Quantifying Selection in Chimpanzee Composite Tool Use at Bossou, Guinea: Novel Material Property Tests of the Archaeological Record

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Abstract of Thesis

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Variables such as rock shape and size affect tool selection decisions of wild chimpanzees during percussive tool use. However, very little is known about how chimpanzees discriminate between different rock types. The lithologies selected for this study were previously analyzed to determine which variables influenced raw material selection by Early Pleistocene hominins. Previous results suggest that hominin selection linked to two mechanical properties: durability and fracture predictability. At the outdoor laboratory, in Bossou, Guinea, we investigated tool selection among a group of wild chimpanzees. We provided them with rock types preferred by hominins to make chipped stone artefacts at the site of Kanjera South, Kenya, which are not available in the modern Bossou habitat. We investigated chimpanzee selectivity by calculating indice of selection based on the use of different rock types. Tests on rock elasticity and micro-hardness allow us to link selection to material properties. Results show that decisions on tool selection by chimpanzees correlate with (invisible) mechanical properties of rocks. Data demonstrate that rock hardness and elasticity drive the selection decisions of both hammers and anvils. This pattern is more evident amongst older individuals with greater efficiency and skill in nut cracking.

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Chapter 1: Introduction

1.1 Background and Significance:

On a daily basis, humans make numerous decisions based on their individual wants and needs. These decisions, whether about the clothing we wear or the food we eat, are made based on a number of different variables – personal preference, culturally-influenced trends, and filial practice and tradition, to name a few (March, 1994). Cultural variables have long played an important role in our decision-making process, and toolstone raw materials selections are first visible in the archaeological record by, at least, 2.6 million years ago, with the manufacture and use of stone tools (Ma; Semaw et al., 2000), but novel data opens the possibility of even earlier occurrences, from around 3.4 Ma (Harmand et al., 2015; McPherron et al., 2010). However, Pliocene research sites represent a gap in the archaeological record. Therefore we cannot be certain that the limited artifact occurrences at 3.4 Ma are based on a common cultural practice or individual performances. Likewise, chimpanzees (*Pan troglodytes*) seem to exhibit preferential selection of various objects in their natural environment, which enable them to adapt to highly competitive and variable environments on the African continent (Biro et al., 2003; Carvalho et al., 2008).

Raw material selectivity and procurement are the topics of numerous studies of Plio-Pleistocene hominins (Harmand, 2007; Braun et al., 2008, 2009a, 2009b; Stout et al., 2010; Delagnes et al., 2011). However, the archaeological record provides a static picture of raw material selection because decisions about raw materials are aggregated in time averaged assemblages. While quantitative studies of raw material selectivity have been employed in the past, few studies provide objective information about the mechanical

properties of the materials themselves (Braun et al. 2009). Due to time-averaging, current interpretations of raw material selectivity tell us that hominins had preference for high quality raw materials over a long time period (potentially tens or even hundreds of thousands of years), but provides little insight into the selection patterns of the individual. The archaeological record shows that tool use played a role in human evolution (McBrearty and Brooks, 2000). Chimpanzees, like hominins, use tools for a wide range of subsistence purposes including: leaf sponges for drinking (Sugiyama and Koman, 1979; 1995; Tomasello, 1994; Tonooka, 2001, McGrew, 2010), termite fishing (McGrew et al., 1983; 1999; Suzuki et al., 1995; Lonsdorf, 2005; 2006; Sanz et al., 2009), bush baby hunting (Pruetz and Bertolani, 2007; Byrne, 2007), and nut cracking (Boesch and Boesch, 1982; 1984; Whitesides, 1985; Sakura and Matsuzawa, 1991; Mercader et al., 2002; Biro et al., 2003; Carvalho et al., 2008) to name a few. Chimpanzees also show commonalities with Plio-Pleistocene hominins in their preferences for tool raw materials (Carvalho et al., 2009). While tool use among chimpanzees has been well documented, presently we do not understand how different stone mechanical properties impact the composite tool selection decisions amongst chimpanzees, our closest living relative, and a taxon commonly selected for comparative studies with hominins. Chimpanzees are used as models for asking questions about many different aspects of human evolution, including tool use, a characteristic that is vital to the understanding of non-human primates, and ultimately tool-using hominins (Toth and Schick, 2009). By understanding the patterns of selection in chimpanzees, it is possible to strengthen the argument for using chimpanzees (*Pan troglodytes verus*) as models for stone tool-using hominins in the late Pliocene. To gain a better understanding of raw material selection by hominins,

and ultimately, tool-using behavior, it may be useful to employ referential models for understanding the complexities of hominin tool use (Wynn et al., 2011; Pruetz and Bertolani, 2007; Stanford, 1996; Erdal and Whiten, 1996; Moore, 1996; McGrew, 1992). However, to do this, it is necessary to understand the stone tool-using behaviors of chimpanzees (Toth and Schick, 2009).

Once considered to be a hallmark of human behavior, stone tool use is not solely found in the hominin lineage (Visalberghi et al., 2009). Composite tool using behavior that is the use of two or more tools, manipulated for the purpose of cracking hard-shelled nuts (Sugiyama, 1997; McGrew, 2010; Price et al., 2009), despite being present in several West African populations of chimpanzees (Guinea: Sugiyama et al, 1979;1981;Biro, 2006; Ivory Coast: Beatty, 1951; Struhsaker, 1971; Boesch and Boesch, 1983; Liberia: Anderson, 1983; Hannah, 1987; Sierra Leone: Whitesides, 1985), is not a common behavior observed in the wild. Furthermore, excluding the Cameroon populations, East and Central African populations of chimpanzees show no signs of nut cracking (Carvalho et al., 2009; McGrew, 2010;). This is particularly important since it has been assumed that all necessary materials for nut cracking are present throughout the chimpanzee geographical range (McGrew et al., 1997). Thus, ecological factors cannot play a role in the emergence of this behavior (Whiten et al., 1999). The lack of an ecological influence on tool use in chimpanzees is a key characteristic in studies of chimpanzee culture, and is important to definitions of culture (McGrew, 1992). Not only is nut cracking not seen across all populations of the species, but also not all members of a nut cracking population will exhibit the behavior (Matsuzawa, 1996). In a recent study of a non-nut cracking chimpanzee population, Koops et al. (2013) tested the opportunity and necessity

hypotheses of food resource availability among chimpanzees. These two hypotheses seek a mechanism to explain the selection decisions of chimpanzees based on two scenarios: (1) whether or not chimpanzees select one option over another when both are available (opportunity), or (2) select one resource over another because it is the most abundant and readily available. By looking at food resource availability, Koops et al. (2013) determined that the necessity hypothesis does not explain tool-assisted insectivory, as both termites and ants were available during ripe fruit scarcity. Neither of these two resources was exploited in any increased manner during ripe fruit scarcity. Furthermore, the population being observed rarely encountered the nuts and stones necessary for nut cracking. Therefore, selection of these foods was not relegated to use as 'fallback' food sources, and can best be explained by the opportunity hypothesis (Koops et al., 2013).

Outside of Great Apes, capuchin monkeys have also displayed stone tool-using behavior that is similar to that of chimpanzees. In Boa Vista, Brazil, one such example of capuchin stone tool use has been studied extensively. Bearded capuchins (*Sapajus libidinosus*) have been studied and observed cracking nuts with stone percussors (Fragaszy, 2004). Capuchins, which are roughly the size of a house-cat (~2.5 kg; Fragaszy and Bard, 1996), adopt a different technique and posture than chimpanzees for cracking nuts. They tend to stand bipedally, with both hands on the percussor (Lui et al., 2009), unlike chimpanzees who tend to be in a seated posture with one hand on the hammer and one hand on the objective piece (Visalberghi et al., 2009). In a second study, which details and discusses stone tool use by Burmese long-tailed macaques (*Macaca fascicularis aurea*), Haslam et al., (2013) studied the use-wear on two distinct stone tool types used for two different activities. These two distinct tool forms are used

for two different foraging activities: axe hammering - typically of oysters attached to large boulders- and pound hammering of unattached encased foods. Haslam et al. demonstrated that the quantitative archaeological use-wear analyses accurately reconstructs the behavioral histories of tool using populations of non-human primates. Tan et al. (2015) expanded on Haslam et al.'s (2013) work and showed that stone tool use in Burmese long-tailed macaques is more complex than previously thought. Rather than two different tool types, as was reported by Haslam et al., Tan et al. recorded seventeen specific action patterns across three different types of hammer stones. Based on the studies of these small-bodied monkeys, it is clear that stone tool-use has been widely adopted not just among great apes, but more broadly in the primate order. The large body of work centered on questions about tool-use among the primate order has demonstrated that this behavior is not at all uniquely human. While archaeological investigations have long sought the mechanisms for raw material toolstone selectiveity, chimpanzee studies investigating toolstone selectivity, with regard to mechanical properties, do not exist.

1.2 Origins of Tool Use and the *Homo/Pan* Last Common Ancestor:

Although the Miocene (23-5.5Ma) is marked by great primate species diversity, it is not until the mid-late Pliocene (~3.5-2.5Ma) that tool use becomes visible in the archaeological record. The oldest deposits with modified stone tools and trace evidence on fossils dates to ~2.6Ma and are found at Gona, Ethiopia (Semaw et al, 2000). However, indirect evidence of stone tool-use from Dikika, Ethiopia suggest that hominins may have been using stone tools as early as 3.4Ma to process animal carcasses (McPherron et al., 2010). Recent research and excavation by the West Turkana Research Project has also yielded vitally important finds at the site of Lomekwi 3, which suggest that the earliest modification and use of stones as tools dates back to 3.4Ma (Harmand et

al., 2015). Although little is known about the function of mid-late Pliocene tools, these large hammers, anvils, and flaked cores (named the Lomekwian industry) suggest that by the mid-late Pliocene, hominins were procuring and manufacturing stone tools.

Early Oldowan sites (~2.0-2.6Ma) are more numerous throughout East Africa and have been extensively studied for over 50 years (Leakey, 1971). Oldowan archaeological sites have often been described as localities with hundreds or even thousands of flakes, cores and fossilized bones. However, the Oldowan exhibits variability; some localities yield many well-made flakes and cores with clear striking platforms and bulbs of percussion, while others are less dense, and show very few diagnostic bone surface modifications (Panger et al., 2002). Variability is also seen in the types of toolstone that are selected for tool manufacture (Braun et al., 2009). The method of manufacture of these tools has been debated, but Schick and Toth (1993) argue that along with free hand hard hammer knapping, a bipolar technique was used. By placing cores on top of a hard objects and striking them with percussors individuals removed sharp edged flakes. The bipolar knapping method has also been used to explain the manufacture of tools found at lomiekwi, West Turkana, which suggests that bipolar technique was being used during the earliest stages of stone tool manufacture. (Harmand et al., 2015). The assemblage reported by Harmand et al. (2015) yields a high percentage of pounding tools (hammers and anvils), which are the same tooltypes used by chimpanzees in order to crack nuts at Bossou and other chimpanzee sites in West Africa.

Parsimony and genetic studies suggest that between 5-8Ma*, Pan* and humans shared a last common ancestor (LCA) (Wood and Richmond, 2000; Prado-Martinez et al., 2013). Like humans, chimpanzees have been directly observed using stone tools

(hammers and anvils) to access the kernel of hard-shelled nuts (Wynn and McGrew, 1989). Since this common characteristic is seen on both sides of hominin and *Pan* phylogenies, it is possible that the last common ancestor was also a tool user (Panger et al., 2002). However, bonobos (*Pan paniscus*), a close relative of chimpanzees, have not been observed in the wild using tools to the same extent as chimpanzees, or to extractive foraging activities (Gruber et al., 2010). Part of the reasoning for this seems to be that bonobo study groups are less numerous than chimpanzee studies and temporally speaking, bonobo research projects have been short lived (Gruber et al., 2010). Despite relatively short research projects as compared to chimpanzee studies, few reports exist of bonobo tool use in the wild (Kano 1982; Ingmanson 1996; Hohmann and Fruth 2003). Due to these limited examples of tool use in the wild, some have looked toward extrinsic (ecological and social opportunities) and intrinsic (predispositions) as a mean for explaining a lack of tool use in bonobos compared to chimpanzees (Koops et al., 2015). In their study, Koops et al. demonstrate that chimpanzees have the tendency to have increased motivation toward manipulation of objects relative to bonobos. The lack of tool-use among bonobos becomes more interesting when one considers the presence of stone tool use among capuchins and macaques. One of the best explanations for this phenomenon is convergent evolution (Haslam et al., 2009). Generally speaking, convergent evolution is the process where non-monophyletic organisms independently develop similar traits as a result of adaptation to similar ecological niches. Genetic sequencing suggests that humans and macaques last shared a common ancestor ~25 Ma (Rogers and Gibbs, 2014). Based on this genetic information and different geographical

locations of the taxa being discussed here, the best explaination for the independent development of stone tool use is convergent evolution Haslam et al., 2009).

Wynn and McGrew (1989) argue that, in comparison to Oldowan technology, chimpanzees exhibit more visible characteristics of distinct 'culture' and high fidelity transmission than hominins have. These studies strengthen the argument for a distinct chimpanzee culture. In a second comparative analysis between chimpanzees and hominin tool-use, chimpanzees share many similarities with early hominins, including hammerstone raw material procurement, learning, and carrying of tools (Davidson and McGrew, 2005). Furthermore, chimpanzees have shown selective preferences for composite tool raw materials based on overall size and mass with regard to both hammer and anvil selection (Carvalho et al., 2008).

1.3 Objectives:

Here, I propose an objective approach to studying variables relevant to understanding extinct hominin and extant *Pan* raw material selection for stone tool procurement, using chimpanzees from the Bossou forest as referential models. The objective of this study is to identify preference for certain lithologies as chimpanzees select stones for nut cracking. In addition to identifying selection patterns of individual chimpanzees, this project has three main objectives:

1. Attempt to understand the relationship of toolstone selection by chimpanzees and raw material mechanical properties.
2. Identify the role that tool reuse plays in tool selection of local and exotic raw materials.

3. Identify the relationship between stone selection and number of chimpanzees nut cracking at the same time, establishing primary and secondary tool kits at the individual level.

Due to the similarities between the environment of extant chimpanzees at Bossou and the mosaic habitats of early hominids (Pruetz 2006, Pruetz & Bertolani 2007; Pruetz & Bertolani, 2009; Reed 1997; Kappelman et al. 1997) as well as the close evolutionary relationship between chimpanzees and *Homo* (Wood and Richmond, 2000), similarities are also expected in the way that chimpanzees and early hominids may have responded to environmental pressures in terms of their tool-using behavior. Ultimately, this research will quantify raw material selectivity in composite tool-using chimpanzees from Bossou for nut cracking. Upon establishment of these variables, quantification and comparison of the influence of different variables through mechanical property tests will provide a selectivity index, which describes chimpanzee preferences to select materials based on their physical properties. Once established, the data from this thesis will feed a larger discussion of primate tool use and will be used to interpret early hominin toolstone selection at Kanjera South, Kenya. Raw behavioral data for this analysis comes from The Bossou Outdoor Research laboratory (Guinea, West Africa). By coding video of nut cracking experiments, studying the invisible, intrinsic, mechanical properties of locally available and exotic lithologies, and comparing selection decisions by chimpanzees and early hominins, a better understanding of Plio-Pleistocene hominin tool use can be gained.

1.4 Modeling Hominins with Non-Human Primates:

Many animals, from New Caledonian crows (Hunt and Gray, 2003) to dolphins (Rendell and Whitehead, 2001; Barrett and Wursig, 2014) to octopuses (Finn et al., 2009)

adopt tool-using behaviors. Likewise, non-human primates will use tools as a mean, among many other purposes, to extract food from mechanically challenging resources. Although it is unclear who the earliest hominin tool user was, the earliest hominin toolmakers began leaving behind modified stone tools at least as early as 2.6 Ma (Semaw et al., 2000). Pliocene hominins have no living analogue with which we can make direct comparisons. Toolmaking has been linked to brain size but evidence of who the first toolmaker was with any taxonomic confidence, remains unknown (Toth and Schick, 2009). However, based on the great antiquity of the Oldowan, it is accepted that relative to anatomically modern humans (*Homo sapiens*), the first tool manufacturer and user was a small-brained biped. This notion is supported by paleontological evidence, which shows only two taxa on the East African landscape: *Australopithecus garhi* and early *Homo* (450cc and 550cc respectively; Toth and Schick, 2009). The lack of early hominin representations in contemporary times suggests that the best possible method to understanding past behavior is through referential models. Generally speaking, primate referential models are supported by homologies with early hominins in brain size/body size, extractive foraging, and the presence of stone tool use, among others (Toth and Schick, 2009). Thus, chimpanzees display a suite of behaviors and morphologies that make them a candidate for modeling hominin tool use and evolution. The following literary review discusses some of the previous studies that have employed this method for understanding various aspects of human evolution.

