An Analysis of the Jamestown Diet

By

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COMMITTEE APPROVAL

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Abstract

This thesis is an analysis of the extreme food restriction of fauna from 1609 to 1610 and 1650. The remains of which were found in archaeological wells at the historic fort of Jamestown, Virginia. The starving time of 1609 and 1610 resulted in the majority of the colony starving to death. There is a high probability many of the animals within the colony also suffered from dietary distress therefore creating a biological bone marker. Analysis of collagen extraction by IRMS, show a dietary difference and increase of δ15N from faunal remains in 1609, which is an indication of extreme food restriction similar to what the colonists would have experienced. The faunal remains were then compared to a second archaeological Jamestown well dating to 1650 to compare the dietary distress of the fauna as the colony grew and developed into a domesticated town.

Chapter 1: Introduction

The first permanent English colony of Jamestown, Virginia was founded through the perseverance of settlers despite encountering starvation after their arrival in the New World. Historical documents and excavations of the fort have divulged the daily activities of those who lived in Jamestown. During the winter months of 1609 to spring 1610, colonists within the fort encountered rampant hunger as food and resources were scarce. In the spring of 1610, few colonists remained alive. The lack of training and skills throughout the colony left the men unable to forage and plant adequate food in the new environment. Regardless of the many hardships, the colony had to quickly adapt to their new surroundings or accept their fate.

There were issues getting the venture started as the voyage to the Americas lacked financial backers and true leaders appointed by investors. By autumn of 1606, the need to dispatch the expedition was mounting because it was believed the colonists would arrive too late to plant crops for the upcoming season. The preparations for the expedition were finally coming together by late November and the three ships designated for the venture to the Chesapeake Bay were loaded with supplies and materials for the voyage. When the Susan Constant, the Godspeed, and the Discovery finally left the Blackwall Yard dock in London on December 20th, 1606, the ships only made it as far as the 'Downs' where the crew waited for a favorable wind for several weeks. The unexpected delay created problems for the food supply with only enough provisions to survive for two months aboard the ships and an additional six months in Virginia until the new crops could support the colonists. The crossing took five months not two, which meant the planting season was missed when the colonists arrived in May (Woolley, 2007).

The Virginia Company gave the colonists explicit orders before they left London about the relations they were expected to maintain with the local Native Americans they encountered. These relations were very important for the colonists to preserve in order to accumulate local food in the storehouses before supplies from England ran out. The Virginia Company sent supply ships every few months to the colony in the New World. The ships came irregularly and the rations aboard were small and spoiled easily on the journey. According to the written and archaeological record, colonies in the New World struggled to survive after the first year due to strain or tensions from nearby Native American groups (Barber, 2008). The first English attempt to settle the colony of Roanoke failed due to the strain on their inability to stock their own food stores during the first winter. Investors that funded the venture into the New World were more concerned with their return investment of commodities than the survival of the men in the colony (Taylor 2002; Cronon 2003). The Virginia Company's demand for a return investment required colonists to pan the river and streams for gold to send back to London instead of planting crops within the fort walls. While gold was never discovered on the island of Jamestown, the archaeological record in both the settlement and nearby native middens have evidence of cultural influences from both groups with native clay pipes, copper scraps, and Powhatan beads and basketry (Barber, 2008).

The Powhatan relied on horticulture to provide the bulk of their diet on corn and beans. According to written accounts of several gentlemen, or men from the upper class social rankings, the colonists would never have survived if it were not for continued trade with the Powhatan in Virginia (Taylor, 2002). The Powhatan relied on the surrounding area for food such as hunting local white-tailed deer (*Odocoileus virginianus*) and fish

from the nearby river and streams. Based on seasonality of trash middens of Native American sites, it becomes apparent that the staple food that was utilized the most during the winter months was oyster (*Crassostrea virginica*). This oyster provides an excellent source of protein, calories, and iron when protein biomass is at its lowest in the winter months (Barber, 2008). The clues for hunting, gathering and foraging in the Chesapeake Bay can indicate where groups were getting their primary source of calories. The various aboriginal groups that frequented Virginia and Maryland had access to similar resources and yet, each village capitalized on those resources in a variety of ways. Some focused on terrestrial animals, some on waterfowl, and others on marine subsistence. The Chesapeake Bay area provided abundant food resources to support the resident population with ease. With two communities in such close proximity to each other in Jamestown, the archaeological record and historic accounts represent contact and trade between the two groups (Barber 2008; Cronon 2003).

Once English colonists arrived in Jamestown, two cultural communities were now vying for local food resources. For several years, the colonists depended on imports from England to supply their food with occasional trading of food from the Natives. Captain John Smith was an English explorer who arrived in 1607 on the first ships that landed in Jamestown. Captain Smith wrote descriptions of the presence of a variety of fish and migratory waterfowl in the Chesapeake Bay, according to Smith, these resources were under utilized by the local Powhatan (Barber, 2008). After several supply ships arrived from London, livestock was sent to the colony to be raised for food or hunting in the form of several chickens, pigs, cattle, dogs, and horses (Woolley, 2007). According to the settlement layer in Jamestown that dates to 1609, which is considered by the colonists'

diaries to be the "starving times", food was so scarce the colonists had no choice but to butcher the animals in the fort rather than reap the benefits from their offspring (APVA, n.d). The few colonists that survived the winter months of 1609 had minimal energy and were ill from lack of nutrients. A scheduled arrival of the supply ship in the spring of 1610 carried Lord De La Warr, a baron who would soon become governor and captain general of the colony, as well as new supplies, food, and more colonists. The arrival of the supply ship could not have come sooner, the colony was in shambles and food was nonexistent in the fort.

Our current knowledge of the historic fort of Jamestown has developed through interpretation of the archaeological record and historical documents. The analysis of the faunal remains can give insight into what occurred in the winter months of 1609. Through the application of stable isotopes to the faunal remains, a more precise food web can be constructed of what the animals on the island were eating and if the local fauna were undergoing some sort of dietary distress. One of the wealthy upper class gentlemen George Percy, president of the colony during the "starving times", stated there was widespread sickness and death of the colonists in Jamestown, "cruell diseases, Swellings, Flixes, Burning Fevers, warres, and mere famine" (Percy 1625).

Evidence found in the archaeological record indicates the colonists' continued to hunt and consume animals when their biomass was at the lowest during the winter months of 1609. If the animals were under nutrient distress or starving, the lean meat they would provide to the colonists would create more health complications. Lean meat does not provide the proper fatty nutrients to the consumer and a continued consumption of such food can lead to protein poisoning. Suddenly switching from a diet that contains

fatty protein to one that has little to no fat will affect the body's ability to produce, absorb, and store necessary vitamins. The necessity for fatty meat in a diet is just as important as supplemental calories and mineral rich foods (Harris, 1985). Protein poisoning will cause diarrhea after a week of consuming lean meat and if the body is unable to acquire any fat, death will quickly occur. There were several historical accounts including the President of the colony George Percy's own diary entry that suggested colonists were suffering from what was called the "bloody flux" or "flixes"(Percy 1625; Woolley 2007). The symptoms of which suggest diarrhea. If in fact the colonists were suffering from continual bouts of diarrhea during the winter months of 1609 to 1610, it is possible colonists consumed excessive amounts of lean meat, which resulted in death from protein poisoning. If colonists were unable to consume the nutrients necessary for survival, then the livestock and rodents that depended on this same resource would also starve and suffer the same decline in health as the colonists. Analysis of biological material of collagen and dietary bioapatite found within bone of animals and humans can provide information about the health and diet of the individual, which can indicate dietary distress or excellent health.

There has been much discussion of what actually occurred on the island of Jamestown when the first English colony was settled in America. There is minimal evidence of what occurred during the winter of 1609 into the spring months of 1610 to the colonists. Historical accounts are often biased and inaccurate. The reason I wanted to conduct research at the archaeological site of Jamestown is due to a personal connection that is created everyday when I hold artifacts newly rediscovered in the Jamestown dirt with a story about the individuals who lived and died at Jamestown. During an internship

at the Smithsonian, I conducted analyses on heavy metal accumulation on human remains suspected to be a victim of cannibalism during the starving time period of 1609 and 1610. After setting foot in Jamestown myself and now after conducting archaeological excavations of the site, I wanted to continue an analysis of the events that transpired during the starving time through the faunal remains suspected to be part of the diet. As archaeological excavations continue to reveal the depth of truth to the past, pockets of doubt have also been created regarding the events that transpired in the winter months of 1609. In order to provide more evidence that the colonists were suffering from starvation caused by protein poisoning, an analysis of the faunal remains will indicate if there was enough in the food stores to provide nourishment to the colonists and the local fauna. The analysis of faunal remains found in the deposition layer of an archaeological well at Jamestown dates to the winter months of 1609 to 1610 and indicate nutrient distress in the samples analyzed. With animals within the fort indicating extreme nutrient distress, this could have been the resulting factor in why there was minimal caloric intake during the period known as the starving times and why this developed into disease and starvation.

Chapter 2: Background

a. The settlement of Jamestown

Three ships set sail on December 20, 1606 from London's Blackwall Yard with the desire to build a successful English colony in the New World. Scattered stories, myths, and exaggerated accounts have created a dependence on archaeological and scientific findings to provide accuracy to the historical documents of the seventeenth century. The success of all colonies in the New World depended on the utilization of local resources and networks to survive. The lack of experience and unforeseen environmental factors created the perfect opportunity for misfortune.

Upon arrival in the New World, the location of the fort needed to be decided upon. Once the ships arrived in the Chesapeake Bay, several skiffs were sent to scout out potential sites for building a colony. The men had three things to keep in mind for a successful colony: fresh water, abundant food, and a high defensive ground. Due to tensions from Spain, colonists were weary of settling in a place that would be vulnerable to attacks. After several days, colonists decided the high ground of the island provided adequate defense against local attacks and an ideal vantage point of ships on the river. Colonists also designed the fort in a triangular shape (see Figure 2) for a better defensive position from northern attacks and expected Spanish attacks from the south. While pleased with their decision to build a fort on the island now known as Jamestown, the men knew their high ground came at the cost of access to fresh water (Cronon 2003; Kelso 2006; Taylor 2002).

Figure 1: The journey of the colonists from England to the New World (Image by: Fitzwater, S., N.D.)

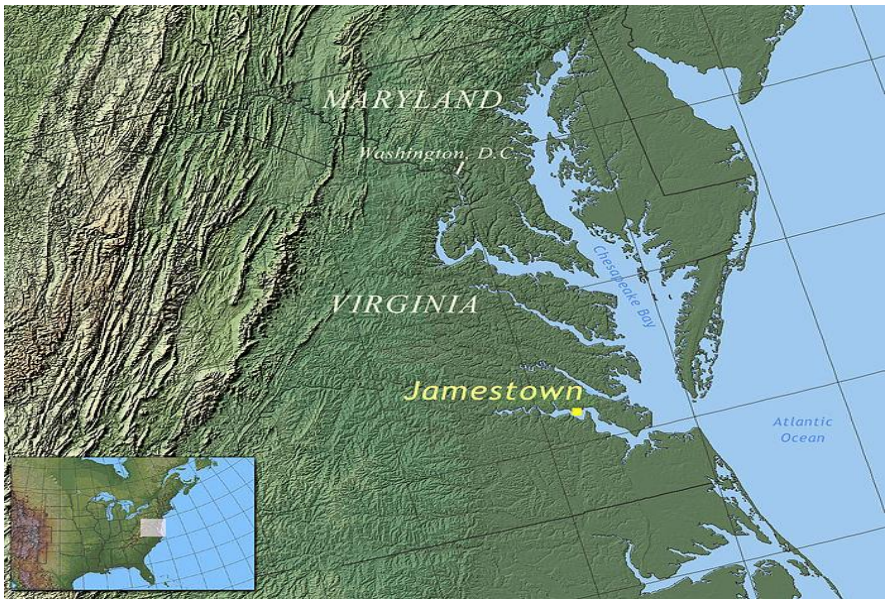

Figure 2: The location of the Jamestown colony in Virginia (Image by: Wikimedia Commons)

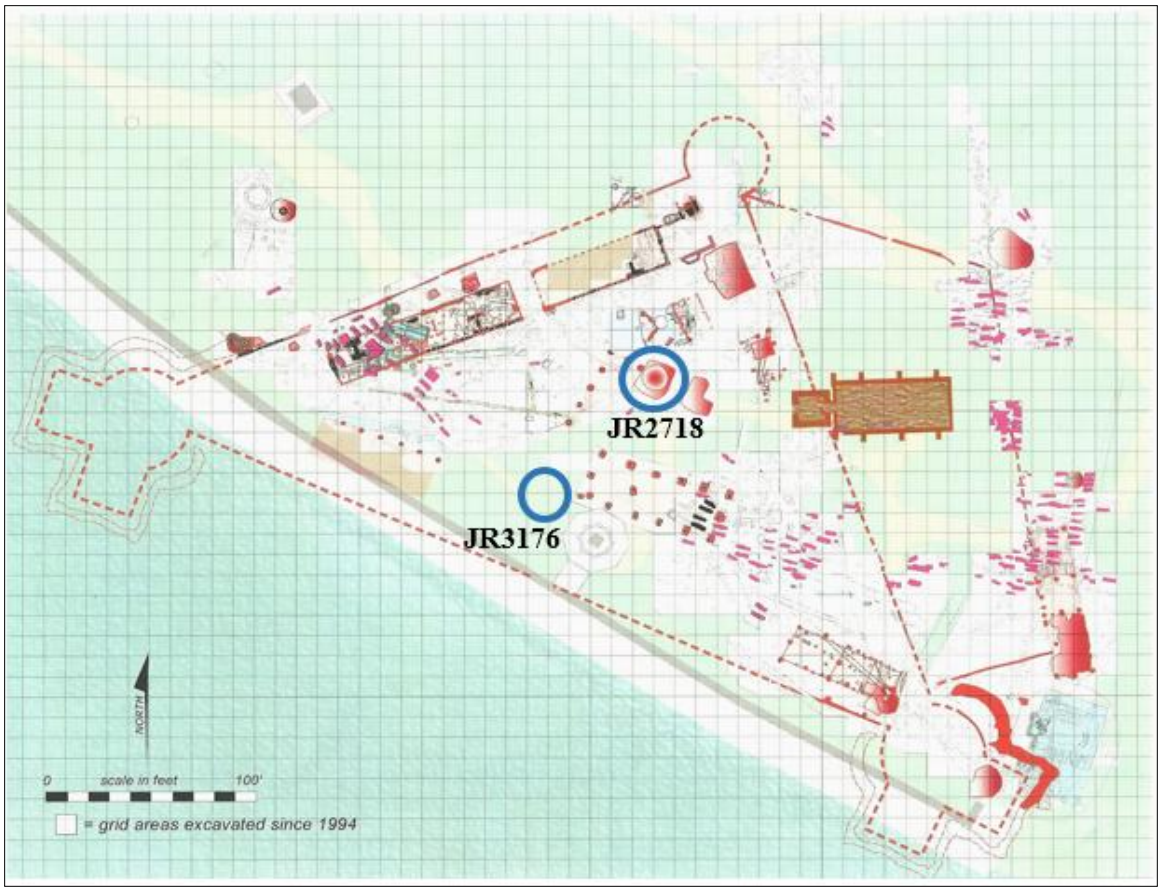

Figure 3: Map of archaeological excavations of Jamestown. Water well structures JR2718, is situated in the center of the fort and JR3176, is near the Southern palisade wall

There were many factors affecting the water quality of the fort, which is why so many wells were dug during the habitation of the fort. Prior to the first hand dug well in 1608, colonists were drinking water from the James River for about a year after their arrival in the New World. The water from the James was high in salinity and during the winter, became too brackish and viscous to drink. In order for the colonists to have an adequate source of water, they hand dug a well near the center of the fort. The first well colonist John Smith mentioned in late 1608 or early 1609 is believed to be well JR2718. John Smith wrote that a well was dug to provide colonists "of excellent sweet water, which till then was wanting… (Haile 1998:319; Taylor 2002)." At the time, the colonists

believed they had discovered a clean water source that could last several years. It has since been discovered that the Jamestown aquifer has constant mixing of sediment and pollutants with little ability to clear out the contaminants (Blanton 2000; Hancock 2000). If the colonists had the ability to dig the well deeper, the quality of water might have improved. There was also the issue of drainage on the island and improper disposal of human waste. Waste from the fort was filtering into the aquifer and contaminating the colonists' drinking water with E. coli (Blanton 2000; Davis 2011; Hancock 2000). Not only was the potential for disease high, there was also arsenic leaching from the rocks in the nearby swamp (Hancock, 2000). Researchers have discovered that the water from the nearby swamp marsh contained arsenic levels as high as 11 parts per billion and the water from wells in the fort were at 0.5 parts per billion. These readings may have increased when the fort was in the middle of a drought. The World Health Organization states that a reading above 10 parts per billion is unhealthy and should not be used as a water source (Davis, 2011).

The quality of water was integral to the everyday life in Jamestown, but also had a large impact on the colonist's health. Core samples were taken from bald cypress trees, which can be dated to 1,000 years ago. The value of analyzing tree rings from bald cypress trees is that the rings easily corroborate meteorological events and climatic trends in relation to the growing season precipitation (Blanton, 2000). Dendrochronology reports from bald cypress trees indicate that one year prior to the arrival of the Jamestown colonists, the area had the worst drought in 770 years and lasted until 1612 (see Figure 4)(Stahle, 1998). This is an important factor to understand about the quality of the wells. If there is limited precipitation, the salinity and therefore the contaminants in the water

will rise exponentially until the watershed is replenished with seasonal storms. This had a significant impact on the health and wellness of the English colonists because the ability to grow successful and sustainable crops was severely impaired by the drought in the area. The colonists were not well equipped to settle in the New World with minimal provisions, inexperienced men, and wildly fantastic ideas about how they were going to survive (Taylor, 2002). The drought affected not only the water sources the colonists had access to but also the crops of both the Powhatans and colonists, which in turn affected the livestock also dependent upon these resources.

