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Addressing Questions of Prehistoric Occupation Seasonality at Freshwater Mussel Shell Ring Sites in the Mississippi Delta: Applications in Carbonate Geochemistry and Zooarchaeology

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Addressing questions of prehistoric occupation seasonality at freshwater mussel shell ring
sites in the Mississippi Delta: applications in carbonate
geochemistry and zooarchaeology

By

Joseph Mitchell

A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Earth and Atmospheric Science
in the Department of Geosciences

Mississippi State, Mississippi

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Addressing questions of prehistoric occupation seasonality at freshwater mussel shell ring
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geochemistry and zooarchaeology

By

Joseph Mitchell

Approved:

Brenda L. Kirkland
(Major Professor)

Evan Peacock
(Committee Member)

Janet E. Rafferty
(Committee Member)

Rinat I. Gabitov
(Committee Member)

Mike E. Brown
(Graduate Coordinator)

Rick Travis
Interim Dean
College of Arts & Sciences

Name: Joseph Mitchell

Date of Degree: August 12, 2016

Institution: Mississippi State University

Major Field: Earth and Atmospheric Science

Committee Chair: Brenda Kirkland

Title of Study: Addressing questions of prehistoric occupation seasonality at freshwater mussel shell ring sites in the Mississippi Delta: applications in carbonate geochemistry and zooarchaeology

Pages in Study 130

Candidate for Degree of Doctor of Philosophy

Seasonality estimates based on archaeological shellfish remains have been an important component of settlement pattern reconstruction. Investigations of this nature allow researchers to place prehistoric people on the landscape at points in space at different times of the year. Many of the previous seasonality studies, however, have focused on marine species from coastal sites, with little attention given to freshwater locales, especially ones in the Mississippi Delta. To address that disparity, this study examines freshwater mussel “season of capture” via analysis of stable oxygen isotope ratios in specimens recovered from two Late Woodland sites located along the Yazoo River, Mississippi.

As freshwater mussel shells are composed of aragonite, a metastable form of calcium carbonate (CaCO_3), they can suffer greatly from the impact of meteoric diagenesis. Because of this, samples must be evaluated for diagenesis prior to any geochemical analysis taking place. Archaeological shell samples were examined via thin-section petrography and scanning electron microscopy (SEM). Visual analysis indicated pristine aragonite microstructure and crystallography in all archaeological shell samples,

and confirmed their suitability for isotope analysis. Vetted shells were then micromilled across accretionary growth bands, and analyzed for their oxygen isotope signatures. Isotope profiles were then interpreted for their individual “season of capture”, and oscillation patterns for 22 shell specimens indicated mussels were being collected in all four seasons. These data support the view that at least some portion of the human population at both sites engaged in shellfishing activities year-round, indicating sedentary populations at both locales.

The shell assemblages were also investigated for the purpose of informing modern conservation efforts (i.e., “applied zooarchaeology”). Nearly 24,000 valves were analyzed taxonomically, yielding the presence of 37 species, of which 24 represented new river records for the Yazoo River. These data provide a valuable historical perspective, cataloging communities as they existed prior to extensive modern impacts, thus representing an ecological baseline to be compared with modern populations. Though modern data are extremely limited for the river, the study revealed it once supported a diverse mussel community containing numerous species currently considered rare, endangered, or extinct in Mississippi.

DEDICATION

To my family, who have always been supportive, and to Claire, for giving me the direction I needed.

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CHAPTER I

INTRODUCTION

Problem Statement

Archaeological freshwater mussel “shell rings” offer a unique perspective on prehistoric human and environmental interaction. These sites, which generally contain hundreds of thousands of aragonite mollusk shells, also present an opportunity to increase our understanding of Holocene sediment accumulation, essentially acting as a historical index of paleo-temperatures, chemical equilibria, and ecological change through time (Alvarez et al. 2010; Andrus 2011; Deith and Shackleton 1998; Waselkov 1987). Though much study has been directed to archaeological coastal clam and oyster middens in the Southeast (e.g., Andrus and Thompson 2012; Bruseth 1980, 1991; Claassen 1986; Marquardt 2010; Russo 2006; Thompson and Andrus 2011), as well as similar sites on the West Coast (e.g., Culleton et al. 2009; Eerkens et al. 2013; Jones et al. 2008; Tellez-Duarte et al. 2008), little attention has been given to prehistoric freshwater mussel rings, especially ones in the Mississippi Delta.

As a largely untapped scientific resource, freshwater shell rings present a unique opportunity to explain a significant portion of the human condition present in the archaeological record. What does it mean to be mobile or sedentary, and what is required for both? Can a population be sedentary that is not agricultural? Are these concepts interdependent? These questions have been discussed at length within archaeology, and

have yet to find much consensus. How archaeologists understand and recognize mobility, sedentariness, and subsistence have long been topics marred by essentialist and normative thinking (Dunnell 1986; O'Brien and Holland 1990). Often, a correlation between settlement pattern and subsistence practices was used to denote whether a population was mobile or sedentary. This resulted in studies making reference to both Archaic and Woodland sites as “basecamps” rather than permanent villages (Rafferty 1994:406; see: Jenkins and Krause 1986; Rogers 1991; Welch 1981). This is also true of shell ring sites, which often were, and still are, described as being either “feasting locales”, “macroband camps”, or “relatively permanent” occupations (DePratter 1979). This confusion generally stems from an assumption of continuum between subsistence and the requirements to “be” sedentary. If a population was dependent on hunting and gathering for their food, it would require mobility to survive (e.g., Faulkner 1977). Conversely, the assumed prerequisite for sedentary living was a reliance on domesticated and cultivated crops, despite a number of studies (e.g., Fritz 2008; Rafferty 1985, 1994; Russo 2004, 2006) noting evidence of sedentary hunter-gatherers throughout both the Archaic and Woodland periods. A recent analysis of botanical remains (from numerous Woodland sites in the Mississippi Delta) revealed the vast majority of plants consumed at these locales were of native-wild variety (e.g., acorns, gourds, and sunflowers seeds) (Fritz 2008:327-333), and that dependence on cultigens did not arise until the Mississippian period (Asch and Asch 1985; Watson 1985).

Ultimately, the question central to this dissertation is whether freshwater mussel shell ring sites in the Mississippi Delta represent sedentary (i.e., year-round) or seasonal occupations. This topic will be addressed by analyzing the stable-oxygen isotope ($\delta^{18}\text{O}$)

signatures within the seasonal growth layers of aragonitic mussel valves. These sites were non-agricultural, with subsistence relying predominately on fishing, game-hunting, and local plant-gathering. Thus, if shown to have been occupied year-round (i.e., by at least a portion of the population engaged in shellfishing activities), rather than seasonally, this study's findings would challenge the normative thinking regarding sedentary living. Additional goals of this research are to advance our understanding of aragonite shell diagenesis and taphonomic processes that exist within the vadose zone of archaeological shell deposits, as well as to further demonstrate the value "applied" archaeology has to modern conservation biology.

This dissertation intends to cover two main themes: mollusk geochemistry and "applied" zooarchaeology. In total, 3 manuscripts are included in this document. The first (currently under review in *Archaeological and Anthropological Sciences*) is an assessment of diagenetic alteration within the recovered archaeological freshwater mussel specimens, via various microscopy techniques. This study was carried out prior to any isotopic examination, and serves as a procedure to evaluate shell specimens for their use in chemical analysis. The second manuscript (to be submitted to the *Journal of Archaeological Science*) contains an analysis of oxygen isotope signatures ($\delta^{18}\text{O}$) within archaeological shell remains. The resultant $\delta^{18}\text{O}$ oscillation trends for each specimen are then interpreted for a "season of capture", which collectively are used to assign seasonality at both sites. The final manuscript (currently under review in *Environmental Archaeology*) provides a comparative assessment of the taxonomic and community makeup of freshwater mussel faunas in the Yazoo River. By analyzing the archaeological mussel assemblages from the study areas, comparisons between those data and modern

collections from the river can inform on a number of ecological and committee characteristics, such as the presence of rare species, juvenile recruitment, population diversity and evenness, biogeography, and state and national conservation statuses for endangered and threatened faunas.

Background: Archaeological Shell Rings

Humans have been exploiting mollusks for millennia, with archaeological shell deposits found throughout the world dating as far back as 130,000 years (Bailey 1975; Binford 1984; Claassen 1998; Erlandson 2001; Meehan 1982; Stein 1992; Waselkov 1987). These sites represent a substantial portion of the archaeological record and are considered some of the earliest large-scale works in the Southeastern United States, with little evidence of significant coastal occupations prior to their construction (Russo 2006; Saunders et al. 1994). Delta shell rings differ in many ways from coastal and other freshwater sites found throughout North America. Shell deposits in the Mississippi Delta (i.e., the Yazoo River Basin) are composed of freshwater mussels, as opposed to clams and oysters, and are often shaped as semi-circular, ring-shaped, or various other geometric forms (Peacock and Jenkins 2010) (see **Figure 1.1**). Delta shell-rings are usually found adjacent to a nearby water source (e.g., interior rivers, lakes, and bayous), from which the mussels were originally collected (Peacock 2002). Though other shell-bearing sites have been found elsewhere in Mississippi, most do not display any “formal structure or layout of shell”, occurring primarily in “general midden deposits and/or as concentrations within pits or other features” (Peacock and Jenkins 2010; Peacock et al. 2011:5).

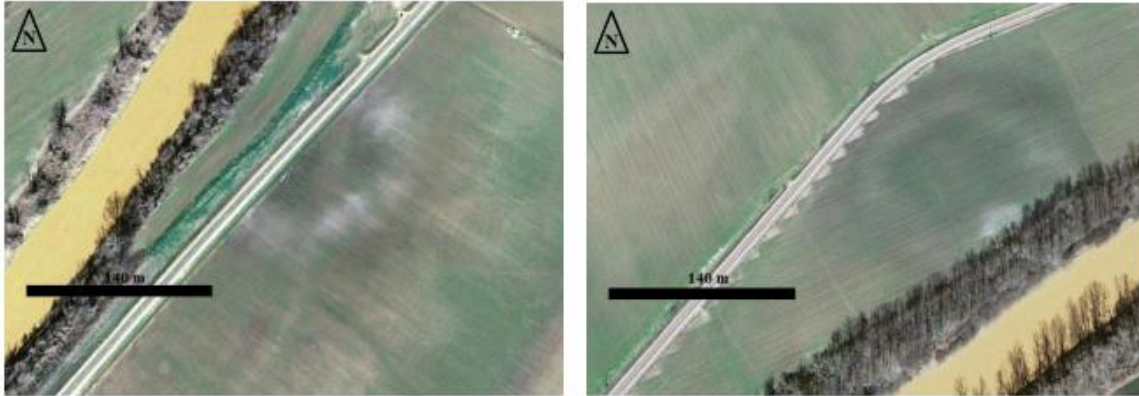


Figure 1.1 Delta shell rings

Aerial photograph of (left) Rugby Farm (22YZ513) and (right) Light Capp (22YZ605) sites. Scale represents 140 meters

The distinctive shape of the Delta shell deposits, coupled with the fact that many are now located on agricultural lands, make them easily identifiable using a variety of visual techniques, especially aerial photo data (Lipo and Dunnell 2008) and Geographic Information System (GIS) imaging queries (Jenkins 2010; Peacock and Jenkins 2010; Peacock et al. 2011:7-10). The increased availability of these technologies has not only expanded our understanding of the spatial distribution of these deposits, but also the sheer number of shell sites throughout the Mississippi Delta. The present number of identified likely shell-rings in the Delta is now 67 (Peacock et al. 2011: Map A-1), which is significantly higher than the previously known value of 47, as noted by Peacock and Jenkins (2010).

Shell rings were first recognized in the Mississippi Delta by Moore (1908), where the presence of a circular buildup of pottery and mussel fragments was recorded, but “excavated without result” (Moore 1908:589). Further investigations in the Yazoo Basin were carried out by Harvard University’s Lower Mississippi Survey (LMS), which took

place in the mid-20th century, and was a regional investigation that noted the presence of 8 semi-circular shell deposits (Peacock et al. 2011:6; Phillips 1970; Phillips et al. 1951). During the LMS survey, all observed shell middens orientated in a circular fashion were associated with the Tchula Lake site (22HU502) as part of the “Tchula Lake settlement pattern”, which was later assigned to the Deasonville Phase of the Late Woodland Period (ca. 300-600 A.D.) (Phillips 1970:270-273). However, the temporal assignment of the Tchula Lake site made by Phillips (1970) was later examined by Dunnell et al. (2002). Radiocarbon dates obtained from mussel samples depicted a calibrated range of 1400-590 B.C., in effect challenging whether the site can be characterized as solely a Deasonville occupation (Lipo and Dunnell 2008:153). Unlike coastal shell middens, which are typically associated with the Archaic-period, the temporal details of Delta rings, as well as how (or if) they are related to one another, is still a matter of debate (Peacock et al. 2011:6). The few Delta shell rings examined thus far have been dated to the Late Woodland period (e.g., Carlock and Rafferty 2009; Peacock et al. 2011; 2012; Raymond 2014), but much more testing is necessary to establish any contemporaneous relationship going forward.

During the LMS work, the primary emphasis in collection and analysis was almost exclusively on ceramics, while non-pottery assemblages were largely excluded (Dunnell 1985:297; Rafferty 2008:99). Like much of the archaeology done during this period, the ultimate goal was a recreated “culture history”. Archaeologists often employed a strict presence/absence use of diagnostic artifact types to denote phases and components, based entirely on the occurrence of those artifacts within a site (Rafferty 2008:100). Unfortunately, the lack of environmental and faunal information on Delta

shell-rings can be mostly credited to past (and present) sampling biases. Historically, mussel shell routinely has been ignored in favor of more “exotic” artifacts, and was rarely used in any archaeological capacity beyond species tabulations and gross paleo-environmental inquiries (Mitchell 2012; Peacock 2000; Peacock and Jenkins 2010). When not being completely overlooked, mussel shell is often just noted as present, but generally not addressed or analyzed in any manner beyond that (e.g., Belmont 1983; Brain 1989; Collins 1932; Connaway and McGahey 1971; Fuller 1992; Hinks et al. 1993; Hyatt 1975, 1992; Marshall 1978; Marshall and Glover 1974; Morgan and Raspet 1979; Penman 1985).

One of the more recent research-based studies of a Delta shell-ring occurred at the Kinlock site (22SU526), which is located near Belzoni, in Sunflower County, Mississippi. The site rests primarily on agricultural property fronting the Big Sunflower River, and consists of a plaza, semicircular shell-ring, and as many as 6 earthen mounds (Phillips 1970). The 2009 Mississippi State archaeology field school employed 3 excavation units and a controlled surface collection (CSC) specifically designed to address questions about shell-ring’s structural orientation, age, and the taxonomic makeup of the local mussel population (Carlock and Rafferty 2009; Mitchell 2012).

The study at Kinlock yielded some interesting findings. Taxonomic analysis and recorded valve counts demonstrated a marked difference in the preservation of shell remains among surface and subsurface assemblages (see Mitchell et al. 2016). Specimens obtained from the plow-zone (i.e., surface and Zone A) displayed lower taxonomic richness and a very high degree of fractioning and external wear, particularly among thinner and less dense species (see also Wolverton et al. 2010). However, shell samples

obtained from the preserved midden (i.e., Zones B and C in the excavation units) were extremely well preserved (Mitchell 2012). Likewise, shells recovered from below the plow-zone are not only ideal for physical preservation, but also obtaining quality specimens for chemical analysis. For shell sites located within the vadose zone, the top of a mussel deposit can act as a buffer to the effects of aragonite diagenesis (i.e., dissolution, secondary cementation, and calcite re-precipitation). This potentially would permit shells from more interior midden contexts to have greater protection and preservation (Andrus 2011; Collins 2012; Chapter 2 this volume; Walter and Morse 1984), thus making such specimens more suitable as resources for geochemical analysis.

Shell Ring Function and Mobility

The function of shell ring sites continues to be a topic of debate amongst archaeologists (e.g., Cameron 2002; Claassen 1992; Gibson and Carr 2004; Marquardt 2010; Milner and Jefferies 1998; Russo 2006; Thompson and Andrus 2011; Wills 2001). Some have hypothesized that shell-rings are the accumulation of shell debris from daily meals, and are often associated with houses and other domestic activities occurring on top of these deposits (e.g., Edwards 1965; Marquardt 2010; Sassaman 2003; Thompson 2006; Trinkley 1980, 1985; 1997; Waring and Larson 1968). In most cases, shell remains are found in association with other animal remains, uneaten plant byproducts, wood charcoal and ashes from cooking fires, broken stone tools, pottery sherds, and various other “trash” debris (Marquardt 2010; Parmalee and Klippel 1974). In contrast, sites where the deposits are more homogenized, often characterized as containing “clean shell” (e.g., Russo 2004; Thompson and Andrus 2011), are generally viewed as evidence of “intentional” mound building or ceremonial feasting (e.g., Claassen 1991a, 1991b, 1992,

1996, 2010; Russo 2004, 2006; Russo and Heide 2003; Sassaman 2003, 2008; Saunders 2004a; 2004b; Thompson 2007).¹ However, as Marquardt (2010) has noted for coastal sites, and others for freshwater sites (e.g., Milner and Jeffries 1998; Morey and Crothers 1998; Peacock 1998; Peacock et al. 2011), the interpretation of clean shell as purposeful “mound building” is currently unsubstantiated, unless it can be confirmed (via testable hypotheses) that these deposits do not represent accumulated middens of habitational debris.

Assessments of prehistoric human group mobility are equally tenuous, with many studies interpreting shell-ring sites as seasonal (or “semi-seasonal”) camps, feasting centers, sedentary egalitarian villages, or a combination thereof (Anderson 2002; Cable 1997; DePratter 1979; Michie 1979; Russo 2004; Russo and Heide 2003; Sassaman 2003; Saunders 2002, 2004a, 2004b; Thompson 2006; Trinkley 1980; Thompson et al. 2004; Waring 1968; Waring and Larson 1968). The descriptors “camp, center, and village”, used in association with terms such as “sedentariness and semi-sedentariness”, are generally applied as an indicator of “settlement size”, rather than permanence at a particular locale (Rafferty 1985:115). This confusion can be avoided by first being explicit in what it means to be sedentary, which as defined by Rice (1975) is a site where “at least part of the population remains at the same location throughout the entire year”. As Rafferty (1985) notes, this definition allows focusing on year-round occupation, regardless of the variation in population size.

Also problematic in this discussion is that many interpretations of shell-ring seasonality are made based on non-seasonal data. For example, Saunders (2004a:61) has defined shell-rings as “locations for macrobands or tribes to gather at certain times

throughout the year for ceremony, feasting, information exchange, mate selection, and other social activities”. This definition was based on the notion that shell-ring sites contain more elaborate ceramic assemblages that are “formally distinct” from non-shell sites (Thompson and Andrus 2011:318). A more appropriate test of a shell-ring’s seasonality is through the analysis of faunal and/or floral remains. At a shell-ring on the South Carolina coast, Trinkley (1980) noted the presence of migratory bird and turtle remains, in addition to shed and unshed deer antlers, as faunal evidence of year-round occupation. Similar findings at Horr’s Island (Florida) by Russo (1998), suggests the site was occupied year-round by at least a portion of the population.

Though the presence/absence of certain faunas is a useful qualitative measure of site seasonality (i.e., when large excavated samples are not available), sometimes a more quantitative approach is necessary. This can be accomplished by assessing the isotopic temperature signatures (i.e., $\delta^{18}\text{O}$) within a mussel’s accretionary growth bands. Water temperature generally fluctuates in a predictable manner (i.e., cooler in the winter, warmer in the summer), and because mussels stop precipitating their shell when they die, an estimation of the water temperature (indicative of season) at the time an animal was harvested is possible (Andrus 2011). From that, one can identify a particular mussel’s “season of capture” (e.g., Andrus and Crowe 2008; Bailey et al. 1983; Carre et al. 2009; Colonese et al. 2009; Harding et al. 2010; Keene 2004; Jones et al. 2008; Kennett and Voorhies 1996; Mannino et al. 2003; Quitmyer et al. 2005; Shchweikhardt et al. 2011; Shackleton 1969, 1973; Thompson and Andrus 2011), and ultimately the time of year people were exploiting shellfish at these sites.

Note

¹Though ethnographic comparisons regarding shellfish exploitation have been made with modern cultures (e.g., May 2005), behavioral explanations for archaeological phenomena should be avoided, as it is impossible to properly “observe” these people and their actions in the anthropological sense. Any interpretations should be framed as hypotheses and tested.

