ASSESSING “LITHIC SOUND” TO PREDICT A ROCK’S EASE OF FLAKING

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By
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ASSESSING "LITHIC SOUND" TO PREDICT A ROCK'S EASE OF FLAKING

Presented by David Scott DeForest

A candidate for the degree of Master of Arts

And hereby certify that in their opinion it is worthy of acceptance.

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……….Thanks Kristi, Bridge, Boo, and Mash
Brueghel

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TABLE OF CONTENTS

Chapter

APPENDIX

LIST OF FIGURES

Figures **Page**

LIST OF TABLES

ASSESSING "LITHIC SOUND" TO PREDICT A ROCK'S EASE OF FLAKING

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ABSTRACT

Objective information concerning "lithic sound's" properties of pitch, duration, and intensity, can inform archaeologists about a stone's candidacy for human use, and whether or not lithic material at a site has been heat treated. A hammer stone machine held and struck specimens under controlled conditions. To process acoustic information, A Kay Computer Speech Laboratory and related software proved effective. Nineteen specimens of stone were tested. Based upon waveform evaluation, heat treated stone had much higher average sound intensity levels than the stone in its unheated condition. Archaeologists could use methods discussed in this study to assess if heat treated siliceous rock is present at sites. After being struck with a hammer stone, significant differences existed concerning the duration and average vibration rates of sound between types of stone, unheated versus heated stone, and high and low quality stone of the same type. Accessory information included observation of how the hammer stone rebounded differently from specimens with obvious flaws, compared to stones with no imperfections. The hammer rebounded farther after striking high quality rock. Knappers use their sense of proprioception to determine a stone's candidacy for reduction. When striking a core stone which will flake predictably, the hand holding the hammer, will rebound quicker and farther back, compared to a low quality stone which absorbs energy.

Chapter 1
Introduction

Using modern acoustic technologies, differences were measure in sound wave duration and frequency response levels produced in stone that was not heat treated and stone that was heat treated. The basic question guiding this study was: Is there more to lithic sound than archaeologists have previously thought?

Minimal work has been carried out into what questions might be answered by studying the acoustic qualities of knappable stone. It was expected that a study investigating the frequency response levels or pitch that lithic material produces after being struck with a hammer stone might reveal information and answer questions concerning mechanical differences between types of lithic material, grades of the same type, and raw versus heat treated specimens.

My interest in the mechanical properties of knappable stone, specifically the sound produced when flint is struck, was kindled after visiting the Crowley Knife River Flint Quarries in Mercer County, North Dakota. When viewing the quarry pits, one cannot help but be impressed by the labor and cultural knowledge the pits represent. Clayton et al. (1970:282) described the quarries of North Dakota as covering 2 to 80 acres with pits being 20 feet in diameter and 3 to 4 feet deep with an abundant litter of chipping debris and broken artifacts present.

In the study of site 23CY641 in Callaway County, Missouri, several large bowl shaped open quarry pits were located on parallel ridges bordering an intermittent stream (University of Missouri-Columbia, Archaeological Survey of Missouri {23CY641}2003). At the site, Native Americans quarried glacially deposited Burlington Chert that rests on bedded Pennsylvania sandstone. Like the Knife River Flint quarries, large numbers of rejected cobbles are found amongst lithic debris and spoil piles.

Lithic tool and debris scatters at quarry sites represent skill knowledge possessed by individuals participating in ancient cultures. In the course of obtaining lithic material for tool making, quarryman surely evaluated a stone's quality and flakeability. Stones deemed candidates for reduction likely possessed a high-density, lacked visible flaws, had fine textured test flakes, and produced a high pitch when tapped or struck lightly with a hammer stone.

The clear pitch that quality stone resonates must have been as pleasing to the ears of past quarryman as it is to today's flint knappers. Lithic sound reflects the inherent physical properties of a stone's composition. Don Crabtree (1967:9) wrote that when appraising the workability of flint-like materials, one might first tap the stone and listen to the sound produced. If the stone gives off a dull sound or thud, one can expect undetectable cracks, fissures, and planes of weakness that reduce the predictability of fracture. If the stone has a sharp bell-like tone, chances are good that the material will be of working quality, meaning fractures resulting from particular applications of force will be predictable.

Lithic material of working quality referred to by Crabtree (1967) possesses the following physical characteristics. Knappable stones have amorphous or cryptocrystalline structure. The minerals of which such stone is formed (silica $Si0_2$) either have not formed crystals (amorphous, like glass), or have formed into networks of microscopic crystals not visible to the naked eye (cryptocrystalline or microcrystalline crystals), such as flint (Whittaker 1994:13). Micro- and macro-scopic crystalline homogeneity is a primary property of flint. The material is the same throughout an individual nodule, being free of impurities or inclusions which could reduce predictability of flaking (Hellweg 1984:20). Luedtke (1992:80) noted that workable lithic material must also have good isotropic properties in all directions. For example, a homogenous chert nodule would have no flaws or cavities while an isotropic nodule would have the same strength no matter how it was oriented in the testing equipment. Another property often mentioned in the literature is variously called elasticity, flexibility, or pliancy. Most practitioners associate elasticity specifically with the ability of a lithic material to resist unwanted fractures such as end shock, or step and hinge fractures (Luedtke 1992:83). Elastic properties of a rock are determined by its mineralogy, grain size, and micro cracks (Berry et al. 1983:153).

One incidental observation of rock properties that has been noted during testing involved differences in how the hammer stone reacted after striking varied types of flint. In types such as Brazilian Agate, and homogenous Burlington Chert, the hammer literally bounced off the specimen like it had struck a "trampoline." This action made the hammer easy to catch after one strike. Conversely, with porous or otherwise low quality stone which absorbed energy, minimal hammer stone rebound occurred, making double hits more likely to occur.

Using a Shore Scleroscope, Goodman (1944:419) studied the resiliency associated with different types of lithic material. She measured the height of rebound of a hammer from horizontally positioned lithic samples. Her tests showed wide discrepancies between limestone and stone tool making materials which included obsidian, different types of flint, fossil wood, and quartzite. Goodman noted that materials increase in resiliency generally in the same order as they increase in hardness with the exception of obsidian. Obsidian is very homogenous and amorphous. Goodman believed that the high homogeneity level of obsidian contributed to its level of resiliency. The differences in rebound in this study reflected varying degrees of energy loss related to differences in the specimen's hardness and affiliated resiliency properties like homogeneity.

HYPOTHESES

This project objectively compared acoustic frequency response levels of different types and grades of lithic material, as well as raw versus heat treated material. It was expected that lithic types, which resonate comparatively long lasting, high clear bell-like pitches, would be associated with superior mechanical properties.

The goal of this research was to objectively measure on a quantitative scale what has previously been a rather subjectively evaluated yet critically important variable with respect to choice of flakeable stone. When this study began, it was hoped that by comparing acoustic frequency response levels and sound duration, hypotheses could be tested with the first one being the following:

Hypothesis I Ho: All types of lithic materials when struck under controlled conditions possess equal acoustic frequency response and sound duration levels.

Hypothesis I Ha: Different types of lithic materials will have unequal frequency response or sound duration levels.

If Hypothesis I Ho is true the sound duration and spectral mean data will statistically be equal for all specimen types. This might prove true if the specimens are similar in their physical properties such as elasticity, density, and lack damping factors which would alter how siliceous material transports sound waves. If Hypothesis Ha I is true, it will be because at least one pairwise comparison of lithic types statistically differed in their spectral mean or sound duration values. For example, Obsidian might have a mean sound duration value of 180 milliseconds and Indiana Hornstone have a mean value of 40 ms. In a pairwise comparison the two would likely be statistically different. Differences could be attributed to damping factors or variations in density or elasticity.

Based on Callahan's (2000:16) lithic scale of quality, it was suspected that material known to have the best mechanical properties would also conduct sound waves having a long duration and fast rate of vibration: in other words, a higher pitch. The faster the rate of vibration measured in Hertz (vibrations per second) the higher the pitch. Callahan proposed his Lithic Grade Scale for Flaked Stone Tool Manufacture as part of his Masters thesis. The scale was later modified by D.C. Waldorf (1984:15). In the scale, lithic materials are assigned grades based upon their ease of workability. Ease of workability is synonymous with the degree of force required to detach flakes predictably from a given stone. At the top of the scale is opal which grades 0.5 (elastic) with the bottom of the scale being Catoctin Greenstone and coarser felsites that grade 5.5 (coarse). Whittaker (1994:66) criticized Callahan's scale as not being a true scale because the points are not real measurements and comprise only an approximate and largely subjective ranking. Whittaker makes a valid point in stating that lithic materials vary greatly over the grades as given, and the ranks are by no means discrete or interval scale (but neither is Moh's hardness scale). Domanski et al's. (1994:204) quantitative work concerning the mechanical properties of stone materials and the effects of heat treatment validated Callahan's scale, which assumed workability correlated with toughness, tenacity, strength, and elasticity. Callahan's Scale seemed like a reasonable basis for a comparison between lithic material's acoustic characteristics and the material's known knapping qualities based upon an expert's knowledge.

I expected that an objective scale could be developed based upon the duration or the frequency response of sound waves vibrating through different types of knappable stone. For example, test results might reveal that lithic material known to be of the highest quality for predictable ease of flake detachment resonate sound for over 150 milliseconds, or vibrate waves an average of 8,000 times or more per second.

Several authors have documented or observed that Native American Indians heat-treated lithic material to improve its workability (Goldschmidt 1951:418; Powell 1875: 27-28; Shippee 1963:271).

During archaeological investigations at Tuttle Creek Dam near Manhattan Kansas, Shippee (1963:271) found a cache of flint flakes and cores capped by three limestone boulders; the flakes and cores were spread evenly over a bed of ashes. The layer of flint was 10 cm thick and the ash averaged about the same thickness. The cores and flakes were described as banded gray chert. The chert was no doubt Florence Type B found within the rolling, prairie cloaked Flint Hills of Kansas.

Hester (1972:63) listed 14 sources of ethnographic evidence of aboriginal heat treating of stone. Quoting from a sample of these will illustrate the heat treatment process. Goldschmidt (1951:419) described the heat treatment process of the Nomlaki of northern California as follows:

> Flint nodules were broken into workable smaller pieces by means of slow, even heating, and chips were separated with a chisel of bone or horn hammered on the butt end. The resulting flakes were then heated by

contact with hot stones and chipped with hard blue pebbles of various sizes. The purpose was not made clear. They were pressure flaked with pieces of bone.

J.W. Powell (1875:27-28) described the heat treatment of stone by the Plateau Shoshoni as follows:

> The obsidian or other stone of which the implement is to be made is first selected by breaking up larger masses of the rock and choosing those which exhibit the fracture desired and which are free of flaws; then these pieces are baked or steamed, perhaps I might say annealed by placing them in damp earth covered with a brisk fire for twenty-four hours, then with sharp blows they are still further broken into flakes approximating the shape and size desired.

Collins and Fenwick (1974:143), after investigating sites in Kentucky, concluded several of the prehistoric cultures that had resided in the state customarily heated part of the stone they flaked.

Several individuals have investigated the propensity of heating lithic material to improve its ease and predictability of flaking and have found similar conclusions. Crabtree and Butler (1964:1) noted that heat treated lithic material can be pressure flaked with less force creating longer flakes when compared to unheated material of the same type. Ahler (1983:6) found that Knife River Flint's flaking qualities greatly improved by heating it to temperatures in the range of 225° –250° C (437°F-482°F). Joyce (1985:39) found that the optimal temperature for heating Texas Alibates flint in order to improve its degree of predictable flaking was at the higher end between 250°C and 350° C. A comparison by Mandeville and Flenniken (1974:47) of Nebraska Nehawka Chert's heated and unheated flaking qualities determined that there was a definite improvement in the flaking qualities of heated Nehawka Chert. Patterson (1979:257) found that Texas chert that had been heat treated required less force to flake and produced larger flakes than unheated chert.

Hypothesis II was developed to investigate changes in acoustic properties after flint is heated on the presumption that heat treatment tends to improve the material's mechanical properties for flaking. The specific interest concerned the predictability of how heat treating changes the duration of sound and rate of vibration of lithic material. Would average sound duration levels and rate of vibration of heat treated materials go up or down consistently compared to their unheated states? In addition, how would these heat treated materials fit on an ease of flakeability scale in conjunction with their acoustic properties? I was also interested in assessing if sound properties could be used to differentiate unheated and heated stone at archaeological sites. The study's second null hypothesis is the following:

Hypothesis II Ho: Lithic material in its "raw" (non-heated) and heat treated conditions will have equal acoustic frequency response and sound duration levels.

Deciding upon an alternative hypothesis II was complicated by the two different general findings archaeological researchers have published concerning the physical changes that occur when lithic material is heat treated. One school of thought has determined that heat-treating creates a more homogenous material which improves lithic material's flaking predictability. Using an electron microscope, Crabtree and Butler (1964:2) examined heat treated and raw flint. They observed that the heat treated pieces had become much smaller, which they surmised was due to recrystallization of coarser fibered micro-granular silica materials. Domanski and Webb (1992:610) used X-ray diffraction data and scanning electron micrographs, but their findings aligned with those of Crabtree and Butler.

Mandeville (1973) used a scanning electron microscope to examine raw and heat treated flakes. She determined that the melting of non-SiO_2 impurities in the materials matrix created changes in fracturing qualities. Purdy and Brooks (1971:323) also used a scanning electron microscope to assess change in heated cherts. They believed that individual mineral grains of microcrystalline quartz are held together more firmly in heated material than in unheated material. They concurred that minute amounts of impurities in the intercrystalline spaces of the chert likely acted as fluxes to fuse a thin surface film of crypto crystals. Binding of the micro crystals resulted in a more homogeneous material that fractured more like glass than a rock aggregate. Using SEM, Purdy (1974:51) found that in heated specimens, fractures were much more likely to split through individual grains and continue through the interstitial area in heated than in unheated flint.

The more homogenous a material, the fewer factors it has present which would dampen sound duration and disrupt wave vibration. Given this frame of reference alternative hypothesis II Ha is the following:

Hypothesis II Ha: After a lithic material has been heat treated, its sound will be of longer duration with corresponding faster rates of vibration compared to its original "raw" state. This means that the tone when struck will be sharper, crisper, and cleaner (less thud-like) after heat treatment.

A second body of archaeological research concludes that heat treating flint creates micro fractures (Flenniken and Garrison 1975:128; Shindler et al. 1982:535; Theil 1972:7; Weymouth and Mandeville 1975:61-67). These same micro fractures that facilitate the predictability of flaking would also serve to dampen sound duration and wave vibration rates of lithic material when it is struck. Damping is the phenomenon relating to energy loss which occurs in a vibrating system (Finch 2005:473). Material scientists have determined that sound wave velocity in rock is impacted by density, elastic properties and especially by the presence of fissures and cracks (Goodman 1980:39). To what degree the sound property of frequency response (pitch) is impacted by the above mentioned concerns is less clear.

In the archaeological literature Theil's (1972) short manuscript was the only original work found that mentions testing the acoustic properties of lithic material. Theil tested the sound wave velocity in heated versus unheated chert. Experimental controls such as whether or not the stone was cut to the same size and the actual testing methods implemented are not described. Although specific velocities were not listed, Theil calculated velocities of sound waves transmitting through her rock specimens and found that the heated specimens showed a reduction in velocity when compared to the unheated controls. She attributed the reduction in velocity of the heated specimens to micro fracturing and water loss in the heated samples.

