DID STONE RAW MATERIAL DIFFERENCES INFLUENCE PREHISTORIC TOOL-MAKING?

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Dedication

This thesis is dedicated to my wife Leah Norris, without your inspiration I would not be here.

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I would like to thank the members of my committee. I appreciate all of your support and help through this process.

Chapter 1:

Introduction

Clarke's scientific approach to archaeology in Analytical Archaeology (1968) was widely overlooked, misunderstood, or simply not applied. In 2010, celebrating 40 years of Clarke, Lycett and Chauhan (2010) revisited "Clarkeian" trends to better understand and (re)assess Paleolithic technologies. They summarized Clarke's Analytical Archaeology in five trends, these consist of, 1) hypothesis testing and formal analysis, 2) quantification and inferential statistical analysis, 3) models, 4) cultural transmission and lineages of artifactual traditions, and 5) morphometrics (Lycett and Chauhan, 2010:2). These five themes consist of a new wave of archaeology utilizing science and statistical analysis to better understand the prehistoric past and human behavior. Intuition and commonsense can at times be counterproductive to studying the archaeological past. Additionally, describing, rather than defining, has been a stumbling block for decades (Dunnell, 1971). A scientific approach to archaeology is a powerful tool that should be added to the qualitative approaches that have dominated for decades. This is because the main benefit of using a scientific approach is its self-correcting nature.Too often at times archaeologists simply reflect their predecessors' opinions, rather than focus on evidence, resulting in little to no advancement in archaeology.

Darwin's ideas of how variation, competition, and inheritance affect change can be applied to understanding how culture changes (Mesoudi, 2011). In other words, a Darwinian approach can be used in understanding the archaeological record as well as past human behaviors. Culture can best be defined as information that is acquired from other individuals via social transmission mechanism such as imitation, teaching, or language where information is knowledge, beliefs, attitudes, norms, preferences, and skills (Mesoudi, 2011:2-3). Using an evolutionary approach to stone tool technology looks at many different variables involved in toolmaking as well as change over time (see Lycett and Chauhan, 2010 and Lycett and von Cramon-Taubadel, 2014). Only by looking at all the variables will we be able to better understand prehistoric human behavior and the processes involved in stone tool technologies. Through this evolutionary lens we can synthesize archaeology (Mesoudi, 2011) allowing the field to grow as a science. For further discussion on scientific archaeology see, Eren et al., 2016; Schillinger et al., 2014; Lycett and von Cramon-Taubadel, 2014; Lycett and Chuahan, 2010; Clarke, 1968.

One sub-field of archaeology that has benefited in recent years from scientific, quantitative, and evolutionary approaches is lithic (stone tool) analysis. Modern humans and our hominin ancestors have used stone as a raw material for tools for over 2.6 million years, and lithic artifacts are by far and away the most abundant specimens archaeologists dig up from the most primeval periods. As such, archaeologists must squeeze as much information as possible from these ancient implements to understand the evolution of technology. One avenue of stone tool study involves the "quality" of the rocks that were used to make tools. Toolstone quality is based on a rock's internal and external properties. Internal properties include brittleness, homogeneity, hardness, elasticity, granularity, and isotopy (Goodman, 1944; Callahan, 1979; Whittaker, 1994; Andfresky, 1998, Eren et al., 2011; Eren et al., 2014). External properties encompass factors such as size, shape, surface regularity, and cortex presence (Ashton and McNabb, 2004; Jennings et al., 2010; Smallwood, 2010; Eren et al., 2011; Eren et al., 2014). All of these factors would have played a role in the prehistoric skill necessary to produce tools, the cultural transmission of stone tool techniques, and the pace of technological evolution.

Over 75 years ago, Goodman (1944) understood the importance of quantifying different mechanical properties (Domanski et al., 1994) and advocated for experiments regarding toolstone quality. There has been only a small amount of experimental research conducted to see if the quality of raw materials influences or constrains the toolmaker as well as the overall outcome of the tool, despite quality being described as a major factor (Andrefsky, 1994; Brantingham et al., 2000; Braun et al., 2009; Browne and Wilson, 2011). Lithic analysts have repeatedly described quality as being one of most important factors in tool production, next to quantity (Andrefsky, 1994; Manninen and Knutson, 2014). With respect to quantity, the distribution and occurrence of knappable raw materials would have been a ‘stable’ and ‘predictable’ phenomenon to prehistoric toolmakers (Goodyear, 1989:3). The evolutionary success of prehistoric peoples was dependent upon their knowledge of the landscape and how to access resources that were pertinent to their survival in an uncostly, efficient manner, not the quantity of raw materials. Only in stratified, sedentary societies would access to raw materials be an issue, where families or prestigious individuals had access to raw material locations, skills, and knowledge (see Stout, 2002, 2005).

Rock quality, however, is a somewhat more subjective concept, dependent on what is being made, who is making the tool, and what aspects of a stone would be considered detrimental to the production goal. Rock quality has been explored in several ways (e.g. Braun et al. 2008, 2009; Eren et al. 2014; Williams et al. 2019), but one aspect of stone tool quality that has been neglected is material strength, or, in other words, the amount of force required to chip a toolstone. This is the subject tested in this thesis. The reason why this is important is because a higher fracture force would require the toolmaker to have a faster hammer blow to chip the rock – reducing hand-eye coordination, and chipping accuracy (Mraz et al. 2019). Thus, an expert may be able to achieve accuracy with the increased speed necessary to fracture a "stronger" raw material, but a novice may not. Prehistoric people may thus have selected rocks, depending upon personal or population skill, which possessed lower fracture forces. Thus, because there is relationship between flintknapping, raw material, and skill, before formally defining my question and hypotheses about toolstone raw material strength, I will review the literature on these topics.

1.1 Flintknapping and skill

There are many complex and different interacting variables that effect the decision-making process of flintknapping (Callahan, 1979; Stout, 2005). The ability to problem-solve is an important factor in mastering flintknapping. In one ethnographic example, the skill needed for Langda to become a master stone-adze maker took at least ten years (Stout, 2002). Mastering any skill has long been understood as someone who has put 10,000 hours or more into a subject (Ericsson, 1993; Gladwell, 2008). In an article published in the scientific journal Intelligence, Hambrick et al. states, "…we have empirical evidence that deliberate practice, while important, is not as important as Ericsson has argued it is—evidence that it does not largely account for individual differences in performance"(2014:113). The next question posited by these researches was, "…what else matters" (Hambrick et al., 2014:113). I think this approach of "what else matters" should be applied to the understanding what factors are affecting toolstone morphologies as well as the cultural or traditional decisions made by prehistoric knappers. Specifically this approach should incorporate recent studies that use an evolutionary approach to understand the variables involved in artifact change within archaeology (see Clarke, 1968; Lycett and Chaunum, 2010; Mesoudi, 2011; Lycett and von Cramon-Taubadel, 2014; Schillinger et al., 2014; Eren et al., 2015; Eren et al., 2016; Key and Lycett, 2017, Norris et al., 2019).

An important factor in the decision-making used in stone tool knapping is the choice and use of the most applicable hammerstone or billet (i.e., hard-hammer percussor vs soft-hammer percussor) (Callahan, 1979:164). Those who were/are experts at this craft, can call upon past experiences to better aid in the decisions of platform preparation and depth, striking angle, velocity or striking blow, as well as hammer choice which seem to influence the overall process of flintknapping (Whittaker, 1994). Experiments should be conducted to better understand how different hammers (i.e., stone, bone, and wood) may or may not affect the thinning processes of bifaces. Callahan as well as many other knappers (Bradley, 1975; Crabtree, 1976; Whittaker, 1994; Inizian, 1999) believed that the correct choice was necessary, however Callahan correlated hammer choice with the grade of toolstone in his scale (1979:168).

There seems to be similarities between chess and flintknapping. There are many variables and high-level decision making when playing chess. A player not only needs to understand his opponent but predetermine future moves and outcomes while solving complex problems. Golf (2015) compares the biochemistry and psychology of chess and classical physical exercise where he states, “In chess and in classical sports, the brain, spinal cord, nerves and muscles cooperate in complete harmony” (Golf, 2015:1). Golf also talks about similarities in mental profiles between chess players and athletes who share similar cognitive properties such as, attention, conflict control, memory, motivation and recognition (Golf, 2015:1). When flint knapping, the objective piece (i.e., raw material) is the opponent. Given enough time and effort, one may approach flintknapping as a chess grandmaster approaches his opponents. Research (see Gobet and Simon, 1998; Campitelli and Gobet, 2008; Bilalić et al., 2009) showed that one significantly increased their chess skills with a combination of practice and coaching (Campitelli and Gobet, 2008). Knowledge (i.e., skill) can be socially transmitted via oblique transmission or from non-parental peer to peer, where the non-parental peer is from an older generation (Mesoudi, 2011). This example is a perfect comparison for the stone-adze makers of Lagnda. Stout (2005) observed in the apprenticeship, the apprentice not only observes (knowledge) but also participates (know-how). This information is transferred via oblique and vertical transmission from his mentor as well as other community members (Stout, 2002; Mesoudi, 2011). If flintknapping is like chess, then given the amount of time (i.e., knowledge), one should be able to display adequate control (i.e., know-how) despite raw material or hammer choice within a few minutes of assessing the overall quality. In other words, your opponent will not stand a chance.

