east of the Mississippi River were found at Etowah and at the Link Farm Site.

The inter-formation provenance results report that 19 swords in the Lower Tennessee River group are sourced to deposits within the Fort Payne formation (Table 8). Four of the swords in the Appalachian group are classified as being crafted from Fort Payne chert (Table 8). The number of swords typed as Fort Payne within the Lower Tennessee River group is surprising due to the proximity of the Dover Quarry sites. In fact, all four of the swords from Stewart County are attributed to deposits of Fort Payne chert. The use of Fort Payne chert in the Appalachian group conforms to traditional distance decay models, however these models may be inappropriate for the swords as discussed above.

The preference for Fort Payne chert is reasonable in terms of availability, package size and quality. Using these three variables, Fort Payne chert is far superior to Lower St. Louis as a material source for the Mississippian sword-form bifaces. The size of Dover chert nodules is observed as rarely exceeding 40 cm in length. After initial reduction of the cortex and thinning, the length of the finished piece would have decreased by at least a third. The Fort Payne chert samples are also observed as occurring in nodular form. In lower sections along the formation thick bedded planes stacked upon one another is the predominant nature of the chert deposit. Specifically, the deposits in and around Humphreys County exist as multiple bedded planes within the soil matrix. Numerous modern excavations along hillsides in the area reveal lateral beds of thick chert. The material outcropping along the bluff adjacent to the Link Farm site is observed as thin lenses which can be excavated with one's fingernail. However, no direct evidence for prehistoric procurement is reported at any of these deposits though Brehm's reference to multiple pits along the surrounding hillsides is intriguing (Brehm 1987).

Intra-formation Sword Provenance

The intra-formation provenance for the swords analyzed is tertiary to the second main objective of the study, but provides potentially valuable data. The ability to source artifacts to specific chert deposits on the landscape is a critical need. The discussion of the intra-formation results for the swords is similarly organized into the two distribution groups.

The four swords identified as Lower St. Louis chert in the Lower Tennessee River group are sourced to the Brigham Quarry site. Additionally one of the swords typed as Lower St. Louis chert in the Appalachian group is also sourced to the Brigham Quarry site. The sword recovered from the Castalian Springs site in Summer County is also attributed to material from the Brigham Quarry. The one remaining sword typed as Lower St. Louis chert from the Appalachian group is sourced to a deposit located along Lake Barkley in Kentucky (Table 9).

The 20 swords sourced to Fort Payne deposits in the Lower Tennessee River group depict a possible preference for material to the north. The Fort Payne deposits along McCormick and Dry Branch Creeks, Kentucky close to the confluence of the Tennessee and Cumberland Rivers are the predicted source for 10 of the swords in the Lower Tennessee River group. However, six of the swords are sourced to deposits in Georgia. The remaining four swords are from local deposits of Fort Payne within Henry, Houston and Humphreys Counties, Tennessee.

The four swords sourced as Fort Payne chert in the Appalachian group are identified as being material from deposits in Henry, Hickman and Houston Counties, Tennessee. No swords were sourced to ‘local’ deposits of Georgia Fort Payne chert. However, care must be taken in over interpreting the results. It is tempting to immediately point to the swords in the Lower Tennessee River group sourced to Georgia deposits and swords in the Appalachian group sourced to Lower Tennessee River deposits as evidence for inter-regional exchange, alliance building, migration, . . . etc. but the given pattern may be an article of sampling.

Summary. The results of the provenance study highlight the potential application of reflectance spectroscopy to chert sourcing. The results also highlight areas needing further research, specifically the non-destructive application of the methods upon the outer weathered surface. The provenance data for the swords fits seamlessly into the existing body of evidence regarding the cultural role of Mississippian sword-form bifaces. The archaeological context, style, iconography and ethnographic record of the swords create a framework upon which significant insight is gained regarding the use of swords as symbolic associations of cosmologic realities. The role that chert source has within the cultural context gives researchers an additional tool to explain use and meaning.