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CHAPTER II

MICROSCOPY ANALYSIS OF METEORIC DIAGENESIS IN ARCHAEOLOGICAL
FRESHWATER MUSSELS FROM THE LOWER MISSISSIPPI ALLUVIAL
VALLEY, SOUTHEASTERN USA

Under Review in *Archaeological and Anthropological Sciences*

Authors: Mitchell, J. ^a, T. Raymond ^b, B. Kirkland ^a

^a Department of Geosciences, Mississippi State University

^b Department of Anthropology and Middle Eastern Cultures, Mississippi State
University

Abstract

Archaeological freshwater mussel deposits constitute a significant resource for ecological, geochemical, and environmental inquiries. As a mussel grows, characteristic chemical and physiological signatures are incorporated into its shell, providing spatially- and temporally-specific data from interior waterways. However, because freshwater mussel shells are composed of aragonite, a metastable form of calcium carbonate (CaCO_3), they can suffer greatly from the impact of meteoric diagenesis. This study considers the chemical diagenesis of freshwater mussel remains from two sites in Yazoo County, Mississippi. We employ two microscopy techniques, petrographic analysis of thin-sections and scanning electron microscopy, as a basic approach for diagenetic assessment, and argue these methods as essential steps for vetting freshwater shells for

chemical analysis. Following visual comparisons with modern specimens, results indicate pristine aragonite microstructure and crystallography in all archaeological shell samples, thus bolstering their suitability for geochemical analysis.

Introduction

For decades the geochemical composition of skeletal aragonite has proven a valuable source for information on past environments (Abram et al. 2008; Bar-Matthews et al. 2003; Cai et al. 2010; Cheng et al. 2009; Cobb et al. 2001; Cole et al. 1993; DeNiro 1987; Denniston et al. 2007; Koch et al. 1994; van der Merwe 1982; Wang et al. 2001; Wang et al. 2004; Zinke et al. 2004). Bivalve mollusks are especially useful in this regard, as the crystalline structure within their shells can serve as a high-resolution index of the various environmental conditions experienced during an organism's lifespan (Davenport 1938; Epstein et al. 1953; Hippler et al. 2009; Immenhauser et al. 2005; Vander Putten et al. 2000; Witbaard et al. 1994). Previous studies have shown accretionary features within bivalve shells can preserve a chronologic record of age, growth rates, air and water temperature, river discharge, rainfall patterns, salinity, and physiological patterns (Chauvaud et al. 2005; Dettman et al. 1999; Elliot et al. 2003; Gillikin et al. 2005; Goodwin et al. 2003, 2004; Lorrain et al. 2004; Schöne et al. 2002, 2004; Surge et al. 2001; Surge and Walker 2005; Wurster and Patterson 2001)

As one of the most diverse faunal groups, bivalves have an extremely wide geographical distribution, and are found in all types of aquatic ecosystems. Likewise, bivalve remains are found as far back as the Cretaceous Period, and are a significant component of the archaeological record (Bailey 1975; Binford 1984; Claassen 1998; Erlandson 2001; Meehan 1982; Stein 1992; Waselkov 1987), being especially prominent

in North America, as marine and freshwater species were a significant food-source for ancient peoples (Mitchell and Peacock 2014; Peacock et al. 2011; Russo 2004). Shell-bearing sites are considered some of the earliest large-scale works in the Southeastern United States, with little evidence of significant coastal occupations prior to their construction (Russo 2006; Saunders et al. 1994). In the early 20th Century, many freshwater species were exploited along rivers in central North America for use in the pearl button industry (Parmalee and Bogan 1998; Williams et al. 2008). Ultimately, bivalves, both marine and freshwater, provide a very wide geographic and temporal range for future studies, bolstering their value as sources of environmental data (Chang et al. 2007; Wanamaker et al. 2011).

Though much study has been directed to archaeological coastal clam and oyster middens in the Southeast (e.g., Andrus and Thompson 2012; Claassen 1986; Bruseth 1980, 1991; Marquardt 2010; Russo 2006; Thompson and Andrus 2011), as well as to similar sites on the West Coast (e.g., Culleton et al. 2009; Eerkens et al. 2013; Jones et al. 2008; Tellez-Duarte et al. 2008), little attention has been given to sites at freshwater locales, especially ones in the Lower Mississippi Alluvial Valley. Despite this fact however, freshwater shell remains are considered among the most reliable sources of radiocarbon dates for late Pleistocene fossil and archaeological sites (Bowler and Wasson 1984; Gillespie 1997; Rick et al. 2005; Roberts et al. 1994; Webb et al. 2007), and a growing number of reports have demonstrated utility of modern mussel faunas for geochemical and environmental studies (e.g., Carroll et al. 2006; Dettman et al. 1999; Goewert et al. 2007; Versteegh et al. 2010a, 2010b).

Here we focus on freshwater mussels recovered from two archaeological sites in Yazoo County, Mississippi. When using prehistoric shells, certain vetting measures must be taken to ensure the samples are pristine prior to any chemical analysis taking place. Even very subtle diagenetic features can significantly alter the isotopic and trace elemental signatures preserved in a shell, which not only reduces the quality of the geochemical data obtained, but also any subsequent interpretations made. Ultimately, the potential presence of diagenetic alteration within a shell sample should always be assessed prior to all ensuing chemical analyses (Claassen, 1998; Collins 2012). If archaeological shell is thus determined to not have undergone chemical alteration, and is free of diagenesis, that sample can be deemed suitable for geochemical study. In this report we demonstrate basic microscopy techniques that, when used in reference to standard carbonate petrography guides (i.e., grains, textures, crystallography, and structure; e.g., Folk 1973; Sandberg 1983; Sholle and Ulmer-Sholle 2003; Tucker and Wright 1990), can unambiguously distinguish between samples that are pristine and those which have been diagenetically altered.

Shell Structure and Geochemistry

The shell of a freshwater mussel is composed of three main parts (see **Figure 2.1**). The periostracum is the outermost layer, and acts as a protective film for the shell and provides pigmentation. The prismatic layer is the middle section, and consists of needle-like crystals, oriented perpendicular to the inner and outer surface of the shell. Last is the nacreous layer (colloquially known as mother of pearl, or nacre), which is secreted as thin, brick-like laminae parallel to the inner surface of the shell and constitutes the bulk of the shell's mass (Tucker and Wright 1990). During shell formation, the mantle, which

surrounds the visceral mass (i.e., soft tissue), lines the interior surface of the valve and accretionally secretes (via bio-mineralization) alternating layers of aragonite (CaCO_3) and organic matter, continuously building the shell through the life of the organism.

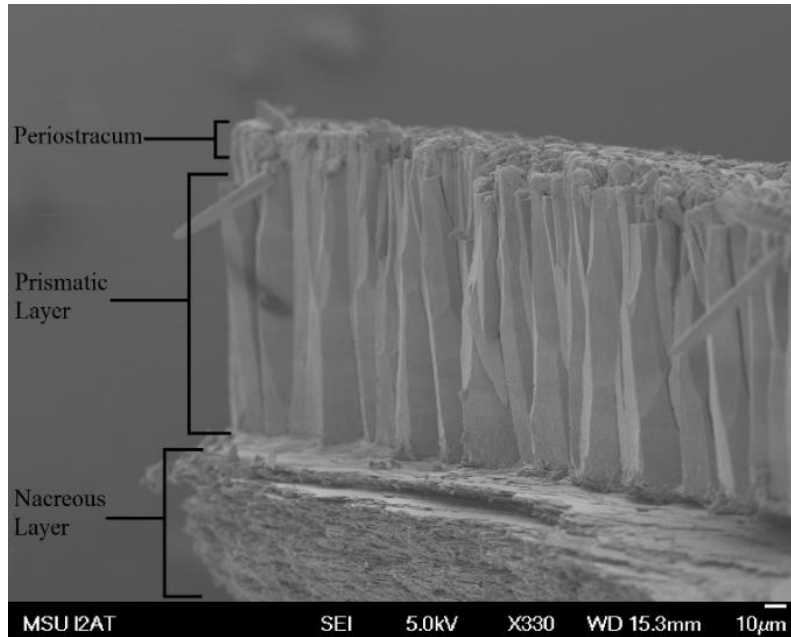


Figure 2.1 SEM image of freshwater mussel shell

Cross-section of modern freshwater mussel shell, showing periostracum, prismatic, and nacreous layers

The mechanisms by which freshwater mussel shells are formed make them very useful for environmental and paleoecological studies (Jones 1993; Lee and Wilson 1969; Wefer and Berger 1991). Throughout a mussel's lifetime, trace elements and isotopes are incorporated from the surrounding water source, being absorbed into the crystalline structure as the mantle bio-mineralizes the shell (Tucker and Wright 1990). This process occurs on the edge of the shell, at the interface between the mantle, the periostracum, and the shell itself (Marin et al. 2012), combining the necessary minerals for construction in

the extrapallial (i.e., area between mantle and shell) fluid (Timmermans 1969).

Ultimately, the shell of a mussel will reflect environmental conditions as a characteristic chemical signature. These signatures are bound within the shell during growth and can provide definitive information about the water source in which the mussel lived (Bruchardt and Fritz 1978; Claassen 1998; Faure and Mensing 2005; Faure et al. 1967; Odum 1951; Wefer and Berger 1991). Because of this, mollusk remains can be used in a number of (regional-, drainage-, or stream-specific) geochemical applications, including elemental sourcing studies (Claassen 1998; Peacock 2009), establishing paleo and historic waterway temperature ranges (Glassow et al. 1994; Jones and Kennett 1999; Kennett 2005), and prehistoric occupation seasonality (Andrus 2011; Andrus and Crowe 2008; Quitmeyer et al. 1997).

Mussel Shell Diagenesis

There are numerous post-depositional phenomena that can negatively impact faunal assemblages at archaeological sites. Mussel deposits, for example, are often subjected to years of wear and fracturing from agricultural activities (e.g., plow-zone tillage) and various taphonomic processes (Claassen 1998; Dunnell 1990; Dunnell and Simek 1995; Lewarch and O'Brien 1981; Muckle 1994; Nielson 1991; Peacock 2000; Sanger 1981; Waselkov 1987). Though the physical condition of shell remains has long been a topic of interest, especially in regard to its influence on species identification and representativeness (e.g., Mitchell 2012; Mitchell et al. 2016; Peacock 2000; Peacock and Chapman 2001; Randklev et al. 2010; Wolverton et al. 2010), considerations of chemical diagenesis has been mostly underemphasized by archaeologists. Fortunately, there exists an abundance of geological and sedimentary literature focusing on all manners of

carbonate structure, chemistry, and deposition (e.g., Ahr 2008; Folk 1974; Sandberg 1983; Tucker and Wright 1990; and references therein).

Diagenesis refers to any physical, chemical, or biological alteration undergone by sediment after its initial deposition within the soil (Gastaldo et al. 1996). For carbonates, chemical diagenesis is viewed as the most important agent of change (Ahr 2008). The outcomes of which generally include dissolution, the development of micro-porosity, secondary cementation, recrystallization, and changes in trace elements and isotopic signatures (Ahr 2008:145; Moore 2001; Tucker and Wright 1990:315). Numerous environmental and depositional factors control these changes, however, and each deposit can be geologically distinct. Also, the “type” of carbonate itself will ultimately determine solubility, as biogenic carbonates contain different mineral phases of calcium carbonate (CaCO_3), each with different levels of stability. Freshwater mussel shells are composed of aragonite, a metastable polymorph of CaCO_3 . Aragonite, along with high-Mg calcite, is unstable at Earth surface pressure and temperature, and will inevitably either dissolve or convert to calcite over time (Tucker and Wright 1990). Once a mussel dies, the shell will begin to degrade as it is no longer being maintained by the mantle. If subjected to meteoric water, an aragonitic shell may undergo rapid dissolution and/or recrystallization. If that happens, the original isotopic and/or elemental signatures stored within shell’s structure will be at worst, lost forever, or at best, severely distorted (Sayani et al. 2011).

For aragonite, the primary factor controlling chemical diagenesis is the presence of acidic meteoric water (i.e., water that falls as precipitation and percolates from the surface down through the deposit profile) (Allan and Matthews 1982; Folk 1974; Harris and Matthews 1968; Magnani et al. 2007; Morse and Mackenzie 1990; Morse et al.

1997). This impact has been discussed at length (e.g., Ahr 2008; Carlson 1983; Tucker and Wright 1990), and typically manifests in aragonite as 1) dissolution of primary crystals, 2) infilling of skeletal pore spaces with secondary cements, and/or 3) recrystallization of aragonite to calcite (Moore 1989; Morse and Mackenzie 1990; Sayani et al. 2011; Webb et al. 2007). This dynamic is also contingent on the equilibrium between the solid phase and the aqueous solution of calcium (Ca^{2+}) present within the environment. Ultimately, the degree of disequilibrium between the water and the deposit is the primary factor controlling the rate of chemical reaction, with the level of dissolution, cementation, and/or re-precipitation becoming amplified as disequilibrium increases (Collins 2012). Though equilibria and the presence of water are important, the extent of change induced can vary dramatically, depending on a variety of other depositional properties, such as sediment porosity, soil CO_2 and pH, and meteoric water temperature (Birkeland 1984; Bischoff 1969; Bohn et al. 1985; Brooks and Whitaker 1997; Goldstein 2008; Ward 1975).

Archaeological mussel shell middens are unique from other carbonate deposits (e.g., limestone, karst, or ancient corals), as the dominant sedimentary matrix constituent is shell, representing animals collected and processed for subsistence purposes by prehistoric peoples, and later discarded with other organic matter and artifacts over time (i.e., essentially as refuse) (Marquardt 2010; Parmalee and Klippel 1974). Additionally, studies have shown that shell middens that have remained subaerially exposed may exhibit excellent preservation of carbonate materials (e.g., Andrus 2011; Collins 2012; Villarreal et al. 2015). Ultimately, the structure of a shell midden can act, in itself, as an agent of preservation. Dense deposits can shield against diagenesis, as the massive

amount of carbonate materials present can buffer the impact of acidic waters, focusing the majority of exposure to shells on the surface and shallower areas of the midden. Moreover, shell from the “plow-zone” (i.e., usually ca. 10 - 20cm from surface) is commonly impacted by physical wear from tillage and taphonomy (Mitchell et al. 2016; Peacock 2000), and specimens here would likely not be the best candidates for chemical analysis. It is possible that sampling more to a midden’s interior would have a higher probability of yielding pristine shells (Andrus 2011).

Study Areas

The Rugby Farm (22YZ513) and Light Capp (22YZ605) sites are located on the Yazoo River in rural farmland southwest of Yazoo City, Mississippi (see **Figure 2.2**). These sites are from a group of over 50 shell rings associated with the ecoregion of the Northern Holocene Meander Belts (Peacock et al. 2011: Fig. 4). The area is situated in the Lower Mississippi Alluvial Valley (specifically within the Yazoo Basin), and is colloquially known as the “Mississippi Delta”. Both sites contain a circular shell-ring that fronts the adjacent river. These sites are separated by only ca. 4.1 kilometers, with 22YZ513 being downstream and to the southwest of 22YZ605 along the Yazoo River. The two sites are roughly the same size, as both have outside and inner ring diameters of roughly 170 m and 115 m, respectively (Peacock et al. 2011; Raymond 2014). At the center of each ring is a plaza that contains relatively few artifacts when compared with the dense surrounding midden.

The Rugby Farm site was first recorded by Chambers (1932) and Ford (1936), and was later discussed by Phillips (1970), as part of Harvard University’s Lower Mississippi Survey (LMS). Temporally, the site is associated with the Deasonville (350-

650 A.D.) phase of the Late Woodland period, though there is evidence of both earlier and later components present at the site (i.e., Marksville [0-350 A.D.] and Coles Creek [800-1200 A.D.] period components); lithic and ceramic artifacts diagnostic of Deasonville were the majority, however (Phillips 1970). The Light Capp site, though not previously investigated (other than via aerial imagery; see Peacock et al. 2011: Fig. 8), is relatively dated as contemporaneous with Rugby Farm, and to the Middle and Late Woodland periods (Raymond 2014). Ongoing work (see Raymond 2014) indicates that both sites represent single, likely sedentary, Middle to Late Woodland occupations that terminate at or near the start of the Mississippi period.

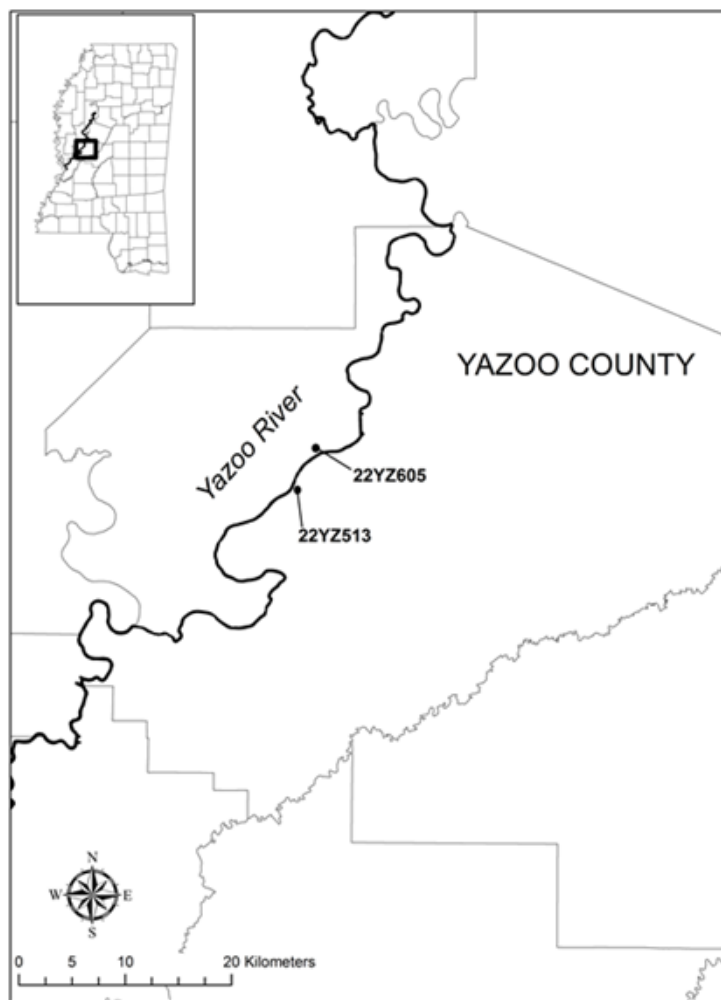


Figure 2.2 22YZ513 and 22YZ605

Map showing location of Rugby Farm (22YZ513) and Light Capp (22YZ605) sites in Yazoo County, Mississippi

Methods and Materials

This study follows standard methods and practices employed in previous carbonate diagenesis studies (e.g., Dickson 1966; Immenhauser et al. 2005; James 1974; Land 1967; Maliva et al. 2001; Matthews 1968; Sayani et al. 2011; Tucker 1988), as well as techniques specific to handling of archaeological shell (see Collins 2012; Leng and Lewis 2016; Villarreal et al. 2015). The combination of thin-section petrography and

scanning electron microscopy (SEM) serves to provide qualitative visual aids (via observed grain-texture and structure; see Folk 1973, 1974) for investigating the aragonite pristineness within the selected mussel specimens. There are multiple types of diagenetic alteration, but here we are specifically interested in detecting evidence of the aragonite to calcite transformation (i.e., dissolution, cementation, and recrystallization). Though additional methods and approaches exist, we feel the two discussed and included here, thin-section petrography and SEM analysis, provide an effective and reliable ‘minimal standard’ for vetting mollusk remains for use as a material resource in geochemical research.

Field Methods and Specimen Selection

Shell was collected in 2013 by Mississippi State University’s archaeology field school. Here, we use shell obtained from 2 excavation units (1 from each site) dug in areas of high concentration of mussel shell. Both units are 1 x 1 m in dimension, and were excavated until artifact-free subsoil was reached. The majority of the shell was located within the dense midden deposits of Zones A and B (see **Figures 2.3** and **2.4**), which at both sites contained a number of other non-shell artifacts, including ceramic pot sherds, lithic flakes, and various bone fragments. Standard excavation methods were applied: zone levels were dug in 10 cm increments (or smaller, if soil horizons visibly changed). All material was separated from the dirt via water screening with 0.635cm (1/4 inch) and 0.159cm (1/16 inch) wire mesh. The artifacts were then transported to the Mississippi State University (MSU) campus for analysis.