Boesch and Boesch (2000) modeled behavior from an evolutionary perspective, in which chimpanzee behavioral diversity should reflect niche diversity. Based on this idea, more demanding habitats should select for increased intelligence. They argue that niche

diversity can be tested among chimpanzees with regard to their natural physical and social worlds, and through cooperative hunting (p.226). Due to a diverse physical habitat, the Enviro-Intelligence Hypothesis predicts that these traits result in diversity in intelligence. While the physical world shapes mental representation and causality, the social world shapes social knowledge and theory of mind—the notion that individuals have the ability to attribute mental states (beliefs, intents, desires, and knowledge) to oneself and others and to understand that other individuals also have mental states (Premack and Woodruff (1978). The usefulness of Boesch and Boesch's (2000) model is highlighted by three common traits shared between chimpanzees and humans: chimpanzees are one of the few fission-fusion species, they are among a small group of non-human primates to hunt regularly, and the only non-human primates to regularly use tools. This model provides a precedent for the present study, which observes chimpanzee raw material selection patterns and uses them to gain past knowledge of the hominin behavioral repertoire.

Novel research in the fields of primate archaeology and primate behavior is not novel in and of itself. Carvalho et al., (2012) conducted field experiments with Bossou chimpanzees aimed at collecting quantitative data to elucidate the evolution of bipedality. Carvalho et al. (2012) demonstrate that chimpanzees will occasionally engage in bipedal locomotion in the wild. This behavior, according to their study, is linked to the competition for unpredictable, hence valuable, resources in the chimpanzee environment. Chimpanzees will often transport items in both hands, relying on the lower limbs solely for locomotion, as a means to escape a socially competitive environment. This study provides evidence for the evolution of bipedalism in accordance with the carrying

hypothesis, suggesting that an increased need to free the hands for carrying objects led to a need for more efficient bipedal locomotion (Carvalho et al., 2012).

In a schema of chimpanzee and hominin comparisons, Wynn et al. (2011) compare the characteristics of chimpanzees and Oldowan hominins. Wynn and McGrew (1989) suggested that the parallel characteristics shared with chimpanzees represent support for a distinct chimpanzee culture. Essentially, they argue that based on our knowledge of the Oldowan, there do not seem to be any striking characteristics of culture, or at the least, there is no way to know the role of social interactions and learning, simply from the archaeological record. Wynn et al. (2011), in a review and update on the Wynn and McGrew (1989) paper, provide stronger evidence than ever for a well-defined chimpanzee 'culture'. Furthermore, the characteristics of this culture (selection, transport, use, reuse, modification, and discard) strengthen evidence for the *Pan*-Oldowan connection in an evolutionary sense. Rather than suggesting that the Oldowan is an adaptive grade, they suggest that it was a variation on an older technology (Wynn and McGrew, 1989). This suggests that distinguishing ape from hominin archaeological records may be problematic. While Wynn and McGrew's, (1989 and 2011) argument appears logical, it should also be noted that no population of chimpanzees has been observed intentionally producing sharp-edged stones in the wild. While on occasion sharp edged flakes will be detached from an anvil during nut cracking, chimpanzees do not use these detached pieces as a tool (Carvalho et al., 2008). Regardless of the absence of data, the technology of chimpanzees offers a lot for modeling not only the earliest hominin technology but also, more broadly, ape tool-use in the late Pliocene.

The use of a great variety of tools consisting of perishable, organic materials by chimpanzees highlights the probability that early hominins likewise had a much richer, more diverse toolkit than is visible in the archaeological record (Toth and Schick, 2009). However, due to the absence of these perishable materials in the archaeological record, many studies are centered on understanding the stone stone tool manufacture and use of Plio-Pleistocene hominins. Since 1990, Toth and Schick have been conducting experimental studies that call for bonobos (*Pan paniscus*) to engage in hard-hammer percussion in order to produce sharp edged flakes to retrieve a food reward. The primary subject used was a young adult male bonobo named Kanzi that was taught by human knappers to produce "Oldowan like" tools. While it appears that most scholars believe early hominin tools were produced using hard hammer hand-held knapping methods, Kanzi was able to demonstrate that a throwing method (throw a core at an anvil, or throw a hammerstone at a core in order to remove flakes) could produce similar sharp edged flakes that could be used to complete tasks.

Kanzi produced an assemblage that was then compared to assemblages from Gona (2.6Ma archaeological material) and a modern experimental assemblage. The data show that the Kanzi-made assemblage is an outlying group. "The morphology of the bonobo cores and flakes appears to have been a function of less impact velocity (a probable biomechanical constraint) as well as less control, a possible cognitive constraint" (Toth and Schick, 2009; p.298). The experiments of Toth and Schick (2009) demonstrate that the expected result and the observed behavior do not parallel one another when comparing the cultural remains of extinct hominins, modern humans and bonobos. This suggests that researchers are missing small details that have a profound effect on the way

we interpret hominin behaviors in the past. The Kanzi experiments demonstrate that the earliest stone tool assemblages are probably much more variable then what has been predicted in the past. Furthermore, the work of Toth and Schick (2009) indicates that there are different, yet efficient stone tools produced by potentially different hominin or non-human primate species. The variability seen in the Kanzi comparisons with Gona and the modern experimental assemblage is possibly due to adaptations to different habitats and environments (Toth and Schick, 2009). Finally, non-human great apes and hominins indeed may have a lot in common with regard to tool use, but chimpanzees are still referential models, not time capsules of our hominin relatives.

Analytical methods for understanding archaeological phenomena have been applied to chimpanzee sites, specifically looking to understand the operational sequence (*Chaîne opératoire*) of chimpanzee tool use. In the first study to focus specifically on the existence of operational sequences during the utilization of stone tools by wild chimpanzees, Carvalho et al. (2008) identifies regional variables that influence regional diversity in tool typology and technology among chimpanzees (p.148). *Chaîne opératoire* provides archaeological researchers with a way to identify different phases of blank production in tool making and use in Paleolithic contexts (Sellet, 1993). Recent studies supported by use-wear analysis suggest that some early hominin activities were similar to the activities that we can now observe extant chimpanzees, such as nut cracking (Caruana et al., 2014). Furthermore, this method can be applied both to modern and prehistoric chimpanzee assemblages like those found in the Taï rainforest that date back 4,300 years (Mercader et al., 2007).

Stone tool assisted nut cracking is common among numerous populations of chimpanzees (*Pan troglodytes verus*) in western Africa. It appears that the type of nut consumed is mainly culturally determined (Biro et al., 2003). These cultures are regional in tool-use technical variations and "modes that cannot be explained on ecological or genetic grounds and that are part of the behavioral repertoire of a community, transmitted in a generational form through social mechanisms" (Carvalho et al., 2008; p. 151). The tool-using techniques that chimpanzees developed and employ can be seen as a form of problem solving, but the degree of technical complexity and variability may be affected by environmental and social factors that demand an adaptive solution. By looking at primatology and archaeology through an interdisciplinary lens, the foundations for modeling the evolutionary origins of technology are present (Marchant and McGrew, 2005).

Selectivity studies are not novel at Bossou. Biro et al. (2003) conducted a study that introduced novel species of nuts to the chimpanzees of Bossou. Oil-Palm nuts are the only species of nut that chimpanzees are observed cracking at Bossou. Biro et al., (2003) introduced the Bossou chimpanzees to two new species of nuts, which are found in nearby forested areas that make up the home ranges of separate chimpanzee populations. Biro et al. (2003) show that responses to the novel nut species differ highly between age groups. While adults will rarely select and crack the two novel nut species, the juveniles will interact with and crack them open with stones. Biro et al. (2003) demonstrate that behaviors and preferences toward novel objects in the chimpanzee environment differ between adults and juveniles.

A recent attempt to describe and discuss toolstone selectivity in chimpanzees has been the work of Schrauf et al. (2012), who showed that stone mass is an important characteristic in chimpanzee stone tool selection. In general, increased mass of the percussor results in fewer strikes needed to crack a nut (Schrauf et al., 2012). Theoretically, this means that a heavier stone will be more efficient than a lighter one. Earlier work conducted by Carvalho et al. (2008) also discussed the importance of mass in hammer selection. Successful in demonstrating that chimpanzees are selective of stone weight in a controlled environment, Schrauf et al. (2012), however, did not quantify chimpanzee selection across different rock types, a characteristic that is present in natural settings where chimpanzee nut cracking occurs. Furthermore, Schrauf et al. (2012) do not quantify the upper and lower boundaries of stone mass that are efficient, a variable that Carvalho et al. (2008) demonstrate is significant to success in chimpanzee nut cracking. I will argue that raw material variability plays a critical role in the selectivity patterns of chimpanzees, a characteristic that is true in our earliest tool using hominin ancestors (Harmand, 2007; Braun et al., 2008, Carvalho et al., 2008, 2009a, 2009b; Stout et al., 2010; Delagnes et al., 2011).

Without modern analogues for early hominins, and a lack of paleontological and archaeological evidence before 3.4Ma, new methods are needed to ask vital questions about non-human primate and hominin behavior. While chimpanzee composite tool use has been documented and studied for years, no studies have attempted to understand if, like our hominin ancestors, chimpanzees select stones of specific mechanical properties. By understanding if chimpanzees prefer harder or softer materials, we can gain information about how our hominin ancestors may have used raw materials as a means to

adapting to their environment. More than ever before, primatology and archaeology are contributing to our understanding of human evolution and early hominin behavior by employing these referential models (e.g. Sirianni et al 2015, Luncz et al 2014; Tan et al 2015; Benito-Calvo et al 2015).

1.5 Hominin Raw Material Selection Studies:

As discussed above, previous studies on the raw material selection by hominins have been very broad with regard to temporal range at a given site. Potentially a primary limiting factor resulting in the low number of studies looking at raw material selectivity is that compared to later archaeological industries, early Oldowan aged deposits (>2.0 Ma) are rare (e.g. Gona, Bouri, Omo River Basin, Olduvai Forge, West Turkana, Koobi Fora, Senga, Hadar, Kanjera South). However limited, these studies have yielded vital information about the cognitive abilities of Plio-Pleistocene hominins. Many of the earlier investigations regarding hominin raw material selection have been very broad in their description, relying on subjective measures of high versus low quality (Andrefsky, 1994). However, recent work has proven to be more quantitative in methods of analysis. Stout et al (2005) showed that among the locally available raw materials at Gona, the most selected raw material was trachyte. This toolstone is of 'high quality' when compared to other locally available materials. High quality materials have been defined as brittle and elastic, isotropic, and cryptocrystalline (Braun et al., 2009). This study was conducted by collecting surface samples that had eroded out of paleo-river systems that would have been a primary source for hominins 2.6Ma.

In studies of raw material selectivity and transport at Kanjera South, Kenya (~2.3Ma); Braun et al (2008, 2009) showed that, while locally available material was being used at the site, exotic material was desired and transported from ~13 km away

from the site. By looking at two important raw material mechanical properties, hominins at Kanjera South were selecting toolstone based on the materials' durability as well as the ability to flake these stones (Braun et al., 2009). When looking at the property of 'fracture predictability', a quality that hypothesized to be crucial to stone tool manufacture, hominin preference is not as obvious as that indicated by durability measures. When these two studies are combined, they show that late Pliocene hominins had a complex selective regime for raw materials (Braun et al, 2009).

In a temporally broad study, Harmand (2007) looked at raw material selectivity and transport from 2.34-.7Ma in the Nachukui Formation, West Turkana. The raw material study was a single aspect of a wider focused, *Chaîne opératoire* reconstruction. Interpretations of raw material were based on petrographical analysis and knapping experiments (Harmand, 2007). From the reconstruction of Lokalalei 2c (2.34Ma), hominins preferentially selected phonolites ~75% of the time while it was not the most abundant resource on the landscape. Trachyte was more abundant on the landscape. It is argued that phonolite as a medium-grained type of rock is a high-grade rock type, most suitable for flake production (Harmond, 2007).

The three discussed studies provide a baseline for this thesis. While they all provide vital information for understanding the selective regime of Plio-Pleistocene hominins, they lack an understanding of how hominins would have interacted at a smaller scale, a result of studying the time averaged archaeological record (Roebroeks, 1988; 1992). Based on the work from Harmand (2007), it is clear that hominins change toolstone preference over time. This change in selection is not driven by material availability on the landscape, as was demonstrated in the Nachukui Formation. To

understand cultural changes in the static archaeological record, we must engage in long-term studies that can be useful as models for understanding hominin behavior.

1.6 Mechanical Property Testing: Archaeological Applications:

Many of the previous studies of mechanical properties have failed to quantify the mechanism(s) driving the selection process. Various mechanical tests can be used to measure rock mechanics. The use of non-destructive measures of rebound hardness have been shown to be directly correlated with the ability to withstand strain, or force (Katz et al., 2000; Yilmaz and Sendir, 2002). It has been shown that there is a correlation between rebound hardness and other mechanical properties of rocks, specifically elasticity (Yasar and Erdogan, 2004). Important studies from Domanski et al (1994) and Noll (2000) showed the importance of these measures to the discussion of stone tool manufacture, with regard to stone fracture. Furthermore, abrasion hardness tests on various raw materials have proven to be useful for characterizing stone tool selectivity (Noll, 2000, Braun et al., 2009). By utilizing these engineering techniques, archaeologists can extract information about selected toolstone materials that played an important role in hominin adaptation to their environment.

Ample support for the importance of mechanical properties of rocks has been made in previous studies with regard to hominin too use. However, they are not entirely applicable to a discussion of composite tool use in chimpanzees, and arguments for the earliest tool use in the hominin grade. Prior to 3.4Ma, there is no evidence of stone tool use in the archaeological record, and evidence at this point in antiquity is based on two sites. If we are to practice under the assumption that composite tool use, similar to that of chimpanzees, was common among early hominins, then measures of fracture predictability and edge durability might play an integral role in raw material selection

during the Pliocene. Furthermore, a direct measure of the rocks' natural hardness and elasticity will also be useful for understanding the mechanics of intact cobbles. Hardness can be defined as a solid object's ability to resist permanent deformation when a compressive force is applied (Cotterell and Kamminga, 1990; Noll, 2000; Braun et al., 2009). Elasticity has been discussed at length in previous studies as being affected by the level of homogeneity (or lack thereof) in a stone (Luedtke, 1992). This measure refers to the ratio of stress to strain (IUPAC, *Compendium of Chemical Terminology*, 1997). Another way to think of elasticity is to imagine a rubber band that has been stretched and let go. It will generally snap back into its original shape. However, eventually the rubber will be stretched to its elastic limit, causing it to be permanently deformed.

Chapter 2: Methods

2.1.1 Bossou Outdoor Research Laboratory:

Research at Bossou-Nimba (7°39′N, 8°30′W), Guinea, West Africa represents one of the few long-term field sites for the study of wild chimpanzees in a natural setting. Research at this field site began in 1976, and has contributed a continuous flow of research projects investigating a wide variety of questions surrounding chimpanzee ecology, demography, social behaviour, health and cognition (Matsuzawa, 2008). Consisting of primary and secondary forests, the Bossou chimpanzees' habitat covers ~5-6km^2, surrounded in all directions by savannah (Sugiyama, 1981).

The population of chimpanzees at Bossou during the 2012 field season was 12 individuals (Males: FF, JJ, PE, TA, Fw, FL; Females: Jr, Jy, Fl, Pm, Yo, Vl). However not all individuals crack nuts: Fw and FL are brothers, and during the 2012 field season were both too young to crack nuts. Fw was still an infant, relying heavily on his mother for transportation and safety. However, FL is older, but 2012 was not a proficient nut-cracker. He would gather stones and nuts in an attempt to crack them, but based on the data collected in this study, he was never successful in gaining access to the kernel. Vl, a very old female was not observed cracking nuts at any point during the video from 2012. The remaining members of the Bossou group were all documented cracking nuts on numerous occasions.

Neighboring groups of chimpanzees inhabit the Nimba mountains to the south-east. This population, ~6km away, represents the closest population to that used for this study. It is suspected that fission-fusion social dynamics between these two groups could have been possible in the past, but within the last ~60 years, this is unlikely due to the lack of continuous vegetation surrounding the Bossou group (Biro et al., 2003).

Behavioral data used for this study come from two sources: (1) video recordings from the 2012 field season (January 30 to February 10, 2012) and (2) detailed field notes collected by Susana Carvalho, Dora Biro and David Braun during each experimental session. During this time, a total of 21 experimental sessions (referred to as "PAB") were conducted. Chimpanzees in the Bossou Forest regularly perform natural nut-cracking behavior, due in part to the ready availability of igneous and metamorphic rocks that are abundant in this area, and abundant supply of *Elaeis guineensis* nuts (Clark, 1967; Carvalho et al., 2008). Consistent with experiments from previous years, nuts and stones were placed at the top of Mount Gban, in the "Outdoor Research Laboratory" (a natural rectangular clearing measuring approx. 7X20m; Figure 2.1). This location is ideal for such experiments because chimpanzees cross over the top of the mountain on a daily basis as part of their regular ranging patterns (Matsuzawa et al., 2001; Biro et al., 2003). This setting provides ideal conditions for observation and ultimately data collection geared toward understanding a wide variety of chimpanzee behaviors. Observations are recorded from behind a wall constructed from vegetation in order to cause as little disturbance to the chimpanzees as possible.