Based on previous research (Flenniken and Garrison 1975:128; Shindler et al. 1982:535; Theil 1972:7; Weymouth and Mandeville 1975:61-67), a second alternative hypothesis can be reasonably proposed.

Hypothesis II Hb: After a lithic material has been heat treated, its sound will be of shorter duration with corresponding slower rates of vibration compared to its original "raw" unheated state. This means that the tone when struck will be duller and less bell-like after heat treatment.

If Hypothesis II Ho proves true it will indicate that heat treating does not significantly change siliceous rock to the extent it alters the manner it which the rock transports sound waves. For example, sound duration and spectral mean values will be statistically equal for the pairwise comparison of unheated and heated Burlington Chert. If Hypothesis II Ha or Hb proves true it will be due to changes occurred in the physical properties of the heated rock due to the creation of micro fractures or recrystalization of the siliceous rock's matrix. These changes would have altered how the heated material transports sound wave energy compare to its unheated condition. It is suspected that if heat treating changes how siliceous rock transports shock waves associated with pressure and percussion flaking it will also change how acoustic waves are transported.

The third set of hypotheses is the following:

Hypothesis III Ho: Low and high quality lithic material of the same type will have equal frequency response and sound duration levels. Low quality material is defined as coarse textured, porous, and or having obvious impurities, inclusions, and fractures. High-grade lithic material has homogenous crypto crystalline structure with no visible flaws or impurities.

Hypothesis III Ha: High quality lithic material will have faster frequency response levels and its sound will be longer in duration than low quality material of the same lithological type.

If Hypothesis III Ho proves true it will indicate the damping factors such as porosity and the presence of inclusions in siliceous rock does not statistically alter how the material transports sound waves. If the study supports Hypothesis III Ha, the results may be related to high quality material being denser, more elastic, and or lacking properties that dampen vibrations. It would be expected that high quality material will have much longer sound duration rates and higher spectral mean values than low quality specimens.

Kent and Read (2002:272) wrote that vibrations do not continue indefinitely after the energy source responsible for the vibration has ceased, rather vibrations die out. The rate at which they die out is a measure of damping, which is the rate at which energy is absorbed. The following is an example of energy absorption related to material hardness that is analogous to this study's high and low quality comparisons.

> When a coin is dropped on a hard tile floor the sound seems to "ring" for a short time. When the coin is dropped on a sofa cushion, the sound is more like a dull thud that quickly dies out. The coin and tile combination produces a low rate of damping, so that sound energy continues for a time beyond the initial impact of the coin on the floor. Therefore the coin rings. In contrast, the coin and cushion produce a sound that is quickly dampened so we hear a thud (Kent and Read 2002:272).

I would expect high quality material to act like the tile (high vibration rate, long lasting) and the low quality material to resonate sound like the cushion (low vibration rate, short duration).

Significance to Archaeology

The realization that only one study (Theil 1972) had been completed regarding "lithic sound," and the questions left unanswered, were compelling to complete this project. The bell-like sound that stone resonates is a mere symptom of inadequately understood dynamics that begged to be explored. To understand what "lithic sound" might reveal about its instrument (rock) required a formal experiment. At the least, the experiment would provide a reliable (replicable) baseline of information, which could serve as a guide for future studies.

It is of value to understand if a stone's ease of reduction can be predicted by its acoustic characteristics or "lithic sound" after being struck with a hammer stone. Imagine that the time is 8600 B.C. and a group associated with the late Paleo-Indian culture that produced Scottsbluff points is observed quarrying (Root et al. 1985:132). Tribesmen are digging for Knife River Flint in open pits on a wind swept short grass prairie in western North Dakota. In testing cobbles, the quarrymen accept or reject rock specimens based partially upon the sound heard after the stones are test struck. Their decisions are supported by education and personal experience.

Knowledge obtainment regarding most any topic is an ongoing process. This study sought to add to the body of knowledge regarding what "lithic sound" can reveal about a stone's potential for predictable flaking.

It is of interest to the field of archaeology to know if different types of stone, varied quality levels of stone, and unheated versus heated specimens have unique acoustic waveforms, or consistent sound duration and pitch levels. Could a comparative scale based upon acoustic data for different types be developed? At the least, what are the "marker" values for frequency response rates and sound duration levels of known high quality and low quality material, and do they differ? Do acoustically based "markers" exist that provide cut off or threshold values, delineating acceptable versus unacceptable flint of any type relating to their flaking predictability?

Heat treating lithic material has long been of interest to the field of archaeology. This study sought to explore the question; can one predict how heat treating changes a stone's predictability for flaking or even heated stone's presence at a site based upon acoustic information?

In addition, it is intriguing to ponder the following question. Is it possible to predict the ease with which a stone can be flaked based solely upon acoustic information? This research used its three hypotheses to explore these two questions.

DISCUSSION

This study expanded archaeology's knowledge of flint, one of mankind's most venerable resources. Clear, long lasting tones which quality flint resonates when struck, disclose information regarding its potential for predictable flaking. Using pitch and sound duration measurements, the study investigated if a lithic material's candidacy for predictable flaking could be quantified.

People are naturally competitive. An extension of this competitiveness relates to humans comparing most anything of substance. Campfires through time have illuminated heated discussions by flint knappers quibbling over which type of stone flakes the easiest, or produce the best quality tools. This study added objective information to the debate.

Chapter 2
Materials and Methods

In order to test the hypotheses of this study, samples of various types of lithic material were acquired. Consistency in fracture, specimen size, heat treatment, and the like had to be controlled in order to produce data requisite to hypothesis testing. In this chapter, I describe the materials used and the methods employed to generate the requisite data.

Materials

Sixteen types of lithic material were obtained from sources throughout the country. I originally intended to test stone types noted in Callahan's Lithic Scale of workability (Callahan 2000:6). Many desired samples proved impractical to obtain. Absent from the collection are coarse grained stone such as the rhyolites, felsites, quartzite, and greenstone. The porous Burlington Chert, Knife River Flint with solidified plant fragments, and a sample of Piaute Agate with a large quartz inclusion must suffice for this series of experiments. A list of the types of stone examined is provided in Table 2.1.

Table 2.1. Types of Stones in the Study.

Alibates Flint
Brazilian Agate
Burlington Chert
Flint Ridge Flint
Florence Type B Chert
Florida Agatitized Coral
Georgetown Flint
Indiana Hornstone
Jasper, Biggs
Jasper, Fancy India
Jasper, Madagascar
Knife River Flint
Novaculite
Obsidian
Piaute Agate
Root beer Flint

The experiment sought to determine physical differences in the stone types. Significant differences would cause variation in how the stones resonated acoustic waves. Density is a fundamental property of geological material and influences how all material, including stone, conducts sound waves. Carmichael (1989:141) wrote that variation in rock densities is primarily related to differences in mineralogy and porosity. The average densities of all of the earth's surface rocks have been estimated at 2.7 to 2.8 gm/cc (Jackson 1970:1). Goodman (1944:432) studied the physical properties of stone materials and assessed the density of nine lithic materials. Her types ranged in density from Obsidian at 2.42 to Quartzite at 2.66 gm/cc.

Any significant change in the stone's density related to heat treatment also needed to be determined. Researchers have been interested in the amount of water that lithic material loses during heat treatment. Theil (1972:5) noted that water loss during heat treatment decreases density. A significant decrease in density due to water loss would lead to a change in how flint resonates sound. Purdy (1974:44) believed that the removal of the intercrystalline water facilitated micro crystals becoming cemented. This allowed a fracture to pass through rather than around individual crystals. A significant change in how crystals are organized resulting from heat treatment would influence both the pitch and duration of sound that flint resonates after being struck with a hammer stone.

The equation for bulk density is (Weight gm)/ (Volume cc). I obtained bulk volume measurements using the buoyancy method. This method is based on the Archimedes' principle which requires the saturated weight of a specimen in air and weight of the specimen suspended in a liquid of known density (Carmichael 1982:4). The weight of an object immersed in a liquid decreases by an amount equal to the weight of the volume of the liquid that it displaces. Since one mL of water has a mass almost exactly equal to one gram, if the object is immersed in water, the difference between the two masses will equal almost exactly the volume of the object weighed (Seely 2000).

An OHAUS Triple Beam Balance 700 Series was used to weigh stone specimens in air and also while suspended in water. Bulk density measurements were figured using the following equation:

Density = (Weight in air)/(Saturated Weight in air)-(Weight in water)

Table 2.2 Weights and Densities of Lithic Specimens.

Lithic Sample	Weight in air (gm)	Weight in water (gm)	Weight in air – weight in water	Density (gm/cc)
Alibates Heated	137	83.7	53.3	2.570
Brazilian Agate	124.5	76.4	48.1	2.588
Brazilian Agate Heated	124.4	76.3	48.1	2.586
Burlington Chert High	122.9	74.1	48.8	2.518
Burlington Chert High Heated	121.9	73	48.9	2.439
Burlington Chert low	113.4	63.5	49.9	2.273
Flint Ridge Flint	126.1	78.2	47.9	2.633
Flint Ridge Heated	125.7	77.4	48.3	2.602
Florence Type B Chert	110.4	66.5	43.9	2.515
Florence Type B Heated	109.7	65.6	44.1	2.488
Florida Agatitized Coral	121.6	74.1	47.5	2.56
Florida Agatitized Coral Heated	120.6	73.3	47.3	2.550
Georgetown Flint	127.9	78.7	49.2	2.600
Georgetown Flint Heated	127.5	78.0	49.5	2.576
Hornstone, Indiana	138.1	85	53.1	2.600
Jasper, Biggs	127.2	77.6	50	2.544

Jasper Biggs Heated	126.0	76.7	49.3	2.556
Jasper Fancy India	147.6	89.1	58.5	2.523
Jasper Fancy India Heated	144.2	88.2	56	2.575
Jasper, Madagascar	130.5	79.8	50.7	2.574
Jasper Madagascar Heated	130.0	79.2	50.8	2.559
Knife River Flint	130.9	84.5	46.4	2.821
Knife River Heated	130.5	80.3	50.2	2.600
Novaculite, specimen 1	117.6	73.3	44.3	2.648
Novaculite specimen 1 Heated	117.3	72.9	44.4	2.642
Novaculite specimen 2	130.2	81.1	49.1	2.652
Obsidian, Black	114.4	65.8	48.6	2.354
Piaute, Oregon low	121	73.9	47.1	2.569
Piaute, Oregon High	122.8	75.5	47.3	2.596
Piaute, Oregon High-Heated	122.0	74.6	47.4	2.574
Root beer Flint	140.6	86.6	54	2.604
Root beer Flint Heated	140.0	86.1	53.9	2.597

The average density of the examined specimens was 2.565 gm/cc with a standard deviation of 0.091 and a variance of .008. Twenty eight of the 32 specimens or 87.5% fell within one SD of the mean density indicating that the values are concentrated near the mean. Differences in how the lithic material conducted acoustic waves are not likely to be related to variation in density.

Descriptively, the unheated (low quality) Knife River Flint was the densest material 2.81 gm/cc and the porous Burlington Chert was the least dense with a value of 2.273

gm/cc. All 13 of the heat treated samples lost water during the heating process which ranged from .1 gram for Brazilian Agate, to 3.4 grams of water weight for Fancy India Jasper. This small amount of water loss did not significantly change the density of heated materials relative to a material's unheated condition.

Several authors (Ahler 1983; Crabtree 1964; Collins and Fenwick 1974; Patterson 1996; Purdy 1974; Purdy and Brooks 1971) have noted color and luster changes of lithic material when it is heated. For future reference purposes, Munsell Color Charts were used to document the colors of each material specimen (see the related color table in the appendix).

General observations concerning each specimen's degree of homogeneity, and or the presence of flaws, such as porosity, impurities, or visible cracks are noted in Table 2.3. Changes which occurred through heat treatment are also noted.

Table 2.3 Observations Concerning Material Quality.

Lithic Sample	Origin	Comments
Alibates Flint	Texas	No imperfections noted, surface luster present likely due to heat-treatment., overall color is a brown matrix streaked with gray, "beef steak."
Brazilian Agate	Brazil	Homogenous, no imperfections noted, bands of color present. heat-treatment created surface luster and darkened colors., appears browner when held up to sunlight.
Burlington Chert High	Missouri	Homogenous, no imperfections noted, heat-treatment caused the Burlington to turn redder and to darken. Heating material created surface luster.
Burlington Chert Porous	Missouri	Porous.
Flint Ridge Flint	Ohio	Heat-treating created surface luster, no surface imperfections noted. .
Florence Type B Chert	Kansas	Blotchy/mottled overall appearance, heat-treating created surface luster and caused material to darken.

Florida Agatitized Coral	Florida	Shallow acne-like holes one mm deep present, heat-treating created surface luster.
Georgetown Flint	Texas	Heat-treating created surface luster, homogenous, no imperfections noted.
Hornstone	Indiana	Homogenous, no obvious surface imperfections noted.
Jasper, Biggs	Oregon	Heat-treatment created light surface luster, 3 mm dimple present on one surface.
Jasper, Fancy India	India	Mottled, heat-treating caused red to turn redder and darker.
Jasper, Madagascar	Madagascar	Heating created surface luster and darkened material, no surface imperfections noted.
Knife River Flint	North Dakota	Overall low quality with light colored layers that consist of solidified plant fragments, heating created surface luster, areas of shallow crazing present on one surface.
Novaculite, # 1	Arkansas	Solid color: homogenous, no imperfections or inclusions present, heat-treating created blotchy streaks of cold hot pink within the primary gray color.
Novaculite # 2	Arkansas	Mottled appearance, homogenous no surface imperfections noted.
Obsidian, black	Oregon	Homogenous, no imperfections noted.
Piaute, Oregon inclusion	Oregon	Two cm by 1.5 cm wide, five mm deep depression lined with quartz crystals present in center of one surface.
Piaute, Oregon high	Oregon	Heat-treatment created very lustrous surface appearance, homogenous with no imperfections present.
Root beer Flint	Texas	Heat-treatment created surface luster, caused material to become lighter. homogenous, no imperfections noted.

Methods

The Mechanical Engineering Department at the University of Missouri-Columbia was consulted on the experiment's design. This revealed that if the size of the samples were controlled, the variables of Young's Modulus and density could be considered together as variables possibly contributing to differences in how specimens resonate acoustic waves. The suggested frequency response equation is:

$$F = \sqrt{\frac{E}{P}} \times \frac{t^2}{L}$$

F=Frequency
E=Young's Modulus
t=Thickness
L=Length
P=Density

Young's Modulus (Finch 2005:44) or tensile modulus is the ratio of the longitudinal stress to strain along the length of a bar. Stress (Houghton 2002:16) is a force per unit area, and strain is a measure of the relative change in size or shape that the stress produces. To study a rock's elasticity, uniaxial compression tests are usually performed on core specimens having lengths approximately twice their diameter. Axial deformations are normally measured over some length by either resistance strain gages, transducers with a deformation jacket which attaches to the specimen, or by a transducer which measures the cross head displacement on the testing machine (Touloukian 1981:127). It was beyond the scope of this study to actually measure differences in the elastic properties of siliceous specimens.

