A CHERT SOURCING STUDY USING VISIBLE\NEAR-INFRARED REFLECTANCE SPECTROSCOPY AT THE DOVER QUARRY SITES, TENNESSEE

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by
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A CHERT SOURCING STUDY USING VISIBLE\NEAR-INFRAED REFLECTANCE SPECTROSCOPY AT THE DOVER QUARRY SITES, TENNESSEE

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ABSTRACT

The field of archaeology is increasingly becoming a multidisciplinary approach to studying the material remains of the past. This trend can especially be seen in chert provenance studies. Chert provenancing, or chert sourcing studies, seek to trace an artifact made of chert back to its original place of procurement. The knowledge gained from these studies can greatly aid researchers’ understanding of the dynamic relationship that prehistoric people had with the landscape and the natural resources available to them. Chert sourcing studies may also tell us about how particular groups moved within a region over time. Finally, this type of data could help archaeologists identify prehistoric trade networks or interaction spheres. A large variety of methods have been developed to perform this type of analysis. The current study uses the fundamental principles of remote sensing to examine the interactions that light has with chert over portions of the electromagnetic spectrum in order to identify variation between and within various outcrops and types. A case study of the prehistoric Dover Quarry sites in Stewart County, Tennessee was selected to test the application of Visible Near-Infrared Reflectance Spectroscopy (VNIR) to sourcing chert samples back to their geologic and geographic origins.
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CHAPTER 1
INTRODUCTION

Purpose of Study

The prehistoric quarry sites of Stewart County Tennessee are frequently referenced in the archaeological literature of the southeastern United States yet little has been done to accurately survey the geologic context, spatial extent, or quantity of prehistoric mining activity at each site. The current study sought to fulfill this need by accurately surveying each site. Samples from the prehistoric quarry sites were then utilized in a case study to test the application of Visible/Near-Infrared Reflectance spectroscopy to chert sourcing.

Prehistoric people had an intimate knowledge of the natural resources available to them. They exploited these resources to varying degrees throughout prehistory. Arguably one of the natural resources most relied upon by prehistoric people was stone. They utilized stone predominately to craft various tools necessary for a wide range of tasks. The most popular stone of choice by prehistoric people was chert or flint. A more in depth discussion of terminology will follow in Chapter 2 distinguishing chert and flint but both were extensively utilized for tools. The physical characteristics of this material made it conducive for the manufacture of sharp durable implements such as knives and projectile points. Due to the usually poor preservation of much of the prehistoric material
culture stone tools (i.e., lithics) are often the only remaining traces archaeologists have of past occupations.

The biased data set we are left with limits our knowledge about prehistoric life and constricts our interpretations. Despite these limitations archaeologists have been able to hypothesize about a number of aspects of prehistoric life from the analysis of lithic assemblages. Elaborate chronologies have been constructed linking prehistoric production techniques and tool forms to temporally dated contexts. With the advent of experimental archaeology the identification of diagnostic polishes and edgeware damage can also give insights into the functionality of stone tools and the type of material modified by stone implements.

Chert provenance studies, also called chert sourcing, examine the geologic origin of a particular chert type recovered from an archaeological site (Luedtke 1979:117). Provenance studies of chert artifacts can provide data about migration patterns and trade networks. By examining the geologic occurrence of chert sources known to have been exploited by prehistoric people and demonstrating a link between these deposits and cultural implements, researchers can trace the movements of an object or a group of people across the landscape. A good example of this comes from a study conducted by Shakley (1992) in which he demonstrated that obsidian artifacts recovered from a number of prehistoric sites were obtained from local secondary alluvial deposits along the Upper Gila River. The source for these obsidian artifacts found at the sites had previously been interpreted as the Yellowstone area. The implication was that prehistoric inhabitants had either migrated from the Yellowstone area or traveled great distances to this source in order to exploit the obsidian deposit. A second example of a chert sourcing study comes
from Nance’s (2000) research that correctly identified chert material from the Morrisoe site as originating from McCormick Creek. Nance’s study confirmed that the majority of the chert materials found at the site came from a local source instead of from the distant Dover Quarry sites which had previously been recognized as the source location.

The relationship between the landscape, natural resources, and how people utilized both can be explored in greater detail from the data generated by these studies. Patterns can be deduced that shed light not only on lithic material procurement localities, but also on production, use, and discard localities. Smaller prehistoric sites lacking diagnostic artifacts or other datable material would take on a greater significance if the stone artifacts could be confidently traced back to their source and other temporally secure sites in the vicinity.

Like many other natural resources the quality of chert varies, and as a result the locations yielding high grade material were heavily exploited after by prehistoric populations. Ethnographic and archaeological evidence both demonstrate that prehistoric populations intentionally selected certain colors, textures, and glosses in chert (Luedtke 1992). As a result of this demand groups living in close proximity to a high quality chert source often manufactured items for trade. Many of these materials were exchanged over great distances and are recovered in a number of archaeological sites within a region. Chert provenance studies identifying the relationship between these items and their geologic origins greatly enhance our understanding of prehistoric economic activities. Chert provenance studies would provide data on where the stone material was being procured, the work shop where the implement was being produced before eventually being traded, deposited, and later excavated by the archaeologist.
Lithic Procurement Strategies

Prehistoric people often traveled great distances to exploit favored outcroppings of chert. Conversely, in geographic regions rich in chert resources tool grade material could be simply procured from local gravel bars or upland seasonal tributaries and other erosional features. Some prehistoric groups cycled through vast amounts of chert while others conserved this resource by developing more multi-purpose tools and heavily existing implements. Both these tendencies illustrate a reliance on chert materials and reflect the importance prehistoric people placed on stone tool manufacture. The extraordinary effort that some groups exerted in obtaining lithic raw materials attests to the value of this resource.

There are three primary extraction strategies utilized by prehistoric populations; these strategies seem to reflect the geologic occurrence of chert materials. In areas were chert residuum existed in glacial till, alluvial deposits, and eroding cut banks, acquisition of stone tool material was relatively easy. In these regions chert material may have been gathered during everyday subsistence activities (Binford 1979). Specific forays focused on the procurement of lithic material were unnecessary. This does not imply that favored outcrops at great distances were not exploited, but demonstrates that the local geologic abundance of tool grade materials made it unnecessary. Acquisition sites from this exploitation pattern would be hard to distinguish in the archaeological record due to the slight trace they leave behind on the landscape. Compounding these issues is the fact that the chert deposits exposed during ancient times may no longer exist as visible features on the landscape (Luedtke and Meyers 1984). The migration of ancient river channels, continuous effects of sheet erosion, and non-localized prehistoric mining activity may
give archaeologists a very limited view of the geologic origins of stone tool assemblages at a specific site. The mixing and unsorted nature of secondary deposits of chert gravels provided a wide selection of various material types. The presence of these materials at a site might leave the faulty impression that the prehistoric inhabitants traveled great distances to obtain this lithic variation rather than gathering it from secondary deposits such as gravel bars.

A second method of chert procurement exists in regions where chert material outcrops as discrete units encased within a parent formation. The geologic occurrence of chert either as bedded lithofacies or nodular inclusions facilitated a different procurement strategy. A more deliberate method of procurement was adopted (Holmes 1919). Antler picks, hammerstones, digging sticks and fire were utilized to extract the chert from the parent formation. The obvious drawback to this approach was that a great deal of time and effort was needed to obtain the material. However, once extracted the material would have been of a far superior quality than chert found in secondary contexts. This is primarily due to the lesser degree of weathering experienced by chert encased in its parent formation. This procurement method leaves a significant mark on the landscape that is often readily identified as a quarry site. Some common features at these sites include large piles of debitage in the form of tested and rejected cobbles or slabs, concavities in the outcrop where chert was extracted, and angular fragments of the parent material in the talus debris.

A third method of prehistoric chert procurement is noted at a number of prehistoric quarry sites (Holmes 1919). At these sites chert residuum is mined out of the soil matrix. Large circular depressions were excavated into the soil in order to obtain the chert
material. The pedogenesis of these soils is directly attributed to the decomposition of the soluble underlying geologic units. The more resistant chert exists as free floating detritus no longer encased within the parent formation. Quarry sites of this nature are often the largest variety of prehistoric mining activity. In areas where these geologic conditions existed, hundreds of depressions may be observed covering great distances such as at the Mill Creek site in southern Illinois.

The intensive use of these quarry sites is demonstrated not only by the sheer number of mining pits but also by the evidence of abandoned excavations that were refilled and re-excavated at a later date. The large dimensions of some of these pits reflect the intense effort to extract an unknown amount of material. The use of digging implements such as antler picks, digging sticks, and chert implements aided the miners’ efforts. The occurrence of the chert materials within the soil matrix must have made the task of obtaining large amounts of material less labor intensive than extraction from the parent formation. These areas appear to have been well known during certain periods of prehistory and the chert material mined from these sites is often widely distributed over great geographic distances.

Prehistoric procurement methods are dictated by the geologic setting in which the inhabitants settled and the nature of the chert materials in the region. This type of environmental determinism should by no means be purported as being the sole factor in understanding how chert was obtained during prehistory. However, a strong correlation exists between the geologic occurrence of chert deposits and the method in which prehistoric people acquired the resource. This relationship can be observed at the Dover Quarry sites of Tennessee which are used as a case study in the current investigation.
Statement of Problems

Dover chert is a material type well known in the archaeological record of southeastern North America. The geographic center for Dover chert has been attributed to the large quarry sites located in Stewart County, Tennessee (Figure 1). A total of five recorded prehistoric quarry sites are listed for Stewart County and will be discussed in greater detail in Chapter 5. The chert materials from these sites exist as large nodules either as residuum in the silty clay soil matrix or as inclusions in the Mississippian aged limestone. As discussed above, the geologic occurrence of these nodules directly influenced the procurement strategy at each site.

Fig. 1. Location of the five previously recorded prehistoric Dover Quarry sites in Stewart County, Tennessee
The presence of chert materials other than Dover in the region demonstrates that a wide range of high quality lithic resources would have been available for prehistoric utilization. Of these other chert types one specific variety of Ft Payne is essentially macroscopically indistinguishable from Dover chert found at the quarry sites. This observation combined with the presence of other Dover like materials outside of Stewart County illustrates the need for a reliable chert sourcing technique capable of quantifying the intra and inter-outcrop variation present among the chert materials in the study area and within the recorded quarry sites in order to provide a reliable database for future provenance studies.

In order to quantify the variation between different chert types in the region and the variation occurring within a specific chert type, this study utilized Visible/Near Infrared Reflectance (VNIR) spectroscopy. VNIR is a non-destructive remote sensing technique that has been used in many disciplines to study how light interacts with different materials. The application and usefulness of this technique was tested on 200 chert specimens taken from the study area. The resulting data were then evaluated to determine if various chert types could be differentiated from one another. The study was then taken further to see if the technique could distinguish Dover chert from one quarry site from Dover chert from a second quarry site. Finally the advantages and disadvantages of using this method were evaluated for provenancing Dover chert.

The development of a non-destructive, fast, and accurate technique will benefit the field of archaeology in general and, more specifically, the researcher who wishes to study the geologic provenance of artifacts. The role that archaeology plays in conservation and preservation makes the destruction of even a seemingly insignificant artifact hard to
justify. A non-destructive technique greatly enhances archaeologists’ ability to analyze a specimen while preserving it for future researchers and public interest. Moreover, an accurate means to identify the geologic origins of a chert artifact enhances archaeologists’ understanding of how prehistoric people utilized these deposits for tool manufacture or trade implements over a temporal and spatial continuum. Researchers could quantify how a specific material type or quarry outcrop was utilized over time by correlating artifacts found in dated contexts to their original place of procurement. Other studies could focus on the ways different groups used different types of chert. These examples demonstrate the advantages that would be gained by the development of a non-destructive, fast, and accurate chert sourcing technique.
CHAPTER 2
GEOLOGY OF STUDY AREA

Any study seeking to identify chert resources exploited by prehistoric people must first recognize the unique geologic formations within a particular region of interest. It is only through the analysis of the geologic, physiographic, and topographic history of the study area that a more comprehensive view of material availability and prehistoric lithic exploitation can be realized. Understanding the geologic formation of chert sheds light on where materials may have been available prehistorically across the landscape due to weathering and other natural processes. An analysis of these geologic processes allows the researcher to interpret inter- and intra-outcrop variability and the reasons certain materials were exploited as opposed to others. It is within this context that an overview of the geologic history of the Dover area is a necessity before proceeding with further investigations.

Dover, Tennessee

The Dover geologic quadrangle map covers an area approximately 780 square kilometers in and around Dover, Tennessee. The information below focuses on the topographic and geologic characteristics of this area with an emphasis on the specific geologic formations that contain chert materials suitable for prehistoric exploitation.
The study area is characterized by dissected hills and patches of dense forest and is composed of geologic formations ranging in age from the Devonian to Quaternary (Marcher 1962a). The region may have been above water during the Ordovician Period as revealed by the lack of deposits of this age which are present to the east in the Central Basin (Bassler 1932). Deposits of the Late Cretaceous and Tertiary Periods occur in the western portion of the area and may indicate that this was a low lying area until after the Pliocene (Marcher 1962a). A broad perspective of the area reveals Dover to be on the southwest flank of the Tennessee lobe of the Illinois basin. The southern section of the area dips to the northeast, but shifts to the east in the northwestern part (Marcher 1962a). The town of Dover lies on the south bank of the Cumberland River and is easily accessed by U.S. Highway 79 and State Highway 49. The area offers a unique perspective on the depositional record of the Highland Rim province.

**Soils**

The soils in the vicinity are primarily assigned to the Baxter-Hammack-Brandon association composed of a brown to reddish brown cherty silt loam. These soils are located on rolling to steep hillsides and hilltops (United States Department of Agriculture, Soil Conservation Service [USDA, SCS] 1975). These sediments are directly attributed to the weathering of limestone formations.

**Highland Rim**

Tennessee is divided into eight topographic regions, each grouped according to its distinguishing traits (Figure 2). The easternmost province is the Unakas, followed to the
Fig. 2. Physiographic Provinces of Tennessee: (a) relationship with underlying geologic units; (b) plan view (from Miller 1974)
west by the Valley and Ridge, Cumberland Plateau, Highland Rim, Central Basin, Western Valley, Coastal Plain, and the Mississippi River Valley. The topographic diversity of these regions provides a variety of different ecological environments and available resources. The main focus of this study is the occurrence and availability of chert deposits. Each of the eight physiographic provinces of Tennessee offers varying degrees of material accessibility. Therefore, an overview of the topographic regions of the state is useful in developing an understanding of where on the landscape chert materials were present.

The Highland Rim is commonly subdivided into east and west portions almost entirely engulfing the Central Basin of Tennessee (Figure 3). This province represents the largest natural division of the state (Bassler 1932). The eastern half of the Highland Rim is often referred to as the “Barrens”. The nickname of the area refers to the poor fertility of the gray soil due to the underlying Ft Payne formation. The weather resistant cherty materials create this barren landscape as it impedes soil formation. The area is characterized by swamps with a dissected escarpment containing numerous narrow valleys grading down to the Cumberland Plateau (Miller 1974). Along this eastern escarpment, sandstone and conglomerate formations cap the plain above protecting the underlying limestone from erosion. As a result, the weathering of the limestone along the escarpment undermines the sandstone creating large blocks that tumble down the cliff.

The western half of the Highland Rim is characterized by rolling terrain with numerous streams producing karst topography from Stewart County to Summer County into Kentucky. Also present are maturely dissected valleys which have filled in with more recent silt deposits (Bassler 1932).
Fig. 3. Generalized geologic map of Tennessee showing the major depositional units, Stewart County highlighted in red. (modified from Miller 1974)
The oldest geologic units in the Dover area were deposited during the Devonian period. These consist of the Camden Chert, Pegram Limestone, and Chattanooga Shale. These are immediately followed by the Mississippian System; the New Providence Shale, Ft Payne, Warsaw, St Louis, and Ste. Genevieve Limestone. Cretaceous aged gravels are sparsely represented by the Tuscaloosa Gravel and the Coffee Sand Formations. The Layfayette Gravels make up the Tertiary System deposits and unsorted gravel, sand, silt, and clay compose the Quaternary aged alluvium (Figure 4).

**Devonian System**

The Devonian system is underrepresented in the geology of the Dover area. Rocks of this age can only be found in the Kentucky Lake vicinity of Scott Fitzhugh Bridge where upward folding has brought them to the surface (Marcher 1962a). The Devonian system is composed of three units, the Camden Chert and the overlying Pegram Limestone. The Upper Devonian contains the Chattanooga Shale which overlies both the Camden and Pegram Limestone. These formations represent the extent of the Devonian aged strata in the region.

**Mississippian Period**

The majority of the geologic units encountered within the study area are attributed to the Mississippian Period (Figure 5). The Mississippian Period is characterized by shallow seas with shifting currents, migrating shorelines, and the deposition of clastic sediment. Much of the land in Tennessee was at sea level characterized by tidal flats and the beginnings of swamp forests into which mud washed (Miller 1974). The majority of
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Fig. 4. Geologic Formations of Western Tennessee grouped by system (Miller 1974)
Fig. 5. Dover geologic quadrangle map showing major formations (modified from Marcher 1964)

Fig. 6. Extent of the Mississippian Embayment (Miller 1974)
the Mississippian aged outcrops are exposed along the Highland Rim providence of central Tennessee. 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 Periods. However, the large inland sea in the east central United States (Figure 6) at this time deposited a large amount of silty limy sediment which was replaced in part by silica.

This formation is called the Ft Payne and is characterized by bedded and disseminated chert, shale, siltstone beds, and dolomitic zones (Miller 1974). This depositional environment is best described as the result of a complex interplay of processes. Crossbedding in the Ft Payne formation indicates strong wave or current action while other units indicate quite waters. Clastic deposits of sand, shale, and chert 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. The most abundant fossils found in the Mississippian System are the crinoids, giving this time period its nickname “The Age of the Crinoids.” Large masses or mounds of crinoids 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 parts of
limestone beds (Miller 1974). The coarse grained limestone deposits are made up of large shell fragments, whereas fine grained limestone consists of organically secreted or chemically precipitated lime ooze. Vertebrate fossils are also present in the Maury shale and Newman limestone.

Safford (1856) was the first to describe the various limestone and chert formations that comprise the Mississippian System in Tennessee. Safford points out the “layers of hornstone or flint, geodes of quartz and beds of cherty limestone” when describing the system (Safford 1856.) He was also the originator of the term “siliceous strata,” using it to describe these geologic units (Marcher 1962a). The Mississippian System begins with the Maury formation overlying the Chattanooga shale, followed by the New Providence Shale, Ft Payne, Warsaw, St Louis, and Ste. Genevieve formations.

Maury Formation

The Maury Shale represents the first episode of deposition during the Mississippian Period. This was the first depositional unit of the Mississippian sea as it advanced south into the Tennessee lobe of the Illinois Basin (Marcher 1962a). The Maury Shale can be described as a light olive gray to yellow gray mudstone, containing many flattened nodules. The exterior of these nodules is yellowish gray with a dark interior. No bedding is present within the formation (Marcher 1962a). An outcrop of the Maury Shale can be viewed on the south side of highway 79 at the east end of the Scott Fitzhugh Bridge. An unconformity exists between it and the underlying Chattanooga Shale indicating an episode of erosion just before the deposition of the formation. This differs from the apparent conformal relationship exhibited by the formation in other parts of the Highland Rim.
New Providence Shale

The stratum overlying the Maury Shale is the New Providence Shale. The New Providence Shale most likely represents a near shore or shallow water phase of the Ft Payne formation (Marcher 1962a). This formation is described as medium gray to gray/green, calcareous clay shale. However, in other parts of the Western Highland Rim it is a dark gray silty shale or mudstone (Marcher 1962a). Glauconite can be found throughout the formation as well as a pale, reddish-brown limestone. Fossil crinoid fragments are common within the formation. The only known outcropping for the New Providence Shale is a syncline at the mouth of Mint Spring Hollow. The relationship between it and the underlying Maury Formation is conformable. An unconformity is visible between it and the overlying Ft Payne Limestone.

Ft Payne Formation

The Ft Payne Formation is a well known formation, not only in Tennessee, but in a number of the east central states including Alabama, Kentucky, Mississippi, Missouri, and Arkansas. Originally named the Tullahoma Formation by Hayes and Ulrich (1903), Bassler (1932) was the first to call it Ft Payne after its type locality in Alabama. The Ft Payne probably represents dark colored highly siliceous deposits that formed further out in the Illinois basin. The maximum thickness of the formation is 136 m, averaging 61 to 76 m thick in the Dover area (Marcher 1962a). Outcroppings occur throughout the southwestern quarter, along Cross Creek south of the Carlisle fault, in the bluffs along Kentucky Lake, Standing Rock, and Leatherwood Creeks (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 are intercalated with siliceous limestone or siltstone containing siliceous geodes. The scraggy chert lithofacies are 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 (1962b) uses the term ‘scraggy’ to describe the chert based upon its blocky appearance caused by small scale folding and faulting after the soluble sediments are leached away.

Characteristics of the Ft Payne Formation include small carbonate rhombs, cubes and irregular masses of unaltered pyrite, and beds of fine- to coarse-grained fossil calcarenite (Marcher 1962a). It should be noted that the occurrence of pyrite is rare as some have been altered to iron oxide. The most abundant fossil type within the Ft Payne are crinoid stems, often located where 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 1962a). 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 area these beds thicken indicating a slow subsidence of the depositional basin (Marcher 1962a). In thin section Ft Payne limestone appears as a microcrystalline mosaic of interlocking calcite and silica particles; crystal boundaries are almost entirely lacking (Marcher 1962b). Small amounts of fibrous silica and microcrystalline quartz are present along with the cryptocrystalline silica. There is a wide range of particle size, but the uniform texture is attributed to recrystallization of the original lime mud (Marcher 1962a). The upper beds of chert in the Ft Payne can be
similar to the overlying Warsaw formation and are often hard to delineate visually in a geologic profile.

Warsaw Formation

The type site for the Warsaw Formation is the city of Warsaw, Illinois. The formation can be found from the Mississippi River extending eastward to the Unakas in Tennessee. Unlike the Ft Payne formation, the Warsaw does not display thickening deposits. This suggests that the subsidence of the Mississippian basin had diminished before the beginning of deposition (Marcher 1962a). The environment of deposition is interpreted as being an open shelf shoal with shallow, warm, turbulent waters. These waters must have been well supplied with food to support the abundant prehistoric life represented in the fossil record (Marcher 1962a).

Bassler (1932) was the first to define the Warsaw Limestone as a separate unit from the Ft Payne. Outcrops of the Warsaw Formation often exhibit crossbedding of thin or laminated strata. The Warsaw is typically 55 m thick, composed of fine to coarse grained calcarenite, dolomitic limestone, and coquinite (Marcher 1962b). Also present are broken fossil and granule sized organic fragments. This unsorted, light colored mixture of fossil detritus and anhedral calcite rarely exhibits any orientation of the particle to the bedding surface (Marcher 1962b). This combined with crossbedding of the broken abraded particles is a good indication of turbulent, well-aerated waters. The presence of corrosion and abraded grains signifies recrystallization episodes during formation. The environmental conditions affected texture and color differences during deposition. The coarser calcarenites are medium gray to yellowish gray while fine textured beds are pale to dark yellowish brown (Marcher 1962a). The upper half of the Warsaw formation is
described as discontinuous and irregular beds that are finer grained and darker in color. They also contain a greater amount of siliceous chert than what typically occurs. These finer grained, dark beds are made up of broken fossil debris which is oriented in a manner that gives them a laminated appearance (Marcher 1962b).