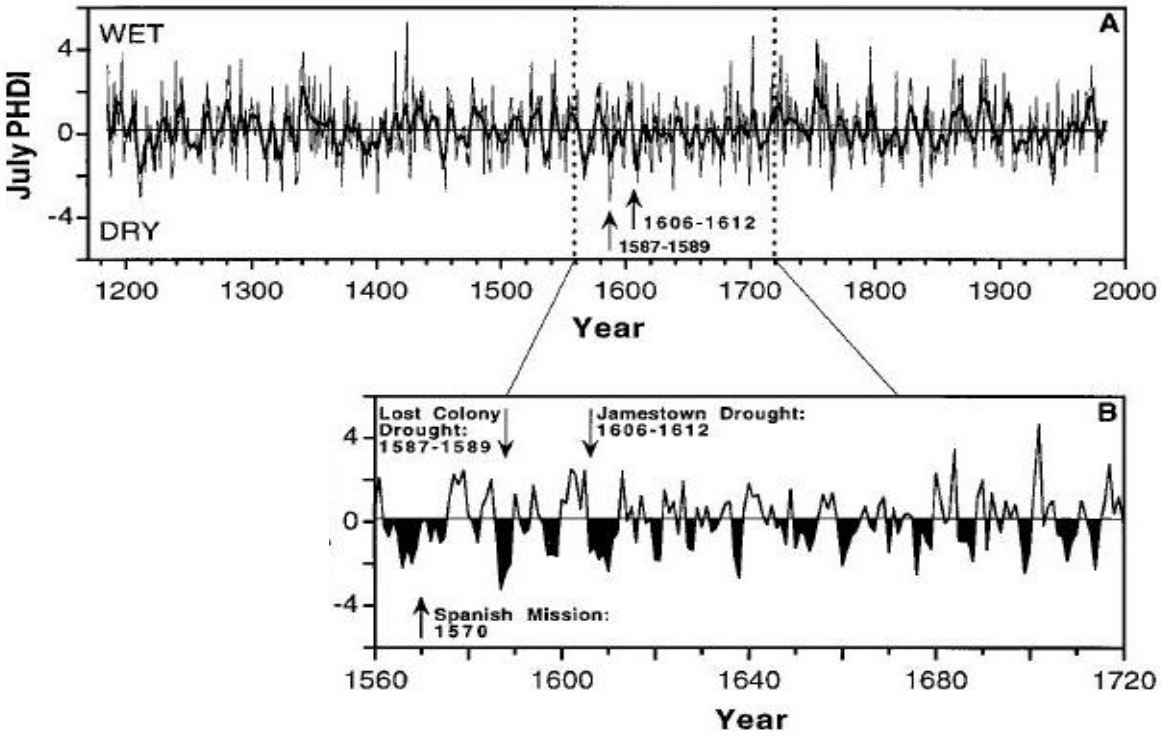

Figure 4: (Stahle, 1998) (A) Tree ring reconstruction Palmer Hydrological Drought Index (PHDI) of the Tidewater Region from 1185 to 1984. (B) The drought that affected the colony of Roanoke and the Jamestown colony

The first well, structure 185: JR2718 (see Figure 5), and its associated artifacts has become of interest to researchers because they can be accurately dated from late 1609

to early 1610. Colonist William Strachey arrived in May of 1610 stating, “James Town…hath no fresh water springs serving the town but what we drew from a well six or seven fathom deep, fed by the brackish river oozing into it; from whence I verily believe the chief causes have proceeded of many diseases and sicknesses which have happened to our people… (Haile 1998:430; Kelso 2006).” The archaeological record was able to provide remnants of a cellar and storehouse several feet from the well with steps leading down the cellar. When the water became too contaminated to drink, the colonists used the well to dispose of refuse from the fort. This provided an accurate deposition layer of the years the well was open.

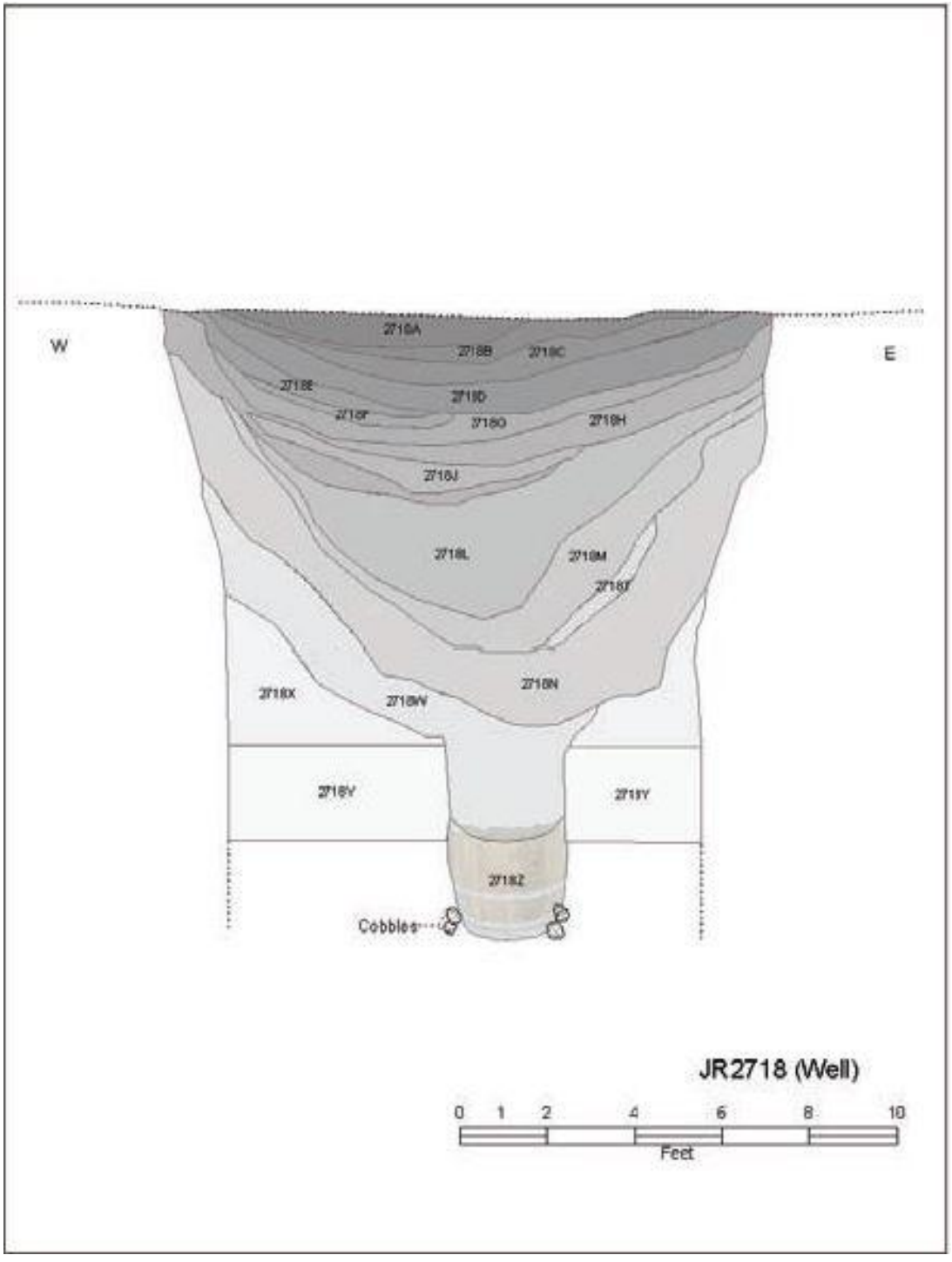

Figure 5: Image of JR2718 well at Jamestown

The well had many layers of deposition after its abandonment in 1610 dating to roughly 1630 or 1640. When a well is filled in, refuse tends to form in a slumped bull's eye with the most recent layers accumulating towards the center of the feature. These layers tend to be the mouth of the funnel, wide at the brim (APVA, n.d.). As layers are compacted and deposited, refuse tends to slant inwards in a Y shape. For the purpose of this study, the layers of interest are the closet to the bottom. Layer W (see Figure 6) and layer N (see Figure 7) of JR2718 were sampled. Layer N had a large deposit of faunal remains consisting of horse, dog and primarily wild animals. Several samples were taken from this layer including avian, small mammal, and large mammal bone due to the artifact dates and the amount of cut marks present on the bone, there is a high probability that this layer is from late 1609 to early 1610. Layer W of JR2718 given the field number JR2718W, was deposited before layer N. This layer was sealed completely by layer N and stops several inches above an oaken cask used to line the well (Figure 5). The cask or lining of the well was found resting on top of several cobbles that were on top of a natural geological formation of bog iron that may have been used to enhance the water flow into the well. Layer W is believed to be a deposition dating to the early months of 1610. This layer has a large deposition of oyster shells. This deposition of oyster shells is an indication that the colonists were consuming large amounts of marine resources instead of primarily large mammals during the first months JR2718 was open. After JR2718 contained water that was no longer drinkable, refuse throughout the fort was deposited with the oldest and smelliest trash first, the deposition of oysters found in layer W.

Based on the excavation map in Figure 3, it would appear that the Jamestown colony was exceptionally close to the water and would therefore have easy access to the

marine wildlife throughout colonization of the fort. As the excavation map indicates, the James River is eroding part of the James Fort and may continue to do so as the years go on. After the colony fell to disrepair and was eventually abandoned, the shoreline the colonists docked their boats has risen and eroded the land. The distance from the colony to the historic shoreline the colonists would have used as their docks is unknown. As part of the fort has been lost over time, it does become apparent that the colonists would not have had close proximity to the water resources that could have aided in the survival of those within the fort during lean winter months.

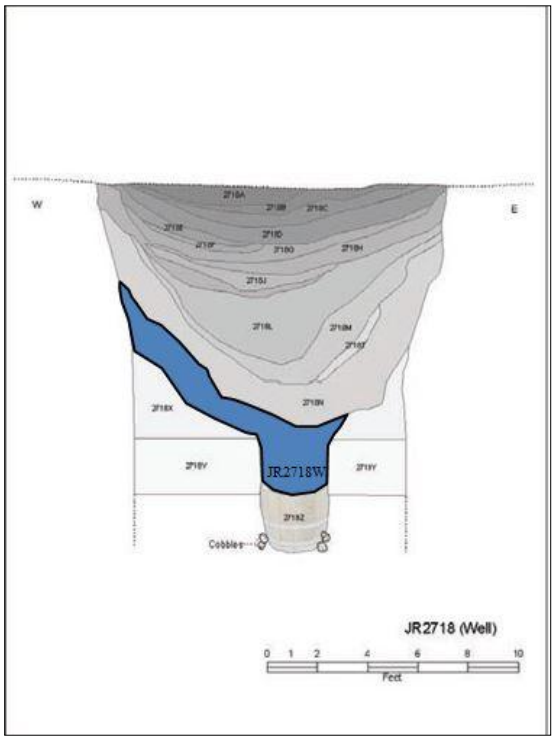

Figure 6: Image of JR2718 well with layer W highlighted

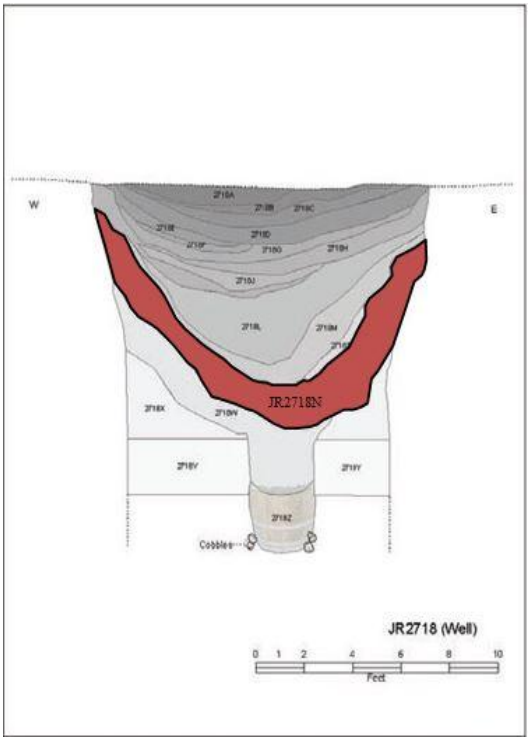

Figure 7: Image of JR2718 well with layer N highlighted

JR2718 layer Z was to be used for control samples to indicate what a healthy diet would look like for animals on the island, but there were few artifacts and faunal remains in this layer. The presence of minimal artifacts and remains could be the result of silt buildup from the aquifer. Samples were selected from layers N and W of JR2718 due to the minimal contamination or mixing of other layers. Layers deposited after layer N have mixed depositions and this can create inaccurate timelines. Layer W does have potential contamination from the builder's trench in layer Y (Figure 6). A builder's trench was dug to support the walls or foundation of the structure and is usually composed of discarded building materials such as bricks, ceramics, nails, and mortar. Layers N and W also have ceramic artifacts dating to 1609 and 1610. The date of the ceramics in these layers also provides a date to the faunal remains.

Structure 190: JR3176 (Figure 8) is a well dated to 1650 based on artifacts found in the builder's trench and in the shaft fill. This well was used until the late 1650's based upon the fill date of artifacts including Green Spring ware. This well was determined to be the best candidate for yielding faunal samples with minimal dietary stress. Having a control for samples in the Jamestown site is necessary to determine if local fauna were truly under distress in 1609. Given the stability of the area in 1650, it is likely that there will be evidence of variation between the two time periods which will be present in the isotopic values.

The control samples that were analyzed from the archaeological well dating to around 1650 were analyzed for the same increase in $\delta^{15}N$ as the JR2718 archaeological well because the colony of Jamestown had abandoned the original fort and developed a town consisting of a government and a more civilized way of life. Cattle were

domesticated and raised on pastures near Jamestown. As the population of Jamestown grew and populated the area, the Powhatan who were native to the area believed their land to be encroached upon and set up a series of attacks on the English colonists to make them abandon the town. In 1646 several treaties were drafted that would create land boundary lines for both the colonists and the Powhatan which sustained peace for both parties for several years. As colonists continued to expand and create Jamestown as the town continued to grow ever more stable and self sufficient in the New World. As survival in the New World became easier, supply ships were a common occurrence and no longer a need for survival.

The townspeople of Jamestown were able to rely on their own crops and livestock for meals. The livestock that was primarily sampled for an increase in $\delta^{15}N$ was cattle brought from England and domesticated in the New World. With domestication comes the reliance on pastures and humans to supply which can easily be regulated by humans. As the 1650's has no mention of starvation or difficulty obtaining food resources, it makes sense that the archaeological excavations of this water well feature produced minimal *Rodentia* bones and consisted primarily of bovine bone which is an indication of domestication and healthy consumption of both humans and animals. As the archaeological fill of the well feature JR3176 indicates a date of 1650's and the history of that time has a steady increase in both health and growth as a town, this feature was chosen as a control for what a regular diet from the 1600's would look like isotopically compared to faunal remains from JR2718.

Samples were taken from layer D and E of JR3176 (Figure 8). Initial observation of layers indicate that condition of bones would not yield good results. Bones were brittle to the touch, flaky, and chalky from most layers in this structure. The majority of bone samples were from layer E because of the improved visual condition of the bone.

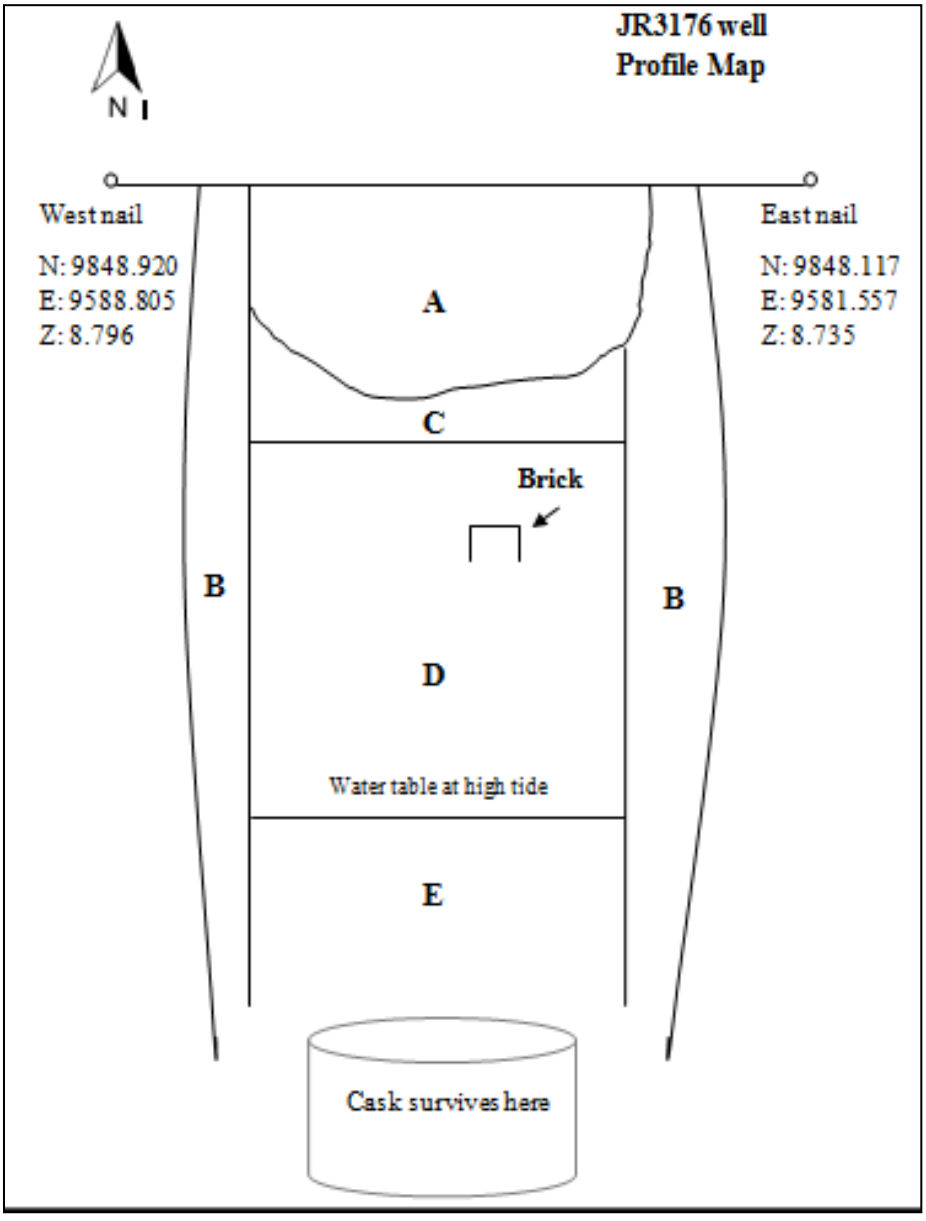

Figure 8: Image of JR3176 well at Jamestown

b. Background of analysis

Bones and teeth provide information about past diets, disease, burial conditions, and life history. Bone chemistry provides the opportunity to understand the correlation between nutrition and diet of an organism (Katzenberg, 2008). Bone is composed of organic material, nucleic acids, proteins, and organic chemicals that provide structure and stability for the human body. When bone is in an archaeological context, the chemical composition of the bone is altered slowly by the physical environment and chemical reactions, also known as diagenesis (Burton, 2008). The post mortem environment provides many opportunities for chemical substitutions from elements in the soil. Hydroxyapatite is the mineral structure of the bone. Bone is primarily made of calcium phosphate molecules, which affect the crystalline structure of the bone. Living bone has hydroxyapatite crystals that are poorly crystalline in structure. Archaeological bone has hydroxyapatite crystals that become larger and more organized (Weiner, 2010).

Bone turnover rate of an organism is important to understand prior to sampling the bone. Bone turnover rate is the amount of time a bone takes before incorporating mineral elements, diet, and disease. Dependent on the age, size, physical activity, and health of an organism, bone remodeling can be a slow or fast process. Bone is composed of two different varieties of bone, cortical and trabecular bone. Cortical bone is the outside structure of the bone that is more thick and rigid and remains less susceptible to diagenetic contamination than the inside structure of the bone. The trabecular bone is the inner portion of the bone and is surrounded by bone marrow and spongy structures (Weiner, 2010). The primary purpose of the trabecular bone is to act like a cushion from the stressors of everyday life such as walking or running. Cortical bone, because of its

structure and rigidity, captures the heavy isotopes the body accumulates, whereas the trabecular bone only stores nutrients. Different areas of the body have more or less trabecular and cortical bone depending on the function. Trace analysis of trabecular bone can otherwise distort the analysis by up to one hundred percent, because this type of bone does not record diet in bioapatite like the cortical bone does (Grupe, 1998:128). Although bone turnover is slow, collagen can record a decade's worth of dietary protein the animal was consuming whereas the bioapatite can provide the overall diet (Muldner, 2011:40). "Stable isotopes are atoms of the same element with the same number of protons but different numbers of neutrons. Since the atomic mass is determined by the number of protons and neutrons, isotopes of an element vary in their masses (Katzenberg, 2008:415)." Unstable or radioactive isotopes decay over time whereas stable isotopes will not change and remain constant.