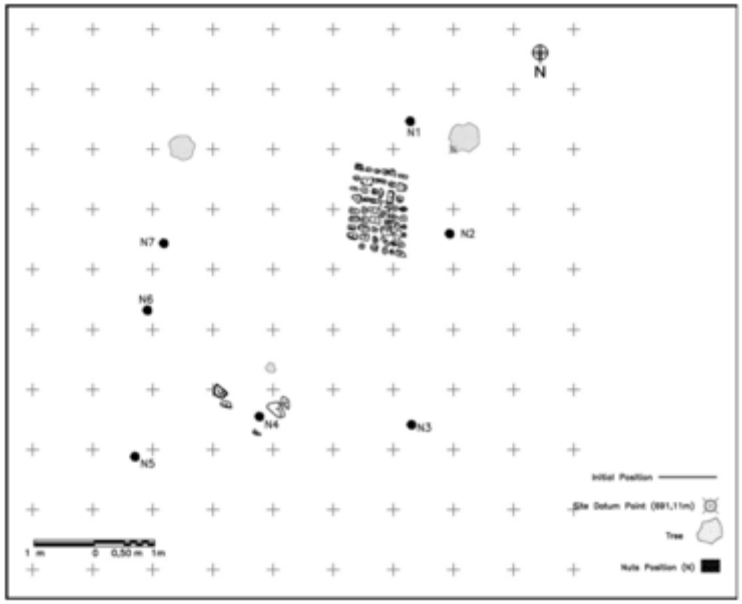

Figure 2.1: Site map for the Bossou Outdoor Research Laboratory taken from Carvalho et al., 2008. Cluster of small, dark circles in the center indicate the position of the stones at the start of each session. Small black dots indicate the location of the seven piles of nuts available for chimpanzees. Two larger dark grey circles indicate the location of trees in the outdoor research lab. The wall of vegetation from behind which the observations are conducted is along the lower edge of the figure.

2.1.2 Materials and Experimental Procedures:

The 2012 experimental sessions were divided into two conditions in which chimpanzees were provisioned with usable stones and nuts. Also common in both conditions was the removal of all locally available stones (amphibolite and African iron-oxide), which the Bossou group was accustomed to using regularly (Benito-Calvo et al., 2015). Condition 1 (PABs 1-7) consisted of providing two lithologies for the chimpanzees to use to process *Elaeis guineensis* nuts, carbonatite and dacite. Condition 2 (PABs 8-21) consisted of providing four lithological options for nut cracking, carbonatite, dacite, granite and phonolite. The total number of stones provided in any given experimental session ranged from 15-28 stones, and in each session 7 discrete piles of nuts were available. For Condition 1, the stones were placed in two rows and the order of raw material was not consistent in sequential experiments; that is to say that the initial

order of the stones varied from session to session throughout the experiment. Condition 2 consisted of four rows of stones that were again in no standardized order by raw material, size or shape. Across both conditions, the locations of the piles of nuts were constant. Each stone was labeled and painted with a letter denoting the raw material, and a number (example: C42; A carbonatite stone, number 42). Prior to the start of the experiment, data was collected from the stones (mass, phi scale axes measurements, Hobson 1979). For all experiments, observations began when the first subject entered the site, and ended one minute after the last subject exited. The primary source of data collection came from two video cameras. Camera 1 was controlled to focus on individual subjects who were nut cracking. Camera 2 remained zoomed out to record all activities across the entire site.

Prior to data collection from video footage, tutorial sessions were arranged with Susana Carvalho to ensure accuracy in identifying individual subjects. Coding of the video began on September 14, 2014 and ended on November 22, 2014. Data collected represents 12 variables listed in Table 1. The goal of collecting data on these variables was to provide a reconstruction of the video, in which one could later identify relationships between individual chimpanzees' selections and the raw materials selected, as well as to compile data for future studies examining questions that are beyond the scope of the present study.

Table 1: Example of data collected for raw material selection by Bossou chimpanzees. The names of each individual are abbreviated with two initials. The age of the individuals is divided between adult and juvenile ("A" and "J"). All times are posted in minutes and seconds. Selections are broken down into two options, matrix ("M") or reuse from another individual ("R").

Obs number	PAB number	Individual	Age	Time of selection	H, A, or B(both)	Time of first use	Time of stop	Hammer number	Anvil number	Selected from matrix or reuse	If reuse- who from?
1	10	FF	A	:26	B	1:10:00	9:23	D4	C41	M	N/A
2	10	TA	A	:27	B	1:54:00	2:38	D7	D8	M	N/A
3	10	PE	A	1:43	B	1:43:00	3:12	D12	C38	M	N/A
4	10	TA	A	2:38	A	3:04:00	24:53:00	D2	D8	M/R	TA
5	10	PE	A	3:12	B	4:32	5:15	C47	G13	M	N/A
6	10	PE	A	5:15	B	5:15	10:51	C47	C42	M/R	PE
7	10	JJ	A	8:26	B	8:26	10:38	G12	C38	R	PE
8	10	Jr	A	9:50	B	9:50	26:48:00	G11	G13	M	N/A
9	10	FF	A	10:39	B	10:40	15:12	D4	C41	R	FF
10	10	JJ	A	10:52	B	10:54	N/A	C40	C42	M/R	PE
11	10	PE	A	10:56	B	11:34	11:45	C47	C42	R	JJ-PE
12	10	FF	A	11:51	B	11:51	27:00:00	D6	C39	M	N/A
13	10	Jy	J	15:41	B	15:41	25:56:00	G12	C38	R	JJ-PE
14	10	PE	A	21:32	B	21:32	27:58:00	C39	D6	R	FF
15	10	Jy	J	34:33:00	B	34:33:00	35:10:00	D2	G13	R	Jr-TA
16	10	JJ	A	45:18:00	B	45:19:00	45:45:00	D?	G14	R	N/A

2.2.1 Mechanical Property Testing: Sample Preparation:

This project calls for the calculation of two very different physical mechanical properties. However, both tests can be conducted on the same rock samples. This is

because the means for determining Leeb Hardness and Young's Modulus of Elasticity are considered to be nondestructive by engineering standards. The six rock types used in this study were gathered from the Homa Peninsula, Kenya in July 2014 by Dave Braun (DRB) and shipped to the United States. Upon arrival, the materials were sorted by lithology by David Braun in the Stone Age Archaeology Laboratory at The George Washington University. Each stone was washed to remove external, surface sediment, and given a numerical designation that was written on the stone in permanent ink. Stones were set out in a cool dry room to ensure that each was dry prior to conducting any mechanical property test. Each stone was then measured for mass (g), maximum length (mm), width (mm), and height (mm) (Table 2).

Table 2: Table showing all of the initial data collected prior to sample preparation, organized by raw material, then by stone identification.

Stone ID	Raw Material	Mass (g)	Max. D. (mm)	Breadth (mm)	Thickness (mm)
1	1	1598.5	189.64	115.07	53.96

38	1	1941	174.46	172.12	69.39
41	1	2099.5	186.99	117.69	95.64
35	2	642.7	117.11	98.17	49.96
3	3	1520.1	151.55	97.51	73.02
7	3	1059.3	124.81	114.31	54.02
9	3	2564.1	179.49	132.29	100.88
15	3	1036.7	106.43	105.53	71.14
17	3	1010.7	128.35	96.11	60.01
27	3	746.9	139.45	105.92	39.5
33	3	808.3	119.04	71.19	66.57
5	4	1116.5	159.36	87.65	51.47
16	4	952.7	113.73	90.23	69.23
18	4	1157.1	124.5	92.64	71.03
19	4	715.5	98.32	88.53	67.09
6	5	591.8	106.21	81.52	48.24
12	5	1195.7	141.38	100.15	76.28
40	5	797.6	107.08	94.66	61.55
42	5	764.2	115.01	89.36	53.68
43	5	1222.3	156.33	81.87	66.14
8	6	902.3	113.06	87.06	65.11
25	6	1212.4	120.69	104.25	73.62
26	6	1266.1	131.42	94.54	85.83
28	6	1220.7	161.73	101.18	48.96
44	6	1513.4	171.47	96.98	90.69
11	7	1052.8	128.97	99.07	78.89
36	7	1929.2	180.23	117.83	63.75
39	7	1159.7	121.39	108.45	66.18
45	7	2218	197.66	89.3	98.38
46	7	1491.4	131.08	96.74	83.15

Initial Leeb hardness test were conducted on the external weathered surface of the stone (cortex). Subsequent Leeb hardness test were conducted on cut and polished samples. The second phase of sample preparation was to cut each stone into two slabs (three cuts per stone). This was done in the Geological Sample Preparation Lab in the Department of Biological Sciences at The George Washington University, under the supervision of Richard Tollo (Figure 2.6a-f). The saw used was a self-feeding lapidary saw (water and oil cooled) with a diamond inlayed slab blade. It should be noted that the use of a self-feeding saw is ideal for measuring Young's Modulus of Elasticity because the instrument requires two parallel surfaces that are both flat and smooth (See section 2.2.3 Mechanical Property Testing: Young's Modulus of Elasticity). Samples were not polished for this study as is recommended for other mechanical property tests because the diamond blade left the internal test surfaces of the rock smooth enough to forgo any secondary smoothing process. After being cut, each slab was then washed thoroughly to remove the water and oil cooling solution from the sample surface. Each slab was labeled based on the parent rock from which it was cut and given a sub-letter designation (i.e. 1a, 1b…etc).

2.2.2 Mechanical Property Testing: Young's Modulus of Elasticity:

To calculate Young's Modulus of Elasticity, slabs were tested with the *Proceq Pundit PL-200* ultrasonic transducer (Figure 2.4). However, before this equipment can compute values of elasticity, it needs values for density and thickness (referred to as "length" on the *PL-200* because it is the length between the two transducers). Density was calculated by weighing each slab in water in a large graduated cylinder. To do this, the mass of each slab (M_1), the mass of the graduated cylinder with water only (M_2), and the mass of the slab suspended in the water (M_3) were measured using a digital scale that

was recalibrated after all three measurements were taken for each sample. All measurements were converted into grams. The density was calculated with the following formula:

$$D = \frac{M_3 - M_2}{M_1}$$

The thickness of the sample was measured using digital calipers to the nearest 1/10mm.

Once all of the necessary variables have been calculated, the ultrasonic transducer was calibrated using 250kHz Proceq shear wave transducers with shear wave couplant and the Proceq Calibration Rod (25.4μs). Once Calibrated, there are three potential configuration options for the transducers; the direct transmission method is the "optimum configuration with maximum signal amplitude and is the most accurate method of pulse velocity determination" (Proceq User Manual, 2013). Thus, it was applied to our study. For each slab, the density and "length" were entered into the *PL-200* prior to taking each measurement. Once a measurement has been taken, the display screen shows the shape of the waveform. The instrument will identify the P-Wave form automatically. The last step is to locate the initiation of the S-Wave so that the onboard computer can calculate the distance and relationship between the two waveforms. The PL-200 measurements of Young's Modulus are calculated in gigapascals (GPa).

2.2.3 Mechanical Property Testing: Leeb Hardness:

To calculate Leeb Hardness (H_L) for each slab a *Proceq Equotip 3 Portable Hardness Tester* was used (Figure 2.5). This handheld impact body propels a carbide ball indenter via an extended spring into the test sample. After contact with the sample, the ball rebounds back into the impact body and passes through a coil, which houses a magnet. As the ball passes by the magnet it creates a voltage signal (*V*). Leeb hardness

values represent the relationship of the rebound velocity (V_r) and impact velocity (V_i) multiplied by 1000 (Proceq Operating Instructions, 2012).

Due to the small size of the samples being tested in this study, it was necessary to deviate from the traditional procedure in the Operators Manual. However, this does not render the test useless. The Operators Manual has a section for applications to light, thin samples, which the material being used for this study qualified. Testing small samples can be difficult because the indenter produces a high amount of force applied to the material. Due to this high amount of force, it is imperative that the test sample be coupled to a larger, solid surface area. If the test surface is not coupled to a significantly more massive surface (lab bench in this study) the indenter will provide inaccurate measures of the test surface. To ensure this did not happen I placed a thin layer of foam (~2cm) between a sample and a hard workbench that was faceted down with a C-clamp. This allowed the hardness tester to accurately read the rebound from the test slab, not from the slab and the hard workbench combined as a result of the reverberations from a small mass on top of a larger one.

Prior to testing the stone slabs, the indenter was calibrated using the "Equotip Hardness Test Block" (763 HLD). This procedure was repeated every 10 samples to ensure accuracy (6 times over the whole study). Each measurement taken consists of an average from 20 indentations, which were taken evenly across the whole slab surface. The Leeb Hardness scale measures values from 1-999 HLD. Due to the variations in lithology heterogeneity, test positions were selected at random to ensure that surface hardness readings were not preferentially selected.

Figure 2.2: Image of the PL-200 ultrasonic transducer at the Stone Age Archaeology Laboratory, George Washington University.

Figure 2.3: Image of Eqotip 3 Portable Hardness Tester at the Stone Age Archaeology Laboratory, George Washington University.

2.3.1 Chimpanzee First Selection and Reuse Analysis:

Research in quantifying selection in the primate order is not novel. Numerous studies have employed various methods for identifying selective patterns with regard to food sources in wild primate populations. However, studies like McConkey et al. (2002) quantification of fruit selection by gibbons cannot be manipulated and applied to chimpanzee composite tool selection for nut cracking. Their study calculates selectivity based on field observations of gibbons, which were then used to calculate the selectivity by using the equation:

$$S_i = f_i / a_i$$

wherein, f_i is the ratio of independent feeding observations on fruit taxon i to total observations, and a_i is the relative proportion of ripe sources. One issue with applying

this formula to chimpanzee tool selection is that the equation does not assume forced competition. At the Bossou Outdoor Laboratory, as many as ten chimpanzees had access to seven discrete piles of nuts. Furthermore, there is one centrally located matrix of stones for chimpanzees to base their selections, which increases their social interactions with one another. A second factor which separates these two scenarios and renders McConkey et al.'s formula ill-equipped to quantify chimpanzee tool selection at Bossou is that the number of stones in each experiment is fixed, limiting the number of options that can be selected and thus resulting in potentially "less desirable" stones being selected and over represented. Finally, it seems clear that while gibbons are feeding from a single tree or cluster of available fruit bearing trees, chimpanzees at Bossou appear to have a social dynamic that acts as a variable that influences selection. This social dynamic is not accounted for by many of the selection equations that have been employed in previous studies. For this study, it is important to understand that while many of the variables can be controlled (raw material type, species of nut, number of nuts and stones provided for the chimpanzees), it is impossible to control for the number of individuals or the sex of those individuals. Thus, a method for quantifying selection that can be flexible enough to accept these variables is needed.

For this study, it was decided that a first selection analysis and reuse analysis were the most ideal ways to quantify selections at the group and individual levels. After coding the 21 different experiments, a subset of data was compiled, which highlighted the first selection of each individual that participated. After coding the videos it was clear that some of the experiments needed to be excluded from the overall analysis of selection by the chimpanzees. Reasons for excluding experiments were if an experiment only had

one individual cracking nuts, or if the chimpanzees arrived at the Outdoor Research Area prior to being able to complete the pre-experiment procedure. The data from each experiment was then compiled for each individual using Microsoft Excel. Each first selection for each individual was broken down by raw material type. Depending on the number of first selections across all of the experiments, either a Chi-Square test or Fisher's exact test was used to calculate the probability of how likely the results are assuming the null hypothesis was true. For these analyses, the null hypothesis was that stone raw material does not play a role in the selective patterns of chimpanzees when nut cracking. If raw materials do not play a role in the selective regime of nut cracking chimpanzees the selection data would be evenly distributed across all four raw materials. Rather than using standard parametric statistical analyses, Monte Carlo tests were then used to retest the data 1000 times, which allowed for a distribution of results to be catered to the exact data collected. This was selected over parametric tests because, generally speaking, parametric tests are calculated by assuming a normal distribution of results is likely.

Due to the expected social complexities of chimpanzee groups, this study applies an analysis of the reuse patterns of composite tool selection. The first selection analysis, discussed above, is intended to identify the preferential raw materials that chimpanzees will select. However, because these experiments will often have several individuals cracking nuts at the same time, it was necessary to identify the relationships of and differences between what an individual will select given the whole population of stones to choose from and those which are selected after being discarded by another chimpanzee. The reuse analysis has previously been applied at Bossou by Biro et al. (in

prep.). The goal of this analysis is to identify the social influences that one individual may have on another. Consistent with Biro et al, a reused tool is defined as a tool that has been discarded and re-selected within one minute after discard. The time of the discard and subsequent selection were both noted, as well as the individuals involved in the exchange. Data from each individual were then compiled in Microsoft Excel and uploaded to R-Studio where Chi-Square and Fisher's exact tests were computed for the recycle analyses. These two statistical tests require expected distributions in order to calculate the deviation of the observed data. The expected distribution was generated in R by taking the number of observations and randomly selecting one of the four available raw materials as many times as were recorded in the behavioral videos. Following the same methods of the first selection analysis, Monte Carlo statistical analyses were run to generate a separate distribution of results for each individual.