CHAPTER 10

CONCLUSIONS

The use of macroscopic visual identification techniques to source chert cultural material is problematic. The application of non-destructive VNIR reflectance spectroscopy and FTIR reflectance spectroscopy to chert provenance studies provides a significant alternative to current petrographic and geochemical methods. The spectral provenance data of Mississippian sword-form bifaces are incompatible with the single source hypothesis. Provenance data of the Mississippian sword-form bifaces also give clues to cultural function by showing that resource distance in this instance may not have been a contributing factor in socio-political meaning. Additionally, the selection of chert resources for sword manufacture at individual Mississippian polities is variable and may not be determined by the broad scope of the study. The provenance data allow for the generation of new hypotheses to explore questions regarding the resource selection decisions of specific Mississippian polities. A new direction for chert provenance studies is called for; one that focuses on the characterization of intra-formation variation. The high-level spatial resolution that intra-formation source data provide, allows researchers to develop and test both low and middle-range theory relating to the acquisition of chert resources.

Reflectance Spectroscopy

The use of reflectance spectroscopy in archaeological applications is increasing. The extreme detector sensitivity, low-cost, non-destructive potential and speed are characteristics making reflectance spectroscopy a desirable analytical tool. The use of reflectance spectroscopy within provenance studies marks a deviation from traditional geochemical methods. Instead of producing trace element data, potentially diagnostic reflectance values as a function of wavelength collectively represent the atomic and molecular configuration of the sample under analysis. The presence of minor mineral groups in the sample is observed by diagnostic spectral features. Before the wide scale adoption of reflectance spectroscopy, the strengths and weaknesses of the techniques within the context of the study need to be considered.

VNIR. The VNIR instruments used in the study are portable and can be taken into the field or brought directly to museum collections. Also, the technique is fast. On average, 30 samples are analyzed per hour with three measurements per sample. Processing of the data in the spectral software program takes a few minutes. VNIR reflectance spectroscopy is cost efficient. The initial investment of the instrumentation is substantial, however continued laboratory use only requires the occasional purchase of a quartz-halogen light bulb ($25) having a use life of over 1,000 hours. Finally, the technique is non-destructive. Diffusely reflected light is gathered by the detector requiring no ablation, dissolving, sample crushing or sawing.

A limitation of the VNIR technique applied to chert sourcing is that destructive analysis may be necessary when sourcing an artifact with a highly weathered surface. A second limitation is the large amount of data produced by a single analysis. The use of a statistical data reduction method is needed to decrease the size of the spectral database. The final limitation associated with the VNIR technique is accessibility to instrumentation. VNIR spectrometers are commonly found at most University or research institutions. The devices are usually housed in Physics or Chemistry departments, but are not always standard equipment at every facility.

FTIR. The FTIR reflectance spectroscopy technique has similar advantages to the VNIR technique. The analysis of samples is fast. Allowing for 45 minutes of instrument initialization, the analysis of 30 samples is approximately 3 hours taking three spectral readings per sample. The processing of the spectra takes an additional 30 minutes. The cost of analysis is limited to the use of laboratory grade liquid nitrogen to cool the external MCT detector. The cost for liquid nitrogen is minimal being only a few dollars per liter. The actual cost of the instrument is substantial. The portion of the sample being analyzed is in the order of 20 microns. The small spot size allows for the micro-analysis of specific portions of the sample and is an advantage compared to bulk analysis techniques. FTIR reflectance spectroscopy is non-destructive. All collection of spectral data is recorded upon the surface or near surface margins of the sample. However, as is shown in the results, severe weathering affects the spectral response.

FTIR reflectance spectroscopy is mainly limited by its immobility. A loan must be secured in order to bring collections to the FTIR spectrometer. A second limitation is artifact thickness. In the current configuration, the Bio-Rad FTS 40 spectrometer can only facilitate artifacts of 3-5 cm in maximum thickness. The removal of the adjustable stage adds an additional 3 centimeters but the analysis of thick specimens is limited. The large amount of reflectance values produced by FTIR spectroscopy creates data handling difficulties. The use of statistical methods is necessary to reduce the spectral datasets into components of variation.

Canonical Discriminant Function Analysis

The use of canonical discriminant function analysis as a statistical method proved to be useful in identifying diagnostic reflectance values at corresponding wavelengths in order to differentiate sample groups. The data reduction capabilities of discriminant function analysis are found to be helpful in dealing with large spectral datasets. The only limitation with assigning classification to unknown samples is that each unknown is assigned to a class within the current chert database. Sample classification for unknown cases is based upon the calculated Mahanolobis distance measurement from the unknown sample to the nearest group centroid. However, the ‘forced’ classifications of unknown samples is suitable given the probability that some chert deposits exploited for Mississippian sword-form biface material may never be sampled or others no longer exist. The characterization of artifact to deposit methodology also justifies assigning class to all unknown samples.