An apprenticeship would seem to be the most viable means of teaching/learning how to flintknap. However, this form of learning may only occur in complex, sedentary societies (Lassen and Williams, 2015). In hunter-gatherer societies, learning would occur through observation and doing (Hayden and Cannon, 1984), which could account for copy-error observed (Eren et al., 2014; Schillinger et al., 2014). Ferguson (2008) posits a learning technique called "scaffolding", which appears in the archaeological record (Smallwood, 2008). This form of learning would involve the novice having expert assistance from time to time. According to Ferguson (2008), a novice would work until reaching a problem that they could not solve. Once at this "stopping" point, an expert corrects the problem, which allows the novice to continue (Lassen and Williams, 2015). If prehistoric flintknapping followed an apprentice model, similar to what Stout (2005) observed in the Langda village, then one might infer the lower quality or less desirable material may have been used to learn on. However, this has not been scientifically tested and would take a considerate amount of time and effort to research. When attempting to make Folsom points, both novice and expert, Lassen and Williams (2015), suggests both may attempt to knap Folsom points when raw materials are readily available. There would be minimal costs in this situation. However, when raw material is not as available or a lower quality, then only experts would attempt to manufacture these points.

Archaeological experiments pertaining to skill has often been measured based on strategic organization of operations, number of flake scars, cutting-edge, width/thickness ration, and debris (Stout, 2005; Bamforth and Finlay, 2008; Eren et al., 2011; Lassen and Williams, 2015). For an example of one detailed breakdown skilled versus unskilled knappers, see Table I and II in Bamforth and Finlay (2008:5-6). When using the tables created by Bamforth and Finlay (2008) it should be noted that "Intentional Overshot Flaking" is not a correct measure for skill (see Eren et al., 2014; Eren et al., 2013) and should be disregarded unless relating to unskilled knappers or mistakes.

According to Stout, preferred outcomes can only be achieved when a knapper is capable of 1) Removing longer and thinner flakes, 2) Using core morphology (i.e., dorsal ridge) to facilitate desired flake removals, and 3) Consistent and effective reduction strategies (2005:335). These preferred outcomes in flintknapping can only be acquired with time and experience as seen through the work of Stone-bead knappers of India in which only masters display homogenic, optimized, stable motor state (Roux et al., 1995; Bril et al., 2000; Stout, 2005).   In conversations with modern flintkappers, platform preparation seems be one of the most critical independent variables reliant upon the knapper (Bradley, 1975; Whittaker, 1994; Apel, 2007).

Without a proper knowledge of this variable as well as the know-how, one will never master flintknapping. Similar to the stone-bead knappers in India, many modern novice flintknappers will know much of the skills needed or the necessary stages (Callahan, 1979) to produce high-quality work, however a novice's level of comprehension is not backed with the experience of a master (Stout, 2005).

1.2 Stone raw material quality and skill

The definition of stone raw material quality has been neglected in archaeological literature and is often a qualitative description (Brantingham et al., 2000; Braun et al., 2009; Browne and Wilson, 2011). Generally, raw materials are known to be 'high quality' based on their names or geographic locations (Goodyear, 1989). For example, in North America, one recognizes 'Flint Ridge' or 'Coastal Plain'. However, these terms are based on geography and their quality has no quantitative basis. The first semi-quantitative approach attempted for assessing the quality of raw materials was conducted by Callahan in which he created a lithic-grade scale based on workability (Callahan, 1979:24; Domanski et al., 1994; Eren et al., 2011). In other words, he assigned numerical values based on how easy a raw material would flake as well as gave 'suggested materials' that would fit in his gradation (1979). For example, he assigned a '1.0' grade to easiest toolstone to work (i.e., Obsidian) and '5.5' to the most difficult toolstone to work (i.e., Greenstone) (Callahan 1979:16). Despite his efforts, little has been added to this since 1979. Due to the lack of progress in understanding the quality of raw materials, archaeologists are only capable of assigning qualitative terms such as, high- or low-quality to raw materials (Eren et al., 2011).

It is vital we understand if and how the internal properties of toolstones affected the choices made by prehistoric flintknappers. If one needs a faster blow to thin a biface, reducing accuracy, then one will need the skill to pull this off without failure – and many novices do not have these skills (Eren et al., 2011). One variable that might increase or decrease the influence of raw material force on stone tool technology is skill. Expanding on the discussion in the previous section, skill can be defined as knowledge (i.e., cognition) and know-how (i.e., motor ability) (Pelgerin, 1990; Bamforth and Finlay, 2008; Apel; 2008). On one hand, knowledge would be socially transmitted through various modes of inheritance as well be subject to different cultural influences, such as prestige bias or copy-error (Eren et al., 2014, Schillinger et al., 2014; Misoudi, 2011) which in turn, would affect the prehistoric skill necessary to produce tools, the cultural transmission of stone tool techniques, and the pace of technological evolution. On the other hand, know-how would be gained through experience or genetically inherited, i.e., natural ability.

The ability to continue to improve skill despite raw material quality was demonstrated in experiments conducted by Eren et al. (2011). Their research focused on if a knapper's replication skills would be hindered by the overall quality of toolstone. Throughout a 20-month long process, Eren et al. (2011) demonstrated through the manufacturing of Levallois technology, switching from a high quality toolstone to a lower quality had to significant effect on the knapper's growing skills. Quality was defined by macroscopic properties through strike-testing which were verified statistically and microscopically (Eren et al., 2011:2733). Throughout the experiment, the knapper's skill was based on previous knowledge and experience of stone tool knapping as well as quantified through predetermined goals, symmetry, overshot flake count, and economy (Eren et al., 2011). Despite the results from Eren et al. 2011 showing that skill can overcome raw material constraints (see Costa, 2010; de la Torre, 2011; Sharon, 2008) they still recommended more experimental research (2011:473).

As an aside, it is important to note that throughout the archaeological literature it has often been thought that raw material quality influenced lithic morphology (Lubbock, 1865; Abott, 1911; Goodman, 1944). The research conducted by Eren et al. (2014) was a replication experiment designed to question the relationship between stone raw materials differences and stone tool form, holding skill constant (2014:473). Using three different raw materials (flint, basalt, and obsidian), Eren et al. (2014) tested if these raw materials would constrain a knapper from being able to copy the shape of a replica handaxe. Their results indicated no significant differences in shape of tools produced from the three raw materials. Two important concepts come from their research. The first is the results produced by Eren et al. (2014) should make archaeologists more cautious when assessing if raw material caused morphological differences between stone tools (i.e., within- and between-assemblage patterns). In other words, if raw materials have any effect, it is just one of many variables within the variation of lithic artifacts (Lycett and von Cramon-Taubadel, 2014:656). These variables, such as knowledge, manual dexterity, skills, or will-power would have greatly affected overall morphology more than raw materials (Eren et al., 2014). The second conclusion, which coincides with many other archaeological studies (i.e., Sharon, 2008; Clarkson, 2010; Costa, 2010; Smallwood, 2012; Buchanan et al., 2014; and Lycett and von Cramon-Taubadel, 2014), is that other variables, such as skill, must "rigorously be sought to fully explain differences in the attributes of classes of stone artifacts found across time and space" (Eren et al., 2014:486).

1.3 Summary and hypotheses

From the above discussion, one can infer that the relationship between stone raw material quality and skill can influence the appearance of stone tools in the archaeological record. Since raw material strength is an important and inherent internal property of raw material quality, understanding raw material strength in important to understanding how individuals and populations produced stone tools. To reiterate from the beginning, a higher raw material strength would require the toolmaker to have a faster hammer blow to chip the rock – reducing hand-eye coordination, and chipping accuracy. Experts can thus more easily produce tools on "stronger" raw materials, whereas given that same material novices will be challenged out of proportion relative to a weaker raw material.

Here, I assess the maximum force to fracture 13 different raw material types. Although toolstone fracture force has been examined before – for example, Dogandzic et al. (2020) recently examined basalt, flint, obsidian, and glass (Dibble and Rezek, 2009; Pelcin and Dibble 1995; Rezek et al., 2011; Magnani et al., 2014; Leader et al., 2017) – this present study focuses entirely on cherts. And while others have examined the fracture strength of cherts before (Braun et al. 2008, 2009; Eren et al. 2014; Williams et al. 2019), the quantity chert types (n=13) and sample sizes (n=30 per each type), has never been presented in the archaeological literature.

I hypothesize that if toolstone fracture strength was a factor that influenced raw material selection and stone tool appearance, then there should be significant differences between the fracture strengths of the 13 chert types. However, if toolstone fracture strength was not a factor that influenced raw material selection, then there should not be significant differences between the fracture strengths of the 13 chert types.