Other important variables that had to be controlled (not allowed to vary from experimental application to experimental application) were hammer stone mass, pendulum speed, and travel distance. To achieve such controls, a mechanical "Hammer machine" or flint knapper performed the following three functions.

- In a fixed position, the hammer machine held a simple pendulum consisting of a hammer stone attached to a length of braided nylon twine. Production of lithic sound resulted when the pendulum hammer struck a specimen of lithic material.

- The machine provided a sliding bolt mechanism resting at a set height that allowed consistent release of the hammer and consistent hammer travel distance, permitting stone samples to be struck with equal force in their center.
- The machine held a 4 cm by 12 cm by 1 cm cut stone specimen in a suspended “gong like” position.

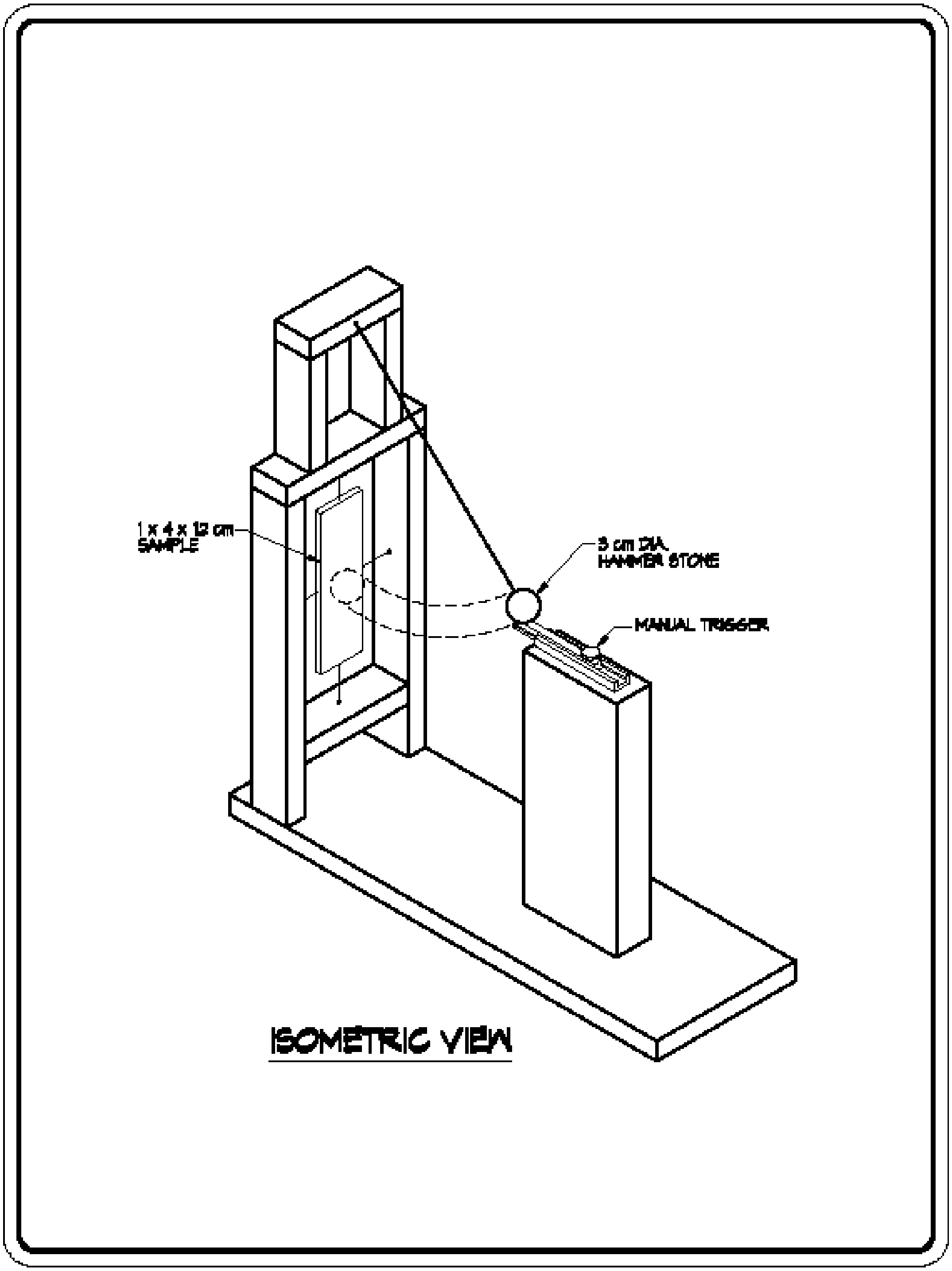


Figure 2.1 Isometric view of hammer machine.

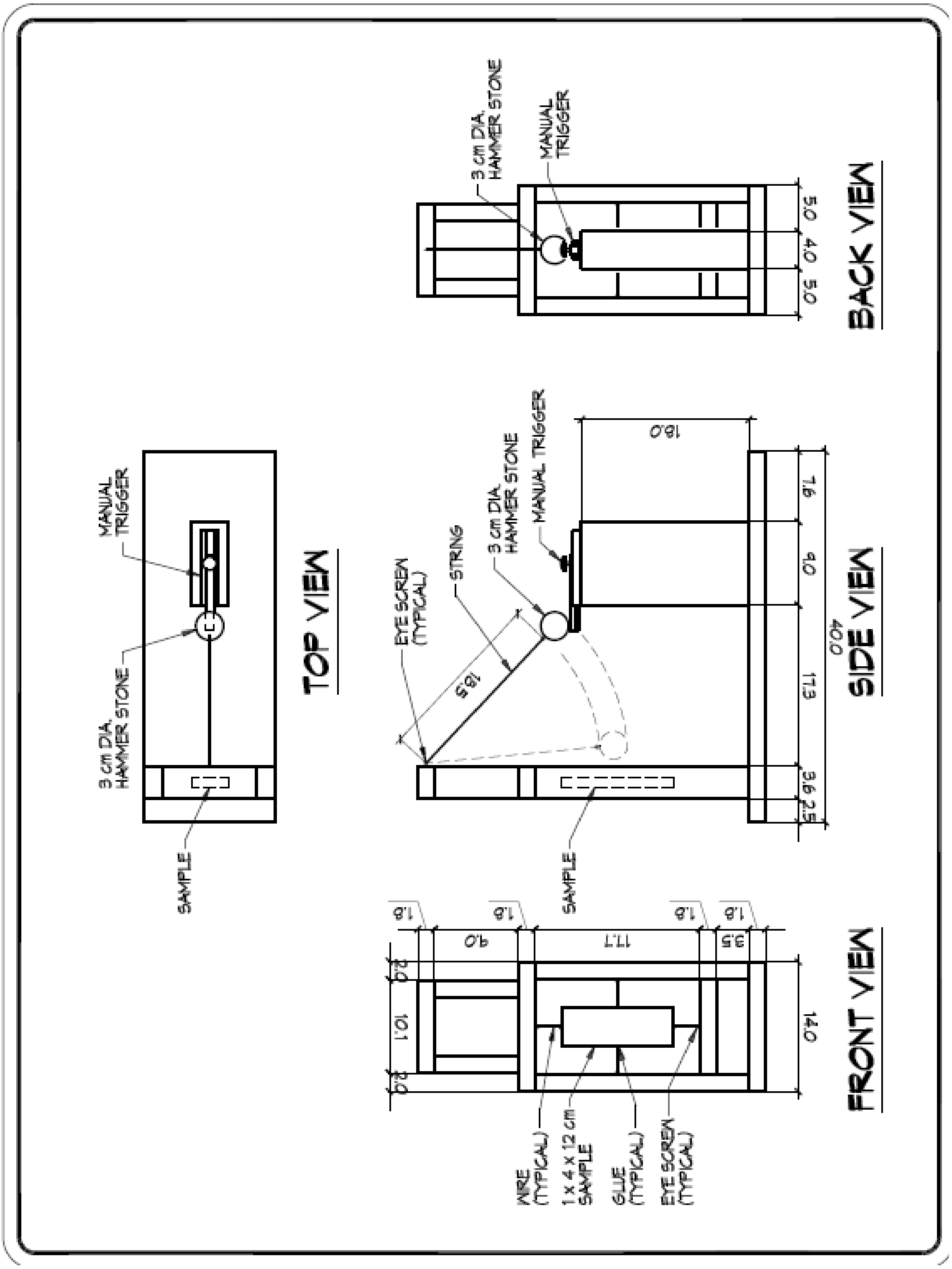


Figure 2.2 Orthographic View of Hammer Machine.

The machine's basic framework consisted of white pine lumber fastened with wood screws. The hammer stone was of Burlington Chert, from Callaway County, Missouri. The hammer stone's 3 cm diameter, 64.4 gm mass and oval shape, emerged after the use of an electric grinder. An electric drill with 3.18 mm drill bits created a hole in the hammer stone. The hole allowed the fastening of a brass eye screw (wire dia. of .266 cm) into the stone. Masonry drill bits "lost their battle" with (did not penetrate) the dense, hard Burlington Chert. After dulling three masonry bits, a diamond tipped bit effectively finished the hole. LIQUID NAILS ® adhesive secured the eye screw in the hammer stone.

A professional lapidary sawed the different types of rock into rectangular specimen blocks measuring 12 X 4 X 1 cm. Commercial grade rock saws cut the material. LIQUID NAILS ® adhesive fastened 24 gauge copper wire to each lithic sample's top, bottom, and two sides in a centered position. The wire fastened the specimens to the hammer machine's frame in a stable position for hammer striking.

It was essential that the study's objective acoustic data parallel flint knappers perception of the sound characteristics associated with quality flint. Much like a knapper removing the cortex of a flint stone to reveal its unknown quality, I desired to unveil a new dimension of understanding pertaining to a stone's potential for reduction by the study of "lithic sound." To reach this objective, frequency response levels, (perceived as pitch), and the duration of sound were chosen as the study's two types of data to collect. Frequency response refers to the rate of vibration of a sound wave. The higher the rate of vibration the higher the pitch, or more bell-like. Sound duration refers to how long the sound wave lasts. At the study's inception it was suspected that quality material lacking flaws such as cracks or inclusions would have relatively fast rates of vibration that last a comparatively long time. These two acoustic wave properties relate directly to the well used axiom that quality flint when tapped will resonate long lasting bell-like tones.

Kay Multi-Speech Model 3700 Main Program © software was used with a Kay Computer Speech Laboratory (CSL 4400 ©) for the experiment. The software in conjunction with the CSL 4400 © recorded the acoustic sounds, organized and processed signals, analyzed data, and displayed acoustical statistics. The CSL provides speech professionals with a broad range of applications in the analysis of speech and voice in exacting speech processing applications. It typically is used for speech analysis, teaching, voice measurement, clinical feedback, acoustic phonetics, second language articulation and forensic work (KayPentax 2006). Testing acoustic characteristics of lithic sound likely was a new use of the CSL 4400.

For testing, a microphone was placed five cm behind the lithic specimens. The microphone needed to be set the same distance from the specimens for each test to standardize the sound intensity being recorded. The recording input level or gain was set at 5.5 for each test. The gain refers to a form of preamplification before the acoustic signal is routed or processed. Unless breakage occurred or double strikes were noted, each specimen was struck a minimum of fifteen times. Results were recorded and saved.

Following the recording of the unheated stone sample's acoustic traits, the wire and adhesive were removed to prepare the material for heat treatment. A general search was conducted to determine the optimum temperature to heat specimens. Ahler (1983:5) recommended that Knife River Flint be heated to 225°-250° C (437°-482°F) to improve flaking qualities. Joyce (1985:39) determined that the optimal temperature for heat treating Alibates Flint was between 250° and 350° C (482° -662°F). Flint Ridge Flint's optimal temperature for heating was determined as 260° C (500°F) (Patterson 1979:34). Pickenbaugh and Collins (1978:9) found that Flint Ridge Flint heat treated at 350°C (622°F) improved in flake reduction qualities. Waldorf (1993:13) suggested heat-treatment temperatures as listed in Table 2.4.

Table 2.4 Heat-Treatment Temperatures for Specimen Types (Waldorf).

Knife River Flint	232° to 260°C (450° – 500°F)
Alibates Flint	232° to 260°C (450° – 500°F)
Flint Ridge Flint	288° to 316°C (550° – 600°F)
Burlington Chert	343° to 357°C (650° – 675°F)
Novaculite	399° to 482°C (750° – 900°F)
Florida Agatitized Coral	316° to 357°C (600° – 675°F)
Georgetown Flint	177° to 204°C (350° – 400°F)

I also consulted with professional flint knappers regarding the desired maximum temperatures to heat samples. Recommendations varied in part due to differences in heating techniques, material color, texture, and whether slabs, spalls, or blanks were being heat treated. Maximum temperature for heat treatment of my samples for 24 hours is summarized in Table 2.5.

Table 2.5 Maximum Temperature Attained

Lithic Type	Celsius	Fahrenheit
Alibates Flint	327	620
Brazilian Agate	232	450
Burlington Chert	327	620
Flint Ridge Flint	327	620
Florence Type B Chert	260	500
Florida Agatizied Coral	260	500
Georgetown Flint	232	450
Jasper, Biggs	246	475
Jasper, India	246	475
Jasper Madagascar	246	475
Knife River Flint	246	475
Novaculite	327	620
Piaute Agate	327	620
Root beer Flint	232	450

The Piaute Agate, Burlington Chert, Novaculite, Alibates Flint, and Flint Ridge Flint specimens were heat treated by a professional flint knapper using a programmable modified kiln. The remaining samples were heat treated in a Black & Decker Toaster-R-Oven ©. Samples were packed in a bread pan using dry sand as a filler to distribute heat evenly. To dry the specimens, they were preheated for 24 hours at 93°C (200°F). I then increased the temperature 10°C (50°F) per hour until reaching the desired temperature depending upon samples being treated. The stones were then “cooked” 24 hours at the maximum temperature. The temperature was subsequently decreased 38°C (100°F) each hour until the oven was turned off and allowed to cool naturally with the door closed.

Density tests of the heated stone were conducted next, followed by a color assessment. The color assessment is in the appendix. Copper wires were fastened to the sides of the samples as noted earlier. Frequency response and sound duration levels were obtained for the heat treated materials using the Kay CSL ©.

During the actual hammer strike phase of experimentation, general observations regarding the sounds heard and experimental errors were recorded. Perceived differences in loudness and tone quality were detectable, as well as occasional double hammer strikes.

The Kay Multi-Speech© software program recorded and saved each sound signal as an individual data source. An initial step taken to investigate the sound signals was to replay each sample and record subjective information about the sound heard. Words and phrases such a clear, clanging, tinny, getting softer and muffled, were used to describe the sounds. This information was later compared to waveforms and other statistics.

I next performed analytical statistics to test the three hypotheses. Each sample's file was opened and individual waveforms viewed. Indicated steps were taken to record the waveform duration measured in milliseconds. The duration had to be documented manually as the software did not save this information as part of its normal operation. Next, a second window for data viewing was opened in the software to allow analysis of the LTA or long term average power spectrum. Data were displayed and statistics selected. Some of the statistics automatically created by the software are listed in Table 2.6.

Table 2.6 Statistical Tests Automatically Calculated by CSL Software.