Commonly occurring fossils include bryozoans, echinoids, brachiopod shells, and threadlike algae. These often combine to form beds of coquinite. These beds can be identified in thin sections as irregularly corroded organic fragments surrounded by secondary calcite. Also present are bryozoan fragments that are encrusted with micro laminated calcite possibly of algal origin (Marcher 1962a). Other thin-sectioning analysis shows fine clayey materials, glauconite, pyrite, rounded quartz particles, and iron oxides. The transition between the Warsaw and underlying Ft Payne can be described as sharply defined, gradational, or conformable and easy to identify. The identification of the overlying St Louis is more difficult and interbedding seems to occur in some places (Marcher 1962a).

St Louis Formation

The St Louis formation, named after exposures in St Louis, Missouri, makes up the dominate surfical geologic unit across the Highland Rim Plateau. Safford (1900) describes the St Louis limestone as a “gray and blue, thickbedded, fossil bearing limestone, usually with nodules of chert and from 250 to 300 feet thick.” Shoal like conditions were maintained during the deposition of the St Louis. 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, quite water to shallow, agitated water (Marcher 1962b). 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 weathering of the formation also contributes to the rolling hilly countryside and the occurrence of sinkholes and caves. The St Louis formation overlies the Warsaw formation conformally, but may be distinguished by its dark colored beds in contrast to the lighter Warsaw (Marcher 1962b). The 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 1962a). One distinguishing characteristic of the St Louis is that crossbedding is not as abundant as in the Warsaw Formation. 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 1962a).

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 shaley 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 including brachiopod shells, blastoids, crinoids, echinoid ossicles, bryozoans, fibrous algae, ooliths, and two types of fossil coral (L. canadense, L. proliferum) are present (Cushman 1931). Thin sections reveal that cryptocrystalline silica, through replacement processes, have destroyed much of the original texture. The matrix consists of feathery quartz, Endothryroid foraminifera, clear crystalline calcite, and organic detritus (Marcher 1962a).
Ste. Genevieve Formation

The Ste. Genevieve formation is the uppermost formation of the Mississippian System exposed in the Dover area. The longer exposure to periods of weathering has reduced this limestone unit to only three outcrops, near Hopkinsville, KY, Clarksville, TN, and in Humphreys County, TN. Ste. Genevieve limestone is described as a light colored, highly oolitic non-silty material (Marcher 1962a). Remnants of the formation can be found as scattered boulders on top of high ridgelines and as downfaulted blocks. The stratigraphic relationship between the Ste. Genevieve Limestone and the underlying St Louis formation is unknown in the Dover area.

A reliable index fossil for the Ste. Genevieve formation is the **Platycrinus Penicillus** (Marcher 1962a). Fauna consisting of bryozoans, brachiopods, corals, and other marine organisms flourished on open marine shelf or barrier banks (Marcher 1962a). Well developed sorting and ooliths formed around fossil fragments are also present in the limestone. This supports the interpretation of a well aerated shallow marine environment. The formation is generally absent in the Dover region prohibiting a more in depth analysis. The St Louis formation is usually unconformably overlain by Cretaceous System sand and gravels due to this absence of the Ste. Genevieve.

Cretaceous System

It is hypothesized that the western section of the Highland Rim Plateau was above water and subject to weathering during much of the Mesozoic Era. No rocks of the Pennsylvanian, Permian, Triassic, or Jurassic Periods are preserved in the Dover area (Marcher 1962a). As previously mentioned the deposition during the Cretaceous Period was predominately sand and gravel alluvium. This assortment of materials was carried
by river systems that eroded the Ozark Dome (Pascola Arch) and other western highlands over 1,600 kilometers to the northwest (Miller 1974). Two formations are present within the Dover area. These are the Tuscaloosa Gravel and the Coffee Sand formations.

Tuscaloosa Gravel Formation

The Tuscaloosa Gravel formation can be found along many of the higher ridgelines and hills in the Dover area. Patches of the formation may be seen on the upland topography along highways 79 and 49. Pockets of Tuscaloosa Gravel may have been deposited inside sinkholes that were formed during weathering of the soluble Mississippian limestone (Marcher 1962a). Weathering has made its occurrence discontinuous across the region. The formation is primarily composed of unsorted chert gravels 2 to 20 centimeters in diameter in a sandy clay matrix (Marcher 1962a). The chert gravels are from the Mississippian-aged limestone formations or Devonian Camden chert that may have mixed with the Tuscaloosa Gravel during erosion of the soluble limestone sinkholes encasing the deposit. The matrix has a high Kaolin content due to the weathering of chert. Sand particles are chert and quartz grains with thin lenses of kaolinitic clay (Marcher 1962a). The beds of this deposit are described as massive without internal structure, bleached, layered with cemented conglomerate, and stained with iron and manganese. A major unconformity is present wherever the formation is in direct contact with the underlying Mississippian aged limestone. The Tuscaloosa Gravel gradationally transitions to the overlying Coffee Sand formation.
Coffee Sand Formation

The Coffee Sand formation is found on top of the dividing ridge between the Cumberland River and Kentucky Lake. The type locality for this formation is Coffee Bluff in Hardin Co., Tennessee. The formation’s matrix is described as a medium to coarse brown reddish sand, highly silty, and iron stained clay containing well rounded quartz pebbles (Marcher 1962a). Limenite and magnetite minerals are present as well as white kaolinitic clay and iron cemented sand (Marcher 1962a). The sorting of these materials is typically good leading to the interpretation of the formation as terrace deposits. The only fossil known to be present in the Coffee Sand formation in the Dover Tennessee area is the Halymenites Major. Cretaceous streams severely dissected the formation adding to severe surficial weathering producing thin erratic thicknesses along its breadth. The Coffee Sand formation is often lumped in with the underlying Tuscaloosa or overlying Lafayatte Gravels.

Tertiary System

The Tertiary System marks the final depositional episode in the Dover Tennessee region. The period began with a prolonged interval of erosion that stripped some of the Cretaceous gravels from the area producing an unconformity when deposition finally began anew. After the Tertiary Period, the present cycle of dissection commenced and only alluvial deposition of Quaternary age slowed this process.

Lafayette Gravel Formation

The Layfayette Gravel formation is the only unit of Tertiary age represented in the geologic profile of the Dover area. The formation may have been deposited by
coalescing alluvial fans built by the ancestral Mississippi, Ohio, Tennessee, and Cumberland Rivers. The northwestern part of the area has the greatest outcroppings of the formation located on high ridgelines and other areas of high elevation. Materials consisting of chert, sandstone, quartz, quartzite pebbles, cobbles, and boulders may be found associated with noncalcareous sands, silts, and clays stained or cemented by oxides of iron and manganese (Marcher 1962a). It is often difficult to distinguish this formation from the Tuscaloosa Gravels as they come in close contact in areas where the Coffee Sand formation is entirely absent. The Layfayette Gravel is distinguished by its rounded limonite, quartz, quartzite, and hematite pebbles often stained with iron oxides. The structure of the formation can exhibit well developed crossbedding. No known fossils are located within the Lafayette Gravels.

**Chert**

The discussion about the topography and geology of the study area is an important precedent for regional chert studies seeking to understand availability and material variation. Prehistoric people would have had an understanding of these material types and knowledge of where to locate them. The great amount of high quality chert in the Dover, Tennessee region may indicate that an embedded procurement strategy was practiced by certain groups at certain periods. However, the use of Dover chert over thousands of years of prehistory, Mississippi period quarry pits along major drainages in the area, and the extensive geographic area where the occurrence of this material type is present in archaeological assemblages testifies to the importance of the resource to prehistoric people.
Despite its widespread reputation as the material of choice for stone tool manufacture, the geologic origins of Dover chert have not been widely researched. Some speculation and tentative assumptions have placed the material somewhere between the St Louis and Warsaw formations. Three possibilities can be drawn from these hypotheses. The first is that the Dover chert being exploited in the Caney Hollow area along Long Creek is entirely contained within the St Louis formation. Conversely, others suggest its origins are within the underlying Warsaw formation. Finally, a third hypothesis states that the material may represent a transitional unit between the two. The following sections explore these possibilities and attempt to describe not only the chert contained within the St Louis and Warsaw formations, but also the chert contained within the Ft Payne formation. An emphasis will be placed on macroscopic characteristics including color, texture, foraminifera, and other unique traits.

Diagenesis

In this study chert is defined as a sedimentary rock composed primarily of micro to crystalline quartz, occurring in bedded or nodular deposits within limestone or dolomite (Rapp 1998). Chalcedony is excluded from this definition due to its fibrous structure. The terms flint and chert are often used interchangeably in the archaeological and geological literature (Luedtke 1992). The major distinction seems to come from macroscopic characteristics or geographic locations such as dark colored cryptostratigraphic material situated in chalk deposits of England and France. The inherent properties of chert such as its Mohs hardness of 7 ohms, interlocking grains and concoidal fracture mechanics make it an ideal material for producing sharp edges (Bauhn 2001). The processes of chert formation continue to be debated among geologists. As a
result of the Deep Sea Drilling Project where cores up to 1,700 m in depth were analyzed, these processes are better understood by geologists (Luedtke 1992). Two main theories revolving around the biogenic or biochemical development of the material are currently accepted among researchers.

The biogenic theory begins with the accumulation of spicules of sponges (silica) and diatom skeletons (opal secreting algae) forming large beds at the bottom of seas or oceans. The precipitation of these particles can also form nodules at the time of sediment deposition (Bassler 1932). Other theories assume that this process can be accomplished by surfical weathering of silica rich materials such as limestone and dolomite. These silica impurities will then segregate into nodules. A similar hypothesis credits biochemical processes. Rainwater percolates through the parent material and silica rich nodules form due to the replacement of the solid rock by the filling in of cavities or by the partial replacement of unconsolidated carbonates along coastal environments (Heaney et al. 1994). This hypothesis also suggests that surface weathering and the percolation of solution can cause beds of chert to form. These beds may often signify unconformities that occurred during a period of erosion that was eventually encapsulated by new deposition. This process may also occur along joint planes were water carrying soluble materials leaches through (Bassler 1932).

A number of these hypotheses and others are outlined in greater detail by a series of publications produced by the Society of Economic Paleontologists and Mineralogists (SEPM) (McBride 1979). This work will not belabor the subject further, but it is important to know that the details about the processes of chert formation may very well be varied and are still a matter of controversy among geologists.
Despite the different theories surrounding the formation of chert, a number of important points can be taken from these discussions. Chert is a sedimentary rock composed of microcrystalline quartz with various impurities, such as clay and carbonate minerals (McBride 1979). Chert is a direct result of depositional and or post depositional processes, and the inherent characteristics of the parent material are reflected within each outcrop. The composition of each formation differs so that each gives rise to its own type of chert (Bassler 1932). In some instances these differences can be quite small but geologists continue to use the occurrence of certain chert types to distinguish geologic formations. In some parts of Tennessee, the Mississippian-aged limestone formations have been identified solely by their unique chert types. The differences between chert types can be quite small especially when the observer only focuses on a few. However, with the proper knowledge and a trained eye for certain characteristics it may be possible to identify chert types with a certain degree of accuracy either visually or as this study investigates, geochemically, and spectrally.

**Dover Material Availability**

As mentioned above, many chert types would have been available to prehistoric people inhabiting the Dover, Tennessee area. The Ft Payne formation is highly siliceous in nature and contains both nodular and bedded chert types of varying consistencies. Both the Warsaw and St Louis formations have chert residues imbedded within their limestone matrices. The remnants of the overlying Ste. Genevieve formation may even contain fragmentary pieces of chert debris that were exploited by prehistoric people to the north where the formation is more substantial. However, this does not appear to be the case in the Dover area. Finally, it is possible to locate chert nodules in the overlying
Cretaceous gravel units. The Tuscaloosa formation is dominant among these as large rounded cobbles of good quality chert may be found along upland stream and tributary beds. The focus is on the five chert types readily found in the Dover area, Ft Payne, Warsaw, St Louis, Ste. Genevieve, and Tuscaloosa.

Ft Payne Chert

Ft Payne Chert is often described as a solid, blocky, brownish to olive-black material found in the Ft Payne formation. The internal structure of Ft Payne chert is very uniform, composed of cryptocrystalline silica with small amounts of chalcedonic silica and irregularly shaped pherulites (Marcher 1962b). A large amount of iron oxides and brown organic material are present distinguishing it from the parent limestone. The material seems to occur in two forms. One type of Ft Payne chert occurs as large rounded masses of dense, dark chert. The second type occurs closer to the top of the formation and is described as highly porous, fossiliferous chert identical to the overlying Warsaw formation (Marcher 1962b). This latter type, referred to as scraggy chert by Marcher (1962b), makes it difficult to define the boundary between it and the Warsaw. However, in the Dover area this scraggy chert is often fine grained and light in color, a light to very light gray, contrasting with the dark bedded type.

The most abundant fossil types in the Ft Payne chert are crinoid stems and brachiopods. The jumbled appearance of this accumulated debris suggests a period of weathering transformed the calcareous parent material to a silicified form (Bassler 1932). Thin sections of the material reveal interlocking patches of chert and siliceous limestone. Chert makes up 75% of the material with microcrystalline quartz and carbonate rhombs.
present in varying amounts. Individual crystal outlines are not discernable with pyrite and iron oxide accessory minerals rarely present (Marcher 1962a).

Warsaw Chert

As previously mentioned, Warsaw chert can be very porous due to a large amount of fossiliferous material resembling the scraggy chert of the upper Ft Payne formation. Marcher (1962b) attributes the origin of most if not all of the material to secondary origins as a result of surface weathering. The early stages of this process are evidenced by a thin siliceous crust on the surface of the limestone. The interface between these two units continues to undergo silification producing large masses of vesicular chert retaining the original texture of the parent material (Marcher 1962a). The process of replacement is systematic to some degree in that the matrix is replaced first, followed by smaller fossils, and finally larger fossils. It is common to see this process halted incomplete as the remaining calcite is eroded giving the material its characteristic porous appearance (Marcher 1962b).

Matted bryozoa fossils make up the dominate fossil type in Warsaw chert. Various other foraminifera types can be distinguished within the material, aiding in identification. These include Fenestella *tenax*, *F. serrulata*, *F. sanctiludovici*, Polypora *varsoviensis*, Worthenopora *spinosa*, Hemitrypa *proutana*, Blastoids: *pentremites conoideus*, Tricoelocrinus *woodmani*, Brachiopods: Spirifer *lateralis*, *S.bifurcates*, Brachythryris *suborbicularis*, Rhipidomella *dubia*, and Reticularia *salemensis* (Cushman 1931). Bassler (1932) attributes much of the basal materials as rotten, conglomeratic, and vesiculose traits to beach deposits at the initial phase of the Warsaw’s deposition.
St Louis Chert

The St Louis formation is often divided into an upper and a lower unit in other neighboring areas. Chert coming from each section differs in appearance, however around the Dover, Tennessee area the presence of the Upper St Louis formation seems to be absent from the geologic record possibly due to erosion. The St Louis 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 similar in texture to the underlying Warsaw chert, but most of the material consists of the denser, darker, variety (Marcher 1962a). 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.

The lower part of the St Louis formation is characterized by beds of dense, dusky, yellowish-brown, highly siliceous, cherty limestone (Marcher 1962b). Thin sections reveal a composition of crystalline calcite with clearly defined fossil edges indicating that the material has not undergone the extensive recrystallization processes common in the Warsaw chert. Fossils include echinoid and crinoid ossicles floating in the material’s matrix. Also observed are fossil Lithostrotion canadense and L. proliferum corals that can be used to distinguish the chert from other varieties in the area. One of the most salient characteristics of the St Louis chert is a banded or laminated appearance caused by abundant organic matter (Marcher 1962b). According to Marcher (1962b) “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. These nodules do not commonly show a radiating internal structure (Marcher 1962b). These three chert types are the major varieties encountered in the Dover, Tennessee area. However, as evidenced by Shackley’s (1992) study of obsidian gravel sources in the Upper Gila River basin, precautions must be taken to not overlook a few other less abundant varieties present in the study area.

Ste. Genevieve Chert

As previously discussed, the presence of the Ste. Genevieve formation in the Dover area is extremely limited. Isolated to only three known outcrops, this formation contains oolitic chert located on top of high ridgelines (Marcher 1962a). It may be possible that the Ste. Genevieve chert is all that remains of this formation due to its resistance to weathering. Not only could this material be preserved on areas of higher elevation, but also may be found in upland stream bed gravels. The chert is typically a yellowish-gray material characterized by ooliths inset into its matrix (Marcher 1962a).

Tuscaloosa Chert

Many of the minor and secondary tributary systems in the Dover area contain large amounts of chert gravels. Also, numerous varieties of chert can be located in large gravel splays along the banks of the Cumberland River. The occurrence of these gravel splays may have provided prehistoric people with high quality materials that would have been relatively easy to exploit. This resource may have provided an embedded or semi-embedded procurement strategy for some groups especially for the manufacture of expedient tools. Much of the chert gravels are of Cretaceous Period origins. Among
these the major geologic unit is the Tuscaloosa Gravel formation and subsequent Tuscaloosa chert. This material may occur as gravel or cobble sized nodules brilliant white to chalky white in appearance. Some of the material may exhibit patches of dark colored chalcedonic or opaline quartz (Marcher 1962a). The dominant fossil types are brachiopods replaced with fibrous quartz.

Tertiary and Quaternary gravels also contain varying grades of chert. The major formation of Tertiary origins in the Dover area is the Lafayette Gravels. Iron stained chert and quartz gravels approximately one inch in diameter are present in this formation, but no other description or mention of the material in an archaeological assemblage has been located.

**Summary**

The state of Tennessee is rich in geologic history representing a good portion of the geologic time scale. Nearly all of the major geologic periods of deposition and erosion can be identified in the various formations across the state. A review of these formations coupled with physiographic and topographic information can give the researcher a better understanding not only of the chert material types present in the area, but also the environments that may have existed at their time of deposition. It is important to understand that these processes altered the landscape creating the modern topography of the state. Much of this landscape has not changed since prehistoric times, allowing us to reconstruct what these people must have encountered as they traversed Tennessee’s physiographic provinces.

One of the main objectives of this study is to understand the geologic record of Tennessee in order to gain a better understanding of the distinguishing characteristics of
various chert materials, their distribution, and availability that prehistoric people would have encountered in the Dover, Tennessee area. Throughout this analysis a wide range of high quality material types were encountered mostly attributed to the Mississippian-aged limestone formations and alluvial gravel splays containing an assemblage of Cretaceous, Tertiary, and Quaternary-aged chert residues. Specifically, four main geologic formations were identified that contain substantial amounts of bedded, nodular, or chert gravels. These were the Ft Payne, Warsaw, St Louis and Tuscaloosa Gravel formations. Two other secondary sources were also identified as the Ste. Genevieve and Tertiary chert gravels. The presence of these materials in the Dover area leads to the conclusion that a number of high quality chert materials would have been available to prehistoric people.

Primary among these is a grayish pale brown to dark brown chert with occasional vugs rimmed with blue-white quartz that was heavily exploited during the Mississippi Period (Gramly 1992). This high quality chert was prehistorically quarried in and around the Dover, Tennessee area and has yet to be conclusively assigned a geologic provenance. This material is commonly referred to as Dover chert and may be better contextually understood by viewing it as a product of these geologic processes and resulting formations. The discussion above may aid in the geologic derivation of this material. It is possible that this information may still remain elusive, but a broad understanding of chert variation and geologic context within the study area is an essential first step to any chert sourcing analysis.
CHAPTER 3

PREHISTORIC QUARRIES

Prehistoric quarry sites of North America have been understudied and, as a result, our understanding of the function, formation, and use of these sites has been limited. The lack of archaeological research at these sites may be due to logistical and analytical constraints. The overwhelming size of quarry sites, as well as the vast number of artifacts found at them, makes even a small excavated sample difficult to obtain. The task is further complicated by the lack of stratigraphically intact cultural deposits, temporally diagnostic artifacts, and datable material (Purdy 1984).

The lack of archaeological literature about these sites indicates that additional work needs to be done despite logistical and analytical drawbacks. The current survey of the Dover Quarry sites is an attempt to fill this gap in the previous literature and should be viewed as a first step in future analysis of the sites. A further discussion of the Dover Quarry sites is continued in the following section, but first a broad understanding of other prehistoric quarry sites of North America is provided in order to place the Dover Quarry sites in this broader context.

The prehistoric quarry sites are many and varied across North America. Native inhabitants mined a number of materials including mica, hematite, catlinite, obsidian, steatite, and chert. The quarrying methods of each of these materials are quite similar
and, as a result, the sites that were produced from these activities are likewise similar. The following is a description of the most recognized prehistoric chert quarry sites of North America. The purpose of this brief introduction is to highlight some of the inherent similarities of these sites despite great temporal and geographic differences. It is within this context that a greater understanding of the Dover chert quarry sites can be realized.

**Previous Research**

During the 19th century an interest in prehistoric sites developed and flourished in North America. Prior to this time Native American sites were noted as something of a curiosity and incorporated into folklore and myth. The larger, more impressive earthworks were often referred to as remnants of the lost tribe of Israel or the people of Atlantis and generally not attributed as the cultural products of indigenous peoples. These views began to shift at the end of the 19th century as antiquarians surveyed large areas utilizing current scientific methods and a more systematic approach. These surveys were usually focused on recording the sites that left a distinct visual impression on the landscape such as effigy and mortuary mounds. Prehistoric quarry sites were also noted as the multiple circular depressions were easily distinguished from natural features.

One of the landmark publications in archaeological literature in general, and specifically on prehistoric quarry sites, was compiled from a series of papers published by the Smithsonian Institution, Bureau of American Ethnology. This publication entitled *Handbook of Aboriginal American Antiquities; Part 1; Introductory The Lithic Industries* was based on extensive observations, maps, and ethnographic evidence collected by William H. Holmes from 1890 thru 1904. This monumental work was first published in
1919 and remains the most comprehensive work documenting the prehistoric quarry sites of the Americas.

Holmes’s work was by no means the only manuscript on prehistoric mining activities as other regionally based surveys also greatly contributed to this body of literature. Gerard Fowke (1885) published an in-depth report of the Flint Ridge site in the 1885 annual report of the Smithsonian Institution, as well as doing a great deal of the preliminary work which Holmes incorporated into his publication (Smith aka Fowke 1885). Additionally, W. A. Phillips (1990) studied the Mill Creek quarry sites of southern Illinois and reported the results in American Anthropologist. Holmes drew on the data obtained from these preceding surveys and incorporated them into his synthesis. The work of these early pioneers set the precedent for the research of Gramly (1992), Ericson and Purdy (1984), and Luedtke (1978, 1979, 1984).

Sites

Flint Ridge

The Flint Ridge site located in Licking and Muskingum Counties, Ohio is possibly the largest and best known prehistoric quarry site east of the Mississippi River. The site is composed of hundreds of pits placed along a narrow ridge line over two kilometers in linear extent. The diameters of the pits vary from a meter to over 10 meters in size. The depths of the pits also varied depending on the location of the bedded chert deposits. Fowke describes an excavation of one of the pits being over 3 meters in depth (Smith 1885).
The chert material at the site exists as a single bed averaging 1.2 m in thickness within the Vanport limestone (Luedtke 1992). Observations made by the current researcher indicate that the primary method of extraction was to undermine the chert stratum and break large blocks off of the exposed ledge. This is in agreement with Fowke’s (1885) and Holmes’s (1919) interpretations. The large pits were excavated through the existing soil matrix in order to expose the more resistant chert stratum. Once this was accomplished it seems likely that fire was used to fracture the top of the formation until the underlying limestone was visible. This method effectively cut a hole in the chert deposits thereby allowing the prehistoric miners to excavate the parent limestone out from under the formation. This method was considerably easier by finding the chert strata in exposed profiles on the sides of hills though the quality of the material was compromised.