Chapter 2:

Materials and methods

2.1 Raw Materials

Rectangular chert samples (n=390) were acquired through Neolithics and separated into 13 categories based on their flint type. Thus, each group had 30 samples and each sample was labeled as its raw material name and specimen number. The 13 raw materials are [San Antonio, Pedernales, Georgetown, Kay County, Keokuk, Coastal Plain, Buffalo River, Hopkinsville, Kentucky Hornstone, Flint Ridge Ohio]. Chert was chosen for this experiment because it is one of the main sources of raw material used by prehistoric stone tool makers, and a large scale "within chert" assessment has never been conducted. Chert can be defined as "all sedimentary rocks composed primarily of microcrystalline quartz, including flint, chalcedony, agate, jasper, hornstone, [and] novaculite…" (Luedtke, 1991:5). This broad definition encompasses many of the toolstones used by prehistoric knappers, however there has often been a divide between the word flint and chert which is based on color and quality. It seems fit to employ the American usage of chert while avoiding the separation of the two.

2.2 Morphometrics

Measurements of each rectangular chert specimen included mass, length, an average of the three width measurements, and an average of three thickness measurements. The rectangular slabs were hand cut as close as possible to 10.16 x 2.40 x 2.12 cm but due to human error were not perfect, hence the extra measurements recorded. Mass was measured using an American Weigh SC-501 Digital Pocket Scale 500x0.01g and recorded in Microsoft Excel Office 365. Length, width, and thickness was measured using a Mitutoyo 500-196-30 Advanced Onsite Sensor (AOS) Absolute Scale Digital Caliper, 0 to 6"/0 to 150mm Measuring Range, 0.0005"/0.01mm Resolution, LCD and recorded in Microsoft Excel Office 365. For the average width and thickness measurements, width was taken at each end and at the midpoint of length. Each of the 13 raw materials and their data were arranged by specimen number and then each measurement was averaged and recorded in Microsoft Excel Office 365.

2.3 Ball-on-Three-Ball Testing Jig

Before a biaxial flexure test could be conducted a ball-on-three-ball testing jig had to be manufactured to fit the Instron Materials Tester. The testing jig was designed and fabricated by Mike Fisch at the Kent State University in the Aeronautics and Technology Building and was constructed using steel. The jig consists of two rectangular bases and three stainless steel rods. The two rectangular bases are 3.18 cm wide. The stainless-steel rods are standard English diameter and are approximately 0.95 cm (3/8"). Each cylinder is kept square by using 0.16 cm pins (1/16") and held into place with allenhead steel fasteners. The two outside cylinders (see Figure 1) can be moved in 0.64 cm increments from 10.16 to 3.81 cm. For this experiment, the cylinders were placed at 5.08 centimeters.

2.4 Flexure Test

A destructive flexure test was conducted on each sample to assess the force needed to break each raw material using the Instron Materials Tester (IMT). The ball-on-three ball test supports each raw material slab on three equally spaced balls, which are concentric to the load. A crosshead displacement rate of 0.5 mm/per minute was used in a three-point configurating. The test involves placing a pre-measured specimen on the ball-on-three-ball testing jig. The load bearing upper section of the IMT is jogged down within a millimeter of the rectangular slab and then the balance is reset to zero. The starting of the test begins by lowering the load bearing upper section until contact is made. Load is continuously measured as the sample is being displaced by the applied force. The IMT software collected measurements throughout the duration of the test which was documented using Microsoft Excel Office 365. This procedure was conducted for each specimen (n=390). The use of a ball-on-three-ball test has primarily been used in Archaeology for studying ceramics (see Neupert, 1994; Beck, 2002; Bebber, 2017) however biaxial flexure tests methods are sufficient for "all planar specimens with irregular geometry" (Eren et al., 2014:477). It should be noted that specimens used in the test experienced overhang like Eren et al. (2014) but did not affect the overall process (Neupert, 1994).

The IMT was used to calculate three variables: maximum force, energy at break, and Young's modulus. However, for this research the focus will be on maximum force or peak load.

"Peak load refers to the maximum amount of load applied during the test. Load was measured in kiloNewtons/meter. This measure provides an assessment of initial strength prior to fracture by measuring the maximum of amount load withstood by the sample" (Bebber, 2017:8).

2.5 Statistical Analysis

The statistical analysis was conducted by Dr. Briggs Buchanan, University of Tulsa. Of the morphometric variables used to measure the experimental chert specimens mass, length, width1, width3, thickness1, thickness2, thickness3, and average thickness have distributions that do not conform to an underlying normal distribution (Table 1). Two morphometric variables, width2 and average width, have distributions that are similar to an underlying normal distribution. The three measures associated with the experimental breakage—maximum force, energy at break, and Modulus mPA—also are significantly different from normal. Given the mostly non-normal sample distributions in these variables we use nonparametric tests in the overall comparisons. Specifically, we use the Kruskal-Wallis test to compare the overall differences in each of the variables by raw material group. We follow-up these analyses of maximum force using Mann-Whitney pairwise tests.

As several of the morphometric variables differ across the raw material groups, the next set of analyses controls for the overall form of the experimental flakes using a general linear hypothesis approach. To do this, we used the lm function in R to construct a model that predicts maximum force by controlling for mass, length, average width, and average thickness by raw material group (i.e., lm(formula = Force ~ Width + Mass + Length + Thick + RM)). We then used Tukey contrasts to make multiple comparisons of the means for each pair of raw materials.

Chapter 3:

Results

Kruskal-Wallis tests of each of the variables by raw material show significant differences (Table 2). Adjusting for the 13 tests we conducted using the Bonferroni method (0.05/13=0.0038) each of the tests remain significant and indicate at least one set of different medians among the raw material groups for each of the variables. Next, we focused on the maximum force needed to initiate an experimental flake. The overall test of this variable showed a significant difference in medians. Using Bonferroni-corrected pairwise Mann-Whitney tests we found that only a small proportion (7 out of 78 pairwise comparisons) revealed a significant difference (Table 3). Four of these seven differences occur with Kentucky Hornstone.

Given the significant differences in the medians of the morphometric variables, we used the general linear approach to control for the major aspects of flake form. The linear model we used controlled for mass, length, average width, and average thickness. The Tukey's contrast results are shown in Tables 4 and 5. Of the 78 pairwise comparisons the tests revealed 20 (or about 26%) were significant (Table 5). Of the raw materials with significant differences Pedernales had the most differences with 4, followed by raw Keokuk and Kentucky Hornstone. The other raw materials including Coastal Plain, Flint Ridge, Kay County, heat-treated Keokuk, and San Antonio, had one or two differences.

Chapter 4:

Discussion and conclusion

4.1 Discussion

When comparing the raw materials, results show a statistical difference among the cherts (11.83%), meaning there were 20 differences among the 169 comparisons (see table 4, figures 2-4). However, there were far more similarities between the chert than there were differences (88.17%). English chert was removed from the study due to its loci. When conducting lithic experiments, it should be noted, Georgetown chert varies. In other words, its internal properties were like all the other cherts (i.e., a range of differences in the amount of force needed to break it between the 12 comparisons). The results can be summarized as, chert is chert, when assigning quality to chert, based on internal properties, they tend to act more similar than different.

It should be noted Keokuk (heat-treated) and Keokuk (raw) are both similar and different, statistically. The results of Bonferroni-corrected pairwise Mann-Whitney tests showed they both where significant and insignificant. Patterson states, "Experiments have shown that heat treatment lowers the tensile strength of some cherts as much as 40%... …tough cherts can be more easily worked and longer flakes can be produced" (1995:72). See also Purdy & Brooks 1971 and Patterson 1981. Since force was the main property assessed, the result of Keokuk (heat-treated and raw) being similar and different could be due to tensile strength. The heat treatment of chert has been known to increase flakeability, edge strength, and reduces the force needed for flake propagation, however it has no major effect on flake morphology (Crabtree & Butler, 1964; Bradley, 1974; Flenniken & Garrison, 1975:129; Peterson, 1976; Rick, 1978:47; Patterson, 1979; Byers et al., 2014; Mraz et al., 2019). Buffalo River chert ranges from glassy to chalky and the heat treatment of the chert is supposed to improve workability as well as bring out the reddish colors. When assessing the internal properties (i.e., measuring the amount of force needed to break each rectangular piece) of Buffalo River (heat-treated) and Buffalo River (raw) they were statistically the same. This analysis of Buffalo River chert can lead one to believe two things. The first being it does not need to be heat treated or the second, it was not properly heat treated. According to Patterson, “Good results in stone tool making cannot be obtained from tough cherts unless heat treatment is employed” (1995:72, see also Crabtree 1967 and Sollberger & Hester 1973:181). It is recommended further analysis on the probability Buffalo River shows no statistical improvement upon heat treatment as well as similar tests be conducted with heat treated versus non heat-treated cherts.

When approaching these results with a knowledge versus know-how model or skill model, chert would be a great raw material for learning due to the consistent force needed to propagate flakes. However, the chert that showed a statistical difference may have been reserved for those with more skills in times of need or to hone one’s skills for more difficult materials. More experiments assessing skill and how raw materials effect skill should be conducted. Eren et al. states, “Clovis projectile points appear to have been made the same way regardless of region” (2015). They later conclude there were regional shape differences attributed to copy-error. A comparative analysis where the internal properties are assessed should be conducted with Upper Mercer, Wyandotte, using the results of Hopkinsville from this study. This analysis would help better understand the manufacturing process as well as whether skilled versus unskilled stone manufacturers were at hand. It is probable that unskilled stone tool manufacturers or novices could be responsible for a higher copy-error.