Evidence of nutritional stress has been found through the nitrogen 15 isotope, hereafter referred to in text ($\delta^{15}N$). Individuals that experience nutritional distress will have an increase in nitrogen values per milliliter due to the body catabolizing the essential amino acids to gain the nutrients from the lack of protein (Deschner, 2011:68). "The enrichment of 15N ($\delta^{15}N$) values in tissues can only be observed under conditions of extreme food restriction or among fasting animals... (Deschner, 2011:68)." If the archaeological record provided resources such as urine, hair, or tissue it is possible that there would be more evidence of the nutritional stress an animal is subject to in such a short period of time. Due to the nature of the archaeological site of Jamestown, bone is the only resource available to test the hypothesis of nutritional distress. This is the drawback of using the bone analysis rather than having access to muscle, hair or blood.

The slow turnover rate of bone can affect the nitrogen levels per milliliter that would indicate the health of the animal. It is possible that the organism could also be responding to the shift in nutritional access that occurs during the seasonality of food. The tissues of the animal become more enriched with $\delta^{15}N$ because the lighter isotope of nitrogen, 14, is excreted and not replaced by dietary protein. This excretion increases the $\delta^{15}N$ as the animal continues to starve. This is why the nitrogen isotope is so important to test on the faunal remains (Gannes, 1997). High quality foods would be present during the warmer months and lower quality food would be stored or available locally during the winter months.

In the JR2718 well, a large majority of remains found in layer W and N contained remains of *Rodentia*. The exact genus is unknown; however, the historical diaries of colonist George Percy indicate a large consumption of grey squirrels and rats by the colonists. The black rat (*Rattus rattus*) is believed to be an integral component in the diet of the colonists during the winter months of 1609 to 1610. As humans populated the world, rats (*Rattus spp*.) have traveled, lived, and colonized alongside their human counterparts. Animals that interact with humans are more likely to have their diet controlled such as pigs and dogs, whereas rats consume human food stores without supervision, which can provide a more accurate depiction of humans and their food consumption (Guiry, 2015). Supply ships from England would be a prime spot for a black rat to live for several weeks and have access to barrels of food meant for the colonists. "Large provision of stores, domestic food stuffs, and agricultural activities around the settlement certainly would have been excellent targets for rat pillaging (Guiry, 2015:12)." Rats are omnivores and are known to eat seeds, nuts, cereals, and vegetation and can

therefore provide information about past environments and human activities. Although rats were prominent aboard the Jamestown ships and most likely stayed within the fort for easily accessible food sources, the colonists would have had an obvious aversion to eating the readily available meat of the rat (see Table 1). The black rat is commonly associated with typhus as well as *Yersinia pestis* (Black Plague). It is possible that the black rat was consumed as a last resort because of this negative association (Gillespie 2004; Harris 1985). Rats have a limited home range, but are affected by regional variability and local resource distribution (Swift, 2017)."The potential array of habitats available to rats living near human settlements means that habitat preferences could have an impact on archaeological rat diets (Guiry, 2015:9)." It is possible there is other genus of rats or *Rodentia* in the archaeological deposition of 1609 and 1610, which would be represented in the isotopic values of the small mammal remains.

Table 1: (Guiry 2015; Hewitt 2011; Innes 2013; Lyman 1979; Puglisi 2008) Caloric intake of possible meat sources for colonists the first years in Virginia based on a 2,500-calorie diet

Genus	Age	Average life span (yrs)	Weight or meat provided	Calories of consumable protein	Number per day to maintain weight
Rattus rattus Black rat	Adult	1-4	113 to 340 grams	200 calories	~15
Odocoileus virginianus White-tailed deer	N. American Adult	4-10	45 kg	18 kg = 21,773 calories	19 steaks weighing 113 grams
Crassostrea virginica Eastern oyster	Adult	20	~85 grams	23 calories	~100

Crassostrea virginica is the commonly found oyster on the Chesapeake Bay. This bottom feeder is an important key to the estuaries found along the eastern coast. Oysters live in dense reefs can contain over a thousand oysters in one square meter (Puglisi, 2008). As oysters are sensitive to salinity of the water, the more salinity, the larger the oysters will grow. When the colonists arrived, the oyster beds were large and provided important nutrients such as zinc and fatty acids. Archaeological excavations and colonists diaries have shown many oysters were eaten throughout the occupation at Jamestown and were an integral part of the everyday diet (APVA. N.d.; Percy 1625).

Odocoileus virginianus is an animal that will provide an accurate malnutrition indicator. The white-tailed deer is extremely vulnerable to environmental fluctuations especially severe drought. With the dendrochronology report of a severe drought throughout the area of Jamestown, and the white-tailed deer traveling within a 1 square mile radius, this would influence the survivability of the deer as well as the grazing range (Innes, 2013). If a deer has limited flora to hide behind or graze upon, the deer will be more susceptible to starvation, predators and hunting (Innes, 2013). When an environment is not conducive to an animal receiving the nutrition necessary, the probability of successful reproduction is unlikely. When the colonists arrived, it is likely there were plenty of deer to hunt between the two cultural communities. However, due to the accuracy and skill of the Powhatan, it is unlikely deer populations were nearby the Powhatan villages or fort of Jamestown. The environmental impacts, malnutrition, over hunting, and lack of viable offspring created tremendous pressure on the deer population as well as the starving colonists. During winter months, deer that live in northern latitudes require increased energy due to their movements in deep snow and prolonged exposure to

extreme temperatures. The consumption of leaves, twigs, bark and branches requires minimal energy, but in the winter months, deer also catabolize their body reserves creating a time of year with high mortality rates (Berteaux, 1998). A study was done in 1996 to discover if nitrogen and carbon isotopes were affected by humidity, temperature, and precipitation of North American white tailed deer. Typically, white-tailed deer eat more C_3 grasses than C_4 plants. If there is an increase in consumption of C_4 plants or grasses this may signal environmental conditions of nutrient stress and increase the $\delta^{15}N$ in bone collagen (Cormie, 1996).

> *"Then haveinge fedd upour horses and other beastes as longe as they Lasted, we weare gladd to make shifte with vermin as doggs Catts Ratts and myce all was fishe thatt Came to Nett to satisfye Crewell hunger, as to eate Bootes shoes or any other leather some Colde come by and those beinge Spente and devoured some weare inforced to searche the woodes and to feed upon Serpentts and snakes and to digge the earthe for wylde and unknowne Rootes, where many of our men weare Cutt of and slayne by the Salvages. And now famin beginneinge to Looke gastely and pale in every face…"* -George Percy, 1625

The caloric intake of the average man in the 17th century depended on his status as well as his activity level. Based upon the excavation of several upper class individuals buried at Jamestown, a rough estimate of height, weight, status and caloric intake for the time period can be calculated. Calculations done on skeletal remains of individuals from the early Middle Ages, of middle class status from northern Europe, Iceland, and Sweden indicate that the average man was 65.75 inches tall during the 17th and 18th centuries (Massimo, 1990). The average male during this time period would be roughly 5'4" with a

moderately active lifestyle and would probably weigh about 130 pounds. In order to maintain his current weight, his daily consumption would be around 2,100 calories (Massimo, 1990). Four upper class men were excavated at Jamestown and averaged based on their skeletal remains that the average height of these four men were 5'6" and their average age was 35 years (Jamestown Rediscovery 2016; Kelso 2006). While measurements of their weight is not available, a rough estimate would be around 150 pounds. Their caloric intake to maintain their weight would be around 2,200 calories (Hicks 2001; Kelso 2006). Estimation for poor or low class individuals was not found to compare to the caloric intake of the other individuals that lived in the Jamestown fort. While the caloric intake for these individuals may vary based on status and access to resources, there are variables that would affect how many calories these individuals consumed. The voyage itself would minimize the amount of food the colonists would have access to, regardless of status. Resources also became scarce when relations with the Powhatan became tenuous during the winter months of 1609; the Powhatan seized the fort, effectively cutting off the colonists from obtaining any food outside the fort (Cronon 2003; Kelso 2006; Percy 1625; Smith 1986; Woolley 2007). Many of the upper class gentlemen and soldiers would decrease their caloric intake and therefore lose weight, which would have a substantial impact on the amount of food they would consume during the lean months. Colonists might also consider themselves to be on the verge of starvation if they are not consuming the right amount of calories.

Conclusions

The location of the Jamestown fort while initially providing security from invaders brought other complications to the eager English colonists. Their arrival in the New World was at the beginning of a terrible drought in the Chesapeake Bay, which in turn affected water quality, growth of crops, and abundance of large fauna. Captain John Smith wrote of the area overflowing in abundant resources, and yet several years after their arrival the colony was close to death during the winter months of 1609 to 1610. JR2718 is believed to be the first well colonists dug in 1608 and was in use until 1610 when colonist William Strachey believed it was full of disease and filth and should be filled in. Faunal samples were taken from layer W and layer N from JR2718 (see Figures 6 and 7) because of the artifacts dating this layer to 1609 and the summer of 1610. A second sampled structure JR3716, dates to 1650. Two layers from this well were also sampled for faunal remains (see Figure 8). Faunal remains were sampled to test the preservation of the organic material in the bone and to further interpret the health and diet of the faunal remains on the island of Jamestown that the colonists would have been eating.

Bone samples of faunal remains were analyzed for n δ^{15}N values to test the theory of starvation affecting not only the English colonists, but the local fauna as well. With an increase in δ^{15}N in the faunal remains, it is likely that the animal was under nutritional stress. If a colonist were to consume an animal under nutritional stress, the nutrients the animal would provide would be minimal in fatty proteins. The continual consumption of lean meat such as this would cause an individual to undergo something known as protein poisoning. Protein poisoning or rabbit starvation causes the human body to metabolize its

own fatty tissue, diarrhea will occur in several days, and then eventual death if the body does not receive the nutrients needed. Based on the accounts of George Percy, colonists were suffering from the bloody flux or diarrhea throughout the colonization of Jamestown, which is why analyzing the food source available to the colonists, is important to understanding exactly what made the colonists ill and die in such a short time.

Chapter 3: Methods

The following is a description of methods used throughout this study. The recovery of the archaeological material and faunal remains represented in this study were collected by approved archaeological methods established at the site of Jamestown. Several individuals performed faunal analysis as the remains were sorted into genus. Historic artifacts were identified and repaired by the expert senior collections manager at the site of Jamestown which established a time period to the deposition layers the faunal remains were found in. Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR) analyzed bone preservation or diagenesis. This provided a baseline for the preservation of bone sampled in the faunal layers. Isotope Ratio Mass Spectrometry (IRMS) analyzed all samples for collagen and bioapatite for faunal dietary protein and the overall diet. This analysis provides the diet of the fauna in 1609 as well as an estimation of health of colonists within the fort.

Field Collection

The Jamestown Rediscovery archaeology staff excavated JR2718: structure 185. A large rectangular feature was exposed under the plow zone near the geographic center of the triangular fort. Excavation began on a structure oriented SW/NE which was nearly perpendicular to the southern palisade wall of the James Fort. The feature at subsoil measured 14’ on the SW axis and 16’ on the NE axis. The feature extended to a depth of 14’ and changed from a rectangular feature, to a large circular shape, which ended in a barrel or cask at the last layer. The well was filled with artifacts, refuse, and faunal remains dating the top deposition layer at 1750 to the deepest layer at 1609 (APVA, N.d.).

Structure 190: JR3176 was also excavated by the Jamestown Rediscovery archaeology staff in 2011 when a circular stain appeared near the SW corner of the 1608 mud and stud church site. Shoveling around the feature revealed a double-ringed feature 3'2" in diameter. A 2" deep test was done in the inner circle and revealed the feature to be a well. Excavation of this feature was done by trowel, dustpan, and scoop. Buckets of soil were washed in 1/8" mesh screens. Water from the water table was not encountered until layer D. Water was encountered at 3'2" above sea level and about 3' into the excavation, a dark ring ¾" thick separated the builder's trench from the shaft fill. This thick brown layer is believed to be the decomposed remnants of the barrel or cask that was once used as a well lining. Once standing water came into the well, soil and artifacts were removed by hand to avoid damage to the artifacts. Excavation of layer D continued until standing water made it difficult to distinguish the builder's trench, layer B, from the shaft fill of layer D. After this, all fill that was removed was labeled layer E. The exact depth of the well could not be determined due to the encroaching of the water and silt but the depth was determined to be 2'2" below sea level. Artifacts from the builder's trench included Green Spring ware from around the 1650's. This suggests the well was constructed no later than 1650 (APVA, N.d.).

Identification of the Faunal Assemblage

Various individuals associated with the Jamestown Rediscovery staff did identification of faunal remains. Once artifacts and remains were water screened in the field, they were bagged and taken to the on-site conservation lab where they were washed more thoroughly by volunteers and sorted into their class and or genus. Most volunteers that help during the winter field season do not have experience identifying faunal

remains. Joanne Bowen is a faunal expert from the Colonial Williamsburg archives who has written several reports on her interpretation on the faunal material from the starving times. She has spent some time going through the faunal collections sorting remains into their respective species. For many remains, the identification beyond genus was impossible due to the fragmented material of the remains as well as the degradation that occurred to the bone.

Sample selection of the faunal assemblage

In order to understand the overall diet of animals living within or nearby the fort, certain animals were selected for sampling. The desired number of samples from each layer was 25 specimens, of which 15 would be small mammal and 10 would be large mammal (see Table 2, Table 3, and Table 4). Small mammals were selected because it was reported that colonists were consuming grey squirrels and rats during the starving time (Percy, 1625). Small mammals were also selected because the bone metabolic rate of a small mammal will be higher due to the size of the organism and the short life time. This would create an ideal representation of both the health of the small mammals as well as the overall diet. Large mammals were selected due to their large contribution to the colonists' diet. Although the representation of poor health may take longer to integrate into the chemistry of the bones, the consumption of large mammals throughout the colonists' diet is important to understand. Avian bone was also sampled then later put aside for future analyses due to the large variation the birds could have that was not primarily terrestrial based.

Several catalogued boxes for JR2718 - layer N (see Table 2) contained remains with evident cut marks, which were not sampled due to the possibility of future research. Other boxes contained remains of both marine wildlife, and large and small *Mammalia*. Fish were not selected for sampling due to their diet being maintained by another ecosystem that was only partially consumed by the colonists. Remains were sampled from two boxes housed in the Jamestown conservation collection for layer N of JR2718 (see Table 2). Initial observation of these boxes included various elements throughout the skeletal system. Most bone elements were not complete. Bone associated with this layer also appeared to be weathered; meaning the surface of the bone may be cracked and brittle due to the removal of moisture and organic material in the bone. Remains that were identified as large mammal seemed to be primarily composed of trabecular bone rather than the desired cortical bone. There were also large bags composed of disarticulated small mammal remains of teeth, skulls and bone elements.

Table 2: Samples taken from JR2718 well layer N

Number	Site	Layer	Structure	Number of samples	Species	Element	Side	Age	Portion	Portion sample came from
1	JR2718	N	185	1	*Rodentia*	incisor	Unk	Unk	complete	disarticulated
2	JR2718	N	185	1	*Rodentia*	incisor	Unk	Unk	complete	disarticulated
3	JR2718	N	185	1	*Rodentia*	incisor	Unk	Unk	complete	disarticulated
4	JR2718	N	185	1	*Rodentia*	molar	Right	Unk	complete	disarticulated
11	JR2718	N	185	1	*Rodentia*	incisor	Unk	Unk	complete	disarticulated
12	JR2718	N	185	1	*Rodentia*	incisor	Unk	Unk	complete	disarticulated
13	JR2718	N	185	1	*Rodentia*	molar	Unk	Unk	complete	disarticulated
14	JR2718	N	185	1	*Rodentia*	molar	Unk	Unk	complete	disarticulated
15	JR2718	N	185	1	*Rodentia*	molar	Unk	Unk	complete	disarticulated
16	JR2718	N	185	1	*Rodentia*	molar	Unk	Unk	complete	disarticulated
5	JR2718	N	185	1	*Mammalia*	molar	Unk	Unk	complete	disarticulated
6	JR2718	N	185	1	*Mammalia*	incisor	Unk	Unk	complete	disarticulated
7	JR2718	N	185	1	*Mammalia*	molar	Unk	Unk	complete	disarticulated
8	JR2718	N	185	1	*Mammalia*	molar	Unk	Unk	complete	disarticulated
9	JR2718	N	185	1	*Rodentia*	molar	Unk	Unk	complete	disarticulated
10	JR2718	N	185	1	*Mammalia*	incisor	Unk	Unk	Anterior face	disarticulated
17	JR2718	N	185	1	*Rodentia*	femur	Right	Unk	Proximal/medial	medial
18	JR2718	N	185	1	*Rodentia*	femur	Right	Unk	Proximal/medial	medial
19	JR2718	N	185	1	*Rodentia*	femur	Left	Unk	Proximal/medial	medial
20	JR2718	N	185	1	*Rodentia*	femur	Right	Unk	Proximal/medial	medial
21	JR2718	N	185	1	*Rodentia*	femur	Right	Unk	Proximal/medial	medial
22	JR2718	N	185	1	*Rodentia*	humerus	Right	Unk	Distal/medial	Medial
23	JR2718	N	185	1	*Rodentia*	humerus	Right	Unk	Distal/medial	Medial
24	JR2718	N	185	1	*Aves*	Unk	Unk	Unk		
25	JR2718	N	185	1	*Aves*	humerus	Right	Unk	Distal/medial	medial
26	JR2718	N	185	1	*Aves*	Unk	Unk	Unk	Medial	Medial
27	JR2718	N	185	1	*Aves*	carpometacarpal	Left	Unk	Distal/medial	Medial
28	JR2718	N	185	1	*Aves*	carpometacarpal	Left	Unk	Distal/medial	Medial
29	JR2718	N	185	1	*Mammalia*	cranial	Unk	Unk		
30	JR2718	N	185	1	*Mammalia*	humerus	Left	Unk	Distal/medial	medial

Boxes containing the remains of JR2718 - layer W (see Table 3) contained bags of separated remains with fragmented bone which enabled easier sampling of the large bone fragments. There were two bags containing jaws and teeth of *Mammalia* and small mammal bones, which allowed for the removal of the whole bone or tooth due to the large proportion available for that layer. Initial observations of remains from this layer were in better condition than the layer above, layer N. Very few bones were flaky with the appearance of bone weathering. Only one bone, a tibial plateau, had the appearance of being fossilized and when a piece was removed with the dremel saw, it took several attempts to remove.