Chert Source Application

Both VNIR and FTIR reflectance spectroscopy are viable chert sourcing techniques. Individually, both techniques report similar accuracy rates. The results of the study demonstrate that the combination of the visible near-infrared and middle-infrared databases is the most accurate. The inclusion of more diagnostic reflectance values at corresponding wavelengths is deemed the optimal analytical strategy. The use of multiple diagnostic variables partially alleviates the problem of alteration of the spectral signature by weathering of soluble mineral groups. The absence of 3 to 4 diagnostic variables in one portion of the sample’s spectrum might harm the source determination. However, a suite of variables may provide enough diagnostic information to make an accurate source determination. The use of the combined VNIR and FTIR dataset is presented as a case study illustrating this point.

Mississippian Sword Source

Additional sampling needs to be undertaken of Fort Payne and Lower St. Louis chert deposits along the Eastern Highland Rim of Tennessee and Kentucky as well as the Fort Payne deposits of northern Alabama. Once a more comprehensive sample database is built then re-comparison of the provenance data might either confirm or reject patterns seen in the current source data. In particular, the intra-formation results suggesting an inter-polity or inter-regional relationship between the Link Farm site in the Lower Tennessee River group and the Etowah site in the Appalachian group need to be explored.

A first step in the inter-regional study would be to map the proveniences for a larger sample of sword-form bifaces. By examination of the spatial relationships and the quantities of the sword-form distributions, the categorization of the two concentration groups might be substantiated. The provenance data present a tentative clue to socio-political ties between polities along the Lower Tennessee River Valley and those along the Upper Tennessee River Valley and slightly further to the southeast at Etowah, Georgia. The Mississippian swords in the sample manufactured from Fort Payne chert acquired from these two areas are evidence supporting the possible associations between the two regions.

Single Source Hypothesis

The provenance results for the sample of Mississippian swords analyzed in the study demonstrate that some previous source assignments to chert deposits located in Dover, Tennessee are inaccurate. The field survey and sampling portions of the study illustrate that multiple chert deposits with overlapping visual properties are found across a large portion of the southeastern United States. The empirical evidence leads us to question the single source hypothesis and the provenance results provide analytical evidence confirming the acquisition of chert for sword-form biface manufacture outside of the Dover vicinity.

The provenance results discourage hypotheses regarding centralized production and redistribution at the Dover Quarry sites as the sources for the swords are distributed among nine deposits. The Brigham Quarry site, the largest of the Dover Quarries by both size and number of pits, is the primary source for the swords typed as Lower St. Louis chert. Both the McCormick Creek, Kentucky and the Georgia (GA4) deposits are the primary characterized sources for swords made of Fort Payne chert. Additional analysis is required to investigate the preference for particular deposits. However, out of the 29 sampled Fort Payne deposits only 7 are characterized as sources for the swords. The data may reflect favored selection.

Selection Factors

The provenance results document a selection preference for chert occurring as in situ deposits. No swords were sourced to fluvial gravel deposits. Exploitation of chert resources within saprolite matrices provides accessibility to the material and some protection from the freeze/thaw cycle. The author was able to physically remove 30 kilogram samples of Fort Payne chert from the soil matrix by hand without the aid of a digging stick, pick or pry bar at a number of locations. Exploitation at locations where complete dissolution of the carbonate matrix is present would have afforded an accessible resource. The burial of deposits below the frost line also offers protection for large, high-quality nodules or blocks. The contraction and expansion of inter-granular water during freeze/thaw cycles rapidly fragments fine grained samples as empirically documented.

The intra-formation sources for 12 of the 30 Mississippian swords are of linear distances greater than 100 kilometers from their discovery sites. As discussed above, linear distance may not be a useful heuristic in examining the role of the sword-form bifaces within Mississippian society. However, the results indicate that a reliance on 'local' resources or resources located in close proximity to find location is the trend for the majority of swords sampled. The preference for selection of grey to brown mottled black Lower St. Louis and Fort Payne chert types suggests that color also may have been a desirable attribute.