Figure 2.4: Six images showing the complete stone samples after preparation. A) shows raw material 1 (Carbonatite) and the six samples cut from three parent stones, B) Shows raw material 3 (Quartzite) and the 14 samples cut from 7 parent stones, C) Shows raw material 4 (Dacite) and 8 samples cut from 4 parent stones, D) Shows raw material 5 (Granite) and 10 samples cut from 5 parent stones, E) Shows raw material 6 (rhyolite) and 10 samples cut from 5 parent stones, F) Shows raw material 7 (Fenitized) and 8 samples cut from 4 parent stones.

Chapter 3: Data and Results

3.1 Mechanical Properties: Tests and Results:

Leeb Hardness measurements are based on a numeric scale from 1 to 999 (Soft-Hard). This study examines 56 total samples taken from six different raw material stones: carbonatite, quartzite, dacite, granite, rhyolite, and fenetized rocks. The 56 stone slabs were extracted from 28 parent stones, which yielded 2 sample slabs each for a total of 56. This study sample counts with uneven quantities of each raw material, due to field sampling biases. Carbonatite = 3, quartzite = 7, dacite = 4, granite = 5, rhyolite = 5, fenetized = 4.

Measurements of the Leeb hardness (H_L) were the first data collected for this study (Figure 3.1). Across all raw materials, carbonatite was the outlier of the group when measuring the cortex (surface) of the stone (Range = 337-407 HLD, Mean = 379 HLD). The remaining raw materials had a considerable amount of overlap, with regard to their cortical Leeb hardness values. Fenetized rock had the largest range of the samples being examined (Range = 618-894 HLD, Mean = 776 HLD). Measurements of fenetized rock overlap with all of the raw materials, with the exception of carbonatite. Cortical measurements for rhyolite were the highest overall, and the lower limits of its range overlap with values from fenetized, granite, and quartzite (Range = 831-914 HLD, Mean = 883).

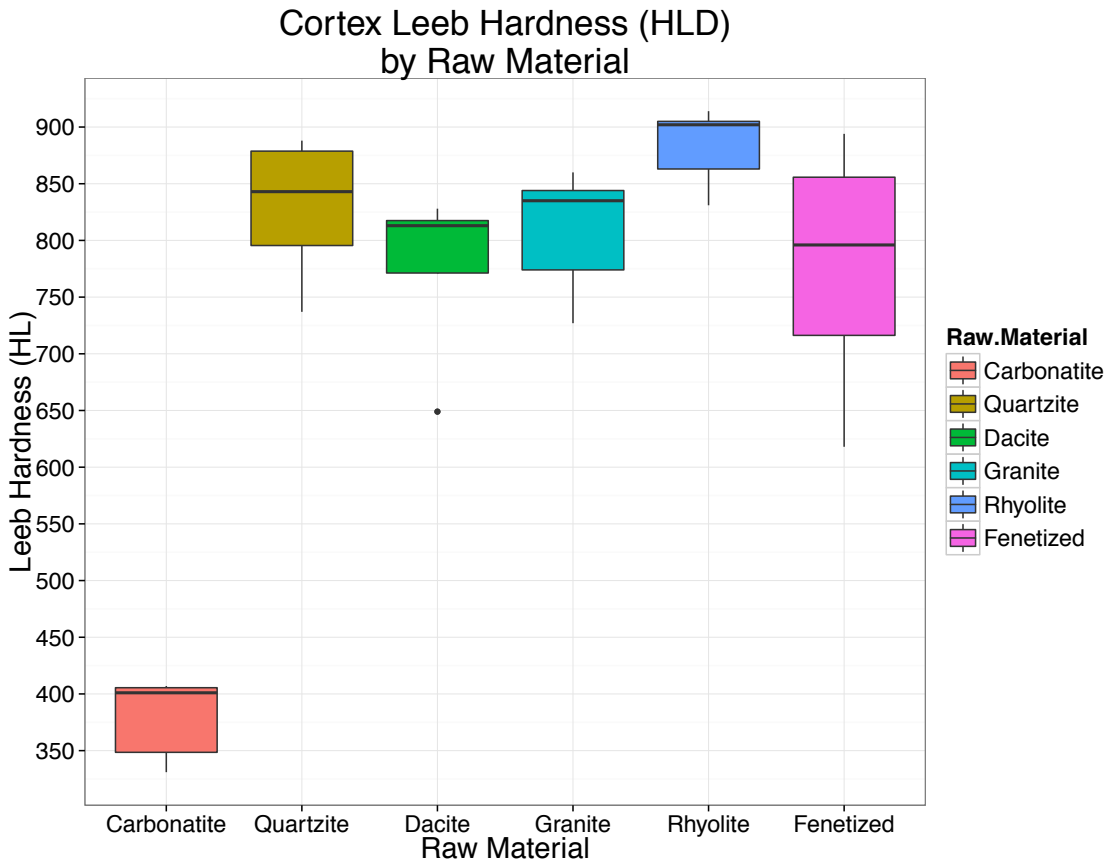

Figure 3.1: Boxplot showing the results of the Cortex Leeb Hardness test identifying the range of each raw material used in this study. The thicker black line in each box indicates the average measurement for each raw material. The stems of the boxes indicate the quartile measurements for a given raw material.

Analysis of variance statistical tests were conducted in order to identify statistical significance in the sample. However, due to the non-normal nature of the data being presented in this study, a non-parametric Kruskal-Wallis test was conducted on the same data (Kruskal-Wallis H = 28.6849, df = 5, p-value = 2.673e-05).

The second analysis was conducted on the internal surfaces of the stone slabs (Figure 3.2). For this analysis, ANOVA tests were not used to test the null hypothesis of chimpanzees do not select composite-tools based on their raw materials because of non-normality. Thus a non-parametric Kruskal-Wallis test was used to test the null hypothesis. Similar to the cortical Leeb data, presented above, the internal Leeb hardness shows that carbonatite recorded the lowest average internal hardness values (Range = 471-651 HLD, Mean = 576). In this dataset, dacite exhibited the largest range of all raw materials, which overlapped with carbonatite, quartzite, granite, rhyolite, and fenetized rock (Range = 595-882 HLD, Mean = 786). This large range can be attributed to the sampling method for taking Leeb Hardness measurements. Due to this method, it is not uncommon for measurements to be taken on internal fractures and inclusions, which were common in the dacite samples used for this study. The highest overall value for internal Leeb hardness was sample number 26b (969 HLD), but this falls outside of the interquartile range and is considered to be an outlier in the group. The raw material with the highest group average was quartzite (Range = 865-939 HLD, Mean = 907.57), and its lower values overlap with granite and rhyolite.

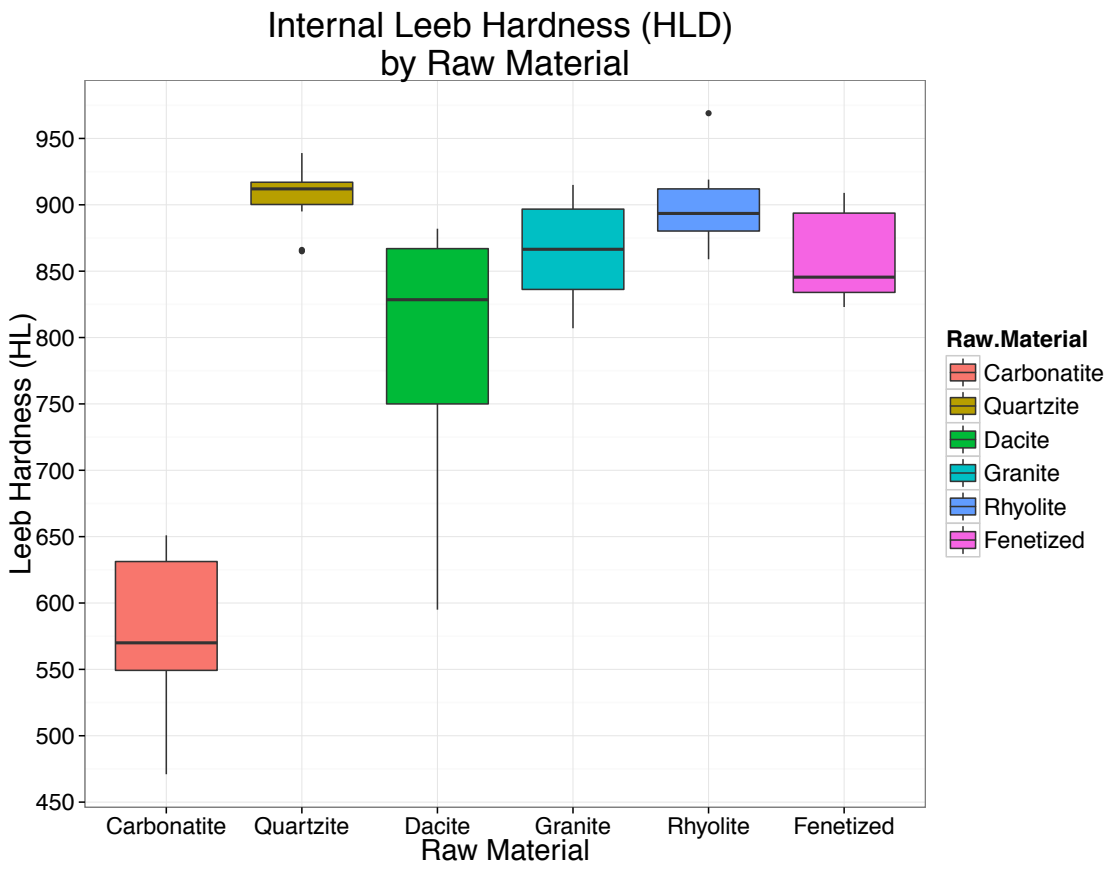

Figure 3.2: Boxplot showing the results of the Internal Leeb Hardness test identifying the range of each raw material used in this study. The thicker black line in each box indicates the average measurement for each raw material. The stems of the boxes indicate the quartile measurements for a given raw material.

The internal Leeb hardness dataset was analyzed in the same fashion that the cortical data was. Analysis of variance statistical tests were used to test for statistical significance in the sample. Based on the ANOVA test, the results of the internal Leeb hardness measurements indicate that we can reject the null hypothesis with a p-value below .05, indicating that there is significant, non-random difference between the 6 raw materials. The results of the Krustal-Wallis test suggest that the null hypothesis can be rejected. (Kruskal-Wallis H= 32.3619, df = 5, p-value = 5.037e-06).

The second material property test conducted on the stone samples was a calculation of Young's Modulus of Elasticity (Figure 3.3). This test was conducted on all 56 samples, from all six raw materials. Young's modulus hypothesis testing methods

were consistent with the previous two studies, wherein data was non-normal and so the parametric tests were excluded and a non-parametric Krustal-Wallis test was employed. With regard to the sample presented here, carbonatite received the lowest Young's Modulus values (Range = 3.23-4.4, Mean = 3.85). The highest scores of carbonatite overlap with the lowest scores from granite. The raw material with the greatest amount of range and variation in elasticity values was rhyolite (Interquartile Range = 10.56-13.32, Mean = 11.9). Rhyolite yielded two values that dropped below the interquartile range (28a and 28b, 6.51 and 6.84 respectively), are viewed as outliers in the subsample of the Young's Modulus data. Rhyolite was also the raw material with the highest values for Young's Modulus recording values ~2X higher than dacite, the raw material with the second highest Young's Modulus values.

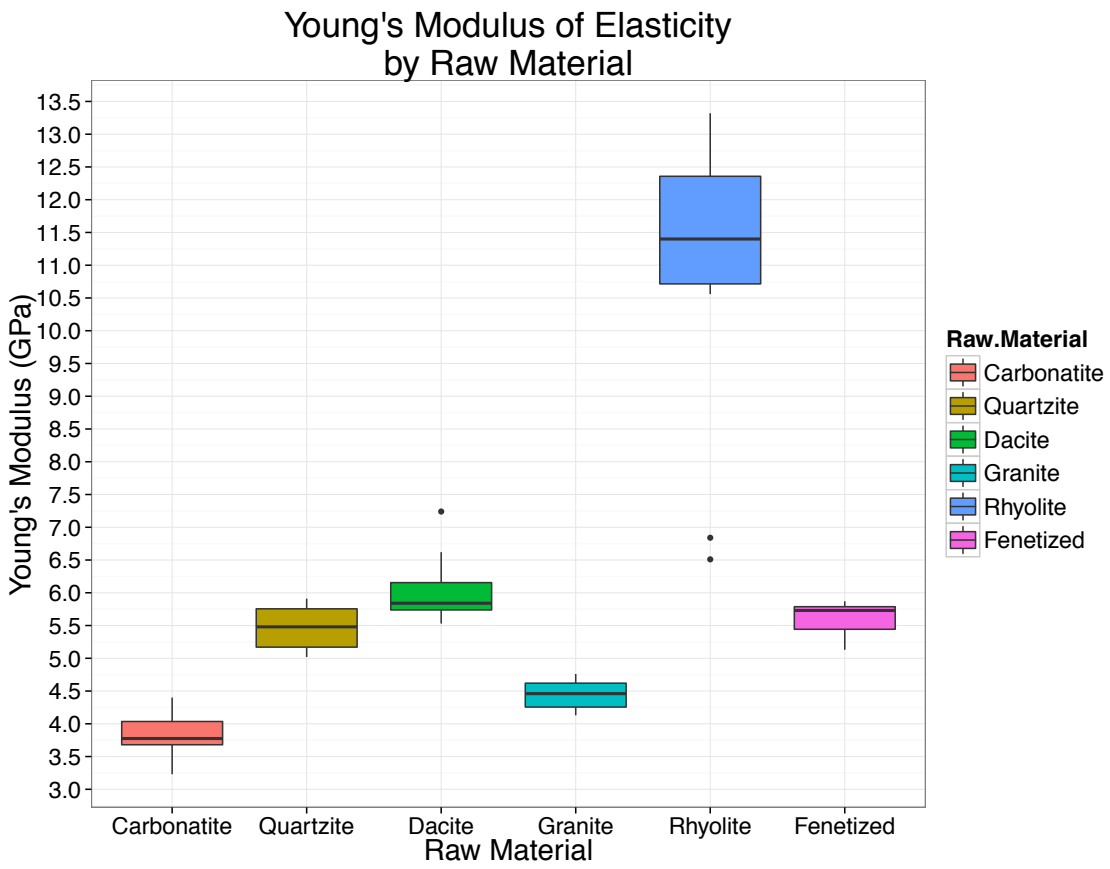

Figure 3.3: Boxplot showing the results of the Young's Modulus of Elasticity test identifying the range of each raw material used in this study. The thicker black line in each box indicates the average measurement for each raw material. The stems of the boxes indicate the quartile measurements for a given raw material. The higher the value with regards to elasticity, the more elastic the material is.

Similar to the Leeb hardness data that was discussed above, the Young's Modulus subset of data was tested for statistical significance using a Kruskal-Wallis non-parametric test. Based on the K-W test, the results of the internal Leeb hardness measurements indicate that we can reject the null hypothesis with a p-value below .05, indicating that there is significant, non-random difference between the 6 raw materials (Kruskal-Wallis H = 47.2835, df = 5, p-value = 4.973e-09).

3.2.1 Behavioral Data: Condition 1

Condition 1 behavioral data was collected from six experimental sessions (PABs 1, 2, 3, 6, 8, and 9) and yielded a total of 66 observations that provided data for the

selection decisions of chimpanzees at Bossou. During condition 1, PAB lengths varied from a total of five minutes to one hour and fifteen minutes. The largest group of chimpanzees at the site during Condition 1 took place during PAB 9 and contained a total of 9 individuals. PABs 1 and 2 both had a single individual nut cracking; as was previously discussed in Chapter 2, instances where only one individual was present resulted in a disqualification from the experiment and overall data set. The average number of individuals cracking at the site during this phase of the study was 4.2 individuals. The overall selections of this condition can be seen in Figure 3.4.