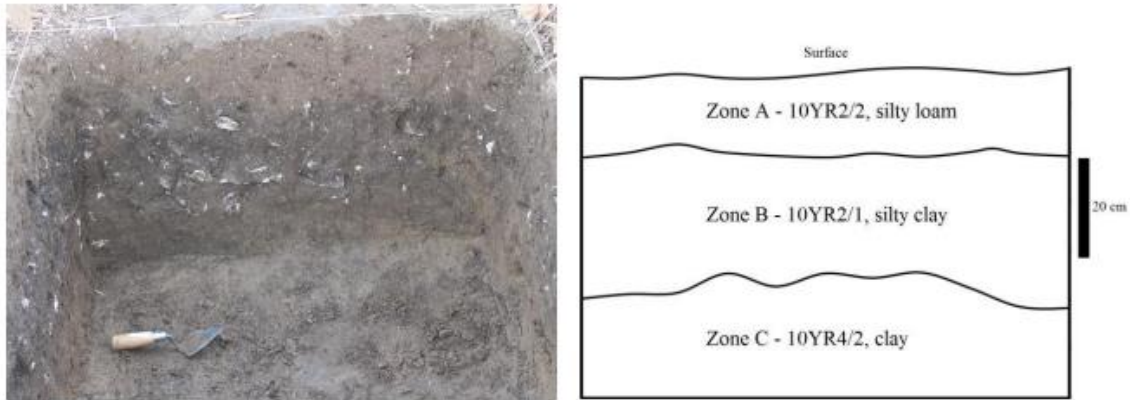


Figure 2.3 22YZ513 excavation unit

Left: 1 x 1 m excavation unit from Rugby Farm (22YZ513). White material visible is freshwater mussel shell. Photograph shows the west wall profile. Trowel indicates both scale and direction of north. Right: stratigraphic illustration showing depth and soil descriptions of west wall profile

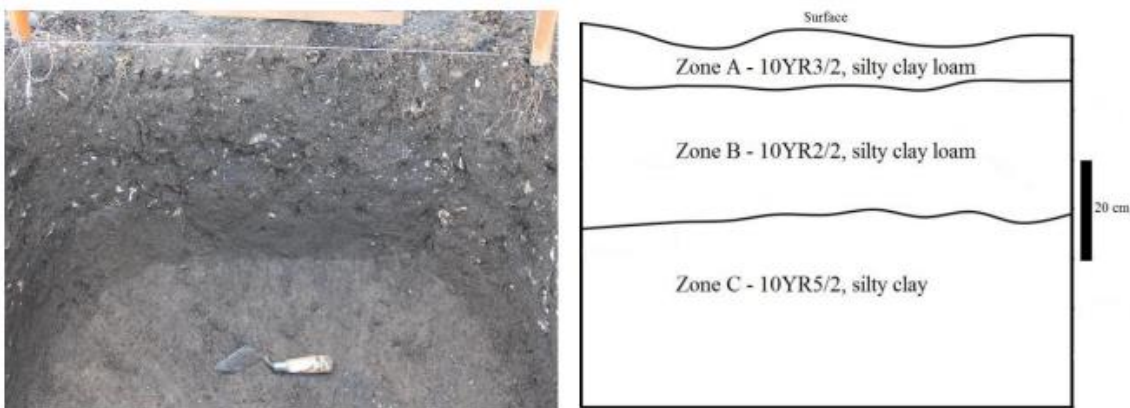


Figure 2.4 22YZ605 excavation unit

Left: 1 x 1 m excavation unit from Light Capp (22YZ605). White material visible is freshwater mussel shell. Picture is of the east wall profile. Trowel indicates both scale and direction of north. Right: stratigraphic illustration showing depth and soil descriptions of east wall profile

Archaeological specimens were chosen based on several criteria. First, only valves of *Amblema plicata* (Say, 1817) and *Fusconaia flava* (Rafinesque, 1820) were included in the study (see **Figure 2.5**). Reasoning for this was threefold: 1) these species

are well represented within the shell assemblages at each site; 2) both have fairly dense and robust shells, which generally contain thicker growth bands clearly visible when sectioned and polished; and 3) these species are being used as part of an ongoing stable isotope and seasonality study. Only complete, un-fragmented, valves were used. This was done with specific attention placed on the presence of intact umbos (i.e., the beak portion of the shell) showing full growth out to the shell's edge (i.e., the ventral margin, or the last part of shell the organism grew). Lastly, to ensure that each organism is represented once, only left valves were used.



Figure 2.5 Selected mussel species

Example modern (top) and archaeological (bottom) specimens of *F. flava* (left) and *A. plicata* (right). All are left valves. Modern specimens provided by the Mississippi Museum of Natural Science

Petrographic Thin-sections and Scanning Electron Microscopy (SEM)

When making the thin-sections, each archaeological mussel valve was cut from the umbo to the ventral margin with a diamond wafer saw, showing a full cross-section of the organism's lifetime of growth. Each specimen was then levelled on a Buehler lapping

bench, and hand polished using carbide paper, starting at 600 grit, and finishing at 1200 grit. Shell sections were then mounted onto pre-frosted glass slides (46 x 27 mm), polished-side down, and encased in blue epoxy resin. Once the epoxy was hardened, samples were cut and polished down to ca. 30 microns, following the same polishing procedure as before, but finishing at 1500 grit, rather than 1200. Thin-sections were also made from modern mussels (see **Figure 2.6**) using the same method, and served as a visual standard for comparison with the archaeological specimens. Using a petrographic microscope, potential differences in crystalline structure and pristineness between the modern and archaeological thin-sections can be assessed, with emphasis on investigating the presence of any dissolution and/or precipitation features within the archaeological shell. All thin-sections are shown below in plain polarized light (PPL).

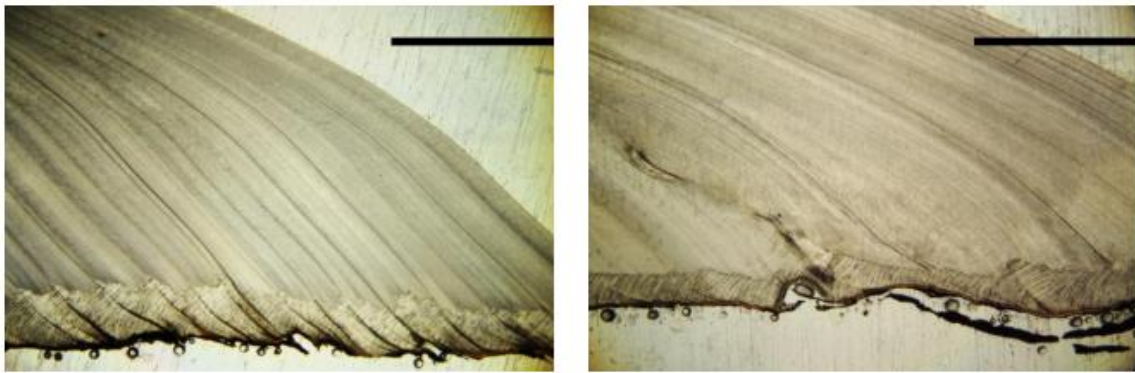


Figure 2.6 Modern mussel thin-sections

Representative thin-sections of modern *A. plicata* (left) and *F. flava* (right). Scale bar represents 3 mm

Modern and archaeological shells were visually analyzed on Zeiss EVO 50 and JEOL JSM-6500F scanning electron microscopes at the Institute for Imaging & Analytical Technologies (I²AT), MSU. Samples were prepared by creating fresh breaks

in the shell and mounting those fragments on stainless steel stubs with carbon tape. This was done to remove any artifact from the diamond saw cutting or polishing steps, essentially presenting a ‘natural’ profile of shell structure, allowing one to view the internal crystalline structure from multiple angles. Each fragment was then sputter-coated with 30 nm of platinum, using an EMS 150T ES coater. Samples were initially coated with only 15 nm, but they showed a considerable amount of electrostatic charge when viewed in the scope; therefore, coating was increased to 30. As with the thin-sections, SEM images were also taken of modern shells for comparison with the archaeological samples (see **Figure 2.7**). Species identification for each included thin-section and SEM image is noted in **Table 2.2**.

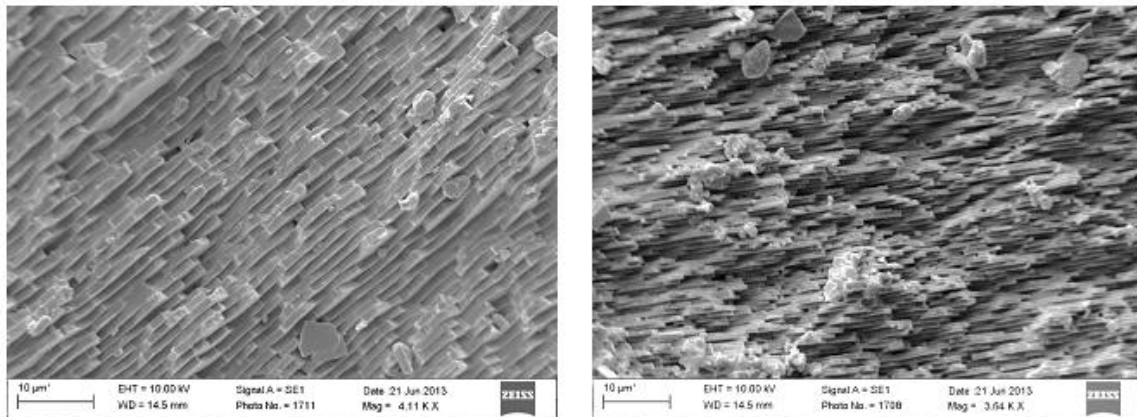


Figure 2.7 Modern SEM images

SEM images of modern *A. plicata* (left) and *F. flava* (right)

Table 2.2 Thin-sections and SEM images for 22YZ513 and 22YZ605

	22YZ513		22YZ605	
	Thin-section	SEM	Thin-section	SEM
Zone A	<i>A. plicata</i>	<i>F. flava</i>	<i>F. flava</i>	<i>F. flava</i>
Zone B1	<i>F. flava</i>	<i>F. flava</i>	<i>A. plicata</i>	<i>A. plicata</i>
Zone B2	<i>F. flava</i>	<i>A. plicata</i>	<i>F. flava</i>	<i>A. plicata</i>
Zone B3	<i>F. flava</i>	<i>F. flava</i>	<i>A. plicata</i>	<i>F. flava</i>
Zone C1	<i>A. plicata</i>	<i>A. plicata</i>	<i>F. flava</i>	<i>A. plicata</i>
Zone C2	<i>A. plicata</i>	<i>A. plicata</i>	-	-

Species ID for each zone and level from Rugby Farm (22YZ513) and Light Capp (22YZ605)

Results

All archaeological thin-sections demonstrate typical freshwater mussel microstructure. Though no organic periostricum was preserved in any of the samples, the outer prismatic layer and nacreous zone are clearly visible (see **Figures 2.8** and **2.9**). When compared to the modern thin-sections, the archaeological specimens show no signs of dissolution or recrystallization, and similarly display growth bands of varying color and thickness, dependent on species, age of the specimen, or where on the valve the image was taken. The only significant physical difference is the presence of stress fractures within some of the archaeological shells, likely due to post-depositional compaction. Some samples do show epoxy seepage, evident in the blurry areas between growth lines, but this should be considered an artifact of the thin-section making process.

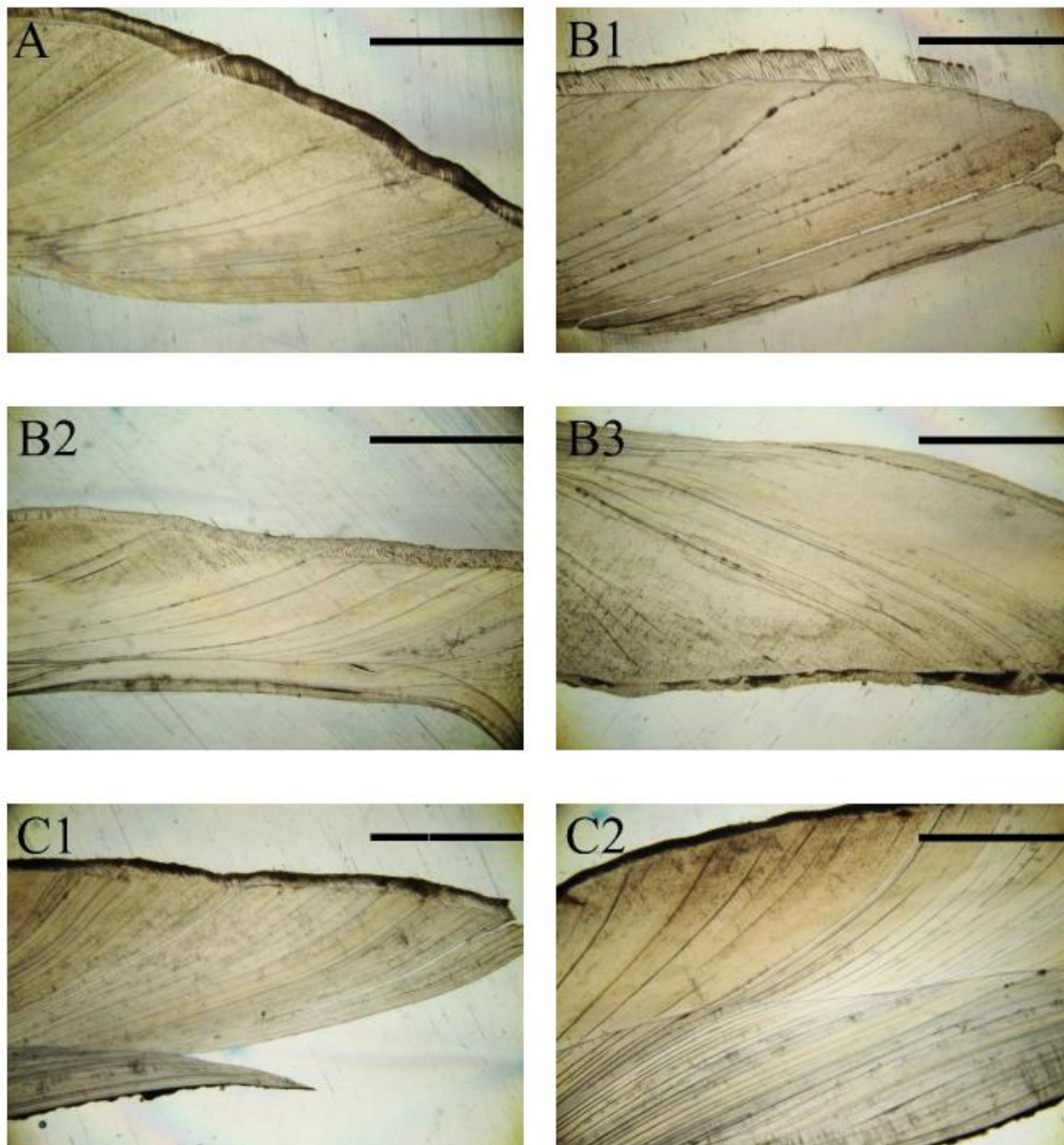


Figure 2.8 22YZ513 thin-sections

Representative thin-sections from each zone and level at Rugby Farm (22YZ513). Scale bar represents 3 mm

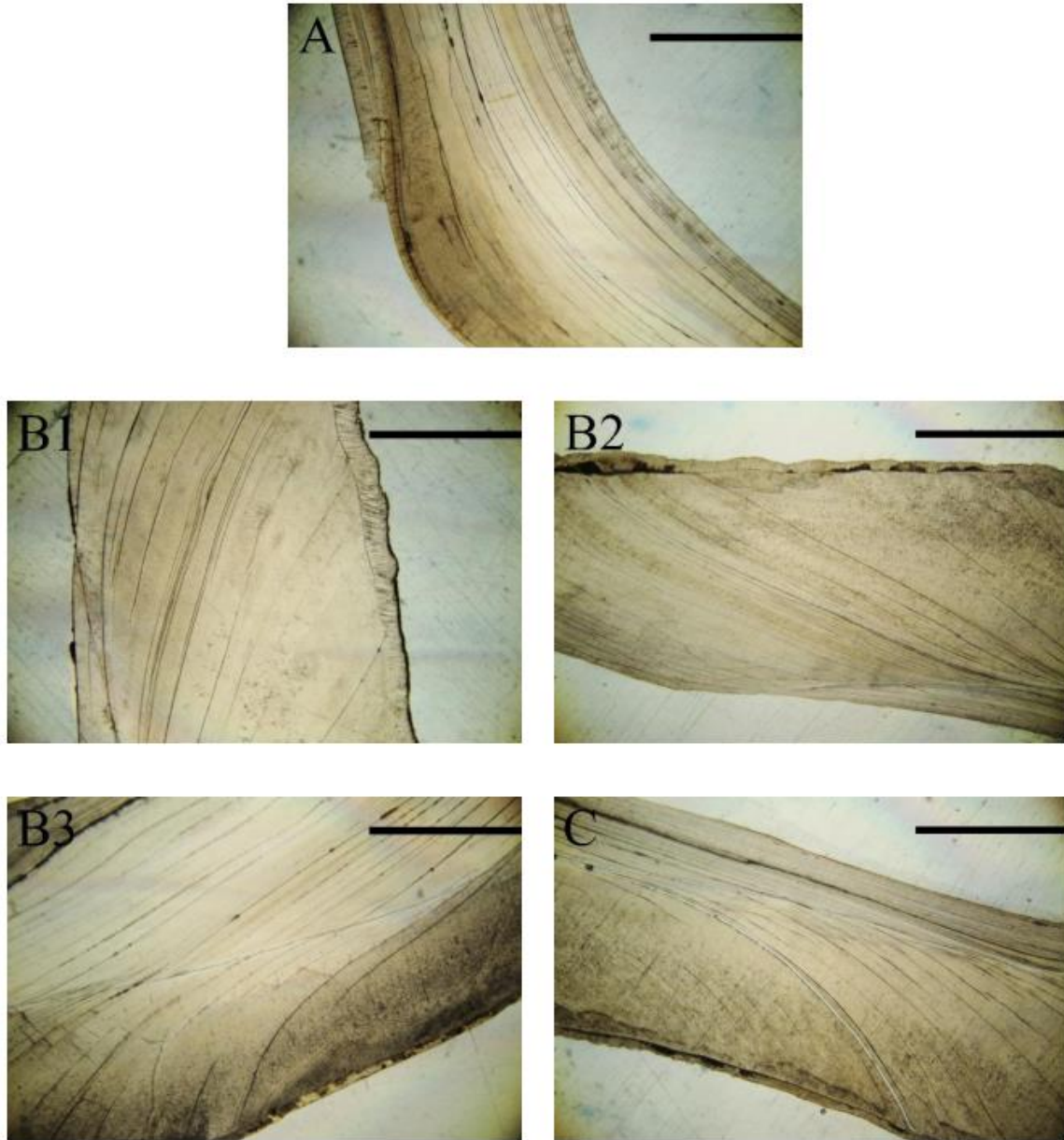


Figure 2.9 22YZ605 thin-sections

Representative thin-sections from each zone and level at Light Capp (22YZ605). Scale bar represents 3 mm

As with the thin-sections, the scanning electron microscopy showed typical aragonite microstructure, both in regards to the prismatic layer and nacreous zone. In each image, the nacreous zone exhibits the characteristic brick-like laminae associated

with aragonitic crystals, as shown from multiple angles and magnification (see **Figures 2.10 and 2.11**). Generally, what is desired are clean surfaces, with sharp edges and angles, and with little to no porosity, either within or between individual crystals (excess pores are usually indicative of dissolution).

