University of Alberta

An Objective Method for Identifying Heat-Treatment in Swan River Chert

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Arts

Department of Anthropology

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Fall 2013
Edmonton, Alberta

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Abstract

Current models for determining when stone artifacts have been heat-treated rely on subjective criteria such as colour and texture. While these criteria are not without their own merits, their subjective nature means that the actual amount of heat-treated material at an archaeological site may be over- or underestimated. This study provides a potential model for objectively identifying heat-treatment in Swan River Chert. The model utilizes a device called an optical profilometer to measure the topography of a flake's ventral surface and is supported by an experimental protocol. The ability to determine objectively when lithics have been heat-treated has the potential to further our understanding of lithic acquisition and reduction strategies in Alberta. The identification model was applied to a series of experimentally heat-treated flakes as well as lithic material from eight archaeological sites in Alberta that date from the Middle to Late Prehistoric periods and it was discovered that heat-treated flakes have a smoother flake surface when compared to unheated flakes.

Acknowledgments

I would to like to thank Dr. Jack Ives for his patience and guidance in making this thesis a reality, Eugene Gryba for all of his advice, and for providing me with innumerable samples of SRC to work with. Dr. Mark Ackerman for instructing me in the proper use of thermocouples, Dr. John Nychka for showing me the possible applications of the optical profilometer for archaeology, and Karen Giering for allowing me access to the archaeological collections at the Royal Alberta Museum. I would also like to thank the staff of the NanoFab laboratory for graciously allowing me access to their workspace and equipment.

A very special thanks also goes to my family who have stood with me through all my successes and failures, and always encouraged me to pursue my dreams.

The Government of Alberta's Roger Soderstrom Grant provided the funding for this research. This grant was established to help advance historic preservation in Alberta by assisting student research.

Table of Contents

List of Tables

List of Figures

List of Photographs

List of Formulas

Chapter 1

Introduction

The use of fire by prehistoric people has been the technological underpinning for the development of all but the simplest of tools. The controlled application of heat was crucial for the development of such innovations as pottery, and continues to play a role in our society within the field of metallurgy. The intentional thermal alteration, or heat-treatment, of stone is one of the most significant discoveries that prehistoric people made; and may have led to the development of more refined methods of knapping, such as pressure flaking. This study attempts to address how prehistoric people were able to use fire to improve the flaking properties of siliceous materials, specifically Swan River Chert; and how this improvement can be measured in a meaningful way.

The principle behind heat-treatment is relatively simple: heating causes certain structural changes that make certain types of siliceous rock behave in a more glass-like manner. This causes the rock to flake in a more predictable fashion, making it easier to perform certain tasks such as pressure flaking. While this process is still not fully understood, the general consensus is that lithic materials that have been heat-treated develop certain functional characteristics that render them easier to work (Rick and Chappell 1983:79).

The intentional heat-treatment of lithics represents one of humanity's earliest efforts to deliberately modify, by heating, an inorganic substance; and the skills that were required for this process may ultimately have led to the

development of pottery and metallurgy (Epstein 1979:36). If we view technological development from within an evolutionary framework, with each new development dependent on its predecessors, then the heat-treatment of lithics becomes an important link between prehistoric and modern technologies. The implications of this relationship are profound, and underscore the necessity of accurately identifying areas in which heat-treatment occurred in order to examine what effect (if any) it had on future technological developments.

The study of heat-treatment is also important because it allows us to gain insights into particular aspects of how a culture functioned, particularly with regard to its technological expertise, its subsistence strategies, its trading practices, and its relationships with other societies (Boras 1991:2). The socioeconomic implications of heat-treatment mean that it cannot be viewed in isolation: it is a development that reflects "the contingency of many systematically related variables… and which should be an important clue as to the functioning of the cultural systems and subsystems in which stone tools were important" (Rick and Chappell 1983:79). This sentiment is echoed by Bleed and Meier (1980: 506) who feel that the rationale for the study of heat-treatment rests on the fact that "human responses to heat-treatment are more significant than the physical changes which take place in heated stones and… should be the major focus of study".

Evidence for the use of heat-treatment has been found in the prehistoric occupations of almost every continent. Its earliest use dates back to over 160,000 years ago in South Africa (Brown, et al. 2009) and ~14,000 years ago in the state

of Idaho (Crabtree 1969). It remained a viable means of producing tools well into the historical period. It is still not entirely clear whether heat-treatment was invented just once, or if it developed independently in multiple places at different times (Epstein 1979:36). Despite the current ambiguity in the data, the fact that this technique is spread over such a wide area and occupies a range of different dates leads me to suspect that the latter option is the most likely one.

Despite the importance of heat-treatment to our understanding of prehistoric societies, it was a technique that was viewed with disdain; and relegated to the realm of "old wives tales" (Mandeville 1973:177). It wasn't until 1964, when Don Crabtree "rediscovered" the technique and published his results in the Idaho State College journal *Tebiwa* that legitimacy was restored to the study of this technique. Since the publication of Crabtree's watershed article, dozens of studies have been performed in an effort to understand the physical nature and cultural implications of heat-treatment. This study will provide additional insights into the heating processes by attempting to recreate the conditions under which lithics may have been heat-treated in the past, as opposed to relying on temperature-controlled kilns.

The reason that I have chosen to focus on experimental replication as opposed to conducting my research out of a laboratory is that experimental replication provides us with a more explicit model through which we can interpret the archaeological record. Many aspects of prehistoric human behaviour are unrecoverable, and cannot be modeled or repeated in a controlled environment. Through the use of experimental archaeology, we are able to develop more

refined models of human behaviour that can serve as analogues for various complex processes that are found in the archaeological record.

The main objectives of this study are:

1) To review the relevant literature on heat-treatment. This includes ethnographic and archaeological reports as well as modern experimental studies.

2) To look at a particular lithic material type known as Swan River Chert (SRC), found widely on the northern Plains; and to examine some of the changes that it undergoes as a result of heat-treatment.

3) To determine if use of an optical profilometer can provide an effective method for determining whether or not a flake has been heat-treated.

In order to accomplish these objectives, samples of Swan River Chert were collected from its bedrock source in Manitoba, as well as from gravel pits in the surrounding area. These samples were then heated in a fire pit, in order to gain a better understanding of how this process may have been carried out; and to examine the effects of a "traditional" heating method on the stone. The use of an optical profilometer was obtained through the Material Engineering Department of the University of Alberta.

Definition of Heat-Treatment

Before getting into a discussion on heat-treatment, it is important to differentiate among a few terms referring to lithics that have been altered to some extent by heat. For the purposes of this study, the term 'heat-treatment' will refer exclusively to lithics that have been heated in a controlled manner, prior to or

during the knapping process, for the purpose of producing certain desirable characteristics (Mercieca 2009:40). 'Heat fracturing' is used to indicate that a piece of stone has suffered one or more physical stresses (e.g., crenation, potlidding, crazing) as a result of heat (Mercieca 2009:40). The term "thermal alteration" is more inclusive; and may refer to one of three types of heating, depending on the degree of intentionality observed (Boras 1991:5). The three kinds of thermal alteration are:

1) Natural thermal alteration: This term refers to materials that have been altered by natural causes, such as forest or grass fires. The physical characteristics most often associated with this type of heating are: a reddish discolouration, potlidding, decrepitation, and calcination (Boras 1991:5). These characteristics are most often associated with sudden or excessive heat exposure, and often render the material completely unworkable. In terms of archaeology, this type of thermal alteration should be fairly obvious owing to the lack of any associated cultural material.

2) Incidental thermal alteration: This process does result from human activities; however, the heating process may be secondary to another activity. The physical characteristics associated with this kind of alteration are often similar to those that result from natural contexts; however, they are found within a cultural context (Boras 1991:6). Fire-cracked rock (FCR), which is the result of stones being used to heat a boiling pit, is an example of this kind of alteration.

3) Intentional thermal alteration: Intentional thermal alteration is the deliberate heating of stone in order to develop characteristics that are desirable for its

subsequent use (Boras 1991:6). This category can include those materials that have been successfully as well as unsuccessfully altered. Materials that have been successfully heat-treated will demonstrate the desired physical characteristics that will be discussed in a later chapter. Materials that were unsuccessfully heat-treated may exhibit some or all of the physical properties that are characteristic of the previous two kinds of alteration; however, a close examination of the material breakdown of a site (particularly if heat-treated materials are present) should reveal whether or not the unsuccessful treatment was the result of a failed attempt at intentional thermal alteration, or due to other factors.

In Chapter 2 I will survey the ethnographic and archaeological evidence that has been published on the study of heat-treatment. Chapter 2 also contains a discussion of an unconventional flaking technique known as "water-chipping" that is mentioned in several ethnographic accounts, and looks at whether or not this procedure would have been a viable method for producing stone tools. Chapter 3 is a review of the existing literature published on heat-treatment, and looks at the macroscopic and microscopic changes that occur as a result of the heat-treatment process. Chapter 4 provides the reader with an overview of what exactly SRC is, its bedrock location, and its distribution across the Prairies. Chapter 5 recounts the methods used during this study, including an explanation of where samples were collected, as well as experimental and analytical procedures. Chapter 6 discusses the application of the experimental procedure from Chapter 5 to actual archaeological collections. Included in this chapter are descriptions of the sites examined and a discussion regarding whether or not the

results from the analysis of archaeological collections compares favourably with the experimental results. Chapter 7 discusses the significance of the previous two chapters, and looks at some of the potential future avenues to continue this research.

Chapter 2

Archaeological and Ethnographic Evidence for Heat-Treatment

In this chapter, I present a brief global overview of the ethnographic and archaeological evidence that we have for the heat-treatment of stone tools. I have also included a section on "unconventional" accounts of heat-treatment that have been recorded in various ethnographies, historical documents, and literature, particularly during the 19th and early 20th centuries. These accounts discuss heat-treatment being used in ways that we now know to be inaccurate or impossible. Despite the inaccuracies in some of these accounts, there are a few which may be able to shed some light on some of the other ways in which people may have used fire as part of a lithic procurement/production system.

Archaeological Evidence for Heat-Treatment

Archaeological evidence for the thermal alteration of lithic materials has been found on every continent except for Antarctica and is invariably associated with pressure flaked, bifacial, implements (Crabtree & Gould 1970:196; Griffiths, et al. 1987:43). Allan Bryan has suggested that the development of intentional thermal alteration was responsible for the widespread development of pressure flaking techniques (Bryan 1978:308). While there is no conclusive evidence to support this assertion yet, there does appear to be a relationship between pressure flaking and thermal alteration; and it is possible that the relationship could be used as an indicator that particular tools or debitage have been subject to deliberate thermal alteration.

The intentional use of heat-treatment to make stone tools can be traced as far back as the Middle Stone Age in Africa (~250,000-50,000 B.P.) (McBrearty and Brooks 2000:453). In Australia, there is probable evidence for heat-treatment that dates back as far as ~32,000 B.P (Flood 1983:46). In Europe, the dates are much more recent, with no evidence for intentional heat-treatment until the Solutrean period (~20,000 B.P) (Robins et al. 1978). The dates in North America are even more recent. An early radiocarbon date on a sample of small mammal bone from Wilson Butte Cave, where evidence for heat-treatment was believed to have been found, came back as ~14,500 B.P (Crabtree 1969:366). This date is no longer widely accepted, and Ruth Gruhn's recent (2006) work at the site has provided a new set of radiocarbon dates placing the earliest occupation of the cave at ~10,700 radiocarbon years B.P.

Most of the evidence that we have for heat-treatment comes from flakes and tools that have certain qualitative measures (e.g., luster, texture, colour) that match modern samples that have been heated to serve as a point of comparison. The exact method that prehistoric people used to heat-treat lithics is still not completely understood, due to the paucity of archaeological sites with definitive heat-treatment features. To date, there are only a handful of sites in the world that have been found that may represent an *in situ* discovery of a feature that was designed for heat treating lithics. One of these sites is at Lake Mungo, Australia; another is the Spillway Site (14PO12) in Kansas, United States of America. The third site is a lithic workshop located in Bell County, Texas, that is briefly described by Sollberger and Hester (1973).