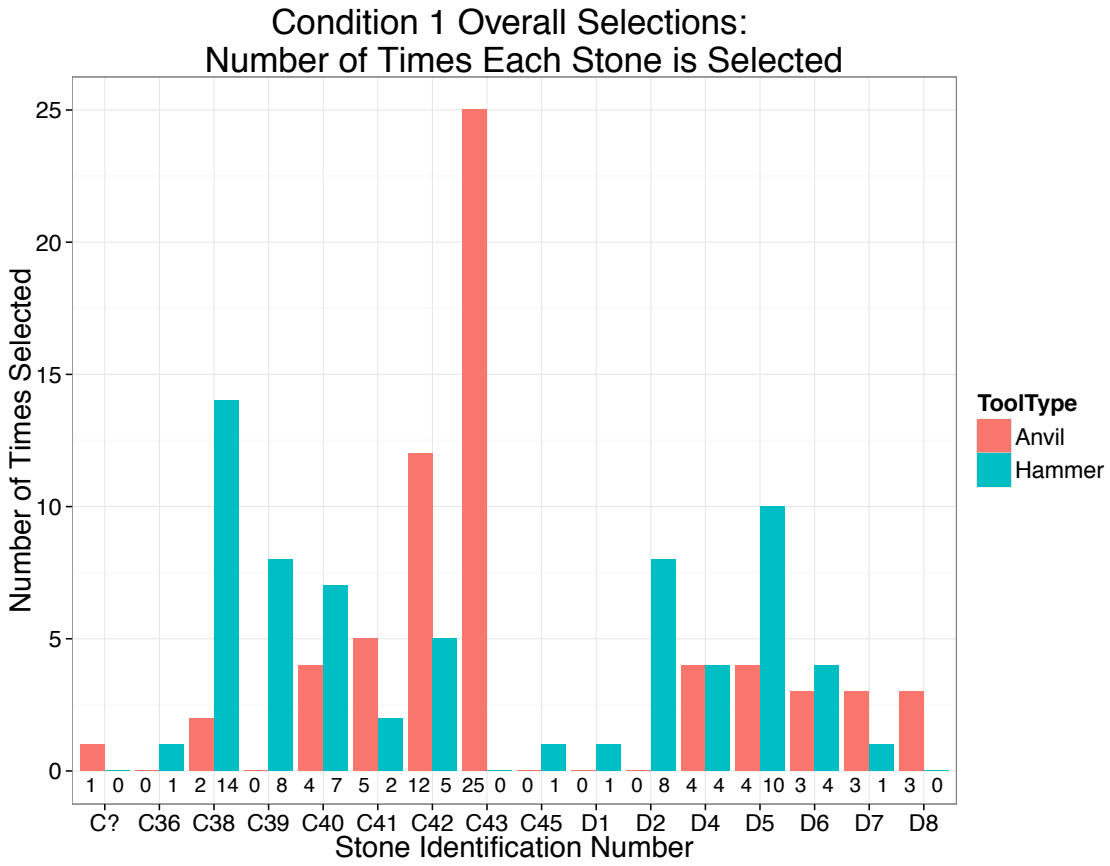

Figure 3.4: Bar chart showing the number of times each individual stone was selected during Condition 1 of the 2012 Bossou field season. The numbers below the bars indicate the exact number of time each was selected. This plot is broken down by tool type (Anvil or Hammer). Color indicates the tool type that the stone was selected for.

Based on the Condition 1 overall observations, C43 was selected more often than any other tool (n=25), and was only selected for use as an anvil. C42 was the second most

selected anvil and, at different points throughout the study, was used both as a hammer and an anvil. The most frequently selected hammer during Condition 1 was C38 (n=14). The second most selected hammer was D5 (n=10). During Condition 1, multiple stones were never selected for use as one of the two tool options (C?, C36, C43, C45, D1, D2, and D8).

The overall selections were then broken down based on the raw material class of stone (Figure 3.5). Between both raw materials that were used during Condition 1 (carbonatite and dacite), carbonatite was selected the most as an anvil (n = 49) and dacite was selected the most as a hammer (n = 28). During Condition 1, both tool types were represented within the two raw material categories.

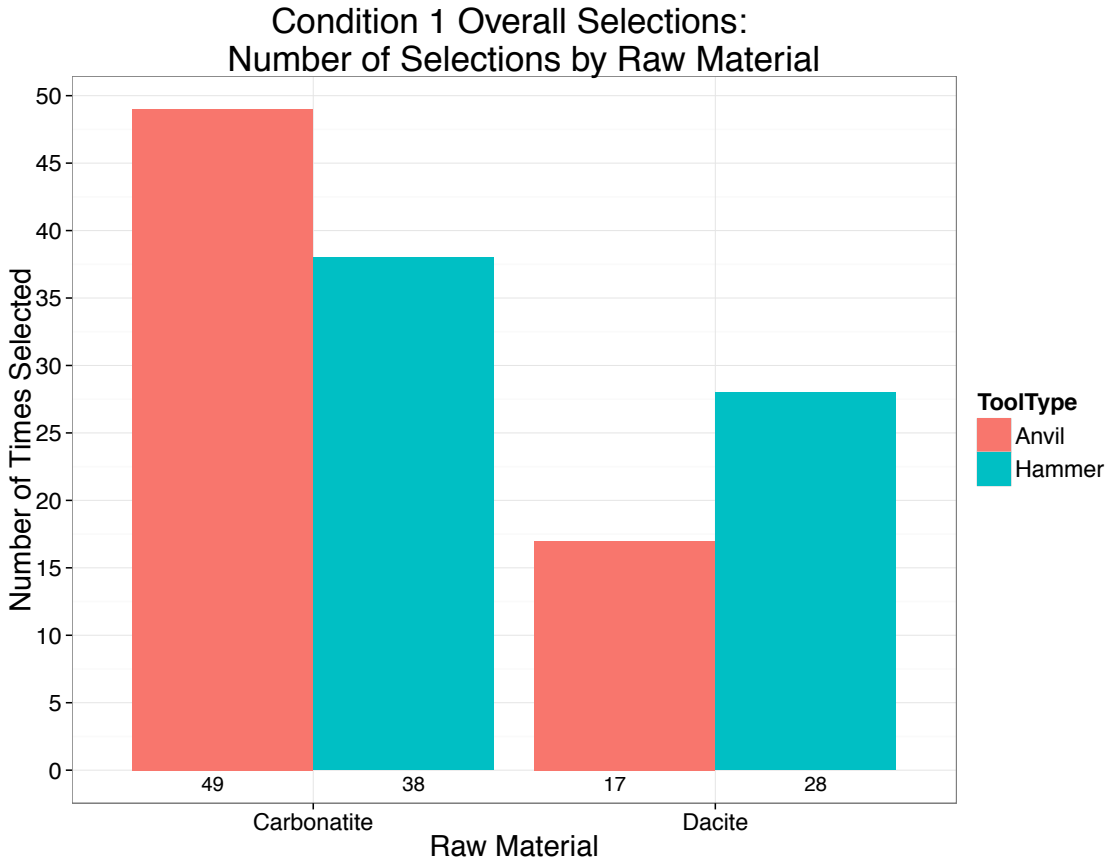

Figure 3.5: Bar chart that pools all of the Condition 1 data from Figure 3.4 into discrete categories of raw material: Carbonatite and Dacite. Numbers located under the bars indicate the actual values. Colors indicate the tool type that was selected by chimpanzees.

Condition 1 selections were analyzed using Chi-Squared tests to identify the significance of selection variations between the two raw materials. With regard to anvil selection, the data recorded for Condition 1 show that based on random selection generated with R, data like those being presented here are not what would be expected based on random chance (Figure 3.6a). Thus, with the p-values below .05, the null hypothesis is rejected and these data are taken to show selection preferences in anvil selection for carbonatite over dacite (Chi-squared = 15.5152, df = 1, p-value = 8.18e-05). However, the same cannot be said of the hammer selection patterns for condition 1 (Figure 3.6b). Based on the same statistical testing, overall hammer selection does not indicate that chimpanzees have preferences for one raw material over the other (Chi-squared = 1.5152, df = 1, p-value = 0.2184).

The second analysis geared toward understanding the behavioral data was a first choice selection analysis. This subset of data represents a total of 32 observations across the 6 experimental sessions that made up Condition 1 and represent the first selections of each individual present in any PAB (Figure 3.7). A breakdown of these data shows that carbonatite was selected the most as both a hammer and anvil (n = 11 and n = 9, respectively). Dacite was a first choice selection a total of 12 times and was used more often as an anvil than as a hammer (n = 7 and n = 5, respectively).

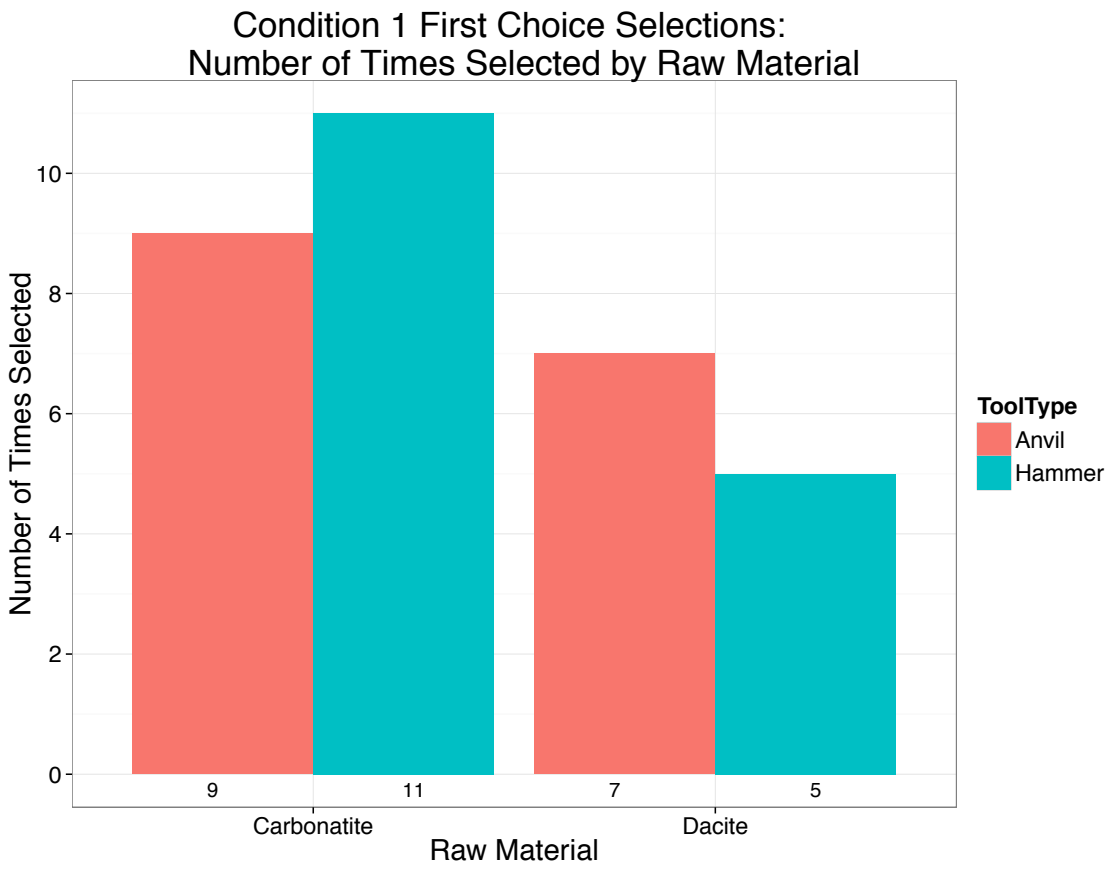

Figure 3.6: Bar chart showing the number of times each raw material was selected during the Condition 1 first choice analysis of data. Colors denote the type of tool that a given raw material was used for.

The first choice selection pattern shows that, similarly to the Condition 1 overall selection pattern, chimpanzees preferentially select anvils, while hammers are not preferentially selected for (Figure 3.8). The Chi-Squared test results show that, with regard to anvils, the null hypothesis can be rejected and the alternative hypothesis can be accepted as the p-value is below .05 (Chi-squared = 6.25, df = 1, p-value = 0.01242). Unlike the anvil selection pattern, first choice hammers from Condition 1 show a similar result, with regard to statistical significance to the overall selection pattern. The 11 selections of carbonatite and 5 selections of dacite do not represent a statistically significant difference, and thus the null hypothesis cannot be rejected (Chi-squared = 2.25, df = 1, p-value = 0.1336).

The Final analysis of Condition 1 was to subset the selection data that represented reused/recycled selections from a previous individual that was nut cracking (Figure 3.9). Of the 66 total observations from Condition 1, 24 selections were classified as reused or recycled (see methods for definition of reuse/recycle).

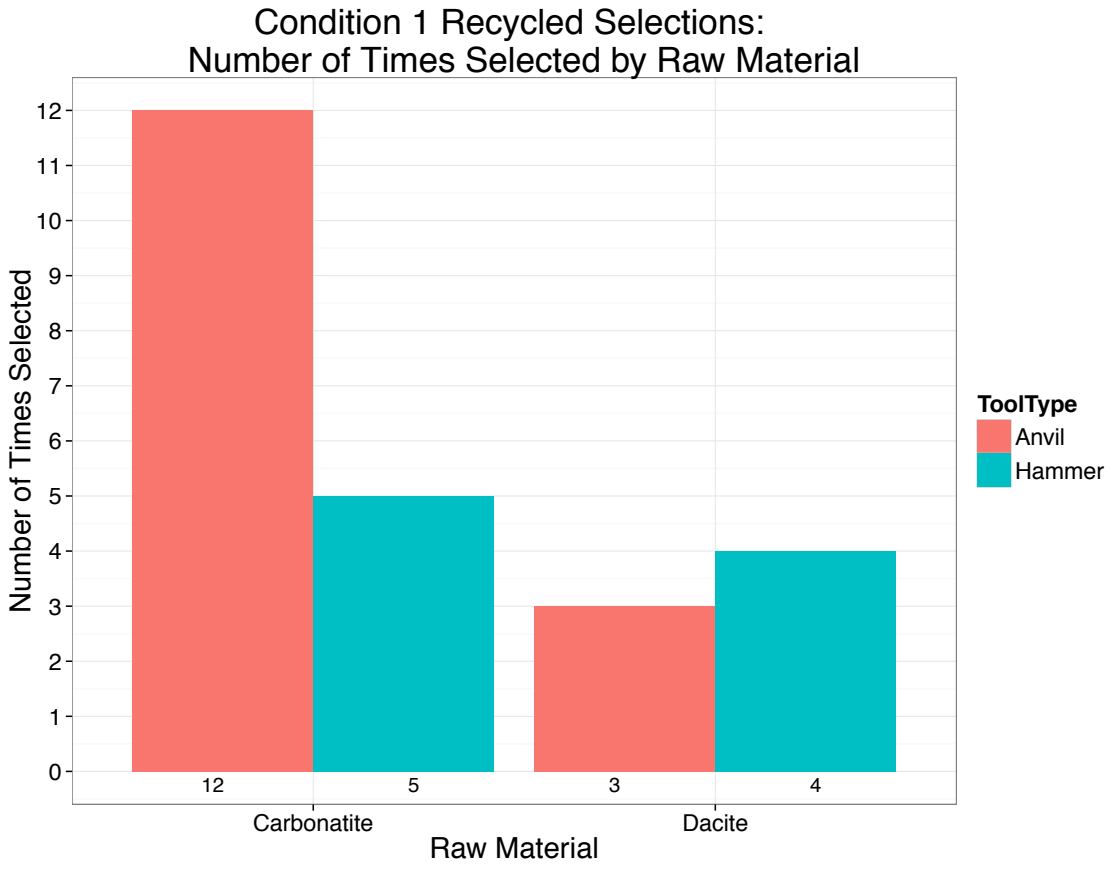

Figure 3.7: Bar chart showing the number of times each raw material was selected during the Condition 1 reuse/recycle analysis data. Colors denote the type of tool that a given raw material was used for.

Carbonatite was selected the most across both raw materials (n = 15). Carbonatite was recycled the most as an anvil during Condition 1 (n =12). Hammer recycle was much less frequent than anvil, and dacite was recycled as a hammer more than carbonatite (n = 4 and n = 3, respectively). The reuse/recycle analysis was tested for statistical significance with the same methods as the overall and first choice selection data were. The Chi-Squared test results show that, consistent with those of the overall and first choice data,

reuse/recycle data demonstrate that chimpanzees exhibit selective preferences for anvil raw material (Figure 3.10a). The p- value is low enough to reject the null hypothesis and accept the alternative hypothesis that selection of a specific raw material over another is not likely due to just random chance (Chi-Squared = 5.4, df = 1, p-value = 0.02014). With regard to the reuse/recycle selections of hammers throughout Condition 1, the results are consistent with the two above analyses, the data do not produce statistically significant values below .05 (Figure 3.10b). Thus, the null hypothesis is intact and cannot be rejected. The difference in values between selection of carbonatite and dacite as a hammer tool is not drastic enough to increase the possibility of a preferential raw material for hammers (n = 5 and n = 4, respectively).

3.2.2 Behavioral Data: Condition 2

Condition 2 behavioral data were collected from a total of 8 experimental sessions (PAB's: 10, 13, 14, 15, 17, 18, 19, and 20) and yielded 165 observations of chimpanzee raw material selection. During Condition 2, PAB lengths varied, ranging from 28 minutes to 1 hour and 30 minutes. The number of individuals present at the research site varied between experimental sessions and ranged from 4-12 individuals, with a mean of 8.125 individuals across Condition 2. The largest group of individuals occurred in PAB 10, and the smallest group occurred during PAB 14. The overall selections for Condition 2, with a breakdown by specific stone ID can be seen in (Figure 3.11).