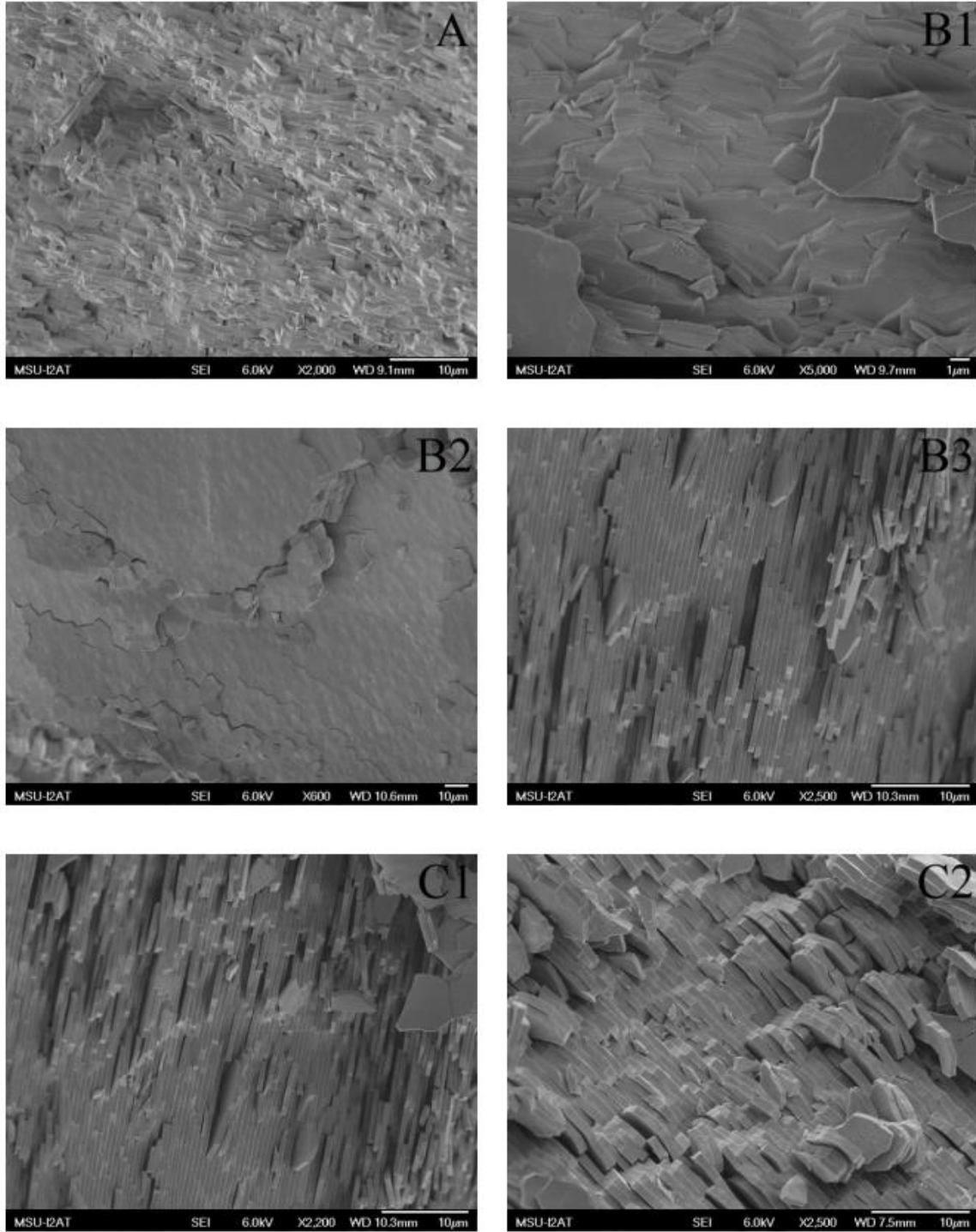


Figure 2.10 22YZ513 SEM images

Representative SEM images from each zone and level at Rugby Farm (22YZ513)

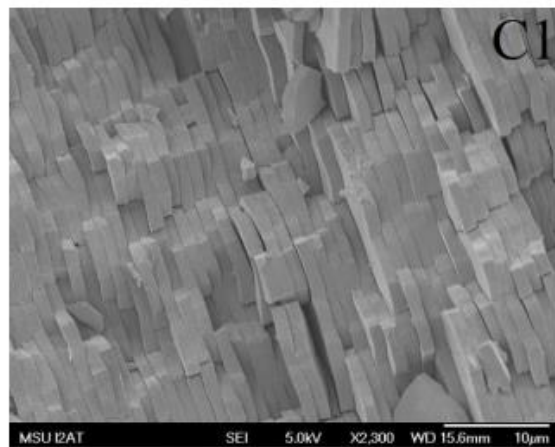
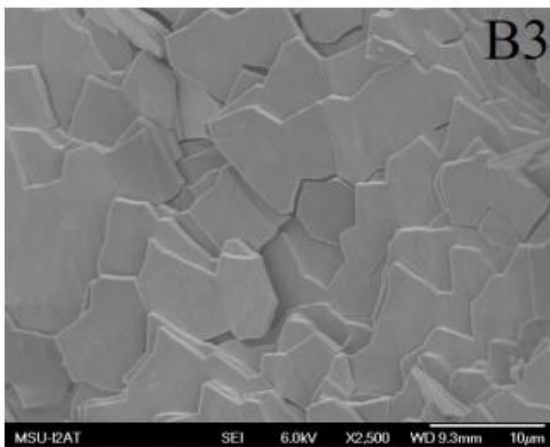
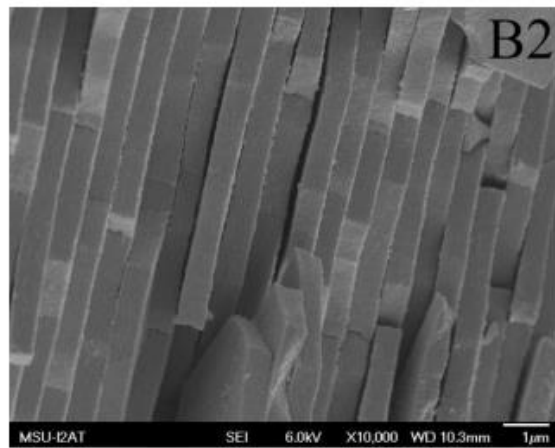
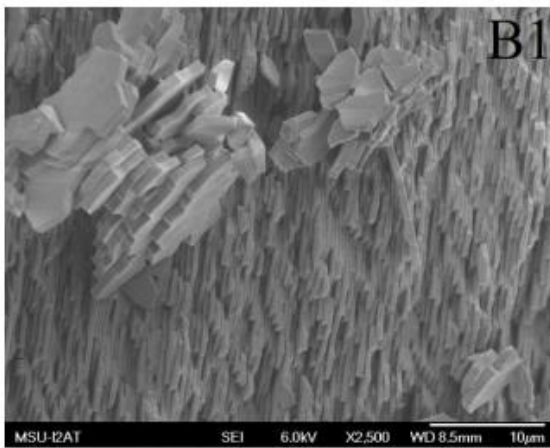
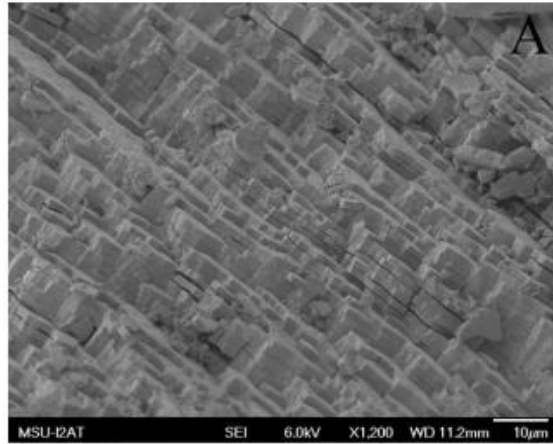


Figure 2.11 22YZ605 SEM images

Representative SEM images of each zone and level at Light Capp (22YZ605)

Discussion

Evidence of dissolution may be difficult to discern. The images were assessed for consistency of crystal shape and consistency of spaces between crystals. Traditionally, carbonate petrographers look for evidence of truncated allochems as evidence of dissolution. At this scale we sought evidence of truncated crystals, or disrupted microcrystalline structure.

All archaeological specimens analyzed via thin-section petrography and scanning electron microscopy display pristine aragonite crystalline structures, with no evidence of fabric dissolution, secondary cementation, or calcite recrystallization. This indicates an absence of post-depositional chemical alteration of the aragonite shell sampled from the two study sites. The only observable physical difference between the modern and archaeological thin-sections is the presence of minor fracture lines within some of the archaeological specimens. This was expected, however, as taphonomic effects and differential preservation are omnipresent factors in archaeological faunal deposits, being especially prominent in mussel middens (e.g., Mitchell et al. 2016; Peacock 2000; Wolverson et al. 2010). In spite of this, the lack of alteration within and surrounding those areas of fracture further demonstrates the quality of the archaeological shell sampled here.

The SEM images show pristine microcrystalline structure in the archaeological shell, closely resembling the state of preservation present within the modern specimens, despite the difference in age and depositional environment. The nacreous zones of each specimen also retain their brick-like crystals, with no signs of laminae fusion, dissolution or formation of calcite crystals. This is significant, as Webb et al. (2007) has previously

noted, via SEM micrographs of Pleistocene aragonite shell, that when the organic material between aragonite crystals dissolves or becomes degraded, calcite cements will often fill in those areas, causing nacreous layers to fuse together. Such cements may have drastically different geochemistry compared to the surrounding aragonite (Muller et al. 2001), and would likely hinder any chemical interpretations (Allison et al. 2007). The samples analyzed in this study show no signs of fused nacreous crystals or equant calcite cement, indicating that calcite precipitation has not occurred.

The archaeological and modern specimens were also viewed in a CL-4 Cold-cathode Luminoscope (see Collins 2012:3698 for instrument parameters). With cathodoluminescence, some aspects of geochemistry, particularly mineral content, can be determined on the basis of emitted luminescence color (Long and Agrell 1965; Mariano 1976; Mariano and Ring 1975). For carbonates, the colors of calcite are generally viewed as orange or red (Klopp 1981; Marshall 1988; Habermann et al. 2000), while aragonite emits a green (Mazzoleni et al. 1995; Richter et al. 2003), or sometimes blue (Collins 2012:Fig.12), luminescence. When viewed in the CL, both our modern and archaeological specimens emitted a bright green luminescence (see **Figure 2.12**), suggesting an aragonitic composition free of calcite. Though cathodoluminescence has been noted as a potential tool for assessing shellfish sourcing and seasonality (see Collins 2012 for discussion), it is not essential for this study, and is generally applied to carbonates of much older geological age (e.g., Angiolini et al. 2008, 2012; Stephenson et al. 2012) when identifying diagenesis. It does, however, provide a basic assessment of mineralogy via observed emitted luminescence, and can be applied to archaeological samples in conjunction with the methods discussed here.

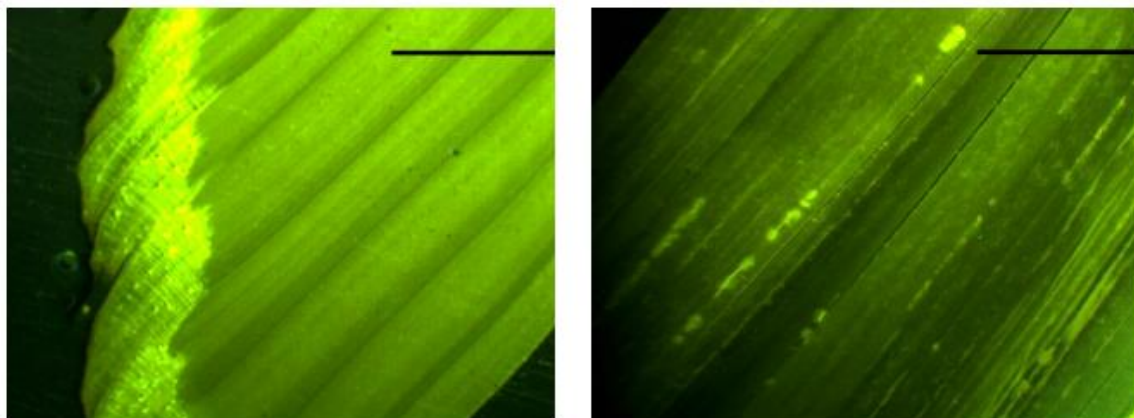


Figure 2.12 Cathodoluminescence images

Example cathodoluminescence images of modern (left) and archaeological (right) freshwater mussel shells. Green luminescence indicates aragonite composition. Scale is 2mm

Ultimately, shell recovered from the Rugby Farm and Light Capp sites can be considered pristine, free of significant diagenesis, and, by choosing the most structurally simple, fully intact sites for drilling/sampling, suitable for use in geochemical analysis. The environmental conditions present at our study areas would seem conducive for shell preservation. However, it is difficult to know if similar conditions exist at other shell-bearing sites, even ones nearby, without further testing. For future inquiries, soil studies at our two sites, along with comparisons with shell from other associated locations, could provide valuable information on the environmental parameters needed for favorable shell preservation. Shell, like bone, preserves best under alkaline conditions (Evans 1972). Acidic soils and/or mechanical reworking of deposits, the latter being very common at shell-rings located on agricultural property, may consequently result in a higher likelihood of not only external wear and fracturing, but chemical alteration (Tuthill 1963). Referencing previous studies of soil chemistry is obviously beneficial (e.g., Arya

and Paris 1981; Hall et al. 1975; Rawl et al. 1982; Saxton et al. 1986), but additional inquiries into the relationship between shell middens and their depositional environment also would have value.

As previously noted, the shell midden itself can be an important factor influencing chemical and physical diagenesis. The volume of shells combined with the structure of a shell midden can create a localized environment where all fluids are saturated with respect to aragonite. In that sense, the midden environment can act as an agent of shell preservation. Because meteoric water can enter a midden both from rainfall and as flowing ground water, shells near the top and near the edges of the midden would be most likely specimens to have undergone some dissolution or alteration. If dissolution occurs in the upper zones or margins, the saturation state of the water with respect to aragonite would increase. Shells recovered from the interior portions of dense deposits, as shown here, could be shielded against chemical diagenesis, by that increased saturation state of the associated fluids. Though some of our specimens do show evidence of interior fracturing and compaction, the created pore-spaces do not seem to have promoted any dissolution. In general, extensive physical erosion of shell is focused at or near the surface of a site (i.e., the plow-zone), with exposure to wear typically decreasing with depth (Andrus 2011; Peacock 2000; Peacock and Chapman 2001). Despite the potential impacts on plow-zone shells, both chemically and physically, thin-sections and SEM images from Zone A at both the Rugby Farm and Light Capp sites exhibited the same degree of preservation as ones recovered from deeper strata.

Conclusions

This study demonstrates that the use of thin-section petrography and scanning electron microscopy provide a simple, yet unambiguous, approach for examining chemical diagenesis in freshwater mussel remains. Visual analysis verified that aragonitic freshwater shell from the Light Capp and Ruby Farm sites has undergone no significant chemical alteration and retains its original microstructure, making it suitable for geochemical analysis. Though few archaeological freshwater mussel studies have been carried out in this capacity, the results shown here are certainly promising, as our study areas show an extraordinary level of preservation, even within the plow-zone deposits. Future studies should continue to provide information on depositional environment, midden porosity, and shell preservation at freshwater sites. As emphasized throughout this study, the degree of diagenetic alteration present within archaeological shell must be established prior to any chemical analysis. Though additional methods are indeed available to researchers (such as x-ray diffraction [XRD], and Raman spectroscopy), the two demonstrated here successfully accomplished the goals of our study, and we argue for their inclusion as a baseline step in any future freshwater mussel diagenesis investigation.

Acknowledgments

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MSU) for creating the map used in Fig. 2. Thin-section materials and supplies were provided by the Russell Fund, Department of Geosciences, MSU.

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CHAPTER III

DETERMINING OCCUPATION SEASONALITY VIA STABLE OXYGEN ISOTOPE
SIGNATURES: A FRESHWATER MUSSEL “SEASON OF CAPTURE”
CASE STUDY FROM THE MISSISSIPPI DELTA

Authors: Mitchell, J. ^a and C.F.T. Andrus ^b

^a Department of Geosciences, Mississippi State University

^b Department of Geological Sciences, University of Alabama

Abstract

Seasonality estimates based on archaeological shellfish remains have been an important component of settlement pattern reconstruction. Investigations of this nature allow researchers to place prehistoric people on the landscape at points in space at different times of the year. Many of the previous seasonality studies, however, have focused on marine species from coastal sites, with little attention given to freshwater locales, especially ones in the Mississippi Delta. To address that disparity, this study examines freshwater mussel “season of capture” via analysis of stable oxygen isotope ratios in specimens recovered from two Late Woodland sites located along the Yazoo River, Mississippi. Isotope profiles from 22 shell specimens indicate mussels were being collected throughout the year. These data support the view that at least some portion of the human population at both sites engaged in shellfishing activities in all four seasons,

indicating a sedentary occupation at each locale, despite lacking the perceived requirement of agricultural subsistence.

Introduction

Archaeological faunal deposits are valuable sources of paleoenvironmental proxy data (Quitmeyer and Jones 1997; Reitz et al. 1996 2008; Rick and Erlandson 2008). Shell middens are particularly useful in this regard (Waselkov 1987; Deith and Shackleton 1988; Stein 1992; Reitz and Wing 1999; Álvarez et al. 2010; Thompson and Worth 2011), and have been noted in nearly every region with a long established history of human occupation (Erlandson 2001; Shone and Surge 2012). As such, they serve as valuable sources for a variety of artifacts (both faunal and non-faunal) that span in age from the late Pleistocene through the Holocene in much of the world (Andrus 2011). Because the dominant matrix constituents composing shell middens are bivalve mollusk remains, which in most cases have been confirmed as representing locally gathered organisms (Claassen 1998; Peacock 2002; Russo 2004), the shells themselves can provide regional- and site-specific data applicable to a number of interdisciplinary inquiries. Humans have been exploiting shellfish for millennia, with archaeological mollusk deposits found throughout the world dating back in some cases over 130,000 years (Bailey 1975; Binford 1984; Claassen 1998; Erlandson 2001; Jerardino and Marean 2010; Meehan 1982; Stein 1992; Waselkov 1987). These sites represent a substantial portion of the archaeological record and, in Southeastern North America, some shell middens are considered among the earliest large-scale artificial constructions.

Because of how aquatic mollusks form their shells, they are valuable as seasonal and environmental indicators (Davenport 1938; Hippler et al. 2009; Immenhauser et al.

2005; Jones 1993; Lee and Wilson 1969; Vander Putten et al. 2000; Wefer and Berger 1991; Witbaard et al. 1994). Throughout a mollusk's lifetime, isotopes and trace elements are incorporated from the surrounding water source and absorbed into its shell's crystalline structure as the mantle bio-mineralizes the shell (Tucker and Wright 1990). Ultimately, a mollusk shell will reflect environmental conditions via a characteristic chemical signature. These signatures are bound within the shell during growth and can provide definitive information about the water source in which the animals lived (Bruchardt and Fritz 1978; Claassen 1998; Deith 1986; Faure and Mensing 2005; Faure et al. 1967; Jones 1980; Jones et al. 1990; Odum 1951; Quitmyer et al. 1997; Rhoads and Lutz 1980; Wefer and Berger 1991). Because of this, mollusk remains can be used in a number of geochemical and archaeological applications, including elemental sourcing studies (Claassen 1998; Peacock 2009), establishing prehistoric waterway temperature ranges (Glassow et al. 1994; Jones and Kennett 1999; Kennett 2005), and, of most importance to this study, occupation seasonality (Andrus 2011; Andrus and Crowe 2008; Quitmyer et al. 1997).

Determination of site seasonality is a valuable tool for understanding prehistoric human mobility (Monks 1981; Rocek and Bar-Yosef 1998). Such inquiries, however, require the analysis of season-specific data. For decades, visual and geochemical analysis of shell growth patterns (i.e., sclerochronology) have been popular techniques (Jones et al. 2007) for assessing monumentality, feasting, and mobility at archaeological sites around the globe (e.g., Jew et al. 2013; Jones 1983; Koike 1980; Lightfoot and Cerrato 1989; Milner 2001; Monks 1981; Quitmyer et al. 1985, 1997; Reitz et al. 2012; Russo 1998; Schone et al. 2002). Because a mussel stops growing its shell when it dies, a

seasonal estimate at the point when it was harvested (i.e., “season of capture”) can be attained, which, in turn, is used to extrapolate the time and duration a particular site was occupied (i.e., whether a site was inhabited year-round, or intermittently) (Harding et al. 2010). This is accomplished by taking powdered samples beginning from a shell’s terminal growth band (i.e., the last part of shell grown before death), and assessing the stable oxygen isotope signature (expressed as $\delta^{18}\text{O}$) over time. $\delta^{18}\text{O}$ values are then interpreted as a profile of growth experienced during a mussel’s lifetime (see Andrus and Crowe 2008; Thompson and Andrus 2011). As mussels growth their shell on a seasonal basis, and as $\delta^{18}\text{O}$ is primarily controlled by temperature, this relationship ultimately provides the rationale behind this kind of “season of capture” analysis.

Though much study has been directed to archaeological coastal clam and oyster middens in the Southeast (e.g., Andrus and Thompson 2012; Claassen 1986; Bruseth 1980, 1991; Marquardt 2010; Russo 2006; Thompson and Andrus 2011), as well as to similar sites on the West and East Coasts (e.g., Culleton et al. 2009; Eerkens et al. 2013; Jones et al. 2008; Tellez-Duarte et al. 2008), little attention has been given to sites at freshwater locales, especially ones in the Lower Mississippi Alluvial Valley. Here we focus on freshwater mussel shells recovered from two archaeological sites in Yazoo County, Mississippi, and present data on $\delta^{18}\text{O}$ values attained from sequentially sampled growth lines within each specimen.

$\delta^{18}\text{O}$ Isotope Geochemistry

Isotopic signatures within skeletal carbonate have long been an important source of information for a number of fields. Previous studies have employed such analyses to assess paleoclimate trends via ocean sea surface temperature (SST) (e.g., Emiliani et al.