Africa

At the Pinnacle Point site in South Africa, there are some archaeological materials which are ~164,000 years old and show evidence of having been heat-treated (Brown et al. 2009:860). This age seems to contradict the widely held belief that heat-treatment was an Upper Paleolithic innovation, and had only developed in the last ~20,000 years (Mourre et al. 2010:659). The research team at the Pinnacle Point site came to their conclusion by measuring the amount of light reflected off the surface of the archaeological specimens (measured using a glossmeter) and comparing it to a control sample (Brown et al. 2009:860). While not all the samples met the criteria set by the experimental data, this research demonstrated that there are objective methods for determining if artifacts have been heat-treated. Based on their findings, the authors of this study felt confident in using this early date as a possible starting point for the intentional heat-treatment of stone tools (Brown et al. 2009:861).

The earliest possible evidence for heat-treatment comes from Blombos Cave, South Africa, where archaeological specimens made from silcrete have been tentatively dated to ~75,000 years ago (Mourre et al. 2010:660). This process was demonstrated by comparing the archaeological specimens with equivalent samples that were prepared under controlled conditions. There are other examples of heat-treatment in Africa that have been documented by M. L. Inizan and colleagues. They report several heat-treated artifacts from the Grotte du Djebel Zabaouine cave site in Algeria, as well as in the Lower Tilemsi Valley of Mali (Inizan 1976:16).

North America

A chalcedony knife from Wilson Butte Cave, Idaho, was associated with a radiocarbon date of 14,500 B.P +/- 500 years; and may have represented the earliest use of heat-treatment in North America (Crabtree 1969:366). As mentioned earlier, the date for the earliest definitive occupation has since been amended to ~10,700 radiocarbon years before present (RCYBP). This revised date still places the earliest occupation on the site within the Early Prehistoric Phase, so it may still be evidence that the first people to arrive in North America were familiar with the heat-treatment process. Evidence for the probable use of heat-treatment by prehistoric groups has also been found in Pennsylvania (Fitting & DeVissher 1966), Florida (Hemmings 1975; Purdy 1975), the Northern Plains (Frison 1983), California (Gould 1976), as well as Texas and New Mexico (Joyce 1985). The use of heat-treatment persists through time, and is part of the technological "toolkit" of pre-contact groups well into the Historic period (Ahler 1983:6; Collins & Fenwick 1974:113, 143; Mandeville 1973:185).

The Spillway Site (14PO12), in Kansas is one of the only sites in the world that seems to have an intact feature that could have been used to heat treat lithic materials. Discovered by J. M. Shippee in 1962, the feature at the Spillway Site is a cache of flint flakes and cores, four inches thick that, were spread evenly over a bed of ashes and capped by three limestone boulders (Shippee 1963:271). This discovery reminded Shippee of a conversation he had with Marvin McCormick, an early flintknapper and one of the first people to successfully reproduce a fluted Folsom point (Whittaker 2004:47). McCormick had related to

Shippee of several occasions that he found it necessary to "temper" some of the materials that he worked with by burying them, building a hot fire over top, and then allowing it to cool slowly (Shippee 1963:271). While Shippee remained unconvinced about the use of heat to improve the flaking properties of certain stones, he acknowledged that this site, combined with McCormick's own experiences, did allow for that possibility to be true (Shippee 1963:272).

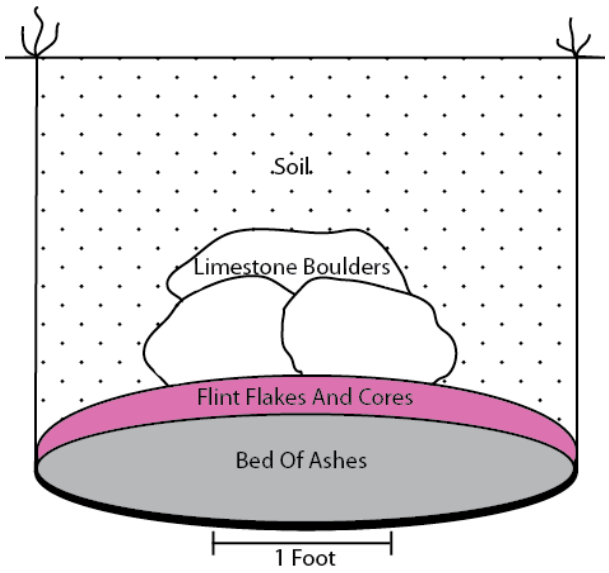

Figure 2.1: Sketch of a possible heat-treated cache (adapted from Shippee 1963: 272)

In Bell County, Texas, J. B Sollberger believed that he had identified another heat-treatment feature. He recorded a fire-darkened area roughly 12-14 feet in diameter that had a large number of chert flakes within it (Sollberger and Hester 1973:182). These flakes were all various shades of pink and red, which caused them to appear different than the chert in the nearby quarry; however, by heating samples of chert from the nearby quarry, Sollberger found that the local cherts took on colours that were similar to the flakes found in the fire-darkened area (Sollberger and Hester 1973:183). This evidence led Sollberger to conclude

that this particular site may have been an area in which chert from the nearby exposures was collected and then heat-treated.

Europe

Evidence for the heat-treatment of lithics in Europe can be traced to the Upper Paleolithic in France. Several specimens from Laugerie Haute indicate that the technique was being used as early as the Middle Solutrean (Collins 1973:465). Based on thermoluminescence analysis, a Late Solutrean laurel leaf fragment from Le Roc seems to have been heat-treated (Rowlett, et al. 1974:42). Electron spin resonance has been used to identify the use of heat-treatment in a number of Upper Paleolithic flints (Robins, et al. 1978:703). In Scandinavia, no conclusive evidence for the heat-treatment of lithics has been identified, although Olausson and Larsson (1982) caution that the distribution of artifacts that they studied was limited in terms of both space and time; and more work needs to be done before any definitive statement can be made.

Middle East

Examples of heat-treated artifacts from this part of the world are extremely rare and do not appear to be associated with any particular artifact type (Griffiths, et al. 1987:43). This observation is in contrast to the North American data that demonstrates that heat-treatment is almost exclusively associated with the production of bifacial implements. The best evidence for heat-treatment in the Middle East comes from a thermally altered chert core and end scraper found in the Upper Paleolithic level 11 at Ksar Akil, Lebanon (Griffiths, et al. 1987:42).

M. L. Inizan and colleagues have also reported evidence for the heat-treatment of points at sites in Syria and Lebanon (Inizian, et al. 1976:16).

Australia

There has been some debate in Australia regarding how long heat-treatment may have been practiced. Kim Akerman (1979) has suggested that the technique is actually a recent one, limited to the Kimberly region in Northern Australia, where it was related to the production of large, ceremonial points that were exported as part of *wunan* exchange ceremonies. On the other side, Flenniken and White (1983) have argued that heat-treatment was known throughout the continent since the late Pleistocene. Evidence to support Flenniken and White's argument for a 'deep history' of heat-treatment in Australia has been reported by Josephine Flood (1983), who describes a hearth containing "lumps of ochre and stone artifacts found deep below the ashes of a fire lit 32,000 years ago" at a site at Lake Mungo. New South Wales, Australia. Michael Hankel (1985) has noted the presence of heat-treated flakes and tools made from silcrete that date as far back as 20,000 B.P. at the Burril Lake and Currarong sites in New South Wales, Australia.

Ethnographic Accounts of Heat-Treatment

As one can see, trying to determine whether or not a particular archaeological feature was used to heat-treat lithics can be a difficult task. Fortunately, some ethnographic accounts have survived in the historical record; and they provide us with examples from around the world that help to us to

understand the decision making process and the methods employed by people in order to heat-treat the lithics that they had collected. The following is a brief review and analysis of some of the ethnographic data that we have on heat-treating techniques from around the world.

Africa

The ethnographic data for heat-treatment in Africa is extremely limited, and the author of this thesis has found only a handful of accounts. One is by T. Radcliffe Robinson, who describes a heat-treatment event in Southern Rhodesia (now Zimbabwe) that was told to him by a Nyasa informant. The informant told him that:

> A boulder of suitable material was obtained from a riverbed. A fire was then made and the boulder placed in the midst of it, burning wood being heaped all over the stone. When the boulder was very hot, it was removed from the fire and placed upon an anvil-stone and held in place by one of the men. The second worker grasped a hammerstone in his two hands and struck the heated boulder a hard blow. As he struck, he drew the hammer towards him slightly. In this manner a flake was detached. The flake was then laid flat upon the surface of the stone as an anvil and the edge was serrated by percussion (Robinson 1938:208).

Based upon my own personal observations, it is difficult to understand the rationale behind this technique. As Mercieca and Hiscock (2008) have demonstrated, there is an inverse, non-linear relationship between the size of the stone being heated and the temperature at which irreversible structural damage occurs. This relationship means that larger rocks are more likely to suffer from thermally induced crazing or cracking at a lower temperature than smaller ones, likely due to the fact that a larger stone will have a different temperature at its center than at its periphery. This situation causes differential expansion, which

may explain the increased incidences of thermal fracture in the large samples. Rocks that have been heated in this manner are almost useless, because they become extremely brittle and no longer flake in a predictable manner. Smaller samples are able to heat up more evenly, a condition which provides them with a greater tolerance for heat fluctuations. It is possible that Robinson has simply misinterpreted the activity that was going on, a topic that will be discussed further later in this chapter.

In an *American Anthropologist* article on stone tool production among modern Xauta populations in southern Ethiopia Kathryn Weedman Arthur (2010) records another, more modern approach to the heat-treatment of lithics. What makes this article of interest to archaeologists is that it may offer a glimpse into the role that gender may have played in the production of stone tools, a topic that is seldom discussed in other studies. In Xauta society, the practice of making stone tools is associated with femininity, so it is the women that are the primary knappers and not the men. The manner in which Xauta women pass down their tool making knowledge is also quite interesting. Mothers teach this skill only to their second or third daughter, as the oldest daughter is often too busy with other household obligations (Arthur 2010:231).

In order to prepare a stone for being worked, the material is placed on top of a broken piece of pottery and covered with an insulator such as leaves, cotton, wool, animal hair, or additional pottery sherds, before a fire is lit over the material to be heat-treated (Arthur 2010:234). The stone is then left to "cook" for between twelve hours and three months, before being removed and allowed to cool for at

least one day (Arthur 2010:234). Determining whether a man made a particular stone tool from an archaeological site or a woman is an almost impossible task; however, ethnographic work such as this study does provide us with tantalizing insights into how prehistoric people may have divided labour along gender lines.

North America

A number of ethnographic accounts about heat-treatment have been recorded in North America, with the earliest reports dating back to the 1870s. Unfortunately, despite the number of accounts available, many of them are quite vague, lacking specific information about the kind(s) of techniques used and even the name of the aboriginal group that was being observed.

One of the earliest and most explicit recorded accounts of heat-treating comes from the journal of J. W. Powell, who describes a heat treating event being conducted by the Plains Shoshone around the year 1870:

> The obsidian or other stone of which the implement is to be made is first selected by breaking up the 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 size and shape desired… (Powell 1875:27-28).

Among Shoshone groups in central Nevada, flint was prepared for tool making by heating it under the ashes of a fire for a period of five nights (Steward 1941:337).

Another account, written by P. Schumacher in 1877, describes how the Yurok of California heat-treated their lithics:

> A piece of one of the… stones, which breaks sharp cornered, and with a conchoidal fracture is heated in the fire, and then rapidly cooled, after which it is struck on the break-edge, by which means it is split into flakes. To such a flake, a

suitable rough shape is given by striking it with a tool … (Schumacher 1877:547-549).