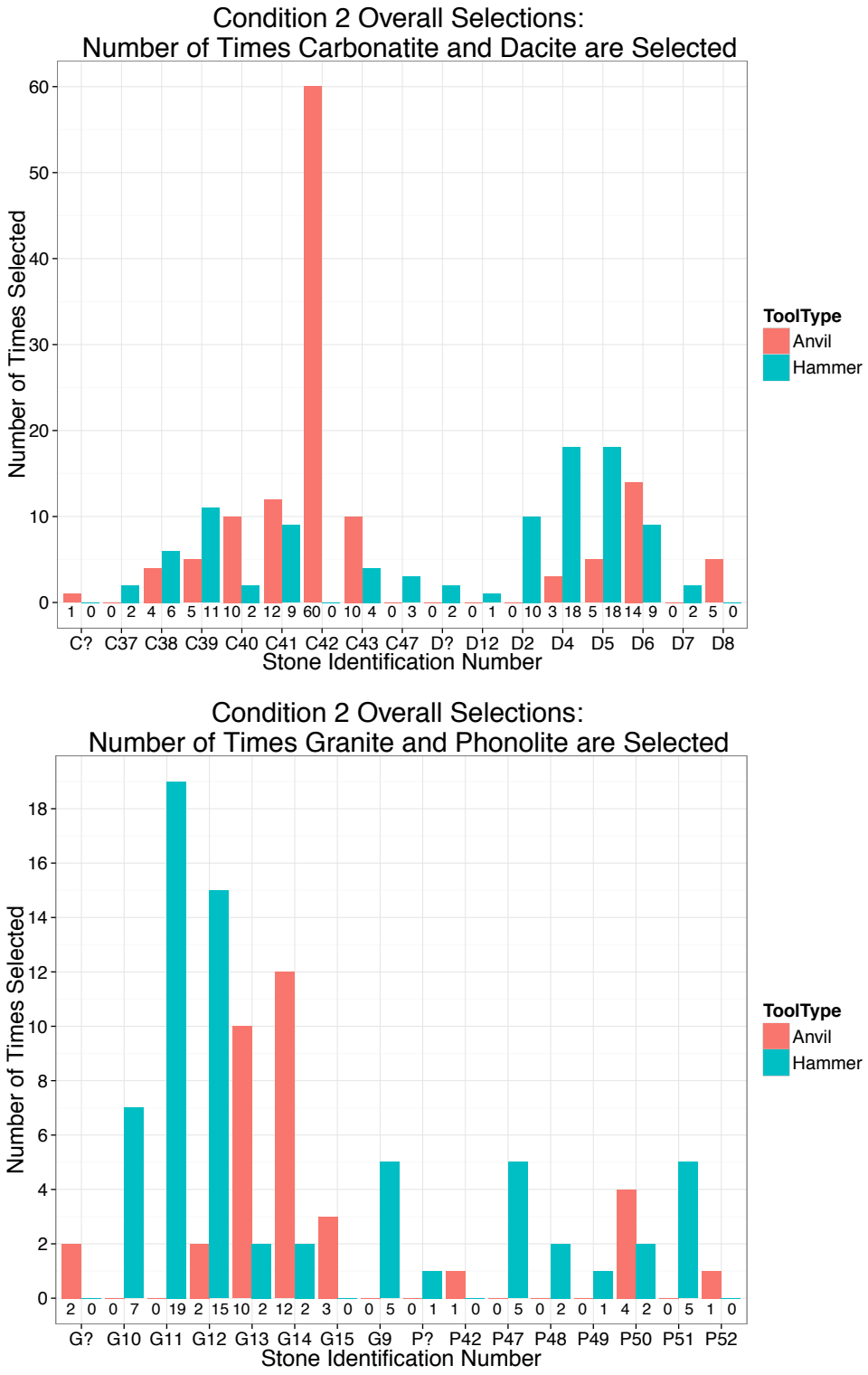

Figure 3.8: Bar chart showing the number of times each individual stone was selected during Condition 2 of the 2012 Bossou field season. The numbers below the bars indicate the exact number of time each was selected. This plot is broken down by tool type (Anvil or Hammer). Color indicates the tool type that the stone was selected for. A) displays the raw materials Carbonatite and Dacite, B) displays the raw materials Granite and Phonolite.

Based on the Condition 2 data, the most selected tool across all experimental sessions was anvil C42 (n = 60). The second highest selected tool across all experimental sessions was hammer G11 (n = 19). No single stone was left unselected for either tool type, but several were never selected as either a hammer or an anvil (C?, C37, C42, C47, D?, D12, D2, D7, D8, G?, G10, G11, G15, G9, P?, P42, P47, P48, P49, P51, and P52).

The overall selections were then broken down based on the raw material class of stone (Figure 3.11). Between all four raw materials that were used during Condition 2 (carbonatite, dacite, granite, and phonolite), carbonatite was selected the most as an anvil (n = 102) and dacite was selected the most as a hammer (n = 60). During Condition 1, both tool types were represented within the four raw material categories. Phonolite tools were the least selected throughout Condition 2. Phonolite contributed a total of 22 out of 327 selections (Anvils = 6, Hammers = 16), representing only 6.72% of total selections.

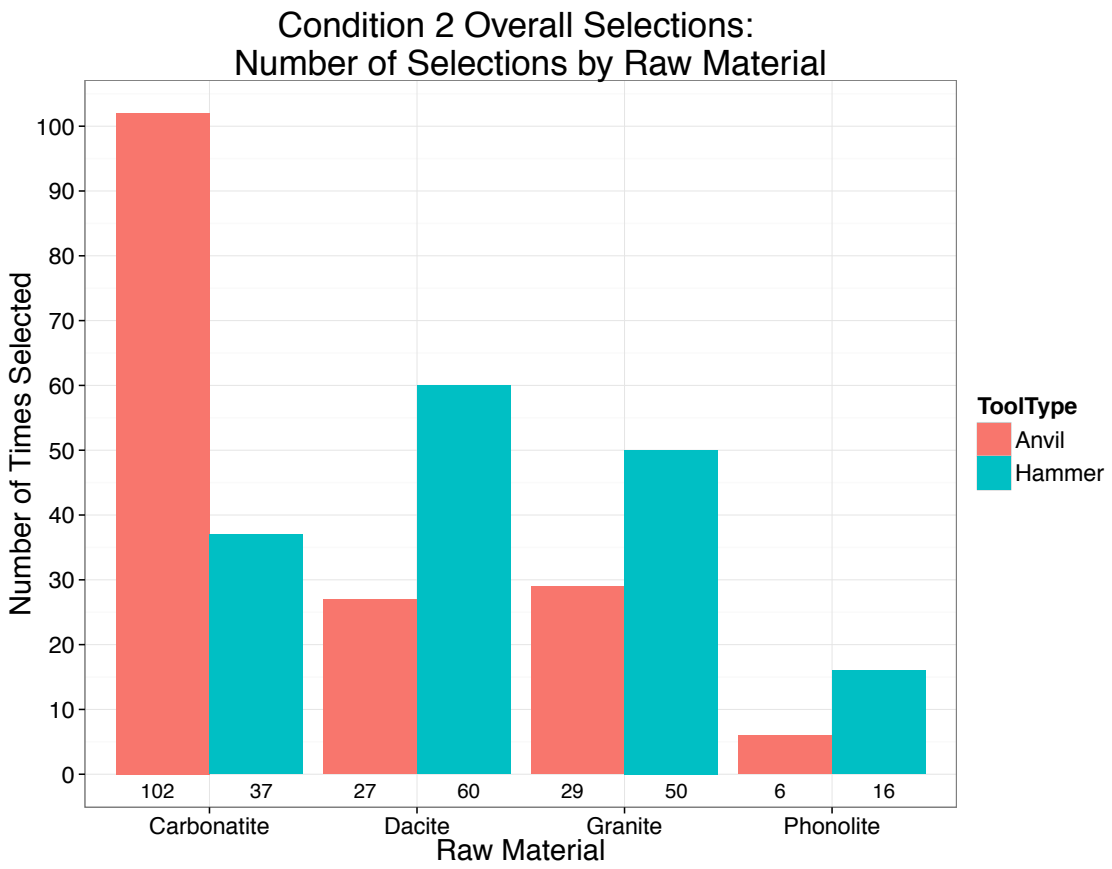

Figure 3.9: Bar chart that pools all of the Condition 2 data from Figure 3.10 into discrete categories of raw material: Carbonatite, Dacite, Granite, Phonolite. Numbers located under the bars indicate the actual values. Colors indicate the tool type that was selected by chimpanzees.

The overall selection data from Condition 2 were analyzed in the same manner as the data from Condition 1. Using ANOVA tests allows for the testing of whether the pattern observed in the behavioral data presented here is consistent with what would be expected given random chance (Figure 3.13). Based on these tests, both tool types (hammers and anvils) have been divided into two subsets of data, which were analyzed separately. The ANOVA tests show that overall stone selection patterns by chimpanzees, for both hammers and anvils, yield a p-value below .05, suggesting that the null hypothesis can be rejected and the alternative hypothesis, chimpanzee stone selection patterns are not consistent with what would be expected given random chance, is still intact. Thus, the overall selection pattern for both hammer and anvil selection across all

individuals present at the research site during Condition 2 suggests that chimpanzees show preferences for specific raw materials over others (Hammers: Chi-Squared = 26.5706, df = 3, p-value = 7.243e-06; Anvils: Chi-Squared = 128.9268, df = 3, p-value = <2.24e-16).

The second analysis conducted on Condition 2 data was the first choice analysis (Figure 3.14). This data comprises a subset of 72 selections from the 165 overall observations (330 total selection decisions). The highest selected first choice tools were carbonatite anvils (n = 16). With regard to carbonatite hammer selection, this material was selected the least as a hammerstone by chimpanzees across all Condition 2 experiments. While granite was selected more often than dacite as an anvil (n = 11 and n = 7, respectively), both granite and dacite stones were selected as the most common raw material choice for hammers (n's = 12), followed by phonolite (n = 8). Phonolite stones were selected the least often as an anvil (n = 2). The patterns of both the overall selection and the first choice selection plots look very similar in that carbonatite anvil selection is far higher frequency than any other raw material and tool type combination. The three remaining raw materials in both analyses were more often selected as hammers rather than anvils.

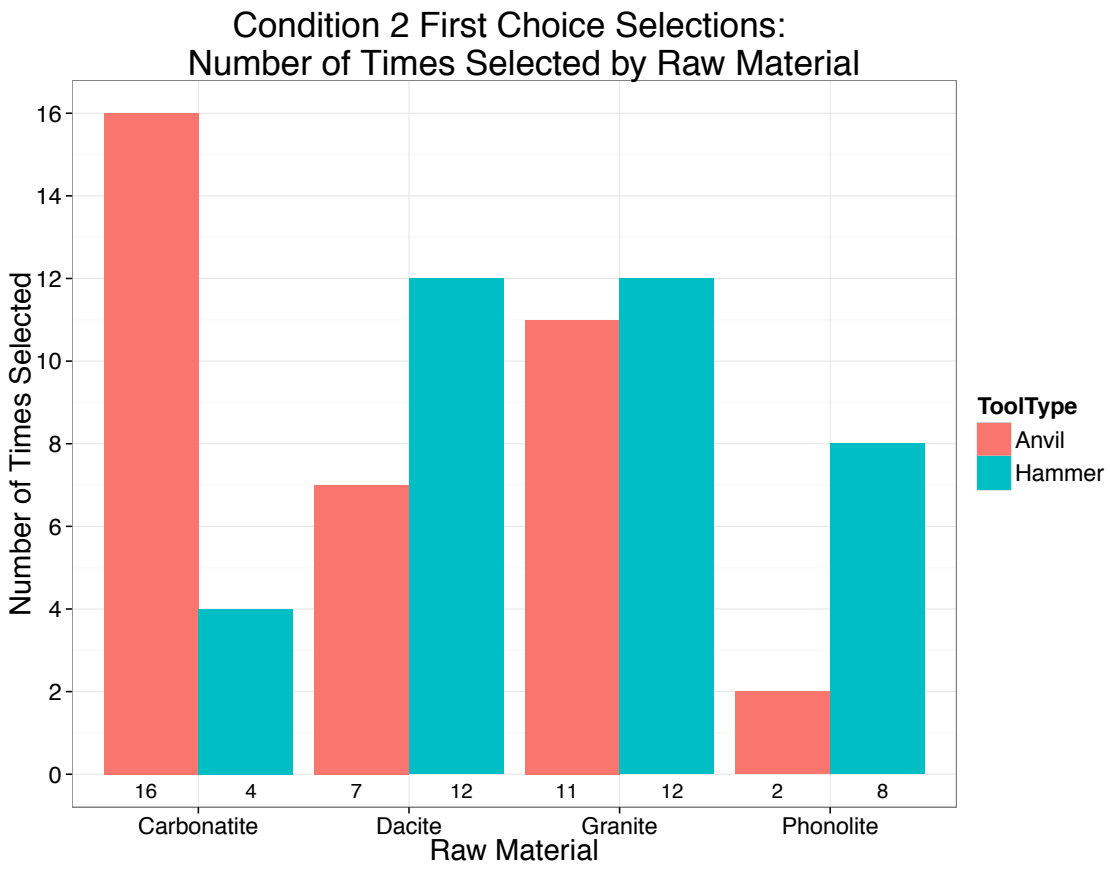

Figure 3.10: Bar chart showing the number of times each raw material was selected during the Condition 2 first choice analysis of data. Colors denote the type of tool that a given raw material was used for.

Condition 2 first choice selections were statistically tested using the same methods as all of the Condition 1 data and the Condition 2 overall selections. ANOVA test results from the first choice selections for both hammers and anvils in Condition 2 are consistent with Condition 1 first choice selections (Figure 3.15). The ANOVA test results show that hammer first choice does not reveal a statistically significant p-value below .05 (Chi-Squared = 4.8889, df = 3, p-value = 0.1801). This suggests that the null hypothesis is still intact and there is no statistically significant reason to assume that chimpanzees at Bossou are selective of hammer raw materials, given the frequency of raw material selections. However, the first choice selection ANOVA performed on Condition 2 data suggests that, with a p-value below .05, the null hypothesis can be

rejected and it is statistically supported that this data supports the alternative hypothesis that chimpanzees at Bossou are selective of specific raw materials for use as anvils (Chi-Squared = 11.7778, df = 3, p-value = 0.008184).

The final analysis conducted on Condition 2 behavioral data was a reuse/recycle analysis. Figure 3.16 displays the count data of selections based on what has been previously defined as reuse/recycle (see methods section for definitions). This analysis shows that, like the previous analyses, the raw material carbonatite was selected the most of any other raw material, and selected the most among all tool types (n = 54), most specifically among anvil selection across all Condition 2 experimental sessions (n = 40). Similar to the pattern seen in the two previous Condition 2 analyses, granite and dacite ranked in the middle of the raw materials that were selected as anvils (n = 7 and n = 9, respectively). Phonolite, as has been consistent throughout both Conditions was selected the least for anvils. Hammer selection for Condition 2 reuse and recycle shows a different pattern from what has been seen in both the overall and first choice selections for Condition 2. In the overall selection analysis, carbonatite hammer selection frequency ranked third highest, only higher than phonolite, and was ranked the lowest in the first choice selection analysis. However, in the reuse/recycle analysis, carbonatite is not only the highest raw material selected as an anvil, but also is tied for the highest frequency in selection as a hammer with dacite (n's = 14). Granite hammers were selected 12 times, and phonolite was the least selected for hammers (n = 2).

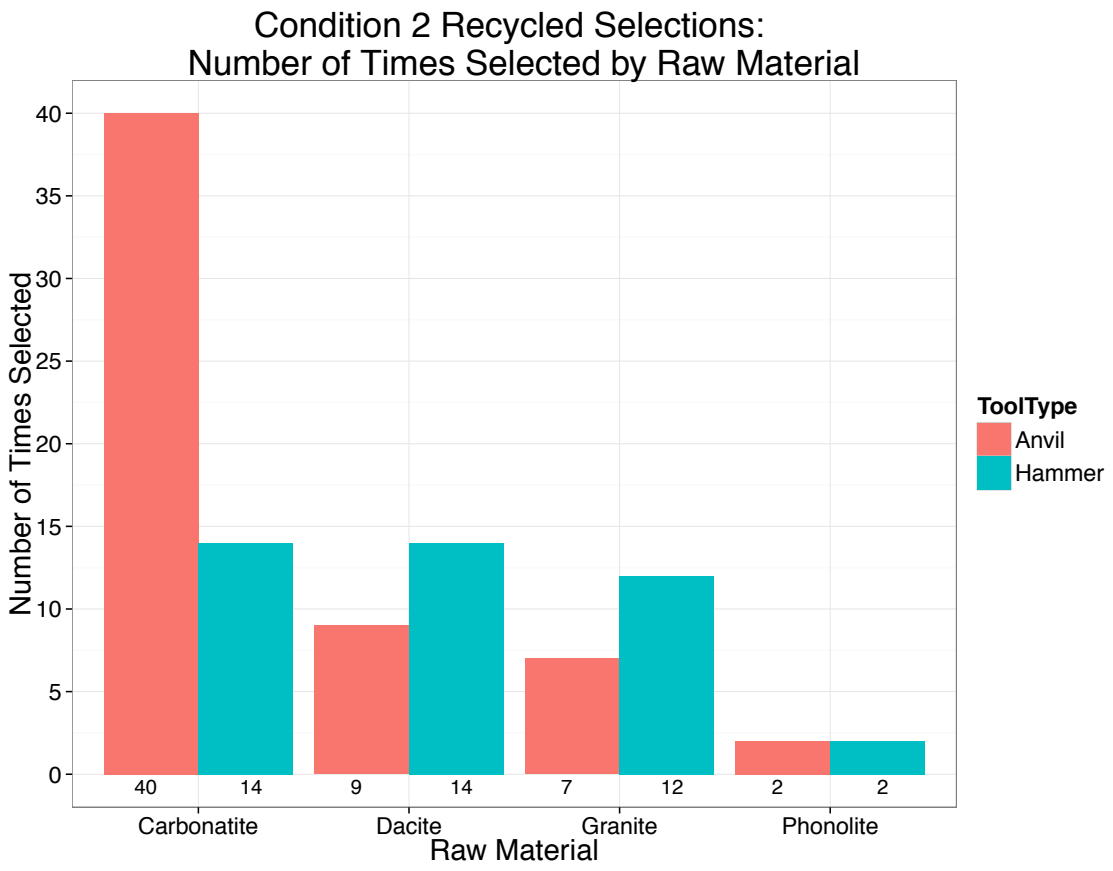

Figure 3.11: Bar chart showing the number of times each raw material was selected during the Condition 2 reuse/recycle analysis data. Colors denote the type of tool that a given raw material was used for.