Minimum Power (dB)	Root Mean Squared (dB)
Maximum Power (dB)	Spectral Mean (Hz)
Mean Power (dB)	Spectral Standard Deviation (Hz)
Standard Deviation (dB)	Skewness
Median Power (dB)	Kertosis

I ultimately decided to only use the spectral mean measured in hertz (Hz). The spectral mean gave me the average rate of vibration or frequency for the duration of an acoustic signal. Spectral mean information combined with the duration of sound gave information that I could use for clear comparative purposes. To organize the results, a spread sheet for each lithic sample's test results was created. The spread sheets listed data in rows for each hammer strike repetition. Columns listed the specific statistics of interest. From this information, additional spreadsheets were developed that allowed statistical analysis of the data using the Sigma Stat © program. For the variables, all repetition data were listed for each lithic type in a column. For the basic variables of duration and spectral mean descriptive statistics were taken.

Statistical Analysis

To test the study's first hypothesis, I placed the data into two separate groups labeled unheated and heated. I had 18 specimens in the unheated group, and 11 in the heated. This grouping method permitted me to isolate the variable lithic type. From this grouping, I expected to be able to determine whether or not different types of lithic material when struck under controlled conditions possess equal or unequal frequency and sound duration levels. The basic question to be answered relative to Hypothesis I was whether or not a significant difference existed between lithological types.

To assess Hypothesis II regarding whether or not unheated and heated material had equal or unequal frequency and sound duration levels when struck, I compared data of ten specimens in their unheated to their heated states. Hypothesis III was assessed by comparing high quality unheated Burlington Chert and Oregon Piaute Agate to low quality specimens of the same type.

I used the Sigma Stat © statistics software program to analyze data. A One Way Analysis of Variance abbreviated ANOVA, was used as an omnibus test to first assess if the data were normally distributed. If the data proved to be normally distributed, the Pairwise Multiple Comparison Procedures (Tukey Test) was used as a post hoc test to compare data for every combination of group pairs with the statistical significance set at ($P<0.05$). If significant differences were noted, the likelihood of being incorrect in rejecting the null hypothesis was less than five percent.

If either the normality test or equal variance test failed, an analysis of variances was invalid due to the data not being normally distributed. The non-parametric Kruskal-Wallis One-Way ANOVA on ranks was performed to determine if the differences in the median values among treatment groups were greater than would be expected by chance, at a statistical significance of $P<0.001$. To isolate the group or groups that differ from the others in nonparametric data, the post hoc All Pairwise Multiple Comparison Procedures (Dunn's Method) was used with the statistical significance set at $P<0.05$.

Method Problems

If this experiment is repeated I recommend making modifications to the hammer machine. The hammer stone hung from the machine frame by a centrally positioned strand of braided twine. Accuracy of hitting the specimens consistently in the center could be improved by having two strands of twine attached to the hammer stone's eye screw. The stands would be fastened at two corners of the machine, forming a v-shape suspension mechanism directly above the hammer stone. This arrangement would lessen side-to-side movement of the hammer as it swung to strike a specimen.

The hammer stone was oval rather than perfectly round or spherical. I manipulated the hammer stone so that the same side of the stone struck each specimen in its center. Accuracy of hammer strikes would be improved by shaping the hammer stone as a perfect sphere.

I fastened copper wire to the specimens using LIQUID NAILS ® adhesive. This system proved satisfactory, but it could be improved by using twine instead of wire. On some test repetitions the sound of the wire may have been recorded by the Kay CSL©. If wire sounds were suspected to have been recorded the related test was omitted.

I initially struck unheated specimens fifteen times each with a hammer stone and then heated twelve specimens for the second phase of testing. My initial thought was to minimize variables such as material homogeneity, and presence of inclusions when comparing heated to unheated specimens of the same type. Following this reasoning, my heat treated specimens were struck at least thirty times relative to the fifteen times a specimen was struck in its unheated state. I suspect that this influenced results. If the test results would prove that heated material consistently had longer durations of sound, faster rates of vibration, or sound waves with more average intensity, it would give credence to the line of thought that heat treating had made the material more homogenous in part by repairing damage possibly done by the initial 15 strikes.

If I repeat the experiment I will cut more specimens from the same rock and test heated rock that had not been previously struck in its “raw” condition. It would be interesting to compare the information generated to heat treated specimens that had been struck in their “raw” state.

I suspect that each time I struck a specimen, internal changes occurred to the rocks. There is minimal doubt that each specimen type inherently had different levels of resistance to change from being struck. As testing progressed through the fifteen repetitions, changes in sound quality could be noted. If the test were repeated, I would prefer to have fifteen samples of each type and strike each specimen only one time. This would eliminate “cumulative lithic trauma” that perhaps “muddied” test results.

During testing, double hammer strikes occasionally occurred. They happened because I could not always grasp the hammer stone after one strike and before it struck the specimens a second time. Some specimen types had so few single strikes that they were rejected for use in the experiment. My fastening and hammer systems could be improved by experimentation to minimize double strikes. I increased the number of strike repetitions when double strikes were noted during testing.

I had some acoustic signal repetitions that were dampened for unknown reasons. Although not observed, I suspect that for brief milliseconds my copper wires may have stifled signals by catching and holding the lithic material in a set position against the wood hammer machine frame. Another possibility is the hammer itself may have at times maintained contact with the lithic specimens after striking them. Any signals that had double strikes or were dampened were deleted from analysis. If the study is repeated I suggest having several “test runs” and actually recording signals to assess and remedy problems associated with damping and double strikes. Figure 2.3 illustrates examples of a typical strike, and a double strike for unheated homogenous Burlington Chert. An example of a dampened wave form for unheated Flint Ridge Flint is also provided.

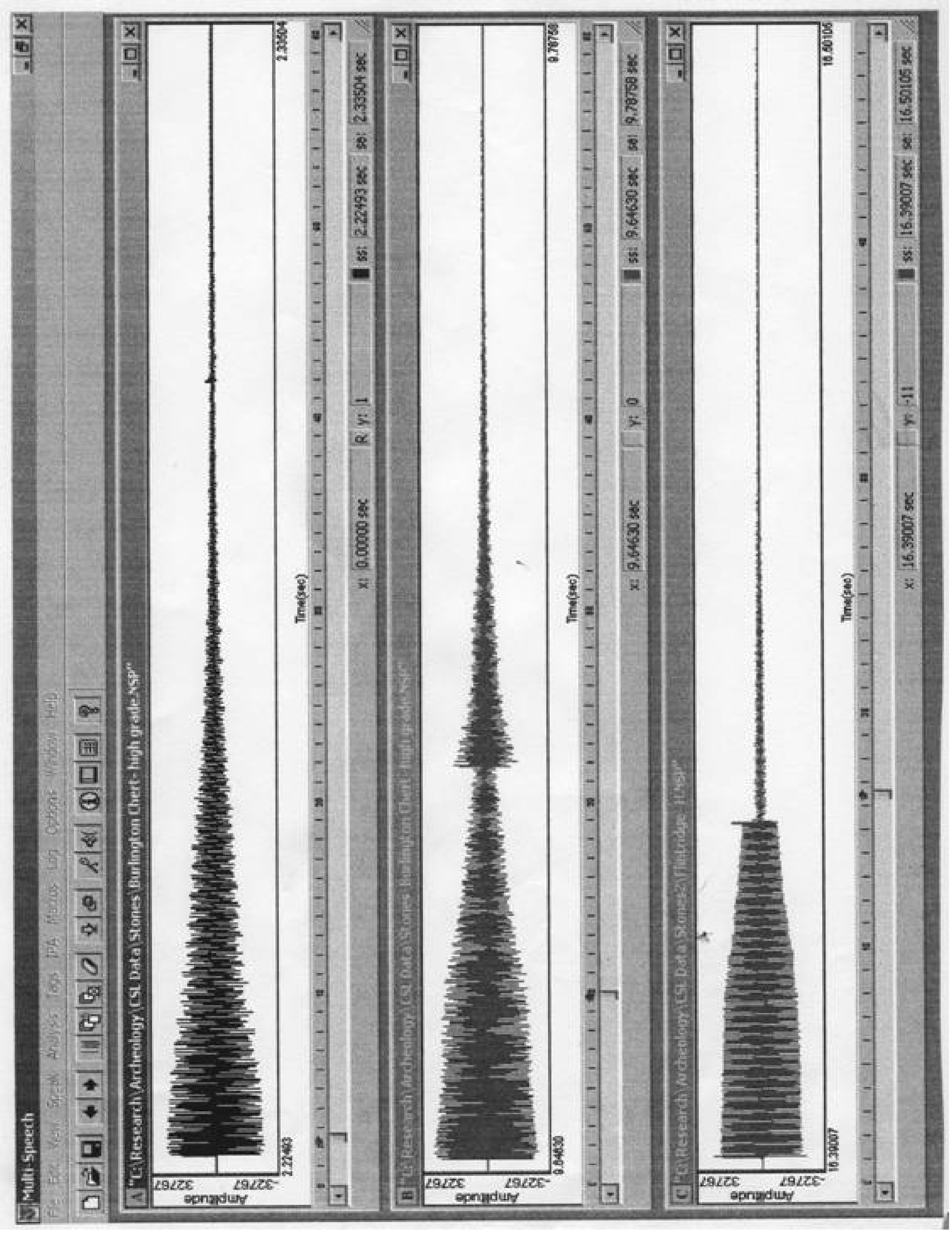


Figure 2.3 Burlington Chert typical waveform (box A), double strike (box B); Flint Ridge Flint dampened hammer strike (box C).

While considering the "raw" data I noted that a few test scores seemed "out of place" despite being single hammer strikes. For example, the heated Novaculite had one spectral mean value of 4,902 Hz when the mean score was 8,421 Hz with a median of 9,031 Hz. I suspect that my few random "outliers" values were due to an unknown experimental error. The majority of the test results had low standard deviation values. Improved experimental controls would lesson the likelihood of "outlier" results.

In comparing different types of lithic material against each other, I suggest in the future using only high quality material. To test hypothesis I, I included Knife River Flint that contained solidified plant fragments, porous Burlington Chert and Piaute Agate that contained a large quartz inclusion. I obtained useful information from these specimens. To purely compare lithic types, it would be better to use material without observable imperfections so that lithic types are being compared without the added quality factor.

When the experiment is repeated, I suggest intentionally drilling holes or sawing cuts into a few specimens of high quality stone. This would allow a comparison of high quality material to compromised material under controlled conditions.

Chapter 3
Results

Flint knappers subjectively know differences exist between how high and low quality siliceous rock resonates sound after being tapped with a hammer stone. Statistical test results described hereafter provide information that deepens archaeology's understanding of what "lithic sound" reveals about lithic material using the factors of lithic type, heated versus unheated material, and material physical condition. The experiment's results are organized into three sections based upon its guiding hypotheses.

Hypothesis I Results

Hypothesis I Ho: All types of lithic material when struck under controlled conditions possess equal frequency response and sound duration levels.

Hypothesis I Ha: Different types of lithic materials when struck under controlled conditions have unequal frequency response or sound duration levels.

Hypothesis I was tested by dividing specimens into two groups unheated: (18 specimen) and heated (11 specimen). To evaluate sound duration for both groups a One Way ANOVA test was performed. For an ANOVA test to be valid, data must be normally distributed and have populations that have similar variances. For this test the unheated specimen's equal variance test failed and the heated specimen's normality test failed.

This indicated that when the variances within each group (15 strike repetitions) were compared with variances between groups (Biggs Jasper to Obsidian) the mean values were found to be distributed asymmetrically. It was not valid to do an analysis of variance. The Kruskal-Wallis test, which performs an analysis based on ranking median values, was used as an omnibus nonparametric test. Test results are summarized in Table 3.1 for duration unheated specimens.

Table 3.1 Duration of Unheated Rocks in milliseconds: Kruskal-Wallis ANOVA on Ranks.

Group	N	Missing	Median	25%	75%
Brazilian Agate	15	1	108.50	103.00	134.00
Burlington Chert: High	15	1	90.00	77.00	97.00
Burlngton Chert: Low	18	0	26.000	24.00	31.00
Flint Ridge Flint	15	0	115.00	110.25	123.50
Florence Type B Chert	16	1	90.00	77.25	94.00
Florida Agatized Coral	15	0	126.00	122.00	131.25
Georgetown Flint	15	2	71.00	66.75	80.25
Indiana Hornstone	15	0	80.00	72.25	87.75
Jasper, Biggs	15	1	117.00	103.00	126.00
Jasper, Fancy India	15	1	87.00	76.00	94.00
Jasper, Madagascar	15	1	49.00	48.00	54.00
Knife River Flint	15	0	30.00	25.25	32.00
Novaculite, #1	15	3	101.00	91.50	117.50
Novaculite #2	15	0	90.00	83.75	101.00
Obsidian, Black Oregon	15	2	77.00	61.25	84.25
Piaute Agate: Low	15	2	59.00	49.25	66.00
Piaute, Agate: High	15	0	86.00	75.50	95.75
Root beer Flint	15	0	93.00	92.00	97.75

Note: H = 208.083 with 17 degrees of freedom. ($P<0.001$)

H is the test statistic of the Kruskal-Wallis test. The H value is compared to a table of critical values based on the sample size of each group. If H exceeds the critical value for H at some significance level it means that there is evidence to reject the null hypothesis in favor of the alternative hypothesis. Table 3.1 provides a range in which the middle half of median values occur for each specimen type. Concerning Brazilian Agate, 50% or the middle half of the sound duration median values fall between 103 ms (25%) and 134 ms (75%). This information allows consideration of how far apart median values are spread for each specimen type. The information is also useful in comparing differences between types.

The Kruskal-Wallis test indicated that the differences in the median values among the treatment groups were greater than would be expected by chance ($P<0.001$). A post hoc All Pairwise Multiple Comparison Procedures (Dunn's Method) $P<0.05$ was used next to isolate the group or groups that differ significantly from others Table 3.2.

Table 3.2 Duration of Unheated Rocks in milliseconds: All Pairwise Multiple Comparison Procedure (Dunn's Method)

Rocks-Unheated Duration	**Median**	**FAC**	**JasB**	**FR**	**BrA**	**Nov#1**	**RB**	**Nov#2**	**Bur**	**Flo**	**JasI**	**Pia**	**Horn**	**Obs**	**Geo**	**PiaL**	**JasM**	**KR**	**BurL**
Florida Agatizied Coral	126		n	n	n	n	n	n	n	y	y	y	y	y	y	y	y	y	y
Jasper, Biggs	117			n	n	n	n	n	n	n	n	n	y	y	y	y	y	y	y
Flint Ridge	115				n	n	n	n	n	n	n	n	y	y	y	y	y	y	y
Brazilian Agate	108.5					n	n	n	n	n	n	n	y	y	y	y	y	y	y
Nocaulite #1	101						n	n	n	n	n	n	n	n	n	y	y	y	y
Root beer	93							n	n	n	n	n	n	n	n	n	y	y	y
Novaculite #2	90								n	n	n	n	n	n	n	n	y	y	y
Burlington Chert (high)	90									n	n	n	n	n	n	n	n	y	y
Florence Chert	90										n	n	n	n	n	n	n	y	y
Jasper. India	68											n	n	n	n	n	n	y	y
Piaute Agate (high)	86												n	n	n	n	n	y	y
Hornstone	80													n	n	n	n	n	n
Obsidian	77														n	n	n	n	n
Georgetown	71															n	n	n	n
Piaute Agate (low)	59																n	n	n
Jasper, Madagascar	49																	n	n
Knife River	30																		n
Burlington Chert (porous)	26																		

Note: No (n) significant difference between pairs present. Yes (y) significant difference between pairs present.