Cultural Function

Provenance data alone cannot clarify the cultural role that Mississippian sword-form bifaces had within Mississippian polities. Provenance data combined with other forms of data including Mississippian iconography, the ethnographic record and archaeological context allow researchers to present a more complete view of this class of symbolic weaponry in Middle Mississippi culture. In this context, provenance data demonstrate that the selection of a resource culturally recognized as exotic did not play a role in the symbolic meaning of the swords. It is argued here that style, possibly with a temporal component, use in ceremony and coloration may have had greater cultural significance.

The direct association of the swords with the Birdman/Falcon Warrior character in Mississippian iconography links the bearer of a chert sword-form biface to the Above Realm and the Morning Star figure. The individual would have been given the right to perform ceremonies possibly prior to sanctioned inter-group violence. The performance of these rights would have afforded the individual considerable social status but also would have ordered the cosmos and linked the group to a collective social identity grounded in the mythological deeds of the ancestors. The ordering of life-forces through these rituals would have secured the position of the people in both space and time and projected their identity into the future.

Future Research

The study demonstrates the potential for continued application of reflectance spectroscopy techniques in chert sourcing studies. The results show that the analysis of interior surfaces produces accuracy results far superior to visual identification. The advantages of the VNIR and FTIR techniques make them more desirable than traditional geochemical or petrographic chert sourcing methods. Continued research and application to other varieties of chert at both the inter- and intra-formation scales is warranted for broader applications. The diagenesis of chert provides a proxy for understanding variation, both the presence of and cause for material differentiation at various spatial levels. Additional testing is needed to understand the varying degrees of patina formation. A large body of literature already exists on this topic yet the effects of surficial analysis are difficult to quantify. The non-destructive potential for both the VNIR and FTIR techniques is an area of research that immediately contributes to provenance studies. Non-destructive analysis provides a compromise between preservation/conservation concerns and needed analysis.

The chert sample and spectral databases generated by the study will contribute to other research dealing with the use of Lower St. Louis and Fort Payne resources by prehistoric people of the Southeast. The addition of new samples and sample locations will expand our understanding of resource selection, use and distribution. The expansion of the chert spectral database will also allow researchers to refine our ability to more closely reflect the procurement decisions of prehistoric people. The continuation of research in the areas of sample and spectral databases will allow researchers to ask anthropologic questions at finer spatial resolutions.

The trends reported in the study regarding the distribution of Mississippian sword-form bifaces and the potential relationship between the Lower Tennessee River and Appalachian groups is worth additional investigation. Patterns in other types of cultural materials might clarify or refute the association. Finally, the role of the Mississippian sword-form bifaces as a symbolic link to the Above Realm is a research topic having the potential to clarify a portion of Mississippian cosmology.

In conclusion, the prehistoric reliance upon chert combined with its long term preservation makes chert provenance research a viable means to study the interactions of prehistoric people with both resources and other people on the landscape. Through large sample sizes obtained from multiple deposits within and between chert bearing formations, future research might quantify variation in chert at spatial scales relevant to our anthropological questions. The internal testing of instrumentation according to accuracy, precision and reliability factors are necessary steps prior to reporting provenance data. Once an understanding of the technique(s) capability is quantified then the provenance data may be contextualized. Only then can chert provenance data reach its ultimate potential and contribute to our understanding of the archaeological record and those that created it.

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APPENDIX

WAVELENGTH (nm) VARIABLES SELECTED IN THE DISCRIMINANT FUNCTION MODELS

I. VNIR inter-formation internal accuracy tests

a. Base model

400	416	438	443	444	448	456	463	481	483
488	507	518	522	523	531	532	541	564	582
583	603	607	614	615	621	635	642	645	650
656	690	696	702	723	726	742	759	761	766
770	774	776	791	802	805	827	831	843	851
852	853	859	875	882	924	960	983	1027	1148
1267	1389	1482	1495	1505	1534	1599	1601	1605	1620
1629	1661	1665	1669	1677	1688	1692	1700	1704	1741
1754	1821	1846	1856	1862	1884	1915	1959	2010	2037
2039	2080	2097	2112	2225	2236	2260	2269	2307	2333
2335	2341	2352	2460	2463					

b.