Table 3: Samples taken from JR2718 well Layer W

Number	Site	Structure	Layer	Number of samples	Species	Element	Side	Age	Portion	Portion sample came from
1	JR2718	185	W	1	*Rodentia*	incisor	Unk	Unk	Complete	Disarticulated
2	JR2718	186	W	1	*Rodentia*	incisor	Unk	Unk	Complete	Disarticulated
3	JR2718	187	W	1	*Rodentia*	incisor	Unk	Unk	Complete	Disarticulated
4	JR2718	188	W	1	*Rodentia*	incisor	Unk	Unk	Complete	Disarticulated
5	JR2718	185	W	1	*Rodentia*	molar	Unk	Unk	Complete	Disarticulated
6	JR2718	185	W	1	*Rodentia*	mandible	Left	Unk	Complete	Distal
7	JR2718	185	W	1	*Rodentia*	mandible	Left	Unk	Complete	Distal
8	JR2718	185	W	1	*Rodentia*	mandible	Right	Unk	Distal	Horizontal ramus
9	JR2718	185	W	1	*Rodentia*	zygomatic process	Right	Unk	Maxilla	Maxilla
10	JR2718	185	W	1	*Rodentia*	cranial vault		Unk		Posterior
11	JR2718	185	W	1	*Rodentia*	mandible	Right	Unk	Complete	Medial
12	JR2718	185	W	1	*Rodentia*	mandible	Left	Unk	Mandible	Medial/distal
13	JR2718	185	W	1	*Rodentia*	maxilla	Left	Unk	Medial	Posterior
14	JR2718	185	W	1	*Rodentia*	mandible	Left	Unk	Gonial angle	Proximal/medial horizontal ramus
15	JR2718	185	W	1	*Rodentia*	maxilla	Right	Unk	Nasal cavity	Distal towards ethmoid suture
16	JR2718	185	W	1	*Aves*	carpometacarpus	Left	Unk	Proximal/medial	Medial
17	JR2718	185	W	1	*Aves*	carpometacarpus	Left	Unk	Complete	Medial/distal
18	JR2718	185	W	1	*Aves*	carpometacarpus	Right	Unk	Complete	Medial/distal
19	JR2718	185	W	1	*Aves*	tarsometatarsal	Left	Unk	Distal	Medial/distal
20	JR2718	185	W	1	*Aves*	tarsometatarsal	Left	Unk	Distal	Medial/distal
21	JR2718	185	W	1	*Mammalia*	forelimb	Unk	Unk	Medial/distal	Medial/distal
22	JR2718	185	W	1	*Mammalia*	rib	Left	Unk	Medial/distal	Medial
23	JR2718	185	W	1	*Mammalia*	rib	Left	Unk	Medial/distal	Medial
24	JR2718	185	W	1	*Mammalia*	femur	Right	Unk	Complete	Distal
25	JR2718	185	W	1	*Mammalia*	humerus	Right	Unk	Medial/distal	Medial
26	JR2718	185	W	1	*Mammalia*	pelvis	Left	Unk	Illiam	Superior illiam
27	JR2718	185	W	1	*Mammalia*	scapula	Left	Unk	medial	Inferior angle
28	JR2718	185	W	1	*Mammalia*	tibial plateau	Left	Unk	Complete	Medial condyle
29	JR2718	185	W	1	*Mammalia*	forelimb	Unk	Unk	Medial/distal	Medial/distal
30	JR2718	185	W	1	*Mammalia*	humerus	Left	Unk	Proximal/medial	Medial

Bones from JR3176-layer D (see Table 4) initial observations revealed that the bone from this particular layer had the best example of poor preservation. The bones appeared to have all organic material leached; bones were very weathered and were flaky and chalky to the touch. Several bones also had contact with copper, which was apparent by the green discoloration left on the surface of the bone. Due to the appearance of the bones, few were selected for analysis. Surprisingly bones from the layer beneath were in better condition and contained large fragmented bones of large mammals. Bones selected from this layer contained only unrecognizable fragments that could not be associated with a specific genus, but due to the size of the bone, it was apparent the remains were from large mammals.

Table 4: Samples taken from JR3176 well layers D and E

Number	Site	Structure	Layer	Number of samples	Species	Element	Side	Age	Portion	Portion sample came from
1	JR3176	190	D	1	*Mammalia*	molar	Unk	Unk	Complete	Disarticulated
2	JR3176	190	D	1	*Mammalia*	molar	Unk	Unk	Complete	Disarticulated
3	JR3176	190	D	1	*Mammalia*	molar	Unk	Unk	Distal	Disarticulated
4	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
5	JR3176	190	E	1	*Mammalia*	third phalanx	Left	Unk	Complete	Distal
6	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
7	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
8	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
9	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
10	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
11	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
12	JR3176	190	E	1	*Mammalia*	fragment	Unk	Unk	fragment	Unk
13	JR3176	190	E	1	*Mammalia*	Rib	Unk	Unk	fragment	Unk

Specimens that were selected for each layer and structure followed the same guidelines based upon the bone element, possible class, quality of bone, and possible age of the organism. Remains that are juvenile could possibly interfere with the isotopic ratio, producing a lower $\delta^{15}N$ ratio than adults in the same environment (Gannes, 1997). Samples were selected that had minimal contact with copper artifacts to avoid any isotopic discrepancies. Bone elements were selected if they were fragmentary or if there was a large proportion of that specific element in that particular layer. Sample removal avoided diagnostic features of the bone to aid future research in distinguishing the element and possible genus.

Sample removal

Samples were removed with a dremel saw model 3000 with a rotating saw approximately 0.5 mm. Prior to being cut, samples were polished or cleaned by a dremel polishing bit attachment to remove any remaining contaminant dirt from the initial cleaning stage performed in the conservation lab. Photographs were taken of each stage of the removal process (Figure 9, 10, and 11).

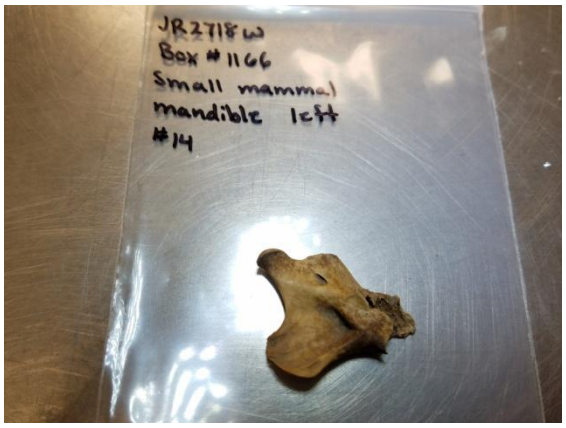

Figure 9: Image of JR2718 well sample #14 from layer W

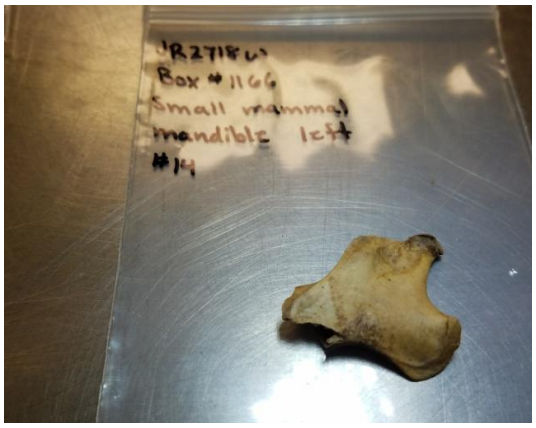

Figure 10: Image of JR2718 sample 14 after cleaning

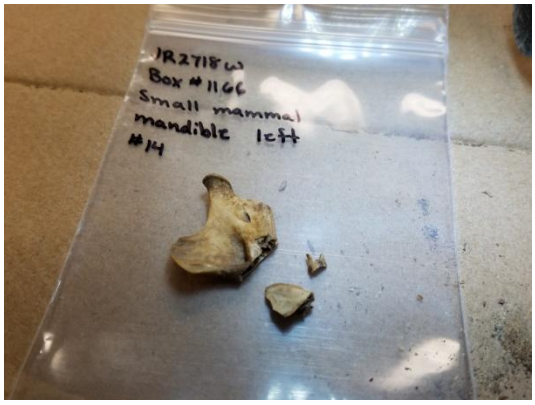

Figure 11: Image of JR2718 sample 14 layer W after removing a subsection

FTIR-ATR data collection

The FTIR analysis was performed using a ThermoFisher Scientific Nicolet IS5 iD7 ATR (Figure 12). ATR stands for attenuated total reflection, which is a commonly used instrument that can measure diagenetic alteration to bone. The ATR unit measures the loss of intensity when the beam comes in contact with the sample. The infrared beam penetrates several micrometers into the sample and the sample absorbs and reflects the

beam, creating a spectrum. This instrument was chosen over the FTIR-KBr because of a study done in 2013 by Hollund indicating that the KBR method requires samples to be added to a chemical binder, which can influence the results, while simultaneously destroying the sample (Hollund, 2013). The ATR instrument has a penetration depth of several micrometers, which creates the need for samples to be in direct contact with the diamond crystal. This method has been proven to show when bone undergoes diagenetic alteration after burial. This provides information about the quality of the crystalline structure of the bone and therefore the quality of the bioapatite and potential collagen. The ATR spectra was collected at 64 scans in the 2500 - 400 cm^{-1} wave number range with background calibrations set at 184 minutes to reduce noise and water collection in the spectrum. This range provides peaks for amide (~1640 cm^{-1}), carbonate (~1415 cm^{-1}), and phosphate (~1030 cm^{-1}, ~605 cm^{-1}, ~565 cm^{-1}) (Figure 13).

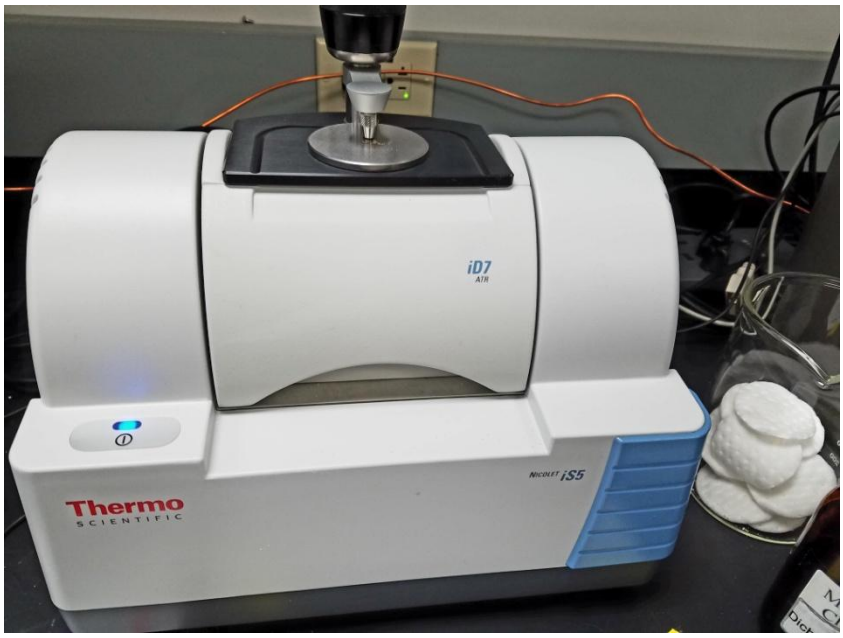

Figure 12: Image of ATR-FTIR

The organization of the mineral crystals are what constitute the molecular structure of bone. As a species matures, the size and shape of the bioapatite crystals increase. “The crystals of bone apatite have highly reactive surfaces, where either Ca^{2+} or PO_4^{3-} ions are exposed. After death, the biologically formed mineral becomes unstable, and because it is still highly reactive, this makes it very susceptible to alteration by the burial environment (Marsh, 2000:440-1).” Absorbance values of the phosphate peaks at wave number ~565 cm^{-1}($v4\ PO_4$) and 605 cm^{-1} ($v4\ PO_4$) are summed and divided by the height at ~590 cm^{-1} to obtain the splitting factor (SF) value (Figure 13) (Hollund, 2013). The SF is an indication of the preservation of the bone and the crystalline structure of bioapatite. Apatites with large ordered crystals show a higher crystallinity index found in ATR-FTIR data, whereas those that have little organization or peaks with more overlap and less distinctions will have a lower crystallinty index (Wright, 1996). Collagen content of the bone is also calculated through the ratio of absorbance intensities of the amide peak at ~1640 cm^{-1} and the phosphate peak at ~1030 cm^{-1} (Am/P) (Hollund, 2013:512). Whereas C/P is an indication of diagenesis in the bone bioapatite. If the splitting factor is less than 3.0, the bone is likely to have collagen and be well preserved. With an increase in SF, the carbonate peaks are expected to decrease, which would result in the representation of a loss of carbonate. High SF values may indicate post mortem increase in crystal size or the dissolution of crystals due to diagenesis. The splitting factor of the carbonate and phosphate peaks from the ATR-FTIR spectra gives the crystallinity of the bone a number that is associated with the modernity of the bone or possible stage of realigning the apatite crystals of the bone as it turns into a fossil as biological material is removed and replaced.

Ten samples were chosen from the four layers to test the preservation of bone (Table 5). Four were chosen from JR3176 and six from JR2718 of these ten samples, six were teeth while the others were various bone elements. About 2 mg of the bone samples were ground using a mortar and pestle and placed on the detection window with the diamond pressed against the surface of the sample. Spectra from the instrument was collected by the software Omnic and analyzed by EssentialFTIR. Data were exported into an Excel spreadsheet to calculate amide to phosphate (Am/P), carbonate to phosphate (Co/P), and the splitting factor (SF) as seen in Figure 13.

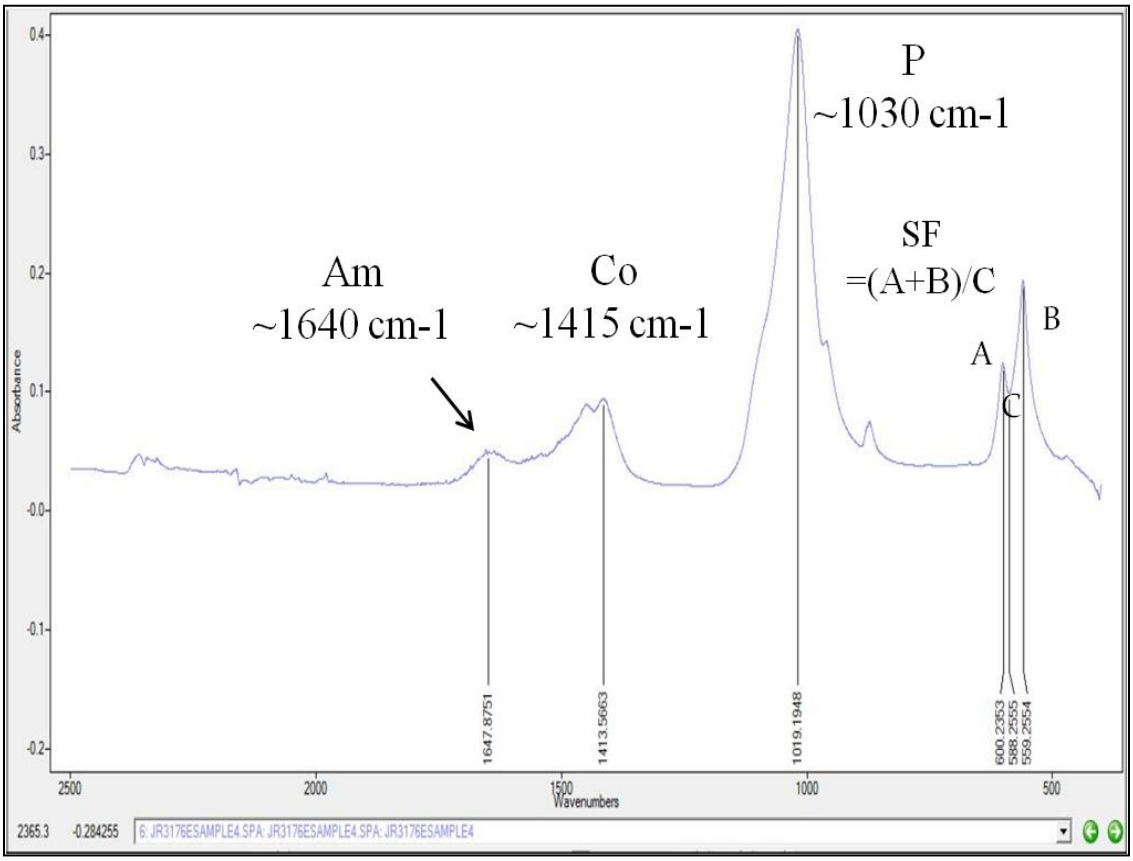

Figure 13: JR3176 Layer E sample 4 spectrum from ATR-FTIR with peaks and valleys labeled

As every bone sample has a variation in the diagenesis or alteration of biological material contingent upon the burial context it is important to analyze samples with the ATR-FTIR to understand how well the collagen and bioapatite has been preserved. In Figures 13 and 14 there are two representations of the variation that can occur to two different individual bones in a similar burial context in the same geographical location and around the same time period. Figure 13 is the ATR-FTIR spectrum of JR3176 Layer E sample 4. As mentioned before, the hydroxyapatite crystals become more ordered and organized the more the biological material is removed and replaced within the bone. A smooth linear line in Figure 13 suggests that sample 4 from Layer E underwent some diagenetic alteration in the burial context. In Figure 14, the ATR-FTIR spectrum is much more ragged and difficult to discern peaks and valleys. Based on the spectrum this individual bone sample is better preserved because the ragged edges are an indication of the preservation of biological material. As both samples have different representations of what the preservation is between the two archaeological wells, it was necessary to test at least ten samples to hypothesize as to which archaeological well had the best preservation and therefore the most accurate extraction of collagen and bioapatite.

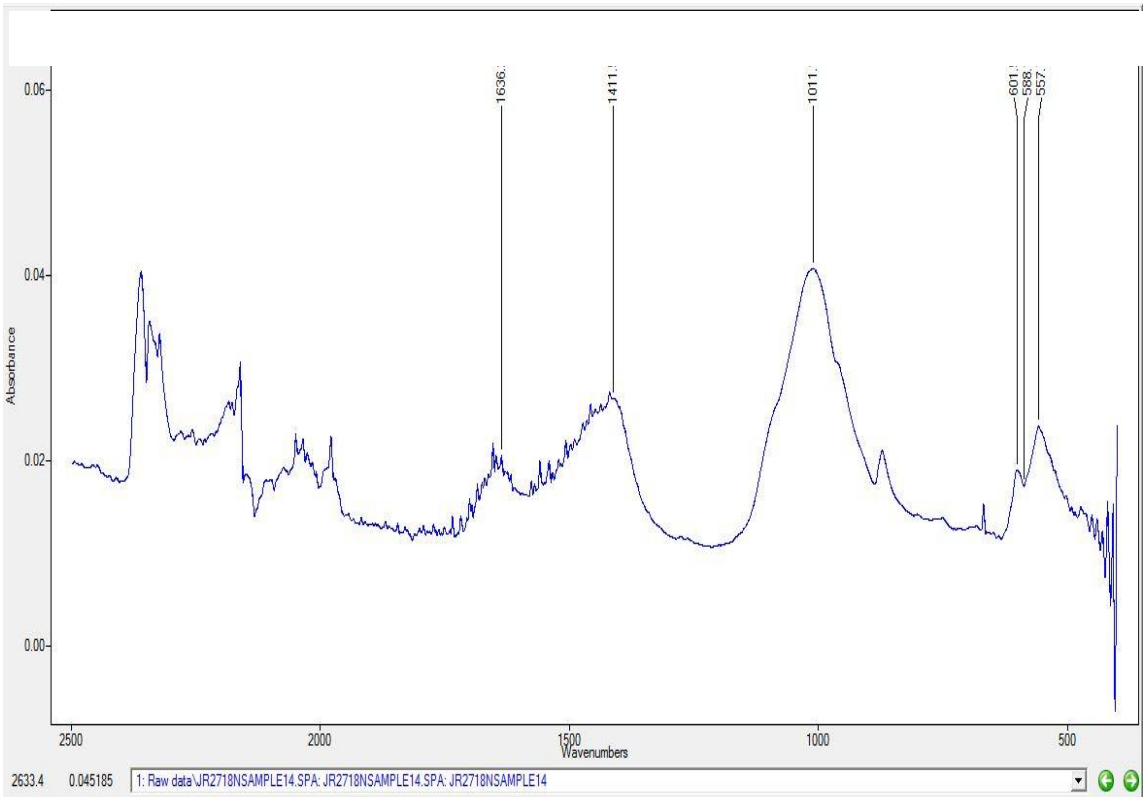

Figure 14: Image of ATR-FTIR spectrum of JR2718 Layer N Sample 14

Table 5: Faunal samples analyzed for ATR-FTIR

Sample number	Site number	Layer	Species	Element	Side	Age	Portion	Portion sample came from
6	JR2718	N	*Mammalia*	incisor	Unk	Unk	complete	disarticulated
14	JR2718	N	*Rodentia*	molar	Unk	Unk	complete	disarticulated
23	JR2718	N	*Rodentia*	humerus	Right	Unk	Distal/medial	Medial
1	JR2718	W	*Rodentia*	incisor	Unk	Unk	Complete	Disarticulated
11	JR2718	W	*Rodentia*	mandible	Right	Unk	Complete	Medial
27	JR2718	W	*Mammalia*	scapula	Left	Unk	medial	Inferior angle
1	JR3176	D	*Mammalia*	molar	Unk	Unk	Complete	Disarticulated
2	JR3176	D	*Mammalia*	molar	Unk	Unk	Complete	Disarticulated
3	JR3176	D	*Mammalia*	molar	Unk	Unk	Distal	Disarticulated
4	JR3176	E	*Mammalia*	fragment	Unk	Unk	fragment	Unk

Isotopic analysis performed on human skeletal remains indicate that the carbon 13 ($\delta^{13}C$) value of bone apatite, or bioapatite largely reflects that of the whole diet, while $\delta^{13}C$ value of collagen reflects the consumption of dietary protein (Ambrose 1990; Kohn et al 2002). In bone formation, collagen is laid down first and apatite mineralization follows. As bone mineralizes, the bone turnover rate replaces the entire skeleton every 5 - 10 years depending on the health, and age of the individual (Pasteris, 2008:97). Diet reconstruction is predicated on the assumption that you are what you eat, and the consumption of various foods will incorporate itself isotopically into the tissues, and bones of an organism. Isotopes are different forms of an element: radioactive and stable. The analysis by the IRMS for stable carbon isotopes of bone apatite hinges on the minimal diagenetic alteration of carbonate during and after burial.