Deciding to accept or reject Hypothesis I Ho was based upon knowing whether or not an adequate number of differences existed between types. Secondary in interest was identifying the actual pairwise lithological type differences. There were 153 pairwise comparisons conducted with 46 comparisons or (30%) indicating significant differences between pairs. It is interesting to recognize the following groups that differed at ($P<0.05$). Knife River Flint which contained much solidified plant fragments and porous Burlington Chert were both significantly different from 10 specimen types. Next in significant differences were Florida Agatizied Coral that differed from ten, and Biggs Jasper, Flint Ridge Flint, and Brazilian Agate which varied from seven types. There is a wide range of median values with Florida Agatizied Coral at 126 ms to the low quality Knife River Flint at 26 ms Table 3.2.

Tables 3.3 and 3.4 summarize results for the duration test on the heated specimens. For the heat treated groups, the differences in the median values among treatments were greater than would be expected by chance ($P<0.001$). To isolate the group or groups that differ, an All Pairwise Multiple Comparison Procedures (Dunn's Method) was used Table 3.4.

Table 3.3 Duration of Heated Rocks in milliseconds: Kruskal-Wallis ANOVA on Ranks.

Group	N	Missing	Median	25%	75%
Alabates Flint	16	1	92.00	89.25	94.00
Brazilian Agate	17	5	115.00	106.50	119.50
Burlington Chert: High	15	5	114.50	95.00	117.00
Flint Ridge Flint	15	4	98.00	81.50	110.25
Florida Agatized Coral	16	3	122.00	118.25	127.25
Georgetown Flint	19	6	108.00	94.00	113.00
Jasper, Biggs	16	7	118.00	117.25	126.25
Japer, Madagascar	16	3	73.00	49.00	78.25
Knife River Flint	16	2	40.00	36.00	43.00
Novaculite:#1	16	2	91.50	81.00	122.00
Root beer Flint	16	1	106.00	92.25	114.50

Note: H=86.965 with 10 degrees of freedom. (P=<0.001)

Table 3.4 Duration of Heated Rocks Measured in milliseconds: All Pairwise Multiple Comparison Procedure (Dunn's Method)

Rocks- Heated Duration	Median	FAC	JasB	BrAg	Burl	Geo	RB	Nov #1 -	FR	Alab	JM	KR
Florida Agatizied Coral	122		n	n	n	n	n	n	n	n	n	n
Jasper, Biggs	118			n	n	n	n	n	n	n	n	n
Brazilian Agate	115				n	n	n	n	n	n	n	n
Burlington Chert (high)	114.5					n	n	n	n	n	n	n
Georgetown Flint	108						n	n	n	n	n	n
Root beer Flint	106							n	n	n	n	n
Novaculite #1	91.5								n	n	n	n
Flint Ridge Flint	98									n	n	n
Alabates Flint	92										n	n
Jasper, Madagascar	73											n
Knife River Flint	40											

Note: No (n) significant difference exists between compared pairs.

No significant differences were found between 55 pairs. Changes in the physical condition of the siliceous rock due to heat treating affected the identification of the group or groups that differed with respect to sound duration.

A One Way ANOVA test was run for the unheated and heat-treated groups concerning their spectral mean characteristics. Results indicate that both the unheated and heated specimens were not normally distributed.

Since the data are nonparametric, a Kruskal-Wallis ANOVA was subsequently run for both treatment groups Table 3.5.

Table 3.5 Spectral Mean-of Unheated Rocks Measured in Hertz: Kruskal-Wallis ANOVA on Ranks.

Group	N	Missing	Median	25%	75%
Brazilian Agate	15	2	3,821	3,815	3,835
Burlington Chert: High	15	1	5,104	4,715	5,866
Burlington Chert: Low	18	0	4,241	3,830	5,238
Flint Ridge Flint	15	3	3,999	3,889	4,030
Florida Agatized Coral	15	0	3,750	3,748	3,755
Florence Chert Type B	16	1	3,406	3,358	3,433
Georgetown Flint	15	2	3,801	3,763	3,924
Indiana Hornstone Flint	15	0	4,190	4,187	4,196
Jasper, Biggs	15	1	3,584	3,572	3,635
Jasper, Fancy India	15	1	4,538	4,440	4,679
Jasper, Madagascar	15	1	4,027	3,929	4,146
Knife River Flint	15	0	3,911	3,858	3,968
Novaculite: #1	15	3	3,914	3,856	4,582
Novaculite: #2	15	0	4,190	4,188	4,271
Obsidian Black Oregon	15	2	3,937	3,908	4,039
Piaute Agate: Low	15	2	3,435	3,429	3,476
Piaute Agate: High	15	0	3,597	3,592	3,602
Root beer Flint	15	0	4,051	4 036	4 090

Note: H=220.162 with 17 degrees of freedom. (P=<0.001)

Significant differences were noted. A post hoc test (i.e. Dunn's Method) was run to isolate the group or groups that differed significantly from one another Table 3.6.

Table 3.6 Spectral Mean of Unheated Rocks Measured in hertz: All Pairwise Multiple Comparison Procedure (Dunn's Method)

Rocks-Unheated Duration	**Median**	**BurH**	**JasI**	**Nov#2**	**Horn**	**BurL**	**RB**	**Nov#1**	**JasM**	**FR**	**Obs**	**KR**	**BrA**	**Geo**	**FAC**	**PiaH**	**JasB**	**PIAL**	**FLo**
Burlington Chert (high)	5,104		n	n	n	n	n	n	n	n	n	y	y	y	y	y	y	y	y
Jasper, India	4,538			n	n	n	n	n	n	n	n	y	y	y	y	y	y	y	y
Novaculite #2	4,190				n	n	n	n	n	n	n	n	n	n	y	y	y	y	y
Hornstone	4,190					n	n	n	n	n	n	n	n	n	y	y	y	y	y
Burlington Chert (porous)	4,241						n	n	n	n	n	n	n	n	y	y	y	y	y
Root beer Flint	4,051							n	n	n	n	n	n	n	y	y	y	y	y
Novaculite #1	3,914								n	n	n	n	n	n	n	y	y	y	y
Jasper, Madagascar	4,027									n	n	n	n	n	n	y	y	y	y
Flint Ridge	3,999										n	n	n	n	n	y	y	y	y
Obsidian	3,937											n	n	n	n	y	y	y	y
Knife River	3,911												n	n	n	n	n	n	y
Brazilian Agate	3,821													n	n	n	n	n	n
Georgetown	3,801														n	n	n	n	n
Florida Agatized Coral	3,750															n	n	n	n
Piaute Agate (high)	3,597																n	n	n
Jasper, Biggs	3,584																	n	n
Piaute Agate (low)	3,435																		n
Florence Chert	3,406																		

Note: No (n) significant difference between pairs present. Yes (y) significant difference between pairs present.

A total of 153 pairwise comparisons was tested, with 53 (34%) significant differences noted. Knowing that significant differences existed, Hypothesis H0 I was rejected. The Florence Type B Chert differed from 11 other types. The low quality Piaute Agate with a 2 cm by 1.5 cm wide, five mm deep depression, Biggs Jasper, and high quality Piaute Agate all differed from 10 other specimen types. The high quality Burlington Chert and Fancy India Jasper both differed significantly from eight other types. The Burlington Chert had the highest median vibration rate per second at 5,104 Hz with Florence Type B Chert median rate being the lowest at 3,406 Hz. A Kruskal-Wallis ANOVA on Ranks was run to assess for differences in spectral mean values Table 3.7.

Table 3.7 Spectral Mean of Heated Specimens Measured in hertz: Kruskal-Wallis ANOVA on Ranks.

Group	N	Missing	Median	25%	75%
Alibates Flint	16	1	3,960	3,951	3,971
Brazilian Agate	17	5	3,771	3,715	3,787
Burlington Chert: High	15	5	3,664	3,617	3,973
Flint Ridge Flint	15	4	3,941	3,908	3,967
Florida Agatized Coral	15	4	3,777	3,770	3,781
Georgetown Flint	19	6	3,804	3,710	3,808
Jasper, Biggs	16	7	3,614	3,612	3,621
Jasper, Madagascar	16	3	3,887	3,859	3,899
Knife River Flint	16	2	3,943	3,867	3,982
Novaculite: #1	16	2	9,031	7,591	9,865
Root beer Flint	16	1	4,092	4,086	4,103

Note: H = 108.189 with 10 degrees of freedom (P<0.001).

Differences in the median values among treatment groups were greater than would be expected by chance. A Dunn's Method All Pairwise Comparison Test was used to determine specific differences Table 3.8.

Table 3.8 Spectral Mean of Heated Specimens Measured in Hertz:- All Pairwise Multiple Comparison Procedure (Dunn's Method)

Rock-Spectral Mean Heated	**Median**	**1-Nov**	**RB**	**Alab**	**FR**	**KR**	**JasM**	**Burl**	**Geo**	**FAC**	**BrAg**	**JasB**
Novaculite (specimen 1)	9,031		n	n	n	n	n	n	n	n	n	n
Root beer Flint	4,092			n	n	n	n	n	n	n	n	n
Alabates Flint	3,960				n	n	n	n	n	n	n	n
Flint Ridge Flint	3,941					n	n	n	n	n	n	n
Knife River Flint	3,943						n	n	n	n	n	n
Jasper, Madagascar	4,887							n	n	n	n	n
Burlington Chert, High	3,664								n	n	n	n
Georgetown Flint	3,804									n	n	n
Florida Agatized Coral	3,777										n	n
Brazilian Agate	3,771											n
Jasper, Biggs	3,614											

Note: No (n) significant difference exists between pairs.

Similar to the Dunn's Method test for heat treated sound duration, the post hoc test for the factor of spectral mean could not isolate a group or groups that were significantly different from each other. The physical changes heat treating causes in lithic material makes the analytical isolation of differences in both sound duration and spectral mean more problematic than when working with unheated material.

Two specimens that fractured during testing revealed that high spectral mean vibration rates cannot be equated with long sound duration values as indicators of high quality flint. The initial hammer strike on the heated Piaute Agate created an abrupt right angle step fracture. As the Piaute Agate fractured, it resonated 10,181 Hz for a short duration of 29 milliseconds. The 10,181 Hz was the fastest average rate of vibration noted for the study.

The porous Burlington Chert fractured after the 18th hammer strike. This specimen gradually increased in vibration rate during testing. The initial spectral mean values for the porous Burlington Chert ranged from 3,553 Hz for the first strike to 3810 for the fifth. The next seven spectral mean values ranged from 4,118 Hz to 4,527 Hz. The final six values demonstrated a general increase in average vibration rate peaking at 10,153 Hz for hammer strike number 17 that lasted only 5 ms in duration

Table 3.9.

Table 3.9 Porous Burlington Chert Last Seven Hammer Strikes Results.

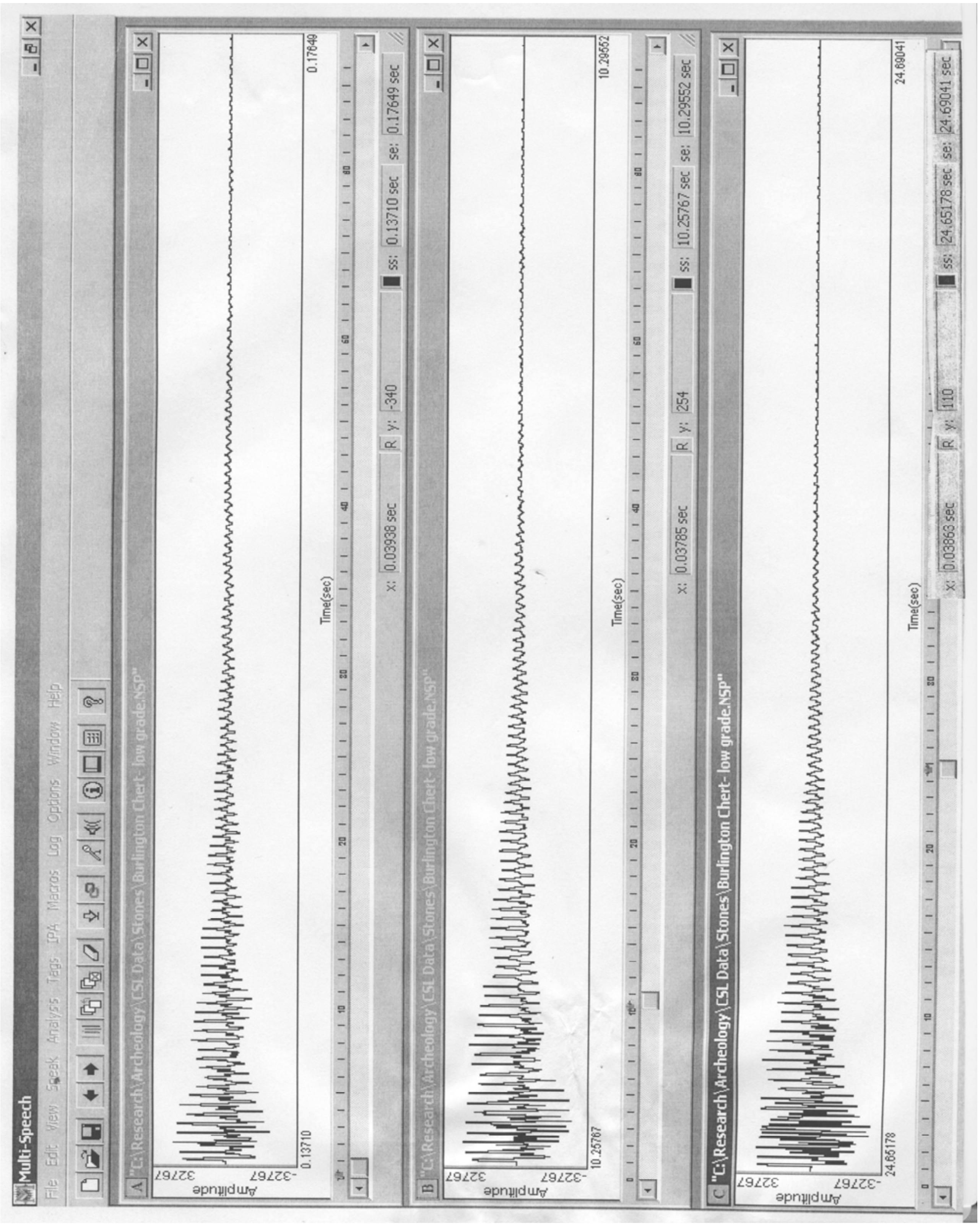
Hammer Strike Number	Sound Duration in Milliseconds	Spectral Mean in Hertz
12	19	4,527
13	24	5,238
14	25	4,530
15	18	5,759
16	18	6,339
17	05	10,153
18	30	7,492

Note: The sound duration mean was 34.72 ms, the mean for spectral mean was 4,871 Hz. The sound duration median was 36 ms, the median for spectral mean was 4,241.

The heat-treated Novaculite (mean 8,421Hz; median 9,031 Hz) was the only sample that had spectral mean values in the realm of the fracturing Burlington Chert and Piaute Agate. It is speculated that the increase in vibration rate was associated with the development of internal changes (micro cracks) related to cumulative trauma that lead to fractures. If specimens with pre-existing significant internal micro fractures are tested in the future the vibration rates will be relatively high in the 6,000 to 11,000 Hz range with low to moderate sound duration levels between 5 ms and 80 ms.