Wyandotte Cave

The Wyandotte Cave site is located in southern Indiana and is the type site for this chert variety. Prehistoric miners exploited chert cobbles from deep within the caves passages by excavating pits into the clay soil matrix (Munson and Munson 1990). Cobbles were also extracted from the interior limestone walls. The chert materials occur as nodules or lenses 30 cm or more in diameter (Luedtke 1992). Once the prehistoric miners had extracted the desired materials they reduced them outside the mouth of the cave producing large debitage piles. This method of lithic extraction is reflected elsewhere in the southeastern United States. Both the Savage Cave site in south-central Kentucky and the 3rd Unnamed site in north-central Tennessee exhibit this type of chert exploitation (Schenian 1985, Franklin 2001).
Crescent Quarry

The Crescent Quarry site is located 40 kilometers west of St Louis, Missouri. The site is characterized by a series of narrow ridgelines covered with prehistoric quarry pits/trenches and debitage extending over 11 km to the southeast (Holmes 1919). The chert exploited at the site occurs in lenses and irregular beds within the Burlington limestone formation. Along the ridgeline weathering has exposed the uppermost portions of the chert stratum. The concentration of prehistoric mining activity seems to be at the base of the slope where higher grade materials could be extracted (Meyers 1970). In some places large nodules of the Burlington chert can be pried from the soil matrix or the underlying limestone formation.

Indian Mountain and Magnet Cove

Indian Mountain and Magnet Cove are the two largest prehistoric novaculite quarry sites in central Arkansas. At both locations prehistoric mining activity is concentrated along the crest of a narrow ridgeline. Large pits and trenches are visible along the landform. Some of these pits are up to 46 m in diameter and 7 to 12 m deep (Holmes 1919). Debitage and rejected blocks cover the surrounding hill slopes and have partially refilled a number of the pits. These sites are even more extensive than the Flint Ridge quarry sites in Ohio (Holmes 1919). Prehistoric miners were exploiting the fine grained novaculite exposed along these ridgelines. The chert may occur up to several meters thick and is often interbedded with shale, sandstone, and limestone (Luedtke 1992). Prehistoric miners would excavate large blocks of the higher quality material until they reached a depth that they were no longer accessible.
Mill Creek

The Mill Creek quarry sites are located in southern Illinois and are composed of a number of pits or shallow depressions concentrated along the hill slopes overlooking the mouth of Mill Creek. These pits cover an area approximately 0.5 square km and range from 3 to 12 m in diameter (Phillips 1900). The pits are entirely encased within the reddish, silty clay soil up to a meter in depth. Prehistoric miners appear to have extracted the chert nodules directly from the soil matrix. The Ullin limestone is the parent formation in which the chert lenses were encased before being freed by chemical weathering of the soluble material (Cobb 2000). As a result the chert nodules may be found in great numbers within the soil matrix making prehistoric exploitation of them relatively easy.

The Mill Creek quarry site can be viewed as the counterpart of the Dover chert quarry sites. The major temporal usage of both sites is attributed to the Mississippi period. The production of chert hoes, adzes, and ceremonial implements at both sites reflects this coexisting relationship. In fact others have argued that the activities at these sites demonstrate economic competition (Cobb 2000). Regardless, the wide distribution of both Dover and Mill Creek chert implements demonstrates the importance placed on these materials and concurrently the importance placed on extracting a continuous supply of high quality chert.

Dover Quarries

Dover chert has become synonymous with Southeastern archaeology in general and is well represented in the archaeological record of Tennessee. Enthusiasts, antiquarians, and professionals alike are familiar with this material and have identified cultural
implements made of Dover chert within prehistoric assemblages as far away as Arkansas and Oklahoma (Gramly 1992). Despite its reputation as a resource heavily exploited by prehistoric people, little research has been aimed at uncovering its geologic origins and distribution. One goal of this study is to examine the topographic and geologic setting, spatial extent, and quantity of prehistoric mining activities of four Dover Quarries in Stewart County, Tennessee.

The majority of archaeological research has attributed the procurement, production, and distribution of Dover chert implements to have originated from the Dover quarries of Stewart County, Tennessee. One noted exception, Smith and Broster (1993), examines other possible procurement locations and the presence of Dover or macroscopically similar chert types. As a result, the Dover quarries have become a popular type location for the material. This may or may not be a justified assumption. Admittedly the prehistoric quarries located around Dover, Tennessee are quite impressive not only for the numerous pits and massive piles of talus debris but also for their size. However, these sites have never been comprehensively surveyed in regard to their spatial extent, density, or topographic and geologic setting. The following data was obtained, in part, to satisfy this perceived need in hopes to encourage future research, but was primarily used in designing an appropriate sampling methodology for the current chert provenance study.

Previous Research of the Dover Quarries

The Dover Quarries seem to have been overlooked by archaeologists of the early 20th Century. The comprehensive surveys by Moorehead (1906, 1910) and Moore (1915) do not mention the Dover Quarry sites. In fact, Holmes’s (1919) *Handbook of North American Lithic Industries* does not examine these sites despite being the comprehensive
volume on the major prehistoric quarry sites in the Americas. The first association with Dover chert and Stewart County did not come until the early 1950s with an article in *Archaeology of the Eastern United States* (Kneberg 1952). In *Tribes that Slumber: Indians of the Tennessee Region*, the chert material used to produce the ceremonial implements of the Duck River inhabitants are attributed to the Dover chert cobbles located “30 miles to the north” (Lewis and Kneberg 1958). Until this time there is no record of controlled excavations at the Dover quarries.

It was not until the investigations of Richard Gramly (1992) from 1983 to 1985, under the aegis of the Buffalo Museum of Science, that large scale excavations were undertaken on sites interpreted as workshop areas in close proximity to the quarry sites. In Gramly’s (1992) monograph, *Prehistoric Lithic Industry at Dover, Tennessee*, the Brigham Quarry site is referred to often and the approximate spatial extent of the quarry is illustrated. The Cross Creek site is also mentioned with brief references to quarry pits and talus debris (Gramly 1992). Some excavation of debris piles was undertaken at both of these sites, but the main focus of the investigations was on related sites in the vicinity (Gramly 1992). In Nance’s (2000) study of lithic materials from western Kentucky and Tennessee, samples of Dover chert were obtained from a portion of the Brigham site which he quantifies as 75 square meters. This is the first mention of the spatial extent of the Brigham quarry site.

**Setting**

The Dover Quarry sites are located in Stewart County, Tennessee along the state’s northern border with Kentucky. The town of Dover is located northwest of the quarry sites at the intersection of state routes 79 and 49 on the south embankment of the
Cumberland River. The area is located within the Western Highland Rim Plateau physiographic region of Tennessee and is characterized by maturely dissected valleys and ridgelines (Figure 2). The topographic relief of the area dips to the northeast and is primarily drained by the Cumberland River which flows to the north to become Lake Barkley. Secondary drainages and tributaries to the Cumberland in the area include Long Creek and Cross Creek flowing from south to north. In addition to these a number of third order tributaries are present and will be further discussed as they relate to individual quarry sites.

The town of Dover lies on the south bank of the Cumberland River. The area offers a unique perspective on the depositional record of the Highland Rim province. The Tertiary System deposits consist of unsorted gravel, sand, silt, and clay comprising the Quaternary-aged alluvium (Marcher 1962a).

**Dover Chert**

Despite the presence of various chert types, prehistoric miners at the Dover Quarry sites focused their efforts on extracting a particular chert type. This chert type occurs locally as large nodules of chert encased within the silty clay mantle on hill slopes and eroding out of sheer limestone bluffs. A major research question that is brought up in the archaeological literature is to what geologic formation is this material attributed (Gramly 1992; Smith and Broster 1993; Nance 2000). A clarification of terms is first needed before proceeding into further discussions.

Dover chert can be described as a light brown to dark brown, medium to fine grained chert with varying dark to light lenticular striations (Figure 7). Crystalline calcite inclusions are often found in the matrix ranging in color from a milky white to light blue.
Fig. 7. Variations and distinguishing attributes of Dover chert; (a) Dark high grade quality samples, (b) lighter variants, (c) striations shown at 50x magnification, (d) macroscopic calcite crystals shown at 100x magnification, (e) sapropelic material [dark blemishes] shown at 150x magnification, (f) macrocrystalline inclusion shown at 200x magnification
The chert occurs in nodular form varying from a few centimeters to fifty centimeters in diameter. The larger nodules are commonly referred to as ‘cannonballs’ (Marcher 1962a, 1962b). No bedded forms of Dover chert were noted within the study area, however, frost fracturing of many of the ‘cannonballs’ resulted in half cobbles. This fracturing was not irregular, but occurs along smooth plains often giving the appearance of angular pieces. The cortex of these nodules is a few millimeters thick consisting of a white to reddish clay rind. Various fossil types can be seen within the cortex. 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 subjected (Marcher 1962b). The dark black, fine grained variety of Dover chert was observed still encased in the parent limestone. The light brown, caramel, or white variety of Dover was predominately observed in specimens located within the soil matrix.
CHAPTER 4
CHERT SOURCING

The provenance determination, or source of a material utilized by prehistoric people, is of paramount importance within the field of archaeology. In recent years the popularity of provenance studies, specifically chert provenance studies, has led to the development of many qualitative and analytical techniques that represent interdisciplinary approaches. The theory, methods, and technology typically employed within the fields of geology, chemistry, nuclear physics, remote sensing, biology, physics, and math have all been utilized in chert sourcing studies. As a result of this multidisciplinary effort the techniques employed in chert provenance studies are as varied as their names imply. Listed below is a brief discussion of some of the more common chert sourcing techniques that may be found in current archaeological literature. A more complete discussion of multiple chert sourcing techniques may be found in Church (1994), Ciberto and Spoto (2000), Odell (2003), and Andrefsky (2005).

Techniques

Macroscopic Identification

Currently the most widely used technique for chert sourcing is the unaided macroscopic or visual identification of the chert type. This is accomplished by noting the
texture, presence of mineral or fossil inclusions, patterning, and above all the coloration of the material. The accuracy of the technique relies almost exclusively on the experience of the researcher and his/her knowledge of the visual characteristics of the chert types in any given region. This technique introduces a great deal of inter-observer error making comparisons between two or more site assemblages inconsistent even when the same researcher analyzed the materials. A 40 to 70% error rate was observed using this type of identification method (Calogero 1992).

The identification of chert types based solely on visual comparisons is not necessarily a chert sourcing technique though it is often equated as such. The goal of this type of analysis is solely to assign a nominal trait to a chert artifact. However, this practice has implications for provenance studies. There are two types of nominal traits that are assigned to chert materials. The first usually refers to the geologic formation in which the material is encased. Examples of these include Burlington, Ft Payne, and Onondaga chert.

Unfortunately a particular formation can outcrop over a large geographic area. The question of spatial resolution then becomes a major concern. An example of this is the common presence of Onondaga chert in the prehistoric assemblages of southwestern Pennsylvania. Onondaga chert outcrops over a large area along the northern Pennsylvania and southern New York border, as well as secondary glacial and alluvial gravel deposits throughout the Allegheny and Ohio River watersheds. The identification of the chert material in these cases only assigns it to a formation and does little to source the material to a particular outcrop or location.
The second type of nominal trait assigned to a chert material refers to a specific location where the chert was first identified or can be best observed. Examples of these include Sonora, Edwards Plateau, Kay, and Wyandotte chert. The material was given a type name based on its occurrence within or in close proximity to these locations. It is important to understand that this nominal characteristic is not always an attempt to differentiate a specific variety of chert, but is often a victim of inconsistent terminology. Therefore, the usage of Wyandotte, Hornstone, and Sonora chert is a reflection of regional traditions and it should be remembered that they all refer to chert materials found in the Ste. Genevieve formation. Dover chert falls into this category and was defined in the preceding chapters.

We see this loose type of terminology in other aspects of geology and archaeology and a complete discussion of these problems is beyond the scope of the current study. A quote by Butler (1984:299-300) summarizes this concern, “One should not forget that decisions on the identity and classification of geological units are sometimes as arbitrary as many traditional archaeological classifications.” A literal translation of these nominal traits may be misleading for the researcher seeking the geologic or geographic origins for a particular material type. A more appropriate way of understanding this use of terminology is that these traits are assigned to chert materials that visually appear to be similar to materials outcropping at a certain location or out of a particular formation. However, it is often the case that a literal understanding of the nominal trait is implied resulting in an assumption that the specific material type came from a specific place on the landscape.
It is important to realize that a macroscopically similar chert type can occur in multiple different geologic formations or outcrop in multiple locations within the same formation (Odell 1996). In other words Sonora chert may be found in other outcrops of the Ste. Genevieve limestone outside of the town of Sonora, Kentucky. Therefore, a chert sourcing study based on the macroscopic identification of chert materials may be viewed as a question of spatial resolution and the presence of distinct material variation. These two concepts are really the crux of all chert provenance studies.

Petrography

Petrography entails the examination of thin sections of chert under magnification. The goal of petrographic analysis is to identify the presence of certain mineral groups that would be diagnostic to the particular sample, outcrop, or formation. The presence, absence, or percentages of mineral groups in highly siliceous stones, such as chert, may be a useful technique in distinguishing material types (Odell 2003). Chert samples are often prepared as thin sections. This is a time consuming and skilled process whereby the material is cut into slender cross sections and ground down and polished until the desired thickness is obtained. A typical thin section is approximately 30 microns in thickness, approximately the width of a human hair. By using an artificial light source and filters it is possible to identify and quantify the mineralogy and fossil inclusions present in the chert sample. This data gives clues to the diagenesis of the chert that may be diagnostic of a particular type.
Geochemical Techniques

There are three main geochemical techniques applied to chert provenance studies. They include Neutron Activation Analysis (NAA), X-Ray Fluorescence (XRF), and Inductively Coupled Plasma (ICP) analysis. Each of these techniques quantifies the elemental composition within a particular chert artifact or sample. The specific focus of these techniques is on trace elements and rare earth elements (REE) which often exist in the parts per billion range necessitating a highly sensitive detection capability.

**Neutron Activation**

Neutron Activation Analysis was one of the first geochemical techniques applied to chert sourcing studies. This technique is highly regarded for chert sourcing applications (Michael Glascock, personal communication). NAA uses a concentrated beam of neutrons to irradiate a sample. This is performed inside a nuclear reactor where the resulting radioactive nucleotides decay into gamma rays (Andrefsky 2005). The type and amounts of 50 different elements can be detected using NAA (Church 1994). A large database of various chert types and other materials has been collected from thousands of samples using NAA and is held at the University of Missouri Research Reactor (MURR).

**Inductively Coupled Plasma**

Inductively Coupled Plasma (ICP) Analysis has been demonstrated to be comparable with NAA. ICP requires that a small sample (0.03g) be dissolved into a leachate. This solution is then fed through radio-frequency coils which heat the solution to 6000°C forming a plasma flame (Pollard and Heron 1995). When plasma is produced from the solution the elemental composition of the chert sample is separated using a
photomultiplier or a mass spectrometer depending on the device. The type and quantity of specific elements are then recorded. The detection limits of the device and the amount of trace and rare earth elements that can be resolved become a crucial factor for this technique. Also, the systematic use of a standard material before each sample reading is necessary to ensure the correct calibration of the device and negate any instrument drift.

**X-Ray Florescence**

X-Ray Florescence utilizes a beam of X-rays to irradiate the surface of a sample. In turn this excites the electrons into higher energy levels. When the electrons settle back to their original state they emit florescent X-rays (Andrefsky 2005). These florescent X-rays are then measured at different wavelengths. The variable intensity peaks along parts of the electromagnetic spectrum signify the presence and quantity of certain elements. The technique is largely reported as being nondestructive, however, the conchoidal surface of chert affects the amount of florescent X-rays that are detected. Also, the penetration depth of the technique is largely restricted to the surface where the degree of weathering may alter the results. These variables often necessitate some sample preparation. Each of the above techniques is influenced by a number of variables that need to be addressed or at least understood before continuing since the VNIR technique has distinct advantages over these more destructive methods.

**Variables**

The one common goal that the petrographic and geochemical sourcing techniques share is to accurately identify the geologic provenance of a chert artifact utilized in the past. This is not a simple or easy process. There are a number of variables that may
affect the ability of any one technique to accurately source a cultural implement made from chert back to its procurement location. Some of these variables include the homogeneous mineralogical and chemical composition of chert, the macroscopic variability of the material, the presence of multiple chert types in a region, the degree of weathering of both the artifact and the quarry sample, and the alteration of past landforms.

A myriad of other variables might affect the accuracy of provenance studies and a complete list would require a more comprehensive study which is outside the scope of the current research project. Some of the major issues, however, will be elaborated upon below. An understanding of these issues is crucial for any chert sourcing study as these variables need to be accounted for throughout the formulation of the methodology and data interpretation processes. An understanding of these issues can then be used to develop adequate sampling procedures along with various sample preparation techniques that may alleviate some of the problems.

Number of Sources

The presence of all chert resources in the study area should be evaluated. If the research design is focusing on sourcing the chert artifacts found at a specific site an examination of the chert resources within a given distance from the site might be utilized (Purdy 1984). This method entails the identification and study of the chert resources within a specific radius of the site. If only one chert type is located in the study area then the researcher can target the amount of variation present in this material. If two or more chert types are found within the study area then the researcher will have to identify the amount of variation present between and within the various chert types (Church 1994).
may be that a specific variation of chert type A overlaps a variant of chert type B. These steps are necessary in order to map out the range of variability and will increase the accuracy of the study.

**Sampling**

Each potential chert source identified within the study area should be sampled. This includes areas known to have been exploited prehistorically such as quarries, outcrops, and also exposures that may not have been available to prehistoric people including road cuts, gravel bars, and cut banks. Even though these features may not have existed prehistorically, they still need to be considered so that, when analyzed, their variation can be incorporated into the known range for a particular chert type (Odell 2003).

In this manner the sampling strategy has to be comprehensive. Whether this method is random or systematic, samples should reflect the entire population(s) at any given location. If samples are clustered or unevenly distributed a limited view of the resource might be rendered leading to inaccuracies in the study.

**Weathering**

All of the chert resources utilized by prehistoric people have undergone some degree of chemical or mechanical weathering. The most common sign of mechanical weathering on chert is in the form of frost fracturing. There are three types of damage caused by the freeze thaw cycle. The most readily identified type is the fracturing of chert into angular blocks. Chemical weathering occurs by the precipitation of soluble materials from the surface regions of the chert (Luedtke 1992). A patina or cloudy appearance may form across the surface of some chert types due to this weathering.
process. As materials are carried away the quality of the material usually is adversely affected. The varying degrees to which a chert artifact or sample may exhibit weathering can greatly alter the results of an analytical method that does not take this into account.

**Thermal Alteration**

The thermal alteration of some chert materials is a well documented practice among prehistoric people (Andrefsky 2005). Some chert types are almost impossible to work into usable tools without first subjecting the material to a controlled heat source. This process alters the elemental composition of the material (Hubbard 2006). Sometimes this thermal alteration is visible as pinkish hues on the artifact or sample, but often this type of alteration is difficult to identify. If left undetected the analysis of thermally altered chert will introduce a considerable amount of variability that is not a natural byproduct of the geologic diagenesis of the material.

**Summary**

The five techniques briefly outlined above represent the most common chert sourcing methods currently employed. Each technique has its advantages and disadvantages, but they all attempt to identify diagnostic features that can be used to differentiate one chert type from another or one chert outcrop from another within the same geologic formation. Each technique also attempts to quantify the variability that may exist in a particular chert type or chert outcrop. These variability ranges can then be used to bracket a particular geographic location in which the material may have originally been procured. This practice now dominates chert provenance studies as researchers have moved beyond the fingerprint approach that assumed each material type contained a unique set of attributes
which would clearly define it from others. It has now become apparent that a great deal of variability can be observed both macroscopically and geochemically within a chert type or single outcrop. These differences can be very small making the formulation of an appropriate research design an important aspect of the study.

**Previous Dover Chert Provenance Studies**

To date there have been two provenance studies performed specifically on Dover chert. The first was a material distribution based survey of macroscopically similar Dover chert types present in the lower Tennessee River drainage and other locations outside of Stewart County (Smith and Broster 1993). The second study was a site based provenance study that utilized geochemical techniques to compare chert artifacts with two macroscopically similar source areas (Nance 2000).

The suspected source of Dover chert has been Stewart County Tennessee. In order to test the validity of this assumption Smith and Broster (1993) conducted a survey in the counties surrounding Stewart County. They found additional outcrops of macroscopically similar Dover chert some of which appeared to have been utilized by prehistoric people. The artifacts coming from sites in close proximity to these sources seems to confirm this hypothesis based upon visually similar material types.

The outcrops identified by the Smith and Broster (1993) occur along the lower Tennessee River drainage in Houston, Hickman, Humphreys, and Benton Counties as well as Stewart County (Smith and Broster 1993). The implication of this study is far reaching for Southeastern archaeology. The large amounts of agricultural implements and ceremonial objects produced and widely distributed during the Mississippi period may not have solely originated from the Dover Quarries of Stewart County. In fact the
identification of macroscopically similar bedded chert near the Link Farm site (40Hs6) may have been the source for the chert that was used to craft the elegant ceremonial swords, maces, etc. found in the Duck River cache. This study shows that visually similar Dover chert materials occur over a large geographic area and that our old assumptions about a single source origin for the material may be in error.

The second provenance study was conducted by Jack Nance (2000) as part of the Lower Cumberland Archaeology Project (LCAP). This study sought to identify the occurrence of chert materials over a wide geographic area of western Kentucky. Nance focused this particular study on the analysis of chert samples taken from McCormick Creek, KY, the Brigham Quarry site (40Sw64), and the Morrisoe (15Lv156) site. The chert sourcing technique used for this analysis was NAA.

Numerous trace elements were identified in the materials and by using classification trees and multiple linear discriminate functions the two visually identical chert types were differentiated (Nance 2000). The results of this study show that the majority of the chert artifacts from the Morrisoe site were produced from the local McCormick Creek chert outcrop. This site based provenance study was important because it demonstrated that chert materials originating from the same geologic formation, in this case the Lower St Louis, could be distinguished using NAA. The study also showed that Luedtke’s (1984) model “assumes a local source for artifacts on a site first before looking at distant origins”, and in this instance was substantiated.

The previously discussed chert provenance techniques illustrate the direction that these types of studies are headed. The last two case studies show the previous chert sourcing studies that have been conducted specifically on Dover chert and prefaces the
current study. In the preceding chapter a new technique for chert sourcing was outlined that builds upon this body of research and continues in the same vein as others before it. A discussion at the end of this study will compare and contrast the various chert sourcing techniques as they pertain to cost, speed of analysis, degree of destructiveness, and accuracy.

**Remote Sensing**

The field of remote sensing has given researchers a new approach to studying the world in which we live and the materials that comprise it. The advent of the space program and the establishment of satellite imaging systems have contributed to a number of fields of research. One of the first applications of this new technology was within the field of archaeology as it gave researchers a much larger perspective on the spatial patterning of prehistoric sites (Wagner 1991). The technology also helped locate previously unidentified prehistoric sites and features. This was accomplished by using a number of analytical methods to study digital images obtained from remote sensors.

The field of remote sensing encompasses a wide range of technical and methodological procedures. Some of these are of great interest to the field of archaeology. The indirect non-destructive observation techniques of remote sensing hold great potential for the archaeologist whose primary concern is for the preservation and conservation of archaeological resources. In recent years, remote sensing devices have allowed archaeologists to non-destructively map out the occurrence and distribution of buried cultural features (Johnson 2006). In this study a traditional remote sensing method and sensor is applied to a chert provenance study.
Reflectance Spectroscopy

Visible Near-Infrared Reflectance (VNIR) spectroscopy is a remote sensing technique that records the interaction of light with a material. The technique is one of many reflectance spectroscopy methods that study how light interacts with matter over portions of the electromagnetic spectrum (Hunt 1982). The premise behind the technique is that different materials produce different reflectance patterns that represent a material’s chemical, molecular, and physical composition.