Bioapatite

Apatite has the ability to accept other elements into the lattice strain, which affects its chemical and physical properties as well as the maximum crystal size. After the death of the organism, the apatite remains active as it goes through elemental substitution until it transforms into a crystal (Pasteris et al, 2008). The ability to recover apatite from bones samples enables for the recovery of information such as the diet or migration information. With these samples, the goal is to analyze the apatite from the teeth samples from both wells and prepare the bones sampled from other skeletal elements for collagen extraction (mandible, cranial elements, scapula, pelvis, rib, and long bone fragments). The analysis of these elements will provide information on diet, and correlate the ATR-FTIR data to the carbonate preservation and overall bone preservation of bone samples from JR2718 and JR3176.

Apatite protocols

Samples are washed with distilled water and sonicated three times for approximately 20 minutes each. After the samples air dry for several days, the samples are finely crushed to obtain a consistent powder. Samples are then weighed to an amount of around 80 to 100 mg of finely crushed powder. H_2O_2 is added at 0.5 ml for every 20 mg of sample. Samples are capped and placed in a refrigerator at 4C for 24 hours. The samples are then poured off, with another treatment of 30% H_2O_2 for 24 hours at room temperature, a third treatment of fresh H_2O_2 is applied for 24 hours at room temperature. Samples are washed with ultrapure water to remove any traces of the H_2O_2 and 1N buffered Acetic Acid to remove any secondary carbonates (same rate as the H2O2). These are sealed and placed at room temperature for 24 hours. Samples are then washed 4 to 5 times with ultrapure water, frozen, and freeze-dried (Correspondence to author, R. Mauldin, March 10, 2017).

Collagen

Bone collagen is an ideal biological material for dietary reconstructions of the past. Collagen is used as a dietary indicator of protein consumption. From this analysis, estimations of the dietary food web of the fauna on Jamestown Island can be made. Although the faunal samples analyzed are not carnivorous by nature, analyses of faunal remains can create an introductory food web when compared to diet of the colonists. "Collagen derives its carbon from ingested and synthesized amino acids (Harrison and Katzenberg, 2003:228)." Isotopic signatures of animals can vary depending on size, age, diet, health, and the incorporation of dietary signatures into the animal tissue. It is

important to study both collagen and dietary bioapatite because animals do not eat a single food group, but rather eat from a multitude of food sources throughout their life. The incorporation of dietary protein is distinct in the collagen values just as bioapatite has specific signatures for C_3 and C_4 in bone.

Collagen protocols

Samples that were analyzed for collagen and bioapatite were prepared for analysis by the Center for Archaeological Research with the University of Texas. Samples were sent to a second contractor for analysis at the Northern Arizona University stable isotope laboratory (Table 6). Several samples sent for analysis were not analyzed due to the small amount of bone that was sectioned from the original bone. Two mg of bone powder was needed for collagen analysis as well as bone that had no evidence of being burned or chemically altered. "For collagen samples, we crushed dried bone into small fragments (0.5e2 mm size) with a ceramic mortar and pestle and sonicated them in ultra-pure water. We changed water after each run, and the process continued until the rinse water was clear. About 100 mg of dried bone was weighed into glass test tubes. Samples were decalcified by reacting with 0.5 N HCl at 4 °C for 30 h (Bocherens et al. 1991; DeNiro and Epstein 1981; Longin 1971). We rinsed samples to neutral and subsequently treated them with 0.1 N NaOH for up to 45 min. The samples were again rinsed to neutral. They were then solubilized in 0.01 N HCl at 70 °C for 11 h. The supernatant was filtered into glass vials, frozen, and freeze-dried under vacuum (Figure 15). Once dried, 600 mg of collagen sample was placed into tin capsules for bulk stable carbon and nitrogen isotope analysis (Mauldin et al, 2013:1374)."

Table 6: Faunal samples analyzed by IRMS

Sample number	Site number	Layer	Species	Element	Side	Age	Portion	Portion sample came from
6	JR3176	Layer E	*Mammalia*	fragment	Unk	Unk	fragment	Unk
7	JR3176	Layer E	*Mammalia*	fragment	Unk	Unk	fragment	Unk
8	JR3176	Layer E	*Mammalia*	fragment	Unk	Unk	fragment	Unk
9	JR3176	Layer E	*Mammalia*	fragment	Unk	Unk	fragment	Unk
10	JR3176	Layer E	*Mammalia*	fragment	Unk	Unk	fragment	Unk
11	JR3176	Layer E	*Mammalia*	fragment	Unk	Unk	fragment	Unk
12	JR3176	Layer E	*Mammalia*	fragment	Unk	Unk	fragment	Unk
13	JR3176	Layer E	*Mammalia*	Rib	Unk	Unk	fragment	Unk
22	JR2718	Layer W	*Mammalia*	rib	Left	Unk	Medial/distal	Medial
23	JR2718	Layer W	*Mammalia*	rib	Left	Unk	Medial/distal	Medial
25	JR2718	Layer W	*Mammalia*	humerus	Right	Unk	Medial/distal	Medial
26	JR2718	Layer W	*Mammalia*	pelvis	Left	Unk	Illiam	Superior illiam
27	JR2718	Layer W	*Mammalia*	scapula	Left	Unk	medial	Inferior angle
28	JR2718	Layer W	*Mammalia*	tibial plateau	Left	Unk	Complete	Medial condyle
23	JR2718	Layer N	*Rodentia*	humerus	Right	Unk	Distal/medial	Medial
30	JR2718	Layer N	*Mammalia*	humerus	Left	Unk	Distal/medial	Medial

Figure 15: Image of samples processed for collagen analysis by IRMS

Conclusion

After excavations were performed in the field, all artifacts were sent into the conservation lab for the Jamestown Rediscovery staff and volunteers to wash and sort into artifact type. Faunal remains were selected from both wells based upon visual observation of the condition of the bone avoiding burned bone, chalky bone, etc. Bone samples were removed by a 0.5 mm dremel saw attachment for ATR-FTIR and IRMS analyses. Ten samples were selected to be analyzed by the ATR-FTIR to create a baseline for which layers within the wells had the best bone preservation. Bone samples were processed for both bioapatite and collagen. Bioapatite can provide information about the overall diet of the faunal remains, whereas collagen provides an isotopic signature on dietary protein. The isotopic signature of both bioapatite and collagen is important because animals do not eat from a single food group and the food or lack thereof is incorporated in the bone of the animal.

Chapter 4: Results

The following data are the results from the application of methods described in the previous chapter. Information of faunal elements in correlation to environmental diagenesis or bone preservation is provided. Results of samples sent for collagen and extraction are also included. Bioapatite results are not included in this chapter and were not received in time to include in the analysis of this report.

FTIR Analysis of Faunal Remains

According to calculations done in 1990 by Weiner and Bar-Yosef, bone can be identified as being archaeological, modern, or fossilized according to the calculation of the splitting factor (SF), and the carbonate/phosphate ratio (C/P). Bones that have a SF of 2.5 to 2.9 are considered modern bone, or bone with substantial preservation of collagen and bioapatite (Table 7). Fossilized bone, or bone with minimal biological preservation can range from 3 to 7. The higher the SF, the more of the bone has undergone a chemical alteration. Bivariate plots of carbonate/phosphate and the splitting factor (SF) (Figure 16) assigned 7 out of 10 faunal samples (70%) into the well-preserved organic material category. Whereas one sample (JR3176D1) had a SF of 2.99, would be considered altered post mortem by the burial environment (Weiner, 2010). The last two samples would be considered fossilized with minimal organic material left in the bone with one sample at 3.19 JR3176E4 and the second sample at 3.25 JR3176D2.

Table 7: Samples analyzed by ATR-FTIR with diagenesis calculations

Sample number			Preservation calculations		
JR2718N6	Peak At	Peak Height	SF	Am/P	C/P
	557.809	0.0526	2.41975	0.57878	0.60665
	586.093	0.0405			
	599.753	0.0454			
	1006.18	0.0933			
	1411.16	0.0566			
	1635.34	0.054			
JR2718N14	Peak At	Peak Height	SF	Am/P	C/P
	557.775	0.0238	2.47399	0.50614	0.65848
	588.182	0.0173			
	601.56	0.019			
	1011.13	0.0407			
	1411.59	0.0268			
	1636.27	0.0206			
JR2718N23	Peak At	Peak Height	SF	Am/P	C/P
	558.661	0.0343	2.3908	0.59319	0.65154
	587.7	0.0261			
	598.677	0.0281			
	1007.59	0.0617			
	1409.67	0.0402			
	1636.22	0.0366			
JR2718W1	Peak At	Peak Height	SF	Am/P	C/P
	559.738	0.0119	2.44318	0.7233	0.67476
	588.806	0.0088			
	598.307	0.0096			
	1016.78	0.0206			
	1419.83	0.0139			
	1635.34	0.0149			
JR2718W11	Peak At	Peak Height	SF	Am/P	C/P
	557.809	0.0276	2.50259	0.43838	0.45859
	589.624	0.0193			
	598.789	0.0207			
	1018.88	0.0495			
	1418.39	0.0227			
	1635.34	0.0217			

Table 7: ATR-FTIR data continued

JR2718W27	Peak At	Peak Height	SF	Am/P	C/P
	560.702	0.1262	2.81258	0.20628	0.39495
	588.864	0.0763			
	599.753	0.0884			
	1019.19	0.2613			
	1413.57	0.1032			
	1646.43	0.0539			
JR3176D1	Peak At	Peak Height	SF	Am/P	C/P
	559.255	0.0849	2.99798	0.13568	0.25188
	586.653	0.0494			
	599.271	0.0632			
	1013.41	0.1592			
	1412.6	0.0401			
	1646.91	0.0216			
JR3176D2	Peak At	Peak Height	SF	Am/P	C/P
	560.22	0.0996	3.25626	0.10938	0.21212
	588.611	0.0519			
	600.235	0.0694			
	1018.71	0.2112			
	1413.08	0.0448			
	1646.91	0.0231			
JR3176D3	Peak At	Peak Height	SF	Am/P	C/P
	559.255	0.036	2.84753	0.27466	0.33232
	587.793	0.0223			
	600.718	0.0275			
	1019.19	0.0659			
	1413.08	0.0219			
	1647.88	0.0181			
JR3176E4	Peak At	Peak Height	SF	Am/P	C/P
	559.255	0.1928	3.19355	0.12263	0.23217
	588.256	0.0992			
	600.235	0.124			
	1019.19	0.4053			
	1413.57	0.0941			
	1647.88	0.0497			

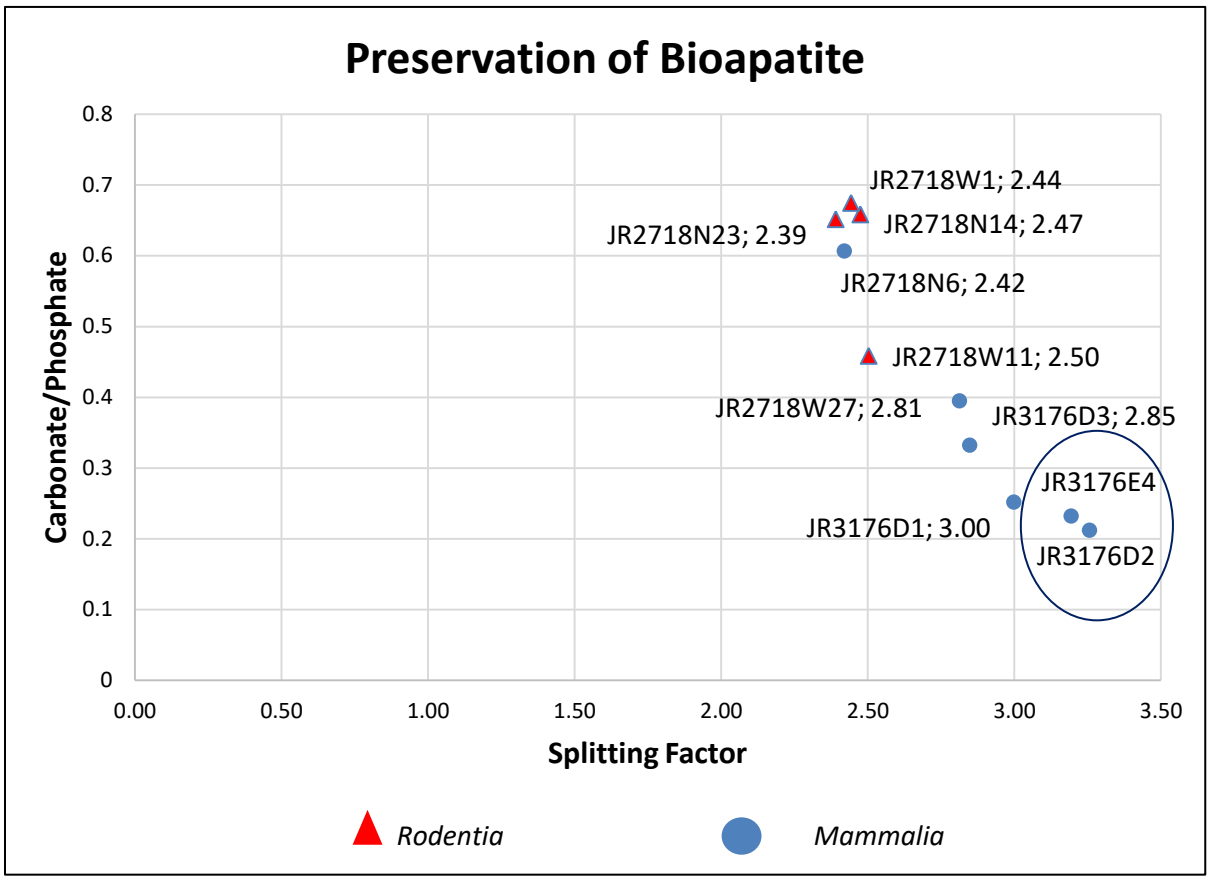

Figure 16: Bivariate plot of carbonate/phosphate and splitting factor of all ATR-FTIR data

These data in Figure 16 represent the preservation of the bioapatite in the bone. Preservation of samples taken from JR2718 layer N had an average splitting factor of 2.42. JR2718 layer W had an average splitting factor of 2.58. JR3176 layers D and E were averaged together and had an average splitting factor of 3.06. Based on the averages of the splitting factors from JR2718, the best preservation of bone can be found in the deposition layers of W and N. The worst preservation was found in JR3176 in both layers D and E, with the average splitting factor of 3.06.

The ten samples that were analyzed for bioapatite preservation were also plotted on a second bivariate plot representing an estimation of collagen preservation. Figure 17

represents the collagen preservation per milliliter of the ten samples taken from the Jamestown site. The ten samples separated into four groups representing the best collagen preservation in the bone samples from JR2718 in both layers W and N. One sample, JR2718W11 could not be grouped into good collagen preservation or poor preservation, but lies somewhere in the middle. Five samples were grouped on the lower end of the graph suggesting the samples have minimal collagen preservation due to diagenesis. Samples JR3176D1, JR3176D2, JR3176E4 (circled in Figure 17) are in a different category due to their low preservation of bioapatite and splitting factor ratio in Figure 16, which indicates that these samples are unlikely to contain any biological or organic material.

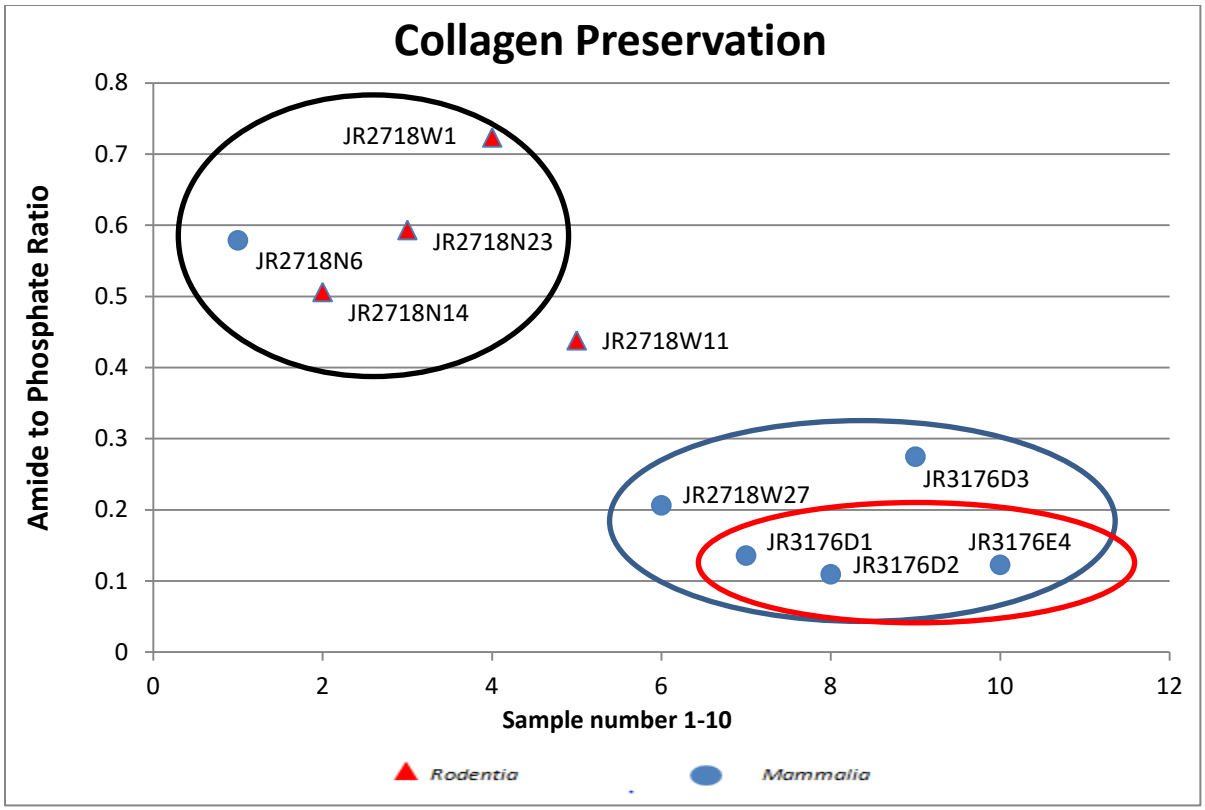

Figure 17: ATR-FTIR analysis of amide to phosphate ratio indicating collagen preservation

IRMS Collagen Results

According to the FTIR analysis on bone preservation, the worst preservation should be found in JR3176 and the best preservation should be found in JR2718. The collagen results from the faunal remains indicate all samples are well preserved with carbon and nitrogen ratios per mil range from 2.84 to 3.52 according to Ambrose 1990. The average of the faunal samples is 3.25, which is right in the middle of this range (see Figure 18). Figure 18 is an image created from IRMS data comparing carbon and nitrogen, two elements used to compare preservation of biological material such as collagen found in bone. Figure 18 also shows an apparent separation between the two historic wells in the amount of collagen preserved. JR2718 has significantly more

collagen in the bone averaging 2.83 whereas JR3176 has collagen preservation averaging 2.73. Although the preservation difference is minimal between the two sites, the visual observation, ATR-FTIR and IRMS analyses confirm JR3176 has poor preservation compared to the JR2718 well.