Hypothesis I Ho is rejected. The omnibus tests performed for the unheated and heated specimens indicated that at least one difference between groups existed. Multiple comparison post hoc testing determined specific pairs which differed for the unheated tests. The post hoc test was not able to identify pairs which differed for the heat treated specimens.

Figures 3.1, 3.2, and 3.3 illustrate waveforms for hammer strikes 1,2,4,12,15,17, and 18 for the unheated porous Burlington Chert. Sound duration remains constant for the examples. This sequence illustrates the gradual decrease in intensity or energy as testing progressed. The waveforms lightened and became flatter having less amplitude. The decrease in intensity is likely related to micro fractures developing as a result of the repeated hammer strikes. The micro fracture’s presence increased after each hammer strike. This is evidenced by sound wave energy progressively decreasing, culminating in the specimen’s fracture during hammer strike #18.



A "C:\Research\Archeology\CSL Data\Stones\Burlington Chert - low grade.NSP"

0.13710 – 0.17649

x: 0.03938 sec R y: -340 ss: 0.13710 sec se: 0.17649 sec

B "C:\Research\Archeology\CSL Data\Stones\Burlington Chert - low grade.NSP"

10.25767 – 10.29552

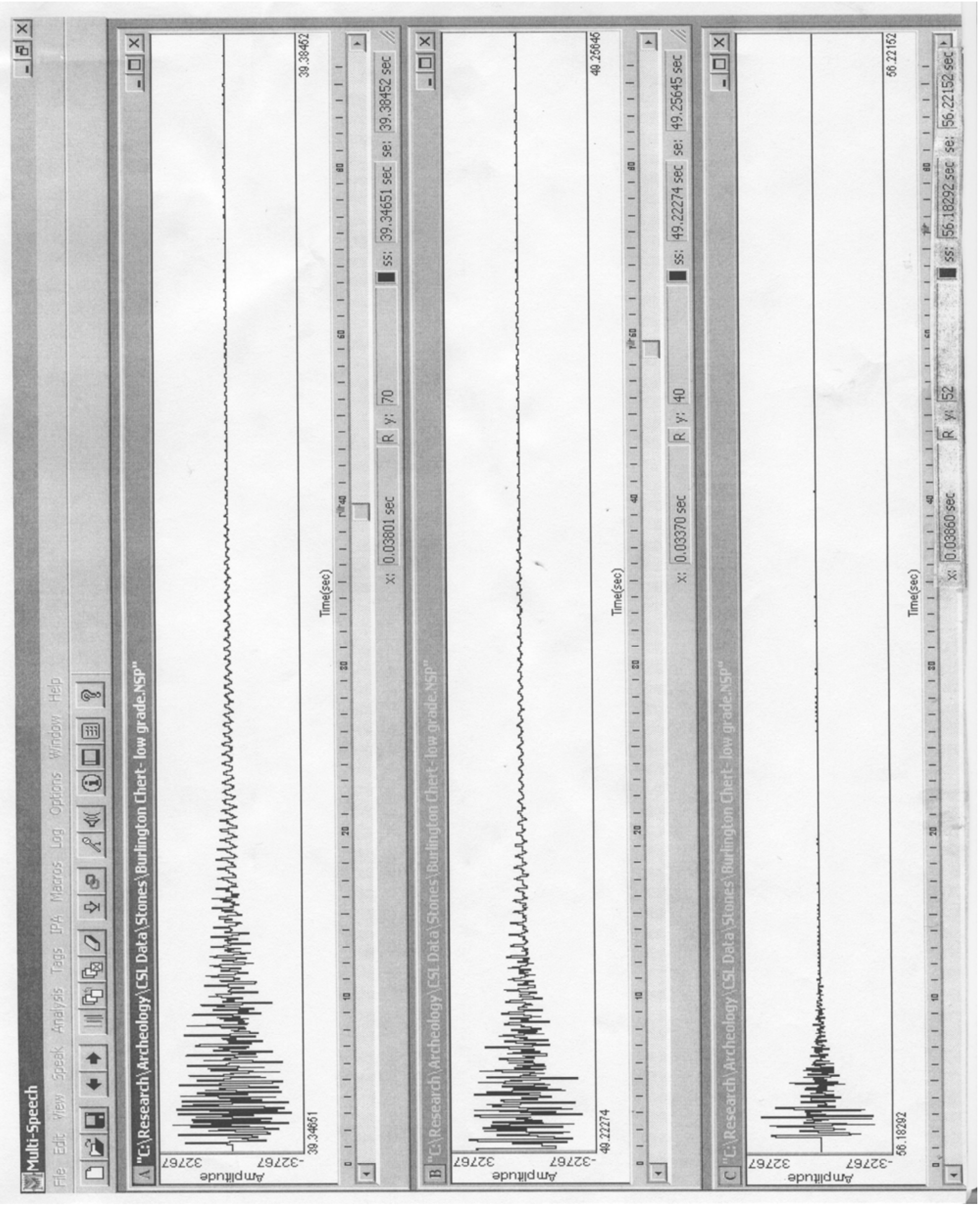
x: 0.03785 sec R y: 254 ss: 10.25767 sec se: 10.29552 sec

C "C:\Research\Archeology\CSL Data\Stones\Burlington Chert - low grade.NSP"

24.65178 – 24.69041

x: 0.03863 sec R y: 110 ss: 24.65178 sec se: 24.69041 sec

Figure 3.1 porous Burlington Chert waveforms for hammer strikes #1 (box A), #2 (box B), and #4 (box C).



A "C:\Research\Archeology\CSL Data\Stones\Burlington Chert- low grade.NSP"

39.34651 39.38452

x: 0.03801 sec R y: 70 ss: 39.34651 sec se: 39.38452 sec

B "C:\Research\Archeology\CSL Data\Stones\Burlington Chert- low grade.NSP"

49.22274 49.25646

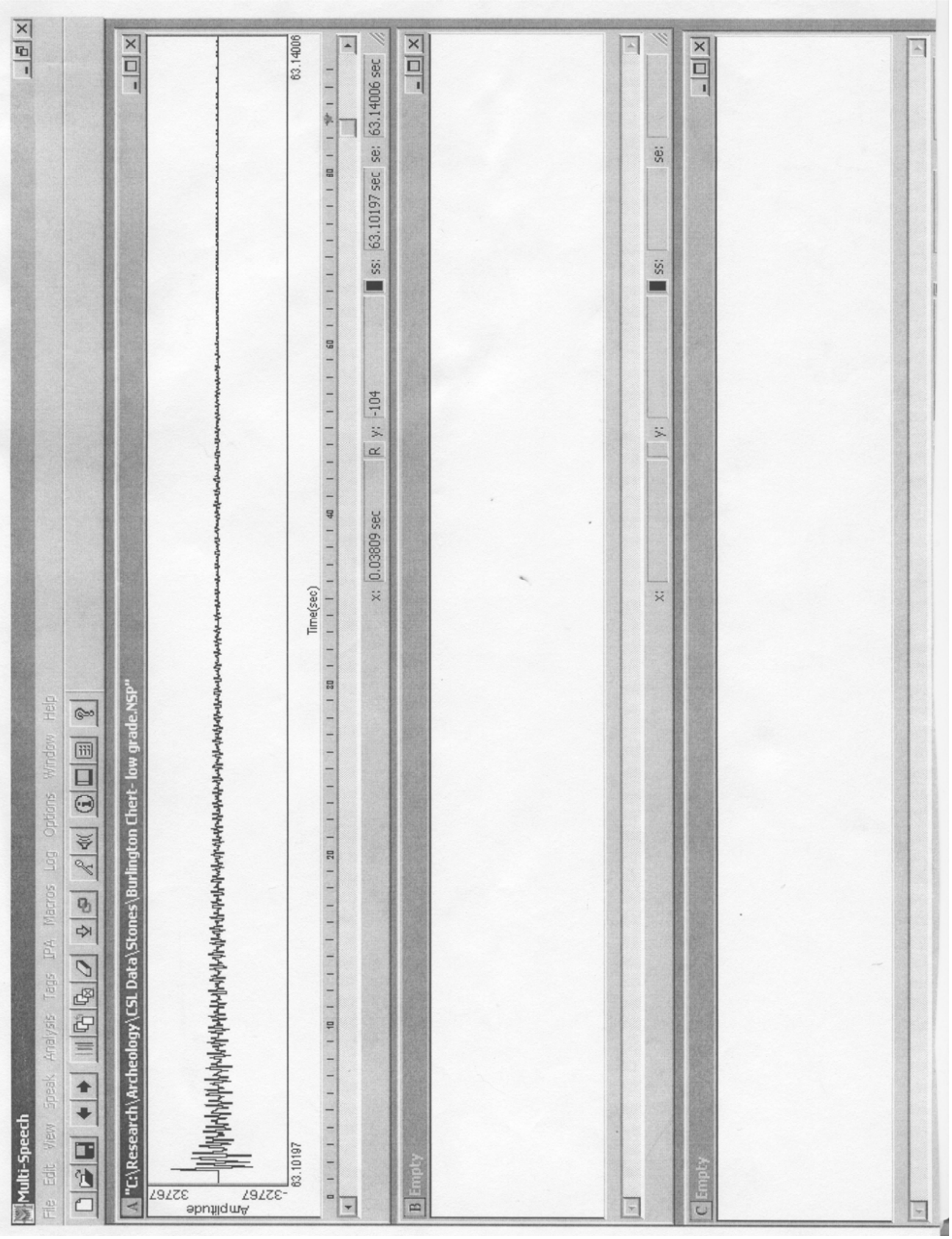
x: 0.03370 sec R y: 40 ss: 49.22274 sec se: 49.25645 sec

C "C:\Research\Archeology\CSL Data\Stones\Burlington Chert- low grade.NSP"

56.18292 56.22152

x: 0.03860 sec R y: 52 ss: 56.18292 sec se: 56.22152 sec

Figure 3.2 porous Burlington Chert waveforms for hammer strikes #12 (box A), #15 (box B), and # 17 (box C).



"C:\Research\Archeology\CSL Data\Stones\Burlington Chert- low grade.NSP"

x: 0.03809 sec R y: -104 ss: 63.10197 sec se: 63.14006 sec

Figure 3.3 porous Burlington Chert hammer strike #18.

Hypothesis II Results

Hypothesis II Ho: When a lithic material has been heat treated, its sound duration and wave vibration rates after being struck with a hammer stone will be equal to its unheated "raw" state.

Hypothesis II Ha: After a lithic material has been heat treated, its sound after being struck with a hammer stone will be of shorter duration with correspondingly slower rates of vibration compared to its original "raw" unheated state.

Hypothesis II Hb: After a lithic material has been heat treated, its sound after being struck with a hammer stone will be of longer duration with correspondingly faster rates of vibration compared to its original "raw" unheated state.

To accept or reject hypothesis II Ho, I needed to determine if a significant number of heat treated specimens differed from their unheated conditions for the factors of spectral mean and sound duration.

Hypothesis II was tested by comparing the duration and spectral mean datum of ten unheated specimens. The specimens were then heated and retested. Results are summarized in Tables 3.10 and 3.11.

Table 3.10 Duration Parametric One Way ANOVA Tests for Significance in milliseconds:
One Stone-Two Conditions: Unheated versus Heated

Rock Type	Means Unheated	Means Heated	Test for Significance	Tukey Diff of Means	Q	P	Difference
Burlington Chert	87	110	ANOVA: Tukey	22.271	4.997	=0.002	yes
Flint Ridge Flint	115	99	ANOVA: Tukey	16.60	3.279	=0.029	yes
Georgetown Flint	74	105	ANOVA: Tukey	31.462	9.719	<0.001	yes
Knife River Flint	29	39	ANOVA:Tukey	10.381	9.427	<0.001	yes
Florida Agatized Coral	126	123	ANOVA	NA	NA	=0.582	no
Brazilian Agate	115	110	ANOVA	NA	NA	=0.451	no
Jasper, Biggs	116	120	ANOVA	NA	NA	=0.443	no
Novaculte (Specimen 1)	104	99	ANOVA	NA	NA	=0.525	no

Note: One Way ANOVA P<0.001:All Pairwise Multiple Comparison Procedures (Tukey Test) P<0.05

Table 3.11 Duration Nonparametric Tests for Significance in milliseconds:
One Stone-Two Conditions: Unheated Versus Heated

Rock Type	Median Unheated	Median Heated	Test for Significance	Dunn's Difference of Ranks	Q	P	Difference
Jasper, Madagascar	49	73	Kruskal-Wallis Dunn's Method	7.269	2.378	=0.017	yes
Root beer Flint	93	106	Kruskal-Wallis	NA	NA	=0.062	no

Note: All Pairwise Multiple Comparison Procedures (Dunn's Method) P<0.05.

The five pairs which are significantly different for sound duration are Burlington Chert heated versus unheated (P=0.002), Flint Ridge Flint heated versus unheated

(P=0.029), Georgetown Flint heated versus unheated (P<0.001), Knife River Flint heated versus unheated (P<0.001), and Madagascar Jasper heated versus unheated (P=0.017). The five types that are not significantly different are Florida Agatized Coral heated versus unheated (P=0.582), Brazilian Agate heated versus unheated (P=0.451), Biggs Jasper heated versus unheated (P=0.443), Novaculite heated versus unheated (P=0.525), and Root beer Flint heated versus unheated (P=0.062). The five types which were not significantly different experienced less internal changes from heating than the five which demonstrated significant differences in pairwise comparisons.

The heated Novaculite (specimen 1), Brazilian Agate, Florida Agatized Coral, and Biggs Jasper had sound duration means which were very similar to their unheated conditions and had large standard deviations. There may have been true differences between samples but they were too small to discover with the selected statistical test. The desired power of the performed test was 0.800. The test power for the four specimens types are listed in Table 3.12. Negative findings are interpreted cautiously due to the low power of the tests. Four of the tests had a power of only 0.048 meaning if there was a true difference it would only be seen approximately 5% of the time versus the desired 80%. The test was under powered. Differences between specimens may actually have been demonstrated if a different test had been chosen. Spectral mean results for the ten specimens tested are listed in Tables 3.13 and 3.14.

Table 3.12 One Way ANOVA Test Power for No Significant Differences: Duration Unheated vs. Heated.

Rock Type	Test Power
Novaculite (specimen 1)	0.048
Brazilian Agate	0.048
Florida Agatized Coral	0.048
Biggs Jasper	0.048

Table 3.13 Spectral Means Parametric Test for Significance hertz: One Stone-Two Conditions.

Rock Type	Means Unheated	Means Heated	Test for Significance	Tukey Diff. of Means	Q	P	Diff.
Burlington Chert	5,461	3,831	ANOVA: Tukey	1,630.723	6.107	<0.001	yes
Brazilian Agate	3,821	3,771	ANOVA: Tukey	13.00	4.32	<0.001	yes
Novaculte (specimen 1)	4,468	8,421	ANOVA: Tukey	3,953	9.206	<0.001	yes
Georgetown Flint	3,849	3,752	ANOVA: Tukey	96.782	3.324	=0.027	yes

Note: One Way ANOVA P<0.001: All Pairwise Multiple Comparison Procedures (Tukey Test) P<0.05.