When considering these differences, they could have played a major role within colonization (see map for pattern of difference and similarities). According to Meltzer (2009) push and pull factors as well as risks played a major part in the colonization of the Americas. These factors included: maintaining resource returns, maximizing mobility, maximizing residence time in resource-rich habitats, minimizing group size, and maintaining contact between dispersed groups (Meltzer, 2009). When looking at the models posited by Kelly and Todd (1988), there were two possible approaches, collecting versus foraging. With a collecting subsistence system, hunter-gatherers would increase their landscape knowledge as well as increase encounters with prey and resources. This subsistence model would increase their knowledge of raw materials as well as increase skills when using new raw materials. Using the model would not only increase knowledge, but it would also maximize colonization factors posited by Meltzer (2009). Having a maximum resident time in resource-rich environments would not only provide colonizers with much needed raw materials but would also "apprentices" the adequate quantity needed in learning stone tool manufacturing.

4.2 Conclusion

In conclusion, chert is chert. Quality can be assessed statistically using an Instron materials tester by measuring the force needed to break raw materials. The breakage experiments conducted with the 13 different raw materials is a robust attempt to better understand the internal properties of raw materials. It is recommended, based on these results, that more experiments like these be conducted (i.e., with Wyandotte and Upper Mercer). Experiments pertaining to skill as well as ways to measure skill should be conducted to see how raw materials may or may not affect one's skillset in stone tool manufacturing and whether or not raw materials had an effect on apprenticeships and novice stone tool manufacturers. The more probable explanation would be a higher percentage of copy-error among novices as opposed to masters. Only through these experiments will we understand what quality means and how to apply it to assemblages of different raw materials. This will allow us to better assess skill levels as well as understand patterns of colonization. Using the data generated further analysis can be conducted to help better understand these circumstances.

References

Andrefsky, William, and William Andrefsky Jr.

Lithics. Cambridge University Press, 1998.

Bamforth, Douglas B., and Nyree Finlay.

"Introduction: archaeological approaches to lithic production skill and craft learning." Journal of Archaeological Method and Theory 15, no. 1 (2008): 1-27.

Basalla, G. 1988.

The evolution of technology. Cambridge Univ. Press, Cambridge, U.K.

Bebber, Michelle Rae.

"Tempered Strength: a controlled experiment assessing opportunity costs of adding temper to clay." Journal of Archaeological Science 86 (2017): 1-13.

Bebber, M. R., Norris J. D., Flood, K., Fisch, M., Meindl, R. S., & Eren, M. I. 2019.

Controlled experiments support the role of function in the evolution of the North American copper tool repertoire. (In Press)

Beck, Margaret E.

"The ball-on-three-ball test for tensile strength: Refined methodology and results for three Hohokam ceramic types." American Antiquity 67, no. 3 (2002): 558-569.

Bilalić, Merim, Peter McLeod, and Fernand Gobet.

"Specialization effect and its influence on memory and problem solving in expert chess players." Cognitive science 33, no. 6 (2009): 1117-1143.

Bradley, Bruce A.

"Lithic reduction sequences: a glossary and discussion." World Anthropology

(1975): 5-13.

Brantingham, P. Jeffrey, John W. Olsen, Jason A. Rech, and Andrei I. Krivoshapkin.

"Raw material quality and prepared core technologies in Northeast Asia." Journal of Archaeological Science 27, no. 3 (2000): 255-271.

Browne, Constance L., and Lucy Wilson.

"Resource selection of lithic raw materials in the Middle Palaeolithic in southern France." Journal of Human Evolution 61, no. 5 (2011): 597-608.

Callahan, Errett.

The basics of biface knapping in the eastern fluted point tradition: a manual for flintknappers and lithic analysts. Eastern States Archeological Federation, 1979.

Campitelli, Guillermo, and Fernand Gobet.

"The role of practice in chess: A longitudinal study." Learning and individual differences 18, no. 4 (2008): 446-458.

Clarke, David L.

Analytical archaeology. Routledge, 2014.

Crabtree, D. E., and B. R. Butler.

"Notes on Experiments in Flint Knap-ping 1: Heat Treatment of Silica Minerals. Tebiwa." Journal of the Idaho State University Museum 7, no. 1 (1964).

Creanza, N., Kolodny, O., & Feldman, M.W. (2017).

Cultural evolutionary theory: How culture evolves and why it matters. Proceedings of the National Academy of Sciences of the United States of America.

Darwin, C. 1859

On the Origin of Species. John Murray, London

Diamond, J. 1978.

The Tasmanians: the longest isolation, the simplest technology. Nature 273:185–186.

Domanski, Marian, John A. Webb, and James Boland.

"Mechanical properties of stone artefact materials and the effect of heat treatment." Archaeometry 36, no. 2 (1994): 177-208.

Dunnell, R. C. 1971.

Systematics in Prehistory. Free Press.

Eren, Metin I., Stephen J. Lycett, Christopher I. Roos, and C. Garth Sampson.

"Toolstone constraints on knapping skill: Levallois reduction with two different raw materials." Journal of Archaeological Science 38, no. 10 (2011): 2731-2739.

Eren, Metin I., Christopher I. Roos, Brett A. Story, Noreen von Cramon-Taubadel, and Stephen J. Lycett.

"The role of raw material differences in stone tool shape variation: an experimental assessment." Journal of Archaeological Science 49 (2014): 472-487.

Eren, M. I. & Buchanan, B. (May 2016)

Clovis Technology. In: eLS. John Wiley & Sons, Ltd: Chichester

Eren M. I., Buchanan B. & O'Brien M. J. (2015)

Social learning and technological evolution during the Clovis colonization of the New World. Journal of Human Evolution 80: 159–170.

Ericsson, K. Anders, Ralf T. Krampe, and Clemens Tesch-Römer.

"The role of deliberate practice in the acquisition of expert performance." Psychological review 100, no. 3 (1993): 363.

Flenniken, J. Jeffrey, and Ervan G. Garrison.

"Thermally altered novaculite and stone tool manufacturing techniques." Journal of Field Archaeology 2, no. 1-2 (1975): 125-131.

Geselowitz, M. (1993).

Archaeology and the Social Study of Technological Innovation. Science, Technology, & Human Values, 18(2), 231-246

Gladwell, Malcolm.

Outliers: The story of success. Little, Brown, 2008.

Gobet, Fernand, and Herbert A. Simon.

"Templates in chess memory: A mechanism for recalling several boards." Cognitive psychology 31, no. 1 (1996): 1-40.

Golf, Sighart.

"Biochemistry and psychology of chess and classical physical exercise: Concurring or conflicting evidence." J Sports Med Doping Stud 5, no. 158 (2015): 2161-0673.

Goodman, Mary Ellen.

"The physical properties of stone tool materials." American Antiquity 9, no. 4 (1944): 415-433.

Hambrick, D.Z., Altmann, E.M., Oswald, F.L., Meinz, E.J., Gobet, F. and Campitelli, G., 2014.

Accounting for expert performance: The devil is in the details. Intelligence, 45,

pp.112-114.

Hayden, Brian, and Aubrey Cannon.

"Interaction inferences in archaeology and learning frameworks of the Maya." Journal of Anthropological Archaeology 3, no. 4 (1984): 325-367.

Henrich, J., & Gil-White, F. J. (2001).

The evolution of prestige: Freely conferred deference as a mechanism for enhancing the benefits of cultural transmission. Evolution and Human Behavior, 22(3), 165–196.

Inizan, Marie-Louise, Michèle Reduron-Ballinger, Hélène Roche, and Jacques Tixier.

"Technology and terminology of knapped stone." Crep, Nanterre (1999): 189.

Kelly, Robert L., and Lawrence C. Todd.

"Coming into the country: Early Paleoindian hunting and mobility." American Antiquity 53, no. 2 (1988): 231-244.

Key, Alastair JM, and Stephen J. Lycett.

"Reassessing the production of handaxes versus flakes from a functional perspective." Archaeological and Anthropological Sciences 9, no. 5 (2017): 737-753.

Lassen, Robert, and Thomas Williams.

"Variation in flintknapping skill among Folsom-era projectile point types: a quantitative approach." Journal of Archaeological Science: Reports 4 (2015): 164-173.

Luedtke, Barbara E.

An archaeologist's guide to chert and flint. 1992.

Lycett, Stephen J., and Parth R. Chauhan.

"Analytical approaches to Palaeolithic technologies: an introduction." In New perspectives on old stones, pp. 1-22. Springer, New York, NY, 2010.

Lycett, S. J. 2011.

"Most Beautiful and Most Wonderful": Those Endless Stone Tool Forms. Journal of Evolutionary Psychology 9:143-171.

Lycett, S.J. & von Cramon-Taubadel, N. (2015).

Toward a “quantitative genetic” approach to lithic variation. Journal of Archaeological Method and Theory 22 (2): 646-675.

McNabb, John, Francesca Binyon, Lee Hazelwood, Anna Machin, Steven Mithen, Michael D. Petraglia, Nicolas Rolland, Mark White, Thomas Wynn, and John McNabb.

"The large cutting tools from the South African Acheulean and the question of social traditions." Current Anthropology 45, no. 5 (2004): 653-677.

Meltzer, David J.

First peoples in a new world: colonizing ice age America. Univ of California Press, 2009.