The Wiyot people of Humboldt Bay, California, also heated pieces of "jasper, chert, obsidian and common flint" before shaping the material into tools (Powers 1877:104). In his ethnography of the Nomlaki of northern California, W. Goldschmidt describes their method of heat-treatment:

> 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 of this heating was not made clear. They were pressure flaked with pieces of bone (Goldschmidt 1951:419).

This method of heat-treatment seems to occur throughout California, and has also been recorded for the Tubatulabal and Northern Paiute (Kelly 1986; Stewart 1941) as well as the Shasta, Nisenan, and Maidu (Voegelin 1938; 1942). The Harney Valley Paiute of Oregon would knap flints by heating the bottom of the rock and then striking it with another stone (Whiting 1950:99). By this method, they were able to make flint "saws" that were used for felling trees (Whiting 1950:99). In the American Southwest, the Shivwits of Arizona had a rather unique method of heat-treatment. They are said to have roasted their flints in a barrel cactus before flaking them (Stewart 1942:264).

George Grinnell describes one instance of heat-treatment being practiced by northern Plains Indians:

> The material used by one of the men is a black obsidian obtained by trade from the Crows to the south, while the other was a piece of milky chalcedony picked up in the mountains to the west. Each of these blocks has been buried in wet earth, over which a fire has been built, the object of this treatment being to bring to light all the cracks and checks in the stone so that no unnecessary labour

need be preformed on a piece too badly cracked to be profitably worked (Grinnell 1898:142).

Unfortunately, Grinnell does not specifically mention the group that he was writing about. Grinnell was a Cheyenne ethnographer; however, based upon his extensive work among the southern Peigan and his mention of "south" in the excerpt above, it seems that a Blackfoot would be most likely (Gabriel Yanicki, personal communication 2010).

A similarly vague account was also published anonymously (though it is suspected to be Grinnell; see Boras 1991) in the 1907 issue of *Field & Stream*:

> It was a common practice for the arrow maker, before beginning work on a block of hard rock from which he intended to knock off the flakes which were to become arrow points or knives, to sweat the block by burying it in wet earth and then building a fire over it. The object of this was to make evident all the cracks and checks in the stone, so that allowance might be made for them when the time came for working it (Anonymous 1907:849).

In addition to describing the utilitarian benefits of heat-treatment, some ethnographies also discuss the non-mechanical/aesthetic properties of heat-treated lithics. One aesthetic feature of particular importance is colour. For example, according to DuBois (1935: 125) the Atsugewi considered all types of chert to be poisonous and believed that particular colours were ideal for taking game animals. The Wintu of northern California would ascribe certain magical properties to particular colours of stone. Grey lithics were believed to be particularly effective against bears, while white and red cherts were considered supernaturally poisonous (Du Bois 1935:125). Since cherts that contain iron (such as Swan River Chert) will take on a pink or reddish hue when they are heated, the heat-treatment

procedure may have had a supernatural component associated with it, designed to improve the success of hunting particular animals (Justice 2002:31).

Asia

Accounts of heat-treatment in Asia are extremely rare, and the only one that even attempts to describe the process comes from E. H. Man's memoirs on the Andaman Islanders of India. In his memoirs, Man describes two instances in which the Andaman Islanders used heat to improve the flaking properties of their stone materials. In the first instance, when an Andaman Islander needed to make a new whetstone, Man writes that:

> A block of soft sandstone is chosen, which, if too large, is placed on a fire until it breaks; the piece best adapted for the purpose is then taken and shaped according to fancy, by the aid of one of the hard smooth stone hammers; after being used a short time the edges wear down, and it answers as a hone for several months (Man 1883:380).

When an Andaman Islander needed to produce some flakes in order to make a tool, Man writes that:

> Two pieces of white quartz are needed… one of the pieces is first heated and afterwards allowed to cool, it is then held firmly and struck at right angles with the other stone: by this means is obtained in a few moments a number of fragments suitable for the purposes above mentioned. A certain knack is apparently necessary in order to produce the kinds of chips which are at the time required: the smallest flakes are obtained in the same manner and never by pressure (Man 1883:380).

Man's account is particularly interesting, because he explicitly states that the Andaman Islanders never used pressure flaking when making their stone tools. As was mentioned at the beginning of this chapter, there appears to be a relationship between heat-treatment and pressure flaking; so to find a place where heat-treatment is used, but pressure flaking is not is very interesting.

Australia

While there is considerable debate about when heat-treatment first began to be used in Australia, there are two reports from Western and Central Australia that indicate that, at the very least, modern Aboriginal toolmakers were aware of the advantages of heat-treatment when producing stone tools. Kim Akerman (1979) describes two accounts of heat-treatment that were passed on by informants from two different Aboriginal groups (the Kidja and Djaru). Radio, who was an elderly Kidja man, described in detail how stones were heated:

> The white chert was obtained from quarry sites and was percussion-dressed into large biface blanks, large primary flakes and chunks of the material were also collected for heating. A pit about one metre long, 60 cm broad and 50-60 cm deep was excavated in sandy soil. A large fire was then built in the pit and on three sides of the ground about it. When this had burnt down the coals were removed from the pit and a layer of unheated sand was placed on the bottom. The cores and blanks were placed on this and covered with more sand.
>
> The coals and hot sand were then shoveled back into the pit until it was full; excess coals were banked around the edges and the whole was covered with dry earth. Emphasis was placed on the fact that no air should get into the oven (Akerman 1979:146-147).

Radio goes on to describe the process as taking three days. On the first day, the pit was heated and the stones placed within it. For the next 36-48 hours, the stones were subjected to a period of prolonged heating and a slow, gradual cooling, finally being removed once the oven was cold to the touch. As Radio describes it, the flakes "are just like bottle (glass), you can take a wire (a pressure flaking tool) to it straight away" (Akerman 1979:147). The cores and blocks were also said to be easier to split and flake.

A Djaru man, by the name of John Lanigan provided a similar description of the heat-treatment process, but he emphasized that the hot earth of the oven was placed over the cool earth in which the blanks were placed, before the coals were replaced (Akerman 1979:149). Another Djaru elder, Charlie Wilbilla, verified Lanigan's account and also offered Akerman several flakes of a white chert that had been treated as proof of these claims.

Norman Tindale (1985) records an account of Kidja elders who placed pieces of *tjamuru* (a white, opaline quartz) under their hearths for heat-treatment. Some of the cores were placed into the hearths as is, while others were knapped and only the flakes were placed into the hearth. According to the Kidja elders, "cooking" the stone made it "lighter" and easier to work; but sometimes the stone would become "too light" or "too dry" (overheated), in which case the stone was no longer suitable for working (Tindale 1985:5).

Unconventional Ethnographic Accounts

While the techniques described above do more or less conform to the "conventional" models of heat-treatment, it is important to keep in mind that not everything that has been written down is necessarily true. The ethnographic literature is also sprinkled with descriptions of some rather unorthodox methods of heat-treatment that are worth mentioning. One of the most interesting ones is the use of water as a tool for knapping stone (water-chipping). With water-chipping, a nearly complete stone tool is heated in a fire and drops of water are dripped onto the edge of the tool. The rapid cooling of the tool caused by the

application of water is believed to cause small, "potlid" style flakes to detach from the tool, (allegedly) giving it a sharp edge.

The belief that water-chipping was a viable method of tool manufacture was widely accepted during the 19th and early 20th centuries by the public; and espoused by so-called "experts" who claimed to know something about "primitive man" and his technical knowledge. People who claim to have witnessed this technique being performed have written several "first-hand" accounts of water-chipping.

Fur trader Ed Nagle, who was working in the area around Great Bear Lake, NWT, wrote a letter to a gentleman from Cowley, Alberta, by the name of Frederick Godsal. In this letter he describes the production of stone arrowheads used by the Athapascan groups in the area:

> Flint is not chipped with stone or with metal, but with water. When an Indian wished to make an arrow head he held a piece of flint in the fire until it was very hot, then allowed a drop of water to from the end of a stick upon the spot to be chipped off. The sudden cooling made the flint chip off immediately; some cunning is of course necessary in the shaping of the arrow head, but the old Indian method is the best that has been found (Nagle 1914:140).

In the same area, F. W. Godsal recorded that:

> Archie Gow, who has just spent two years in the extreme north, spending one winter at the mouth of the Mackenzie River… told me that he had seen (arrowheads) made, and I, of course asked him about it. The flint is heated and then cold water dropped on with a bird's feather (Eames 1915:65).

Mabel Miller (1897) reported the use of water chipping by the Maidu of California, who would heat the raw material in the fire until it had reached a certain, desirable temperature. Once this temperature was achieved, the material was struck with a spike-like hammerstone that had been dipped in cold water.

The drop of water, coming into contact with the hot stone, combined with the stroke of the hammerstone, caused the material to flake in the desired manner.

Wilfred Powell (1883) recorded another version of this technique during his time among the islanders of New Britain. When the men needed to make a club, they would first take a piece of granite and heat it until it was red hot. The granite is then removed from the fire; and drops of water are dripped onto the same spot over and over, causing flakes to fly off. This process is repeated until a hole has been formed in the centre of the stone. It is then hafted onto a wooden handle and held in place with resin from the breadfruit tree.

In Australia, Robert Turner recorded this unique method of knapping by a group of Aborigines:

> My informant told me that he had seen the natives making spear-heads by pressure flaking many times, but this method was new to him. He said that the native first flaked off a piece of stone, which he placed in cold water. After a time it was put on another stone, and then, taking a lump of spinifex-grass gum and a fire-stick, the Aboriginal let a drop of the gum fall on to the flake, which caused small splinters to fly off. It was then placed back in the water to cool again, before the same treatment was applied once more. The process was repeated time after time until the flake was reduced to the desired shape (Turner 1934:228).

Thomas Fraser, who had spent time with the Seri Indians of northwest Mexico, records a more detailed account of how water-chipping might have been used. In the 1919 *Handbook of Aboriginal American Antiquities*, Smithsonian archaeologist W. H. Holmes provides us with Thomas Fraser's description of a water-chipping event:

> I watched this particular artist for several hours until he had completed an arrowhead… Putting three small pieces of flint among the coals of a hot fire on the ground, he places a small stone basin containing a little water within his reach; beside this are several straws or reeds of different sizes, together with a few small

stems of native grass. Presently the first piece of flint placed in the fire is dragged out upon a flat stone by means of a hooked stick, and as the end of the larger straw or reed is dipped in the basin, it will be observed that a drop of water clings thereto; this is lightly touched to the thoroughly heated stone and a small chip flies from the surface. This performance is repeated with astonishing rapidity, until the stone refuses to respond to the touch, when it is returned to the fire and the second stone is treated in the same way, the chips always flying fast and furious. As the work progresses and the stones are reduced in size and begin to assume the required shape, smaller straws are used, until the final pointing, sharpening, and smoothing is done with the small grasses that pick up a very tiny drop of water and safely remove a very diminutive chip (Holmes 1919:365).

In spite of the widespread acceptance of the use of water as a flaking tool, there were some people who remained skeptical of this technique. W. H. Holmes was one of the first people to recognize that there might be a problem with this technique. When commenting on Fraser's water-chipping event, Holmes could not understand why several hours would have been spent toiling to produce an arrowhead using this method, when a person could fashion one in only a few minutes using a hammerstone and bone flaker (Holmes 1919:365).

In an attempt to determine if water-chipping was a legitimate tool for removing flakes, H. Holmes Ellis ran a series of experiments to try and determine its efficacy. The results were discouraging. The first thing that Ellis noted was that when flints are exposed to an open flame, for even a short period of time, they shatter into angular fragments that were impossible to use to any practical advantage in making a stone tool (Ellis 1965:43). When cold water was applied to the now heated angular fragments, there was very little reaction. More often than not, the heat of the stone would simply cause the water to boil and evaporate; and when small flakes were produced by this method, their direction and position could not be controlled (Ellis 1965:43).