The electromagnetic spectrum is divided into sections according to the wavelength or frequencies. Reflectance spectroscopy primarily analyzes two main areas of the electromagnetic spectrum, the visible (380-700nm) and the near infrared (700-2500nm). The way our eyes function is an example of a spectrometer that is capable of observing radiation in the visible part of the electromagnetic spectrum. The shorter wavelengths (i.e. higher frequencies) are visualized as the color purple or blue while longer wavelengths (i.e. lower frequencies) are seen as the color red with all of the other color variations in between.

The visible spectrum is only one component of the electromagnetic spectrum. The entire electromagnetic spectrum has multiple components ranging from gamma rays to radio waves. Reflectance spectroscopy when used in imaging sensors, often referred to as imaging spectroscopy, primarily focuses on a small part of this spectrum. Other remote sensing methods are capable of analyzing different components such as the thermal infrared region of the electromagnetic spectrum to study how radiation, in the form of light, reacts with a material.
The principle of remote sensing is to study the reaction of light with a given material in order to make observations about the type, composition, and properties of the object being studied. There are three primary reactions that light can have with an object. Light can be reflected, transmitted, or absorbed by a substance. VNIR spectroscopy records the various interactions between light and matter across a portion of the electromagnetic spectrum.

Spectrometer

A spectrometer, also referred to as a spectrophotometer or spectroradiometer, is a hyperspectral sensor capable of recording the interactions of light with a material over the visible and near infrared parts of the electromagnetic spectrum. A more thorough definition can be found in the Analytical Spectral Devices Inc. (ASD) technical reference guide (Hatchel 1999). This device is non-destructive and records reflectance values across a wavelength range of 350 to 2500 nanometers (nm). The spectrometer used for this study is an ASD FieldSpec portable spectroradiometer and is currently housed at the Murray State University Hyperspectral Laboratory.

The device is encased in a hard plastic shell with a fiber optic cable consisting of three spectrometer probes. The first of these probes is a VNIR (visible near-infrared) followed by two SWIR (short wave infrared) spectrometers. Together they record the reflectance values across the spectral range mentioned. The sampling interval for the device is 2 nm with a spectral resolution of 4 to 10 nm. This spectral resolution begins to degrade at the end of the spectrum (e.g., 2500 nm). The relatively fine resolution of the spectrometer is an important capability as a resolution of 25 nm or more rapidly loses the ability to resolve important mineral absorption spectral features (Clark 1999). The
spectrometer is extremely fast with the ability to record the 350-2500 nm spectrum range with 2,150 bands in 0.1 seconds.

The fiber optic cable is secured inside a handheld device fitted with a bubble level. The handheld attachment facilitates rapid aim and placement of the probe tip while at the same time providing angular control. This allows the placement of the sample at a ninety degree angle to probe which is crucial for obtaining accurate results, ensuring consistent setup, and avoiding specular reflection. The probe tip is encased in a one degree foreoptic attachment providing a comprehensive field of view over the surface of a sample.

The laboratory configuration of the spectrometer consists of an adjustable stand with scissor clamps holding the handheld attachment with the fiber optic cable fed through the base. A wooden tray that has been coated with black absorbent paint is directly underneath acting as a receptacle for samples. The device is supplied with an artificial light source consisting of a tungsten-quartz halogen light operating at a color temperature of 3000 degrees K (Hatchel 1999).

Applications of Reflectance Spectroscopy

VNIR/SWIR spectroscopy is a remote sensing technique that has been in use in science and industry for over fifty years (Hatchel 1999). The speed and non-destructive nature of the sensor are advantages that have contributed valuable data to a number of scientific fields. VNIR spectroscopy is currently applied in the chemical, pharmaceutical, food and beverage, petrochemical, pulp and paper, textile, paint, and tobacco industries as well as in many other fields (Hatchel 1999). The technique is also put to extensive use in satellite imaging programs. Spectrometers are also used to ground truth certain types
of land cover in order to help classification studies on imagery gathered from satellite and aerial platforms.

Geology

The field of geology has also greatly benefited from the use of VNIR spectroscopy. The technique was first applied by National Aeronautics and Space Administration (NASA) programs as part of planetary explorations. These planetary research studies utilized spectrometers to identify surface mineralogy (Clark and Roush 1984). The devices were also mounted on satellites and obtained valuable petrologic information as they orbited various planets in our solar system including Earth (Moody 2002).

Geologists currently use VNIR spectroscopy to identify minerals in the laboratory and in the field. Researchers use the reflectance spectra gathered on unknown samples and compare these with spectra from known minerals in order to identify them. Using this method of mineral identification, researchers isolate certain features that are diagnostic of the particular specimen. These diagnostic features are wavelength dependent and are often referred to as spectral features. A more sophisticated method of performing this analysis involves using various statistical methods such as linear regression models on the spectra of unknown samples compared to numerous spectra of known samples in a database. A more complete discussion of these methods of spectral analysis can be found in the literature (Adams 1975; Hunt 1977, 1982; Gaffey et al. 1993; Salisbury 1993; Clark 1995, 1999; Moody 2002).

Since the advent of VNIR spectroscopy, researchers have been compiling the spectra of various known materials. Specifically, geologists have recorded the spectra of known mineral samples and created large databases from them. These databases are commonly
referred to as spectral libraries. The compiled information provides a database in which the spectral response of an unknown specimen may be placed in an attempt to identify them. The theory behind this approach to spectral analysis is that certain materials have diagnostic features that will distinguish them from others. This acts as a spectral fingerprint, which can then be placed within a spectral library to provide a match or a best fit comparison. A few of these spectral libraries are available to the public via the internet while some of the most comprehensive are found at the United States Geologic Survey (USGS) Digital Spectral Library, John Hopkins University (JHU), Arizona State University, NASA Jet Propulsion Laboratory (JPL), and the NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) program.

Archaeology

The field of archaeology has been slow to realize the potential application of the VNIR spectroscopy. VNIR spectroscopy is mentioned in only a few archaeological publications to date (Luedtke 1992; Church 1994; Carr and Turner, 1996; Long et al. 2001; Hubbard et al. 2003, 2005; Hubbard 2006). This trend may be shifting because in recent years interest has increased within the discipline. In addition to these research efforts, a few studies have examined the potential application of reflectance spectroscopy to archaeological problems.

DeSouza’s (2003) study of paint pigments on ancient Greek pottery vessels was one of the first published archaeological applications of reflectance spectroscopy. In this study a Miniaturized Mossbauer Spectrometer MIMOS II was used to identify the mineralogical composition of red and black Hellenistic figures on ceramic vessels. DeSouza (2003) was able to determine that the pigments were primarily composed of
hematite and other iron bearing minerals. A second ongoing study is being conducted by the Illinois State Museum. In this study a Portable Infrared Mineral Analyzer (PIMA) is used to examine Cahokian clay figurines and Hopewellian pipes. The spectral data obtained from these specimens are aiding researchers who are attempting to source the clay that was used to manufacture these items. Currently the device is being applied to sourcing catlinite pipes and flint clays from Midwestern sources.

Carr and Turner (1996) used VNIR spectroscopy to gather ground truth data on chert and soil samples from a prehistoric quarry in order to aid in spectral classification of satellite imagery. The study was able to successfully predict the location of additional prehistoric quarries in the Horse Prairie region of southwestern Montana (Carr and Turner 1996). This innovative approach will be discussed in greater detail as a direction for future research at the end of Chapter (6).

Hubbard and others (2003, 2005) used VNIR spectroscopy to differentiate between two macroscopically similar chert types. Hubbard’s (2003, 2005) studies used a spectrometer to analyze the spectral differences in Upper Mercer and Flint Ridge chert types. These two Ohio chert types are visually indistinguishable from one another. Using methods discussed in detail below, Hubbard and others (2005) were able to correctly identify 98% of the specimens sampled. He later used VNIR spectroscopy in his unpublished master’s thesis to source steatite artifacts to their respective outcrops where the material was exploited prehistorically (Hubbard 2006).

These studies show that the application of VNIR spectroscopy can significantly contribute to archaeological research. The technique is applicable to provenance studies seeking to identify chert types utilized by prehistoric people. First some principles of
reflectance spectroscopy must be discussed to develop a general understanding of the methodology behind the technique.

**Principles**

As mentioned, VNIR spectroscopy measures and records the interaction of radiation (in the form of light) with a material across the visible and near-Infrared portions of the electromagnetic spectrum. When light strikes a material it can react in one or a combination of different ways. Three of the major ways that light can react with a material are reflectance, transmittance, or absorbance (Figure 8). By analyzing a material’s interactions with light it may be possible to identify certain components of it. The primary concern of this study is how light is absorbed by various chert types; however, a basic discussion of each reaction will engender a more comprehensive understanding of the methodology behind VNIR spectroscopy.

**Reflectance**

One of the primary reactions incident light has with a material is reflectance. In almost all cases a portion of incident light is reflected off of the surface or near surface of a material. There are four types of surfaces, ideal specular, near-specular, near-diffuse and ideal diffuse reflector (i.e. Lambertian surface) (Figure 9). Specular reflection is defined as the angle of reflection equaling the angle of incidence. This type of reflection is mirror like in nature and is typically undesirable in reflectance spectroscopy. Ideal specular reflection refers to a surface that reflects nearly all of to the entire incident light. Near-specular reflection is similar to ideal however less of the incident light is reflected.
Fig. 8. The main interactions between light and chert (modified from Luedtke 1992)
Fig. 9. The four types of surfaces; (a) ideal specular, (b) near-specular, (c) near-diffuse, (d) ideal diffuse
There is practically no information gained from the specular reflection of a material except that regarding surface texture (Hubbard 2006). It may be possible to identify a material based on specular reflection or surface texture, but it is not explored as a viable method in this study.

The last type of reflectance, diffuse, can be defined as the opposite of specular reflectance. In diffuse reflectance the incident light is reflected equally or nearly equally in all directions. There are two types of diffuse reflectance, ideal and near. Ideal diffuse reflectance most closely matches the definition as incident light is scattered equally in all directions. Near-diffuse reflectance also scatters light in all directions but to a lesser degree. It is this reaction that light has with a material that makes it desirable for material identification. A common misconception is that this type of reflectance is purely a surficial phenomenon (Hubbard 2006). The degree to which photons penetrate a material’s surface and remerge allows reflectance spectroscopy methods to be a practical means of material identification. A photon enters a material to a certain depth where it may undergo variable refractions before being absorbed or reemerge as diffused light (Hubbard 2006). This reaction of light is often called diffuse reflectance and can be used to make assumptions regarding the presence of various absorption features (Hubbard 2005). The degree to which a material diffusely reflects incident light is dependent on a number of variables.

A few of the variables that control how light is reflected from a surface are the presence and amount of an absorber, grain size, spacing, surface roughness, and frequency of light. The grain size of a material is potentially the single most significant factor affecting incident light reflection. The relationship between a material’s grain size
and the portion of light reflected from its surface can be described as inversely proportional. As the grain size of a material increases the subsequent reflectance values decrease. This is due to the incident light being absorbed more across a larger surface area. An example of this phenomenon would be the use of various film types in photography. The different types of photographic film refer to the size of halite crystals on the film strip. The larger film sizes used in darker conditions, (e.g., 800), are composed of large grained halite crystals which absorb a greater amount of light. The frequency and spacing of varying grain sizes are also determining factors. Unless the material’s grain sizes are homogeneous, the proportion of larger grains to smaller grains will become contributing factors to light reflectance.

Another variable that affects how light is reflected from a material is the coloration of the specimen. Dark colored materials absorb the majority of incident light at the surface therefore photon penetration is limited. This may be particularly problematic for certain chert types that are dark in coloration. Information crucial to identification may be very subtle if present at all due to the shortened photon path length.

Heat treatment of a material may also affect its spectral signature (Figure 10a). This is mainly of interest when examining the spectra of certain chert types. The prehistoric thermal alteration of chert was a relatively common practice and is often a necessary process in order to produce stone tools. The thermal alteration of chert modifies the material at the molecular level. First, free water molecules locked within the cryptocrystalline matrix are boiled off. Next, hematite is produced due to the oxidation of ferrous iron (Hubbard 2005). This change may be seen visually as pinkish hues in the material. Finally, the decomposition of major components within the material begins to
occur at higher temperatures. All of these processes may affect the spectral signature of a chert type especially in the iron absorption spectral features.

Similarly, the amount of water present in chert will alter the spectral signature of the specimen (Figure 10b). As previously mentioned, various amounts of water are present within chert. These absorption bands exist as deep features centered at 1400nm and 1900nm. Chert specimens that have been soaked in water for a prolonged period of time show a significant vertical shift in these regions. The phenomenon is assumed to be due to excess amounts of water located at or near the surface. The dominance of these water absorption features may obscure more subtle diagnostic features. A cure to this is simply to make sure that all specimens are either dried at low temperatures or allowed to air dry over a significant period of time. These precautions should be enough to ensure the evaporation of near surface moisture.

Weathering was also found to alter the spectrum of chert (Figure 10c). Unfortunately the degree of weathering on a specimen is hard to quantify. Weathering on chert types is primarily due to bleaching by ultraviolet radiation and the chemical precipitation of soluble materials such as iron out of the cryptocrystalline matrix. As a result of this bleaching or patination the spectrum of the material seems to be affected mostly in the visible part (350 - 750nm). Some chert types are more resistant to these natural processes and seem to be only slightly altered whereas other types exhibit a bleached appearance. The highest degree of weathering appears at or near the surface of the material type and may extend into the material at varying depths. The leaching out of soluble materials may strip potentially diagnostic absorption features from the chert type.
Fig. 10. Effects of variables on the spectral response of chert; (a) heat treatment, (b) water content, (c) weathering, (d) probe to surface angle
Finally, instrument setup may also affect how light is reflected. The specimen surface to probe angle is one important factor that has the potential to alter the spectral signature (Figure 10d). This relationship is loosely termed angle dependency. Previous studies have shown that a surface to probe angle of 90 degrees is amenable for diffuse reflectance spectroscopy (Hubbard 2005). As little as a two degree shift has been shown to significantly alter the spectrum (Hubbard 2006). By increasing the surface to probe angle the reflectance values decrease. Other researchers maintain that angle dependency is not as important since band depth, shape, and position are basically consistent (Clark 1999). Clark (1999) provides the example of an eye gathering spectral data on an object at various angles. The eye normalizes the data presenting the true color of the object despite different viewing angles. Nevertheless a surface to probe angle of 90 degrees should be maintained to prevent spectral inversion.

Related to angle dependency is the surface to probe distance. The greater this distance, the more potential there is for noise or signal degradation. Noise can be introduced by high humidity levels in the atmosphere and background light. Stefano and others (2002) suggested a surface to probe distance of 0.5 mm to optimize the signal to noise ratio (S/N). This will be discussed in further detail in the methodology section.

Transmittance

A second interaction incident light may have with a material is that it may be transmitted. Transmitted light is defined as incident light that passes through the entire width of the material. The incident light may be reflected or refracted from one grain to the next as its travel path through the material is rarely direct. The ability of a material to transmit incident light may not necessarily be a diagnostic trait of the material but rather
a function of sample width. In VNIR spectroscopy it is important to know if incident light is able to be transmitted through a material as significant error may be introduced. This error may be caused by the material on the opposite side of the sample causing background interference.

Absorbance

The final interaction, covered in this study, that incident light has with a material is absorbance. When incident light strikes a material it can be absorbed by that material or the chemical or elemental composition of the material. The amount of light absorbed is wavelength dependent and is graphically expressed as either a Lorentzian, Gaussian, or mixed Lorentzian/Gaussian curve (Mark and Workman 2003). Therefore, the amount of photons absorbed by the material can be plotted graphically in relation to the wavelengths at which this interaction takes place. The absorption coefficient is a function of wavelength (Clark 1995). Researchers quantify how much light is being absorbed by a material using Beers Law. There are many factors that dictate the amount of light that is absorbed by a material and for a more comprehensive discussion refer to Hunt and Salisbury (1970, 1971); Hunt et al. (1971); Hunt (1977); and Clark (1999). This study primarily focused on two processes that determine the amount of incident light that is absorbed by a material. These processes are described as electronic and vibrational.

Electronic Processes

At the atomic level atoms and ions exist at a certain energy state (Clark 1999). When photons are continuously absorbed by an atom the predefined energy state increases exponentially. Conversely, when a photon is released from an atom, the energy state of
that atom decreases. However, this release of energy rarely occurs at the same wavelength. The resulting spectrum reveals information about the chemical composition of the material. The most common information revealed by this process is the presence or absence of certain transitional elements. Some of these transition elements include Ni, Cr, Co, and Fe. (Clark 1999). These elements are missing one or more electrons in their outer shell causing their energy level to split within a crystal field. A photon is then acquired to balance out the electrons energy level states.

Iron is the most common transitional element in minerals (Clark 1999). Iron is also common in most chert types to a degree that its absorption spectral feature can be readily identified. Iron ions split in various ways depending upon the crystal fields present in a mineral and this directly alters the size of the absorption feature. This makes it possible to identify specific mineral composition as in the De Souza (2004) case study previously mentioned.

A second electronic process that causes distinctive absorption bands is called charge transfers. In a charge transfer interaction an element absorbs an incoming photon, which causes one of its electrons to jump to another element. The red color of iron oxides is primarily caused by this phenomenon (Morris et al. 1985). By studying the spectral response of a mineral undergoing charge transfer, one may be able to identify its mineral composition.

The final electronic processes covered in this study are absorption bands caused by color centers. Color centers are a function of an imperfect crystal, which is illuminated by solar radiation (Clark 1999). As their name implies the internal structure of these color centers produce the varying hues and tones of many minerals that are commonly
identified macroscopically. The imperfect crystal structure of the mineral can be caused by impurities. These impurities may attract electrons in turn prompting the absorption of photons to facilitate this bonding (Clark 1999).

**Vibrational Processes**

A second major contributor to the creation of absorption features is brought about by internal vibrations and their subsequent overtones. These features occur in the infrared part of the electromagnetic spectrum from 1200nm to 40,000nm. Clark (1999) describes the molecular bonds or crystal lattice of a mineral as springs with weights attached. When incident light interacts with these types of bonds the transferring of electrons triggers a vibration. In minerals some of the most common of vibrational absorption features are caused by the presence of water molecules. The spectral features produced by water occur at 1400, 1900, and 2400nm. This is true for quartz and other minerals predominately composed of quartz such as chert.

The atomic composition of some minerals contributes to the amount of this spectral response. The OH bonding in water, called hydroxyl bonding, causes these vibrations when irradiated with photons. The silicon and oxygen stretch (Si-O) bonding in chert also contributes to the vibrational absorption features. In this manner the careful analysis of spectral data can give the researcher information about the chemical bonding of the mineral being studied.

Finally the presence of certain carbonates and carbonate ions shows diagnostic vibrational absorption bands (Clark 1999). This may be especially interesting when studying chert due to the variable amounts of carbonate ions present in some types. An absorption feature caused by the presence of various carbonates might be diagnostic of
certain cherts. However, fine grained minerals like clay and chert have very little reflectance values in the mid-Infrared and may not show strong spectral signatures (Clark 1999).

Researchers are able to visualize and quantify these interactions with the aid of sensors like a spectrometer. By studying certain diagnostic spectral features it is possible to not only identify unknown material types, but also their elemental and chemical compositions. Historically this type of identification has been performed by spectral analysts who visually identified spectral features and compared them with known samples. Whereas this may be an accurate means to distinguish certain material types, most spectral research to date is accomplished using various analytical or statistical methods. These methods are capable of isolating and quantifying more subtle spectral features that may not be visibly distinguishable from other reflectance values. These techniques are particularly useful when studying the spectra of chert samples.

**Quantitative Analysis**

The visual analysis of certain parts of a spectrum may be enough to identify the material in question. When viewing multiple spectra of similar materials, this may prove an inadequate method for isolating diagnostic features. Chert is primarily composed of cryptocrystalline quartz (Luedtke 1992). This makes the identification of specific chert types by spectral comparison extremely difficult. Due to these complications it is necessary to perform a number of processing methods to the spectrum in order to display absorption features of interest.

This method is called baseline correction and is a commonly performed spectral processing method. A spectral baseline is loosely defined as the background curve, or the
overall shape, of the spectrum (Hubbard 2006). The baseline, or continuum, is a large background absorption feature upon which others are superimposed (Clark and Roush 1984). The overall shape of the baseline can be affected by a number of variables including grain size, viewing angle, wavelength dependent scattering, and instrument drift (Hubbard 2006). Any of these variables can affect the overall size of the baseline and may be corrected for with the simple addition or subtraction of a set value across the spectrum’s entire length. One of these methods was used to correct for vertical offsets in the data set and will be discussed in detail later.

The removal of the baseline segregates most of the individual absorption features in the spectrum. This makes the ability to distinguish material types easier for both visual and quantitative methods. As Clark (1999:53) states, this process puts the spectral features on a level playing field so that they may be compared. One method of baseline removal uses polynomial functions to calculate the slope of the spectra and subtract this from the total thereby leveling the data and exposing the superimposed absorption features. These methods have their drawbacks when comparing silicate minerals that are spectrally very similar. The removal of the baseline also means the elimination of potentially important data from the spectrum. By definition, the baseline is possibly composed of a larger absorption feature such as those caused by iron or other broad features in the middle-Infrared region (Hubbard 2006). Therefore, a method which incorporates the entire spectrum is a more attractive alternative especially when dealing with spectrally similar materials such as chert.
Derivative Transformation

A second method that incorporates the entire spectrum of a material in the analysis process involves the use of derivatives. Derivatives have been used in reflectance spectrometry for a number of years and are becoming a popular means for analyzing absorption band features. A basic definition for a derivative is that it is the measurement of the slope of the underlying curve (Mark and Workman 2003). This is calculated by a simple formula with a user specified incremental moving window that steps the derivative across the spectrum. This formula can be expressed as the change in two given reflectance values \((r_1-r_2)\) divided by their associated wavelengths \((\lambda_1-\lambda_2)\). This expression can be simplified as \(\Delta r/\Delta \lambda\). The \(\Delta \lambda\) (change in wavelength) is the incremental window which is user specified. Since the spectrometer records reflectance values from 350nm to 2500nm, a total of 2,150 values (bands), this window can be as small as one or as large as 2,149. A common example of a first derivative calculation with a moving window of 10nm would be the reflectance value at 360nm minus the reflectance value at 350nm divided by 360 minus 350. This method is commonly referred to as the “finite difference approximation method” (Figure 11) (Mark and Workman 2003).

The very nature of the moving window is a compromise between the mathematical true derivative and the realistic dataset. The smaller the window is (e.g., one) the closer the derivative is in calculating the true slope of the spectrum. However, the dataset is inherently noisy. In this case a moving window of one would enhance this noise. A larger window would act both as an averaging agent, smoothing the data, while at the same time retaining any subtle absorption features. A window too large may mask certain absorption features by lowering the reflectance values or even distorting the
Fig. 11. Two Gaussian absorption bands (top) transformed into their first derivative (middle) and second derivative (bottom) equivalents using the finite difference method (Mark and Workman 2003).

Fig. 12. A first derivative transformed Gaussian curve showing the affect that different spacing intervals in the denominator has on the overall shape of the spectra, spacing = 5 to 40 nm (Mark and Workman 2003).
spectral features (Figure 12). In locating this medium a bit of trial and error may be necessary. Background information about the spectra being collected and the goals of the study will be important considerations. The selection of an appropriate moving window will optimize the signal to noise ratio.

The derivative spectral data can then be multiplied by the log transformed inverse of reflectance ($\Delta r/\Delta \lambda (\log(1/r))$). The log transformed inverse of reflectance function has been commonly used in reflectance spectrometry to compensate for the complex scattering process that photons experience when encountering a material. When this function is combined with the derivative data a crude approximation of absorption can be obtained. This method is commonly referred to as Visible/Near-Infrared Reflectance Analysis (VNIRA) (Clark 1999). These quantitative processes combine to express the large amounts of spectral data into a form in which they can be reliably identified.