Similar to the above analyses, ANOVA was conducted on the reuse/recycle subset of data to test the null hypothesis that chimpanzees at Bossou do not select specific raw materials for specific tool types in order to crack nuts (Figure 3.17). Based on the data from the two separate tool type groups, hammer and anvils, the ANOVA tests show that with regard to both tool types, statistically significant p-values were retained (Hammer: p-value = 0.0241, Anvil: p-value = 2.693e-13), suggesting that the null hypothesis can be rejected and that frequencies, like those observed in the data presented here, are highly unlikely given random chance.

Chapter 4: Discussion and Conclusions

The results of this thesis, and the experiments and observations discussed in the background (Chapter 1) contribute to a body of knowledge that allows anthropologists to gain a better understanding of chimpanzee behavior. Although small, the dataset provided here represents a valuable contribution to the field, emphasizing that by elucidating in fine detail the tool-using behavior of our closest living relatives, inferences can be made which further increase the understanding of tool-using hominids during the Pliocene.

4.1.1 Discussion: Condition 1 Behavioral Data

The data presented in section 3.2.1 (Condition 1) of this thesis is different from that which can be seen in the data from Condition 2. During Condition 1 of the study, chimpanzees were introduced to two completely novel toolstones (carbonatite and dacite), which were the only available stones for nut cracking at the research site for 6 experimental sessions. Based on previous studies, it is clear that chimpanzees are often neophobic, hesitant to engage in activities with novel items, and the chimpanzee population at Bossou has been documented in the past to exhibit this behavior (Biro et al., 2003). However, the previous study demonstrated this behavior when introduced to novel species of nuts. Biro et al. (2003) also showed that the selection of nuts varies across different age groups, where juveniles were more likely to select the novel nut species not commonly found at Bossou than adult chimpanzees. For the present study, there were no juveniles present at Bossou who were capable of nut cracking, and so this result is not documented in the current this study. Condition 1 data, from the present study, should be viewed as a pilot study for the results found in Condition 2. The reasoning for this is due to the novelty of stone raw materials provided for chimpanzees at this time, the consistent

participation of a single individual at the site, rather than multiple individuals, and the overall size of the Condition 1 data set.

The overall selection pattern of Condition 1 (Figure 3.5) demonstrates that when presented with two novel toolstones, chimpanzees at Bossou selected carbonatite more often than dacite. This result is consistent across tool-types, hammers and anvils. With regard to the ANOVA statistical testing conducted in order to test the null hypotheses for both tool type selectivity, that while anvil selection seems to be based on raw material, the selection of hammers does not share the same result. This result is consistent with those from Condition 1 First choice selections (Figure 3.7) and reused/recycled selections (Figure 3.9). While chimpanzees select carbonatite more often for hammer and anvil tool use than dacite, only anvil selection results demonstrate a statistically significant figure, which rejects the null hypothesis. With regard to reuse/recycle selections, Bossou chimpanzees repeat the same pattern of selection, however during this analysis there is a much more drastic result between the raw materials selected for anvil use. Carbonatite anvil selections in Condition 1 represent 80% of all anvil reuse/recycle selections.

While these data provide an end result demonstrating that Bossou chimpanzees are selective of carbonatite as an anvil over dacite, the shortcoming of the Condition 1 data is that they are quite small in sample size (n= 132 total selections). This further supports the notion that Condition 1 of the 2012 Bossou experiments should be considered pilot data for the more robust Condition 2 data set.

4.1.2 Discussion: Condition 2 Behavioral Data

The Condition 2 behavioral data are vital to the present study and represent the foundation for the remaining discussion and conclusions from this thesis. This portion of the study contributes a much larger dataset than Condition 1, and is comprised of more

experimental sessions. During this time, chimpanzees were provided with four raw materials to choose from: carbonatite, dacite, granite, and phonolite of which two (carbonatite and dacite) were previously given to chimpanzees to use for nut cracking activities. During this portion of the study, chimpanzees made a total of 327 selections (Figure 3.12) of which 102 were carbonatite anvils (31.19%). In Condition 2, carbonatite anvils represent the highest selected raw material and tool-type. When reviewing Figure 3.12, no other raw material was selected as an anvil more than it was selected as a hammer. Based on the overall selections, this pattern shows, at least superficially, that there is a heavy preference for carbonatite as an anvil. Given the available data from Condition 2, ANOVA results confirm that in fact, when comparing the results of all anvils selected, there is a statistically significant relationship in the selection pattern, which demonstrates that the superficial pattern is in fact representative of a high degree of selection in anvils (Figure 3.13b). However, this pattern is not surprising considering the results of Condition 1. With regard to the overall selection pattern of Condition 2, it is clear that hammer selection is drastically different than Condition 1. While all four raw materials were used as hammers, the Condition 2 overall pattern of selection suggests that there is also a degree of preference in raw material selection. The highest selected raw material for use as a hammer was dacite (n = 60), followed by granite (n = 50). The ANOVA results further confirms that, along with Condition 2 anvils, hammer raw material plays a role in the selective process when chimpanzees crack nuts.

While the results from the overall selection analysis are interesting and suggest that selection of toolstones is, at least to some degree, dependent on raw material type, there is a flaw in using overall selection as a means to concluding selectivity. This analysis, while

comprehensive, does not account for agency within the group. For example, if a single individual were to continuously change tools and repeatedly select one tool type, then the overall data set would not be representative of the selectivity pattern of the group. With regard to the present dataset, a single individual exhibited these behaviors and accounts for a large proportion of the carbonatite anvil selections. In order to navigate around such biases in the overall selection patterns, the first choice analysis was used to gain a better understanding of group wide selection practices.

The results of the Condition 2 first selection analysis (Figure 3.14) are interesting. Although there were some individuals who were overrepresented in the overall selection pattern, the first selections from each individual during each experiment from Condition 2 show a very similar pattern. Like the overall selection data, the first selection plot shows that carbonatite anvils were highly selected for over any other raw material and tool-type combination (n = 16). Like the overall selection pattern, the three remaining raw materials, dacite, granite, and phonolite were all selected more often as a hammer then as anvil. The first selection analysis also reveals a new pattern, which was not seen in the overall selection analysis; chimpanzees are now selecting phonolite (the least selected raw material overall for either tool-type) more often as a hammer than as an anvil. This pattern may reflect that chimpanzees prefer this material over carbonatite as a pounding tool, but at this point it is it would be premature to conclude this, due to a relatively small sample size. Regardless of the phonolite anomaly, it is clear that with regard to the first selection analysis, chimpanzees are indeed preferentially selecting carbonatite over other materials as an anvil (Figure 3.15b). However, unlike the results of the overall selection analysis, the first selection analysis has not yielded a statistically

significant ANOVA result for hammer raw material selection, suggesting that the null hypothesis can still be intact. In this analysis, both dacite and granite were selected equally as a first choice hammer (n = 12 for each) followed by phonolite (n = 8) and carbonatite (n = 4). While the ANOVA test results suggests that chimpanzees may not be selective of any one specific raw material over another for use as a hammer, it is quite possible that this result could be due to the small sample size of the data set.

The final analysis conducted on the Condition 2 behavioral data was the reuse/recycle analysis. The goal of this study was to identify which raw materials were selected based on their prior use. By understanding the reuse of tools during complex social interactions like nut cracking, it might be possible to identify the mechanism by which chimpanzees develop their preferences for composite tool raw materials. When considering this data, it is necessary to mention that similar studies of reuse and recycle are currently underway (Biro et al., In Prep.), with the goal of identifying the relationship between reuse/recycle patterns in juveniles compared to adults. However, for the present study this could not be done, due to a lack of juveniles during the 2012 field season.

The data for the reuse/recycle selection analysis consist of 100 total selections throughout Condition 2. Consistent with the Condition 2 selection analyses discussed above, carbonatite anvils represent the highest selected population (n = 40, 40% of all reused materials), followed by dacite (n = 9), granite (n = 7), and phonolite (n = 2). Unlike the overall and first choice selection analyses, carbonatite represents a majority group for hammer selection, being selected equally as many times as dacite (n = 14 for both raw materials), followed by granite (n = 12), and phonolite (n = 2). Possibly the most thought-provoking outcomes of the reuse/recycle analysis are the results of the

ANOVA tests. Not surprisingly, statistically significant values were retained for the anvil analysis, suggesting that the null hypothesis can be rejected and chimpanzees exhibit selection preferences for carbonatite as an anvil (Figure 3.17b). However, the results of the ANOVA for hammer selection were, similar to the overall selection pattern, statistically significant (Figure 3.17a).

These results are very interesting with regard to the social dynamics of stone tool selection amongst chimpanzees at Bossou. While the anvil selection pattern has been consistent across Condition 2, the reuse/recycle analysis suggests that the pattern observed represents at least two possible mechanisms for learned behavior: (1) Chimpanzees are selecting carbonatite as an anvil because they observe others in the community successfully cracking nuts in an efficient manner with this material, or (2) chimpanzees are selecting carbonatite as an anvil due in part to the social dynamics of rising and falling social statuses. Unfortunately, due to time limitations, efficiency data was unable to be collected for the current data set. The reasoning for the second scenario is represented, although not discussed in detail here, by the transition in social status of two males, JJ and FF. Prior to the start of the 2012 field season, FF was identified as the alpha male of the Bossou group. However, it has been observed since the 2012 field season that JJ is currently the alpha male. This jostle for alpha male position seems to have been an ongoing social dynamic during the 2012 field season and is documented in the reuse/recycle data presented here. Specifically, during Condition 2, several interactions between JJ and FF show that they are often reusing tools from one another and switching selection multiple times during a single session. Often times grandiose displays are the catalysts for reuse/recycle of tools between these two individuals.

Regardless of the exact mechanism for this socially learned behavior, it is clear that observing chimpanzees while nut cracking not only allows anthropologists the understand a vital part of chimpanzee subsistence, but also provides a window into understanding the foundations of social learning in chimpanzee communities.

4.2. Discussion: Mechanical Properties and Behavioral Data

The overall goals of this section are to discuss the importance of the material property data presented in Section 3.1, and to examine these data and their importance to the selections observed in Sections 3.2.1 and 3.2.2. Based on the following discussion, data collected from Leeb hardness and Young's Modulus of Elasticity suggest that not only are chimpanzees selective of specific raw materials for different tool-types, but are selective of materials that are most suitable for a specific purpose based on their mechanical properties. While this thesis makes no claim that chimpanzees comprehend the complexity of the specific material sciences involved in the analyses of stones, it is clear that there is a relationship between chimpanzee stone tool selection and the natural mechanical properties of the stone.

This study measured three mechanical property variables: Leeb hardness of both the cortex and internal surfaces and the Young's Modulus of Elasticity. In total, six different raw material toolstone types were selected for this study (carbonatite, dacite, granite, rhyolite, quartzite, and fenetized rocks). Based on the results, the raw material with the highest cortex values is rhyolite. While it does yield the highest overall values, this material has considerable overlap with quartzite, and the lowest quartile overlaps with granite and fenetized rock. The raw material with the lowest cortical Leeb hardness value is carbonatite. When compared it the other five raw materials used for this study, carbonatite yields significantly lower hardness values for the surface of the stone (more

than 400 HLD less than the average fenetized rock score. These data clearly show that with regard to hardness, carbonatite has the softest stone surface, thus making it the most susceptible to permanent deformation from compressive forces and rhyolite has the hardest stone surface. While rhyolite has a considerable amount of overlap with several of the other raw materials in the study, the outlier of the group is carbonatite.

The second mechanical property value recorded was the internal measurement of Leeb hardness for the six lithologies used in this study. The overall pattern is very similar between the internal and cortex Leeb hardness. While several of the raw materials overlap in internal hardness, with quartzite yielding the highest overall average values, carbonatite yields significantly lower values for internal Leeb hardness. Across all stones, the internal surfaces of the material tends to be higher than it's cortical measurement, suggesting that weathering likely plays a role in the quality (high or low hardness values) of the stones available. Unlike the cortical Leeb hardness values, carbonatite internal Leeb hardness values do yield overlapping measurements with the lower extreme values of dacite. This result is likely due to the internal flaws and inclusions.

The final mechanical property measurement recorded was Young's Modulus of Elasticity. Unlike the hardness variables collected in the first two analyses, the data for elasticity show an opposite pattern in which one lithology (rhyolite) is significantly more elastic than the other five. With the exception of the rhyolite outliers, all of the measurements within the inner quartile range are at least 3 GPa higher than the second highest raw material (dacite). The least elastic raw material in this study was carbonatite, which overlaps with granite—the raw materials with the largest grain size. These data suggest that several lithologies have low elasticity scores relative to rhyolite. When all of

the mechanical property data are summarized together carbonatite stands out, having the lowest hardness and elasticity values, suggesting that it is a stiff, soft stone—sometimes considered to be less 'brittle' and easier to deform (Cotterell and Kamminga, 1987). Less clear are the data from granite and dacite, wherein both raw materials have higher values than carbonatite in all three measurements, overlap with one another in both cortex and internal Leeb hardness scores. However these two lithologies are different with regard to their elasticity, where dacite yields considerably higher values, demonstrating a higher elasticity overall for this raw material. The value of these mechanical property tests is clearer when they are compared to the selection patterns of the chimpanzees at Bossou, which highlight the usefulness of mechanical property data to raw material selectivity studies in chimpanzees.

Although the data set is small, during Condition 1 of this experiment (Section 3.2.1) Bossou chimpanzee tool selections favor carbonatite as a raw material that is best for an anvil. This selectivity pattern is consistent throughout all analyses during this study; Condition 1 overall, first choice, and reuse/recycle and Condition 2 overall, first choice, and reuse/recycle analyses resulted in statistically significant ANOVA test scores, which rejected the null hypothesis. However, with regard to hammerstone selection, the pattern of selection does not exhibit the same consistency of results. P-values retained from ANOVA statistical tests showed that while one raw material was selected more often than another (carbonatite over dacite), the difference in frequency of selection was not statistically significant. As was discussed above, this inconsistency is accredited to the novelty of the stone raw materials and the chimpanzee phobia of new objects in their natural environment. However, during Condition 2 of the results show a slightly different

pattern, which suggests that during the overall and reuse/recycle analyses, but not the first choice selection, chimpanzees are selective of hammerstones. As has been discussed in the methods section of this thesis, the main determinant of selectivity is the first choice selection analysis. However, this result is interesting because it suggests that while chimpanzees at Bossou do not have a preference for one specific hammer raw material, the reuse/recycle analysis suggests that chimpanzees are indeed identifying that once an individual selects a specific material for a hammer, observers prefer to select and reuse/recycle specific stones over other materials. This suggests that all individual participants may have been neophobic with the toolstones available. Based on the count data from the overall and reuse/recycle analyses, there is a pattern in which chimpanzees preferred dacite or granite as a hammer to phonolite.

The selection patterns of the Bossou chimpanzees suggest that the material properties of stones available influenced their decisions. The most selected anvil raw material is carbonatite. Carbonatite mechanical property results show that this material is the softest cortex (~350-400 HLD), softest internal surface (~450-650 HLD), and was the least elastic (~3.25-4.25 GPa). These values suggest that carbonatite, as an anvil, will deteriorate differently than other materials used for this study. Materials with higher hardness values will withstand permanent deformation from pounding pressures better. Due to their higher Young's Modulus of Elasticity, dacite and granite are stiffer and have the ability to rebound back into their original shape under higher amounts of force. Based on subjective observations, it appears that while chimpanzees use carbonatite as an anvil, the repeated pounding of a harder, more elastic stone on a carbonatite anvil does not result in large-scale conchoidal fracture, but in a small-scale deformation. The continued

use of carbonatite for the anvil function results in minor deformation of the stone itself. Deformation of carbonatite through extensive use results in the formation of concavities in the location that the nut rests. Furthermore, these concavities provide stability and balance for the nut on the anvil, making it easier to support and strike the nut.