Despite Ellis' less than encouraging findings, the sheer number of ethnographic accounts that describe water-chipping would seem to suggest that water was sometimes used in the production of stone tools. Unfortunately, later attempts to replicate this phenomenon have also met with limited success. M. D. Mandeville's own experiments with chert found that when it is subject to direct heat, the material becomes so permeated with hairline cracks that it becomes useless (Mandeville 1973:179). Her attempts at removing flakes using water were even less successful than Ellis'. She was unable to remove a single flake by dripping cold water onto a hot piece of flint (Mandeville 1973:179). Barbara Purdy and H. K. Brooks also conducted a similar study; and concluded that when chert is heated in a direct fire, the material becomes too heavily crazed to be of any use to the knapper (Purdy and Brooks 1971:324).

Another possibility to consider is that the people who were recording these stories were either misinterpreting what was going on, or what had been told to them. Both Ed Nagle and F. W. Godsal did not actually witness the events that they described, though the latter claimed to "know" that flint could be chipped by water after it had been heated (Eames 1915:68). R. J. Squier believes that Mabel Miller might have misunderstood some of the activities that related to stone tool manufacture. He says:

> Perhaps the greatest benefit… was to help in cooling off the hot flake of flint so that it might be more comfortably handled! There are some grounds for doubt that Miller actually observed such a procedure. It should be noted that similar explanations of Indian flint chipping were current at the time Miller wrote her account; perhaps she observed an Indian washing adhering material off his stone flaker preparatory to its actual use and connected this in her mind to the use of cold water in chipping flint (Squier 1953:26).

The use of fire to assist in the quarrying of desirable raw materials is another technique that has been documented in the archaeological and ethnographic record. Fire as a quarrying aid has been documented for the prehistoric Old Copper Indians along the Upper Great Lakes. They would build fires over veins of copper and then douse them with water, causing the copper to break off the rock matrix (Quimby 1960:52). At novaculite quarries in Arkansas, there is some archaeological evidence to suggest that fire may have been used to assist in the quarrying process. Certain faces of the novaculite, that have been protected from weathering by overhanging ledges, display blackened patches that may be the result of ancient fires (Holmes 1919:198). In his 1902 *Archaeological History of Ohio* Gerard Fowke describes how he believes fire was used at a quarry in Flint Ridge:

> Careful observation of this pit and others as well enables us to follow the prehistoric quarryman in his labours. He selected a spot where he thought the superincumbent earth was not heavy enough to render the task of removing it too tedious, but at the same time was ample enough to prevent injury to the stone from weathering. He then sunk a pit, as large as he wished, to the surface of the flint. On this he made a fire; and when the stone was hot he threw water on it, causing it to shatter. Throwing aside the fragments, he repeated the process until he penetrated the underlying limestone to a depth, which allowed him sufficient room to work conveniently. The top and freshly made face of the flint was thickly plastered with potter's clay, after which fire and water were again utilized for clearing away the limestone until a cavity formed beneath the flint layer. Thus a projecting ledge would be left, from which the burnt parts were knocked off with heavy stone hammers until the unaltered flint was exposed… (Fowke 1902:622-623).

Ellis (1965) has also expressed reservations about Holmes' and Fowke's conclusions, since, in his opinion, the "uniform presence in all of the sites of fissures and exposures which made available a large supply of raw material" and

the "large wastage of material necessary with the fire treatment" made the use of fire as a quarrying aid unnecessary/inefficient. While the archaeological data to back the claims of Holmes and Fowke is still not definitive, they do provide us with another way of trying to explain the seeming inaccuracy of some of the ethnographic accounts of water-chipping.

Summary

Evidence for heat-treatment has been found on every continent and its use extended well into historic times. The oldest known use of heat-treatment is currently dated to approximately 164,000 B.P at Pinnacle Point cave site in South Africa. In Australia, the technique can be tentatively dated to 32,000 B.P, while in Europe its use is associated with Solutrean technology dated to ~20,000 B.P. Heat-treatment in North America has been documented to be in use in the Paleoindian era.

Archaeological and ethnographic evidence suggests that the most likely method of heat-treating stone would have involved placing the desired stones into a pit, covering them with earth or some other insulating material and lighting a fire over top. The stones were left in the ground for a period of several hours up to several days in order to cool. Once they had sufficiently cooled, the stones could then be removed and fashioned into tools.

Within the ethnographic record in Africa, there is an interesting look at the role that gender may play in stone tool production. While it would be premature to suggest that the Xauta are indicative of all prehistoric civilizations, the fact that

heat-treatment is a gendered task for them does raise some interesting questions about the role of gender in the production of stone tools.

The ethnographic record also contains several accounts that document the use of water in flaking stone tools. Modern experiments have been unable to replicate the results described in these accounts, so their veracity can be considered suspect. It is possible that the people who recorded these events simply misunderstood what they had been told, or simply mistook one type of event (using fire to quarry raw materials) for another (making tools).

Chapter 3

Material Changes as a Result of Heat-Treatment

In order to better understand the implications of heat-treatment on lithic production, we must first be able to recognize when it has occurred. Several characteristics have been identified that seem to be associated with the heat-treatment process. While none of these characteristics is indicative of heat-treatment on their own, their collective appearance on a lithic may be used as a reliable indicator that heat-treatment has taken place.

Generally speaking, stones that have a granular texture are less suitable for tool production than stones that have a more homogenous appearance. This feature is why obsidian is considered to be a desirable material for making tools. Its homogenous, cryptocrystalline nature results in flakes that have a well-developed conchoidal fracture, and produce a very sharp cutting edge (Crabtree 1972:5, 79). In contrast, a material like quartz, which has a macrocrystalline structure, may be a less desirable (although still usable) material for making certain kinds of tools, as this type of structure tends to flake only when force is applied in a certain direction. This feature limits the type and size of flakes that can be detached from the parent material.

Faced with having to choose between working with an inferior material, or expending time and energy securing higher quality materials, prehistoric flintknappers may have developed heat-treatment as a way to make more efficient use of locally available raw materials by turning them into something that behaves

like the more desirable (but perhaps out of the way) materials. These changes are the result of a change in the material's fracture force conductivity, which allows for greater control when removing flakes.

Attempts to quantify this change began during the 1960s, with Crabtree and Butler's 1964 paper *Notes on Experiment in Flintknapping: 1, Heat-Treatment of Silica Materials*, considered to be the seminal work in this area of study. Other early experimental investigations into the effects of heat-treatment on lithic materials are those by Barbara Purdy (1974) and her collaboration with H. K. Brooks (1971), as well as Margaret Mandeville (1973), who attempted to determine an objective method for identifying heat-treated lithics in archaeological assemblages. In addition to these works, experimental studies were also conducted on lithics from specific sources. This research has created a valuable database that describes the effects of heat-treatment for specific material types. Studies have been carried out on Onondaga Chert (Cowan: 1987), Central Pennsylvania Jasper (Schindler, et al 1982), Arkansas Novaculite (Flenniken and Garrison 1975), Knife River Flint (Ahler 1983), Biggs Junction Chert (Towner 1985), Ohio Flint Ridge Flint (Pickenpaugh 1978), Florida cherts (Purdy and Brooks 1971), Chouteau, Burlington, and Jefferson City cherts (Ray 1982), as well as English (Griffiths et al. 1987), Scandinavian (Olausson 1983), and Australian (Akerman 1979, Flenniken and White 1983) cherts.

As a result of these studies, there is now a great deal of data available on the effects of heat-treatment on lithic materials that allows us to make some preliminary statements about what happens when they are heat treated. These

generalizations can be broken down into two broad categories: macroscopic and microscopic.

Macroscopic Changes

When examining lithics for macroscopic changes, there are four categories in which most archaeologists are interested:

1) Colour: Materials that have been heat-treated will often undergo some kind of colour change. The most common colour change that is observed is a reddening of the material; however, other colour changes have been recorded as well (see Table 5.1)

2) Lustre: Materials that have been heat-treated acquire a more glossy, glasslike appearance. This change is seen in the increased reflectivity of newly flaked surfaces.

3) Texture: Heat-treated materials often look smoother and less granular. Their surfaces are often described as having a "waxy" or "greasy" feel to them.

4) Rippling: Heat treated materials may exhibit an increase in the instances of rippling on detached flakes.

Colour Change

A change in colour is one of the most obvious indicators that a particular material may have been heat-treated. As mentioned earlier, the most common colour change that is associated with heat-treatment is a reddening of the material, believed to be the result of the oxidation of iron impurities (Mandeville 1973:191, Purdy and Brooks 1971:323). Barbara Purdy and H.K. Brooks (1971:323) state

that an iron content of approximately 2,500 ppm (parts per million) was the minimum amount necessary to initiate a colour change in Florida cherts; higher concentrations of iron led to a darker, more obvious reddening.

Changes in the intensity of colour are also known to occur. Thermally induced darkening has been observed by Ahler for Knife River Flint (1983:3), while a "bleaching" or "smoked" appearance has been described by Jack H. Ray for Chouteau, Burlington, and Jefferson City cherts (Ray 1982:74). One quality of note about changes in colour is that they often occur at temperatures that are lower than those required to improve the flaking properties of raw material (Collins and Fenwick 1974:36; Flenniken and White 1983:43; Mandeville 1973:198; Purdy and Brooks 1971:323; Rick and Chappell 1983:71). The colour change can also be prevented altogether if the material was heated in a reducing atmosphere (an atmosphere in which oxidation is prevented by the removal of oxygen) (Rowlett, et al 1974:42). These observations mean that, while colour may be a good starting point when one is trying to determine whether or not a particular artifact has been heat-treated, it should not be used as the sole indicator.

At temperatures over 600°C, many siliceous materials acquire a grey or white discoloration, crazing and cracking begin to develop, and the material begins to have a "sugary" texture to it (Ahler 1983: 3; Eugene Gryba, personal communication 2010). These features are likely the result of the release of carbon dioxide that is caused by the thermal decomposition of calcite present in the material (Griffiths, et al 1987:51). Materials that have been heated to this

temperature become extremely brittle, crushing rather than flaking. This property makes them unsuitable for producing stone tools.

While colour change is one of the most obvious indicators of heat-treatment, the natural colour variability found in many material types, as well as the possibility that the material may have subject to unintentional thermal alteration from non-anthropogenic sources, makes it an unreliable criterion for identifying heat-treatment in archaeological collections. Despite this caveat, the usefulness of colour as a diagnostic trait can be enhanced if one or more of the following characteristics are also present.

Lustre

Lustre is defined as "the appearance of a material in reflected light" (Berry, et al 1983:140). The impression of lustre is produced by the amount and nature of light reflected from the surface of a given material. It is dependent on the surface characteristics of the material and the quantity of light being reflected. A smooth surface will reflect more light than an uneven surface, even if both are from the same material.

James Healy (1966:6) has suggested that lustre can be used as an indication of the potential workability of a particular material, with lustrous materials flaking in a manner that is glasslike. The high reflectivity that is associated with lustrous materials indicates that the material is lacking a definite crystalline structure (Boras 1991:14). This lack of structure facilitates the propagation of force through the material when it is struck, and produces conchoidal fractures. Materials that have a low lustre are often made up of large

grains or have heterogeneous structure, and are often a poorer choice for manufacturing stone tools. The change in lustre that is associated with heat-treatment may not be readily apparent, but it can be detected on the flake scars of the parent core and on the ventral surface of flakes that have been heat-treated (Mourre et al 2010:660).

The analysis of lustre on the flake scars of debitage and formed tools has been used by Michael Collins (1973) to identify the use of heat-treatment on Solutrean artifacts from France; and by Vincent Mourre and colleagues (2010) to show that the intentional heat-treatment of stone tools at Blombos Cave, South Africa may extend into the Middle Stone Age. While remnant low lustre areas may be removed during the production of a tool (e.g., a projectile point), Rick and Chappell (1983:71) suggest that it should be possible to identify intentional heat-treatment, if the complete manufacturing sequence is present in an assemblage. This technique has the advantage of identifying which flakes were removed before heat-treatment and which ones were removed after heat-treatment. This approach allows us to determine at what stage in the tool reduction sequence heat-treatment was used (Rick and Chappell 1983:72). Debra Schindler and her colleagues (1982:537) performed this type of analysis on the Houserville (36 Ce65) lithic workshop located in Pennsylvania. She observed that 84% of crude bifacial thinning flakes, 80% of intermediate bifacial thinning flakes and 42% of primary reduction flakes showed evidence of heat-treatment. This analysis suggests that heat-treatment was an integral part of the biface manufacturing process; although it may have been employed even earlier in the reduction

sequence if the knapper felt that they were working with a nodule that was of particularly poor quality.