Spectral matching of unknown specimens to known specimens has been performed using a number of mathematical comparisons. Each of these methods has shown utility in various uses, however, the correlation coefficient ($r$) has proven to be a fast and reliable means of comparing spectral datasets. The correlation coefficient is sensitive to spectral shape differences and can be easily computed by most software packages (Hubbard 2006). The large amounts of data that make up a single spectrum can be quickly placed within a matrix of known spectra in order to find a best match comparison (Appendix A).

**Disadvantages of VNIR**

VNIR is an established analytical technique in many industries and fields. The potential application of the technique within the field of archaeology is justified by the
results of the current study and previous studies. However, there are a number of potential drawbacks to this technique due to a variety of factors. First is the sheer volume of spectral data that is gathered with each reading. A total of 2,150 reflectance values summarily represent a single spectral reading. Compounding this is the need to often take a number of readings per sample to accurately account for inter-sample variation.

Due to the large amount of raw data a certain understanding of computer skills might be required to process it. Knowledge of spreadsheet functions and computer programming may be necessary to handle and manipulate the spectral data. This is also true for the interpretative aspect of spectral data.

The technique has also been criticized as being too sensitive to crystal or chemical structure. Slight variations between these variables may significantly hinder the ability of the technique to accurately identify an unknown specimen if the specimen’s spectral variability has not been properly identified. Conversely reflectance spectroscopy is insensitive to some mineralogy. An example of this is the Si-O stretch absorption feature in quartz, which is spectrally neutral in the VNIR (Clark 1999). Therefore, any spectral variations in quartz are primarily associated with impurities (Hubbard 2006). This can be applied to chert as 89.9% of chert is composed of SiO$_2$ (Hunt 1982).

As previously mentioned the dark coloration of certain chert types may hinder the acquisition of reflectance data in the VNIR regions of the electromagnetic spectrum. A second potential problem with analyzing chert samples is their tendency to fracture concoidally. The uneven surface makes it difficult to find a flat area to analyze causing a number of reflection issues discussed above. An uneven surface also varies the probe to sample distance. A way to address these potential problems is to prepare the chert
samples with a water cooled rock saw or pulverize and sort the sample by grain size thus providing an even surface. These destructive methods may not be acceptable for the archaeologist who wishes to analyze actual artifacts. The small differentiation of various surface angles is alleviated for the most part by taking the derivative of the spectral data.

Finally, more research needs to be done focusing on the nature of absorption features present in chert in the visible, near, and middle-infrared regions. How these features occur and are altered are of primary concern to a researcher wishing to map out the spectral variation of a particular chert type. Quantifying this spectral variation is of paramount importance for studies whose aim is to match an unknown type to a known outcrop. Therefore, the behavior and position of potentially diagnostic absorption features is crucial.

**Advantages of VNIR**

The potential application of VNIR spectroscopy far outweighs the drawbacks, namely because it is a fast, reliable, and non-destructive method. Such an analytical technique is well suited to archaeological research. This is partially why the field of remote sensing has seen an increase in the number of archaeological applications in the past few decades.

The nondestructive nature of VNIR spectroscopy is particularly attractive to the archaeologist who primarily analyzes perishable artifacts. The loss of even a small amount of these artifacts is difficult to accept especially for those who wish to preserve the material for future generations of researchers. Samples can be analyzed multiple times on different occasions without any detrimental effects to the integrity of the artifact as long as the artifact is not light sensitive. The ability of the technique to be used repeatedly is also of importance to the researcher.
Consistent equipment set up and sampling parameters can provide a researcher with replicable data sets. There is a less than 0.02% error between spectrums gathered consecutively (Hatchel 1999). Even with instrument drift occurring over a thirty minute time interval, the ASD user manual claims that only a minor shift of plus or minus 0.2% in reflectance values occurs (Hatchel 1999). This degree of accuracy allows the researcher to compare data sets collected on different occasions and by other laboratories as long as consistent procedures are followed. This characteristic of VNIR spectroscopy allows various spectral data to be compiled forming libraries against which unknown samples may be quickly compared.

The rapid nature of data collection is also a benefit to the researcher who wishes to analyze large numbers of samples. Even allowing for a thirty minute equipment set up and initializing time period, the technique is remarkably fast, capable of analyzing over a hundred samples in an hour. The device gathers a full spectrum of reflectance data in 0.1 seconds, therefore, the most time consuming process is simply arranging the sample under the probe (Hatchel 1999). No sample preparation is necessary other than the standard cleaning and drying of the material prior to analysis unless more destructive techniques are desired.

Unlike other geochemical techniques, VNIR spectroscopy requires very little background training for basic data acquisition. Other than setting up the equipment and taking it down, there are few complicated processes entailed. The compatible software is conducive to a Windows® operating environment allowing the researcher a number of options to manipulate, view, or export the data. The relative low cost of the device and software pales in comparison with even some of the less expensive geophysical and
geochemical analytical methods. The analysis of a single chert sample may range in price from five to forty dollars. These costs add up exponentially as the number of samples required for chert provenance studies is usually large.

The future potential for VNIR spectroscopy in chert provenance studies is immense. This research primarily uses the technique to differentiate between specific chert types (inter-outcrop variation) (i.e., St Louis chert vs. Ft Payne chert). This study will also explore the ability of the technique to distinguish between chert types of the same material that originate in the same geologic formation, but occur in different outcrops (intra-outcrop variation) across the landscape (i.e., St Louis chert from Brigham Quarry vs. St Louis chert from Cross Creek). In this manner the potential of VNIR spectroscopy may be conceptualized as a question of resolution.

The ability of the technique to source a chert artifact back to its specific outcrop in an area where that chert type proliferates is a valuable tool for archaeologists looking at migration patterns and trade networks. Taking this line of thought a step further, it may be possible to identify the specific quarry pit or location on the outcrop where the stone was mined. In this manner researchers could examine the use of the quarry spatially. The combination of temporal data from the correctly sourced artifacts could potentially reconstruct the use life of the quarry site. The sensitivity of VNIR spectroscopy to oxygen hydroxide bonding (OH) features in clay mineralogy, iron oxides, iron hydroxides, and quartz makes this method well suited to study chert materials. The resolution of this technique in these regions is better than X-ray diffraction (XRD) (Clark 1999).
VNIR spectroscopy might also be a well suited technique to identify chert artifacts that have been thermally altered. Previous investigations have shown the reliability of this application (Hubbard et al. 2005; Hubbard 2006). VNIR spectroscopy may also be used in a more traditional sense, to calibrate aerial or satellite imagery. Aerial platforms, such as an Airborne Visible-Infrared Imaging Spectrometer (AVIRIS), are capable of gathering spectral data over large areas. The potential application of AVIRIS data to chert identification can be seen in one case study where mining waste was mapped along the Alamosa River in Colorado. The results of this study showed that the spatial and spectral resolution was fine enough to identify fist sized specimens of OH bearing materials in plowed fields lining the river (Keuhn 2000).

The application of VNIR spectroscopy within the field of archaeology is therefore a methodology worth exploring. The fast, replicable, non-destructive, and cost effective attributes of the technique make it an attractive alternative to other traditional geochemical sourcing methods. This research examines its use in chert provenance studies in which the technique may be an appropriate means to identify the geologic origins of archaeological specimens.
CHAPTER 5

METHODOLOGY

Field Methodology

Multiple surveys were conducted between April 2008 and March 2009. One of the initial goals of the survey was to quantify the number of quarry pits/amorphous trenches at each site in order to select a representative sample of the chert present. These numbers should be taken as approximations due to certain restrictions such as visibility, terrain, prehistoric refilling, and historic disturbances. Historic disturbances such as logging, iron ore mining, and enthusiast’s excavations were noted at a few sites. However, many weeks of fieldwork were dedicated to the location and mapping of each quarry pit and it is assumed that these quantitative descriptions are an accurate depiction of the spatial distribution for each site.

The term quarry pit is defined here as the occurrence of a circular to oval depression in the soil matrix with directly associated lithic debitage that was produced as a direct result of prehistoric mining activities. This definition excludes semicircular depressions caused by tree falls or historic iron ore pits lacking an association with chert debitage. This definition is narrow in order to exclude non-cultural depressions despite possibly missing some small scale cultural pits such as prospecting pits. In some areas the sheer number of overlapping and consecutive quarry pits created a phenomenon which can be
best described as amorphous trenches. These trenches were recorded as well with an effort to differentiate individual quarry depressions. The size of these quarry pits ranged from a few centimeters to three meters in depth with diameters ranging from one to five meters across. Finally, at some sites the Dover chert materials were encased in their limestone matrices prompting the researcher to refer to these as outcroppings. A detailed survey of the five previously recorded quarry sites (40Sw64, 40Sw66, 40Sw67, 40Sw68, 40Sw80) in Stewart County was initially conducted to facilitate the development of a sampling strategy for chert provenance study.

Site 40Sw68 was not identified and will be discussed in Chapter 6. Spatial data for individual quarry pits/outcrops were obtained with a handheld GPS unit at an accuracy ranging from 4 to 7 meters. Greater spatial resolution was attempted with a GeoTrex® Trimble unit. Due to weather conditions, topographic relief, and satellite telemetry a more accurate resolution was not attainable. Coordinates for each quarry pit/outcrop were recorded referencing North American Datum 1983 (NAD83) Universal Transverse Mercator Zone 16 North. Elevation data was also recorded at the top of each quarry pit. Each pit was then assigned an arbitrary sequential number which was written on a piece of flagging tape and suspended above the pit to prevent duplication errors. Each quarry site area was systematically surveyed on foot by pacing arbitrary transects perpendicular to the axis of the ridgeline. This was done until no signs of prehistoric mining activity were encountered for an approximate distance of 200 meters in either direction from the last recorded quarry pit.

In addition to the four prehistoric quarry sites, a total of seven non-cultural deposits were sampled to provide a comparable data set of other chert materials that were
available to prehistoric people in the area (Figure 13) (Table 1). The first of these locations (Location 1) was a modern fill deposit located along the western embankment of Long Creek Road above Long Creek at the head of Caney Hollow. Large chert cobbles that had been exposed during excavations adjacent to the area were observed as clean fill making up the road bed. The chert material was visually identical to the Dover material that was excavated out of the soil matrix at the Brigham Quarry site. Locations 2 and 3 were secondary alluvial deposits of chert gravels located along South Cross Creek and Long Creek respectively. Location 4 was an abandoned historic limestone quarry just south of Carlisle, TN. Using the Dover geologic quadrangle, Location 4 was confidently situated within the Warsaw formation and provided chert samples of this type. Locations 5 and 6 were additional outcrops of the Warsaw formation. Location 5 was an exposure occurring along the east bank of Long Creek immediately adjacent to Location 1 and the mouth of Caney Hollow. The limestone is exposed here along a 230 m section with a vertical relief of 115 m asl. Location 6 is similarly exposed along a 180 m tract of East Fork Creek. Large lenses and bedded outcrops of Warsaw chert were observed at this location. A possible hammestone was observed under one of the limestone ledges indicating prehistoric activities. No other quarrying activity was noted, therefore, the cultural affinity of the object is questionable.

Location 7 lies within Houston County on the southern edge of the Wells Creek structure along Wells Creek and represents the only outcrop of Ft Payne chert identified in the vicinity. The Ft Payne formation is present in Stewart County and can be observed along the Carlisle fault line in the southeastern part of Stewart County. Exposures of the limestone were noted along the minor drainages in the area. The chert lenses found at the
exposures were too small to be conducive for analysis and fit the descriptions of Marcher (1962a, 1962b) for the top margins of the Ft Payne Formation. Chert material was not found in any substantial amount other than as secondary deposits. As a result, a brief visit to the Wells Creek formation was conducted as the previous research of others (Dragoo 1973; Gramly 2000, 2001) indicated substantial outcrops of Ft Payne chert exist along the interior concentric walls of the structure. The Ft Payne chert exists at this location as three discrete beds of dense dark fine grained material. Samples were taken from each of these 11 locations covering an approximate area of 135 square kilometers and collectively represent the primary analysis group of chert materials examined in the study (Figure 13) (Table 1).

Table 1. Descriptions for the primary analysis group of chert samples

<table>
<thead>
<tr>
<th>Sampled Locations</th>
<th>Description</th>
<th>n</th>
<th>Sample #’s</th>
<th>Geologic Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prehistoric Quarries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brigham Site</td>
<td>Prehistoric Quarry</td>
<td>20</td>
<td>64-#</td>
<td>St Louis</td>
</tr>
<tr>
<td>Cross Creek Site</td>
<td>Prehistoric Quarry</td>
<td>20</td>
<td>66-#</td>
<td>St Louis</td>
</tr>
<tr>
<td>Thompson Hollow Site</td>
<td>Prehistoric Quarry</td>
<td>20</td>
<td>67-#</td>
<td>St Louis</td>
</tr>
<tr>
<td>Commissary Ridge Site</td>
<td>Prehistoric Quarry</td>
<td>20</td>
<td>68-#</td>
<td>St Louis</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geologic Outcrops/Deposits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location 1</td>
<td>Embankment Fill</td>
<td>20</td>
<td>1-#</td>
<td>St Louis</td>
</tr>
<tr>
<td>Location 2</td>
<td>Alluvial Gravel</td>
<td>10</td>
<td>2-#</td>
<td>Unknown</td>
</tr>
<tr>
<td>Location 3</td>
<td>Alluvial Gravel</td>
<td>10</td>
<td>3-#</td>
<td>Unknown</td>
</tr>
<tr>
<td>Location 4</td>
<td>Historic Mine</td>
<td>20</td>
<td>4-#</td>
<td>Warsaw</td>
</tr>
<tr>
<td>Location 5</td>
<td>Limestone Outcrop</td>
<td>20</td>
<td>5-#</td>
<td>Warsaw</td>
</tr>
<tr>
<td>Location 6</td>
<td>Limestone Outcrop</td>
<td>20</td>
<td>6-#</td>
<td>Warsaw</td>
</tr>
<tr>
<td>Location 7</td>
<td>Limestone Outcrop</td>
<td>20</td>
<td>7-#</td>
<td>Ft Payne</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total (n)</strong></td>
<td></td>
<td>200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 13. General location of all chert samples taken for the primary analysis group (n = 200). (a) Dover, Cumberland City, and Erin National Aerial Imaging Program (NAIP) photographs, (b) digital elevation map
Sampling

Sampling is an integral part of any research study and is arguably the most important aspect for many. A number of factors influence the development of an appropriate sampling methodology including: 1) the size of the area, 2) the research questions being asked, 3) the target population, and 4) the level of representativeness required (Church 1994). In this paper the study area is defined as the three major chert resources available for prehistoric exploitation in Stewart County. Specifically the present study focused on the material present at four prehistoric quarry sites and seven chert outcrops/deposits within the study area. The goals were to identify inter and intra-outcrop variation in order to distinguish chert types and chert outcrop locations using VNIR spectroscopy. Specifically it investigates whether VNIR spectroscopy can identify an adequate amount of variation present among the sampled population to distinguish one chert sample from another. The target populations are the 11 deposits of chert identified during the survey summarized in Table 1. The consideration of these factors is necessary before establishing a sampling methodology.

The goal of any provenance study is to identify and quantify the full range of variability present within the material type being analyzed. A sample is said to be representative if it encompasses this range. An appropriate sample size is necessary to achieve this goal. The sample size has to be large enough to be representative of the population and also small enough to be manageable in order to conform to the logistical constraints of the particular project. Previous chert provenance studies have sought to identify a specific number of chert samples needed to represent the internal variation (Luedtke 1978, 1979; Luedtke and Meyers 1984; Malyk-Selivanova et al. 1998). The
sample sizes were calculated using a function of the coefficient of variation of trace and rare earth elements versus precision at the 95% confidence interval, a method utilized in statistics by Yamane (1967) and Blalock (1972). Luedtke and Meyers (1984) showed that the larger the elemental coefficient of variation present within the chert type the more samples are necessary for analysis. The size of the coefficient of variation is not necessarily a function of the physical size of the region being analyzed. However, the size of the study area is another factor that has an effect on sample size. Luedtke (1976) demonstrates that the larger the study area the larger the sample size needs to be.

Selivanova et al. (1998:676) suggested a sample size of 15 to adequately represent the range of variability in any single chert outcrop or alluvial deposit. Drennan (1996:109) identifies a sample size of 30 as the most desirable number for large sample sizes according to Student’s $t$ coefficient values.

The research summarized above suggests a desirable sample size ranging from 15-30 specimens per chert outcrop/deposit. However, the low coefficient of variation present within the reflectance data for chert prohibits its use in this manner to pre-determine sample size as Yamane (1967) and Blalock (1972) did. The problem of selecting an appropriate statistical approach to sampling is further compounded by the fact that most techniques assume a normal distribution. This is rarely the case in geology and archaeology. The presence of more than one measurable population of the same chert type might exist at any given chert deposit. An example of this comes from chert exposed within the Cordell Formation, Michigan where the coloration of the material ranges from a dark chocolate brown to a pale bluish grey less than a few centimeters apart (Luedtke 1976). Based on previous geochemical research and the amount of
trace/rare earth element variation, a sample size of 20 was determined to be an adequate representation of variability within a specific chert deposit.

**Sampling Methodology**

Variation within a geologic formation may occur in several ways. Luedtke and Meyers (1984) propose six models to describe each type of variation present in a geologic formation. In model 1 variation can be evenly distributed throughout the geologic formation. Therefore any one sample from the formation should contain a representative amount of all trace materials present (Luedtke and Meyers 1984). Small samples sizes should be sufficient to represent this kind of material. However, variation evenly distributed throughout the formation would make it difficult to identify materials from any single outcrop (Luedtke and Meyers 1984). Model 2 also describes a formation containing variability that is equally distributed but unlike in model 1 this variation has a much larger range. A larger sample size would be necessary to quantify this variation but the samples may be gathered over a relatively small area (Luedtke and Meyers 1984). Model 3 describes variation that is not evenly distributed but shows a vertical structuring possibly due to the deposit forming slowly over time (Luedtke and Meyers 1984). An adequate sampling methodology would have to proportionally gather material across the entire vertical extent of the formation that was being quarried by prehistoric people. Conversely in Model 4, a horizontal distribution of variation would entail the proportional sampling of the entire vein (Luedtke and Meyers 1984). Model 5 describes a combination of these latter two examples: variation would occur at regular intervals both vertically and horizontally in the formation. A large systematic sampling strategy would be necessary to completely cover the extent of the outcrop (Luedtke and Meyers 1984).
In the final example, Model 6, variation within a formation is irregularly concentrated in one area while sparse in another area. The effect of leaching and migration of soluble materials, coupled with various fossil inclusions may cause this type of irregular distribution (Luedtke and Meyers 1984). Model 6 may be the most common for sedimentary formations and requires sampling of both horizontally and vertically distributed materials (Luedtke and Meyers 1984). Individual quarries within the formation may or may not be distinguished due to the sporadic occurrence of variation.

The six models briefly described above are a good reference to keep in mind when developing a sampling strategy. As these models suggest, a sample must be representative of the variation present within the outcrop or deposit that was being exploited. In order to represent as much variation as possible, this study assumes the highest and most irregular kind of variation, that which is described in Model 6. However, it is important to keep in mind that any sampling method assumes that all variations of the material type still exist at the quarry. This may be a faulty assumption as a specific variant may have been exhausted by prehistoric activity or destroyed by natural or modern processes such as colluvial deposition and logging activity.

Assuming the presence of both vertical and horizontal variation, the current study utilized a judgmental sampling strategy. First a digital plan view of each site was generated using Environmental Sensitivities Research Institute (ESRI) ArcMap 9.2. Each map was then overlain by an arbitrary grid composed of 10 by 10 m cells (Figure 14).

Overlaying this grid helped to guide the selection of sampling points by guarding against clustering of judgmentally selected sample locations. The location of the sampled quarry pits was also influenced by the intensity of the mining activity at that portion of
The sampling strategy utilized in this study was biased, however comprehensive coverage of the entire site was deemed necessary in order to quantify all possible variation. A random sample runs the risk of obtaining a limited view of the material variability that was most intensively exploited at the site.

A total of 200 samples were collected and analyzed in this study (see Table 1). A total of 80 samples were gathered from the four quarry sites. The majority of chert samples obtained from the Dover Quarry sites were from the waste debris scattered around the quarry pits. The only exception to this was 10 samples extracted from the limestone bluff exposure at the Cross Creek site. In addition to these, 120 samples were
obtained from the 7 other chert outcrops/deposits. One hundred specimens (100) from Locations 1, 4, 5, 6, 7 were obtained as well as 20 from locations 2 and 3. As Locations 2 and 3 represented secondary deposits of chert they were not as intensively sampled due to a general lack of geologic provenance. Chert deposits located in secondary deposits should not be neglected in provenance studies as they represent an easily exploitable resource for prehistoric people that, depending on the geomorphology of the tributary, may or may not have existed prehistorically. The limited sampling at these locations is not a result of neglect, but rather because the primary focus of the study was on testing the ability of VNIR spectroscopy to chert sourcing, in situ deposits were more desirable than secondary deposits.

Samples were bagged in the field and given a unique two part provenience number reflecting the site location and specimen number. Once brought back to the lab samples were individually washed clean of all dirt and lichen in tap water and allowed to air dry for a minimum of two weeks. The quarry samples were then examined for cultural modification, typed, weighed, and photographed. Despite an attempt to only sample large relatively unmodified debitage from the quarry sites a significant amount (n = 33, 16%) of the quarry samples appear to have been utilized. Admittedly, the type of edgeware observed may have occurred due to natural process, but a few specimens exhibited heavy polish on one or both sides indicating cultural use (Keeley 1980). These implements were unique enough to tentatively suggest their use as digging implements. The 120 non-cultural samples were also washed and allowed to air dry for a minimum of two weeks before analysis.
Each of the 200 samples exhibited some degree of weathering (patina) along the outer surface. Preliminary studies by the author indicate that the penetration depth of diffuse reflectance may be able to compensate for surficial weathering. The inability to quantify the degree of weathering each specimen has undergone necessitated performing analysis from a clean interior surface rather than the outer portion of the specimen. To accomplish this, a fragment was driven off of each specimen to expose the unweathered, or less weathered, surface upon which spectral analyses were performed. A fragment considered desirable for analysis was one larger than three centimeters in diameter, with a relatively flat surface, and thick enough to prevent transmittance of the incident light. The provenience of each sample was maintained as the sample was allowed to air dry to ensure that any latent moisture retained in the samples was reduced. As discussed previously in Chapter 4, the effects of water content can reduce the overall reflectance values of the specimen. This is due to the fact that water is an excellent absorber of light.

Control Group

A second group of chert samples from the researcher’s personal collection was included in this study to further test the ability of the technique to differentiate between chert types. This sample group consisted of 88 specimens representing 43 different stone material types collected from all over the continental United States, Belgium, Belize, Brazil, and Australia. The major material type in this collection is chert (n = 69) but also includes obsidian, rhyolite, indurated shale, quartz, and quartzite. These 88 samples were included in order to provide a control group. If any of the 200 primarily analysis group specimens were sourced to one of the control samples it would indicate a serious misidentification. All 288 samples were analyzed using a spectroradiometer which
recorded reflectance data for each specimen. Each sample’s reflectance data is cumulatively referred to as its spectral signature or spectrum. The term spectra is used when referring to more than one spectrum. The following section describes this methodology in greater detail.