c.

b. 10% unknown sample

400	416	436	439	443	444	448	456	481	483
507	518	522	531	541	564	603	607	614	615
621	630	635	645	679	690	696	723	726	742
759	766	770	774	776	791	795	802	805	827
831	843	852	859	875	882	891	893	983	998
1276	1278	1394	1413	482	1505	1534	1601	1605	1614
1620	1665	1669	1695	1700	1738	1761	1793	1856	1862
1901	1910	1959	2048	2097	2225	2236	2269	2333	2335
2341	2352	2445							

c. 20% unknown sample

400	416	436	443	444	448	456	481	483	522
531	541	564	594	614	615	630	642	679	690
696	723	742	759	766	770	774	776	802	805
831	843	848	852	859	873	874	882	891	893
983	998	1267	1476	1482	1505	1534	1604	1614	1620
1761	1856	1862	1866	1901	1910	1925	1959	1999	2048
2080	2269	2333	2335	2352					

d. 30% unknown sample

400	416	443	444	481	483	518	522	583	696
742	759	766	770	774	776	791	801	805	831
843	852	859	882	891	893	969	971	983	998
1273	1482	1505	1534	1601	1605	1620	1665	1669	1692
1695	1700	1761	1814	1884	1901	1910	1959	1980	2236
2269	2333	2335	2357	2391	2392	2445			

4. FTIR inter-formation internal accuracy tests

a. Base model

2669.481	2705.718	2741.956	2947.3	3019.775	3043.933	3164.724	3273.436	3394.227
3623.73	3708.283	3780.758	3913.628	4179.368	4215.605	4324.317	4481.346	4517.583
4553.82	4650.453	4843.719	5036.984	5326.883	5338.962	5459.753	5689.256	5737.572
5858.363	5930.838	6051.629	6305.29	6365.686	6643.505	6703.9	6860.929	6945.482
7042.115	7416.567							

b. 10% unknown sample

2705.718	2741.956	2947.3	3019.775	3043.933	3273.436	3394.227	3623.73	3780.758
3913.628	4179.368	4215.605	4324.317	4396.792	4481.346	4517.583	4553.82	4650.453
4747.086	4843.719	5036.984	5326.883	5338.962	5459.753	5689.256	5737.572	5858.363
5930.838	6051.629	6305.29	6365.686	6643.505	6703.9	6860.929	6945.482	7042.115
7416.567								

c. 20% unknown sample

2693.639	2705.718	2741.956	2947.3	3019.775	3043.933	3164.724	3273.436	3394.227
3623.73	3780.758	3913.628	4179.368	4215.605	4324.317	4481.346	4517.583	4553.82
4650.453	4747.086	4843.719	5036.984	5326.883	5459.753	5508.069	5737.572	5858.363
5930.838	6196.578	6703.9	6860.929	6945.482	7042.115			

d. 30% unknown sample

2669.481	2705.718	2741.956	2947.3	3043.933	3273.436	3708.283	4215.605	4324.317
4481.346	4517.583	4553.82	4747.086	5326.883	5508.069	5689.256	5737.572	5858.363
6051.629	6305.29	6365.686	6945.482	7042.115	7102.511	7416.567	7718.544	8092.997
8636.557	9204.273	11342.27	12320.68	12852.16	13685.62	14289.58		

5. VNIR intra-formation internal accuracy tests

a. Base model

400	416	436	438	439	443	444	448	456	463
472	481	483	488	499	507	518	522	523	531
532	541	547	564	568	570	582	583	588	594
599	603	607	614	615	621	630	635	642	645
650	656	668	670	679	690	696	702	718	723
726	742	759	761	766	770	774	776	791	795
801	802	805	818	827	831	843	848	851	852
853	859	873	874	875	878	882	891	893	924
947	960	969	971	983	998	1002	1027	1148	1174
1221	1224	1226	1234	1250	1267	1271	1275	1276	1277
1278	1301	1372	1389	1417	1476	1482	1495	1505	1524
1534	1557	1582	1599	1601	1604	1605	1612	1614	1620
1624	1629	1661	1665	1669	1677	1688	1692	1695	1700
1703	1704	1732	1738	1739	1741	1750	1754	1758	1761
1766	1776	1788	1793	1806	1814	1821	1833	1846	1851
1853	1856	1862	1884	1901	1910	1915	1925	1959	1980
1989	1999	2010	2021	2026	2037	2039	2046	2052	2057
2070	2080	2097	2103	2112	2129	2152	2197	2225	2236
2243	2255	2260	2269	2303	2307	2333	2335	2337	2341
2352	2357	2391	2392	2449	2453	2460	2463		