While lustre does seem to be an excellent indicator for determining whether or not an artifact has been heat treated, there are other factors, both natural and anthropogenic, that can increase the lustre of an artifact. Surficial weathering and patination can affect the appearance of lithic materials by obscuring certain physical characteristics (Brink and Dawe 1989:189). Wind abrasion can result in the formation of a waxy, glossy surface patina (Collins and Fenwick 1974:140; Sollberger and Hester 1971:182). "Tool polish," a kind of gloss that is formed as a result of the friction generated when a stone tool is used repeatedly, can also affect the appearance of lithics. Neolithic sickle blades developed this characteristic polish as a result of the friction of the blade against the silicates in plant stems (Odell 2003:176). Manitoba archaeologist Gary Wowchuk (personal cmmunication 2011) has done some experimental heat-treatment on taconite from the Thunder Bay region to determine if heating the material has any effects in its physical properties. He found that the material actually loses its lustre when heat-treated. Silica present in the soil can accumulate on buried artifacts, artificially enhancing their lustre (Rick 1978:57). It is also possible for gloss to develop as the result of the migration of water-borne silica from the interior of the material to the surface (Shepherd 1972:121).

Texture

Like lustre changes, a change in the texture of a particular lithic type is most obvious in finer-grained materials and becomes harder to detect as the raw

material becomes coarser (Mandeville 1973:191; Sollberger and Hester 1971:182). Fine-grained materials are said to develop a "waxy", or "greasy" texture after being heated, although what exactly these terms mean is at the discretion of the author. On its own a change in texture should not be considered to be a reliable indicator of heat-treatment, since how an object "feels" is an incredibly subjective measurement. In order to maximize the efficacy of this criterion for determining whether heat-treatment has occurred, any archaeological specimens should be compared against materials that have been heat treated in a controlled environment.

Rippling

"Ripples" that appear on flakes scars and on the ventral surface of the resulting flakes are an expression of the compressive forces that caused the flake to be removed from its parent core. The increased visibility of ripples as a result of heat-treatment is likely due to the tendency of heated treated materials to flake along the line of force, producing a more defined conchoidal fracture (Boras 1991:17). While this characteristic has been documented for certain cherts (e.g., Ray 1982:71), it should be noted that some cherts, such as SRC have a high degree of intra-sample variability and may not necessarily have a conchoidal fracture pattern. This possibility makes rippling unreliable for use as an indicator that heat-treatment has occurred. Much as with lustre, in order for the appearance (or lack thereof) of ripples to be used to determine when a particular lithic has been heat-treated, a collection of heated and unheated lithic samples must be used as a point of comparison.

Summary of Macroscopic Changes

Several criteria have been identified that can serve to differentiate heat-treated materials from untreated materials at the macroscopic level. The four indicators to be aware of are:

1) Changes in colour.

2) Changes in lustre.

3) Texture.

4) Improvement in the visibility of rippling on flake scars and the ventral surfaces of flakes.

Of these four indicators, lustre seems to be the one that is most consistently associated with heat-treatment. The other choices, while useful, may be considered too unreliable or subjective a measure to be used to objectively determine when heat-treatment has occurred; however, if all four of these indicators are present in a given archaeological sample, it can be stated with reasonable confidence that those particular artifacts had been heat-treated.

Microscopic Changes

Despite almost thirty years of research into this topic, there is still no firm consensus on what happens to chert at the microscopic level when it is heated that improves its flaking qualities. So far, four explanations have been put forth to try and explain what happens at the microscopic level when cherts are heated. They are:

1) Recrystallization of silica.

2) Intergranular fusion.

3) Microcrack formation.

4) Fluid migration.

Recrystallization of Silica

Under a scanning electron microscope (SEM), Don Crabtree and B. Robert Butler (1964:2) observed a decrease in the size of the crystals in heated cherts; and postulated that the coarser silica materials had recrystallized into a smaller size, causing the lustre to change from dull to greasy, and increasing the elasticity of the material. Later research by Barbara Purdy and H.K. Brooks (1971:323), and J. W. Rick (1978:39) demonstrated that there is no appreciable decrease in crystal size.

Intergranular Fusion

A similar theory known as intergranular fusion was another early attempt to explain the effects of heat-treatment on siliceous materials. Intergranular fusion is said to occur as a result of impurities (non-siliceous elements present in a material's crystalline matrix) acting as a flux, which melts and produces a thin film that fuses the SiO_2 crystals together (eutectic fusion) (Purdy and Brooks 1971:323). This produces a material that requires less force to flake, since the force of the percussive instrument (hammerstone, billet, etc) is now able to proceed through crystals rather than around them (Purdy and Brooks 1971:324). Margaret Mandeville (1973) recorded a similar observation, although she suggests that the bonding occurred within the crystalline matrix of the material crystals rather than between them as suggested by Purdy and Brooks (1971).

While this early research was an important step in furthering our understanding of how lithics change when they are heated, these studies are not without their flaws. The biggest problem with these early theories is that they do not accurately reflect what is known about how SiO_2 behaves when it is heated. The melting point for SiO_2 is very high (~1,700°C); and while it is possible for this temperature to get as low as 1,000°C as a result of the presence of sodium, potassium, lithium, calcium, or magnesium ions, this temperature still lies outside the range that can be achieved by an ordinary campfire (Griffen 1992:28; Luedtke 1992:104; Mandeville 1973:188).

Microcrack Formation

The microcrack model has been one of the more accepted theories to date, but it does have some problems of its own that have yet to be adequately addressed. According to the microcrack model, heating increases the number of microscopic flaws in the chert and/or distributes them more evenly, causing fractures to occur in an easier and more controlled manner (Luedtke 1992:104). Experiments (e.g., Flenniken and Garrison 1975) seem to suggest that these microflaws are caused by the differential expansion of quartz when it is heated. D. R. Griffiths and his colleagues (1987:48,51) have suggested that water trapped between quartz grains may have a role to play. As the chert is heated past its boiling point and becomes steam, it begins to expand. The resulting hydraulic pressure may cause the formation of microflaws within the material. It has also been proposed that (at least for Bald Eagle Jasper) the oxidation of goethite ($FeO \cdot OH$) to hematite (Fe_2O_3) during the heat treating process may be responsible

for the formation of microcracks, since hematite is smaller and denser than goethite (Schindler, et al. 1982:529). Further evidence for this phenomenon comes from Weymouth and Mandeville (1975:66), who interpret the broadening X-ray diffraction peaks of heat-treated cherts as indicative of a decrease in the size of crystal grains.

While this model does seem to offer a possible explanation for what is going on, from an engineering perspective there does appear to be a problem with this line of reasoning. When a force is applied to an untreated, cryptocrystalline matrix, it should propagate in a relatively straight line, changing direction only when it encounters a particularly large or dense crystal (John Nychka, personal communication 2011). When that same force is applied to a material that has a series of microcracks in it, the force now has to propagate around these microcracks. Any time a force has to change direction, energy is lost and more force is required for the crack to pass completely through the material (John Nychka, personal communication 2011). This property means that a series of microcracks might actually increase the toughness of the material as opposed to reducing it. This problem seems to have been confirmed by D. R. Griffiths and colleagues (1987:51), who observed that the microfracturing of chert grains is a consequence of overheating and makes the material more prone to crushing than flaking.

Fluid Migration

While the idea that impurities in the chert melt, fusing the SiO_2 crystals together, is an unlikely scenario, D. R. Griffiths and colleagues have proposed

that a type of structural recrystallization does occur as structural water in the chert is heated up to 300°C. As the temperature rises up to 300°C, an increasing portion of this trapped water is forced into microfluid inclusions instead of being lost (Griffiths, et al. 1987:51). This feature causes the shiny lustre that is characteristic of heat-treated materials (Griffiths, et al. 1987:51). In an experiment conducted with Brandon flint that was heated to ~400°C, the migration of water into fluid inclusions is demonstrated by the appearance of a broad proton resonance feature (Symons 1986:251, 253).

In a typical chert nodule or cobble, the structure is composed of a framework of lepispheres (spherical quartz aggregates measuring 5-20 μm in diameter) and silicified skeletal fragments in an interstitial cement of structurally disordered microcrystalline chalcedony (Bradley and Clayton 1986). In unheated cherts, the structural chalcedony has a higher water content and is more prone to fracture than the surrounding lepispheres. As a result, fractures tend to propagate through the chalcedony and around the lepispheres, leaving hemispherical projections in the fracture surface (Griffiths, et al 1987:49, 51). When the chert is heated, the interstitial chalcedony becomes annealed as structural water migrates into fluid inclusions. The annealed chalcedony is structurally comparable to the lepispheres, allowing fractures to travel easily through both of them. Flaking of the heated material is now less affected by the original structure of the chert, and can be more easily controlled by the knapper.

The idea that the density of certain parts of the microstructure are altered during the heating process has in analogue in ceramic production, in which a

reaction known has "liquid phase sintering" has been observed. Liquid phase sintering is a process of adhesion and densification that occurs when:

> … some constituents of the body (e.g.- fluxes such as feldspar) begin to melt, forming a liquid. As sintering proceeds, more of the solid melts, so that the particles draw closer together and the pores between them get smaller, giving rise to shrinkage, loss of porosity and densification of the body (Rice 1987:94).

Rice (1987:94) also notes that sintering occurs at a lower temperature in fine-grained ceramics, a conclusion which seems to be consistent with the results observed by archaeologists interested in the heating of lithics (e.g., Ahler 1983; Mandeville 1973; Purdy and Brooks 1971).

The major argument against this observation is that much like Crabtree and Butler's (1964) notion that crystal size decreased in heated materials mentioned above, the crystalline structure of SiO_2, or any of the impurities present, does not begin to change in any appreciable manner until temperatures are far hotter than those that can be achieved with an ordinary campfire are reached.

Physical and Mechanical Changes

The final set of criteria that we can look at, when attempting to identify heat-treatment, are the physical and mechanical differences between heated and unheated cherts. The most common physical changes that are observed are:

1) Length of flakes and edge angle:

In John Rick's work on the heat-treatment of cherts, he noticed a correlation between flake size, the edge angle of a stone tool and whether it had been heated or not. With heated chert, Rick (1978:47) found that he could press

off flakes at angles that are nearly parallel to the surface of the material, producing long, thin flakes. When this procedure was attempted with unheated specimens, the fracture would only travel a short distance before stopping and causing a flake to break off and leave a step fracture.

The ability to press off flakes at an almost parallel angle to the tool's edge also results in a much shallower edge angle. Rick's experiments found a mean reduction of 9° in the edge of tools that had been heat-treated. There was not a single instance in which the edge angle of a heated specimen was greater than that of an untreated specimen (Rick 1978:Table 13). By pressing off flakes at a shallow angle, the finished tool becomes much sharper and more suited to certain tasks (such as cutting).

2) A reduction in the weight and thickness of removed flakes:

Mandeville and Flenniken's work with Nehawka chert (1974:147) showed that while there is no appreciable reduction in the length and width of flakes from heated and unheated samples, there is a difference in the thickness and concomitantly, the weight of flakes removed.

3) A reduction in material fracture strength:

The heating of cherts has been shown to reduce the tensile strength of the material by as much as 45%, although the compressive strength of the material can be increased by as much as 40% if the material is allowed to cool slowly (Purdy 1975:135; Olausson and Larsson 1982:278).