Mesoudi, A., Whiten, A., & Laland, K. N. (2004).

Is human cultural evolution Darwinian? Evidence reviewed from the perspective of The Origin of Species. Evolution, 58(1), 1–11.

Mesoudi, A. 2011.

Cultural evolution. Chicago, IL: University Chicago Press.

Mraz, Veronica, Mike Fisch, Metin I. Eren, C. Owen Lovejoy, and Briggs Buchanan.

"Thermal engineering of stone increased prehistoric toolmaking skill." Scientific reports 9, no. 1 (2019): 1-8.

Neupert, Mark A.

"Strength testing archaeological ceramics: a new perspective." American Antiquity 59, no. 4 (1994): 709-723.

Norris, J. D., Stephens, C., & Eren, M. I. (2019).

Early- and middle-stage fluted stone tool bases found near Fox Lake, Wayne County Ohio: Clovis or not? Journal of Archaeological Science: Reports, 25, 1-6.

O'Brien, M. J., and R. L. Lyman. 2000.

Applying evolutionary archaeology. Kluwer Academic, New York.

Patterson, Leland W.

"Thermal damage of chert." Lithic technology (1995): 72-80.

Rick, John W., and Sylvia Chappell.

"Thermal alteration of silica materials in technological and functional perspective." Lithic technology 12, no. 3 (1983): 69-70.

Schillinger, K., Mesoudi, A., & Lycett, S. J. (2014).

Copying error and the cultural evolution of "additive" versus "reductive" material traditions: an experimental assessment. American Antiquity, in press.

Smallwood, Ashley M.

"Clovis biface technology at the Topper site, South Carolina: evidence for variation and technological flexibility." Journal of Archaeological Science 37, no. 10 (2010): 2413-2425.

Sollberger, John B., and Thomas Roy Hester.

"Some additional data on the thermal alteration of siliceous stone." Bulletin of the Oklahoma Anthropological Society 21 (1973): 181-185.

Stout, Dietrich, Blandine Bril, Valentine Roux, SophieA DeBeaune, J. A. J. Gowlett, CharlesM Keller, Thomas Wynn, and Dietrich Stout.

"Skill and cognition in stone tool production: an ethnographic case study from Irian Jaya." Current anthropology 43, no. 5 (2002): 693-722.

Stout, Dietrich, Jay Quade, Sileshi Semaw, Michael J. Rogers, and Naomi E. Levin.

"Raw material selectivity of the earliest stone toolmakers at Gona, Afar, Ethiopia." Journal of Human Evolution 48, no. 4 (2005): 365-380.

Trigger, B. G. 1989.

A history of archaeological thought. Cambridge: Cambridge University Press

Whittaker, John C.

Flintknapping: making and understanding stone tools. University of Texas Press, 1994.