Table 3.14 Spectral Means Non-Parametric Tests for Significance in hertz: One Stone-Two Conditions.

Rock Type	Medians Unheated	Medians Heated	Test for Significance	Diff. of Ranks	Q	P	Diff.
Florida Agatized Coral	3,750	3,777	Kruskal-Wallis: Dunn's Method	9.376	3.088	=0.002	yes
Jasper, Madagascar	4,027	3,887	Kruskal-Wallis: Dunn's Method	10.236	3.348	<0.001	yes
Root beer Flint	4,051	4,092	Kruskal-Wallis: Dunn's Method	7.267	2.261	=0.024	yes
Flint Ridge Flint	3,999	3,941	Kruskal-Wallis:	NA	NA	=0.580	no
Knife River Flint	3,911	3,943	Kruskal-Wallis:	NA	NA	=0.383	no
Jasper, Biggs	3,584	3,614	Kruskal-Wallis:	NA	NA	=0.101	no

Note: Kruskal- Wallis ANOVA on Ranks P<0.001: All Pairwise Multiple Comparison Procedures (Dunn's Method) P<0.05.

The seven comparisons which are significantly different for spectral mean are Burlington Chert heated versus unheated (P<0.001), Brazilian Agate heated versus unheated (P<0.001), Florida Agatized Coral heated versus unheated (P=0.002), Novaculite heated versus unheated (P<0.001), Georgetown Flint heated versus unheated (P=0.027), Madagascar Jasper heated versus unheated (P<0.001), and Root beer Flint heated versus unheated (P=0.024). The three types that did not differ significantly are Flint Ridge Flint heated versus unheated (P=0.580), Knife River Flint heated versus unheated (P=0.383), and Biggs Jasper heated versus unheated (P=0.101). Knife River Flint, Flint Ridge Flint, and Biggs Jasper had differences in values that were not great enough to exclude the possibility that the differences were due to sampling variability.

In a cursory look at means and medians, the value changes were minimal to moderate except for the Novaculite. The Novaculite unheated spectral mean, was 4,468 Hz and changed to 8,421 Hz in its heated condition.

Hypothesis II Ho is rejected. The Multiple comparison tests indicated that for sound duration five of ten pairs differed with seven pairs differing when their spectral means were compared.

Hypothesis III Results

Hypothesis III Ho: Low and high quality lithic material of the same type will have equal frequency response and sound duration levels.

Hypothesis III Ha: High quality lithic material will have faster frequency response levels and its sound will have longer duration than low quality material of the same type.

To test Hypothesis III, Burlington Chert and Piaute Agate were selected to compare high and low grades for the factors of sound duration and spectral mean Tables 3.15 and 3.16.

Table 3.15 Duration Test for Significance in milliseconds: Two Stones Same Type: One High Quality the Other Low Quality.

Rock Type	Means High	Means Low	Test for Significance	Tukey Diff. of Means	Q	P	Difference
Burlington Chert	87	26	ANOVA: Tukey	61.929	26.264	<0.001	yes
Piaute Agate	85	60	ANOVA: Tukey	24.672	7.053	<0.001	yes

Note: One Way ANOVA P<0.001: All Pairwise Multiple Comparison Procedures (Tukey Test) P<0.05.

Both samples passed the normality and equal variance tests. Differences in the mean values among the treatment groups were greater than would be expected by chance for the Burlington Chert and Piaute Agate (P<0.001). Both of the high quality specimen types had higher mean values than their low quality counterparts.

Table 3.16 Spectral Means Test for Significance in milliseconds: Two Stones Same Type: One High Quality One Low Quality.

Rock Type	Median High	Median Low	Test for Significance	Q	P	Difference
Burlington Chert	5,104	4,241	Kruskal-Wallis Dunn's Method	2.431	=0.015	yes
Piaute Agate	3,597	3,435	Kruskal-Wallis Dunn's Method	3.800	<0.001	yes

Note: Kruskal-Wallis ANOVA on Ranks P<0.001: All Pairwise Multiple Comparison Procedures (Dunn's Method) P<0.05.

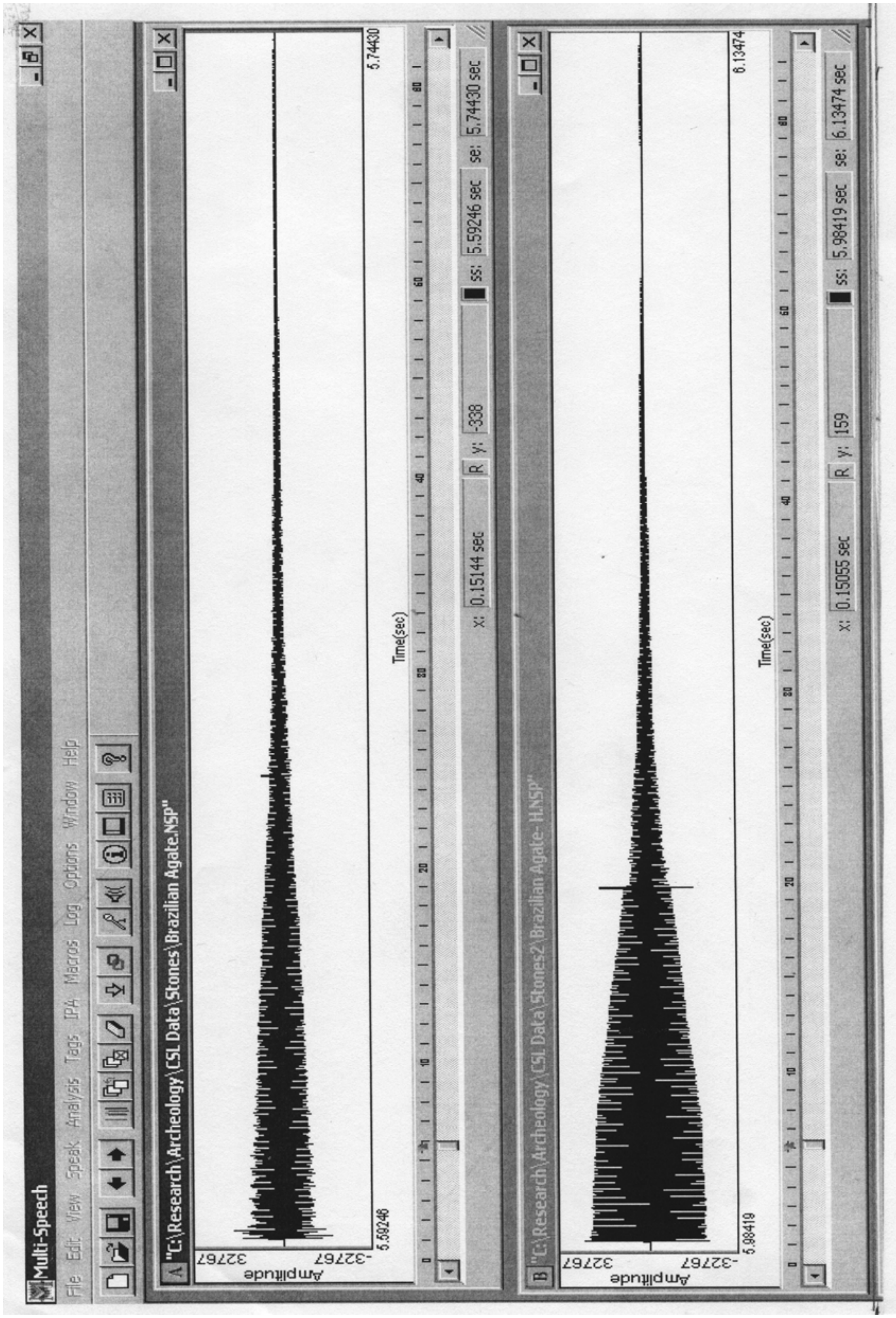
For spectral mean, the normality test failed for both Burlington Chert and Piaute Agate. The Kruskal-Wallis ANOVA was used as an omnibus test. Test results for the Burlington Chert and Piaute Agate indicated that the differences were greater than would be expected by chance.

Hypothesis Ho III is rejected. Multiple comparison tests indicted that high and low quality specimens of the same time differed significantly for both sound duration and spectral mean.

The sound waveforms display a distinct difference in heated versus unheated specimens. The heated and unheated specimens' waveforms generally have similar maximum amplitude intensities. The heated specimens' waveforms of the same stone however were much darker indicating that they have greater average intensity. This observation indicated that heated waveforms had greater intensity and energy than unheated waveforms of the same type. This phenomenon held true for all ten pairs of heated versus unheated specimens and was consistent throughout hammer strike repetitions.

Intensity is the rate at which energy is transferred through a medium. Intensity and loudness are related; the more energy present the louder the sound (Mackenzie 1964:21). Loudness is a perceptual entity of the physical property intensity. Factors which affect how acoustic energy will be transported through a medium are an inertial factor, elasticity, and damping factors. Dense materials have a greater inertia and tend to resist a force; this increased resistance by the greater mass causes a reduction in the amplitude pulse. More elastic mediums offer less resistance to a force and allow a greater amplitude pulse to travel through it being less rigid (and therefore more elastic), the same force causes a greater amplitude (Physics Classroom 2002). Damping factors present in a medium such as a rock being porous, crazed, or cracked, will reduce sound wave intensity. Note the progression of waveforms following hammer strikes listed in Figure 3.1 for the porous Burlington Chert. It is readily observable how the Burlington Chert begins to lose average intensity or energy from the start of the test due to the damping affect of internal cracking until it fractures during hammer strike #18.

Waveforms in figures 3.4, 3.5, and 3.6 illustrate differences observed between the unheated and heated sound waveforms for Brazilian Agate (hammer strikes # 2), Biggs Jasper (hammer strikes #2), and Novaculite #1 (hammer strikes #1). The heated specimens are significantly darker indicating that they have greater average intensity or energy.



A "C:\Research\Archeology\CSL Data\Stones\Brazilian Agate.NSP"

5.59246 5.74430

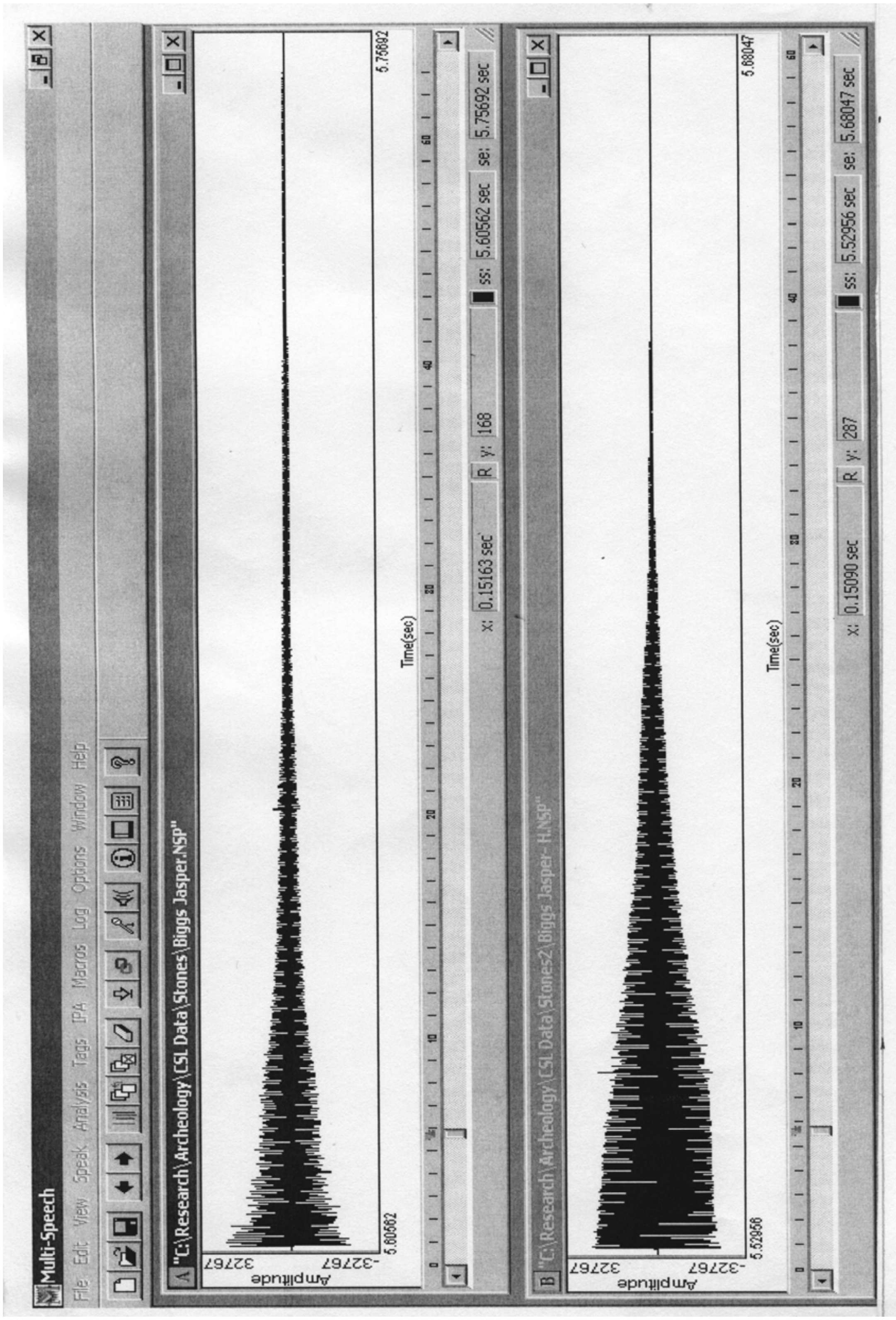
x: 0.15144 sec y: -338 ss: 5.59246 sec se: 5.74430 sec

B "C:\Research\Archeology\CSL Data\Stones2\Brazilian Agate- H.NSP"