1964; Jones and Kennett 1999; Jones et al. 2005; Walker and Surge 2006), precipitation patterns (e.g., Gajurel et al. 2006; Harding et al. 2010; Kennett and Voorhies 1995), river discharge (e.g., Kaandorp et al. 2005; Ricken et al. 2003), and seasonality of prehistoric shellfish harvesting (e.g., Bailey et al. 1983; Carré et al. 2009; Claassen 1983; Coutts 1970; Colonese et al. 2009; Keene 2004; Jones et al. 2008; Kennett and Voorhies 1996; Mannino et al. 2003; Milner 2001; Quitmyer et al. 2005; Shackleton 1969, 1973; Thompson and Andrus 2011).

As a temperature/seasonal proxy, the applied basis for $\delta^{18}\text{O}$ research is that of a “paleo-thermometer”, which was first discussed by Urey (1947), and later extended to include both inorganic and biologic carbonates (Epstein et al. 1953; McCrea 1950; Shanahan et al. 2005). Investigating isotopic variation for seasonal reconstruction is contingent on first understanding the relationship between temperature, the $\delta^{18}\text{O}$ of the surrounding water ($\delta^{18}\text{O}_{\text{water}}$), and the $\delta^{18}\text{O}$ of the shell ($\delta^{18}\text{O}_{\text{shell}}$) (Dettmann et al. 1999:1049; Shanahan et al. 2005:3950). The amount of carbonate material added to a shell, as well as its chemical make-up, are influenced by many factors, including the organism’s age, reproductive cycle, available nutrients, and water temperature (Goodwin et al. 2003). Studies have shown that $\delta^{18}\text{O}$ fractionation coincides with the conditions of the surrounding water (Epstein et al. 1953; Grossman and Ku 1986; Wefer and Berger 1991), with shell growth being more pronounced during warmer months and less in colder months, ultimately representing an observable seasonal cycle (Dettmann et al. 1999; Dettmann and Lohmann 2000; Schone 2003). This cycle is a function of how $\delta^{18}\text{O}$ is represented in the surrounding water, essentially gauged by the ratio of the two main oxygen isotopes, ^{18}O and ^{16}O . At higher temperatures, water that is isotopically “light”

(i.e., molecules with ^{16}O) is evaporated preferentially, enriching the residual water with the “heavier” isotope (i.e., ^{18}O) (Tallez-Duarte et al. 2008:50). Given this, numerous studies have concluded the carbonate/ $\delta^{18}\text{O}$ relationship reflects an interaction with water temperature and isotopic content, more so than any other factor, making it the ideal proxy for paleo-temperature and seasonal studies (e.g., Brey and Mackensen 1997; Dunca and Mutvei 2001; Dunca et al. 2005; Goodwin et al. 2003; Jones et al. 1978, 1989; Kennish and Olsson 1975; Pannella and MacClintock 1969; Versteegh et al. 2010b; Urey 1947).

Materials and Methods

Specimens used in this study are from two primarily Late Woodland (Deasonville) period (AD 300 – 600) sites in Yazoo County, Mississippi. The Rugby Farm (22YZ513) and Light Capp (22YZ605) sites are located on the Yazoo River in rural farmland southwest of Yazoo City, Mississippi (see **Figure 3.1**). These sites are from a group of over 50 “shell-ring” sites associated with the ecoregion of the Northern Holocene Meander Belts (Peacock et al. 2011: Fig. 4). The area is situated in the Lower Mississippi Alluvial Valley, specifically within the Yazoo River Basin (an area colloquially known as the “Mississippi Delta”). Both sites contain a circular shell-ring and deposit of deep midden.

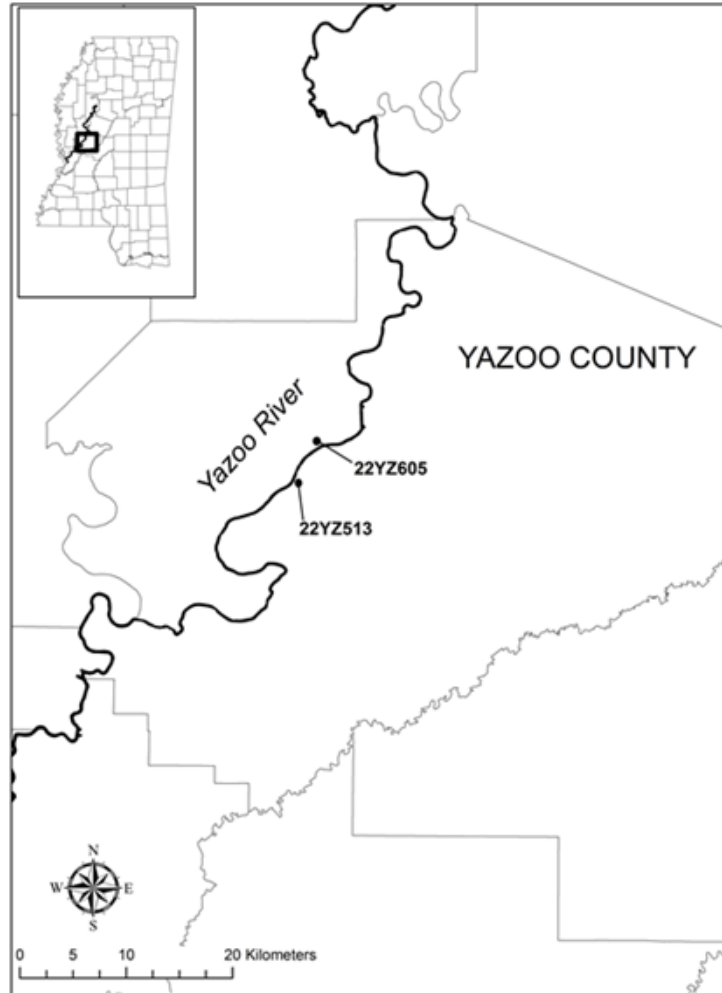


Figure 3.1 22YZ513 and 22YZ605

Map showing location of Rugby Farm (22YZ513) and Light Capp (22YZ605) sites in Yazoo County, Mississippi

Laboratory methods follow procedures demonstrated to be effective in previous shell isotope studies (e.g., Andrus and Crowe 2000; Thompson and Andrus 2011; Thompson et al. 2015). Excavated mussel shells were selected based on several criteria. First, only valves of *Amblema plicata* (Three Ridge) and *Fusconaia flava* (Wabash Pigtoe) were included in the study (see **Figure 3.2**), as they are well represented within the shell assemblages at each site and both have fairly dense/robust shells, which

generally contain thicker growth bands clearly visible when sectioned and polished. Only complete, un-fragmented, valves were used, with specific attention placed on the presence of intact umbos (i.e., the beak portion of the shell) showing full growth out to the shell's edge (i.e., the ventral margin, or the last part of shell the organism grew). Lastly, to ensure that each organism is represented once, only left valves were used. Young specimens were preferred, as they were likely growing more rapidly before capture and thus may be sampled at higher temporal resolution. Specimens were bisected, encased and mounted on petrographic slides with epoxy, then thick-sectioned (to ca. 5 mm) using a diamond wafer saw.

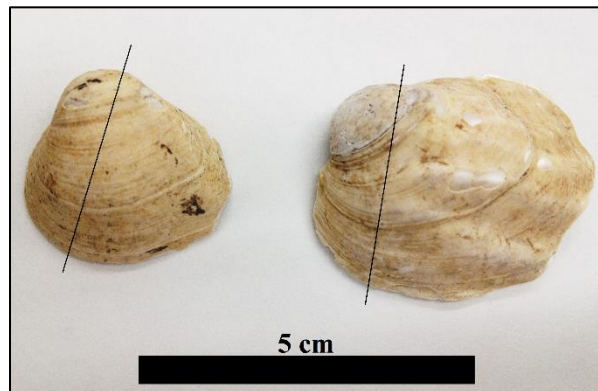


Figure 3.2 Selected mussel specimens

Representative specimens of *F. flava* (left) and *A. plicata* (right). Both are left valves. Lines represent bisecting transects

Each shell was then sampled using the New Wave Research Micromill housed at the Department of Geosciences, Mississippi State University. Milling and collection techniques generally follow those employed in previous studies involving carbonates specimens (e.g., Charlier et al. 2006; Dettmann et al. 1999; Hoffmann et al. 2009; Spotl

and Matthey 2006). Micro-mill techniques have been in use in sedimentology and rock petrology for over 25 years (Dettman and Lohmann 1995; Fouke and Rakovan 2001; Prezbindowski 1980; Verschure 1978), and are currently the most commonly used tools for high resolution sampling of accretionary carbonates (Patterson et al. 1993; Wurster et al. 1999). Incremental carbonate samples were taken from each valve following the organism's ontogeny (parallel to growth), starting at the edge of the shell, and milling towards earlier growth. Generally between 16 to 20 samples were taken from each specimen. An attempt was made to collect a minimum of 40 micrograms per sample, with a maximum of 110 micrograms.

The resultant powdered carbonate samples were weighed, loaded into 4.5 ml borosilicate vials, and analyzed via standard practice at the University of Alabama Stable Isotope Laboratory, Department of Geological Sciences. All samples were analyzed for $\delta^{13}\text{C}$ (though not included here) and $\delta^{18}\text{O}$ using a Thermo Gas Bench II coupled to either a Thermo Delta V or Thermo Delta Plus isotope ratio mass spectrometer in continuous flow mode. After flushing with ultra-pure He prior to extraction, the carbonate samples were reacted with orthophosphoric acid in the sealed vials at 25 °C. Values are reported in parts per mil (‰) relative to the Vienna Pee Dee belemnite (VPDB) standard by correcting to multiple NBS-19 analyses (typically 10 per run). NBS-19 was also used to assess and correct for drift and sample size linearity if needed. The range in standard deviation (1σ) of the NBS-19 standards for each run was .06 ‰ to .12 ‰ for $\delta^{18}\text{O}$, with an average precision of .09 ‰. All $\delta^{18}\text{O}$ values are shown in **Table 3.2** and **3.3**.

Results

Tables 3.2 and **3.3** contain $\delta^{18}\text{O}$ values measured in shells recovered from Rugby Farm and Light Capp. Most shells showed at least a partial sinusoidal $\delta^{18}\text{O}$ profile (i.e., a negative or positive trend), but five (highlighted) demonstrated no apparent regular pattern of oscillation (i.e., being more or less flat lines). The $\delta^{18}\text{O}$ ranges from each shell (min, median, max) from Rugby Farm and Light Capp are plotted in **Figure 3.3**. Overall, $\delta^{18}\text{O}$ ranges within individual shells from -4.86‰ to -8.29‰. Samples that are recorded as “error” either did not have enough carbonate powder to attain an accurate value, or had too much, causing the mass spectrometer reading to spike. Some data are also missing. For Rugby Farm, values from 9 specimens (Zn a and b; Zn B Lv 2 c; Zn B Lv 3 b and d; and Zn C Lv 2 a, b, c, and d) have not yet been received, while Light Capp is missing data from 8 shells (Zn B Lv 2 a, b, c, and d; Zn C Lv 1 a, b, c, d).

Table 3.2 $\delta^{18}\text{O}$ values for shell recovered from Rugby Farm (22YZ513)

		Samples in sequence of earlier in ontogeny/umbo (left) out to growth edge (right)																		
22YZ513																				
Zn A	a	-5.93	-5.90	-5.99	-6.17	-5.81	-5.93	-5.96	-5.96	-5.70error	-5.86	-5.71	-5.66	-5.77	-5.42	-5.46	-5.34	-5.59	-5.45	
	b	-6.65	-6.40	-6.63	-6.44	-6.68	-6.41	-6.36	-6.38	-6.34	-6.29	-6.25	-6.42	-6.13	-6.27	-6.19	-6.44	-6.37		
	c	-6.29	-6.35	-6.25	-6.43	-6.36	-6.13	-6.33	-6.19	-6.14	-6.20	-6.04error	error	-6.31	-6.43	-6.30	-6.55error	-6.78		
	d	-5.40	-5.23	-5.55	-5.62	-6.42	-6.25	-6.50	-6.77	-6.68	-6.66error	-6.79	-6.59	-6.39	-6.70	-6.46	-6.47	-6.28error	error	
Zn B Lv 1	a	-6.56	-6.60	-6.83	-6.75	-6.85	-6.70	-6.69	-6.72	-6.71	-6.80	-6.72	-6.84	-6.70	-6.82	-6.95	-6.76	-6.83	-6.97	
	b	-6.76	-6.67	-6.52	-6.50	-6.37	-6.29	-6.24	-6.38	-6.35	-6.33	-6.42	-6.23error	-6.27	-6.28	-6.07	-6.10	-6.43	-6.52	
	c	-5.38	-5.71	-5.50	-5.55	-5.68	-6.38	-6.13	-5.85	-6.27	-6.39	-6.92	-7.08	-6.66	-6.81	-6.86	-6.85	-6.67	-6.86	-7.21
	d	-6.40	-6.37	-6.25	-6.35	-6.14	-6.10	-6.26	-6.03	-6.31	-6.23	-6.17	-6.35error	-6.41	-6.26	-6.35	-6.45	-6.44error		
Zn B Lv 2	a	-6.49	-6.15	-6.12	-6.07	-6.33	-6.35	-6.44	-6.70	-6.41	-6.29	-6.34	-6.46	-6.36	-6.18	-6.03	-6.21	-6.29	-6.35error	
	b	-6.31	-6.28	-6.23	-6.13	-6.13	-6.06	-6.24	-6.13	-5.93error	-6.00	-5.95	-6.00	-6.12	-6.08	-6.30	-6.32	-6.55	-7.17	
	c	-5.78	-5.86	-5.82	-5.85	-6.03	-5.88	-5.97	-6.28	-6.42	-6.37	-6.24	-6.37	-6.41	-6.45	-6.36	-6.43	-6.33	-6.67	-6.61error
	d	-6.13	-5.64	-5.47	-5.34	-5.01	-4.86	-4.88	-4.52	-4.96	-5.60	-6.28	-6.55	-6.29	-6.50	-6.51	-6.27	-6.34	-6.45	-6.53
Zn C Lv 1	a	-5.97	-5.58	-5.84	-6.06	-6.02	-6.38	-6.28	-6.36	-6.54	-6.43	-6.35	-6.49	-6.01	-5.71	-5.56	-5.78	-5.58	-5.42	-5.43
	b	-6.22	-6.81	-6.41	-6.36	-6.68	-6.96error	-7.00	-7.00	-6.82	-6.14error	-6.22	-6.00	-6.27	-6.42	-5.97	-5.99	-6.34	-6.43	
	c	-6.23	-6.12	-6.25	-6.11	-6.22	-6.31	-6.26	-6.41	-6.25	-6.23	-6.48	-6.28	-6.74	-6.54	-6.40	-6.38	-6.47	-6.34	
	d																			
Zn C Lv 2	a																			
	b																			
	c																			
	d																			

All values are reported in parts per mil (‰) relative to the Vienna Pee Dee belemnite (VPDB) standard. Highlighted shell ranges have no apparent oscillation pattern

Table 3.3 $\delta^{18}\text{O}$ values for shell recovered from Light Capp (22YZ605)

		Samples in sequence of earlier in ontogeny/umbo (left) out to growth edge (right)																			
22YZ605 Zn A	a	-5.58	-5.72	-6.14	-6.36	-7.01	-6.86	-6.78	-7.07	-6.99	-6.90	-7.03	-7.00	-6.80	-6.72	-6.97	-6.96	-6.89	-6.99	-7.00	error
	b	-6.98	-6.86	-6.64	-6.80	-6.58	-6.60	-6.59	-6.63	-6.55	-6.74	-6.67	-6.81	-6.69	-6.95	-7.11	-7.06	-7.41	-7.25		
	c	-7.23	-7.05	-7.03	-6.76	-7.08	-6.97	-7.47	-7.47	-7.16	-7.05	-7.14	-6.98	-7.03	-7.22	-7.04	-7.29	-7.43	-7.22	-7.08	
	d	-5.91	-5.76	-5.70	-5.67	-6.07	-6.02	-5.97	-6.41	-6.03	-5.85	-5.82	-5.88	-6.24	-5.94	-6.37	-6.20	-6.26	-6.12	-5.74	-5.71
Zn B Lv 1	a	-6.69	-6.51	-6.73	-6.49	-6.56	-6.20	-6.71	-6.45	-6.43	-6.50	error	-6.25	-6.56	-6.29	-6.28	error	-6.73	-6.19	-6.10	
	b	error	-6.75	-6.43	-6.52	-6.03	-6.51	-6.96	-6.88	-6.98	-6.49	error	-6.96	-6.75	error	-6.49	-6.53	-6.49	-6.18	error	
	c	-7.00	-6.95	-7.02	-6.74	-7.06	-6.86	-6.91	-6.79	-7.05	-6.88	-6.93	-6.78	-6.54	-6.77	-6.77	-6.85	-6.43	-6.31	error	-6.07
	d	-6.29	-6.27	-6.06	-6.11	-6.24	-6.24	error	-6.05	-6.14	-6.21	-6.27	-5.95	-6.24	-6.12	-6.07	-6.34	-6.28	-6.44	-6.90	-7.28
Zn B Lv 2	a																				
	b																				
	c																				
	d																				
Zn B Lv 3	a	-5.85	-5.64	-5.96	-5.69	-6.10	-6.24	-6.31	-6.37	-6.30	-6.29	-6.58	-6.08	-6.37	-6.36	-6.37	-6.54	-6.83	-7.81	-7.24	-8.56
	b	-6.68	-6.78	-6.85	-6.64	-6.62	-6.60	-6.73	-7.04	-7.07	-6.97	-7.10	-6.59	-6.70	-6.08	-6.03	-5.76	-5.46	-5.34	error	
	c	-7.59	-7.48	-7.77	-7.72	-8.13	-8.29	-7.97	-7.93	-7.90	-8.02	-7.98	-7.61	-7.77	-7.40	error	-7.34	-7.35	-7.05	error	-7.04
	d	-6.00	-6.09	-6.14	error	-6.47	-6.54	-6.56	-6.52	-6.52	error	-6.56	error	-6.80	-6.63	-6.71	-6.66	-7.49	error	-7.12	-7.39
Zn C Lv 1	a																				
	b																				
	c																				
	d																				

All values are reported in parts per mil (‰) relative to the Vienna Pee Dee belemnite (VPDB) standard. Highlighted shell ranges have no apparent oscillation pattern

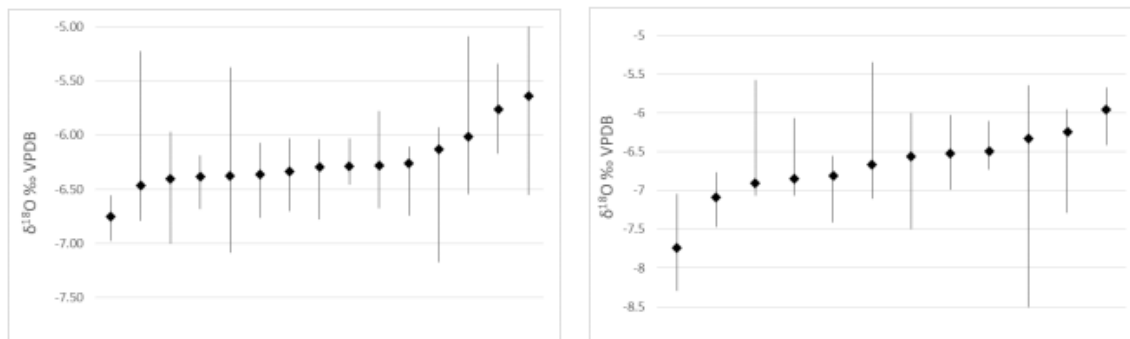


Figure 3.3 $\delta^{18}\text{O}$ medians and ranges

Median $\delta^{18}\text{O}$ values (black diamonds) and ranges (vertical bars) for all analyzed shells from Rugby Farm (left) and Light Capp (right). X-axis are sample valves plotted from most negative to most positive. Y-axis is $\delta^{18}\text{O}$ in parts per mil (‰) expressed relative to VPDB

Discussion

Season of Capture

All archaeological specimens were subjected to high spatial resolution oxygen isotope analysis in order to determine their season of capture, and thus the season(s) of site occupation (Andrus and Crowe 2008). Although no absolute temperature values are provided here, as that would require both the temperature and isotopic signature of the water (i.e., $\delta^{18}\text{O}_{\text{water}}$) at the time the shells were collected (not obtainable from archaeological specimens), seasonality can still be assessed on a qualitative basis by analyzing the amplitudes and relative shapes in the $\delta^{18}\text{O}$ profiles for each specimen. Of the 27 mussels sampled (15 from Rugby Farm, 12 from Light Capp), 22 produced observable profiles to determine season of capture. The five shells that did not display an oscillating $\delta^{18}\text{O}$ profile, or a recognizable portion of one, were designated as “uninterpretable”.