**Analytical Methodology**

Reflectance spectra for each sample were obtained by using an ASD FieldSpec portable spectroradiometer (Figure 15). The device was turned on and allowed to optimize for 30 minutes prior to use. After the device was allowed to optimize a white reference was taken as a baseline measurement. A white panel made from the material Spectralon® provided this nearly 100% reflective lambertian surface. The artificial illumination for this measurement and all subsequent measurements was supplied by a stable DC powered quartz halogen lamp and metal reflector operating at a color temperature of 3000° K (Hatchel 1999). The device was systematically optimized and a white reference was taken every fifth measurement throughout analysis to control for instrument drift. Each chert sample was placed 13 cm beneath the one degree foreoptic attachment with the interior surface facing upwards. The relatively flat surface of the sample was adjusted until it formed a perpendicular angle to the level probe detector. Fine modifications to the sample position were accomplished by placing a small amount of Silly Putty® underneath making sure that no excess material was exposed for accidental analysis. The platform on which each sample was placed consisted of a plain rectangular piece of sheet metal coated with a flat black paint. The entire platform was further encased within a similarly black painted wooden tray (Figure 15). The dark
background material ensured that nearly 100% of the diffuse reflectance data was absorbed minimizing any data contamination.

The spectrometer gathers reflectance data continuously, therefore each specimen was placed under the fiber optic probe with foreoptic attachment and the spectrum was automatically generated on a portable laptop with compatible software. Fine adjustments to the positioning of the sample were performed in order to provide an optimum spectral signature while maintaining the probe to surface distance and 90° angle. Two vertical offsets occurring at the joints of the three photon detectors at 1000-1001 nm and 1775-1776 nm were minimized using these fine adjustments. Finally a single spectrum was saved for each specimen. The one degree foreoptic attachment provided a comprehensive view over the majority of each sample’s surface. This

Fig. 15. ASD FieldSpec portable spectroradiometer used to record reflectance data for all chert samples
accounted for any inter-sample variation such as mineral content, fossil inclusions, and multiple colorations.

Once each sample’s spectral signature was saved the data was exported as a tab delimited ASCII text file containing 2,150 reflectance value measurements recorded for each wavelength from 350 to 2500 nm. Each value is expressed as a percentage of reflectance and is graphically depicted as either a Lorentzian, Gaussian, or mixed Lorentzian/Gaussian curve. The cumulative set of all reflectance values of a specimen is referred to as its spectral signature or spectrum. The spectra of all of the chert samples were imported into a spreadsheet using Microsoft Excel® where various processing procedures prepared the raw data for analysis.

The spectra for all 288 chert samples were placed as columns and labeled according to the original field designations. The first processing step was to remove the two vertical offsets occurring at the joins of the three photon detectors. This may not have been entirely necessary as the spectra were later transformed into derivative data but to minimize any and all possible sources of error the removal of the vertical offsets was carried out. The offsets were corrected by mending the first and third sections of the spectral reflectance curve to the second or middle (Figure 16). A simple formula was created in Microsoft Excel® to perform this task.

The repaired spectra were then ready to be analyzed using the Visible/Near-Infrared Reflectance Analysis (VINRA) technique (Equation 1).

\[
\frac{dy}{dx} \log(1/R) \quad \text{(Eq.1)}
\]

where \(dy\) = the change of reflectance (R), \(dx\) = the change of wavelength, \(R\) = reflectance (unitless except in percentage)
The finite difference approximation method described by Mark and Workman (2003) was used to compute the derivatives. This method is described as a moving average at a user specified window to reduce noise inherent in each spectrum while still retaining small absorption features, see Derivative Transformation section in Chapter 4 for a more thorough discussion of these techniques (Hubbard 2005). The combined effect of the formulas gave an approximate amount of absorption for each spectra (Clark 1999).

The user specified derivative interval is a compromise between levels of noise and resolution. The larger the moving window is the more of an averaging effect it has on the data thereby reducing the noise inherent in the data set. The averaging effects caused by large moving windows may obscure small absorption features that could potentially be diagnostic of the particular sample. Conversely a small moving window might augment existing noise in the data set overshadowing true features. Two intervals were used on each of the 288 spectra to compute the derivatives. First a moving window of ten was

Fig. 16. Highlighted vertical offsets uncorrected (bottom) and corrected (top) at 1001 and 1776 nm
employed followed by one of seven to see which produced better results. A simple formula was developed in Microsoft Excel® to generate both data sets. The first data set contained the 288 spectra transformed by the VNIRA method with a moving window of ten. Each spectrum of the 288 chert samples was cumulatively represented by 215 values reduced from the original 2,150. The second data set contained the 288 spectra of chert samples computed with a moving window of seven. By using a smaller moving window more data points were generated. A total of 307 data points represented each spectrum of the 288 chert samples.

**Evaluating the Data**

A correlation matrix of all transformed spectra was generated using Pearson’s product moment correlation coefficient (Equation 2).

\[
    r = \frac{\sum(X - \mu_X)(Y - \mu_Y)}{N \sigma_X \sigma_Y}
\]

(Eq. 2)

where \( r \) = Pearson product-moment correlation coefficient, \( X \) and \( Y \) = random variables, \( x \) and \( y \) = definitive data points, \( N \) = total number of data points

The ability of the VNIR method to correctly identify a chert type and an outcrop location was evaluated by looking at the highest correlation score for each sample (Figure 17). A chert sample was deemed correctly typed if its highest correlation score was with another sample of the same material. For example, if sample 64-3 from the Brigham Quarry site had its highest correlation score with any of the 19 other samples taken from the same site (i.e., 64-1, 64-2, ..., 64-20) or any of the 60 samples gathered from the three additional Dover Quarry sites (Cross Creek Site, Thompson Hollow Site, and Commissary Ridge Site) it was interpreted as being correctly typed (Figure 17a) (Appendix B). Figure 17a illustrates the matching spectra of the two highly correlated
chert samples (64-3 and 80-17) resulting in a large $r$ value. Figure 17b illustrates poorly matched spectra which result in a low $r$ value. Similarly Warsaw sample 4-15 would be considered correctly typed if its highest correlation score was with any of the other Warsaw samples taken from Locations 4, 5, and 6. This classification evaluation is referred to below as a *Level I accuracy assessment*. This accuracy assessment constitutes inter-outcrop variation.

This study investigated a second level of assessment which looked at the ability of the VNIR technique to identify intra-outcrop variation. A sample was deemed correctly sourced if its *highest* correlation score was with another sample from the same outcrop or deposit. An example of this would be if sample 64-3 from the Brigham quarry site had its highest correlation score with any of the other chert samples taken from the Brigham Quarry site (i.e., 64-1, 64-2, …, 64-20). Likewise Warsaw sample 4-15 was deemed correctly sourced if its highest correlation score was with any of the other 19 samples taken from Location 4 (i.e., 4-1, 4-2, …, 4-20). This level of analysis is referred to below as *Level II accuracy assessment* (Figure 18).

The results of these correlation matrices were examined for both sheets of data to see which moving window interval of ten or seven produced a more accurate data set within the 200 samples analyzed (Appendix A). Accuracy was assessed by using the second level of comparison illustrated immediately above. The results indicated that a moving window of seven produced a more accurate data set. A smaller moving derivative window was not attempted as this would introduce considerably more noise into the data set. Admittedly the small moving window of seven under samples the near-infrared part
Fig. 17. VNIRA transformed spectra depicting; (a) Dover chert sample 64-3 correctly correlated to Dover chert sample 80-17, $r = .943$ and (b) sample 64-3 negatively correlated to a Novaculite sample, $r = .060$
Fig. 18. VNIRA transformed spectra depicting; (a) Dover chert sample 80-20 incorrectly correlated to Dover chert sample 64-18, \( r = .978 \) and (b) sample 80-13 correctly correlated to sample 80-17, \( r = .984 \)
of the spectrum as the spectral resolution of the device degrades to 10 nm in this portion. Further testing showed that the removal of the tail end of each spectrum (2226 – 2500 nm) also improved classification accuracy. This portion of the spectrum is located in the near infrared region of the electromagnetic spectrum and contains most of the noise present in the data set. This is primarily due to a general loss of spectral resolution. The third photon detector in the spectroradiometer samples every 10 nm instead of every 2 nm. Noise is a typical feature of this portion of the data set and produced false correlation scores due to the erratic nature of the low resolution data (Figure 19).

The 80 spectra representing samples taken from the four Dover Quarries were compared to each other and the other 208 samples to assess the accuracy of the device on these two levels of comparison described above. The results presented below are accuracy assessments based upon the correlation scores from the 288 spectra after being transformed by the VNIRA method. Classification accuracy was determined using the two levels defined above.

![Fig. 19. Highlighted noise at the tail end of the transformed spectra due to degrading spectral resolution](image)
CHAPTER 6
RESULTS AND DISCUSSION

Results of Fieldwork

The current study examined the five recorded prehistoric sites in Stewart County that are designated as quarry sites: Brigham Quarry (40Sw64), Cross Creek (40Sw66), Thompson Hollow (40Sw67), Unnamed (40Sw68), and the Commissary Ridge Site (40Sw80). The survey failed to find the location of the fifth site (40Sw68) and therefore no data was obtained from it. As previously mentioned the purpose of the survey was to quantify the amount of prehistoric quarrying activity and spatial extent of each site. Currently no other study has gathered this information that is crucial to the interpretation of each site. A few observations are made below describing the area in which each site was recorded and some speculation as to its geologic position is detailed. A summary of the results of the survey is listed in Table 2.

Table 2. Results for all four of the Dover Quarry sites surveyed in the study

<table>
<thead>
<tr>
<th>Quarry Site</th>
<th>Number of pits</th>
<th>Linear extent (m)</th>
<th>Area (m²)</th>
<th>Elevations (m asl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prehistoric Quarries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brigham</td>
<td>341</td>
<td>450</td>
<td>38,730</td>
<td>132 – 149</td>
</tr>
<tr>
<td>Cross Creek</td>
<td>N/A</td>
<td>280</td>
<td>6,800</td>
<td>112 – 124</td>
</tr>
<tr>
<td>Thompson Hollow</td>
<td>253</td>
<td>420</td>
<td>28,500</td>
<td>124 – 140</td>
</tr>
<tr>
<td>Commissary Ridge</td>
<td>2</td>
<td>90</td>
<td>1,700</td>
<td>129 – 131</td>
</tr>
</tbody>
</table>
Brigham Quarry

The Brigham Quarry site (40Sw64) is probably the most cited and best known of the Dover Quarries. Of the five sites surveyed in this study it is also the largest in spatial extent and number of quarry pits. The site was recorded in 1972 and was listed on the National Register of Historic Places in 1973 (Tennessee Division of Archaeology 1972).

The Brigham Quarry site is located on the north slope of Caney Hollow. The mouth of Caney Hollow lies perpendicular to Long Creek and extends to the west of Long Creek for approximately one kilometer before turning to the south. The prehistoric quarries are located at this far western extent of the hollow along the toe slopes of the ridgelines. At the time of the survey the property was still maintained by the Brighams as pasture land with a few small tracts existing as cultivated areas. The hill slopes lining the hollow are covered with deciduous woodland and secondary undergrowth. The area is primarily drained by unknown seasonal tributaries and Caney Hollow creek which flows east into Long Creek.

Spatial Distribution

Approximately 341 pits/amorphous trenches were observed and recorded over an area of 38,730 square meters and a linear distance of 450 meters. The site is split into three sections by two unnamed seasonal drainages that flow southeast to Caney Hollow Creek. All of the pits are located along the terminus of the hill slopes at a restricted elevation range of 132 to 149 meters above sea level (Figure 20). Due to the restricted elevation range of the quarry pits the general distributions of the mining activities follow the contours of the topography.
Fig. 20. Brigham Quarry Site; (a) spatial distribution of individual quarry pits/Mississippi house platforms, (b) aerial photograph, (c) underlying geology [Warsaw limestone (*blue*)], (d) digital elevation model with contour intervals [20 ft]
Some of the quarry pits are visible as slight circular depressions on the leaf littered forest floor, but others are massive in comparison exceeding five meters in diameter and three meters deep. The hill slopes in and around the quarry pits are covered withdebitage consisting of cortical flakes, discarded cobbles, and bifaces. These piles are so dense in places that the ground is completely blanketed. Gramly (1992:37) excavated one of these piles and determined it to be a cache of prepared cores for later use. Despite this find, most of the debitage seems to be composed of waste flakes from prepared cores. There are also a number of stage two bifaces discarded for various reasons during production. Surprisingly, a number of utilized pieces of debitage were also observed. The larger specimens may have been used as digging implements as there is considerable edge damage and use polish on the bulbar ventral surface.

The traces of quarry activity are not evenly distributed across the site. In some areas the quarry pits are clustered making it hard to distinguish individual excavations. In these areas the excavated area appears to be a continuation of sequential pits leading up the hill slope. In this manner a degree of systemization can be perceived. Gramly (1992) investigated one of these trenches and proposed that they represented a desperate attempt by the prehistoric miners to obtain materials as the resource became scarcer.

The current survey added a third section that was not previously identified within the Brigham quarry site extending the site an additional 150 meters to the northeast. No evidence of quarrying was observed along the south flanking hill slopes of Caney Hollow despite topological similarities. Further to the northeast a single pit was encountered isolated from the quarry by 150 meters. Even further to the northeast a cluster of three circular pits are located on the south facing bluff overlooking the mouth of Caney
Hollow. All four of these pits are identical to those located within the quarry site except that debitage entirely absent. No chert debris, cobbles, or any other form of lithic material was observed. These pits are approximately 3 meters in diameter and 2 meters deep. They are substantial excavations requiring a significant investment of time and energy. The locations of each were recorded, however, they were not included in the total number of pits for the Brigham quarry site due to the lack of prehistoric debitage. There are two plausible explanations for these that pits. First, these could represent prehistoric prospection pits as they are located at similar elevations and topographic setting as those within the site. This may explain the isolated pit at 110 meters distant, but hardly accounts for the cluster of three pits 780 meters to the northeast. A second and more plausible explanation is that these represent evidence of 19th century iron ore mining which was prevalent in Stewart County. Identical pits of this nature were observed along the Cross Creek drainage in close proximity to a recorded mid 19th century iron ore mine.

Other Cultural Features

A second discovery which has more implications for future site investigations and interpretations of the site was made during a Murray State University field trip to the quarry in the spring of 2008 when Dr. David Dye located what appears to be a Mississippian house platform. The site is situated on top of a relatively flat protruding lobe of the ridgeline. This location has a commanding view of the northeastern section of the site. The area is circular with a diameter of approximately 7 meters. The northwestern side of the feature appears to be depressed into the gently sloping landform whereas the southeastern side of the feature is built up to create a seemingly level
platform. A small concentration of fire altered silicified limestone blocks is visible in the eastern half of the feature. Scattered throughout the limestone are secondary and primary flakes and what appears to be a quartzite cobble. Quarry pits of large dimensions can be observed in close proximity to the site. No other features of this nature were observed on the immediate uplands overlooking the site.

A second possible Mississippian house platform was observed along an unknown tributary that splits the site in two and serves as the property boundary between the Brighams and a local hunt club. This feature is less impressive than the one discussed above and may be an ancient meander of the entrenched tributary. However, the feature is circular with similar dimensions except for the extreme southwestern side that is being eroded by the tributary. No cultural materials were noticed with the exception of the large amounts of chert debitage that litters this shallow valley.

The Brighams have been stewards of the site for years and, as a result the site is remarkably well preserved. Despite this care, a number of historic impacts were observed at the Brigham quarry site and these will be briefly addressed. As previously mentioned the hollow is currently utilized as pasturage. The fence line for the pasture field incorporates a portion of the quarry pits. These are located at the extreme southern end of the site. As a result of bovine trampling these features are somewhat subdued and exist as shallow depressions. A wagon road is present winding uphill to the northeast following the contour of the slope. Evidence of disturbance by collectors is apparent from theunnatural piles of bifaces on tree stumps and freshly broken cobbles. Two quarry pits were observed that appeared to be recent in origin as tree roots were exposed in the profiles. The most significant disturbance to the site occurs on the hunt club
property on the far southwestern section of the site. Recent logging activities have greatly impacted quarry pits at the highest elevations in this sector. Bulldozer excavations have leveled the secondary undergrowth and torn up the ground to such extent as to obliterate an unknown number of quarry pits leaving behind piles of debitage mixed in with the disturbed soil.

Evidence for Geologic Provenance

At the Brigham Quarry site the Dover chert nodules or cannonballs occur within the reddish-brown silty clay soil matrix. This soil matrix is the direct result of the weathering of the St Louis formation. The St Louis limestone has weathered to such a degree that little trace of it remains on the hill slopes flanking Caney Hollow. The remaining vestiges of the formation can still be observed capping the hilltops and ridgelines above. The Dover chert nodules are more resistant to these weathering processes and, have therefore been freed of their limestone parent material, and are situated in the soil that blankets the hill slopes at the Brigham Quarry location. The spatial distribution of the quarry pits is tightly confined to a certain elevation range that follows the topographic contours around the site. A general plan view of the individual quarry pits at the site illustrates this relationship between the location of the Dover nodules and the topographic relief (Figure 20).

It is clear that the native miners did not excavate directly into the underlying limestone in most cases. Only a few limestone blocks or debris were encountered. Also the walls and floors of the quarry pits were composed of the reddish brown silty clay soil to some depth. This is not a result of recent infilling, but an indicator that the Dover chert nodules were being extracted directly from the soil matrix. If the nodules had been
directly quarried from the limestone a fair amount of limestone debitage would be intermixed with the lithic debris. Also, the walls and floors of the quarry pits would be composed of the limestone matrix that the nodules were extracted from. This quarrying method was used at the southern portion of the Cross Creek site where the nodules had been quarried directly from the exposed limestone bluff face.

The location of the Dover nodules may be a reflection of slope creep or other post depositional processes. Once free of the encased limestone the nodules may have settled down slope from the parent limestone. A more likely explanation is that the nodules that were being exploited by the prehistoric miners were relatively in situ and may be located at the base of the St Louis formation. Three blocks of macroscopically distinct Warsaw chert were observed adjacent to a few of the quarry pits. This was also viewed as an indication that the underlying Warsaw limestone was in close proximity to the Dover chert nodules. This relationship can be seen in and around pits 10 through 13.

At this location what appears to be a natural defile was heavily exploited by the prehistoric miners. Three extremely large pits are excavated into the walls of this spring head exposing the underlying limestone. Pit number 10 can be best described as a concavity into the limestone. In its western profile Dover chert nodules can be observed within their parent limestone matrix. The elevation of the Dover nodules at this location coincides with the elevation ranges for the surrounding quarry pits. To a certain extent, this natural feature and the labor of the prehistoric miners have given us a window into the unique geologic record for the Brigham Quarry site.
Cross Creek Quarry

The Cross Creek Site (40Sw66) is located 5.7 km southeast of the Brigham Quarry site along the Cross Creek Federal Reserve, Cross Creek drainage (Figure 21). The site is on private property north of Carlisle, Tennessee. Currently the site is primarily a fallow agricultural field bordered by mixed deciduous trees. Just inside the western tree line, a formidable bluff face leads down to Cross Creek. The site record form describes the site as an open cultivated field with debitage piles and an associated stone box cemetery (Tennessee Division of Archaeology 1964a). Gramly visited the site and conducted brief excavations into one of the debitage piles at the edge of the bluff overlooking Cross Creek (Gramly 1992). The main prehistoric quarrying activities can be viewed along this sheer bluff face. The extreme southern end of the landform is characterized by a steep almost vertical outcropping of limestone. The gradient of the bluff face decreases considerably to the north. Evidence of prehistoric mining activities is scattered over a linear extent of 280 meters along a north/south axis of this bluff face. Where the limestone is exposed, signs of prehistoric mining can be observed in the form of angular blocks of limestone, in situ Dover cobbles with steppe fracturing on the anterior surface, and possible signs of fire alteration along the outcropping. One section of the outcrop appears to be completely unnatural in appearance as it can be described as a limestone wall. The face of this section is completely vertical with equidistantly spaced split Dover nodules (Figure 22). A one meter wide foot path leads in front of this exposure.

Spatial Distribution

The Dover chert nodules can be seen encased in the parent limestone along this outcropping across an area of 2,100 square meters. The occurrence of the Dover chert
Fig. 21. Cross Creek Quarry Site; (a) spatial distribution of individual quarry pits/outcrops, (b) aerial photograph, (c) underlying geology [Warsaw limestone (blue)], (d) digital elevation model with contour intervals [20 ft]
Fig. 22. Limestone bluff outcrop at the Cross Creek Quarry showing *in situ* Dover chert nodules each approximately 30 cm in diameter, facing south.
nODULES appears to be tightly confined within a range of approximately 112 to 124 meters above sea level. Chipping debris and other chert debitage is present in this area as well. As the bluff face lessens to the north extensive piles of debitage can be seen completely blanketing the hill slope in places. These debitage piles cover an approximate area of 3,700 square meters. Most of this debris appears to be cortical flakes signifying blank or core preparation. Similar to the Brigham Quarry site, there are also stage two bifaces and utilized flakes present.

Gramly (1992) describes quarry pits along this bluff face; the current survey did not encounter any discernible quarry pits akin to those witnessed at the Brigham Quarry site. Slight depressions or concavities were observed along the northern slope line of the site which may represent these types of features. It appears that the Dover nodules were almost completely free of their limestone encasements in this area and may have been available to prehistoric procurement right along the surface. It seems plausible that some degree of effort was required to pry them from the remnants of the parent limestone. The elevation ranges for these debris piles and seemingly unnatural depressions is consistent with that observed at the southern end of the exposure.

Other Cultural Features

There are a number of other cultural features at the Cross Creek site. First, there is a recorded stone box cemetery located almost directly above the bluff face. This area is overgrown by thick secondary growth, but angular limestone slabs were observed in the vicinity. Second, a small cave opening is present at the southern terminus of the site. The opening is approximately two meters wide and one meter high. The vestibule continues for four to five meters east before making an abrupt turn to the north and
immediately ending. No signs of cultural use were observed except for a few large secondary flakes which appear to have washed in. Neither the walls nor ceiling showed smoke staining. In addition to these features, large piles of secondary flakes and utilized lithics were seen along the top of the bluff edge just inside the wood line. One of these was excavated by Gramly (1992) and may be evidence of further production after the cortex was removed on the slope below.

Historic impacts include signs of recent logging activities. These impacted the stone box cemetery and obliterated much of the bluff edge. Silt runoff from logging and consecutive years of cultivation has resulted in silt blanketing much of the bluff face. The area is well known by some local collectors in Carlisle and evidence of their activities was observed at the site by bifaces precariously placed upon limestone ledges.

**Evidence for Geologic Provenance**

The geologic setting is similar to that described for the Brigham Quarry site. The bluff face and adjacent hill slopes are mapped within the Warsaw formation (Figure 20c). The St Louis formation is mapped in the vicinity on areas of high elevation. An initial conclusion might be drawn placing the occurrence of the Dover chert cobbles into the Warsaw formation, but a reexamination of the evidence indicates that the nodules are outcropping at the base of the St Louis formation. The Dover chert nodules are located along a specific vertical extent of 130 to 140 m above sea level. As previously discussed the steep bluff face characterizing the southern portion of the site lessens to the north until it almost completely levels off. The spatial resolution of the geologic quadrangle map used for the survey was large enough that a vertical difference of 10 to 20 m would
not be adequately resolved. Also limestone at the base of the bluff face matches the macroscopic descriptions for the Warsaw formation presented by Marcher (1962a, 1962b). No unconformities were noted between where the Dover chert nodules were situated and the underlying limestone, however this conformal relationship between the St Louis and Warsaw is documented in previous research (Marcher 1962a, 1962b).

Thompson Hollow Quarry

The Thompson Hollow Quarry (40Sw67) is located on the western bank of Cross Creek almost directly across from the Cross Creek Site. Thompson Hollow is easily accessed via route 49 located directly north of Carlisle, Tennessee. Thompson Hollow Creek runs east through the hollow before emptying into the Cross Creek drainage. The site is located on private property and was recorded by the presence of Dover chert cultural materials (Tennessee Division of Archaeology 1964b). The site is situated on the north side of the hollow entirely covered by mixed deciduous woodland.