5.98419 6.13474

x: 0.15055 sec y: 159 ss: 5.98419 sec se: 6.13474 sec

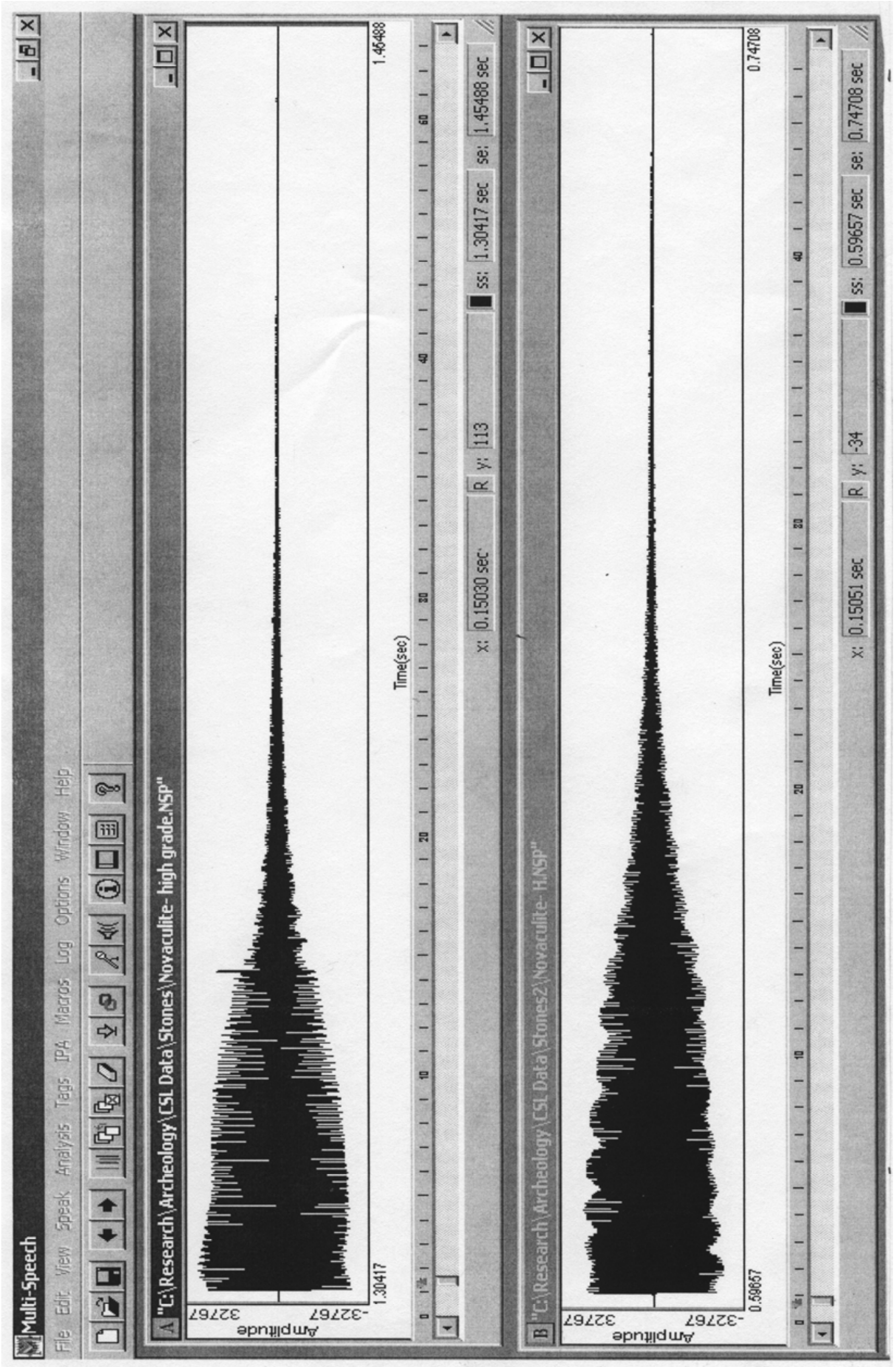
Figure 3.4 Brazilian Agate unheated hammer strike #2 waveform (box A); Brazilian Agate heated hammer strike #2 (box B).



x: 0.15163 sec R y: 168 ss: 5.60562 sec se: 5.75692 sec

x: 0.15090 sec R y: 287 ss: 5.52956 sec se: 5.68047 sec

Figure 3.5 Biggs Jasper unheated hammer strike #2 waveform #2 (box A)
Biggs Jasper heated hammer strike #2 (box B)



x: 0.15030 sec R y: 113 ss: 1.30417 sec se: 1.45488 sec

x: 0.15051 sec R y: -34 ss: 0.59657 sec se: 0.74708 sec

**Figure 3.6 Novaculite unheated hammer strike #1 waveform (box A)
Novaculite heated hammer strike #1 waveform(box B)**

Chapter 4
Conclusion

This study used modern acoustic technologies to investigate the properties of "lithic sound." Knowledge obtained will prove useful to archaeologists by enhancing their understanding of siliceous stone, one of mankind's oldest resources. An ever-present question entwined in all aspects of the study was to determine if it was possible to predict the ease with which a stone could be flaked based solely upon acoustic information. Within the parameters of the study's major findings, it was conclude that acoustic information can be used as a strong predictor concerning the ease with which a stone can be flaked, and whether or not lithic material has been heat treated.

Hypothesis I Ho was rejected. The comparison of different unheated lithological types revealed an adequate number of pairwise comparison differences to conclude that unheated rock types often differ in acoustic properties. The heated duration and spectral mean omnibus nonparametric test results indicated differences greater than would be expected by chance. Post hoc tests failed to isolate the groups or groups that differed. Physical changes that occur during the heat treatment of lithic material likely made all types more similar in there acoustic properties versus their unheated conditions. This made differences less apparent than with the unheated specimens.

Lithic material that has short sound duration levels of 40 ms or less regardless of spectral mean levels cannot be easily flaked. This is due to factors such as inclusions, internal cracks, and porosity. These conditions absorb and restrict energy related to the flaking process. In addition, specimens with short sound duration levels display waveforms having low average intensity levels. The unheated porous Burlington Chert and Knife River Flint with solidified plant fragments accounted for 20 comparison differences. During testing near the end of the series of 15 hammer strikes, the sound of the strikes often became "thuddier"or duller. This was reflected in a decrease in duration levels. For example, the heated Madagascar Jasper's mean duration was 66 ms, with its median being 73 ms. The stone's last two duration levels were 33 ms and 34 ms. The material was likely near breaking as the Porous Burlington Chert had, which displayed similar duration results. The process of repeatedly striking the lithic specimens must have been creating internal changes within the material, perhaps unobservable fractures were occurring. As testing progressed through the 15 hammer strike repetitions, the associated waveforms lost intensity or energy as noted in the porous Burlington Chert example Figure 3.1. Significant unobservable fracturing associated with hammer strikes decreased acoustic energy.

As noted in the Method Problems subsection, the "low grade" factor "muddied" the type comparisons. This oversight did provide useful information and helped gain answers to the study's most pressing question; can acoustic properties be used in and of themselves to predict the ease (and predictability) with which siliceous stone can be flaked? The Knife River Flint (30 ms) and the porous Burlington Chert (26 ms) had the two lowest unheated median sound duration measurements. From my own personal experience, and that of a professional flint knapper's, the two mentioned specimens would have been impossible to flake predictably.

Lithic material with high spectral mean values (>6,000 Hz) and short sound duration levels of 40 ms or less should be suspected to have major internal cracks. If stressed, the material has a propensity to abruptly fracture. Findings related to the study's two specimens which incurred complete fractures support this opinion. The porous Burlington Chert fractured on its 18th hammer strike. Most of the damage likely occurred on the 17th hammer strike considering the evidence of it demonstrating a short 5 ms duration and very high spectral mean value of 10,153 Hz. The high quality heated Piaute Agate fractured on its initial hammer strike. The Piaute Agate had a spectral mean of 10,181 Hz and duration of 29 ms. It appears that as lithic material incurs catastrophic fractures sound duration levels shorten while the spectral mean values become quite high. Internal fractures which dampen sound duration, intensity, and velocity, do not decrease the vibration rate, or the pitch of sound waves as they vibrate through rock.

Lithic material with moderate to high spectral mean values of 3,500 Hz to 8,000 Hz, sound durations of 80 ms and above, and a high level of average intensity in their sound waves, should be considered candidates for predictable flaking.

Comparisons of the unheated specimens to their heated conditions lead me to reject Ho II. There were an adequate number of differences to conclude that heat treatment changes siliceous rock's acoustic properties when compared to their unheated condition. Five of the ten comparisons were significantly different for duration. Four samples that tested no difference had very low test powers. Negative findings were interpreted cautiously due to the less than 5% chance of observing differences if they were present. Seven of the 10 comparisons of spectral mean values revealed significant differences.

Results were inconclusive regarding which alternative hypothesis to accept based upon mixed findings regarding whether or not heated specimens had increased or decreased sound duration and spectral mean values compared to unheated specimens.

Heat treated specimens have significantly higher average sound intensity or energy levels than unheated specimens. When comparing waveforms of the heated versus unheated conditions, the heated waveforms consistently were much darker having overall greater average intensity or energy. Heated lithic material undergoes changes, which allow an increase in intensity of acoustic energy to be transmitted when compared to unheated flint of the same type. Based upon average intensity waveform consideration, heat treatment appears to have at least partially repaired damage that resulted during the 15 hammer strikes in the material's unheated test condition. The unheated material's waveforms average intensity levels after their 15th hammer strike typically showed decreased intensity. After being heat treated, the waveform intensity typically is increased beyond intensity levels noted during the unheated trials.

Heat treating increases both the acoustic energy of sound waves and the efficiency and ease which heated material can be fractured. This fact is likely related to the findings of Crabtree and Butler (1964:2), Domanski and Webb (1992:610), Mandeville (1973:177) and Purdy and Brooks (1971:323). These researchers essentially suggested that heat treating flint makes it more homogenous through recrystallization processes.

Archaeologists are interested in being able to detect if lithic material at sites have been heat treated (Ahler 1983; Collins and Fenwick 1974; Crabtree and Butler 1964; Joyce 1985; Mandeville and Flenniken 1974; Purdy 1974; Rick and Chappell 1983). Ways to detect heat treated flint include observation of changes in luster, color, ease of flaking and decreased translucency. I suggest that acoustic waveforms can be used to detect heated versus unheated flint. Rigid controls outlined in this experiment reveal that heat treated flint has markedly greater average intensity than unheated flint.

The direct comparison of low and high quality Burlington Chert and Piaute Agate indicate rejection of the third null hypothesis. High quality specimens had longer sound duration and higher spectral mean vibration rates than did the low quality materials. The materials are significantly different. High quality specimens also had wavejforms which demonstrated higher average intensity levels than the low quality material.

This research indicates that at this time it is not feasible to develop an objective scale to rank different types of lithic material based upon acoustic data. With better experimental controls and clearer understanding of the many factors involved, it may however be possible. A future study investigating sound wave intensity levels is suggested. It appears that heat treating makes specimens resonate waves which demonstrate more periodic harmonization (more musical versus noise) along with increased average intensity than unheated material. This observation was not investigated fully due to time constraints.

From my incidental observations of hammer strike rebounds, it is reasonable to postulate that flint knappers use their sense of proprioception to assess a core rock for ease of flaking.. Proprioception is defined as the awareness of posture, movement, and changes in equilibrium and the knowledge of position, weight, and resistance of objects in relation to the body (Thomas, 1977). Humans within their muscles, tendons and joint capsules have proprioceptors which afford them (even with their eyes closed) to know their position in space, any body movement occurring, and the degree of force required for a particular activity (Schmidt 1978:95). Flint knappers may unknowingly use this information to detect quality material. A hard, homogenous siliceous stone may cause the hand holding a hammer stone to rebound after striking a core stone, quicker and further back than a stone which is soft, porous, or otherwise of low quality.

Appendix Specimen Color Descriptions

Lithic Sample	**Origin**	**Unheated color**	**Heat Treated Color**
Alibates	Texas	NA	2.5YR 4/3 reddish brown. 10YR 6/1 gray 7.5YR 4/2 brown 7.5 YR 5/3 brown 7.5YR 4/3 brown
Brazilian Agate	Brazil	described on white background 5PB 4/1 dark bluish gray 10YR 4/4 dark yellowish brown 7.5YR2.5/2 very dark brown described held up to sunlight 5Y 6/2 light olive gray 10 YR 5/4 yellowish brown 7.5YR 3/3 dark brown	described on white background 10B 5/1light bluish gray 10 YR 4/1 dark gray 7.5 YR 5/2 brown 7.5 YR 4/1dark gray 5B 7/1 bluish gray 5YR 3/ 4 dark reddish brown 5YR 5/2 reddish gray 5YR 2.5/1 black Described held up to sunlight 10YR 6/3 pale brown 10YR 7/2 light gray 5Y 8/2 pale yellow 7.5 YR 2.5 /2 very dark brown 7.5 YR 5/8 strong brown 2.5 YR 4/8 red 5YR 3/4 dark reddish brown

Burlington Chert High	Missouri	10YR 6/2 light brownish gray 2.5Y 7/1 light gray 2.5Y 7/2 light gray 7.5 YR 4/4 brown band	10 YR 5/2 grayish brown 7.5 YR 6/2 pinkish gray 7.5 YR 7/2 pinkish gray 7.5 YR 4/2 brown 2.5 YR 5/4 reddish brown 2.5 YR 3/3 dark reddish brown
Burlington Chert Low	Missouri	5Y 7/3 pale yellow 2.5Y 8/2 pale yellow	NA
Flint Ridge Flint	Ohio	5PB 6/1 bluish gray 10B 3/1 dark bluish gray 5PB 5/1 bluish gray 10YR 6/6 brownish yellow	10Y 5/1 greenish gray 10B 7/1 light bluish gray 10Y 3/1 dark greenish gray 10Y 6/1 greenish gray 5Y 6/2 light olive gray 5YR 4/3 reddish brown 10B 5/1 bluish gray
Florence Type B Chert	Kansas	N4/1 dark greenish gray 10YR 5/1 gray 2.5Y 8/2 pale yellow	N 3/ very dark gray 10B 4/1dark bluish gray 10YR 5/1 gray 10B 5/1 bluish gray
Florida Agatatized Coral	Florida	5GY 7/1 light greenish gray 5Y 8/1 white –gold flecks	10 YR 5/1 gray 10YR 5/2 grayish brown 10YR 4/1 dark gray 10YR 5/3 brown 2.5Y 6/1gray 2.5Y 7/1 light gray
Georgetown Flint	Texas	10B 3/1 very dark bluish gray 10B 4/1 dark bluish gray	N3/ very dark gray 5PB 4/1 dark bluish gray

Hornstone	Indiana	10B 3/1 dark bluish gray 10YR 6/1 gray (spot) 5Y 5/1 intermittent gray (bubble)	NA
Jasper, Biggs		N2.5/ black 5PB 6/1 bluish gray-waves - of lighter gray on black charcoal grey	N 3/ very dark gray 5PB 5/1 bluish gray 2.5 Y 4/1 bands dark gray 7.5 YR 3/3 spots dark brown
Jasper, Fancy	India	10R 4/6 red 10B 4/1 dark bluish gray	2.5 YR 3/6 dark red 2.5 YR 5/1 reddish gray 2.5 YR 3/1 dark reddish gray N5/ gray 5YR 5/4 reddish brown 10YR 5/6 yellowish brown
Knife River Flint	North Dakota	10YR 4/6 dark yellowish brown 10YR 2/1 black 10YR 6/2 light brownish gray	7.5 YR 2.5/1 black 10YR 5/1 gray 10 YR 6/2 light brownish gray 10YR 5/2 grayish brown 10R 3/3 banding, dusky red
Novaculite, # 1	Arkansas	N6/ gray	N 5/ gray
Novaculite # 2	Arkansas	N5/1 gray N3/1 very dark gray	NA
Obsidian, Black	Oregon	N 2.5/ black	NA
Piaute, Oregon low	Oregon	10YR 4/3 brown 2.5Y 6/1 gray 5B 5/1 bluish gray	NA

Piaute, Oregon high	Oregon	5PB 6/1 bluish gray	5PB 5/1 band, bluish gray
		N 3/ very dark gray	N 3/ very dark gray
		7.5 YR 3/ 4 dark brown	2.5YR 5/2 weak red
			2.5YR 3/2 dusky red
			2.5YR 4.2 weak red
Root beer Flint	Texas	10 YR 3/1 very dark gray	10YR 4/1dark gray
		7.5 YR 3/ 4 dark brown	10YR 6/1 gray
		10YR 6/2 light brownish gray	10R 3/3 dusky red

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