b. 10% unknown sample

400	416	436	438	439	443	444	448	456	463
472	481	483	488	499	507	518	523	531	532
541	547	564	568	570	582	583	588	594	599
603	607	614	615	621	630	635	642	645	650
656	668	670	679	690	696	702	723	742	759
761	766	770	774	776	791	795	801	802	805
818	827	831	843	848	851	852	853	859	873
874	875	878	882	891	893	924	947	960	969
971	983	1027	1148	1174	1221	1224	1226	1234	1250
1267	1271	1273	1275	1276	1277	1278	1290	1301	1334
1389	1394	1417	1476	1482	1495	1505	1516	1524	1534
1557	1582	1599	1601	1604	1605	1612	1614	1620	1624
1629	1661	1665	1669	1677	1688	1692	1695	1700	1703
1704	1732	1738	1739	1741	1750	1754	1758	1776	1788
1793	1806	1814	1821	1833	1846	1851	1853	1856	1862
1884	1901	1910	1915	1925	1959	1980	1983	1989	1999
2010	2021	2026	2037	2039	2046	2052	2057	2070	2080
2097	2103	2112	2152	2197	2225	2236	2243	2255	2260
2269	2274	2303	2307	2333	2337	2341	2352	2355	2357
2391	2392	2449	2453						

c. 20% unknown sample

400	416	436	438	439	443	444	448	456	463
472	481	483	488	499	507	518	522	523	531
532	541	564	568	570	582	583	588	594	599
603	607	614	615	621	630	635	642	645	650
656	668	670	679	690	696	702	718	723	726
742	759	761	766	770	774	776	791	795	801
802	805	818	827	831	843	848	851	852	853
859	873	874	875	878	882	891	893	924	947
960	969	971	983	1027	1148	1174	1221	1224	1226
1234	1250	1267	1271	1275	1276	1277	1278	1290	1301
1372	1389	1413	1417	1476	1482	1495	1505	1516	1524
1534	1557	1582	1599	1601	1604	1605	1612	1616	1620
1624	1629	1661	1665	1669	1677	1688	1692	1695	1700
1703	1704	1732	1738	1739	1741	1750	1754	1758	1776
1788	1793	1806	1814	1821	1833	1846	1853	1856	1866
1884	1901	1915	1925	1959	1980	1983	1989	1999	2010
2037	2046	2052	2057	2070	2080	2097	2103	2112	2129
2152	2197	2225	2236	2243	2255	2260	2269	2307	2333
2337	2341	2352	2357	2391	2392	2460			

d. 30% unknown sample

400	416	436	439	443	444	448	456	463	472
481	483	488	499	507	518	522	523	531	532
541	547	564	568	570	582	583	588	594	599
603	607	614	621	630	635	642	645	650	656
668	670	679	690	696	702	718	723	726	742
759	761	766	770	774	776	791	795	801	802
805	818	827	831	843	848	851	852	853	859
873	874	875	878	882	891	893	924	947	960
969	971	983	1027	1148	1174	1221	1224	1226	1234
1250	1267	1271	1275	1276	1277	1278	1290	1301	1334
1389	1394	1417	1482	1495	1500	1505	1516	1524	1534
1557	1582	1599	1604	1605	1612	1616	1620	1624	1629
1661	1665	1677	1692	1695	1700	1703	1704	1738	1739
1741	1758	1766	1776	1806	1814	1821	1833	1846	1851
1853	1856	1866	1884	1901	1915	1925	1959	1980	1983
1989	1999	2010	2037	2039	2046	2052	2057	2070	2080
2097	2103	2112	2152	2197	2225	2236	2243	2255	2260
2269	2303	2307	2333	2335	2337	2341	2352	2357	2391
2392	2449	2460							