4) Reduced incidences of hinge and step fracturing during the manufacturing process:

Michael B. Collins and Jason M. Fenwick (1974); Margaret D. Mandeville and J. Jeffrey Flenniken (1974); J. Jeffrey Flenniken and Ervan G. Garrison (1975); and Ronald H. Towner (1984), have all reported that heat-treatment reduces the frequency of hinge and step fractures in the tool manufacturing process.

5) Higher frequency of lateral snap during the manufacturing process:

Lateral snap (also called perverse fracture) is caused by the application of too much force to the side margins of a biface while thinning it (Hellweg 1984:65). A reduction of the tensile strength of the material may be the cause of this phenomenon. At a workshop site in Marion County, Florida, Barbara Purdy 1975) found hundreds of Florida chert preforms and nearly completed projectile points that had been rejected because of lateral snap. The increased frequency of lateral snap was attributed to the heat-treatment process, which reduced the strength of the material by approximately 45% (Purdy 1975:135).

Flaking Changes

The two main factors that have an effect on the flaking properties of chert are: tensile strength and elasticity. Tensile strength is an important concept, and has already been referred to several times in this thesis. Generally speaking, tensile strength refers to the ability of a material to resist deformation by external forces (Merriman 1965:1002). In terms of lithic analysis, tensile strength can be considered a measure of how much energy is required in order to detach a flake

from a core (Purdy 1974:49). Elasticity is a measure of the ability of a material to return to its original form after a force has been applied to it (Hellweg 1984:107).

As mentioned in previous sections, the application of heat to siliceous materials such as chert decreases its tensile strength, making it easier to flake. This quality has important implications for the kinds of applications towards which heat-treatment can be successfully applied. While heat-treated edges are sharper than their untreated counterparts, they are not as durable (Rick 1978:54, Sollberger and Hester 1971:181). This feature makes them a less than ideal choice for heavy stress tasks such as hide working (Rick 1978:54).

This reduction in tensile strength is often equated with an increase in the brittleness of the material (Olausson and Larsson 1982:283). An experiment performed by D. R. Griffiths and colleagues (1987:44-45) found that brittleness is an undesirable trait that causes the material to crumble into angular fragments when force is applied; however, there are other factors at work during heat-treatment than just reduced tensile strength. Jack H. Ray (1982:80) shows that while tensile strength is reduced as a result of heat-treatment, there is an *increase* in the chert's material elasticity, suggesting that the relative brittleness of a material is not the primary determinant in the changes that occur in heat treated cherts. Ray hypothesized that the increase in material elasticity gives the flake a certain amount of "bend", that allows for more precise control when pressure flaking (Ray 1982:80).

Weight Loss

Most cherts lose some weight when they are heated. This weight loss typically falls between one and three percent, and is likely due to the evaporation of water as its boiling point is reached and exceeded (Inizian et al 1976:6, 18; Mandeville and Flenniken 1974:147; Purdy 1974:39; Rick 1978:33; Schindler et al. 1982:529). Walter Shepherd (1972:205) recorded weight loss in excess of four percent, but these flints had been completely dehydrated and would not have been suitable for knapping. Finer grained materials appear to alter faster and lose more weight than coarser grained materials (Purdy 1974:44; Behm and Faulkner 1974:275). This weight loss is closely related to the temperature at which the materials are being heated, with higher temperatures resulting in a greater loss of weight (Purdy 1974:Table 5).

In chert, water is found in three forms (Griffiths et al 1987:48):

1) As hydroxyl groups on grain and subgrain boundaries.

2) As molecular water in microscopic fluid inclusions.

3) Adsorbed on the surface.

At ~100°C the adsorbed water is driven off as steam, but the structurally bound water is does not begin to disappear until the temperature reaches ~250°C-450°C (Griffiths, et al 1987:51; Mandeville 1973:197; Shepherd 1972:205). At these higher temperatures, the loss of water from the microscopic fluid inclusions is often accompanied by desirable changes in the flaking properties of the material (Griffiths, et al 1987:51). Once the temperature exceeds 450°C, the chert becomes dehydrated, as all the chemically bound water has been lost (Shepherd

1972:205). Once the temperature reaches between 600°C and 700°C, carbon dioxide (CO_2) is released as a result of the thermal decomposition of relic chalk (calcite) within the chert (Griffiths, et al 1987:51; Mandeville 1973:197).

Undesirable Changes

When chert is heated, different parts of it can expand at different rates than the rest of the material. These thermal stresses can cause irreversible and detrimental changes in the material, and are one of the most common reasons that a heat-treated material may be rejected. When heated, there are two kinds of thermal stress that chert is exposed to: the first one is the normal expansion and contraction of the material associated with normal/gradual temperature changes; the second is the result of sudden shifts in temperature that cause internal stresses that the material is unable to cope with (thermal shock) (Rice1987:105).

The most common effects of excessive thermal stress are: decrepitation (severe cracking and disintegration) (Purdy 1974), crazing (minute cracks that do not pass all the way through the material), potlidding (the removal of lenticular flakes, leaving a concave scar on the surface of the rock) (Andrefsky 2005), and calcination (the reduction of the material to a white, extremely friable state). J.W. Rick (1978:Table 7) and Margaret D. Mandeville (1972:189) have both observed that coarser gained cherts are more likely to resist thermal shock than finer grained cherts.

The damage caused by the over/rapid heating of chert appears to be related to the dehydration of the material. It has been hypothesized that the increased tendency for overheated cherts to crush rather than flake may be the result of

microfractures that have formed within the material as a result of hydraulic pressure (Griffiths, et al. 1987:51). J. W. Rick (1978:27) made a similar observation in his work with Burlington chert, hypothesizing that the increased decrepitation noticed in its fine grained versions is likely the result of an increased build up of water pressure inside the material, since vaporization would be inhibited by the denser crystalline structure.

A related idea is that the lack of microscopic voids in denser materials allows no outlet for differential expansion to take place, causing the material to break apart. Cherts that are more porous have a greater resistance to thermal stress, since the pores allow for the expansion of material crystals (Rice 1987:367). This observation seems to suggest that porous materials that readily absorb water would be most amenable to heat-treatment. The relative porosity of a chert is one quality that would have been easy for prehistoric peoples to determine, as L.W. Patterson and J. B. Sollberger (1979:50) have observed that some porous rocks will change colour when they absorb water.

Chapter 4

Swan River Chert and Its Distribution

This chapter provides a definition for Swan River Chert (SRC); and describes some of its unique features that allow it to be identified, both in the field and in the lab. Since the act of heat-treatment carries with it certain risks (e.g., thermal shock), it is worth looking at why people chose to make use of this technique and under what circumstances it would have occurred.

Defining Chert

Before entering into a discussion on what SRC is, it may be helpful to first provide a definition of what a chert is, indicate some of its common features, and show how it is different from other types of lithics that we find in the archaeological record. This is an important distinction to make, because the meaning of certain terms can vary depending on whether you are speaking with an archaeologist or a geologist. Generally speaking, chert is the term for all sedimentary rocks composed primarily of microcrystalline quartz, including flint, chalcedony, agate, jasper, hornstone, novaculite, and several types of semiprecious stones (Luedtke 1992:5). Historically, there has been some confusion regarding the use of the words 'chert' and 'flint'. In the ethnographic record these words are used almost interchangeably, with many ethnographers and historians referring to the knapping of 'flint' in areas where this material is not known to exist (e.g., Lehmann 1985). Among archaeologists, some consider chert to be a variety of flint; while other archaeologists contend that flint and chert

are two different materials (Luedtke 1992:5). The division in their usage seems to be geographic, with most American geologists considering flint to be a type of chert and British geologists contending that flint is a completely different material (Luedtke 1992:6). The distinction between chert and flint may also be based on the taphonomic processes that create them. Flint typically forms as nodules in chalk beds, while cherts typically form in sedimentary layers/contexts. For the purposes of this thesis, whenever the word chert is used, it is being used in the same manner that American geologists would use it.

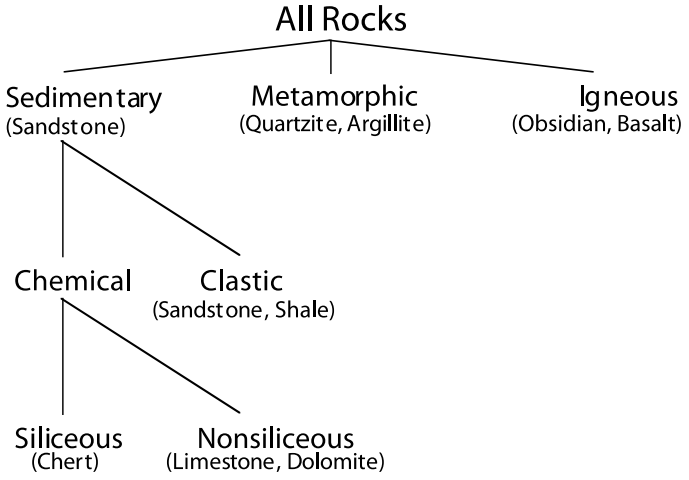

Figure 4.1: Diagram of chert in relation to other rocks (adapted from Luedtke 1992:9).

The makeup of chert is primarily quartz (SiO_2), with some highly variable impurities such as iron oxides, clay, and carbonate minerals (Campling 1980:291; Sheperd 1972:32). Quartz belongs to a family of minerals known as silicates, which includes all minerals with the chemical composition SiO_2. Despite having a similar chemical composition, the crystalline structure of these minerals can differ greatly. Temperature and pressure greatly influence the type of silica mineral that forms. Only one of the minerals, α-quartz, is completely stable under surface temperatures and pressures (Griffen 1992:Fig 1-1). The other forms

(β-quartz, tridymite, cristobalite, coesite, and stishovite) all require high temperatures and/or pressures to form; and will eventually turn into α-quartz when exposed to surface temperatures and pressures (Griffen 1992:21). Unless otherwise stated, the word quartz is used here to refer specifically to α-quartz, since it is the only one that is relevant to the topic being discussed.

When looking at the structure of chert, another term that will frequently come into use is 'chalcedony'. In archaeology, the term is used rather broadly to refer to any kind of translucent chert. In petrology (the study of the composition of rocks) 'chalcedony' is used to refer to a fibrous form of quartz (Blatt 1982:386). While there is room for some overlap between these two features (most cherts that are comprised of chalcedony are indeed translucent), they are not congruent. An example is Knife River Flint, which is translucent, but is made up of granular as opposed to fibrous quartz (Clayton, et al. 1970:287). For the purposes of this thesis, the use of 'chalcedony' will follow the petrographer's definition and refer to fibrous quartz as opposed to granular quartz.

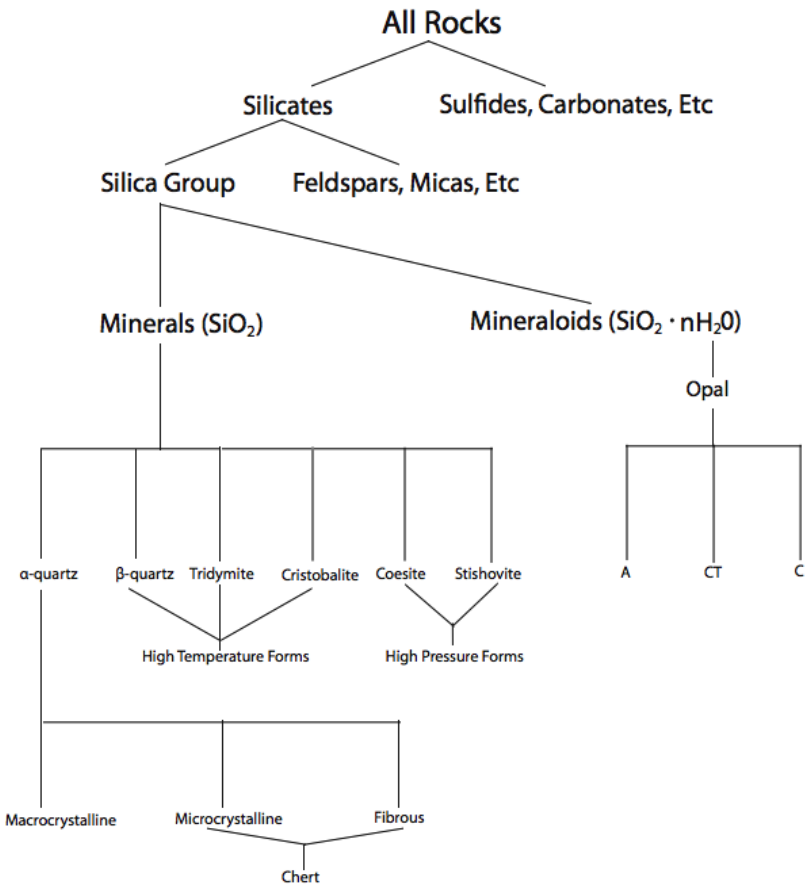

Figure 4.2: Relationship between the silicate minerals (adapted from Luedtke 1992:9).