Spatial Distribution

The Thompson Hollow Quarry site is consists of 253 quarry pits and amorphous trenches covering an area of 28,500 square meters (Figure 23). These quarry pits are spread out over a linear distance of 420 meters along a north east/ south west axis. They are not equidistantly spaced but occur as clusters and concentrations. The dimensions of each pit vary, but are comparable to those described previously at the Brigham Quarry site. The location of these quarry pits are tightly constrained to a specific elevation range of 124 to 140 meters above sea level. As a result, the distribution of the quarry pits
Fig. 23. Thompson Hollow Quarry Site; (a) spatial distribution of individual quarry pits, (b) aerial photograph, (c) underlying geology [Warsaw limestone (*blue*)], (d) digital elevation model with contour intervals [20 ft].
follow the contours of the topography. A number of comparisons between this site and
the Brigham Quarry site are discussed below.

The Thompson Hollow Quarry site and the Brigham Quarry site both demonstrate a
similar pattern of material exploitation. First, the south facing sides of the hollows were
extensively mined. This may represent a coincidence rather than cultural site exploitation
preferences. The large cannonballs of Dover chert may only occur at these locations as
opposed to being evenly distributed over the region and therefore the location of these
sites does not indicate a decision by the miners to excavate the south facing hill slopes in
a particular hollow. Secondly, the excavation of large circular pits and amorphous
trenches was the preferred extraction technique for both sites. The presence of large
amounts of cortical debitage at both sites indicates that the cobbles were being reduced
on site for later preparation elsewhere. Finally, the prehistoric miners were excavating
the cobbles directly from the soil matrix as the soluble limestone had completely eroded
away. There was a complete absence of limestone blocks at the site further bolstering
this hypothesis.

The presence of the Dover chert nodules seems to have been limited to a certain
degree as the mining activity is confined within a discrete elevation range and terminates
abruptly at the northeastern and southwestern portions of the site. At these locations the
quarry pits diminish in size and depth. The frequency and size of debitage also
significantly diminish. These observations may be indicative of the finite nature of the
resource and signs that the quarry had been utilized to its full extent.
Other Cultural Features

The condition of the site seems to be better than that of the Brigham site and in this regard is more impressive. However, there are some disturbances due to logging and development. The southwestern section of the site is located on local hunt club property and has been impacted by logging, but not to the same extent that the Brigham Quarry site has suffered. The main impacts to the site have come from a modern dirt road that was bulldozed into the hill slope directly off of route 49. This north eastern section of the site has also been partially impacted by the creation of an artificial level platform on top of which a trailer, boat, and car have been placed. These impacts do not seem to have disturbed or obliterated very many quarry pits as they both occur in areas where prehistoric mining activity seems to have dwindled. A third disturbance is located at the center of the site at an elevation range that slightly exceeds that of the quarry pits. The disturbance consists of a large semi circular earthen embankment facing the southeast, perpendicular to the slope of the landform. The length of this earthen structure is approximately 20 meters and at its center it is 3 meters high. The antiquity of the structure is unknown having tree growth of over 30 years maturity on top it. No cultural implements were observed other than a piece of iron equipment lying nearby. The function of this earthen embankment is unknown, however, the presence of at least two bulldozers in the area suggests its modern origins. During the course of the survey, orange flagging tape was observed marking out the proposed right of way of a utility line that will impact an unknown number of quarry pits.
Evidence for Geologic Provenance

The occurrence of the Dover chert nodules at the site was attributed to the St Louis formation. The lack of limestone blocks, debitage, and outcroppings are indicators that most if not all of the St Louis limestone has been eroded leaving behind the chert residuum in the soil matrix.

Commissary Ridge Site

The Commissary Ridge Site (40Sw80) is located on an isolated bluff overlooking the Cumberland River to the south (Figure 24). The site is located approximately 5 km to the north and northeast of the three previously discussed quarry sites. The site is primarily drained by Commissary Ridge Creek located on the eastern flank of the landform and the Cumberland River. The damming of the Cumberland River and its subsequent inundation has formed Lake Barkley along this section. The site is covered by young deciduous woodland and thick secondary undergrowth. Part of the site is maintained as Burcham cemetery characterized by short lawn grasses and coniferous trees. The Federal Reserve preserving this recreational area also incorporates the site.

Spatial Distribution

Initially the Commissary Ridge Site was recorded as containing the presence of stone box graves and a quarry/workshop (Tennessee Division of Archaeology 1978). At 20,000 square meters the size of the site is quite substantial (Tennessee Division of Archaeology 1978). No signs of quarrying activity were encountered in this immediate area, however, a sheer bluff face of exposed limestone is present along the western flank of the landform. No Dover chert debitage in the form of encased nodules or lithic debris
Fig. 24. Commissary Ridge Quarry Site; (a) spatial distribution of individual quarry pits, (b) aerial photograph, (c) underlying geology [Warsaw limestone (Mw)], (d) digital elevation model with contour intervals [20 ft]
was observed for approximately 300 meters to the northwest. At this point broken pieces of Dover nodules were encountered in runoff debris along the hill slope. A single quarry pit was located at the edge of the bluff face with a few piles of debitage in close proximity. A second quarry pit was encountered 90 meters to the northwest. The elevation ranges from 129 to 131 meters above sea level. Sparse amounts of Dover chert debitage were observed in between these isolated quarry pits encompassing an area of 1,700 square meters. No other sign of prehistoric mining activities were encountered.

The location of these two pits is in close proximity to site number 40Sw79 of unknown cultural affiliation but may be associated. Regardless of the site’s affiliation with site 40Sw79 or the Commissary Ridge Site, the quarrying activities seem to have been an isolated incident of short temporal duration. Further analysis of this may provide us with a unique insight into the prehistoric exploitation of Dover chert.

**Other Cultural Features**

The cemetery component of the Commissary Ridge site is composed of an unknown number of stone box graves. The construction of Commissary Ridge road has impacted the site’s western boundary. A more severe impact was the development of Burcham Cemetery. This is an early to mid 20th century historic cemetery with a dozen visible headstones. Secondary and utilized flakes made from Dover chert can be seen scattered throughout the headstones. On the eastern border of the cemetery the remains of three stone box graves can be seen. Some of these appear to have been looted and the limestone slabs are stacked in piles.
Evidence for Geologic Provenance

The Dover chert nodules occur on top of the bluff face lying just under the leaf litter within the thin soil matrix. They do not appear to occur in great numbers but seem to be capping the underlying limestone which comprises the high bluff face. No Dover chert nodules were observed in situ along the limestone outcrop, however small lenses of Warsaw chert can be seen.

Unnamed Quarry

The fifth and final previously recorded quarry site is an apparently unnamed site recorded as site number 40Sw68. The site was recorded at the far southwestern extent of Caney Hollow, “one and a half miles west of Long Creek” (Tennessee Division of Archaeology 1967). Despite two days of survey no signs of prehistoric quarrying were encountered in the form of quarry pits or debitage. Similarly no debitage was observed in the drainages in the vicinity. However, there were small nodules of Dover chert materials weathering out of the soil matrix. These occurred as spherical nodules only a few centimeters in diameter being almost perfectly rounded. The material was heavily weathered and unsuitable for tool production.

These spherical nodules were seen in rock gardens in at least two historic dwellings in the vicinity. The observation of chert nodules in rock gardens might potentially be a tool for identifying the occurrence of Dover chert nodules in the local area. Large amounts of debitage were also observed at two residences in Thompson Hollow. The recording of 40Sw68 may have been in error. Despite this setback it illustrated the uneven distribution and occurrence of the large Dover chert nodules across the landscape strengthening the hypothesis that these nodules may only be present in great amounts at
certain locations in the surrounding area. Therefore it might be in error to assume continuous beds or strata of Dover chert.

Summary

These five previously recorded sites represent the known Dover quarries of Stewart County. It should not be assumed that these are the only prehistoric quarries in Stewart County or the surrounding vicinity where prehistoric miners exploited large nodules of Dover chert. Local informants in Dover and Carlisle, Tennessee allude to the existence of other similar sites. In particular a large quarry site is rumored to exist along the bluffs of the Cumberland River near Fort Donaldson. The investigation and subsequent surveying of these sites is important for archaeologists who seek to understand the exploitation and distribution of this resource in the prehistoric record.

Geologic Context

The geologic provenience of the Dover chert nodules has been the subject of speculation by archaeologists for years. The problem is that all four of the Mississippian aged limestone formations (Ste. Genevieve, St Louis, Warsaw, and Ft Payne) contain good quality chert that, in some cases, are macroscopically similar to what is called “Dover chert.” This begs the question as to which formation Dover chert belongs. Nance (2000) suggests that the Dover chert materials could be contained within the St Louis formation, Warsaw formation, or represents a transitional layer between the two. Gramly (1992) assigns the Dover chert nodules exclusively to the St Louis formation. Complicating the issue is that local flintknappers and enthusiasts often consider Dover chert to the Ft Payne formation (Multiple personal communications).
Some of this confusion may stem from one of the original geologic surveys of this part of Tennessee by Bassler in 1932. In Bassler’s classification of the geologic formations, he did not subdivide the four Mississippian aged limestone into discrete units; instead he assigns them all to the Ft Payne formation (Bassler 1932). Complicating this is the occurrence of a dark variety of the Ft Payne chert which resembles the high quality, dark variety of the Dover chert. This is problematic for researchers attempting to distinguish the two material types macroscopically. The association of Dover chert with the Ft Payne formation can be easily dismissed since the nearest outcropping of the limestone is located along a northeast/southwest trending Carlisle. The nearest outcropping of the Ft Payne formation to the Dover Quarry sites, Thompson Hollow and Cross Creek is approximately 2 km to the south. The occurrence of the Dover chert as nodules also undermines its association with the Ft Payne formation, the chert types of which occur in two distinct lithofacies (Marcher 1962b).

As previously discussed, Marcher (1962b) groups the Ft Payne chert into two distinct types, bedded chert and scraggy chert. The bedded variety is 4-12” thick and is of primary origin forming as segregated silica beds during the Mississippian embayment. The weathering of concentrations of sapropelic material along planes gives the rock a laminated appearance (Marcher 1962b). It is this laminated appearance that looks identical to the dark variety of Dover chert.

The youngest of the Mississippian aged limestone formations, the Ste. Genevieve, only exists in a few isolated pockets in the far northern sector of Stewart County. Ste. Genevieve formation is not mapped anywhere near the four quarry sites discussed. The chert materials from this formation may still be seen as white to light grey rounded
nodules at higher elevations in the area. These nodules are sometimes of high quality chert characterized by concentric circles giving the material a bullseye appearance. The presumed chert residuum of this formation was only observed at areas of high elevation above the Cross Creek site and was not observed at any other location.

Therefore, this leaves two remaining possibilities for the geologic provenance of Dover chert: the Warsaw and St Louis formations. The 7.5 Minute United States Geologic Quadrangle map for the Dover region clearly places all four of the prehistoric quarry sites within the Warsaw formation. However, the St Louis formation is mapped in close proximity occurring at slightly higher elevation ranges. This could persuade an investigator to favor Nance’s (2000) hypothesis of a transitional layer of Dover chert nodules between the two formations. In fact, the presence of the Warsaw formation was confirmed at all four sites and observed at each location. Previous research in the area states that the Warsaw-St Louis contact is difficult to recognize with certainty (Marcher 1962b). Therefore one might assume that the provenance of Dover chert might well be situated within the Warsaw formation, however, a degree of caution must be taken at this juncture. The scale of the Dover Geologic Quadrangle map is roughly 1:24,000 with contour intervals of 20 feet (Marcher 1964). This spatial resolution may be too coarse grained for examining the conformable boundary between the two formations. In fact each of the four Dover Quarry sites are located on sloping topographic relief where extrapolation techniques are commonly used to generate formation boundaries (Marcher 1962a). As mentioned above the sole existence of the Dover chert nodules in the soil matrix at two of the Dover Quarry sites, Commissary Ridge and Thompson Hollow, demonstrates a complete lack of in situ geologic provenance as the parent limestone has
completely eroded away. These are just a few of the considerations that need to be accounted for when understanding the geologic provenance of the Dover chert materials at each of the four prehistoric quarry sites.

Detailed analysis by a trained professional geologist may help the researcher who is more interested in obtaining anthropological data but wishes to understand the geologic context of the site. Without a complete petrologic analysis it may be difficult to comment on the formation of these chert types. It is possible, however, to take the macroscopic descriptions of Marcher’s (1964a, 1964b), Larson and Barnes’s (1965) studies and apply them to observations made at each of the four Dover Quarry sites. Soluble weathering of limestone coupled with soil erosion provided prehistoric miners with a large quantity of high quality chert that was relatively easy to procure from the thin soil matrix (Figure 25).

The almost complete lack of limestone blocks or outcroppings at the Brigham, Thompson Hollow, Commissary Ridge, and the northern half of the Cross Creek quarry sites illustrates the likely occurrence of the Dover chert nodules in this manner. Recent tree falls in the study areas support this assumption as Dover chert nodules were observed in the root bulbs. An observation by Mr. Brigham also describes the post depositional accumulation of the Dover nodules within the soil matrix. During the construction of Long Creek Road, which runs north and south paralleling the drainage of the same name, a number of road cuts were made by the construction crews to level the proposed road way. One of these road cuts lies slightly to the south of Caney Hollow, located just above a meander of Long Creek. Here Mr. Brigham described a ‘layer’ of large Dover chert nodules noticeable within the exposed hill slope profile. This stratum of Dover
Fig. 25. Slope profile showing the relationship between the soil mantle and underlying limestone formation, along highway 49 northeast of Dover, TN
chert nodules was located three feet below the present fence line on the eastern side of the road (James Brigham, personal communication 2008). The backhoe had apparently uncovered a large concentration of the nodules in the hill slope very similar to those prehistoric peoples may have sought. The workers took this material and used it as clean fill for the western side of Long Creek Road. The piles of broken cobbles and nodules can still be seen as part of the existing road bed leading down to Long Creek below. Some of these cobbles are in excess of 50 cm in diameter and though considerably weathered still possess excellent flaking characteristics. Larson and Barnes (1965) describe a number of similar locations where the chert nodules were excavated from the hillside and used to bolster the adjacent road bed.

The body of previous geologic research in the area attributes the Dover chert nodules found at each of the four prehistoric quarry sites as occurring in the St Louis limestone. Observations made in the field show that, due in part to weathering and other post depositional processes, this delineation can be difficult to ascertain. However, the descriptions, analysis, and conclusions made by previous geological surveys are comparable to the evidence observed in the field and present here. The geologic provenance of the Dover chert was confidently assigned to the base of the St Louis formation.

**Results of VNIR Analysis**

The results of the VNIR were divided into two levels of accuracy assessment to best describe the ability of the spectroradiometer to classify a sample (Table 3). The first level of accuracy assessment examined how well the VNIR technique classified chert from the same geologic formation to other, often macroscopically similar, chert types
Level I accuracy assessment would therefore be a measurement of the ability of VNIR to distinguish inter-outcrop variation (between chert types, e.g., Dover versus Warsaw). The spectral signatures of the 80 Dover chert samples from the four quarry sites were first examined in this manner. A quarry sample was deemed correctly identified as Dover chert if its highest correlation score was with another sample from the same quarry or another Dover Quarry. The results of this initial accuracy assessment showed that a total of 76 out of 80, or 95% of specimens were correctly identified as Dover chert (Table 4). Three of the four samples misidentified came from the Cross Creek Quarry. These three specimens were all taken from in situ deposits along the bluff face and potential reasons why they were not classified as Dover chert will be discussed later.

Table 3. Accuracy assessments for the 200 primary analysis group samples

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<td>Commissary Ridge</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>13</td>
<td>65</td>
</tr>
<tr>
<td>Subtotal</td>
<td>80</td>
<td>76</td>
<td>95</td>
<td>35</td>
<td>44</td>
</tr>
<tr>
<td>Geologic Outcrops/Deposits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location 1</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>15</td>
<td>75</td>
</tr>
<tr>
<td>Location 2</td>
<td>10</td>
<td>NA</td>
<td>NA</td>
<td>6</td>
<td>60</td>
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<tr>
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<td>10</td>
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<td>NA</td>
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<td>90</td>
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<tr>
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<td>20</td>
<td>16</td>
<td>80</td>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td>Location 5</td>
<td>20</td>
<td>16</td>
<td>80</td>
<td>11</td>
<td>55</td>
</tr>
<tr>
<td>Location 6</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>Location 7</td>
<td>20</td>
<td>NA</td>
<td>NA</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Subtotal</td>
<td>120</td>
<td>72</td>
<td>90*</td>
<td>63</td>
<td>53</td>
</tr>
<tr>
<td>Total (n)</td>
<td>200</td>
<td>148</td>
<td>93**</td>
<td>98</td>
<td>49</td>
</tr>
</tbody>
</table>

*120-40NA  **200-40NA
The second level of accuracy assessment examined how well the technique classified chert samples taken from the same quarry site. As such, Level II accuracy assessment is a measure of the ability of VNIR to distinguish intra-outcrop variation (within a chert type, e.g., Brigham Quarry versus Thompson Hollow). The spectral signatures of the 80 Dover chert samples from the four quarry sites were first examined in this manner. A quarry sample was deemed correctly identified as originating from that quarry if its highest correlation score was with another sample from the same quarry. Level II analysis is a more rigorous evaluation of the data as each sample has only 19 other possible matches in order to be deemed correctly classified as opposed to 79 possibilities in Level I. The results of this analysis showed that 35 out of 80, or 44% of the samples were correctly identified to their respective quarries (Table 4).

Table 4. Accuracy assessments for the 80 samples from the four Dover Quarry sites

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Geologic formation</th>
<th>n</th>
<th>Level I</th>
<th>% Identified</th>
<th>Level II</th>
<th>% Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prehistoric Quarries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brigham</td>
<td>St Louis</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Cross Creek</td>
<td>St Louis</td>
<td>20</td>
<td>17</td>
<td>85</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Thompson Hollow</td>
<td>St Louis</td>
<td>20</td>
<td>19</td>
<td>95</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Commissary Ridge</td>
<td>St Louis</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>13</td>
<td>65</td>
</tr>
<tr>
<td>Total (n)</td>
<td></td>
<td>80</td>
<td>76</td>
<td>95</td>
<td>35</td>
<td>44</td>
</tr>
</tbody>
</table>

The samples taken from Location 1 were not included in the Level II accuracy assessments due to their secondary context. However, they were described as coming from road construction that excavated a portion of the hill slope immediately adjacent to where they were sampled placing them as chert residuum of the St Louis formation (James Brigham personal communication 2008). Level I analysis of the 20 samples taken
from Location 1 show that 20 out of 20, or 100% were correctly classified as Dover chert (Table 7). Level II analysis showed that 15 of the 20, or 75% had their highest correlations with samples taken from Location 1 (Table 7). If the 20 samples are included in the two levels of accuracy assessment results for the 80 Dover Quarry samples Level I assessment increases to 96 out of 100, (96%), correctly identified as Dover chert. Level II assessment increases to 50 out of 100, (50%), were correctly sourced to their individual quarry/deposit.

The same assessments could be used to determine how Warsaw and Ft Payne sample groups were classified. The chert types identified as Warsaw chert totaled 60 samples obtained from 3 locations (Locations 4, 5, and 6). (Table 5) These chert specimens were taken in situ from the Warsaw Formation. Level I analysis showed that the technique correctly classified 52 out of 60, (87%), of the specimens. Level II analysis showed that 29 out of 60, (48%), of the specimens was correctly classified as have originated from their sampled locations.

Table 5. Accuracy assessments for the 60 Warsaw samples

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Geologic formation</th>
<th>n</th>
<th>Level I</th>
<th>% Identified</th>
<th>Level II</th>
<th>% Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 4</td>
<td>Warsaw</td>
<td>20</td>
<td>16</td>
<td>80</td>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td>Location 5</td>
<td>Warsaw</td>
<td>20</td>
<td>16</td>
<td>80</td>
<td>11</td>
<td>55</td>
</tr>
<tr>
<td>Location 6</td>
<td>Warsaw</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>Total (n)</td>
<td></td>
<td>60</td>
<td>52</td>
<td>87</td>
<td>29</td>
<td>48</td>
</tr>
</tbody>
</table>

Finally, the 20 samples of Ft Payne chert, taken from Location 7, were assessed following these same levels of comparison (Table 6). Admittedly the sample size of this variety is small and not representative of the macroscopic variation described by previous
researchers (Dragoo 1973; Marcher 1964a, 1964b). Despite these limitations, the results highlight an important aspect of the study. The Level I assessment for the Ft Payne chert showed that 4 out of 20, or 20% of the specimens were correctly classified (Table 6). As there were no other comparison samples the results are identical for the Level II assessment. The majority (n = 15) samples had their highest correlation scores with samples from the Dover quarries.

Table 6. Accuracy assessments for the 20 Ft Payne samples

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Geologic formation</th>
<th>n</th>
<th>Level I</th>
<th>% Identified</th>
<th>Level II</th>
<th>% Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 7</td>
<td>Ft Payne</td>
<td>20</td>
<td>NA</td>
<td>NA</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total (n)</strong></td>
<td></td>
<td>20</td>
<td>NA</td>
<td>NA</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>

The 20 samples obtained from secondary alluvial deposits (Locations 2 and 3) were also classified according to these levels (Table 7). Level I assessment for the 20 samples from Locations 2 and 3 was not applicable due to the questionable geologic origins of the chert. The tributaries along which they were gathered lay within or were adjacent to all three of the chert bearing Mississippian formations (Ft Payne, Warsaw, and St Louis). Level II analysis was preformed to see if these samples could be classified as discrete chert deposits. The accuracy assessment for Location 2 showed that 6 out of the 10, (60%), of the specimens were correctly classified. Location 3 had a total of 9 out of the 10 specimens, (90%), correctly classified (Table 7). Again the alluvial gravel samples may not be representative of the true variability existing at Locations 2 and 3, however, it is interesting to note that 75% (n = 15) of the time the specimens had their highest correlations with others from the same location.
Table 7. Accuracy assessments for the 40 secondary context samples

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Geologic formation</th>
<th>n</th>
<th>Level I</th>
<th>% Identified</th>
<th>Level II</th>
<th>% Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td>St Louis</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>15</td>
<td>75</td>
</tr>
<tr>
<td>Location 2</td>
<td>Unknown</td>
<td>10</td>
<td>NA</td>
<td>NA</td>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>Location 3</td>
<td>Unknown</td>
<td>10</td>
<td>NA</td>
<td>NA</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td><strong>Total (n)</strong></td>
<td><strong>40</strong></td>
<td><strong>20</strong></td>
<td><strong>20</strong></td>
<td><strong>100</strong></td>
<td><strong>30</strong></td>
<td><strong>75</strong></td>
</tr>
</tbody>
</table>

*40-20NA

**Summary**

The analysis above highlighted both Level I and Level II accuracy assessments for the three major chert types sampled (St Louis, Warsaw, and Ft Payne). This broad level of comparison showed that the VNIR technique was able to correctly identify specific chert types over 90% of the time. What this means is that using the VNIR technique we can confidently identify a specific chert type such as Dover chert but cannot identify which quarry/oucrop it came from in the study area. Whereas, this level of comparison presents an important ability of the device to detect inter-outcrop variation, a more detailed analysis of the data shows additional information about the quarry or deposit that may direct future studies.

The Brigham, Commissary Ridge, and Thompson Hollow sites all had Level I accuracy assessment scores over 90% (Table 3). Samples taken from the Cross Creek site represented the lowest Level I assessment score at 85%, but overall the scores were similar. The Level II assessment scores showed more varied results. The Commissary Ridge site had the highest Level II assessment score of 65%, or 13 of the 20 samples had their highest correlation scores to other samples from within the site. The Brigham and Thompson Hollow sites had the next highest Level II assessment scores at 50%, or 10 of
20 and 40%, or 8 of 20 specimens sampled respectively were correctly identified as originating from that particular quarry. The greatest variation in Level II assessment scores came from the Cross Creek quarry having a low percentage, 20%, or 4 out of 20 correctly classified. The differences between these Level II assessment scores illustrates that the variability within Dover chert is not homogeneously distributed across the formation. This may also have been caused by the degree of weathering that the specimens exhibited at each site. The misclassified Cross Creek samples (n = 16) all came from in situ nodules that visually appeared well protected from chemical leaching of soluble particulates.