6. FTIR intra-formation internal accuracy tests

a. Base model

2572.848	2609.085	2669.481	2693.639	2705.718	2741.956	2947.3	3019.775	3043.933
3056.012	3152.645	3164.724	3176.803	3200.961	3273.436	3394.227	3478.781	3623.73
3708.283	3780.758	3829.074	3913.628	4179.368	4215.605	4239.764	4263.922	4324.317
4384.713	4396.792	4481.346	4517.583	4747.086	4843.719	5036.984	5133.617	5206.092
5326.883	5338.962	5423.516	5459.753	5508.069	5592.623	5616.781	5737.572	5858.363
5906.68	5930.838	5991.233	6051.629	6196.578	6305.29	6365.686	6595.188	6643.505
6703.9	6788.454	6860.929	6945.482	7042.115	7102.511	7416.567	7597.753	7718.544
8346.658	8407.054	8443.291	8636.557	8769.426	8926.454	9204.273	10726.24	11088.61
11342.27	11426.83	11801.28	12320.68	12852.16	13685.62	13758.09	13806.41	14289.58
14398.29								

b. 10% unknown sample

2572.848	2609.085	2669.481	2693.639	2705.718	3019.775	3043.933	3056.012	3152.645
3164.724	3176.803	3273.436	3394.227	3478.781	3708.283	3780.758	3913.628	4179.368
4215.605	4239.764	4263.922	4324.317	4384.713	4396.792	4481.346	4517.583	4553.82
4650.453	4747.086	4843.719	5036.984	5133.617	5206.092	5326.883	5338.962	5423.516
5459.753	5508.069	5592.623	5616.781	5689.256	5737.572	5761.73	5858.363	5906.68
5930.838	5991.233	6196.578	6305.29	6365.686	6595.188	6643.505	6703.9	6788.454
6860.929	7102.511	7416.567	7597.753	8346.658	8407.054	8443.291	8636.557	8769.426
8926.454	9204.273	11269.8	11426.83	11801.28	12320.68	12852.16	13758.09	13806.41
14289.58	14398.29							

c. 20% unknown sample

2572.848	2609.085	2669.481	2693.639	2705.718	2741.956	3019.775	3043.933	3056.012
3152.645	3164.724	3176.803	3273.436	3394.227	3478.781	3623.73	3708.283	3829.074
3913.628	4179.368	4215.605	4239.764	4263.922	4324.317	4396.792	4481.346	4517.583
4553.82	4650.453	4747.086	4843.719	5036.984	5133.617	5206.092	5326.883	5338.962
5423.516	5459.753	5508.069	5616.781	5689.256	5737.572	5761.73	5858.363	5906.68
5930.838	6051.629	6305.29	6365.686	6643.505	6703.9	6788.454	6860.929	7042.115
7102.511	7416.567	8346.658	8443.291	8636.557	8926.454	9204.273	10726.24	11801.28
12163.65	12852.16	13758.09	13806.41	14289.58	14398.29			

d. 30% unknown sample

2572.848	2609.085	2669.481	2693.639	2705.718	2741.956	2947.3	3019.775	3043.933
3056.012	3152.645	3164.724	3176.803	3200.961	3394.227	3478.781	3623.73	3708.283
3829.074	3913.628	4179.368	4215.605	4239.764	4263.922	4324.317	4384.713	4396.792
4481.346	4517.583	4650.453	4747.086	4843.719	5036.984	5133.617	5206.092	5326.883
5338.962	5423.516	5459.753	5508.069	5592.623	5616.781	5689.256	5737.572	5761.73
5858.363	5906.68	5930.838	6051.629	6196.578	6305.29	6365.686	6595.188	6643.505
6703.9	6788.454	6860.929	6945.482	7042.115	7102.511	7597.753	7718.544	8092.997
8346.658	8407.054	8443.291	8636.557	8769.426	8926.454	9204.273	11088.61	11342.27
11426.83	11801.28	12163.65	12320.68	12852.16	13685.62	13697.7	13758.09	13806.41
14289.58	14398.29							

7. Mississippian swords VNIR inter-formation provenance

416	436	444	448	456	481	483	522	531	541
564	568	588	603	607	614	615	621	630	635
642	645	679	690	696	723	742	759	766	770
774	776	791	795	802	805	831	843	848	852
873	874	882	891	893	983	1276	1394	1413	1482
1505	1534	1604	1614	1620	1665	1669	1677	1692	1695
1700	1738	1761	1806	1856	1866	1884	1901	1910	1959
1999	2048	2052	2097	2152	2225	2269	2333	2335	2352
2445									