'Source' is another term that will be used rather frequently. Often, this term refers to the primary source of a particular material type, such as a quarry. Chert can also be recovered from secondary sources (locations where materials have been transported by natural means), such as streambeds, beaches, or glacial deposits. Although a bedrock source for SRC is known, most of the SRC found in an archaeological context comes from secondary deposits that are the result of glacial activity (Eugene Gryba, personal communication 2010).

Cherts may be formed by the precipitation of silica from solution in marine environments, or by silica replacement of minerals in limestone and other rocks (Campling 1980:291). Most cherts exhibit conchoidal fracture (the shape of

the fracture is controlled by the stresses applied to the material and not by some preferred orientation of the material), which makes them ideal for the production of stone tools.

What is Swan River Chert?

Swan River Chert gets its name from the Swan River Valley in Manitoba, where it is abundant in archaeological sites as well as in primary and secondary deposits. SRC is typically found as cobbles that range in size from 64 mm to 256 mm (Leonoff 1970:29), although the author has found cobbles up to 650 mm in size at the Mafeking quarry. The concentration of SRC is highest in southwestern Manitoba (Low 1996:165); however, it has been found in secondary deposits as far west as Lethbridge, Alberta; as far north as Glacial Lake McConnell (north of Fort McMurray); and south into areas of North Dakota, Minnesota, and Montana (Grasby et al 2002:276). The presence of SRC in these secondary deposits seems to be closely related to the distribution of glacial deposits from Wisconsinian glacial activity (Low 1995, 1996), although the presence of SRC at archaeological sites in the Rocky Mountain Foothills may be the result of having been transported there by prehistoric peoples moving on and off the Plains (Gryba 1983:46).

Photo 4.1: Large SRC cobble from the Mafeking quarry, Manitoba.

Photo 4.2: Second example of a large SRC cobble from the Mafeking quarry, Manitoba.

Identification Techniques

Macroscopic

The macroscopic texture of SRC is typically rather vuggy (small cavities, often filled with fine crystals), with many small cracks present. The density of vugs can vary widely between cobbles of SRC found at a particular location, and some cobbles are definitely more homogenous in appearance than others. The vugs are typically lined with small (< 1mm) quartz crystals (Grasby, et al 2002:275). Owing to the structural variability found between cobbles of SRC, it should come as no surprise that it exhibits a wide range of fracture patterns. Generally speaking, SRC exhibits conchoidal to sub-conchoidal fracture patterns; however, N. R. Campling has noted that certain varieties of SRC (typically the darker coloured varieties) tend to have blockier fracture patterns, although this distinction was not pursued with any scientific rigour (Campling 1980:294).

The surface of SRC cobbles is typically a discoloured white, grey, or brown. The interior is highly variable in colour. Whites, beiges, greys, pinks, reds, and oranges have all been observed in freshly cracked (and untreated) specimens. The lustre of untreated specimens is typically dull, with a slight gloss present on some samples. Some specimens of SRC have also been found to contain small fossils and corals of Silurian/Ordovician origin that may help in identifying the material (Low 1996:168). When SRC is heated, its surface becomes glossy, and has a waxy feel to it. The colour of the material also changes, sometimes quite significantly. Red is the most common colour associated with heated SRC; however, other colours have been observed (see

chapter 5 for some of the other colours observed as a result of the heat-treatment process).

This wide variability has also led to some problems in the identification of SRC in archaeological contexts, based on macroscopic features. For example, SRC is often identified simply as a generic white or red chert (Low 1996:167). In the southern limits of its range, SRC has also been identified as a "porous quartzite" (Low 1996:167). This designation is incorrect, as SRC is not a quartzite at all, but a distinctly identifiable chert.

Microscopic

Examination of thin sections of SRC by N.R. Campling (1980) and Stephen Grasby and colleagues (2002) reveal a complex microscopic texture that is characterized by:

1) Granoblastic subhedral to euhedral quartz, often in radial aggregates.
2) Cryptocrystalline chalcedony forming spherical aggregates and filling small vugs.
3) Massive anhedral cryptocrystalline quartz forming the matrix.

Until quite recently, the bedrock source for SRC was unknown, and it was suggested that the material may have come from a Paleozoic limestone formation that had overlain the Canadian Shield and been transported by Pleistocene glaciers (Campling 1980:292, 299). On the basis of certain fossils that were found in some of the cobbles, it has been proposed that SRC was likely formed during the Silurian or Ordovician ages (~ 488-416 million years ago) (Low 1996:168).

Source Location

Stephen Grasby, Eugene Gryba ,and Ruth Bezys (2002) identified a primary bedrock source for SRC at the Mafeking quarry in west-central Manitoba. The quarry is located along Highway 10, approximately 18 km north of the town of Mafeking; and was originally quarried for high-Ca limestone (Grasby, et al 2006:150). The Mafeking quarry represents a relatively rare exposure of the Point Wilkins Member of the Devonian Souris River Formation in terms of its vertical and lateral extent (Grasby, et al 2002:276-277). The presence of at least twenty-five solution 'chimneys' has been recorded by people surveying the quarry (Fedikow, et al 1996; Bezys et al 1997), and is one of the most interesting features of this area.

As described by Stephen Grasby and colleagues (2006:151), the silica chimneys in Mafeking are unique structures, with no similar features having been found that are not volcanic, or geothermal in origin. In general, these chimneys are conical, upwards-flaring features that vary in size between 10-25 metres in width and at least 10 metres in height (Grasby, et al 2002:277). The chimneys have an outer rind of siderite, one to eight centimetres thick, surrounding a core zone of unconsolidated siliceous silt and green clay (Grasby, et al 2002:277). Nodules of chert have been found in the band between the rind and the core zone, and tend to be aligned with the outer wall of the chimney (Grasby, et al 2002:Fig. 4). How these chimneys were formed is still something of a mystery; however, the microfossils in the chimney's core zone are the same as those in the host rock,

suggesting that they are a dissolution/replacement feature and may be hydrothermal in origin.

A later paper by Stephen Grasby, Ruth Bezys, and Kathleen Londry (2006) goes on to try and clear up some of the mystery surrounding the formation of these silica 'chimneys'. They developed a geochemical model that suggests that the solution chimneys are dissolution/replacement features, which are the result of paleo-brine spring channels flowing through the limestone bedrock. This development caused the carbonates of the host bedrock to become undersaturated, while silica became oversaturated (Grasby, et al: 2006:152). The excess silica would eventually settle out and form into the chert nodules that are found at the quarry today.

Photo 4.3: View of the Mafeking Quarry facing north. Much of the quarry is now flooded, making access to many of the cut faces difficult.

The gravel pits that were examined would have been situated along the edge of Glacial Lake Agassiz, and the SRC found in the numerous gravel pits in

the Swan River area were likely deposited as Glacial Lake Agassiz receded from the Duck Mountain plateau (Eugene Gryba, personal communication 2010). Evidence for this development can still be seen in the exposed walls of these gravel pits, where strand lines are clearly visible. The one exception to this observation is Les Engolt's quarry. While large quantities of SRC were found, no strand lines were noticed in any of the walls; and all the rocks are distributed randomly throughout the matrix. This observation suggests that the SRC at Les Engolt's quarry was likely deposited during a massive wash out event (Eugene Gryba, personal communication 2010).

Photo 4.4: Example of the strand lines found in the gravel pits along the shore of Glacial Lake Agassiz.

Photo 4.5: Distribution of cobbles within the matrix at Les Engolt's Quarry.

Summary

SRC is a unique variety of chert which has a series of macroscopic and microscopic traits that differentiate it from other chert types. One of the most unique features of SRC is the colour change that it may undergo as a result of being heated. This potential colour change can be a quite distinct feature, which makes SRC ideal for testing various hypotheses about heat-treatment. The distribution of SRC across the Plains is likely due to glacial activity. This explanation seems to be confirmed by the presence of SRC within the strand lines of Glacial Lake Agassiz, as well as its distribution across Saskatchewan and southeast Alberta.

Chapter 5

Experimental Methodology

This chapter discusses the types of heat-induced changes seen in Swan River Chert. Included are qualitative measures such colour, lustre, texture, and flakability as well as quantitative changes like weight loss and flake roughness. All the colour descriptions provided were made under fluorescent light in the Institute for Prairie Archaeology, located on the University of Alberta campus. The results of X-ray diffraction (XRD) and UV light analysis are also included in this section.

Objective Criteria for Measuring the Effects of Heat-Treatment

To date, most of the quantitative research in the study of heat-treatment has been based on experimentation with non-archaeological specimens. While the work of researchers like Mandeville (1973), Rick (1978), Purdy and Brooks (1971), and Mercieca and Hiscock (2008) is extremely important and has given us insight into how temperature affects the flaking properties of a variety of siliceous materials, it is not without limitations. As their experiments were destructive in nature, their methods are simply not feasible for studying existing archaeological collections.

In order to develop a non-destructive means of determining whether or not an artifact has been deliberately heat treated, I approached the Materials Engineering department at the University of Alberta campus to see if they had a device capable of meeting my requirements. Dr. John Nychka, a professor in the

Materials Engineering Department, recommended a device called an optical profilometer that is used in the nanofabrication industry to characterize the surface of extremely small and delicate objects, such as microchips. By using this device, Dr. Nychka believed that it should be possible to measure the effects of heat-treatment, since heat treated materials should, in theory, have a much flatter surface than unheated materials. This reasoning is based on the fact that fractures travel further and more predictably in heat-treated materials (Flenniken and Garrison 1975:129).

Reference Samples

Samples of Swan River Chert were collected from Swan River, Manitoba, in the summer of 2010. Six gravel pits (Gravel pits 1-5 and Les Engolt's quarry) were visited, although SRC could only be collected from four of them, as two of them (Gravel pits 1-2) were still active. Samples of SRC were also collected from its bedrock location in the Mafeking quarry, and from a small exposure along the road to gravel pit 1. Eugene Gryba also graciously provided numerous samples of raw and heat-treated samples of Swan River Chert for comparative purposes.

Figure 5.1: Map of sites where SRC was collected.

Sampling and Methodological Procedure

In order to establish a baseline against which archaeological specimens could be compared, the author created his own fire pit and heated some samples

of Swan River Chert based on the ethnographic procedures and previous work by modern scholars discussed in chapters 2 and 3. The fire pit measured 60 cm in diameter, and had a depth of 20 cm. More elaborate heat treating structures have been constructed (e.g., Mandeville & Flenniken 1974); however, it was the goal of the author to create a structure that could have feasibly been constructed using prehistoric technologies. The pit illustrated here is an example of a feature that could have been constructed with simple tools such as digging sticks; it may be representative of the kind of pits constructed by prehistoric groups. To insulate the cobbles from the heat of the fire, the fire pit was filled up with sand.