The seven geologic outcrops/deposits sampled also exhibited variability in their Level II assessment scores. Samples taken from Locations 2, 3, and 7 were not able to be evaluated during Level I assessments due to either a lack of geologic provenance or multiple type comparisons (e.g., Ft Payne from Location 7). However, they did exhibit a great deal of variability in their Level II assessment scores. Out of the seven Locations, Location 3 had the highest Level II assessment score of 90%, or 9 out of 10 correctly classified. The reduced number of samples did not allow for direct comparison to locations where 20 samples were obtained, but it is interesting to note that specimens from secondary context found at Location 3 were still internally consistent with one another. Location 1 also showed a lot of internal consistency with a Level II assessment score of 75%, or 15 out of 20 samples correctly identified within the same deposit. Once again these specimens were interpreted as coming from secondary contexts because of their existence as clean fill. If the descriptions of this deposit are accurate, it would demonstrate that the material all came from a relatively small deposit where the hill slope
was cut away for road construction. Level II assessment scores for Locations 2, 4, and 5 all closely matched one another having scores ranging from 55 to 60%. Location 6 had a Level II assessment score of 30%, or 6 out of 20 were correctly classified as having originated from the same outcrop. This was interesting since all of the 20 samples were taken from a relatively small outcrop of approximately 60 meters in linear extent. The Warsaw chert deposits outcropped at this location in thick horizontal beds confined within a vertical extent of 6 m. The elevation range for these deposits is 128 to 134 m asl. Expected results for the Level II assessment score would be much higher due to the confined nature of the deposits. The low Level II assessment score might be representative of substantial intra-outcrop variation. Following this line of thought, variation within samples of Ft. Payne chert taken from Location 7 should also be internally consistent as all of the 20 samples were taken from three bedded planes of chert outcropping along an approximate 5 m exposure. Instead their Level II assessment score was 20%, or four of the 20 having their highest score with samples from the same location. The Level II assessment score for Location 7 samples represented the lowest of all 11 sample groups analyzed. As this variety of Ft Payne chert is quite dark these results may be due to the lack of reflectance data acquired during the analysis procedure.

One interesting point to note is that if the Ft Payne outcrop was mapped as the St Louis formation, hence referring to the chert type as Dover, its Level I assessment scores would have been high, 15 of the 20, or 75% of the samples would have been identified with Dover chert samples obtained from the quarry sites. Therefore, it is possible that these samples are Dover chert. However, mainly due to its occurrence in bedded forms and
weathering characteristics, the mapping of this outcrop in the Ft Payne formation is accepted by the current researcher.

Finally mention should be made of the 88 control samples included in the analysis. Out of the 200 primary analysis group specimens only three or .015% were misclassified as one of the control samples. Specifically of the three samples misclassified (66-6, 7-8, 2-10) specimens 66-6 and 7-8 were both mismatched to a Flint Ridge sample. The Dover (66-6), Ft Payne (7-8), and Flint Ridge samples were all dark in coloration. The spectroradiometer was found to record very little reflectance data from darker specimens of chert. This phenomenon is primarily attributed to the fact that very little diffuse reflectance is being recorded by the spectroradiometer and will be discussed in greater detail later in this chapter. Sample 2-10 was mismatched to a sample of chert from Belize. The provenance of sample 2-10 is undeniably questionable as it was recovered in an alluvial gravel deposit, but we can safely assume that it was incorrectly identified with the chert from Belize. A possibility for this misidentification comes from the orange-red hues that both specimens exhibit. The reddish coloration of the samples might be an indicator that there is a large amount of iron (Fe) in the material. Iron is a strong absorber of incident light and has been found to mask all other potentially diagnostic features (Hubbard 2006).

The 88 control samples exhibited multiple color variations making them visually similar to some of the primary analysis group specimens. The majority of the control samples were chert (n = 69), therefore, they were chemically similar to the primary analysis group being composed of nearly 90% silicon. We might also assume that they formed under similar depositional or post-depositional conditions. The ability of VNIR
to distinguish between the primary analysis group and the control group demonstrates the accuracy of the technique to distinguish different chert types, inter-outercrop variation. This small contribution to the study should not be overlooked.

Discussion

The ability of VNIR spectroscopy to confidently differentiate between three visually similar chert types illustrates the potential that this analytical technique has for future chert sourcing studies. The survey of the four Dover Quarry sites in Stewart County contributes to the archaeology of the southeastern United States by quantifying the extent of prehistoric exploitation and places these sites in their geographic context. The implications of assigning Dover chert to the St Louis formation suggest that large nodules or cannonballs of the material may occur wherever the St Louis limestone is noted, particularly where it contacts with the underlying Warsaw. This is a large area extending across central Tennessee northward into western Kentucky and southern Illinois. As previously mentioned the work by Smith and Broster (1993) demonstrates that Dover chert would have been available to prehistoric people outside of Stewart County. The descriptions of St Louis chert from southern Illinois appear to be identical to the variations observed in Dover chert from Stewart County (Meyers 1970). This begs the question whether or not it has been an accurate assumption that all implements made of Dover chert originated in Stewart County, Tennessee. The presence of other quarry sites which may have supplied prehistoric peoples with a large surplus of material for trade or tool manufacture has yet to be explored in detail. Another viable question is to what degree was Dover chert easily procured from secondary sources and loose soil matrices and how much of this material contributed to the archaeological record?
At each of the Dover Quarry sites, natural exposures of the underlying chert nodules were observed. Prehistorically the observation of Dover chert nodules in tree falls or along entrenched drainages may have led to the extensive exploitation of each site. The prehistoric miners exhibited an intimate knowledge of the land by identifying these areas and taking full advantage of the resource. The evidence suggests that large accumulations of these nodules did not occur everywhere and where they did it seems that these areas were mined until resource depletion inhibited the expansion of the site.

This observations leads to other issues related to economics, centralized control, specialized industries, trade, ownership, and temporal use of the quarry sites. Were these quarry sites predominately developed and utilized during the Mississippi period? Was the production and development of the quarry controlled by a distant centralized power or driven by economic demand? Was there competition for the production of implements stemming from the quarries at Mill Creek, Illinois (Cobb 2000)? Did one group of people lay claim to these sites and therefore restrict access as the presence of stone box cemeteries in close proximity to the Dover Quarry sites implies? The discovery of Mississippian house platforms at the Brigham Quarry site raises the question of a permanent population of prehistoric miners. These issues are various and pose a daunting task for the researcher who seeks to understand these sites.

There is little debate over the significance and sheer size of the Dover Quarry sites, notably the Thompson Hollow and Brigham sites. The extent of prehistoric exploitation revealed at these sites is impressive and may not be matched in the area. However, the need for comprehensive surveys in conjunction with predictive modeling is apparent and will aid future research. This type of data is imperative for studies seeking to quantify
prehistoric exploitation of Dover chert. Only through these comprehensive efforts might we begin to uncover the spatial and temporal distribution of the material that was so heavily exploited by prehistoric people at the Brigham, Cross Creek, Thompson Hollow, and Commissary Ridge sites. A step toward this future research can be seen by the accuracy results of the VNIR technique to correctly source a chert specimen.

The results of the analysis were presented as two different levels of accuracy. The first level (Level I accuracy assessment) showed the ability of the technique to differentiate between chert types (Table 3). This means that the technique was able to identify enough of the inter-outcrop variation to correctly classify chert types not found within the same geologic formation. By using the analytical methods described above, samples from the four Dover Quarries were correctly classified 95% of the time.

However, the accuracy of the method decreased substantially when trying to differentiate samples of the same chert type occurring at different quarry sites/outcrops within the same geologic formation (Level II accuracy assessment). It may be possible that there is not enough intra-outcrop variation to be able to make this identification. The range of sample variation for the material outcropping at the four quarry sites may overlap significantly enough to be statistically equivalent. A second possibility is that either the technique (VNIR spectroscopy), the method of analysis used (VNIRA combined with Pearson’s correlation coefficient), or a combination of both was simply unable to quantify this variation. The sourcing of chert implements of the same chert type to specific outcrops in the same geologic formation would pose a larger task for VNIR as evidenced by the Level II assessment scores. The ability of the technique and method of analysis can be conceptualized in terms of spatial resolution. Whereas the
technique was not capable of distinguishing intra-outcrop variation over a small area, it was able to do so across a larger geographic area.

Archaeologists who undertake chert sourcing studies are attempting to do one of two things: 1) identify potential outcrops of chert across a specified study area (material based study) or 2) understand whether the chert material came from local or exotic sources (site based). Each of these approaches has its own particular goals. The material based study is usually conducted over a broad geographic region. The identification of formations containing chert deposits is often a first step in this approach. Usually a type collection is gathered representing the macroscopic variability of the types. This collection is an attempt to qualify the range of chert types present in the study region. The results of this research project demonstrate that VNIR spectroscopy is an adequate technique to do these types of analyses with one noted exception that will be addressed below. The second type of chert sourcing study is from a site based perspective where a smaller geographic region is targeted. Only one or two chert types might be present within the sites assemblage. The majority of these materials are usually inferred to have been acquired from local sources. Therefore researchers are more interested in chert outcrops and deposits located along a single geologic formation. Multiple outcrops of the formation may be present in the area reflecting a need to identify and quantify intra-outcrop variation. In this instance the techniques and methods used in this study would be a less than desirable approach.

The concerns associated with intra-outcrop variation might be reduced in areas where chert resources are scarce. The identification of exotic material would be not be problematic for VNIR as evidenced by the results of this study and others (Hubbard et. al
2003, 2005). Only two of the 88 exotic samples were classified as locally occurring variants. One of these was from the problematic Ft Payne samples.

Throughout this study and in prior experiments, it was found that dark colored chert types were difficult to correctly classify and typically had low scores in the Level I and Level II assessments. These errors can be seen in the analysis of the Ft Payne samples as well as the three misidentified chert samples from the Cross Creek site (66-4, 66-6, and 66-10). As previously mentioned, all three samples were taken from *in situ* chert nodules exposed in the bluff face (Figure 22). The protection afforded by the surrounding limestone matrix sheltered them from the extensive weathering that affected other samples taken from the northern portion of the site. Macroscopically these chert samples were dark black or dark purple in coloration with a striated appearance. This variety of Dover chert was also observed at the three other sites and represented the best quality material for stone tool production due to its exceptionally fine grain size and superior flaking characteristics.

All 20 of the Ft Payne samples were macroscopically indistinguishable to this variant of Dover chert. The only differences observed were in the geologic occurrence of the deposits, how each chert type weathered, and the smell of the material. Dover chert was observed as only occurring as large nodules, termed “cannonballs” by Marcher (1962a, 1962b), whereas the Ft Payne chert was observed as discrete thick beds of dense chert. Weathered specimens of Dover chert were observed as taking on increasingly lighter hues of brown until becoming white in appearance. Weathered samples of the Ft Payne obtained from secondary sources exhibited a wide variety of color ranges from dark black to dark blue to tan brown. When freshly broken, the Ft Payne chert had a strong
petroleum smell that was not noticed in any other chert type in the area. The dark varieties for both the Ft Payne and Dover chert produced very low reflectance values for analysis. Diffuse reflection was limited due to the fact that most of the incident light was absorbed by these samples. One of the two exotic materials misidentified as Dover chert was a dark variety of Flint Ridge chert which may have also lacked diffuse reflectance data.
CHAPTER 7

CONCLUSIONS

The goals of the study were two-fold. The first goal focused on accurately surveying and describing the four previously recorded Dover Quarry sites of Stewart County, Tennessee. The survey of the Brigham Quarry (40Sw64), Cross Creek (40Sw66), Thompson Hollow (40Sw67), and Commissary Ridge (40Sw80) sites was also undertaken to contribute to our understanding of these well known quarries as this level of analysis had not previously been established or disseminated. The second goal examined the utility of VNIR spectroscopy as an analytical technique applicable to chert provenance studies.

The spatial distribution of each of the four Dover Quarry sites allowed for observation of the vertical and horizontal occurrence of the chert materials that prehistoric inhabitants were exploiting. An unexpected result of the survey was the observation that prehistoric mining activity was intimately tied to the geologic occurrence of the material at any given location. The prehistoric mining activity encountered at each site was inconsistent due to the large size of the Dover chert cobbles occurring at that particular location. The large distribution of hundreds of quarry pits at the Brigham and Thompson Hollow sites reflects the presence of the Dover chert cobbles in the soil matrix and contrasts sharply to the Cross Creek site where more energy would have been
required to pry the nodules out of the existing limestone bluff face. The Dover material that occurred in the soil matrix would have been easily dug from the fine silty clay but the quality of the material would not have been as good due to a higher degree of weathering. A higher quality material was acquired at the Cross Creek site due to the greater amount of protection afforded by the surrounding limestone. Observations such as these demonstrate that much can be learned by studying quarry sites that have often been neglected by the archaeological community due, in part, to logistical constraints related to the large quantities of artifacts usually spread over a considerable area.

The application of VNIR spectroscopy within chert provenance studies is a potentially non-destructive, fast, and accurate technique to distinguish different chert types both over broad and regional geographic areas. The high degree of accuracy the device has in differentiating chert types would directly contribute to chert sourcing studies by correlating a material to its geologic formation. The technique also shows potential in distinguishing chert specimens from the same formation, but outcropping at different locations.

The greatest contribution to future research that VNIR spectroscopy can provide is an accurate and non-destructive method to source an artifact back to its original place of procurement. VNIR spectroscopy provides a method to rapidly analyze a large number of samples over a short period of time. The approximate amount of time spent to record the spectra of the 200 samples used in this study totaled approximately four hours. This is in addition to systematically optimizing the device every fifth sample. The software used to graphically display the reflectance data is user-friendly and provides several of compatible options for data export. Once compiled in a spreadsheet format, the file size
did not usually exceed nine megabytes in size. The processing and analysis of the spectra was not labor intensive and was facilitated by basic propagating formulas that could be applied instantaneously over multiple spectra. The ability of the device to analyze large numbers of samples and the ease with which data was processed made it possible to produce same day results. The digital format of the data and its relatively small size decreases problems related to compatibility and storage. The researcher used a small portable flash drive to transport 619,200 data points representing the spectral signatures of the 288 chert samples and was able to rapidly load them into widely used software packages. The spectral reflectance values can be visually displayed in any number of standard graph generating programs. The simplistic nature of the data set makes it possible to quickly compare a spectrum with potentially thousands of other spectra.

Several spectral depositories are already established in which unknown mineral samples can be evaluated within the comparative collection in order to make identifications. Future researchers could create spectral libraries for chert samples as Luedtke (1992) began with NAA and is continued currently at the Missouri University Research Reactor (MURR) by Michael Glascock and others. Multiple chert spectral repositories could be generated simultaneously based on the research efforts of many institutions. The resulting data could then be stored in a central repository where unknown samples from archaeological sites or outcrops could be compared against the referenced samples. These advantages are in stark contrast to the time consuming, difficult to operate, potentially hazardous, and destructive analytical methods outlined in Chapter 4.
The cost of the technique is relatively low, after the initial investment in the equipment, compared to other traditional chert sourcing methods currently in use such as petrography, NAA, and ICP. A hyperspectral device similar to the one used in the current study may be purchased from a number of well established vendors specializing in remote sensing equipment for approximately $70,000. The original purchase of the device is a large expense but can be quickly justified by comparing the prices involved with even the least expensive chert sourcing technique. In addition to the cost of equipment, preparing a thin section for petrographic analysis is typically priced at $15 to $20 dollars. A chert sourcing study covering a large region with 100 chert samples or more could see the funding for analysis quickly evaporate. As previously discussed, even local studies looking to determine chert sources may gather large amounts of samples to accurately represent inter and intra outcrop variation therefore encountering similar funding constraints. Provenance studies using geochemical techniques such as NAA and ICP can expect to pay much more ($25-$45) to analyze a single sample.

Possibly the greatest advantage of VNIR spectroscopy is its non-destructive characteristic. In this study chert samples were prepared by detaching a portion of the specimen to obtain measurements on unweathered surfaces. This method was chosen so that the resulting data set would be as uniform as possible and not influenced by the degree of surficial weathering that a sample exhibited. In fact, the very nature of diffuse reflectance may obtain data from the interior of the sample that is not as severely altered. Sample preparation techniques that are also thought to provide a better data set would be the grinding up and grain sorting of the sample and the removal of ferrous materials (Hubbard 2006). Sample preparation techniques that are more destructive in nature
might be an acceptable way of analyzing material gathered from quarry sites or outcrops as little data is lost if items are sampled that exhibit very little to no cultural use. The destruction of this debitage might be a means to obtain the best possible analytical results to provide a data set that most closely represents the spectral variation at the quarry/deposit location. The destruction of artifacts in this manner would be unacceptable and cultural implements would not be prepared using such methods. The results of non-destructive analysis on chert artifacts may improve due to a purer outcrop/deposit reference set. Clearly more research is needed to determine the effect that weathering, especially chemical weathering has on a chert’s spectral signature. The non-destructive capabilities of the device are worth exploring as this would allow researchers to analyze cultural objects that would not be subjected to some of the other more destructive techniques such as NAA or certain methods of ICP with the exception of ICP-LA.

Despite its many advantages, VNIR spectroscopy does have a few limitations. First it may require a basic knowledge of computer programming in order to process the large amounts of data generated. Secondly, the limitations caused by a lack of data when analyzing dark colored chert samples are a drawback for the technique which uses reflectance data to map the location of diagnostic features. If very little or no light is reflected off the sample then this could potentially cause misclassifications in the analysis process as evidenced by the Dover and Ft Payne chert samples having their highest correlation score with a Flint Ridge specimen from the control group.

The accuracy of any chert sourcing study might be heavily influenced by the number of chert outcrops and deposits located and sampled within the study area. The exclusion
of one or a few locations where prehistoric people may have procured chert may create a void in the data set. Precautions need to be taken to ensure that all possible variability is accounted for in a chert type or outcrop. The need for a well developed sampling method is a crucial factor in achieving this goal. The sampling of chert deposits that would not have been available to prehistoric people such as road cuts or recently deposited alluvial gravel bars will aid the development of a representative sample. Materials sampled from these locations can only increase the comprehensiveness of the data set. Prehistoric quarry sites that have been overexploited by the ancient quarries or are no longer in existence due to modern day disturbances may also be detrimental to sourcing studies. This problem further strengthens the need for comprehensive sampling.

The problem of sourcing a mineralogically homogeneous material to existing or non-existing outcrops has plagued archaeologists who study how prehistoric people exploited chert resources. The task is made even more daunting once the realization is made that each specific material type, outcrop, or deposit has a distinct fingerprint of variability which would allow a researcher to confidently assign a geologic provenance. Previous research has demonstrated that a range of variability exists within a chert type and between its various outcrop locations (Malyk-Salivanova et al. 1998). Malyk-Salivanova and others (1998:694) introduce the term “geochemical quarry fields” to describe the range of chemical variability found in prehistoric quarries along the western Brooks Range. The source of a particular sample was determined by its correlation score with one of the geochemical quarry fields (Malyk-Salivanova et al. 1998). By looking at this cumulative range of variability as diagnostic of a particular chert type or outcrop, future researchers may better differentiate source locations.
**Future Research**

Visible Near-Infrared Reflectance Spectroscopy is a practical technique to use in chert provenance studies. The ability of the device to quantify a diffuse reflectance interaction that incident light has with a chert material across multiple band widths has been demonstrated by this study and Hubbard’s and others (2005) to be a feasible analytical method for archaeologists seeking to source chert materials. The application of this technique has important implications for future geoarchaeological research.

Typically VNIR analysis has been performed in the field of remote sensing as a method of gathering spectral ground truth data in order to classify features in satellite imagery (Kuehn 2000). The data gained from hyperspectral field instruments such as the one used in this study help gather data for feature detection studies in digital image processing. The success of spectral identification studies in the field of remote sensing demonstrates that it may be possible to identify archaeological sites based upon the spectral signatures of chert present at the surface. The spectral data gathered by this study and future ones may be used to process satellite imagery so that chert spectral anomalies might be identified via existing classification methods. After georeferencing the imagery to existing base maps, the potential archaeological anomalies might be investigated. There are a number of considerations that these studies would have to take into account, including spatial and spectral resolution of the satellite imaging system. The spatial resolutions of these sensors range from kilometers to centimeters. The type of spatial resolution needed for archaeological purposes would have to be a meter or less to resolve the small spectral signatures characteristic of these sites. A second major concern for these studies is ground cover. The presence of trees, underbrush, and other
features would obstruct a clear view of the ground surface. Therefore this type of research might be best applied by using a multispectral sensor with fine spatial and spectral resolution such as the AVIRIS device in arid or recently cultivated areas.

Many of the prehistoric quarry sites previously discussed contain large clusters of chert debitage visible on the surface. The location of these sites might be redundant information since the likelihood that they are already recorded is high due to their size and visibility on the landscape. Despite this possibility, valuable information might be gathered relatively quickly. The large tracts of land maintained by the Bureau of Land Management (BLM) in the western regions of the country could be surveyed quickly and the prehistoric sites containing large quantities of chert artifacts may be readily identified using these methods. One site type that should be easily identified is prehistoric quarry sites. As evidenced by the current study of the Dover Quarries and other similar surveys, prehistoric quarry sites contain large amounts of chert debitage spread over large areas. Sensors with coarser spatial resolutions up to ten meters should be able to identify the spectral signature of the chert debris blanketing the hill slopes and land immediately surrounding the quarry site. The large amount of chert may even allow sites to be detected in wooded areas, such as what is found at the Dover Quarry sites. Imagery gathered during the late winter or early spring months when there is little vegetation might be able to detect surficial debitage. A study by Carr and Turner (1996) demonstrated that a study like this might be possible.

Carr and Turner (1996) used ground truth data acquired from geophysical survey, spectral analysis, and aerial photography on an existing prehistoric quarry site to classify satellite imagery. Reflectance data were gathered with a FieldSpec®-FR spectrometer in
a controlled lab environment. The data aided their classification of additional prehistoric quarry sites within the Landsat TM satellite imagery. The successful identification of previously unknown prehistoric quarry sites in the Horse Prairie region of southwestern Montana showed that the combined application of VNIR spectral data with satellite imagery could predict the location of archaeological sites.

Provenance studies continue to be an integral research objective aiding our understanding of prehistoric life. The Dover Quarries in Stewart County, Tennessee, are interpreted as playing a major role in the distribution of Mississippian ceremonial and agricultural implements throughout the southeastern United States. Arguably more work needs to be done in assessing the degree to which the Dover chert resources were exploited, traded, and utilized not only by the prehistoric people of the Mississippi Period but also by groups throughout much of the prehistoric record. The continued development and refinement of the Visible/Near-Infrared Reflectance spectroscopy technique within chert sourcing studies would greatly assist in interpreting how this resource was distributed and how prehistoric people moved around the landscape. The use of VNIR within chert sourcing studies highlights the increasingly multidisciplinary approach that continues to grow in the field of archaeology. The combined application of multiple disciplines in order to answer anthropological questions is a viable way of looking at a research question from different perspectives. This study successfully used established techniques and methods within the fields of geology and remote sensing to conduct a chert provenance study for the Dover chert material type in Stewart County, Tennessee.
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U.S. Department of Agriculture, Soil Conservation Service


Wagner, D.


Yamane, Taro

APPENDIX A

CORRELATION MATRIX EXAMPLE
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APPENDIX B

HIGHEST CORRELATION SCORES EXAMPLE
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