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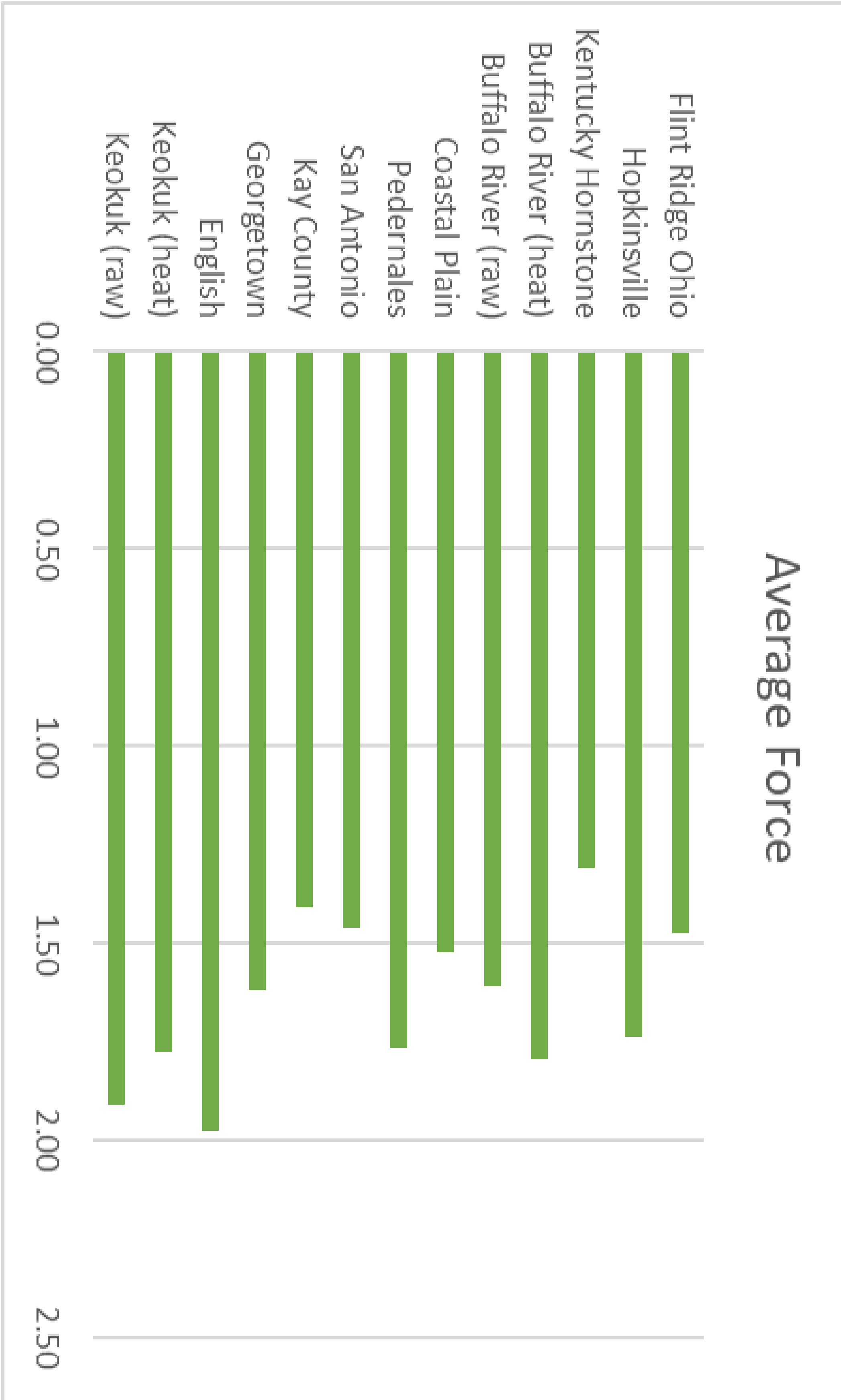
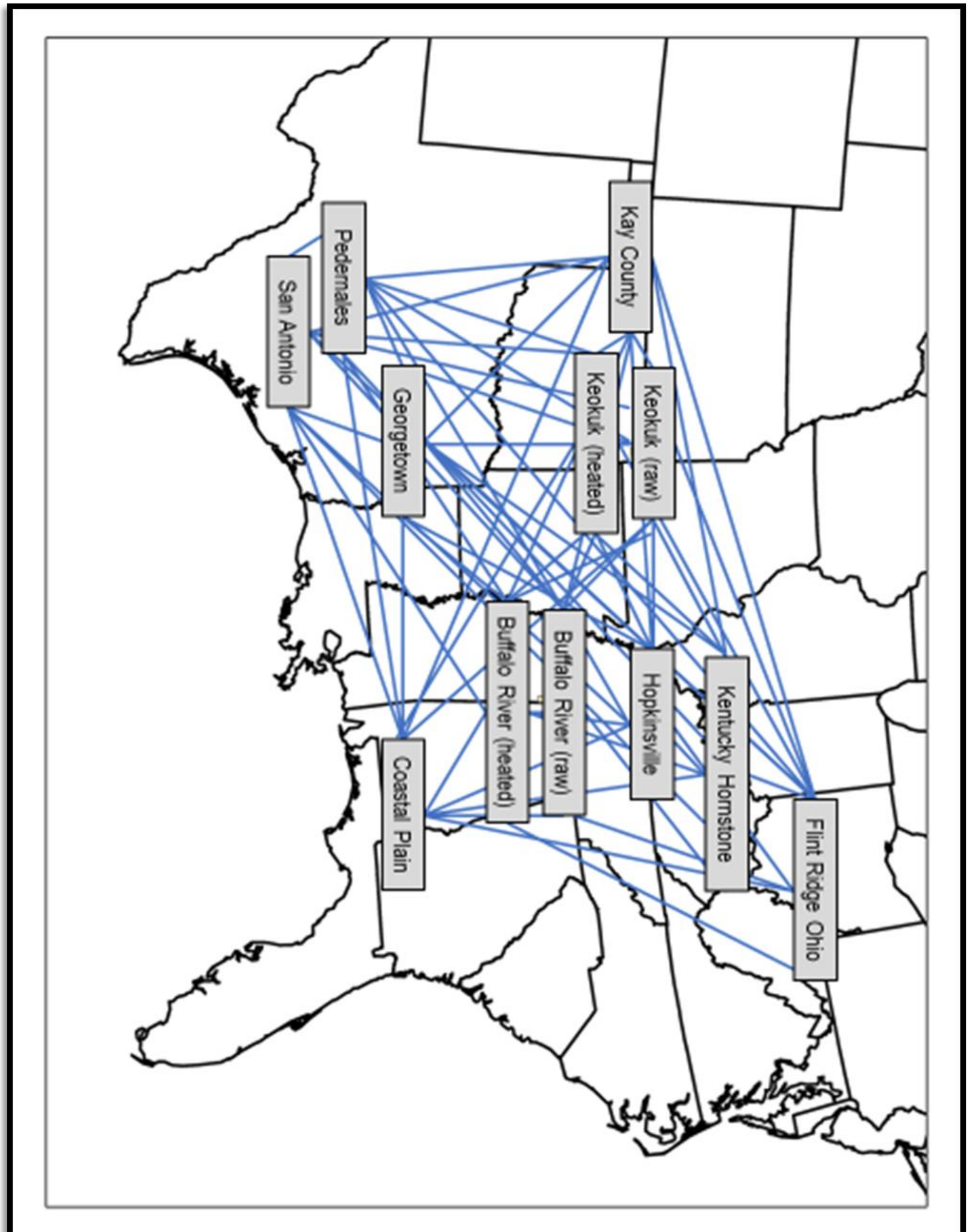
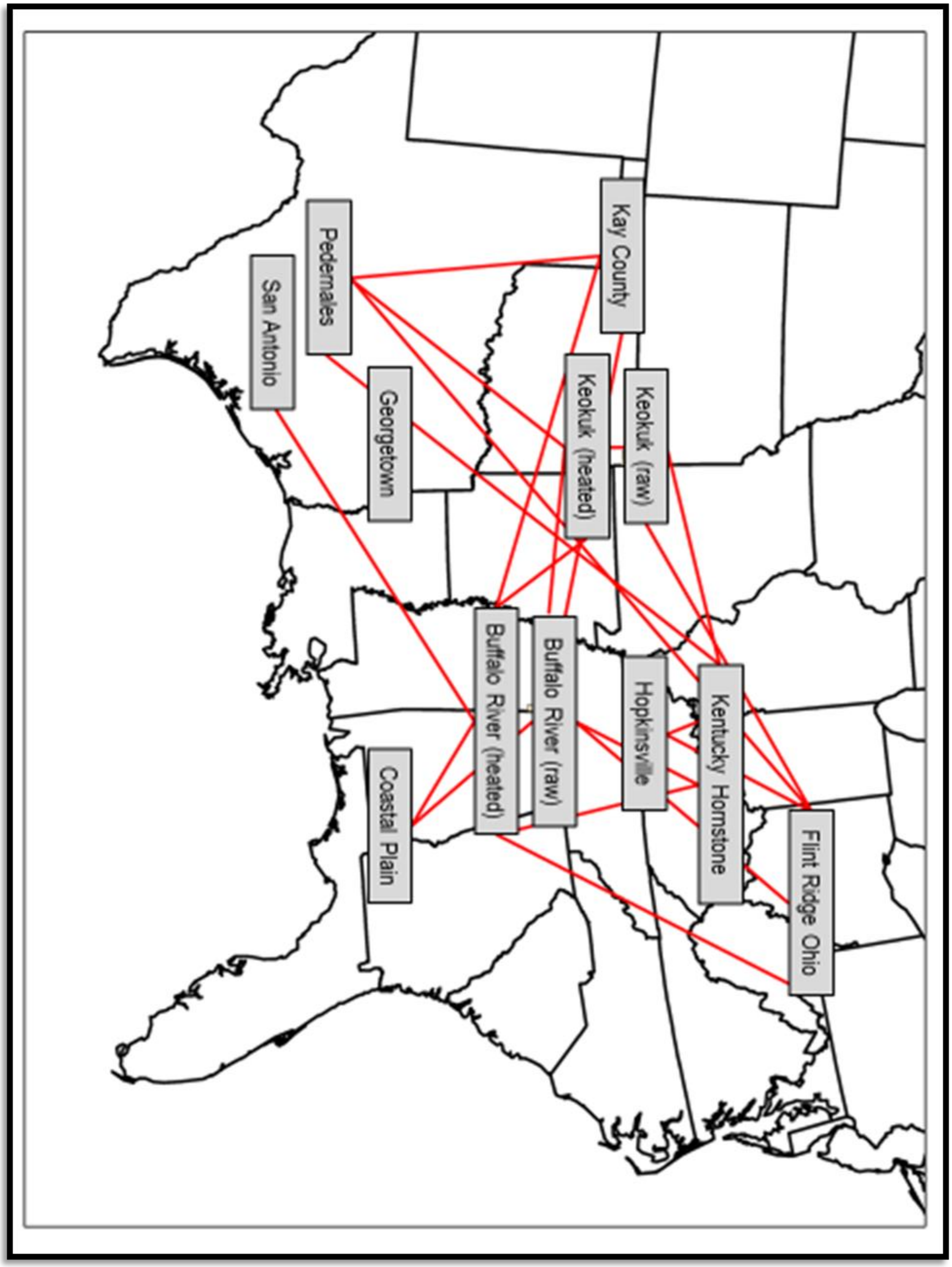
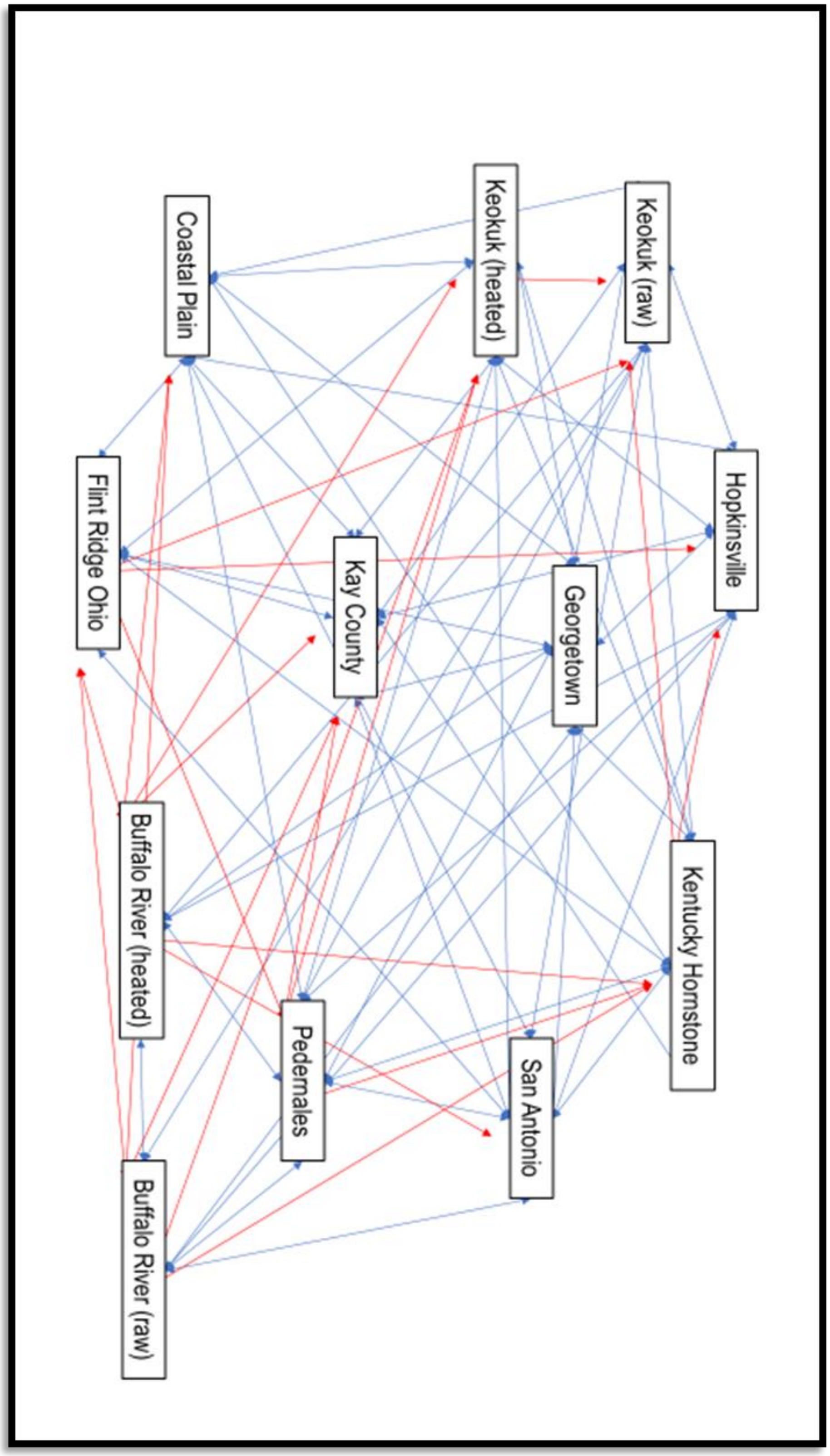

Average Force
Flint Ridge Ohio
Hopkinsville
Kentucky Hornstone
Buffalo River (heat)
Buffalo River (raw)
Coastal Plain
Pedernales
San Antonio
Kay County
Georgetown
English
Keokuk (heat)
Keokuk (raw)
0.00
0.50
1.00
1.50
2.00
2.50