The analyses of collagen data from the IRMS when compared to the $\delta^{13}C$ (‰) $\delta^{15}N$ (‰) ratio in Figure 19 indicates there is a difference in diet and preservation within the two Jamestown well structures that were sampled. Layer W is represented by a yellow circle, a green diamond represents Layer E and Layer N is distinguished by the square symbol but has two different shades. Layer N has two different species sampled in the collagen data and both fall in different areas within Figure 19. The blue square of Layer N is a *Rodentia* bone sample that falls within the same cluster of the *Mammalia* samples within the same structure JR2718. The red square is an outlier bone sample from Layer N. Figure 19 compares $\delta^{13}C$ (‰) $\delta^{15}N$ (‰) because an increase in the amount of the nitrogen isotope within an animal can indicate the animal was under dietary distress. As Figure 19 shows there is a significant separation between the layers of one structure and another, which is an indication of differences occurring during the time period it was deposited. The data suggests the samples from Layer E most likely the large mammals ate similar foods but had a wide range of foods. Layer W had better collagen preservation according to Figure 17 however indicates animals were eating more of the same foods but had worse nutrition and therefore had an increase in $\delta^{15}N$ (‰).

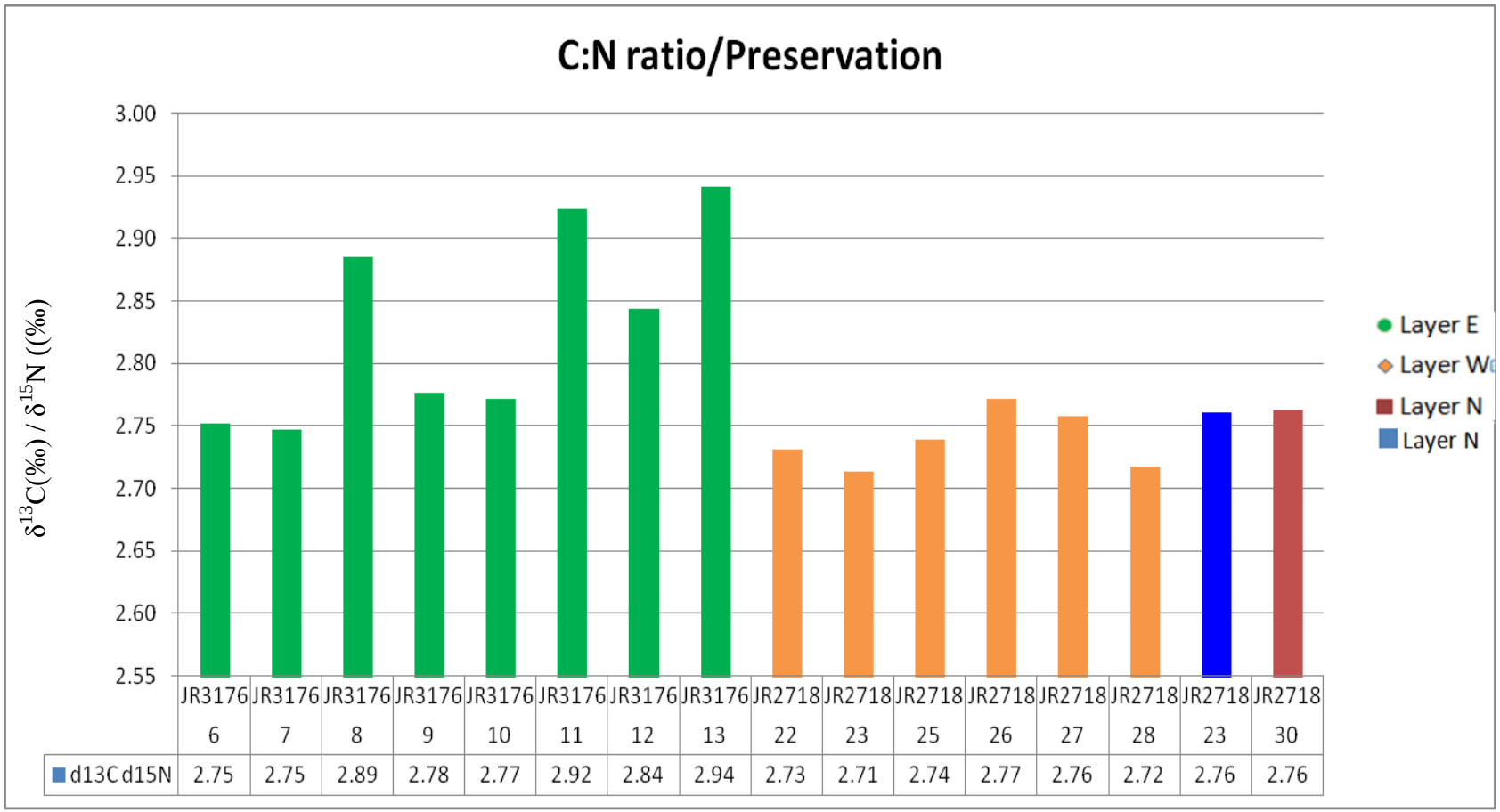

Figure 18: IRMS comparison of carbon and nitrogen isotopes for collagen preservation

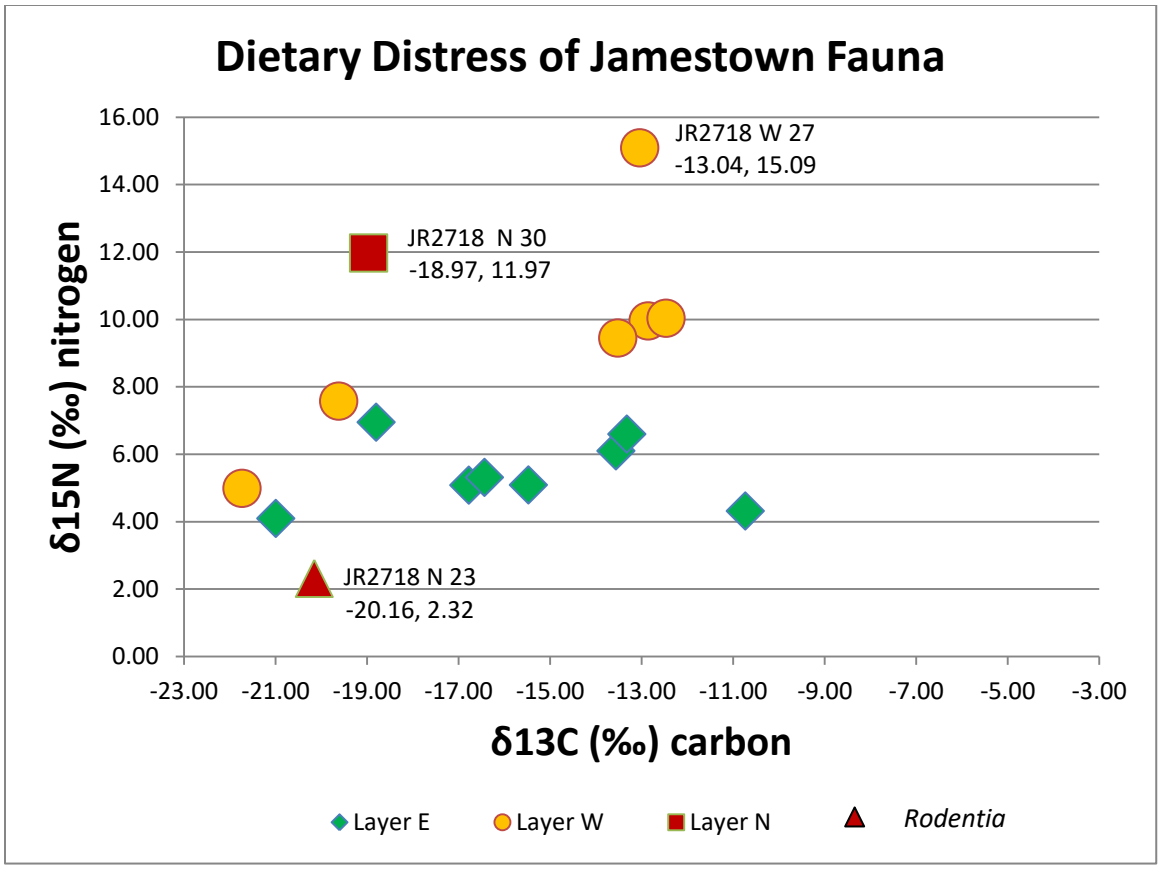

Figure 19: IRMS analysis of diet from collagen data that indicates dietary distress of fauna. Samples are Mammalia unless otherwise stated

Table 8: Samples analyzed by both the ATR-FTIR and IRMS

Sample	Site	Provenience	Species	Element	Side	Age	Portion
27	JR2718	W	*Mammalia*	scapula	Left	Unk	medial
23	JR2718	N	*Rodentia*	humerus	Right	Unk	Distal/medial

Two samples were analyzed by both the ATR-FTIR as well as the IRMS. Figure 17 shows the level of collagen preservation that should be expected from the faunal samples from both layers in JR2718. Table 8 is a list of the samples. These two samples are both outliers in the analysis as the JR2718 N 23 sample is lower in the chart, and is

the only *Rodentia* sample analyzed for collagen. JR2718 W27 is an outlier as well. Both samples are accurate in the amount of collagen that was predicted from the ATR-FTIR analysis in Figure 17.

IRMS Bioapatite Results

As the apatite results were not returned in time, there are no data to report for this section. However, it is possible to speculate as to what the results would be for both JR2718 and JR3176. As seen in Figure 16, there should be a difference in the preservation levels found between the layers. There should also be a difference found between features and layers as found in Figure 19 when comparing $\delta^{13}C$ and $\delta^{15}N$. As bioapatite is more of a representation of the overall diet of the animal or human sampled, this would be an essential component in determining how the diet of the fauna on the island changed from 1609 to 1650.

Chapter 5: Discussion

This chapter will review the analyses done to the faunal remains and the implications these results may have for further understanding the health and diet of the fauna at the site of Jamestown. The analyses of faunal material from the Jamestown settlement provides correlations between preservation, diet, and biological material to further understand and interpret the events that occurred during the winter months of 1609 into the spring of 1610. Various limitations about the results and conclusions drawn from this research will be addressed. FTIR analysis of the faunal remains from JR3176 provided further verification that the bones recovered from layers D and E were leached of their organic material more so than remains analyzed from JR2718. Collagen analysis indicates a significant difference in the two populations of JR2718 and JR3176 in regards to diet and preservation, which is corroborated by ATR-FTIR data. Bioapatite samples were not received by the time this report was completed to integrate the results and form conclusions.

Prior to analysis of remains, visual observations of each bone sample were noted. Visual observations of samples from JR3176 indicated that many of the faunal remains may not contain a significant amount of organic material due to the white chalky nature of the periosteal surface. FTIR data indicated this observation to be accurate. The historic ceramic artifacts recovered from the builder's trench of JR3176 indicate faunal remains were deposited no later than 1950. These remains were in situ or its original burial environment, for roughly 361 years. Bone can be preserved for hundreds of years in the proper burial environment. The faunal remains from JR3176 are a very good indication of

how detrimental the burial environment of a sandy, wet, well can be to remove the organic material of the bone in such a short time.

The deposition layers of JR2718 proved to have better preservation for faunal material than JR3176 according to the FTIR analysis, which compared samples from both structures. While there is little time that passed between the deposition dates of the two wells, the wells were located roughly 20 feet away from each other and contained varied degrees of preservation. The depth of the wells could have been a major contributing factor to the quality of preservation of the faunal remains and historic artifacts. JR2718 was described as reaching approximately 36 feet in depth (with a cellar attached) whereas JR3176 reaches a depth of approximately 8 feet according to excavation reports (APVA., N.d.). This depth estimation may be shallow considering the excavation shaft of the well consistently filled with silt and water when measuring the depth of JR3176. The bottom two deposition layers were selected for faunal analyses from both structures. Layers that were in direct contact with water had a negative effect on the preservation of the collagen and apatite by leaching the organic material within the bone.

The condition of bones found in JR2718 contained bone, which was well preserved according to initial visual observations, which were then corroborated by the FTIR data. Although JR2718 has deposition layers that are 41 years older than JR3176, several variables may have affected the preservation in the two wells. JR2718 was only open for a short period, because the water quality steadily decreased. The quality of water was exacerbated in the first years of the colony, because the area was undergoing a severe drought. The well was built in the middle of sediment, and bacteria, mixing with sewage seeping from the fort, which created terrible water quality. Refuse that was deposited in

this well would have been exposed to a more bacteria filled environment than that of JR3176. Although JR2718 was only accessible for roughly three years, JR3176 was used for about ten years. The length of time the water of the well from JR3176 was exposed to the environment, allowed ample opportunity for bacteria to breed while oxygen was readily available. The increased exposure to the elements created the perfect environment for significant chemical alteration to the deposition of bones. Biological alteration of archaeological bone can affect and accelerate the degradation of bone preservation by increasing bone porosity (Jans, 2004). A combination of variables such as, the depth of the wells at 12 feet and 8 feet, the duration the wells were in use, and the drought affecting JR2718, all correlate to the differential preservation of the bone. If JR3176 had been dug deeper, and was open for a shorter period of time, the preservation of the faunal remains from 1650 would have been similar to that of JR2718 from 1608.

The Jamestown Diet

The site report from JR2718 indicated there was a large deposition of mollusk or oyster shells in layer W. This abundance of oyster shells may provide further information indicating the colonists were undergoing a period of nutritional stress. The Powhatan Indians had large deposits of oyster middens associated with the winter months (Barber, 2008). This large deposition of oysters in layer W is the only one in this particular well. Which would indicate there was a short time where the colonists relied on or had access to foraging for this particular resource. The Powhatan Indians ate a considerable amount of oysters when resources were minimal during the winter months because of the nutrients the meat from the oyster provided (Barber, 2008). The lack of oyster deposits throughout JR2718 would corroborate the account of many colonists, that the winter of

1609 to 1610 there was limited access outside the fort to resources that could have prevented the colonists from starving (Kelso 2006; Percy 1625; Taylor 2002; Woolley 2007).

Based upon the deposition layers of both wells it becomes apparent there is a difference in eating habits from 1608 to 1650. A large percentage of remains in JR2718 were small mammals whose presence could be attributed to burrowing activity and interest with the refuse the colonists were depositing in the well. However, according to the site excavation reports from A.P.V.A., there were no soil disturbances around the shaft of the well. It is, therefore, more plausible that the *Rodentia* fell into the well in search of the refuse colonists were placing in JR2718, or the *Rodentia* were, part of the colonial diet as George Percy, the Colonial Virginia governor claimed in his diaries (Percy, 1625). However, these remains are also in the same assemblage as large faunal remains with cut and butchering marks commonly associated with the processing of meat. Although positive identification of the faunal material in both wells is difficult to ascertain with the fragmented material deposited in the well, colonist accounts from John Smith and governor George Percy both wrote about hunting local white-tailed deer and feeding upon their own cattle (Haile 1998; Percy 1625). Which suggests the faunal material in JR2718 could contain remains of deer, and cattle. The deposition layers of JR3176 however contained faunal remains most likely from local cattle raised in the area, which suggests the colonists who still inhabited the island were consuming large fauna. It is very likely from the fragments found in the deposition layers that the colonists had regular access to large cuts of meat. There was no evidence of small mammal remains in

JR3176, which is also another indication that this time period was more nutritionally stable than that of 1608 to 1610.

The departure of the Jamestown colonists in 1606 were unlikely to succeed in colonization of the New World when the venture started with poor planning of proper provisioning of food. The rations and food supplies aboard the three ships were to last the colonists several months after their arrival in Virginia. Rations were small, scarce, and unlikely to contain foods that were adequate in nutrients to keep the 104 colonists and 40 mariners strong and healthy for their adventure to the Americas. The costly delay of being marooned in the 'Downs' at the beginning of the voyage created a strain on the small rations from the benefactors of the Virginia Company. Upon arriving in the New World, the exertion of cutting down trees, pitching tents, and building fortifications, combined with inadequate nutrition and poor food quality the strenuous activities quickly took their toll (Smith, 1986). Both John Smith and George Percy wrote of twenty-five colonists dying barely a month after their arrival from extreme weakness and sickness (Percy1625; Smith 1986). The colonists were also suffering from the effects of malnutrition.

The food bias to eat foods familiar to their English palates may have affected the colonists' ability to be fully cognizant of the potential of local flora and fauna. The desire to consume food that was familiar would have continued until provisions were depleted. With rations running low, and missing their window to plant for the upcoming winter, it became a necessity for the colonists to trade for food with their Powhatan neighbors. Only to find that this constant encroachment on the Powhatan food stores was steadily depleting the Powhatan's small stores of beans and corn (Cronon 2003; Milton 2000;

Oliver 2005). Commonly the food stores were a supplemental food source to the hunting and foraging for the Powhatan during the lean winter months. The Powhatan maintained a minimal crop yield that was continually strained by the English colonists and exacerbated by the drought (Barber 2008; Stahle 1998; Taylor 2002; Woolley 2007; Wright 1947).

While the drought was a major factor in the ability of the colonists to produce flourishing and sustaining crops for several years, a pattern of malnutrition became apparent especially during the winter months. JR2718 provides an indication of the colonial diet until the well was completely filled in with refuse. Layer W in JR2718 contained oysters when the marine life was most abundant during the summer months (Percy 1625; Smith 1986; Woolley 2007). Layer N contained a varied deposition with butchered remains of large mammals as well as a large accumulation of small mammal bones. Based on the ships logs from 1609, there were very few large mammals brought from England and those few animals were designated for breeding and farm domestication. It is unlikely the colonists would have consumed these animals unless it was necessary. When the relations with the Powhatan became tenuous during the winter months of 1609, the First Anglo-Powhatan War began. The Powhatan seized the fort, effectively cutting off the colonists from obtaining resources outside the fort (Cronon 2003; Kelso 2006; Percy 1625; Smith 1986; Woolley 2007). The layers deposited after layer N in JR2718 contained a wide variety of marine faunal remains, and tens of thousands of animal remains. The consumption of marine based foods in a period of one year could be an indication of the improved conditions within the fort. The layers deposited after layer N in JR2718 signifies there was an abundance of outside food

resources available, including large mammals such as deer as well as marine based food that is an indication the nutritional intake of the fort was improved. Therefore, layers N and W from JR2718 should be the best layers to indicate malnutrition within the fort from 1609 to 1610.