8. Mississippian swords FTIR inter-formation provenance

2669.481	2705.718	2741.956	2947.3	3043.933	3273.436	3394.227	3623.73	3708.283
3780.758	3913.628	4179.368	4215.605	4324.317	4481.346	4517.583	4553.82	4650.453
4843.719	5326.883	5338.962	5459.753	5508.069	5689.256	5737.572	5930.838	6051.629
6305.29	6365.686	6643.505	6860.929	6945.482	7042.115	7597.753	8769.426	8926.454
9204.273	11342.27	12163.65	12320.68	12852.16	13697.7			

9. Mississippian swords VNIR/FTIR inter-formation provenance

416	438	439	443	444	448	456	481	483
488	568	594	603	607	614	615	621	635
679	696	723	742	759	766	770	774	776
791	802	805	831	848	852	859	874	882
971	983	1267	1276	13697.7	1372	1482	1524	1534
1605	1620	1665	1669	1695	1700	1704	1761	1814
1856	1862	1901	1910	1999	2048	2152	2335	2352
2357	2445	2705.718	2741.956	2947.3	3019.775	3043.933	3176.803	3273.436
3913.628	4179.368	4215.605	4324.317	4481.346	4843.719	5508.069	5592.623	5689.256
5737.572	5761.73	5858.363	5930.838	6305.29	6365.686	6860.929	6945.482	7042.115
8346.658	8407.054	8636.557	11342.27	12852.16	14289.58			

10. Mississippian swords Dover group intra-formation provenance

439	463	472	507	518	532	564	570	583
588	599	615	642	645	668	723	726	766
795	801	805	831	843	851	852	873	878
947	983	1234	1278	1505	1665	1688	1703	1732
1738	1806	1821	1833	1851	1853	2046	2225	2335
2445	2669.481	2947.3	3019.775	3043.933	4239.764	4517.583	5036.984	5133.617
5459.753	5689.256	5761.73	5906.68	5930.838	6595.188	6643.505	6788.454	7042.115
8346.658	8636.557	8769.426	12852.16	13697.7	14289.58	14398.29		

11. Mississippian swords Fort Payne intra-formation provenance

416	436	438	439	443	444	448	456	463
472	481	483	488	499	507	518	522	523
531	532	541	547	564	568	570	582	583
588	594	599	603	607	614	615	621	630
635	642	645	650	656	668	670	679	690
696	702	718	723	726	742	759	761	766
770	774	776	791	795	801	802	805	818
827	831	843	848	851	852	853	859	873
874	875	878	882	891	893	924	947	960
969	971	983	1027	1148	1174	1221	1226	1234
1250	1273	1276	1278	1290	1301	1334	1394	1476
1482	1500	1505	1516	1524	1534	1582	1599	1601
1604	1605	1612	1616	1620	1624	1629	1661	1665
1669	1677	1692	1695	1700	1703	1704	1732	1741
1750	1758	1776	1788	1806	1814	1821	1833	1846
1851	1853	1862	1884	1901	1910	1915	1925	1959
1980	1989	1999	2010	2026	2037	2046	2048	2052
2070	2080	2097	2103	2152	2197	2225	2236	2243
2255	2260	2269	2307	2337	2341	2352	2391	2449
2572.848	2609.085	2669.481	2693.639	2705.718	2741.956	3019.775	3043.933	3056.012
3152.645	3176.803	3478.781	3913.628	4215.605	4239.764	4263.922	4324.317	4396.792
4481.346	4517.583	4650.453	4747.086	4843.719	5133.617	5206.092	5326.883	5338.962
5423.516	5459.753	5592.623	5616.781	5689.256	5737.572	5858.363	5906.68	5930.838
6051.629	6196.578	6305.29	6365.686	6595.188	6643.505	6860.929	6945.482	7042.115
7416.567	7597.753	7718.544	8407.054	11342.27	11426.83	12163.65	12320.68	12852.16
8443.291	8636.557	8769.426	8926.454	9204.273	13697.7	13758.09	13806.41	14289.58
14398.29								