Kay County
Pedernales
San Antonio
Georgetown
Keokuk (heated)
Keokuk (raw)
Buffalo River (heated)
Buffalo River (raw)
Hopkinsville
Kentucky Hornstone
Flint Ridge Ohio
Coastal Plain


Kay County
Pedernales
San Antonio
Georgetown
Keokuk (heated)
Keokuk (raw)
Buffalo River (heated)
Buffalo River (raw)
Hopkinsville
Kentucky Hornstone
Coastal Plain
Flint Ridge Ohio


Coastal Plain
Keokuk (heated)
Keokuk (raw)
Flint Ridge Ohio
Kay County
Georgetown
Hopkinsville
Buffalo River (heated)
Pedernales
San Antonio
Kentucky Hornstone
Buffalo River (raw)

Variable	Mass	Length	Width1	Width2	Width3	Avg. Width	Thick1
N	390	390	390	390	390	390	390
Shapiro-Wilk W	0.9668	0.9508	0.9504	0.9941	0.8996	0.9942	0.9885
p(normal)	<0.0000*	<0.0000*	<0.0000*	0.1382	<0.0000*	0.1433	0.0037*
Variable	**Thick2**	**Thick3**	**Avg. Thick**	**Maximum Force (kN)**	**Energy at Break (J)**	**Modulus (Young's) mPA**	
N	390	390	390	390	390	390	
Shapiro-Wilk W	0.9764	0.9718	0.9761	0.981	0.9403	0.9843	
p(normal)	<0.0000*	<0.0000*	<0.0000*	<0.0000*	<0.0000*	0.0003*	

Variable	**Hc (tie-corrected)**	***p***
Mass	152	<0.0000
Length	124.3	<0.0000
Width1	63.38	<0.0000
Width2	83.69	<0.0000
Width3	53.47	<0.0000
Average width	82.23	<0.0000
Thickness1	61.32	<0.0000
Thickness2	94.27	<0.0000
Thickness3	72.75	<0.0000
Average thickness	88.97	<0.0000
Maximum force	51.21	<0.0000
Energy at break	58.94	<0.0000
Modulus mPA	84.89	<0.0000

	Flint Ridge Ohio	Coastal Plain	Buffalo River (raw)	San Antonio	Keokuk (raw)	Pedernales	English	Georgetown	Kay County	Buffalo River (Heat-treated)	Keokuk (heat-treated)	Kentucky Hornstone	Hopkinsville
Flint Ridge Ohio	-	1	1	1	0.2483	1	0.5685	1	1	1	1	1	1
Coastal Plain	1	-	1	1	0.3146	1	1	1	1	1	1	1	1
Buffalo River (raw)	1	1	-	1	1	1	1	1	1	1	1	0.7385	1
San Antonio	1	1	1	-	0.03677	0.5439	0.5811	1	1	0.5685	1	1	1
Keokuk (raw)	0.2483	0.3146	1	0.03677	-	1	1	1	0.000742	1	1	0.000116	1
Pedernales	1	1	1	0.5439	1	-	1	1	0.04338	1	1	0.004958	1
English	0.5685	1	1	0.5811	1	1	-	1	0.08691	1	1	0.007638	1
Georgetown	1	1	1	1	1	1	1	-	0.9931	1	1	0.09642	1
Kay County	1	1	1	1	0.000742	0.04338	0.08691	0.9931	-	0.09642	1	1	0.5202
Buffalo River (Heat-treated)	1	1	1	0.5685	1	1	1	1	0.09642	-	1	0.01475	1
Keokuk (heat-treated)	1	1	1	1	1	1	1	1	1	1	-	0.2255	1
Kentucky Hornstone	1	1	0.7385	1	0.000116	0.004958	0.007638	0.09642	1	0.01475	0.2255	-	0.0569
Hopkinsville	1	1	1	1	1	1	1	1	0.5202	1	1	0.0569	-

Raw Material			Estimated Std. Error		
Buffalo River (raw)	***VS***	Buffalo River (Heat-treated)	-0.08889	0.1129	**Same**
Coastal Plain	***VS***	Buffalo River (Heat-treated)	-0.52586	0.11779	**Same**
English	***VS***	Buffalo River (Heat-treated)	-0.39229	0.13699	**Same**
Flint Ridge Ohio	***VS***	Buffalo River (Heat-treated)	-0.67722	0.12445	**Same**
Georgetown	***VS***	Buffalo River (Heat-treated)	-0.41941	0.13221	**Same**
Hopkinsville	***VS***	Buffalo River (Heat-treated)	-0.24969	0.12177	**Same**
Kay County	***VS***	Buffalo River (Heat-treated)	-0.56053	0.12448	**Same**
Kentucky Hornstone	***VS***	Buffalo River (Heat-treated)	-0.78502	0.13748	**Same**
Keokuk (heat-treated)	***VS***	Buffalo River (Heat-treated)	-0.62492	0.13549	**Same**
Keokuk (raw)	***VS***	Buffalo River (Heat-treated)	-0.23284	0.12885	**Same**
Pedernales	***VS***	Buffalo River (Heat-treated)	-0.16343	0.1283	**Same**
San Antonio	***VS***	Buffalo River (Heat-treated)	-0.44641	0.12498	**Same**
Coastal Plain	***VS***	Buffalo River (raw)	-0.43697	0.11894	**Same**
English	***VS***	Buffalo River (raw)	-0.3034	0.13799	**Same**
Flint Ridge Ohio	***VS***	Buffalo River (raw)	-0.58832	0.12482	**Same**
Georgetown	***VS***	Buffalo River (raw)	-0.33052	0.12989	**Same**
Hopkinsville	***VS***	Buffalo River (raw)	-0.1608	0.12163	**Same**
Kay County	***VS***	Buffalo River (raw)	-0.47164	0.12343	**Same**
Kentucky Hornstone	***VS***	Buffalo River (raw)	-0.69612	0.13419	**Same**
Keokuk (heat-treated)	***VS***	Buffalo River (raw)	-0.53603	0.13802	**Same**
Keokuk (raw)	***VS***	Buffalo River (raw)	-0.14394	0.12789	**Same**
Pedernales	***VS***	Buffalo River (raw)	-0.07453	0.12633	**Same**

San Antonio	***VS***	Buffalo River (raw)	-0.35751	0.12291	**Same**
English	***VS***	Coastal Plain	0.13357	0.12342	**Same**
Flint Ridge Ohio	***VS***	Coastal Plain	-0.15136	0.11366	**Same**
Georgetown	***VS***	Coastal Plain	0.10645	0.11912	**Same**
Hopkinsville	***VS***	Coastal Plain	0.27617	0.11505	**Same**
Kay County	***VS***	Coastal Plain	-0.03467	0.11542	**Same**
Kentucky Hornstone	***VS***	Coastal Plain	-0.25915	0.12564	**Same**
Keokuk (heat-treated)	***VS***	Coastal Plain	-0.09906	0.12189	**Same**
Keokuk (raw)	***VS***	Coastal Plain	0.29303	0.11921	**Same**
Pedernales	***VS***	Coastal Plain	0.36244	0.11765	**Same**
San Antonio	***VS***	Coastal Plain	0.07946	0.11596	**Same**
Flint Ridge Ohio	***VS***	English	-0.28493	0.11726	**Same**
Georgetown	***VS***	English	-0.02712	0.11994	**Same**
Hopkinsville	***VS***	English	0.1426	0.11843	**Same**
Kay County	***VS***	English	-0.16824	0.11955	**Same**
Kentucky Hornstone	***VS***	English	-0.39273	0.13709	**Same**
Keokuk (heat-treated)	***VS***	English	-0.23263	0.11292	**Same**
Keokuk (raw)	***VS***	English	0.15945	0.11433	**Same**
Pedernales	***VS***	English	0.22886	0.12182	**Same**
San Antonio	***VS***	English	-0.05412	0.12317	**Same**
Georgetown	***VS***	Flint Ridge Ohio	0.2578	0.11474	**Same**
Hopkinsville	***VS***	Flint Ridge Ohio	0.42752	0.11397	**Same**
Kay County	***VS***	Flint Ridge Ohio	0.11668	0.11355	**Same**
Kentucky Hornstone	***VS***	Flint Ridge Ohio	-0.1078	0.12416	**Same**
Keokuk (heat-treated)	***VS***	Flint Ridge Ohio	0.0523	0.11704	**Same**
Keokuk (raw)	***VS***	Flint Ridge Ohio	0.44438	0.11491	**Same**
Pedernales	***VS***	Flint Ridge Ohio	0.51379	0.11498	**Same**
San Antonio	***VS***	Flint Ridge Ohio	0.23081	0.1145	**Same**
Hopkinsville	***VS***	Georgetown	0.16972	0.11622	**Same**