Sequential sampling across the lines of growth in a mussel shell can reveal a pattern of $\delta^{18}\text{O}$ oscillation, and thus season of capture. Wave peaks will correspond to thermal minima, while troughs correspond to thermal maxima (Krantz et al. 1984; Wefer and Berger 1991; Dettman and Lohmann 1993). To assess this, $\delta^{18}\text{O}$ values for the 22 shells containing oscillating profiles were organized into X:Y charts, as done in previous studies (e.g., Andrus and Crowe 2008; Thompson and Andrus 2011; Thompson et al. 20015). Each profile is then divided into three equal sections (see **Figure 3.4a-v**), done relative to each shell's $\delta^{18}\text{O}$ range. This is done because each organism can have a distinct physiological response in shell growth to seasonal temperature change, as evidenced by individual differences in minimum and maximum $\delta^{18}\text{O}$ amplitude (Andrus 2011). For seasonal interpretation, particular importance is placed on the last $\delta^{18}\text{O}$ value in a shell's profile, which is taken to represent the isotopic signature at the time of the organism's death (i.e., when it was collected). However, for context, it is necessary to show $\delta^{18}\text{O}$ values over a particular span in a shell's growth (representing "time"), as an isolated value would not permit a seasonal assignment (Andrus and Crowe 2008). A "winter" season was assigned to shells in which the last $\delta^{18}\text{O}$ value was in the upper third of the profile. "Summer" was assigned to shells whose last $\delta^{18}\text{O}$ value was in the lower third. A spring or fall season was assigned to values falling in the middle (transitional) section, depending on the $\delta^{18}\text{O}$ trend direction (i.e., positive trends indicate fall, and negative trends indicate spring).

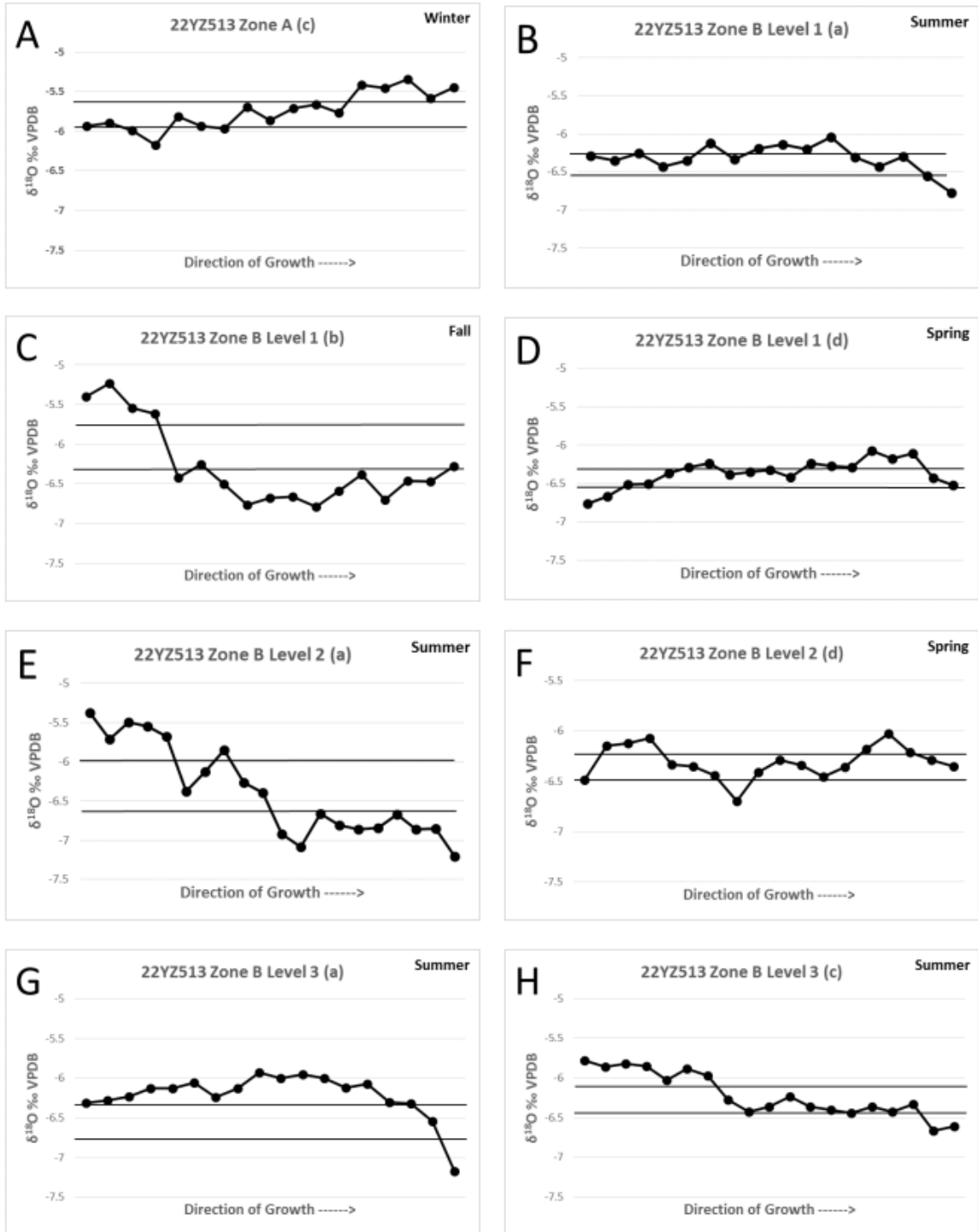


Figure 3.4 $\delta^{18}\text{O}$ oscillation profiles for 22YZ513 and 22YZ605

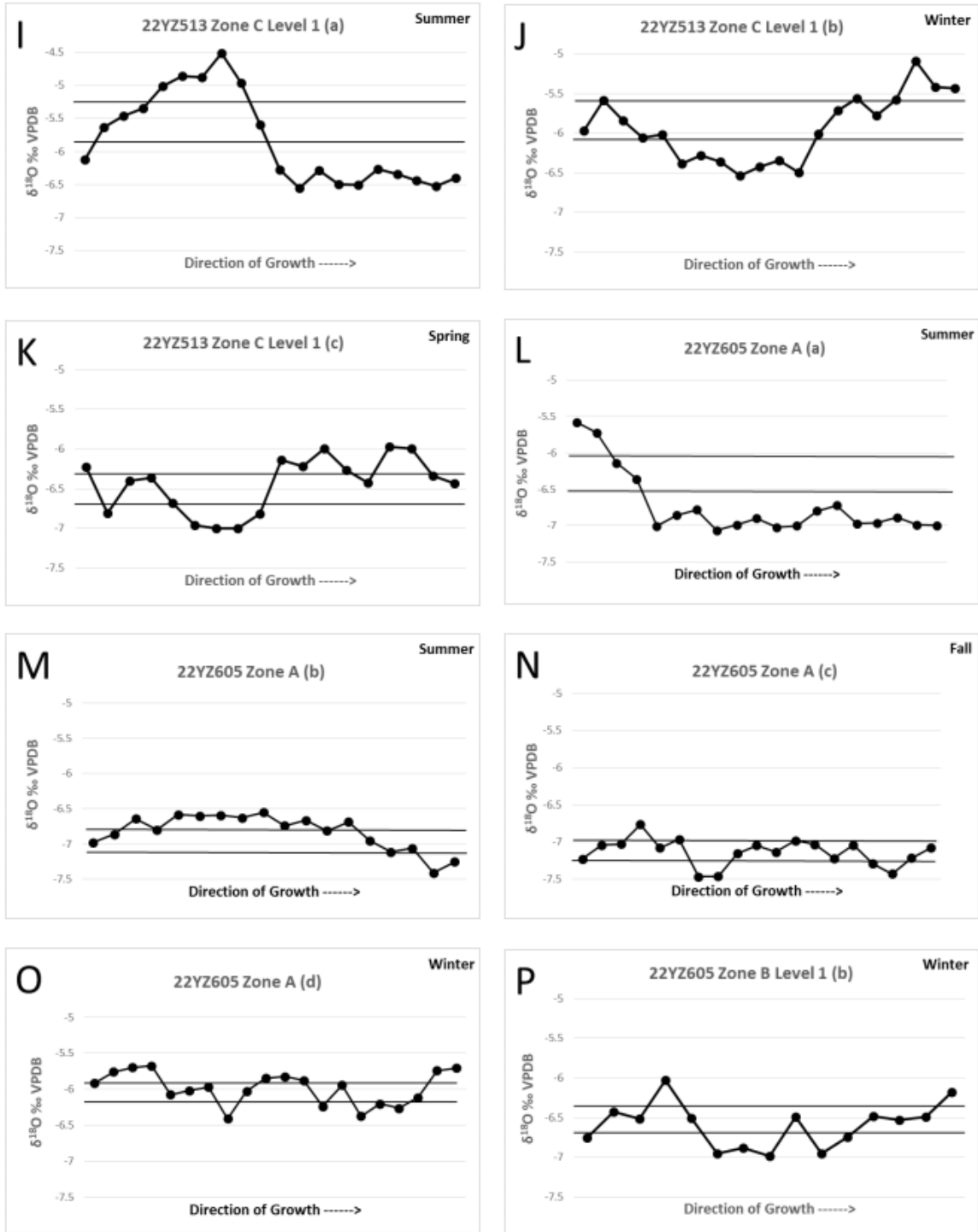


Figure 3.4 (Continued)

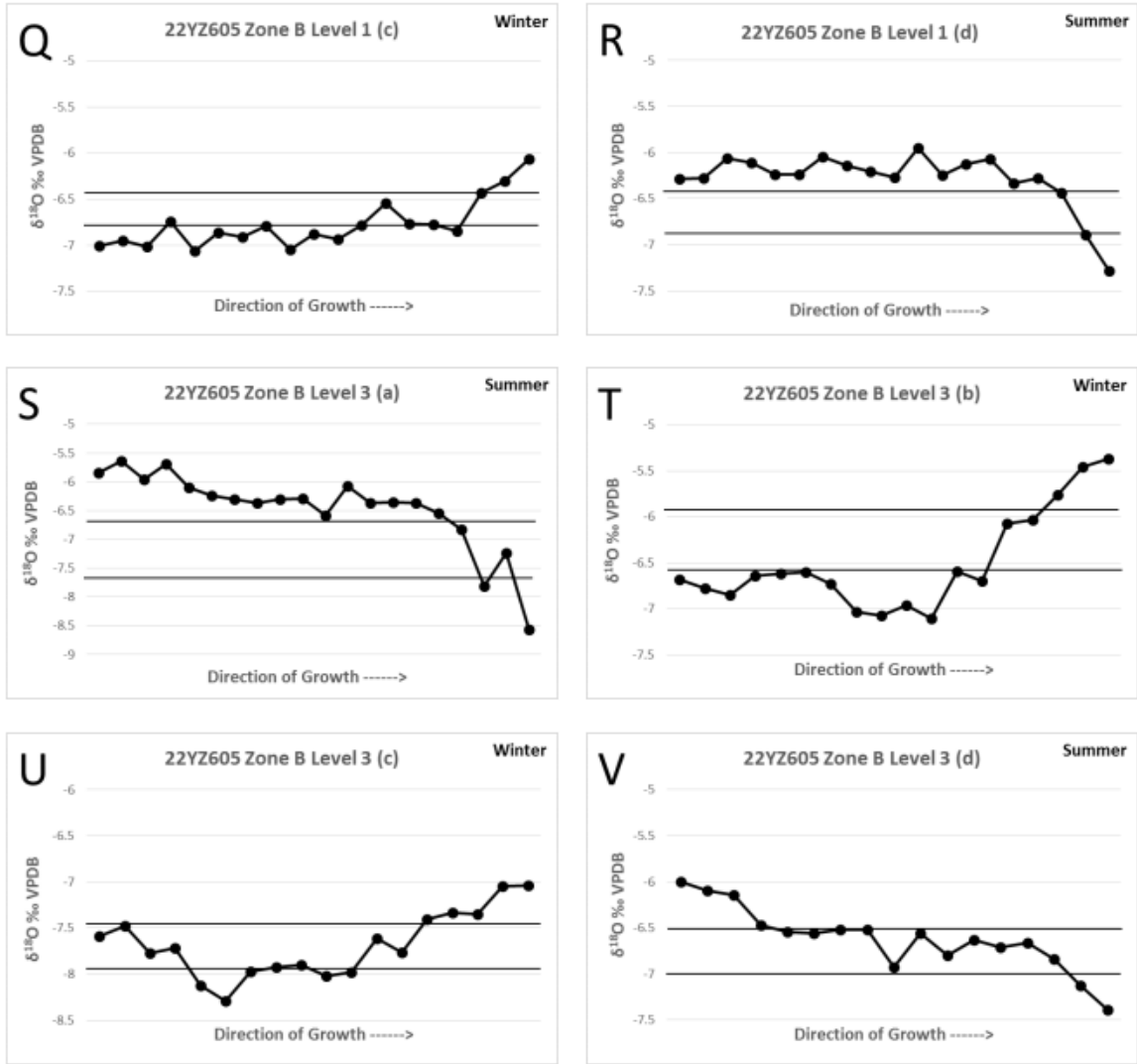


Figure 3.4 (Continued)

Shell $\delta^{18}\text{O}$ oscillation profiles from Rugby Farm (22YZ513) and Light Capp (22YZ605). Seasonal assignment noted in top right corner of each chart. $\delta^{18}\text{O}$ in parts per mil (‰) expressed relative to VPDB

In total, all 4 seasons are represented in the 22 profiled shell specimens (see **Figure 3.5**). Winter and summer account for the majority of the seasonal assignments (with 7 and 10, respectively). Though both spring and fall seasons were assigned, they cannot in themselves be considered definitive, as the middle third portion of the $\delta^{18}\text{O}$

range is essentially a transition period between colder and warmer temperatures, ultimately representing a gross estimate within the minimum and maximum range of values. The more meaningful results shown here are there are at a minimum 3 seasons (i.e., cooler periods, which transition to warmer periods, and vice-versa) represented at both study areas. This demonstrates a high likelihood that shellfish were being exploited at these sites on a year-round basis, thus indicating a sedentary population.

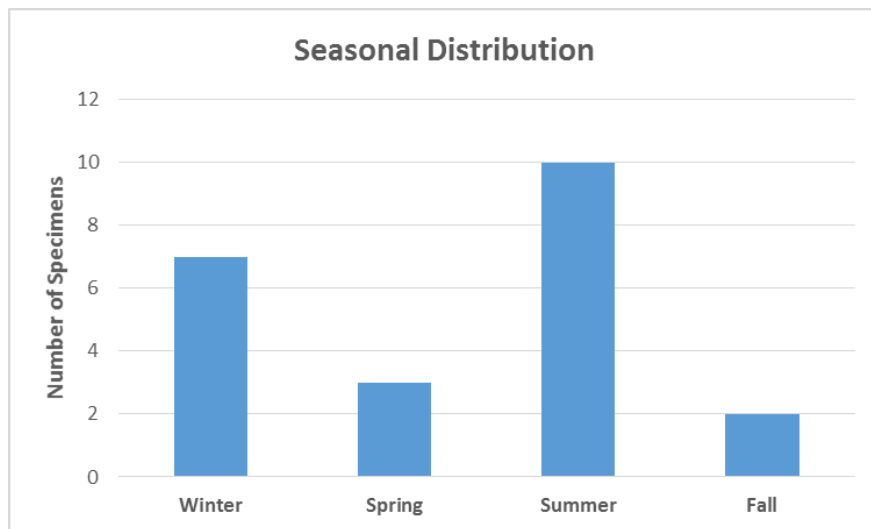


Figure 3.5 Seasonality histogram

Histogram depicting seasonal assignments among combined samples from Rugby Farm (22YZ513) and Light Capp (22YZ605)

Potential Issues with $\delta^{18}\text{O}$ Interpretations

There are numerous factors that can negatively affect a season of capture determination. For example, diagenetic alteration within selected mussel samples would undoubtedly impact isotopic analysis, potentially distorting interpretations of $\delta^{18}\text{O}$ magnitude and range (Ahr 2008; Moore 2001; Sayani et al. 2011; Tucker and Wright 1990). Ultimately, any chemical alteration within a shell sample should be assessed prior

to all ensuing chemical analyses (Claassen 1998; Collins 2012; Mitchell et al. *under review*). All of the shells used in this study were critically evaluated for evidence of diagenesis, particularly aragonite to calcite transformation (see Moore 1989; Morse and Mackenzie 1990; Webb et al. 2007). Via analysis of petrographic thin sections and scanning electron microscopy, our specimens were found free of any significant chemical alteration (see discussion in Mitchell et al. *under review*), and deemed suitable for isotopic analysis.

Another concern for season of capture studies involves how sequential sampling across shell growth lines accounts for time-averaging and spatial resolution (Richardson 2001), as different approaches (e.g., how many samples are taken, and how far apart they are in succession) can yield vastly different results. Ultimately, how growth and time are averaged within a shell can be observed. Here, since growth line width varied amongst samples, we attempted to “fit” as many sampling transects into as small a growth section as possible, hoping to attain at worst a monthly $\delta^{18}\text{O}$ profile. This was done by keeping the distance between sequential samples fairly consistent for all shells sampled. As shown in **Figure 3.6**, though milling transects are fairly similar in width, one can attain both a yearly and monthly picture of $\delta^{18}\text{O}$ oscillation. For example, judging from the oscillation profile, specimen “Zone B Level 2 (d)” depicts $\delta^{18}\text{O}$ values spanning nearly two years of growth (i.e., fall-winter-spring-summer-fall-winter-spring). Conversely, specimen “Zone A (a)” contains growth bands that are markedly wider, which when sampled, yielded an $\delta^{18}\text{O}$ oscillation that captures only a few months of growth (i.e., winter-spring-summer). Though profiles similar in scope to “Zone B Level 2 (d)” are generally preferred in season of capture studies, a narrower seasonal depiction can expose

change in more detail season-to-season (Goodwin et al. 2003). We feel the results shown here depict a good mix of both profile types.

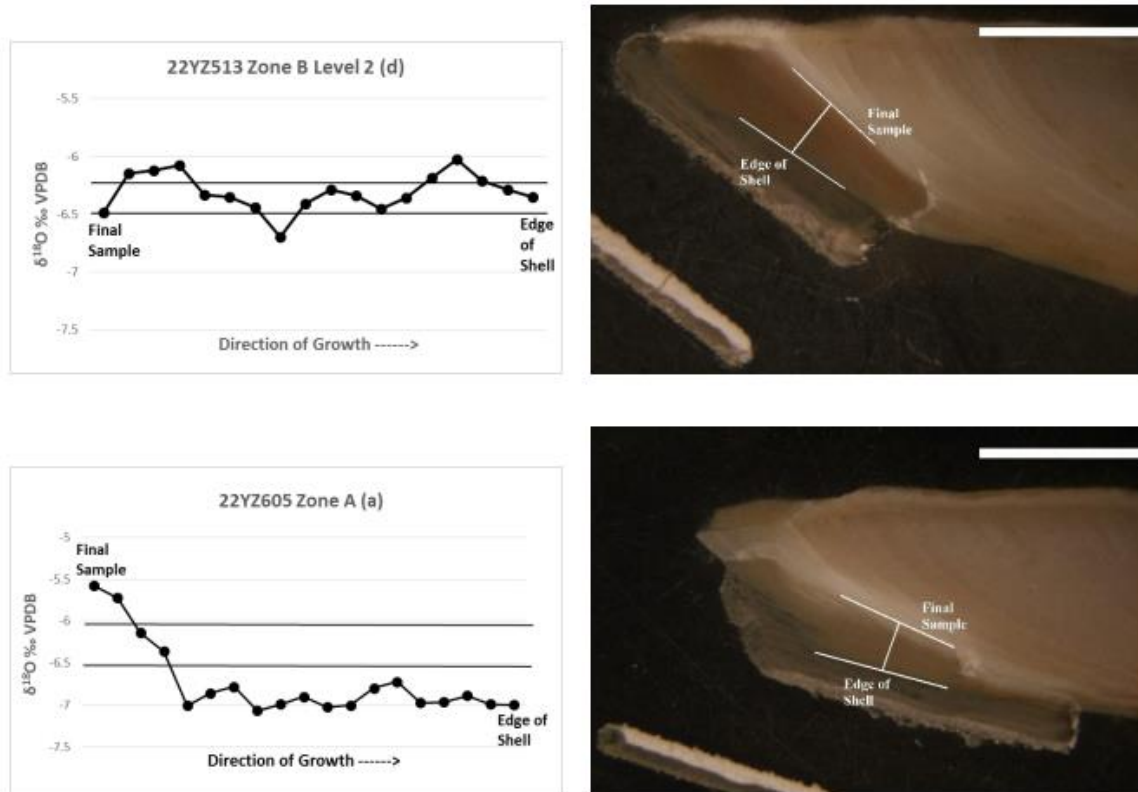


Figure 3.6 Representative $\delta^{18}\text{O}$ profiles and correlating shells

Top: 22YZ513 Zone B (d) with associated specimen. Bottom: 22YZ605 Zone A (a) with associated specimen. White brackets indicate sampling tracks, from the edge of the shell (sample 1), towards earlier growth periods (final sample). Scale bars represent 4 mm

Perhaps the most notable factor affecting season of capture assessments are how different species, and even individual mussels, can undergo a variety of physiological responses to environmental changes and/or disturbances (Andrus 2011; Schöne 2008). For bivalves, it has been well noted that a significant temperature-dependent isotope fractionation exists between the organism and its surrounding water (e.g., Chauvaud et al.