Interpreting hammer selection among the chimpanzees is less straightforward at Bossou. During Condition 2, the most selected hammers were dacite (n = 60) and granite (n = 50). Dacite cortical Leeb hardness (~775-825 HLD) and internal Leeb Hardness (~600-875 HLD) overlapped heavily with granite cortical and internal values (cortical = ~725-810, internal = ~825-925 HLD). However, dacite as a hammer was selected more often than granite in both overall selection and reuse/recycle analyses (dacite n = 14, granite n = 12). During the first choice selection analysis, both raw materials were preferentially selected the same number of times (n = 12). While the first choice selection demonstrates that these materials are equally selected, which is interpreted here as being due to considerable overlap in cortical and internal Leeb hardness, the difference in reuse/recycle selections is not statistically significant and suggests that granite is just as likely to be selected by chimpanzees at Bossou for use as a hammer. When considering the overall selection data, which comprises reuse and first choice selections, a much more robust dataset is present. This overall selection pattern does yield statistically significant differences in the selections between granite and dacite. However, because the overall patterns is a mix of multiple social interactions and selections that are both reuse and first choices, this result is viewed as superficial, and ultimately insignificant. Since dacite was available during Condition 1, and granite was not, it seems likely that higher values in dacite selection are due to increased experience with the raw material.

The least selected hammer raw material throughout Condition 2 was phonolite (n = 6). Interestingly, during the first choice analysis, phonolite was selected more often than carbonatite, suggesting a preference for dacite, granite and phonolite over carbonatite. This pattern indicates that while carbonatite is selected scarcely as a hammer, it is most suitable for use as an anvil, and the remaining materials are most suitable as hammers. While there is some indication that hammer raw material does play a significant role in nut cracking, due to a lack of data for phonolite, which is selected much less frequently overall for nut cracking than dacite and granite, it is impossible to understand lack of preference for phonolite in the context of its mechanical properties.

Based on the data presented above, it is clear that with regard to the variables selected for data collection, chimpanzees at Bossou are highly selective of stone raw materials for composite tool-assisted nut cracking. Carbonatite, a soft, stiff stone, which deforms in a very characteristic manner, was selected the most out of any other raw material for the role as an anvil. Both dacite and carbonatite were provided for chimpanzees during Condition 1, and the pattern is less obvious. This result is likely due to the novelty of the stones, and chimpanzees' fear of new objects in their environment. However, in Condition 2, it is clear that the pattern of selection is undeniable, especially when comparing both conditions. It is possible to conclude that during Condition 2, chimpanzees opted to select the two materials that they were most accustomed to. However, if a comparison is made between the time span of Condition 1 (9 PAB's) and Condition 2 (11 PAB's) it is assumed that since Condition 2 was as at least as long as Condition 1 the chimpanzees had adequate exposure to the separate conditions' tool sets. Furthermore, if an argument were to be made in support of selection based on the least

novel items, then it would not make sense for both dacite (present in both conditions) and granite (solely present in Condition 2) to have been selected equally in the first choice selection analysis.

A second discussion, necessary to understanding the tool stone selection of chimpanzees is the use of a first choice analysis. This analysis allows for researchers to record selection data for each individual based on their first overall selection upon arriving into the study site. By relying on first choice data over a simple overall pattern, a more accurate interpretation and selection pattern can be seen for each individual's preferences. For this study, three different analyses were conducted: overall selections, first choices, and reused/recycled tools. These three analyses appear to offer three different scaled views of nut cracking behavior at Bossou. While first choice selections provide a better focus on an individual's preferences, the overall pattern of selection is interpreted as being similar to what is seen in an archaeological assemblage. Like a time-averaged assemblage, the overall selection pattern does not provide data for social interactions between chimpanzees. The overall selection pattern is a broader way of interpreting the selection patterns of Bossou chimpanzees. Variables such as the number of individuals nut cracking, the number of males compared to females, whether or not the alpha male is present, whether or not it is an adult or juvenile making the selection and potentially many more contribute to the overall selection pattern.

The reuse/recycle analysis is a method of data collection, which provides vital information about social interactions between individuals and how they can have an influence on the selective preferences of other chimpanzees. This analysis is crucial to the study because it has been suggested that chimpanzees learn behaviors such as tool use via

"master-apprenticeship" (Matsuzawa et al., 2001). This model proposes that learning to crack nuts with stones involves the observation of an experienced nutcracker by a novice that is not proficient in nut cracking, where the former plays no active role (i.e. does not "teach" the learner) other than performing the actions and tolerating the learner's observation. This analysis is important to the present study: while many of the individuals were already proficient nutcrackers, none of them were experienced with any of the exotic raw materials presented in the study. As was previously discussed in Section 1.1, among groups of proficient nut cracking chimpanzees it is possible that not all individuals will learn the behavior. Thus, by observing the reuse/recycle patterns of selection, it is possible to identify individuals who opt to 'upgrade' their tools for ones that the individual has observed another member of the group using with success.

The data collected for the three primary analyses are not balanced. However, what this study has done is show two analyses of selection, which are nested within the overall selection pattern. By showing the patterns of selection for individuals primary, preferential selections (first choice analysis) and selections based on observing other individuals in the group it is possible to look at two separate influences of chimpanzee raw material selection. When compared to the overall pattern of selection for Condition 2, there is a very similar pattern. The similarity between these three analyses (Figures 3.12-3.16) suggests that the overall selection analysis is an adequate measure for chimpanzee raw material selection at a group level. In fact, the two plots that are closest to one another in shape are the overall and first choice analyses. However, the volume of data for the first choice analysis is small. Compared to over 300 total selections accounted for in the overall selection pattern, the first choice analysis data set is

considerably smaller. With regard to the reuse/recycle analysis, the data less closely match the overall and first choice selections. During this experiment, the rank order by raw materials are the same, however it should be noted that carbonatite anvils were selected 40 times, no other raw material or tool-type was selected more than 15 times. This is worth noting because selections are weighted toward the importance of carbonatite as an anvil, rather than any other material for either tool type. When considering the mechanical property data collected, dacite and granite had considerable overlap in both Leeb hardness and Young's Modulus of Elasticity. During all three analyses, both of those tools were selected similarly as hammers and the results of Chi-Square tests suggest that they are not statistically different from one another. The result of both granite and dacite being selected similarly throughout Condition 2 highlights the fact that chimpanzees may be recognizing the mechanical properties of the stones themselves.

Three shortcomings of this thesis are 1)that it does not produce an index for chimpanzee raw material selectivity; 2) does not quantify the nut-cracking efficiency of one raw material over another, and 3) the probability of available stones for selection has not been accounted for. As such it is not possible at this time to actually identify selectivity among the chimpanzee at Bossou. An understanding of sectivity requires knowledge of the availability of the stones. The complex social dynamic of the Bossou nut cracking means that ay any given time several of the stones would not have been available because other individuals were using them. As such selection of certain raw materials can provide trend level understanding of selection but cannot convincingly identify selection. A future goal will be to identify the probability of each available stone

for section by chimpanzees. If selections are made during low probability scenarios (i.e. if chimpanzees select one raw material over another even when that raw material is rare), support for raw material selectivity can be made. Furthermore, by identifying an accurate measure for efficiency of raw material selection and use, a more useful measurement of selectivity can be determined.

4.3 Discussion: Chimpanzee Raw Material Selection and Human Evolution

Raw material selection studies have been conducted on numerous occasions in order to better understand our prehistoric ancestors' toolstone preferences. By understanding the raw material selection patterns of chimpanzees, we have gained a better understanding of how they adapt to their environment through tool-use. Since the inaugural work of Jane Goodall at Gombe National Park, numerous studies have been centered on understanding how chimpanzees cope with their environments by using tools. The present study attempts to bridge primate behavioral studies and mechanical property studies of stone and how toolstone raw material and invisible mechanical properties influence the selections of stones. The mechanical property methods outlined in this study and previous studies can be and have been applied to the archaeological record to understand the preferential selection patterns of Plio-Pleistocene hominins. However, as is noted in Section 1.1, the archaeological record is plagued by natural depositional limits, which result in loss of data through the process of time averaging. Thus, by employing the above outlined methods, knowledge about Pliocene tool-using primates, including hominins, can be gained. Through an indirect referential model this study provides supplemental information that can be used with the archaeological record to make inferences about our past.

The raw materials provided for chimpanzee participants during the 2012 field season, and ultimately the data being provided here represent an important bridge between what we know about our Plio-Pleistocene ancestors and the raw material selection of our closest living relatives, chimpanzees. The use of stone raw materials from Kanjera South, Kenya is vital to this project because it allows researchers to see the same materials used as tools ~2.0Ma being used in a modern context. As was noted previously in Chapter 2, it is not believed that chimpanzees are time capsules of archaic hominins, but as has been suggested by others (see Foley and Gamble, 2009) that the use of these non-human primates as referential models has shown to be useful for making inferences about the past. The following discussion will compare the results of these mechanical property studies alongside the previous archaeologically based raw material and mechanical property studies. By doing so, we will see that raw material selectivity of our ancestors and among the extant chimpanzee population of Bossou is a complex relationship with many similarities and differences.

Raw material selectivity and preference studies examining the Pliocene archaeological record have not been exhaustive. Isaac (1972) first suggested that there is a connection between the physical properties of stone and Oldowan technology. It has been nearly a half-century since this argument was made and while the number of studies focusing on raw material mechanical properties is slowly growing, none have been centered on the connection between Pliocene hominins and chimpanzees. Since Isaacs' (1972) suggestion, several authors have made the argument that raw material constraints have imposed serious effects on the quality of tools manufactured and used in the archaeological record (Andrefsky, 1994; Crabtree, 1967; Inizan et al., 1992; Kuhn, 1995,

1992; Roth and Dibble, 1998), suggesting that hominins would have selected the most optimal materials in their environment for the manufacture of stone tools. Braun et al. (2009) successfully identified the preferences of late Pliocene hominins at Kanjera South, Kenya. By showing that individuals were selecting raw materials based upon their durability and not fracture predictability. This work as well as other studies centered on stone fracture mechanics demonstrated Isaac's theory to be accurate. These studies have also led researchers to understand that hominins were transporting raw materials great distances due to their preferences in toolstone (Braun et al., 2008). A key component to this study was the application of quantifiable chimpanzee behavioral data in combination with objective material property data. While many of the previous studies (outlined in Chapter 1), applied quantifiable material property data to the archaeological record, many did not apply a referential model. By collecting chimpanzee behavioral data, it is clear that individual preferences, social dynamics, and potentially numerous other unseen variables play a crucial role in preferential selection regimes among chimpanzees, and this was likely very similar to hominin behavior. What this study has provided is the first quantifiable evidence highlighting the importance of stone mechanical properties in the selection process of chimpanzees from Bossou.

The referential models used here represent one side of the commonly selected experimental designs. Actualistic studies, utilizing the knapping skills of modern humans are a common occurrence in archaeological research. Nonaka et al. (2010) and Stout et al. (2008) adopt this method for the manufacture of sharp edged flakes for their experiments. In a very similar manner to this project, modern human knappers are not ideal candidates

for stone tool manufacture experiments because they, like chimpanzees, are not representative of the populations of hominins on the landscape prior to 2.0Ma.

In the studies being compared to the work of this project, data has demonstrated that hominins select raw materials for a wide array for reasons. In West Turkana, Kenya, hominins selected raw materials and engaged in systematic reduction strategies different from other late Pliocene sites based on the internal structure of the stones available in local rivers (Harmand 2007, 2005). This suggests that tool-using behavior is dynamic and variable across the landscape, and the tool users will adapt to the materials available. A prime example of this variability among chimpanzee populations is the difference in tool preference between Bossou and Taï. At Taï, chimpanzees will use both wood and stone as a hammer, and the selection of which tool to use is dependent on the species of nut that an individual is cracking (Boesch and Boesch, 1982, 1983). Fracture predictability, a property of stone that has long been considered to be vital to the manufacture of stone tools was passed over in favor of edge durability at Kanjera South (Braun et al., 2009). At Gona, similar to Kanjera South, hominins were highly selective of raw materials that were not necessarily the easiest to acquire, suggesting that raw material quality was of the utmost importance in tool manufacture (Stout et al., 2005). For Stout et al.'s (2005) paper, two of the four variables observed involved grain size of phenocrysts. The present study does not record phenocryst size, however, it is assumed that there is a relationship between grain size and elasticity. This relationship can be seen with the results of the Young's Modulus of Elasticity tests that were conducted in this study. Subjectively, the largest grain sized material was granite, the second lowest elasticity (carbonate was first).

Like the raw material studies discussed in this thesis, chimpanzees, like Plio-Pleistocene hominins exhibit a sophisticated level of raw material selectivity.

4.5 Conclusions:

Research in raw material studies of Early Stone Age hominins has steadily grown over the last ~30 years, due in part to the guidance of Clark (1972). Initial studies were centered on subjective measures of stone material quality. In recent years, studies have been centered on not only identifying patterns in hominin raw material selectivity, but also the methods of quantitatively identifying what high quality raw materials are. Prior to the present study, no study exists that examines these quantitative measures among wild extant chimpanzees. Our closest living relatives, the chimpanzees, are regular tool users at Bossou and among other West African populations. The use of composite tools to crack open hard-shelled nuts to access the nutrient-rich kernel is a complex behavior that requires a high level of skill and time to develop. The learned behavior of cracking nuts is a process that requires years of practice and observation (Inou-Nakamura and Matsuzawa, 1997). One of the many substantial factors contributing to this behavior is raw material selection, that is the knowledge of which toolstones are optimal for cracking the nut.

Non-destructive engineering techniques were employed to collect Leeb hardness and Young's Modulus of elasticity data from six stone that were used by hominins at the site of Kanjera South, Kenya: carbonatite, dacite, granite, rhyolite, quartzite and fenetized rock. Of these six exotic types, four were introduced to chimpanzees at Bossou: carbonatite, dacite, granite, and phonolite. Based on the mechanical property data, carbonatite yielded the lowest scores for Leeb hardness and Young's Modulus of Elasticity, and dacite and granite yielded much higher values for both Leeb hardness and

Young's Modulus of Elasticity but overlapped significantly with one another. Data for phonolite was not available for this study, due to sampling issues.

Behavioral data was collected from 21 experimental sessions during the 2012 field season at Bossou. During this time, chimpanzees participated in two separate experimental conditions. Condition 1 provided chimpanzees with two novel stone types: carbonatite and dacite. Condition 2 provided chimpanzees with all four stone types: carbonatite, dacite, granite, and phonolite. Due to a smaller dataset and increased experiments with low numbers of participants, Condition 1 is considered to be a pilot data study for the more robust Condition 2 data set.

Data from Condition 2 yielded inferences about selection. The overall patterns of the experiment suggest that carbonatite (a relatively soft and inealastic material) was selected more frequently than other rock types. Similarly, the chimpanzees at Bossou selected dacite and granite, two much harder and more elastic materials, more frequently. Over time, as carbonatite deforms from nut cracking, a concavity develops in the anvil. The concavity provides a more consistent and easier to manage resting place for the nut while the individual cracking prepares to use the hammer as a percussor. The results of the two remaining analyses, first selection, and reuse/recycle are very similar to the overall pattern of selection, suggesting that when an individual has his/her primary choice of raw material selection, carbonatite will be a resulting choice for an anvil 30.5% of the time. Hammer first choice selections are split between dacite and granite stones, suggesting that chimpanzees identify that these two materials have the highest hardness values of the four possible stones available. However, the raw material that is least selected for across all three analyses is phonolite. It is not known why phonolite was selected so rarely. This

incongruity will be the topic of future investigations related to this study. The last analysis conducted was a reuse/recycle analysis of selections. Based on this analysis, carbonatite was overwhelmingly selected most frequently as an anvil 68.9% of the time. This analysis is important because all of the materials presented in this study were novel to the participants. The results of the reuse/recycle analysis suggest that anvil selection was more frequently focused on carbonatite, while hammer selection occurred at similar rates between carbonatite, dacite and granite. The results for first choice and reuse/recycle analyses suggest that when presented with novel composite toolstone raw materials, chimpanzees identify stones that are capable of cracking nuts, successfully (cracking the shell, but not destroying the kernel inside). The results of these two tests also show that chimpanzees consistently select and reuse carbonatite anvils and either dacite or granite hammers. However, because the data from these two analyses was so similar, it appears that chimpanzee base knowledge (that is the whole developmental process of learning to crack nuts) provides individuals with enough experience to identify efficient raw materials effective for nut cracking.

In summary, the novel use of mechanical property tests in combination with chimpanzee behavioral data provides a model that quantifies the selective regime of extant chimpanzees from Bossou. This study demonstrates that, like our hominin ancestors, chimpanzees will frequently select stones based a complex set of mechanical property characteristics and variables. Unfortunately a lack of understanding about the overall availability of the different rock types during instances of selection means that we cannot determine the overall strength of selectivity amongst the chimpanzees. Based on the data presented here, chimpanzees at Bossou frequently selected anvils made of softer

and less elastic rocks, while hammers selections are based on stones having higher hardness values and being more durable. This study opens the field of paleoanthropology to new questions about the behaviors of our extinct hominin ancestors and closest living relatives, chimpanzees. This provides intriguing insights into the possibility that the last common ancestor was proficient at making and using tools and may have implemented selection pattern of stone that were similar to that documented amongst Pleistocene hominins.

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