Collagen Analysis

The extraction of collagen is necessary for the analysis of the consumption of dietary protein through the $\delta^{15}N$ and $\delta^{13}C$ values per mil. The $\delta^{13}C$ values can also indicate the type of diet the animal is likely to have been on such as primarily C_3 or C_4. An animal that feeds primarily on C_3 plants such as beans, rice, and wheat will have a value around -26‰ $\delta^{13}C$. An animal that consumes more C_4 plants will center around -18 to -12‰ $\delta^{13}C$ (O'Brien, 2015:570). The range of collagen extraction for animals from JR2718 -12.47 to -21.73‰ $\delta^{13}C$ indicates animals were consuming primarily C_4 plants from 1608 to 1610. JR3176 carbonate values range from -10.73 to -20.99‰, which would indicate that animals were still consuming a similar diet with better nutrition in the 1650's with the consumption of primarily corn and shrubs.

Upon analysis of JR2718 layer W, sample 27 from Figure 19, it was noted that the $\delta^{15}N$ value was higher than other faunal samples at 15.09, it is possible that W27 could be a human remain sample based on the significant nitrogen value, which is typically that high due to the consumption of freshwater resources. As the archaeological depositions and colonial accounts indicate freshwater sources were taken advantage of, the explanation of such a high $\delta^{15}N$ value for that particular sample can be a possible explanation of the outlier value. A secondary explanation is the consumption of omnivore

protein, which could be incorporated by consuming animal products or the incorporation of freshwater resources into the food. This explanation tracks more with the demand for all food to be utilized and consumed within the fort as resources were limited (Müldner, 2005:44). As there is no record of marine resources contributing to the diet of terrestrial animals within the fort, sample JR2718 W27 is an unusual outlier. $\delta^{15}N$ values for the consumption of aquatic animals is estimated at (~+9 to +17‰) (Privat et al. 2001:785). The range of samples from both archaeological wells analyzed by IRMS are 2.32 to 15.09 ‰ (per mil) $\delta^{15}N$. While a conclusion cannot yet be drawn about the incorporation of marine food into the diet of animals within the fort during the starving times, this is one possible explanation for the increase in $\delta^{15}N$ for JR2718 sample W27.

The analysis of $\delta^{15}N$ can indicate the trophic level or biomarker an animal receives as it consumes food lower on the food chain. As this occurs, the animal's trophic levels will reflect that consumption and the $\delta^{15}N$ values per mil will increase 3‰ to 4‰ higher than what was consumed. The higher on the food chain, the higher the $\delta^{15}N$ value. Based on this information, the $\delta^{15}N$ values of the samples analyzed from archaeological well JR2718 and JR3176, the animals can be considered primary consumers and tertiary consumers with a range at 2.32 to 15.09‰. Primary consumers are considered herbivores and tertiary consumers are omnivores who will consume both protein of other animals as well as plants from the surrounding area. Expected trophic values of primary consumers or herbivores is ~8-10‰ $\delta^{15}N$ and expected values of tertiary consumers or omnivores are ~11-13‰ $\delta^{15}N$ (O'Brien, 2015). With the analysis of the trophic levels in both archaeological wells at Jamestown, it is very likely that W27 from JR2718 is actually an omnivore. If in fact that sample were to be human, it would have a higher $\delta^{15}N$ value

closer to 18 or 20‰. The $\delta^{15}N$ values indicate where the animal samples from Jamestown would be considered herbivores on the food chain and the $\delta^{13}C$ values indicating a diet of primarily C_4, there is still a difference in the nitrogen values between the 1608 well of JR2718 and 1650 well of JR3176.

The analysis of collagen provided further evidence of malnutrition affecting the animals within the fort of Jamestown in 1609. Collagen extraction compared Layers N, W from JR2718 dated from 1609 to 1610, and Layer E from JR3176 dated to 1650. Figure 19 provides an image of how much $\delta^{15}N$ accumulation in the dietary tissue can provide information about how extreme hunger or fasting can be represented. An animal or human that is undergoing dietary distress will excrete nutrients found in $\delta^{14}N$ but will continue to accumulate $\delta^{15}N$ per mil as the animal continues to starve. Layer E (Figure 19) is an indication the animals of 1650 were not under dietary distress and were healthier than the animals from 1609 and 1610 as the $\delta^{15}N$ levels were significantly lower.

Chapter 6: Conclusions

This study has examined the archaeological structures excavated at the Jamestown site in an attempt to understand the cause and effect of starvation within the seventeenth century fort. Variation of organic preservation was based on infrared spectra of faunal bone by the ATR-FTIR. *Rodentia* and *Mammalia* bone was sampled from two wells, JR2718 and JR3176. The chemical analysis of the faunal remains was done by IRMS and used to determine the health and diet of the faunal remains sampled.

Many colonists' lives were lost within the first few years of settlement in Jamestown due to various causes including attacks from the Powhatan, starvation, and disease. As the English continued to press their luck with their Powhatan neighbors and steal food from their villages, the Powhatan had no choice but to defend their territory and attack the colonists as the tensions between the two cultural groups increased. The mortality rate increased within the fort when a lack of available food caused by the drought impeded the success of crop production and therefore created malnutrition throughout the fort. Malnutrition can mean a shortage of food or an inability to obtain food. Eating habits can affect what foods are culturally acceptable which in turn can affect the health of an individual. "The general concern in evolving good eating practices is how to attain good health, satisfy hunger, and reap the reward of the pleasure of eating good food (Desrosier, 9)." George Percy wrote that the men of the colony in the winter months of 1609 were suffering from "crewell hunger (Percy, 1625)." In order to feel full, essential amino acids must be included in the diet to achieve the full-satisfied feeling that comes from the consumption of fat. A diet with a lack of fat will not provide the full feeling, which creates a continual need to eat. With the colonists crops severely affected

by the drought, and with no word of a supply ship arriving, it is likely the local fauna were just as affected. The starvation of the fauna on the island means colonists were consuming lean animal meat, which could have been what was causing the colonists to undergo what George Percy referred to as cruel hunger.

According to Marvin Harris, local foods, or foods that are unfamiliar to the colonists will be consumed last and preferentially English food will be consumed first (Harris, 1985). This theory is difficult to prove in the archaeological record because organic material is not preserved. The deposition layers of both wells do not contain organic material of past consumption. With the structure of JR2718 and JR3176 both being wells, it would be difficult to accurately test this theory because of the bio degradation. It may be possible to test artifacts within the well such as plates or bowls that would have been used for consuming foods such as plant phytoliths associated with plant matter. This information could provide more information about the plant matter or organic matter that was consumed throughout the Jamestown settlement.

Marvin Harris also mentions that it may be difficult to know exactly what the colonists may have considered edible. As an individual starves, foods such as mold or grain with worms writhing in the barrel may not seem edible or appetizing regardless of the nutrients it may provide. As mentioned before, *Rodentia* have the best representation of the human diet because of the convenience of eating easily accessible food within the colony. As food stores diminished within the colony humans, *Rodentia,* and *Mammalia* will begin to experience a decrease in caloric intake. Just as *Rodentia* rely on the food stores for the bulk of their diet, so do *Mammalia* rely on humans to provide and facilitate their food. As grazing in the pasture was not implemented until after 1610 when Lord Del

a Warr arrived with a supply ship of livestock after the starving winter of 1609, animals within the fort relied solely on humans. This dependence on humans is one possible explanation for the increase in the $\delta^{15}N$ values represented in the collagen extraction results from the IRMS in Figure 19. The analysis of collagen provided further evidence of malnutrition affecting the animals within the fort of Jamestown in 1609. Collagen extraction compared Layers N, W from JR2718 dated from 1609 to 1610, and Layer E from JR3176 dated to 1650. Layer W had a significant difference in $\delta^{15}N$ levels to Layer E with an average of 8.92 (Appendix B: Figure 1). All samples from Layer E maintained a similar $\delta^{15}N$ value with an average of 5.44 (Appendix B: Figure 2). Animals represented in Layer W had undergone dietary distress and had accumulated more $\delta^{15}N$ as the animal continued to starve as indicated in Figure 19. As the body experiences nutritional distress, "the enrichment of 15N ($\delta^{15}N$) values in tissues can only be observed under conditions of extreme food restriction or among fasting animals... (Deschner, 2011:68)." Layer E (Figure 19) is an indication the animals of 1650 were not under dietary distress and were healthier than the animals from 1609 and 1610 as the $\delta^{15}N$ levels were significantly lower. Extraction of collagen indicated the fauna of the island during th 1650's as well as early years of the fort, consumed primarily corn based food based on the $\delta^{13}C$ values of the faunal remains. Although consuming a similar diet, the 1650's still indicate better nutrition with a decrease in the average $\delta^{15}N$ values.

The samples that were analyzed to test the preservation of JR2718 and JR3176 were small in number. It might be more conclusive to run ten or fifteen additional bone samples from each layer and structure to compare the variation of bone preservation. The preservation in JR3176 was low, containing almost no organic material in the bone. As

layers D and E were closest to the water table, it is possible the faunal material was subjected to diagenetic alteration from the aqueous environment. JR2718 had better preservation that may be attributed to layers W and N being further away from the water table and therefore preserving the bioapatite and collagen as the bone remained in a dry environment. Future analysis for preservation of organic material within the Jamestown wells may be beneficial to understanding at what depth the preservation of bone is compromised.

The future analysis may provide information that can be helpful for analyzing the preservation of biological material in human remains throughout the island. Human remains are buried all throughout Jamestown Island at various depths, orientations, and a variety of mortuary practices. If an average depth of poor preservation can be established, perhaps the human remains can be excavated and placed in a different location for future generations or research. Future analysis of the remains of the Jamestown colonists would provide further information about the diet and health of those who survived the starving times or those who died during the winter months of 1609 to 1610. The analysis of faunal remains as well as human remains of the Jamestown colonists would also be interesting to compare to nearby Powhatan sites. While analysis of the Jamestown fauna was an integral component of the colonial Jamestown diet, a further comparison of Powhatan trash middens would provide a discussion of how two different cultural communities utilized their resources after the English began to colonize in the New World. It would also be interesting to analyze how diet changed throughout the years the English were in contact with the Powhatan through the excavation and analysis of trash middens of the two groups.

One variable that may be contributing to the deterioration of bone preservation is the pH value of the water within both wells sampled. PH values of water and soil is a significant factor for preservation of bone. Soil that is loess or sandy in nature will undergo weathering and the burial of bones in this environment especially in a wet environment can affect the preservation of the bone. The chemical composition of silica is by nature unstable and more likely cause diagenetic alteration to the bone. The site report of both wells indicate that both structures are composed of loess. If there is a large amount of organic material the pH level would decrease. As the organic material breaks down, the environment becomes more unstable creating the perfect environment for diagenetic alteration to occur to the bone (Weiner, 2010). The site reports indicate there was soil and water samples taken from each of the wells. It would be interesting to compare the pH values to the bone preservation to draw any correlation.

The focus of the research on the winter months of 1609 and 1610 to look at the starvation or extreme nutritional deficiency of faunal remains is due to several documented accounts of colonists who lived through the starving times. Based upon the rational *Rodentia* are consuming food resources of humans within the fort, the *Rodentia* will replicate a similar isotopic signature of an increase in $\delta^{15}N$ that only occurs through extreme nutritional deficiency or starvation. Just as the colonists were suffering during those winter months, the fauna within the fort would also suffer a similar fate because of their reliance on humans to sustain their food source. The *Rodentia* diet would be an accurate representation of the human diet based on the assumption that *Rodentia* are small omnivores that eat convenient food. The *Mammalia* during this time would have a high dependence on humans for their nutritional intake because grazing was not

implemented until after supply ships arrived in 1610. The practice of grazing implies a level of stability and domesticity for livestock as well as the individuals within the colony. As the period of extreme nutritional distress only lasted for a short time, it was necessary to sample faunal remains believed to be from 1609 to 1610.

While there are many variables that can contribute to the events that transpired during the starving time of 1609 to 1610, the results of faunal nutritional distress as found in the IRMS data still provides evidence of the conditions within the fort. The analysis of faunal remains can indicate not only how much food was shared with the livestock within the fort, but also more evidence supporting how little food was available to the colonists. While the exact cause of the bloody flux cannot be proven, the starvation of the fauna within the fort can still be a cause for the colonists becoming increasingly sick and hungry while continually contributing to the cause by consuming lean protein of fauna within the fort. As Figure 19 indicates, the faunal remains that were analyzed for an increase in $\delta^{15}N$ showed a variation between the two archaeological wells dating to 1608 and 1650. JR2718 showed a higher $\delta^{15}N$ value, which would indicate dietary distress and JR3176, represented a lower $\delta^{15}N$ value, which is expected for the stable domesticated time period. The faunal remains found within archaeological well depositions are indications of these animals contributing to the dietary food web colonists consumed which is why analyzing the faunal analysis was so critical to provide context to the next step of the project to analyze human remains for a more complete food web.

The two archaeological wells JR2718 and JR3176 have significant differences between them. JR2718 Layers W and N dating to 1609 to 1610 are the two layers with the best preservation and the best indication that there was a significant depletion of

available nutrients as indicated by the extraction of collagen. JR3176 Layers E and D dating to 1650 are the two layers with the worst preservation and the best health in terms of dietary intake. The comparison of the two archaeological wells from Jamestown, VA shows that subsistence in 1609 and 1610 was indeed lacking for both colonists and animals that resided within the fort. The malnutrition the animals suffered in the fort is possibly a contributing factor to the demise of the 340 colonists that perished during the winter months of 1609 into the spring months of 1610.

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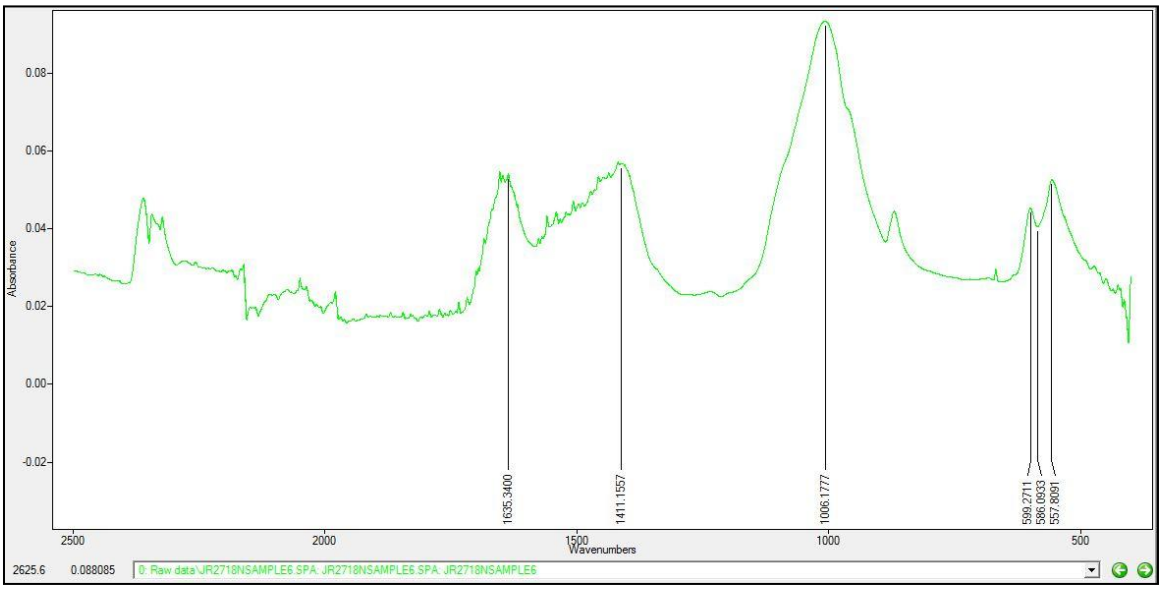
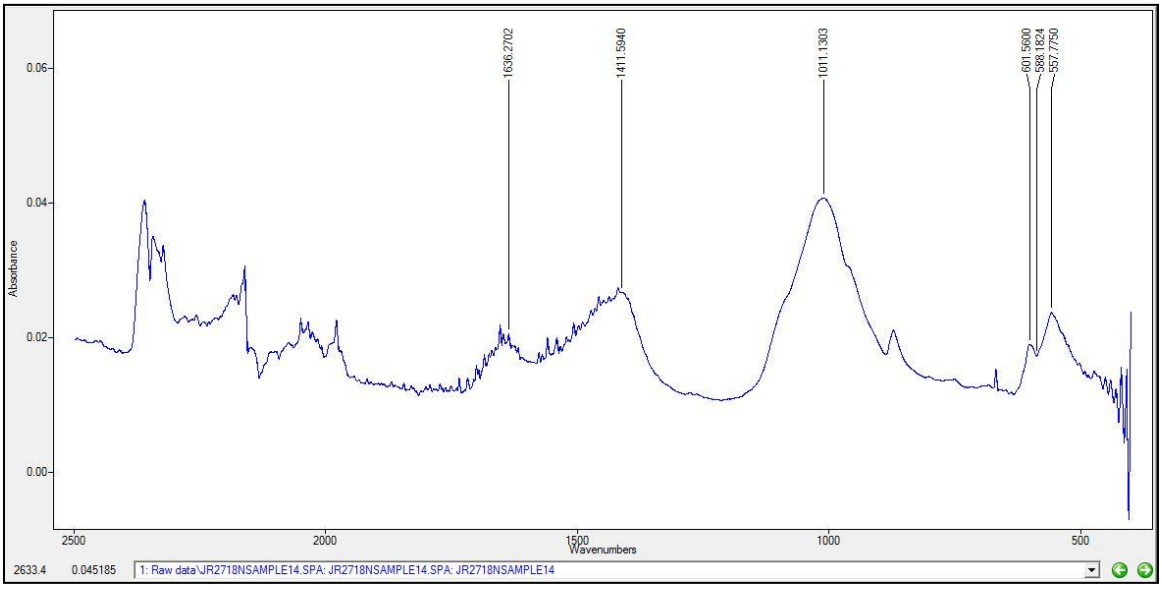
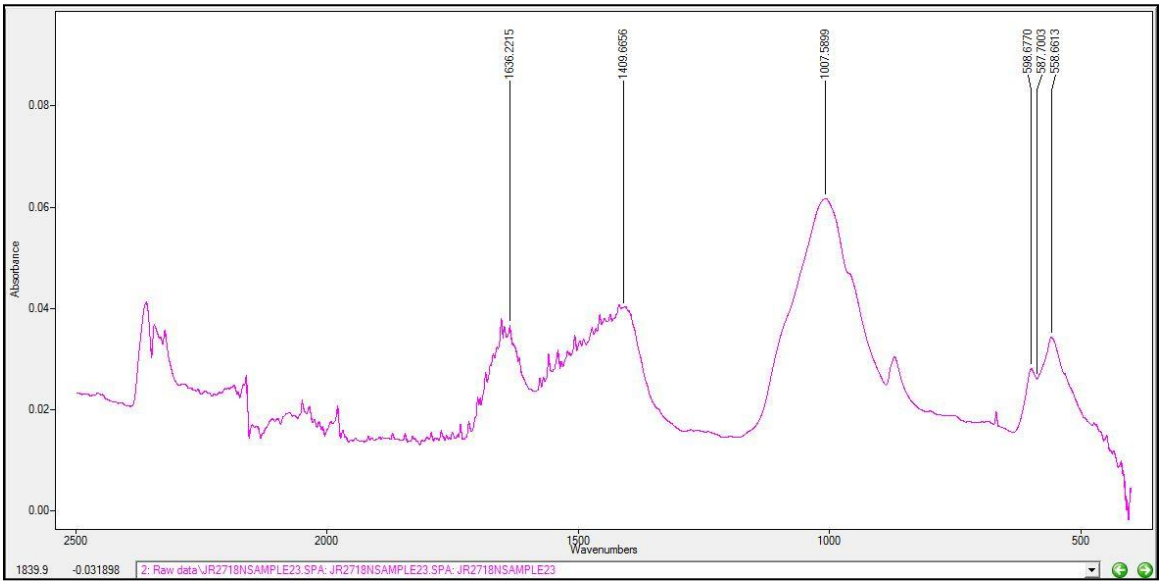
APPENDIX A: ATR-FTIR SPECTRAL ANALYSIS OF FAUNAL REMAINS FROM JR2718 ARCHAEOLOGICAL WELL AND JR3176 ARCHAEOLOGICAL WELL JAMESTOWN, VIRGINIA