2005; Elliot et al. 2003; Epstein et al. 1953; Dettman et al. 1999; Goewert et al. 2007; Grossman and Ku 1986; Surge et al. 2001; Versteegh et al. 2009, 2010a). Some species, however, display an offset in metabolic processes (Fenger et al. 2007; Wefer and Berger 1991), often in the form of growth cessations or diminishment generally experienced during seasonal extremes (i.e., maximum and minimum temperatures) (Andrus 2010; Andrus and Thompson 2012; Carroll et al. 2006; Dettman et al. 1999; Jones and Quitmeyer 1996; Thomas and Andrus 2011; Veinott and Cornett 1996). Growth cessations are also characteristic of ontogenetically older individuals, as growth bands will generally decrease in both abundance and width as the organism ages (Goodwin et al. 2003), which is why it is best to avoid older specimens (as done here).

To account for these physiological issues, researchers generally have used mark-recapture methods on living mussels to understand the relationship between their shell growth and ambient environmental conditions (e.g., Carroll et al. 2006; Dettman et al. 1999; Haag and Commens-Carson 2008; Howard and Cuffey 2006; Neves and Moyer 1988). This method involves marking shells, returning them to their habitat, then retrieving them at a later date to examine the growth characteristics which have occurred since the initial marking. Shells are then compared with the temperature and dissolved oxygen data from the organism's water source, which are taken systematically during the experiment. Unfortunately, this method, though effective, is very time consuming (taking at least a year), and often suffers from a low return of marked specimens, especially in dynamic stream habitats. Also problematic is that over-handling of live specimens can cause the organism to develop "disturbance rings", which can appear similar to normal

growth rings, leading to potential interpretational errors (Rypel et al. 2008; Haag and Commens-Carson 2008).

For researchers investigating ancient and archaeological shell for paleotemperature purposes, these modern analogues have generally been utilized for two reasons: 1) to confirm that the particular mollusk species being studied grows its shell seasonally; and 2) to provide an expected and predicted range of both water temperature and $\delta^{18}\text{O}_{\text{water}}$ for their particular study area. These studies have mostly been applied to marine species and saltwater/brackish environments. For the purposes of this study, however, modern data are not necessary. The goal here was not to define an absolute temperature range for the study area, but to test whether these sites were occupied by people exploiting shellfish across multiple seasons. The basis for such a distinction relies on the fact that the freshwater mussels sampled did indeed grow their shells on a seasonal basis. Though very few archaeological reports have confronted this topic (e.g., Quitmeyer et al. 1997), there have been numerous studies confirming that growth rings in freshwater mussels are precipitated seasonally (e.g., Fritz and Poplawski 1974; Rypel et al. 2008; Stuiver 1970; Veinott and Cornett 2011). One study, in particular, has significant value for this discussion. A recent report by Haag and Commens-Carson (2008) validated the seasonal growth of 17 freshwater mussel species collected from the Little Tallahatchie River (Panola County, Mississippi), including specimens of *A. plicata* and *F. flava*. This is notable for two reasons: 1) this study confirms the suitability of *A. plicata* and *F. flava* as seasonal indicators; and 2) the Little Tallahatchie River is also located in the Mississippi Delta, so growth rates observed in the modern specimens by Haag and

Commen-Carsons (2008) would likely be very comparable to faunas living in the Yazoo River.

Conclusions

Although there are sometimes concerns with the accuracy and precision of geochemical analyses, it is important to consider evidence in its totality, rather than any single sample or value when assessing a site's overall seasonality (Blitz et al. 2014; Thompson et al. 2015). There is always the chance a season of capture assignment could be incorrect, hence the need for an adequate and representative sample size; a single shell should not be interpreted as an infallible indicator of seasonality. We feel the sampling strategy employed here provides sufficient evidence for a season of capture assignment, as multiple specimens were taken in each zone and level from excavation units dug at Rugby Farm and Light Capp, ultimately providing a multi-context and multi-specimen dataset.

This study confirms that season of capture can be determined through analysis of patterns of $\delta^{18}\text{O}$ incremental values in freshwater mussel remains. Evidence for shellfishing, and thus occupation, is present for all four seasons at Rugby Farm, and all but spring at Light Capp. It should be noted, however, that 'season of capture' and 'season of collection' do not always correlate (Andrus 2011), and it is possible that sites were occupied longer than the season of capture data may indicate (e.g., in the case of sites only showing a partial year of occupation). Hence, the season of capture findings should be considered a "minimal" assessment of occupation, which for both sites, points to at least a portion of the population being present year-round. This is the first such study from the Mississippi Delta, and the findings discussed here contradict the previous

archaeological notions of what is ‘required’ for sedentary living. As non-agricultural occupations (Raymond 2014), these two sites could sustain year-round populations, with shellfishing apparently being a major component of the population’s subsistence. Similar findings have previously been established for coastal Archaic-period shell rings, so that Late Woodland sites in the Mississippi Delta exhibit a similar dynamic is noteworthy, and challenges the overall normative thinking of many archaeologists’ conceptualization of mobility and subsistence.

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CHAPTER IV
PREHISTORIC MOLLUSCAN FAUNAS OF THE YAZOO RIVER, MISSISSIPPI,
USA: ARCHAEOLOGICAL PERSPECTIVES FOR MODERN CONSERVATION

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Author: Mitchell, J. ^a

^a Department of Geosciences, Mississippi State University

Abstract

Archaeological faunal assemblages can provide data valuable to modern conservation ecology. For example, while freshwater mussels (Bivalvia: Unionidae, Margaritiferidae) are common constituents in the archaeological record of North America, today they are one of the world's most imperiled faunal groups. Efforts to aid habitat restoration, population growth, and species reintroduction can be informed by studies of prehistoric mussel assemblages. These data can provide a historical perspective, cataloging communities as they existed prior to extensive modern impacts, thus representing an ecological baseline to be compared with modern populations. This study focuses on two late prehistoric (ca. 300 – 600 A.D.) sites on the Yazoo River, where nearly 24,000 freshwater mussel valves were recovered. Though modern data are extremely limited for the river, analysis revealed it once supported a diverse mussel community containing numerous species currently considered rare, endangered, or extinct in Mississippi. In total, the combined shell assemblages yielded 24 new river

records for the Yazoo River. One species in particular, *Quadrula fragosa*, represents the second such occurrence in Mississippi, and bolsters its candidate status as a new state record, as argued in a recent report from a neighboring river in the Yazoo Basin.

Introduction

Archaeological faunal remains have become a valuable resource for studying ecological and environmental change through time (Frazier 2010; Lauwerier and Plug 2004; Lyman 1996, 2006; Lyman and Cannon, 2004; Peacock et al. 2011, 2012, 2014; Wolverton and Lyman, 2012). For conservation efforts, the utility of archaeological deposits has been recognized (e.g., Anderson et al. 2010; Bailey et al. 2000; Crumley 1994; Frazier 2007; Lyman 1996, 2006) and demonstrated in a growing number of reports (e.g., Haag 2009; Lyman and Cannon 2004; Wolverton and Lyman 2012). Understanding the history of a species now regarded as threatened or imperiled, such as its original geographic range, is an important aspect of conservation ecology. The perspective provided by zooarchaeology in this regard is significant, as it permits the characterization of faunal communities as they existed prior to extensive modern impacts (Cvancara 2000; Haag 2009; McGregor and Dumas 2010; Mitchell and Peacock 2014; Peacock 2012). Ultimately, establishing a true ecological ‘baseline’ for comparison with modern communities is a feasible goal, but requires reference to the abundant prehistoric and historic record (e.g., Pauly 1995).

Freshwater mussel (Bivalvia: Unionidae, Margaritiferidae) remains are commonly found at archaeological sites in North America, and elsewhere (Brown et al. 1994; Peacock and Jenkins 2010; Peacock et al. 2011). Beyond purely archaeological inquiries, freshwater mussel remains have been a central topic in a growing body of

interdisciplinary literature. Studies from Mississippi (e.g., Bogan 1987; Hartfield 1993; Mitchell 2012; Mitchell and Peacock 2014; Peacock and James 2002; Peacock and Mistak 2008; Peacock and Mitchell 2015; Peacock et al. 2011), and other states (e.g., Barber 1982; Gordon 1983; Peacock et al. 2013; Randklev and Lundeen 2012; Randklev et al. 2010), have shown that archaeological mussel deposits frequently contain species not previously known to have existed in a given water body, or even drainage.

Archaeological data therefore can be very useful for conservation efforts by providing a more complete picture of past mussel community structures. This is especially pertinent for areas where modern biological surveys have not been carried out, or where historical data are lacking.

Although freshwater mussels were historically diverse and abundant throughout much of North America, many species are now in steep decline and mussels generally are considered one of the most imperiled faunal groups globally (Bogan 2008; Haag 2009; Grabarkiewicz and Davis 2008; Lydeard et al. 2004; Machtinger 2007; Neves et al. 1997). It is now believed that nearly 80% of freshwater mussel species are endangered in the United States (Mazzacano and Jepsen 2011), while for Mississippi alone, the state Department of Wildlife and Fisheries currently recognizes at least 23 species as either endangered, threatened, or imperiled, while several others are “presumed extinct” (Jones et al. 2005; Mississippi National Heritage Program 2011). Much of this decline has been credited to waterway impoundment, pollution, and other types of habitat destruction that (Aldridge 2000; Bogan 1993; Haag and Warren 1998; Strayer et al. 2004; Williams et al. 1993; Williams et al. 2008). Ultimately, data obtained from shell-bearing sites can be

used to establish the pre-industrial ranges and expected natural proportions of mussel species in aquatic systems now significantly altered.

Previous analysis of archaeological shell has resulted in many new river records for a number of species, and, in some cases, has led to major extensions in known geographical ranges (e.g., Mitchell and Peacock 2014; Peacock and Chapman 2001; Peacock 2002, 2012; Peacock and James 2002; Peacock et al. 2013; Peacock et al. 2014; Randklev and Lundeen 2012). Ideally, archeological shell deposits, especially those which are longer-term, can accurately represent what was available in a particular prehistoric mussel community (Matteson 1958, 1959; Parmalee and Klippel 1974; Parmalee et al. 1972), given repeated sampling over different portions of local mussel beds (i.e., space-time-averaging) by prehistoric shellfishers (e.g., Christian and Harris 2005; Dorsey 2000; Lyman 2003; Miller and Payne 1993; Otaola et al. 2015; Peacock 2000; Peacock et al. 2013). Adequate sampling will thus produce data representative of the archeological deposit, which, unless demonstrated otherwise, may be taken as representative of past faunas (Peacock et al. 2012; see Mitchell et al. 2016 for a discussion of sampling and preservation and their influence on species representativeness).

Here, data are presented on mussel shell obtained from two prehistoric sites located adjacent to the Yazoo River, in Yazoo County, Mississippi, followed by a discussion of the differences between those assemblages and modern faunas recorded in the waterway. There currently are very limited modern mussel data for the Yazoo River, so archaeological shell from the river takes on particular importance for establishing an

ecological baseline for future conservation and management purposes (Peacock and Mitchell 2015).

Methods

Specimens used in this study are from two primarily Late Woodland (Deasonville) period (AD 300 – 600) sites in Yazoo County, Mississippi. The Rugby Farm (22YZ513) and Light Capp (22YZ605) sites are located on the Yazoo River in rural farmland southwest of Yazoo City, Mississippi (see **Figure 4.1**). These sites are from a group of over 50 “shell-ring” sites associated with the ecoregion of the Northern Holocene Meander Belts (Peacock et al. 2011: Fig. 4). The area is situated in the Lower Mississippi Alluvial Valley (specifically within the Yazoo River Basin), in the area colloquially known as the “Mississippi Delta”. Both sites contain a circular shell-ring and deposit of deep midden. They are only separated by ca. 4 kilometers, with 22YZ513 being downstream to the southwest of 22YZ605 along the Yazoo River.

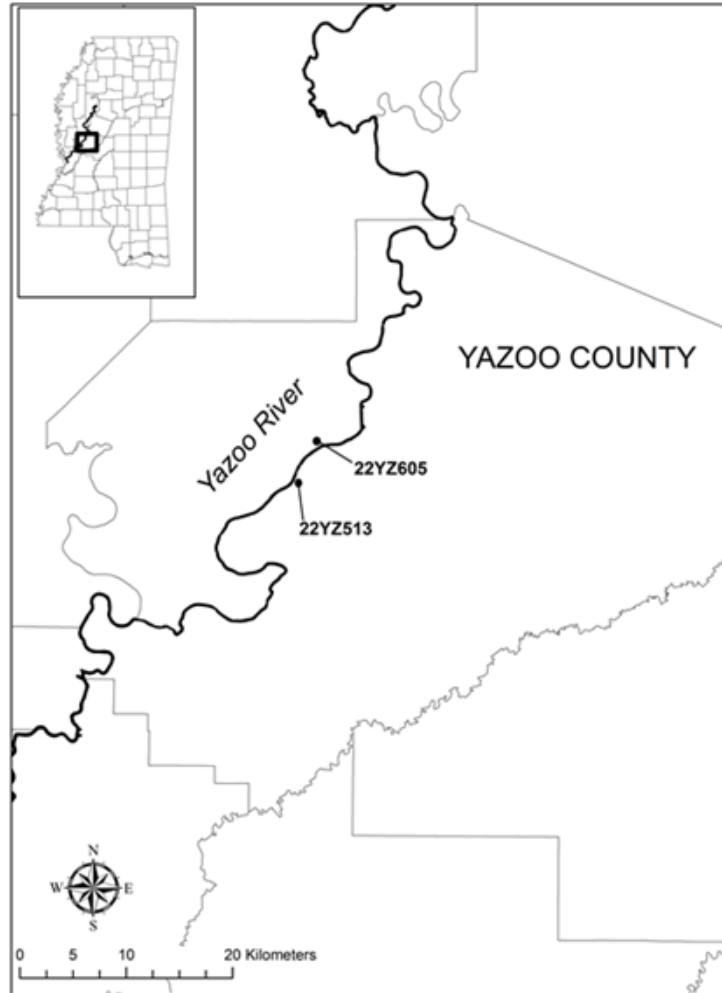


Figure 4.1 22YZ513 and 22YZ605

Map showing location of Rugby Farm (22YZ513) and Light Capp (22YZ605) sites in Yazoo County, Mississippi

Shell specimens were collected in 2013 by Mississippi State University's archaeology field school via a controlled surface collection (CSC) and 7 excavation units, 3 at 22YZ513 and 4 at 22YZ605. All units (1 x 1 m in dimension) were excavated until sterile subsoil was reached, and both sites produced a number of non-shell artifacts, including ceramic pot sherds, lithic flakes, and various bone fragments (Raymond 2014). Standard excavation methods were applied: zone levels were dug in 10 cm increments (or

smaller, if soil horizons visibly changed), and all material was separated from the dirt via water screening with .635 cm (1/4 inch) and .159 cm (1/16 inch) wire mesh.

Shell was analyzed to the genus and species level using various guides (e.g., Burch 1975; Cummings and Mayer 1992; Howells et al. 1996; Parmalee and Bogan 1998; Williams et al. 2008) and the freshwater mussel comparative collection housed at the Cobb Institute of Archaeology, Mississippi State University. Taxonomy was assigned using Turgeon et al. (2008) with minor updates.

Results

A total of 23,899 valves retaining umbos were recovered from the Rugby Farm and Light Capp sites (surface and excavated contexts combined), from which 37 species were identified. These species (left and right valves combined) are listed in descending order of abundance in **Table 4.2** (left and right values from each provenience are available upon request).

Table 4.2 Archaeological freshwater mussel data from the Rugby Farm (22YZ513) and Light Capp (22YZ605) sites, and Mississippi Museum of Natural Science records of modern occurrence for the Yazoo River.

Species	Archaeological				Modern (MMNS)	Conservation Status	
	22YZ513 #	22YZ605 #	Combined Total #	%		State	National
<i>Reginaia ebena</i>	2283	3733	6016	37.166%		S4	CS
<i>Pleurobema rubrum</i>	1097	2151	3248	20.065%		S1	T
<i>Plectomerus dombeyanus</i>	847	1142	1989	12.288%	X	S5	CS
<i>Oboquaria reflexa</i>	315	553	868	5.362%	X	S5	CS
<i>Quadrula postulosa</i>	299	508	807	4.985%	X	S5	CS
<i>Fusconaia flava</i>	258	407	665	4.108%		S5	CS
<i>Quadrula quadrula</i>	217	311	528	3.262%	X	S5	CS
<i>Amblema plicata</i>	161	251	412	2.545%	X	S5	CS
<i>Quadrula nodulata</i>	145	267	412	2.545%	X	S3	CS

Table 4.2 (Continued)

<i>Obovaria olivaria</i>	85	155	240	1.483%		S2	SC
<i>Elliptio dilatata</i>	66	146	212	1.310%		S1*	CS
<i>Obovaria subrotunda</i>	41	82	123	0.760%		S2	SC
<i>Lampsilis teres</i>	47	28	75	0.463%	X	S3	CS
<i>Quadrula verrucosa</i>	23	51	74	0.457%	X	S4	CS
<i>Cyprogenia aberti</i>	23	46	69	0.426%		S3, S4	CS
<i>Lampsilis hydiana</i>	29	29	58	0.358%		S2	CS
<i>Lampsilis siliquoidea</i>	21	29	50	0.309%		SH	T
<i>Ligumia recta</i>	22	22	44	0.272%		S2	SC
<i>Quadrula apiculata</i>	17	25	42	0.259%	X	S5	CS
<i>Truncilla truncata</i>	9	26	35	0.216%	X	S5	CS
<i>Villosa lienosa</i>	22	13	35	0.216%		S5	CS
<i>Quadrula cylindrica</i>	10	22	32	0.198%		S1*	T
<i>Meglonaia nervosa</i>	9	21	30	0.185%	X	S4, S5	CS
<i>Quadrula metanevra</i>	6	24	30	0.185%		SH*	CS
<i>Arcidens confragosus</i>	8	14	22	0.136%		S4	CS
<i>Plethobasus cyphus</i>	4	10	14	0.086%		S1*	T
<i>Quadrula fragosa</i>	2	10	12	0.074%		-	T
<i>Lampsilis cardium</i>	7	4	11	0.068%		S3, S4	SC
<i>Ligumia subrostrata</i>	4	3	7	0.043%		S5	CS
<i>Obovaria unicolor</i>	1	6	7	0.043%		S3	SC
<i>Potamilus purpuratus</i>	2	4	6	0.037%	X	S5	CS
<i>Toxolasma parvum</i>	4	0	4	0.025%		S4	CS
<i>Ellipsaria lineolata</i>	0	3	3	0.019%		S3	SC
<i>Strophitus undulatus</i>	2	1	3	0.019%		S1	CS
<i>Truncilla donaciformis</i>	1	1	2	0.012%	X	S2	CS
<i>Lampsilis ornata</i>	1	0	1	0.006%		S3	SC
<i>Lampsillis radiata</i>	0	1	1	0.006%		-	CS
<i>Anodonta suborbiculata</i>	0	0	0	0.000%	X	S3, S4	CS
<i>Leptodea fragilis</i>	0	0	0	0.000%	X	S5	CS
<i>Potamilus ohioensis</i>	0	0	0	0.000%	X	S3	CS
<i>Pyganodon grandis</i>	0	0	0	0.000%	X	S5	CS
<i>Toxolasma texasiensis</i>	0	0	0	0.000%	X	S4	CS
<i>Unio merus tetralasmus</i>	0	0	0	0.000%	X	S5	CS
<i>Utterbackia imbecillis</i>	0	0	0	0.000%	X	S5	CS
Total Identified	6088	10099	16187	100%			
Unidentifiable	3209	4503	7712				
Total Analyzed	9297	14602	23899				

= number of valves, and % = percent identified valves. State conservation status derived from Jones et al. (2005): S1 = critically imperiled; S2 = imperiled; S3 = rare or uncommon; S4 = widespread, abundant, and apparently secure within the state; S5 = demonstrably secure within the state; SH = of historical occurrence within the state. An asterisk indicates that species is listed by the US Fish and Wildlife Service as either threatened or endangered. National conservation status derived from Williams et al. (1993): T = threatened; SC = special concern; CS = currently stable

Discussion

Unfortunately, modern mussel survey data from the Yazoo River are very limited. A challenge that often arises when comparing modern and archaeological assemblages is accounting for ‘time-space-averaging’ (Christian and Harris 2005; Dorsey 2000; Lyman 2003; Milller and Payne 1993; Otaola et al. 2015; Peacock et al. 2013). For example, archaeological sites often contain tens of thousands of valves, as at both Rugby Farm and Light Capp, so an assemblage presumably represents long-term collecting by numerous households over a relatively small area (Peacock 2002). Conversely, modern mussel surveys typically represent very time-limited collections over areas that are widely distributed in space, the results of which can vary considerably from year to year. Accordingly, comparisons between archaeological and modern faunas have tended to be more qualitative (e.g., Lyons et al. 2007, Tevesz et al. 2002). Despite this fact, however, archaeological studies can still provide very useful biogeographical data (such as range extensions via species presence/absence), as well as insights on prehistoric aquatic environmental conditions (as certain species favor clearer water, while others can be more silt-tolerant).