Kay County	***VS***	Georgetown	-0.14112	0.11366	**Same**
Kentucky Hornstone	***VS***	Georgetown	-0.3656	0.12248	**Same**
Keokuk (heat-treated)	***VS***	Georgetown	-0.20551	0.12195	**Same**
Keokuk (raw)	***VS***	Georgetown	0.18658	0.11584	**Same**
Pedernales	***VS***	Georgetown	0.25599	0.11282	**Same**
San Antonio	***VS***	Georgetown	-0.02699	0.11322	**Same**
Kay County	***VS***	Hopkinsville	-0.31084	0.11258	**Same**
Kentucky Hornstone	***VS***	Hopkinsville	-0.53532	0.1316	**Same**
Keokuk (heat-treated)	***VS***	Hopkinsville	-0.37523	0.11847	**Same**
Keokuk (raw)	***VS***	Hopkinsville	0.01686	0.11455	**Same**
Pedernales	***VS***	Hopkinsville	0.08627	0.11438	**Same**
San Antonio	***VS***	Hopkinsville	-0.19671	0.11433	**Same**
Kentucky Hornstone	***VS***	Kay County	-0.22448	0.12738	**Same**
Keokuk (heat-treated)	***VS***	Kay County	-0.06439	0.12	**Same**
Keokuk (raw)	***VS***	Kay County	0.3277	0.11518	**Same**
Pedernales	***VS***	Kay County	0.39711	0.11238	**Same**
San Antonio	***VS***	Kay County	0.11413	0.11247	**Same**
Keokuk (heat-treated)	***VS***	Kentucky Hornstone	0.1601	0.13963	**Same**
Keokuk (raw)	***VS***	Kentucky Hornstone	0.55218	0.13003	**Same**
Pedernales	***VS***	Kentucky Hornstone	0.62159	0.12613	**Same**
San Antonio	***VS***	Kentucky Hornstone	0.33861	0.12345	**Same**
Keokuk (raw)	***VS***	Keokuk (heat-treated)	0.39209	0.11677	**Same**
Pedernales	***VS***	Keokuk (heat-treated)	0.46149	0.12274	**Same**
San Antonio	***VS***	Keokuk (heat-treated)	0.17852	0.12409	**Same**
Pedernales	***VS***	Keokuk (raw)	0.06941	0.11693	**Same**
San Antonio	***VS***	Keokuk (raw)	-0.21357	0.11719	**Same**
San Antonio	***VS***	Pedernales	-0.28298	0.11221	**Same**
Buffalo River (raw)	***VS***	Buffalo River (Heat-treated)	-0.787	0.9999	**Same**
English	***VS***	Buffalo River (Heat-treated)	-2.864	0.1759	**Same**

Georgetown	***VS***	Buffalo River (Heat-treated)	-3.172	0.0783 .	**Same**
Hopkinsville	***VS***	Buffalo River (Heat-treated)	-2.051	0.6934	**Same**
Keokuk (raw)	***VS***	Buffalo River (Heat-treated)	-1.807	0.8415	**Same**
Pedernales	***VS***	Buffalo River (Heat-treated)	-1.274	0.9875	**Same**
English	***VS***	Buffalo River (raw)	-2.199	0.5865	**Same**
Georgetown	***VS***	Buffalo River (raw)	-2.545	0.3447	**Same**
Hopkinsville	***VS***	Buffalo River (raw)	-1.322	0.9829	**Same**
Keokuk (raw)	***VS***	Buffalo River (raw)	-1.126	0.9958	**Same**
Pedernales	***VS***	Buffalo River (raw)	-0.59	1	**Same**
San Antonio	***VS***	Buffalo River (raw)	-2.909	0.1571	**Same**
English	***VS***	Coastal Plain	1.082	0.9971	**Same**
Flint Ridge Ohio	***VS***	Coastal Plain	-1.332	0.9818	**Same**
Georgetown	***VS***	Coastal Plain	0.894	0.9996	**Same**
Hopkinsville	***VS***	Coastal Plain	2.4	0.4407	**Same**
Kay County	***VS***	Coastal Plain	-0.3	1	**Same**
Kentucky Hornstone	***VS***	Coastal Plain	-2.063	0.685	**Same**
Keokuk (heat-treated)	***VS***	Coastal Plain	-0.813	0.9998	**Same**
Keokuk (raw)	***VS***	Coastal Plain	2.458	0.402	**Same**
Pedernales	***VS***	Coastal Plain	3.08	0.1023	**Same**
San Antonio	***VS***	Coastal Plain	0.685	1	**Same**
Flint Ridge Ohio	***VS***	English	-2.43	0.4203	**Same**
Georgetown	***VS***	English	-0.226	1	**Same**
Hopkinsville	***VS***	English	1.204	0.9923	**Same**
Kay County	***VS***	English	-1.407	0.9717	**Same**
Kentucky Hornstone	***VS***	English	-2.865	0.1733	**Same**
Keokuk (heat-treated)	***VS***	English	-2.06	0.686	**Same**
Keokuk (raw)	***VS***	English	1.395	0.9737	**Same**
Pedernales	***VS***	English	1.879	0.8027	**Same**
San Antonio	***VS***	English	-0.439	1	**Same**
Georgetown	***VS***	Flint Ridge Ohio	2.247	0.5521	**Same**
Kay County	***VS***	Flint Ridge Ohio	1.028	0.9982	**Same**
Kentucky Hornstone	***VS***	Flint Ridge Ohio	-0.868	0.9997	**Same**

Keokuk (heat-treated)	***VS***	Flint Ridge Ohio	0.447	1	**Same**
San Antonio	***VS***	Flint Ridge Ohio	2.016	0.7164	**Same**
Hopkinsville	***VS***	Georgetown	1.46	0.9623	**Same**
Kay County	***VS***	Georgetown	-1.242	0.99	**Same**
Kentucky Hornstone	***VS***	Georgetown	-2.985	0.1313	**Same**
Keokuk (heat-treated)	***VS***	Georgetown	-1.685	0.8967	**Same**
Keokuk (raw)	***VS***	Georgetown	1.611	0.9236	**Same**
Pedernales	***VS***	Georgetown	2.269	0.5359	**Same**
San Antonio	***VS***	Georgetown	-0.238	1	**Same**
Kay County	***VS***	Hopkinsville	-2.761	0.222	**Same**
Keokuk (heat-treated)	***VS***	Hopkinsville	-3.167	0.0797 .	**Same**
Keokuk (raw)	***VS***	Hopkinsville	0.147	1	**Same**
Pedernales	***VS***	Hopkinsville	0.754	0.9999	**Same**
San Antonio	***VS***	Hopkinsville	-1.721	0.8822	**Same**
Kentucky Hornstone	***VS***	Kay County	-1.762	0.8632	**Same**
Keokuk (heat-treated)	***VS***	Kay County	-0.537	1	**Same**
Keokuk (raw)	***VS***	Kay County	2.845	0.1834	**Same**
San Antonio	***VS***	Kay County	1.015	0.9984	**Same**
Keokuk (heat-treated)	***VS***	Kentucky Hornstone	1.147	0.995	**Same**
San Antonio	***VS***	Kentucky Hornstone	2.743	0.2305	**Same**
San Antonio	***VS***	Keokuk (heat-treated)	1.439	0.9663	**Same**
Pedernales	***VS***	Keokuk (raw)	0.594	1	**Same**
San Antonio	***VS***	Keokuk (raw)	-1.822	0.8336	**Same**
San Antonio	***VS***	Pedernales	-2.522	0.3589	**Same**

Raw Material			Estimated Std. Error		
Coastal Plain	***VS***	Buffalo River (Heat-treated)	-4.465	<0.01 ***	**Different**
Flint Ridge Ohio	***VS***	Buffalo River (Heat-treated)	-5.442	<0.01 ***	**Different**
Kay County	***VS***	Buffalo River (Heat-treated)	-4.503	<0.01 ***	**Different**
Kentucky Hornstone	***VS***	Buffalo River (Heat-treated)	-5.71	<0.01 ***	**Different**
Keokuk (heat-treated)	***VS***	Buffalo River (Heat-treated)	-4.612	<0.01 ***	**Different**
San Antonio	***VS***	Buffalo River (Heat-treated)	-3.572	0.0228 *	**Different**
Coastal Plain	***VS***	Buffalo River (raw)	-3.674	0.0170 *	**Different**
Flint Ridge Ohio	***VS***	Buffalo River (raw)	-4.713	<0.01 ***	**Different**
Kay County	***VS***	Buffalo River (raw)	-3.821	<0.01 **	**Different**
Kentucky Hornstone	***VS***	Buffalo River (raw)	-5.188	<0.01 ***	**Different**
Keokuk (heat-treated)	***VS***	Buffalo River (raw)	-3.884	<0.01 **	**Different**
Hopkinsville	***VS***	Flint Ridge Ohio	3.751	0.0133 *	**Different**
Keokuk (raw)	***VS***	Flint Ridge Ohio	3.867	<0.01 **	**Different**
Pedernales	***VS***	Flint Ridge Ohio	4.468	<0.01 ***	**Different**
Kentucky Hornstone	***VS***	Hopkinsville	-4.068	<0.01 **	**Different**
Pedernales	***VS***	Kay County	3.534	0.0255 *	**Different**
Keokuk (raw)	***VS***	Kentucky Hornstone	4.247	<0.01 **	**Different**
Pedernales	***VS***	Kentucky Hornstone	4.928	<0.01 ***	**Different**
Keokuk (raw)	***VS***	Keokuk (heat-treated)	3.358	0.0456 *	**Different**
Pedernales	***VS***	Keokuk (heat-treated)	3.76	0.0117 *	**Different**