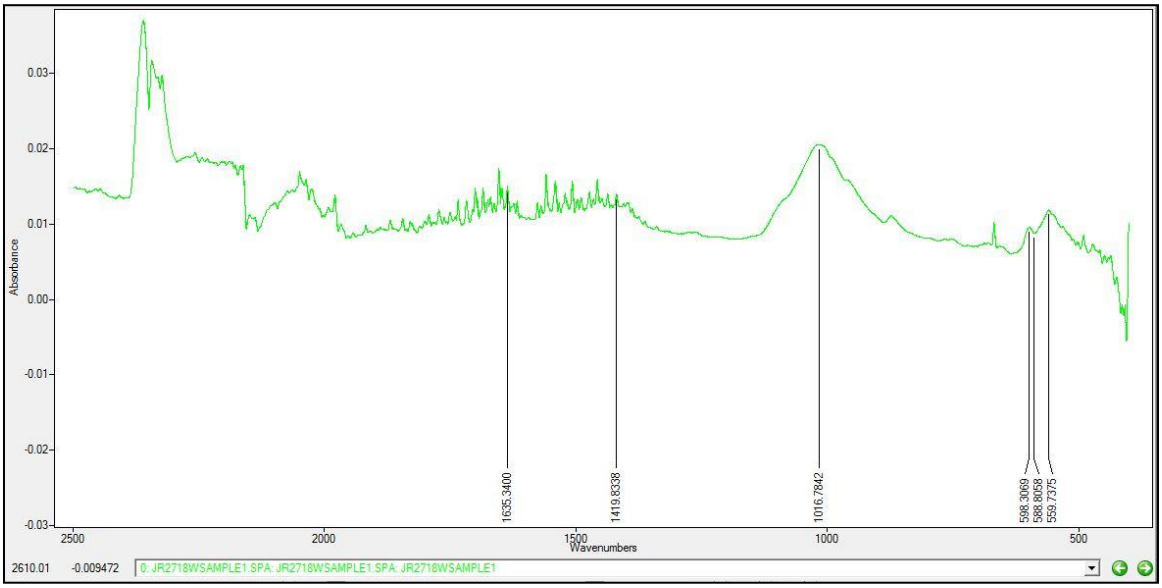
Spectrum 1: JR2718 Layer N sample 6



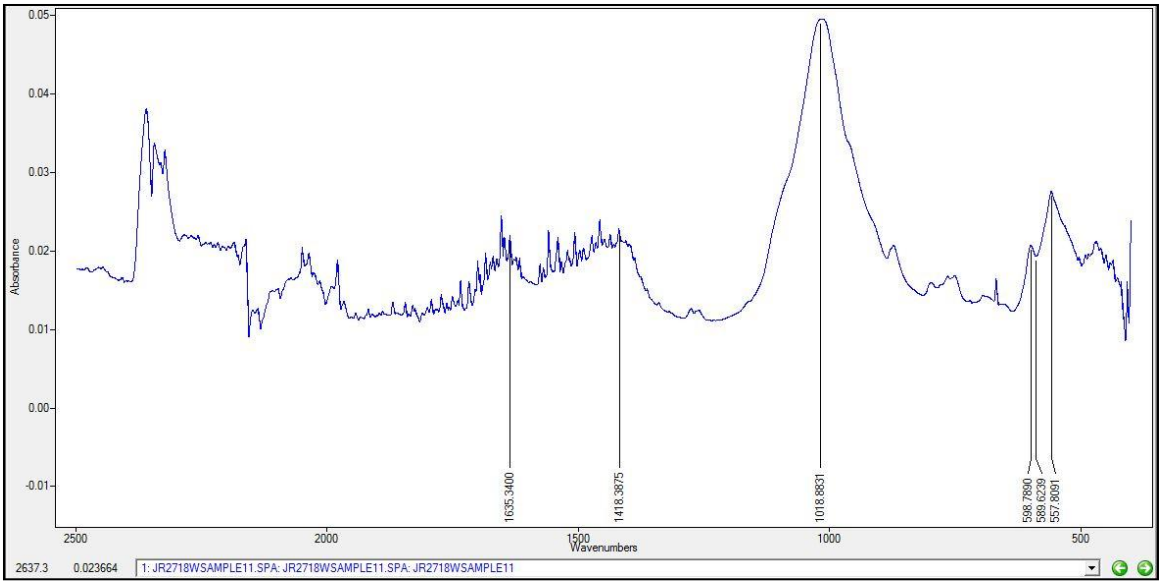
Spectrum 2: JR2718 Layer N sample 14



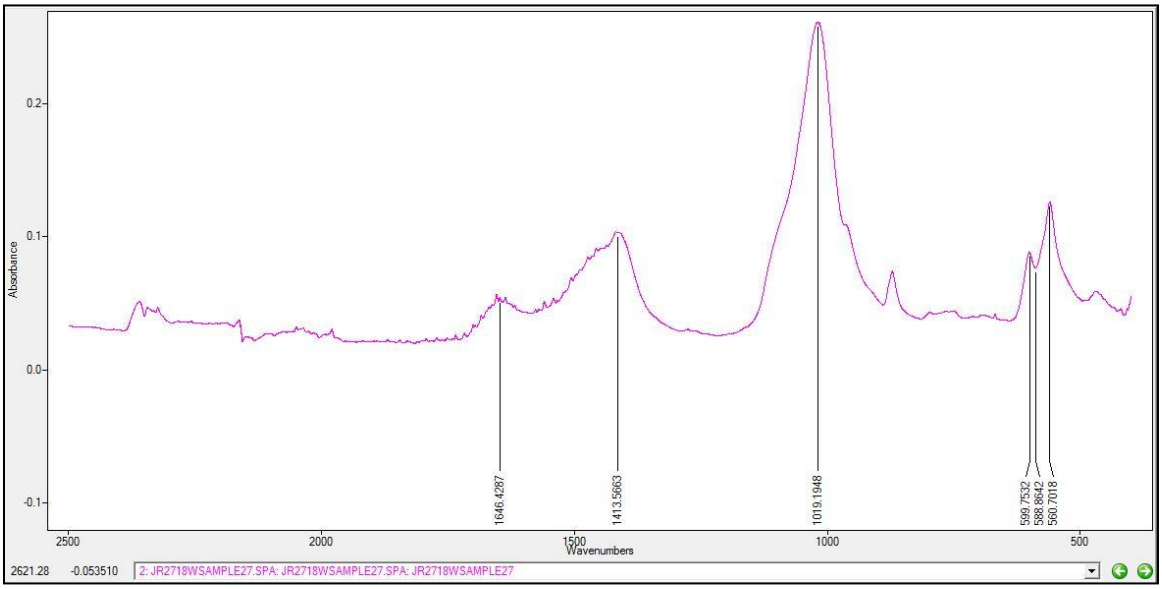
Spectrum 3: JR2718 Layer N sample 23



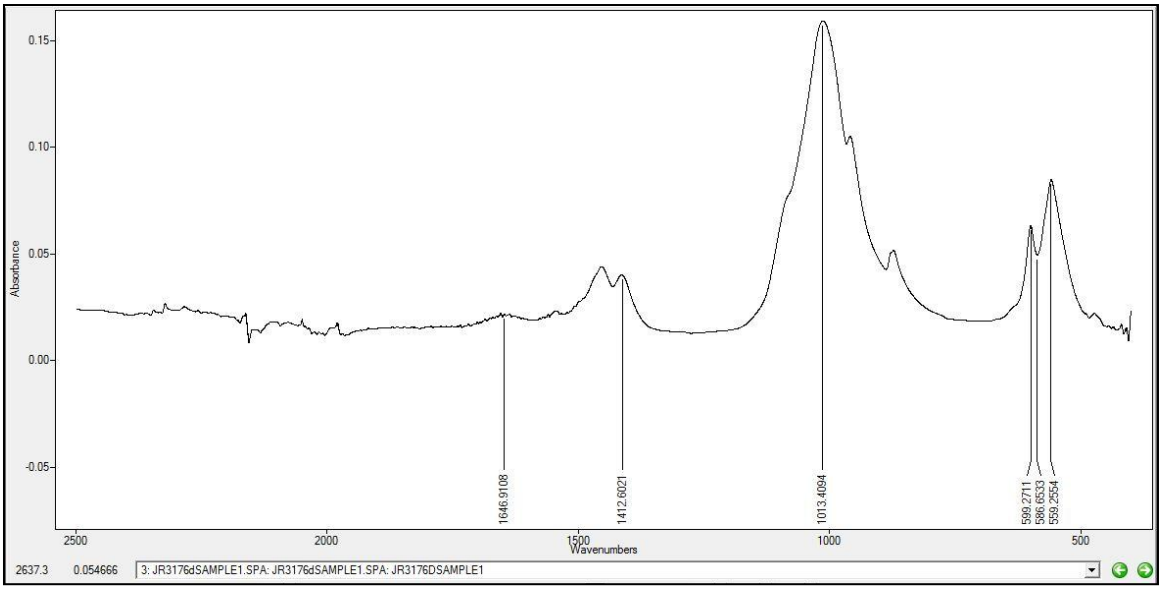
Spectrum 4: JR2718 Layer W sample 1



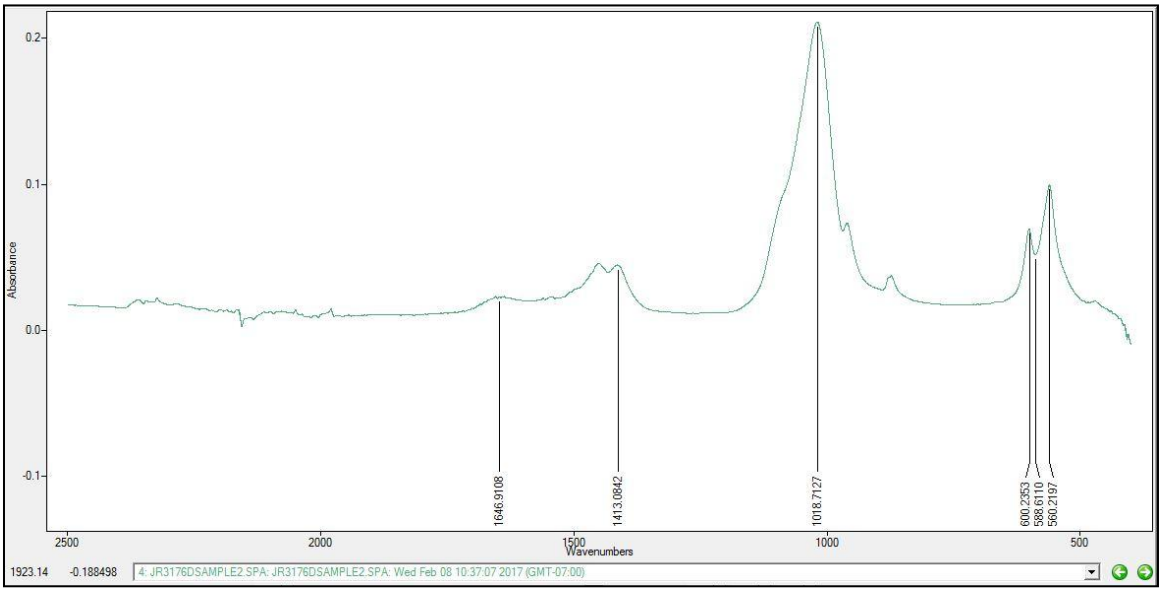
Spectrum 5: JR2718 Layer W sample 11



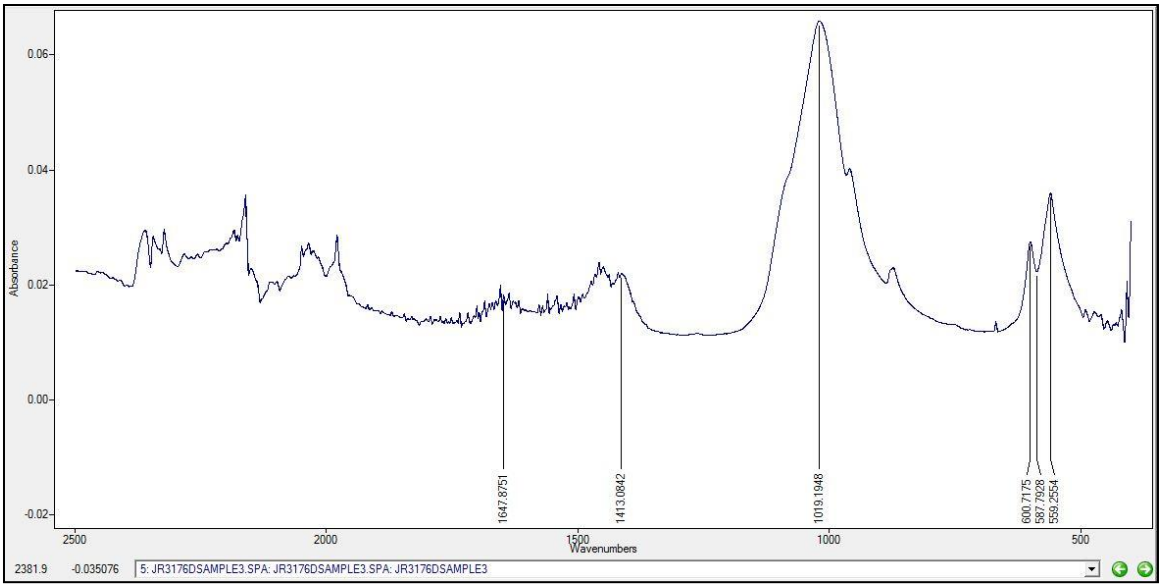
Spectrum 6: JR2718 Layer W sample 27



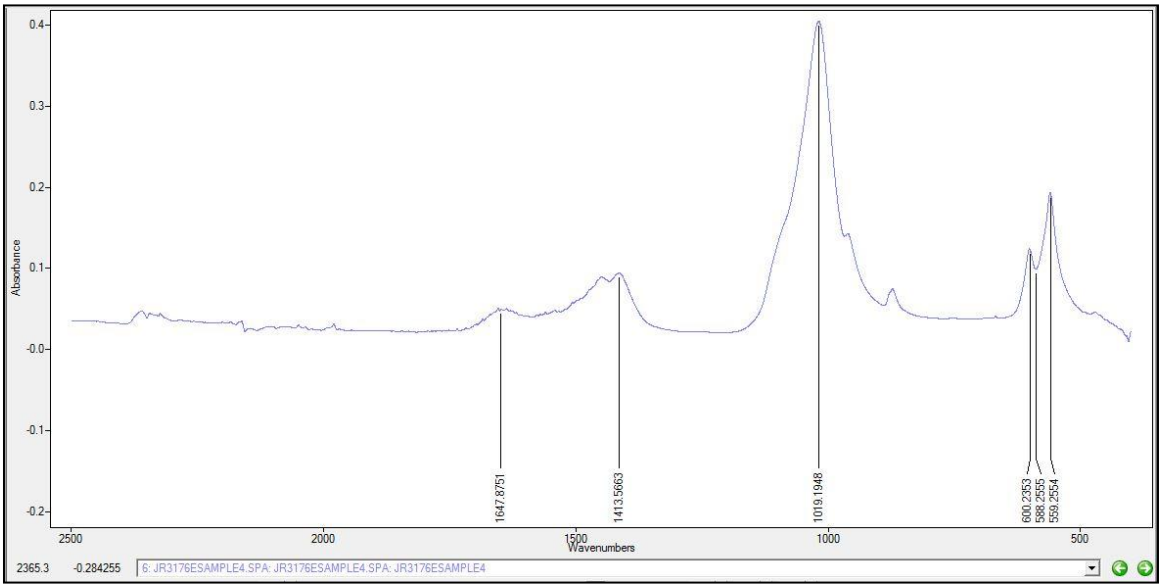
Spectrum 7: JR3176 Layer D sample 1



Spectrum 8: JR3176 Layer D sample 2



Spectrum 9: JR3176 Layer D sample 3



Spectrum 10: JR3176 Layer E sample 4

APPENDIX B: IRMS COLLAGEN DATA ANALYSIS OF FAUNAL REMAINS FROM JR2718 ARCHAEOLOGICAL WELL AND JR3176 ARCHAEOLOGICAL WELL JAMESTOWN, VIRGINIA

Table 9: JR2718 Layer W samples analyzed by IRMS

Sample	Sample	Site	$d^{13}C$	$d^{15}N$	%C	%N	C/N	Atomic C/N	Provenience	Structure	Species	Element	Side	Age	Portion	Portion sample came from
			(‰)	(‰)												
3474	22	JR2718	-12.86	9.96	41.35	15.14	2.73	3.19	W	185	*Mammalia*	rib	Left	Unk	Medial/distal	Medial
3476	23	JR2718	-12.47	10.04	40.13	14.79	2.71	3.16	W	185	*Mammalia*	rib	Left	Unk	Medial/distal	Medial
3477	25	JR2718	-19.62	7.58	36.37	13.28	2.74	3.19	W	185	*Mammalia*	humerus	Right	Unk	Medial/distal	Medial
3478	26	JR2718	-13.52	9.45	38.04	13.72	2.77	3.23	W	185	*Mammalia*	pelvis	Left	Unk	Illium	Superior illium
3479	27	JR2718	-13.04	15.09	36.72	13.31	2.76	3.22	W	185	*Mammalia*	scapula	Left	Unk	medial	Inferior angle
3480	28	JR2718	-21.73	4.99	39.76	14.63	2.72	3.17	W	185	*Mammalia*	tibial plateau	Left	Unk	Complete	Medial condyle
3482	23	JR2718	-20.16	2.32	38.29	13.87	2.76	3.22	N	185	*Rodentia*	humerus	Right	Unk	Distal/medial	Medial
3483	30	JR2718	-18.97	11.97	35.41	12.82	2.76	3.22	N	185	*Mammalia*	humerus	Left	Unk	Distal/medial	medial
Average			-16.55	8.92			2.74									
Standard deviation			3.9082131	3.979460368			0.02227									

Table 10: JR2718 Layer E samples analyzed by IRMS

Sample	Sample	Site	$d^{13}C$	$d^{15}N$	%C	%N	C/N	Atomic C/N	Provenience	Structure	Species	Element	Side	Portion
			(‰)	(‰)										
3466	6	JR3176	-16.78	5.08	40.02	14.54	2.75	3.21	E	190	*Mammalia*	fragment	Unk	fragment
3467	7	JR3176	-13.56	6.10	35.08	12.77	2.75	3.20	E	190	*Mammalia*	fragment	Unk	fragment
3468	8	JR3176	-10.73	4.32	28.28	9.80	2.89	3.36	E	190	*Mammalia*	fragment	Unk	fragment
3469	9	JR3176	-13.32	6.60	33.82	12.18	2.78	3.24	E	190	*Mammalia*	fragment	Unk	fragment
3470	10	JR3176	-18.80	6.95	38.27	13.81	2.77	3.23	E	190	*Mammalia*	fragment	Unk	fragment
3471	11	JR3176	-16.43	5.31	26.51	9.07	2.92	3.41	E	190	*Mammalia*	fragment	Unk	fragment
3472	12	JR3176	-15.47	5.09	30.65	10.78	2.84	3.32	E	190	*Mammalia*	fragment	Unk	fragment
3473	13	JR3176	-20.99	4.10	34.54	11.74	2.94	3.43	E	190	*Mammalia*	Rib	Unk	fragment
Average			-15.76	5.44			2.83							
Standard deviation			3.2568366	1.027957583			0.07887							