A list of species historically known to have been in the river was provided by the Mississippi Museum of Natural Sciences (MMNS) and these are noted in **Table 4.2**. Analysis of the Rugby Farm and Light Capp shell assemblages yielded 37 species, 24 of which are not identified in the modern collection, and thus constitute new river records for the Yazoo River. These species are as follows (in order of abundance): *R. ebena*, *P. rubrum*, *F. flava*, *O. jacksoniana*, *E. dilatata*, *O. subrotunda*, *C. aberti*, *L. hydiana*, *L. siliquoidea*, *L. recta*, *V. lienosa*, *Q. cylindrica*, *Q. metanevra*, *A. confragosus*, *P. cyphyus*,

Q. fragosa, *L. cardium*, *L. subrostrata*, *O. unicolor*, *T. parvum*, *E. lineolata*, *S. undulatus*, *L. ornata*, and *L. radiata*. Six species are present in the MMNS collection, but absent from the archaeological assemblages: *A. suborbiculata*, *L. fragilis*, *P. ohiensis*, *P. grandis*, *T. texasiensis*, and *U. imbecillis*. These faunas have previously been reported from archaeological sites in the Yazoo Basin (Peacock et al. 2011; see Gilleland 2016 for occurrence of *A. suborbiculata*), but their absence here is possibly due to differential preservation negatively affecting thin-shelled species. Alternatively, both *P. grandis* and *U. imbecillis* typically favor more lentic environments, so their absence from sites along the main river is not surprising. Though archaeological data on the Yazoo River are also limited, a recent report (see Peacock and Mitchell 2015) from a backwater area of the river yielded a similar taxonomic makeup as the one shown here, outside of a few faunas (i.e., *E. lineolata*, *L. subrostrata*, *O. unicolor*, *L. ornata*, and *Q. fragosa*; the latter two will be discussed below).

Since archaeological shell assemblages are generally comprised of mussels which were locally gathered (see Peacock 2000; Peacock et al. 2012), the taxonomic makeup of these sites may be used to understand the aquatic environmental conditions that existed there at the time. For example, *E. dilatata* is frequently characterized as a clear-water species (e.g., Parmalee 1967, Starret 1971), and its presence here (as well as at other archaeological sites in the Yazoo Basin [see Hartfield 1993:table 1, Peacock et al. 2011:map A-10]), and absence from modern populations, points to changes that likely have occurred as a result of increased turbidity (e.g., Dineen 1971, Hoeh and Trdan 1984, Klippel et al. 1978, Starrett 1971, Taylor and Spurlock 1982, White 1977). The same applies to *C. aberti*, an Ozarkian species now known to have had a wide prehistoric

distribution in the Yazoo Basin (Bogan 1987, Hartfield 1993, Jones et al. 2005, Peacock and James 2002, Peacock et al. 2011), but absent from modern collections there.

However, other common species recovered at Rugby Farm and Light Capp (e.g., *A. plicata*, *F. flava*, *O. reflexa*, *P. dombeyanus*, *Q. pustulosa*, *R. ebena*) are characterized as relatively silt-tolerant (Peacock 1998), and are found throughout the Yazoo Basin, both historically and in modern times. The environmental picture provided here, indicates that shells were collected from multiple environments near the respective sites, both from the main (more turbid) river, as well as the surrounding (more lentic) microhabitats, like oxbow lakes and ponds.

There are several species recovered in this study that are particularly noteworthy from a biogeographical perspective. *P. cyphus* and *Q. cylindrica* are both listed as “critically imperiled” species in Mississippi, as well as nationally (Jones et al. 2005), so documenting their historical presence and range in the Yazoo River has importance. *S. undulatus* is also listed as critically imperiled in Mississippi, and has been rare in modern times (Jones et al. 2005). Though present at both Rugby Farm and Light Capp (n=1 and n=2, respectively), it appears equally uncommon prehistorically, with only two other archaeological occurrences documented for Mississippi, both on the Big Sunflower River (Mitchell and Peacock 2014; Peacock et al. 2011; see Peacock et al. 2013 for examples from Bayou Bartholomew, AR). *L. ornata*, is noted as secure in Mississippi, but is more commonly found in eastern and southern tributaries, as well as Lake Pontchartrain, Louisiana (Jones et al. 2005). This also seems to be the case prehistorically, as *L. ornata* has only been recorded from sites in the Tombigbee River Drainage (Peacock et al.

2011:map A-18). The single valve recovered at Rugby Farm, thus represents the only archaeological example from the Yazoo Basin.

The most significant find, however, was the presence of twelve *Q. fragosa* valves from Rugby Farm and Light Capp (n=2 and n=10, respectively). Morphologically, this species can be confused with other *Quadrulas*, namely *Q. quadrula*, as both possess a sulcus with varying expression of nodules and pustules present on either side. However, *Q. fragosa* is distinguished by its “pronounced wing or expanded posterior slope, posterior to the beak” (Parmalee and Bogan 1998:212), a more inflated shell, and more elevated umbo (Baker 1928), all of which are features clearly expressed on the specimens recovered here. Also, these posterior-dorsal slopes are markedly wider, more alate, and contain more sculpture (Baker 1928; Watters 1988) than the *Q. quadrula* specimens from the study sites (see **Figure 4.2**).



Figure 4.2 *Quadrula fragosa*

Left: representative specimen of *Q. fragosa*. Right: representative specimen of *Q. quadrula*. Both are right valves

Historically, *Q. fragosa* was more common in the Midwest, but was found in southern tributaries of the Mississippi River in Tennessee, Arkansas, and Louisiana (Harris 2006; Hemmingsen 2008; Parmalee and Bogan 1998; Posey et al. 1996; USFWS 1997). Like many other freshwater species, its range has been significantly reduced over time as a result of damming, impoundment, and decreased water quality (Doolittle 1988; Fuller 1980; Graczyk 1986; Havlik 1987; Heath and Rasmussen 1990). *Q. fragosa* is now listed as “endangered” by the United States Fish and Wildlife Service (USFWS 1991), and considered likely extirpated from its entire historic range except for one (possible) remnant population in the St. Croix River, between Minnesota and Wisconsin (Cummings 1991). However, the original range of *Q. fragosa*, as currently understood, was such that the presence of the species in a medium-sized river in northwest Mississippi is plausible, especially given its presence in western tributaries of the Mississippi River in Arkansas (Harris 2006; Hemmingsen 2008; Peacock et al. under review; USFWS 1997). The status of *Q. fragosa* as a new state record for Mississippi has recently been proposed by Peacock et al. (under review), where 161 specimens were recovered from two sites on the Tallahatchie River, in Leflore County, Mississippi. The 12 specimens discussed here would appear to support such a claim, and further extend the range of *Q. fragosa* into the Yazoo Basin.

Concerns for Bias

Comparison of archaeological and modern mussel assemblages is complicated by a number of factors. There are several biases/effects that can negatively impact what can be said from an archaeological assemblage. Researcher bias generally concerns inadequate sampling of archaeological deposits and the effects that has on any subsequent

interpretations. With mussel deposits, the problem that often arises is the need to account for time-space-averaging, given that individual clusters of shell could represent particular sections of a mussel bed from the river or stream where they were gathered, as well as different collecting periods. Because of this, it is useful to not only sample from the subsurface, but also from multiple zones on the surface of a shell deposit (Mitchell et al. 2016). As noted earlier, a total of 7 excavation units and a CSC were applied to the study areas, so the likelihood that a representative sample has been obtained is high.

A dynamic out of the researcher's control, however, is differential preservation (also referred to as "preservation bias"), which commonly impacts archaeological shell remains, particularly those in the plow-zone (i.e., surface and near surface contexts) and typically has a greater impact on species with less dense/more elongate (i.e., "rod-shaped") shells (Mitchell et al. 2016; Peacock 2000; Peacock and Chapman 2001; Wolverton et al. 2010). Though shell shape is indeed a factor, density in the umbonal area tends to be the most important factor for species identification (Mitchell 2012). For example, *E. dilatata* and *P. dombeyanus*, both of which have rather thin and elongate shells, are easily identified even when highly fractured, primarily due to their pseudocardinal and lateral teeth often remaining intact (see Mitchell 2012:figs. 5.11 and 5.12). For the more dense/"cup-shaped" species, deterioration of external morphology (e.g., pustules, nodules, and ridges) can negatively affect some species, as that is typically the deciding factor for identification. For instance, some species of *Quadrula* can be indistinguishable from each other when highly eroded. Because of this, specimens identified to genus only were recorded as "unidentifiable".

Ultimately, the percentage of unidentifiable shell in an assemblage can provide a gross estimate of preservation at a site. Analysis of both the Light Capp and Rugby Farm shell demonstrate a significant difference in preservation between plow-zone (i.e., CSC and Zone A) and midden (Zones B and C) contexts (see **Table 4.3**), which was expected. However, as numerous thin-shelled taxa (e.g., *L. teres*, *P. purpuratus*, *V. lienosa*) were recovered, preservation bias does not appear a major factor at either site. Overall, both sites combined to have nearly 68 percent of the recovered mussel valves identifiable to species, which is a fairly typical value for well-preserved sites in the Southeast (Peacock 2009).

Table 4.3 Plow-zone vs midden contexts

#	Plow-zone				Midden			
	22YZ513	%	22YZ605	%	22YZ513	%	22YZ605	%
Identifiable	2924	55.2	5709	62.5	3164	79.1	4390	80.3
Unidentifiable	2375	44.8	3426	37.5	834	20.9	1077	19.7
Total	5299	100	9135	100	3998	100	5467	100

Comparison of identifiable and unidentifiable valves between the Plow-zone (Zone A and CSC combined) and Midden (Zones B and C combined) contexts. # = number of valves, % = percent of total

There is also the concern that prehistoric shell-fishers preferentially selected and/or avoided certain species because of particular tastes or other non-random cultural traits (i.e., the “culture filter”, see Daly 1969; or “cultural bias”, see Peacock et al. 2012; Theler 1991). The presence of such a dynamic would undoubtedly affect any interpretations of biogeographical patterns and ranges. One way to explore this concern is to examine the size distribution of shells recovered. For instance, given the relatively low energy return (Parmalee and Klippel 1974), small specimens might have been avoided,

with preference given to collecting larger organisms. Many archaeological reports note mussel shells ranging down to very small sizes (e.g., Mitchell and Peacock 2014; Peacock 2000; Peacock et al. under review) with size-class distributions indicative of normal populations (Peacock 2000; Peacock and Mistak 2008; see also Peacock 2012:fig. 3.1). Though a detailed size-class analysis was not applied here, it is clear that very small individuals of many different species are well represented in both assemblages (see **Figure 4.3**), ultimately challenging the notion that small species, and/or juvenile individuals, were intentionally being avoided. Also, simply given the abundance (i.e., taxonomic richness) of taxa present at both sites (n=37), it is likely whatever was available in the river at the time was collected (and later deposited), with no preference to particular species.



Figure 4.3 Juvenile specimens of freshwater mussels from Rugby Farm and Light Capp

Top Row (left to right): *L. recta* (left valve), *F. flava* (left valve), *O. reflexa* (right valve), and *R. ebena* (right valve). Bottom Row (left to right): *O. subrotunda* (left valve), *Q. verrucosa* (left valve), *T. truncata* (right valve), and *Q. quadrula* (right valve)

Conclusions

The shell assemblages recovered from Rugby Farm and Light Capp are valuable for a number of reasons. For one, when compared to modern data, the number of extended ranges and new river records from each give a much larger picture of the original mussel population that existed in the Yazoo River. This not only provides a more baseline assessment of the community structure within the river, but can better inform reintroduction efforts for species no longer present in the region. Also, considering the taxonomic richness and inclusion of so many small specimens, the shells recovered at Rugby Farm and Light Capp represent diverse and seemingly healthy populations, with strong juvenile recruitment across numerous species; this is especially important, as modern surveys from neighboring rivers have noted juvenile recruitment lacking in many current populations (see Miller and Payne 1995, 2004; Miller et al. 1992 for discussion on the Big Sunflower River). Though the assemblages do not appear very even (see discussion of evenness/diversity in Mitchell et al. 2016), as only two taxa account for over 57 percent of the total population (i.e., *R. ebena* and *P. rubrum*), this is possibly the result of a preservation bias favoring thicker, more “cup-shaped”, species. Obviously, the presence of *Q. fragosa* is noteworthy, as it bolsters the claim for a range extension made by Peacock et al. (under review), and demonstrates the species’ occurrence in another river in the Yazoo Basin. Consequently, as conservation efforts for many mussels have been met with much difficulty (USFWS 1997), any and all new information pertaining to the historic habitats of *Q. fragosa* has value.

Malacologists and conservationists are constantly developing more effective strategies to grow populations, improve survival rates, and aid recruitment of relocated

faunas in affected mussel communities (Machtinger 2007). Ultimately, the absence of a true ecological baseline in how mussel communities are assessed and understood is a limiting factor, but one that can be addressed by utilizing zooarchaeological data. This notion of employing historical/archaeological resources is not new to conservation biology. The concept known as the “shifting baseline syndrome” (SBS), as discussed by Pauly (1995), contends that fishery sciences do not have the historical perspective, nor the formal approach, for dealing with presently extirpated faunas that once existed in great abundance. This problem arises due to each generation of scientists accepting the present population characteristics (e.g., stock size, species composition, diversity) as their ecological baseline, and it is that standard which is used to evaluate further change (Pauly 1995). Accordingly, developing a dialogue for integrating prehistoric and historic data into present models of conservation is crucial. As there are few modern or historical data from the Yazoo River, the findings discussed here provide a benchmark that would otherwise be inaccessible. It is hoped that this report will increase recognition of the importance zooarchaeological data have for conservation biology.

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CHAPTER V

CONCLUSIONS AND FUTURE WORK

This dissertation presents an initial investigation of occupation seasonality (via $\delta^{18}\text{O}$ analysis) at prehistoric shell ring sites in the Mississippi Delta. Similar studies have successfully been applied to marine specimens from coastal locals (e.g., Andrus and Crowe 2008; Thompson and Andrus 2011; Thompson et al. 2015), but this work represents one of the few aimed at prehistoric freshwater mussels (e.g., Dettman 2011, albeit not for the purpose of seasonality). Though 22 useful oscillation patterns were attained, 5 shells were deemed “uninterpretable”, and unfortunately could not provide any valuable information as to their seasonality. Previous studies of modern freshwater mussels have noted occasional difficulty when interpreting seasonal growth bands, especially in ontogenetically older specimens and ones that have experienced growth cessations during periods of thermal minima and maxima (Rypel et al. 2008). Future studies should aim to address the degree of these dynamics within archaeological shell, and how such physiological effects can impact $\delta^{18}\text{O}$ oscillation interpretation. More comparison with modern studies would aid in this, as well as provide a more quantitative basis for advancing archaeological freshwater shell as valuable resources for regional climate-change proxies. The study demonstrated here applied $\delta^{18}\text{O}$ interpretation as a qualitative indicator of prehistoric shellfishing (via “season of capture”), which has value in itself, but correlating those data with modern analogues could provide a useful range in

both water temperature and $\delta^{18}\text{O}_{\text{water}}$ variation experienced during each animal's lifetime, making such work applicable to other disciplines.

Prior to isotope analysis, the archaeological shell specimens were assessed for post-depositional chemical alteration. This study confirmed that the mussel valves contained pristine microstructure, were free of diagenesis, and suitable for geochemical study. The diagenesis study contained here represents only the second such study applied to archaeological freshwater mussel remains (e.g., Collins 2012). The need for such a vetting process cannot be overstated, and all future shell ring studies employing geochemical analysis (e.g., isotopes, trace elements) should apply similar investigations. For example, though the specimens studied here were pristine, as well as those described by Collins (2012), shell samples recently sampled from the Vaughn Mound Site (22LO538) are of much poorer quality (see **Figure 5.1**). Both of these SEM images show characteristic evidence of diagenesis (dissolution and laminae fusion). Investigation of the Vaughn Mound shell is currently ongoing, but the limited viewing so far reinforces the need for such analysis, as well as raises questions regarding differences in the depositional and environmental conditions of sites such as Rugby Farm and Light Capp, compared to Vaughn Mound.

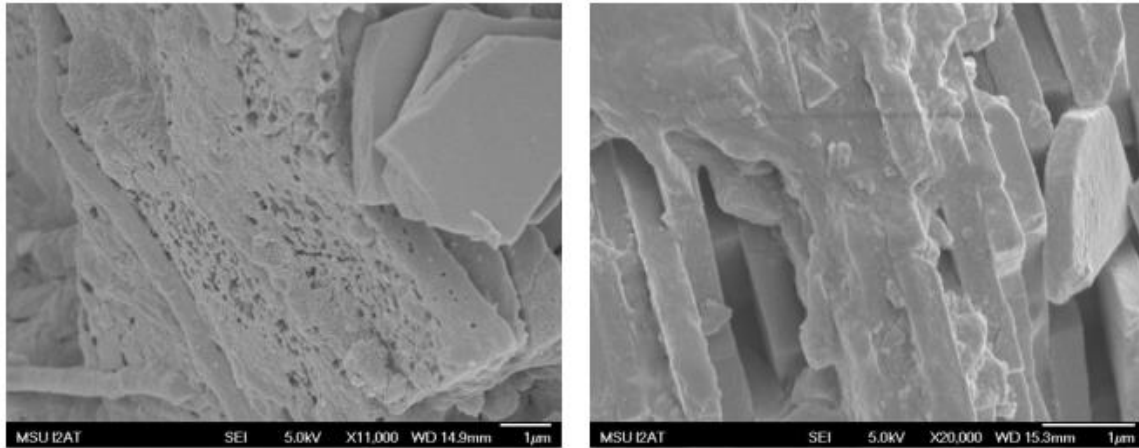


Figure 5.1 Vaughn Mound SEM images

Left: shell specimen showing evidence of dissolution. Right: shell specimen showing fusion of laminae structures

The final study in this dissertation expanded the known ranges of 27 freshwater mussel species into the Yazoo River, as well as demonstrating the presence of *Quadrula fragosa*, which was previously noted as a new state record for Mississippi by Peacock et al. (under review). These findings are significant for a number of reasons. For example, “applied zooarchaeological” studies, such as this, have continually presented a more comprehensive account of baseline community characteristics at each sampled location, as compared to modern survey data, especially regarding taxonomic richness, diversity and evenness, and rare and/or threatened faunas (e.g., Mitchell and Peacock 2014; Peacock et al. 2011). An additional, and currently unexplained, discovery from the Rugby Farm and Light Capp shell assemblages, is the presence of a very unique morphological feature found on numerous (n=213) shell specimens. This feature, present in valves of *Reginaia ebena*, is expressed as distinct lines, oriented perpendicular from normal growth

bands, from the umbo to the edge of the shell along each valve's anterior margin (see Figure 5.2).



Figure 5.2 Shell specimen from Rugby Farm

Left valve of *R. ebena* showing unexplained morphological feature

The cause of these lines is unknown, and although *R. ebena* is a common constituent of shell assemblages in the Mississippi Delta, this feature has not been mentioned in any previous archaeological shell study. Freshwater mussels are noted as being extremely plastic organisms (Haag 2012), which could be an explanation here, as these particular shells were responding to some type of environmental pressure or condition. However, though some have observed similar morphological features in modern faunas (Bob Jones, Wendell Haag, personal communication, February 2016), explanations for this characteristic, including any related environmental conditions, are seemingly absent from the literature.

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