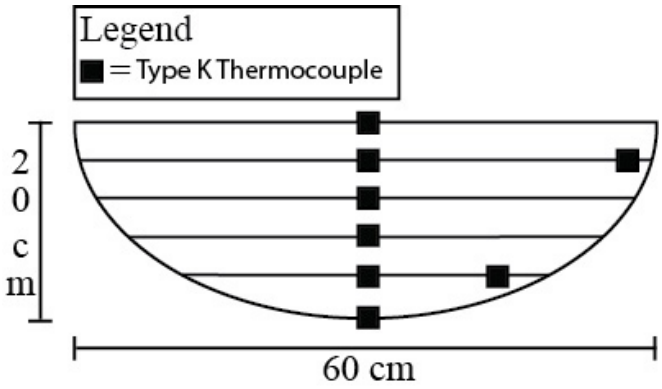

Figure 5.2: Fire pit diagram.

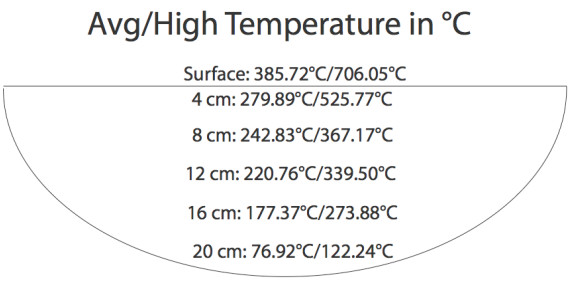

Figure 5.3: The average and maximum temperatures in the fire pit at 4 cm intervals.

Sixteen cobbles were selected for this part of the experiment. Before heating, a portion of each cobble was removed to serve as a control. Cobbles

were named in accordance with their location (M = Mafeking Quarry, L = Les Engolt's Quarry, GP = Gravel Pit), year of recovery, and order in which it was collected. For example, the name M-10-003 would refer to the third cobble collected from the Mafeking quarry in the year 2010. The pieces that were to be heated were first weighed in order to determine how much mass (if any), is lost during the heat-treatment process. Using a Munsell Colour Chart, the colour of each cobble was also recorded so that the relationship between temperature and colour could be determined.

A particular question that the author sought to answer was the optimum depth below a heat source at which heat-treatment successfully occurs. To answer this question, cobbles were placed at 4 cm intervals below the heat source in an effort to determine the optimal depth for heat-treatment. In order to accurately measure the temperature at each of the 4 cm intervals, Dr. Akerman of the University of Alberta's Department of Mechanical Engineering provided a Fourier Daq Pro 5300 data logger with Type K thermocouples. The data logger was selected for its ability to record data from eight thermocouples simultaneously. This feature allowed me to place thermocouples at each of the five centimetre intervals and within the fire itself in order to get a better understanding of how heat is distributed in a fire pit. Type K thermocouples were used, because their operational range (-200°C to +1350°C) falls well within the temperature range of a standard campfire.

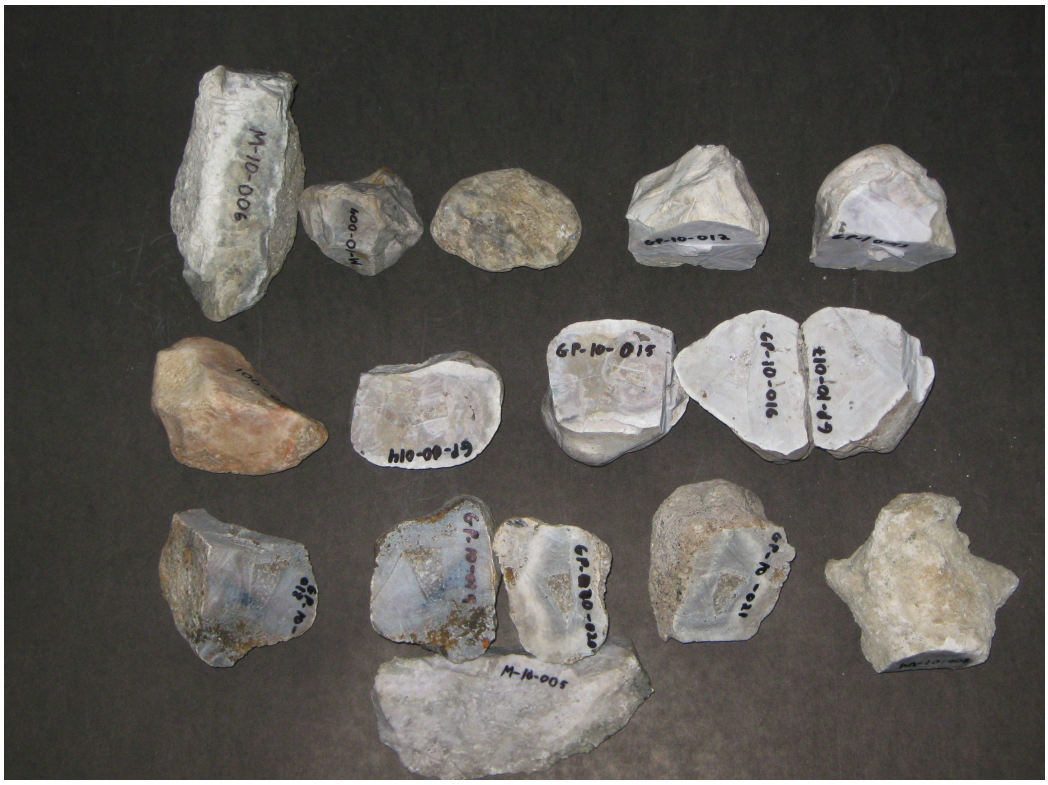

Photo 5.1: SRC cobbles selected for heat-treatment.

A fire was created using a mixture of spruce (*Picea*) and pine (*Pinus*) wood. The heat-treatment process lasted for a total of 14 hours. Six hours were spent tending to the fire and adding wood when necessary. Over the next 8 hours, the fire was allowed to go out naturally and the coals heated the SRC. Once the coals had gone out, the SRC was left in the sand to cool overnight. This amount of time was selected based on conversations with Eugene Gryba, an archaeologist in Alberta and expert flintknapper. Once the cobbles had cooled, they were reweighed and the Munsell chart was used again to determine if any of the cobbles exhibited a change in colour.

Observed Changes in Heated SRC

Colour

Unheated nodules of Swan River Chert resemble a medium-grained quartzite, and are predominantly light gray (7.5YR 7/0, 10YR 7/1, 10YR 7/2, 2.5Y 7/1, N 7/), gray (7.5YR 5/0, 7.5YR 6/0, 10YR 6/1, 2.5Y 5/0, 5Y 5/1, 5Y 6/1, N 5/) and dark gray (2.5YR 4/0, N 4/) in colour. Some pieces were also observed to have a reddish (2.5YR 6/4) or olive (5Y 5/3) colour to them.

All nodules that were placed in the fire pit exhibited some kind of a colour change, although the amount of colour change varied depending on the depth. Nodules that were placed at the bottom of the fire pit (20 cm b.s.) developed a slight reddish-pink discolouration on the cortex, but the interior of the nodule remained virtually unchanged. The nodules buried in the 4-8 cm b.s. range developed a much more dramatic colour change, with the cortex and the interior of the nodules being affected. Nodules at this depth changed from gray to a light reddish brown. Nodules that had been placed directly into the fire developed a pale, chalky pink colour with a white residue deposited throughout the piece.

Sample #	Munsell # Before Heating	Munsell # After Heating
M-10-003	7.5YR 6/0	2.5 Y 6/2
M-10-005	7.5 YR 7/0	N 7.25/
M-10-006	2.5 YR 4/0	N 6/, Band: 10R 6/4
M-10-008	7.5YR 5/0	N 4.5/
GP-10-012	N 8/ & N 7/	N 9/ & N 8/

Sample #	Munsell # Before Heating	Munsell # After Heating
GP-10-013	N 8/ & N 7/	N 9/ & N 8/, Band: 2.5YR 6/10
GP-10-017	5Y 6/1	5YR 8/1
GP-10-014	2.5Y 6/4 (main), 2.5YR 5/2 (swirl)	5YR 5/2 (main), 10R 5/4 (swirl)
GP-10-016	5Y 6/1	5YR 8/1
GP-10-019	5Y 5/1	2.5YR 6/4, 10B 4/1 (Dark Spot)
GP-10-020	5Y 5/3	2.5YR 5/2
GP-10-015	2.5Y 6/4 (main), 2.5YR 5/2 (swirl)	5YR 5/2 (main), 10R 5/4 (swirl)
GP-10-018	5Y 5/1	2.5YR 6/4, 10B 4/1 (Dark Spot)
GP-10-021	5Y 5/3	2.5YR 5/2
L-10-001	7.5 YR 7/4	2.5YR 6/4
M-10-004	7.5YR 6/0	2.5 Y 6/2

Table 5.1: Colour Change Table For SRC.

Flake Properties

Flakes were removed from the SRC nodules using direct percussion with a quartzite hammerstone in order to get a better understanding of the effect of heat-treatment of the flaking properties of SRC. The flaking properties of unheated pieces of Swan River Chert ranged from fair to poor depending on the nodule. Trying to detach flakes from the unheated SRC required a fair amount of physical force, especially when compared to the heated SRC. It was difficult to control the size of the flakes and the striking platforms from which they would be removed. In addition, these flakes are typically larger, and blockier in shape when compared to the flakes removed from heat-treated SRC. Nodules that were heated at temperatures less than 240°C showed no appreciable change in the flaking

properties of the material. Flakes from nodules that were heated above 240°C, exhibited a well-developed conchoidal fracture pattern, and rippling was present on the ventral surface of some of the flakes. A small piece of SRC was also placed directly in the fire to examine the effects. This piece became quite dry and brittle, and developed a sugary texture. When it was struck, it quickly crumbled and shattered instead of producing flakes.

Changes In Mass

The mass of the unheated nodules of SRC was between 230.80 and 868.70 grams. After heating, all the nodules except for one (L-10-001) lost a measurable amount of mass. Weight loss was between 0.2-0.7% of the original mass of the nodule; proximity to the heat source seemed to have no effect on the amount of weight loss. Since all the pieces in this study were exposed to temperatures over 100°C for a period of time, the weight change can likely be attributed to a loss of water trapped in the nodule as it turned into steam. This assertion is also reflected in the works of D. Griffiths and colleagues (1987) and Harry Micheelsen (1966).

Sample #	Weight Before Treatment (g)	Weight After Treatment (g)	Percent Weight Change	Depth Below Heat Source (cm)	Average Temperature at Depth (°C)
M-10-003	230.8	229.38	-0.60%	20	76.92
M-10-005	523.7	522.57	-0.20%	20	76.92
M-10-006	868.7	868.6	-0.01%	16	177.37
M-10-008	449.6	447.03	-0.60%	16	177.37
GP-10-012	510.83	509.34	-0.30%	12	220.76
GP-10-013	426.72	425.57	-0.30%	12	220.76
GP-10-017	505.22	503.78	-0.30%	12	220.76
GP-10-014	377.77	376.31	-0.40%	8	242.83
GP-10-016	579.77	575.77	-0.70%	8	242.83
GP-10-019	532.7	529.07	-0.70%	8	242.83

GP-10-020	308.09	305.9	-0.70%	8	242.83
GP-10-015	630.48	627.95	-0.40%	4	279.89
GP-10-018	471.15	470.06	-0.20%	4	279.89
GP-10-021	569.32	567.91	-0.20%	4	279.89
L-10-001	400.4	400.5	0.20%	4	279.89
M-10-004	239.7	238.82	-0.40%	4	279.89

Table 5.2: Amount of Weight Lost as a Result of Heat-treatment.

Characterizing The Flake Surface: Profilometry

A profilometer is any device that is used to measure the profile of a surface, in order to characterize its roughness. There are two main types of profilometer: the contact profilometer and the optical profilometer. Contact profilometers work in a manner that is analogous to the needle on a record player. A small (20 nm to 25 µm radius) diamond stylus is moved across the surface of an object for a specified distance and with a specified force; and any variations in its surface are recorded, creating a 2 dimensional image of the object's surface profile.

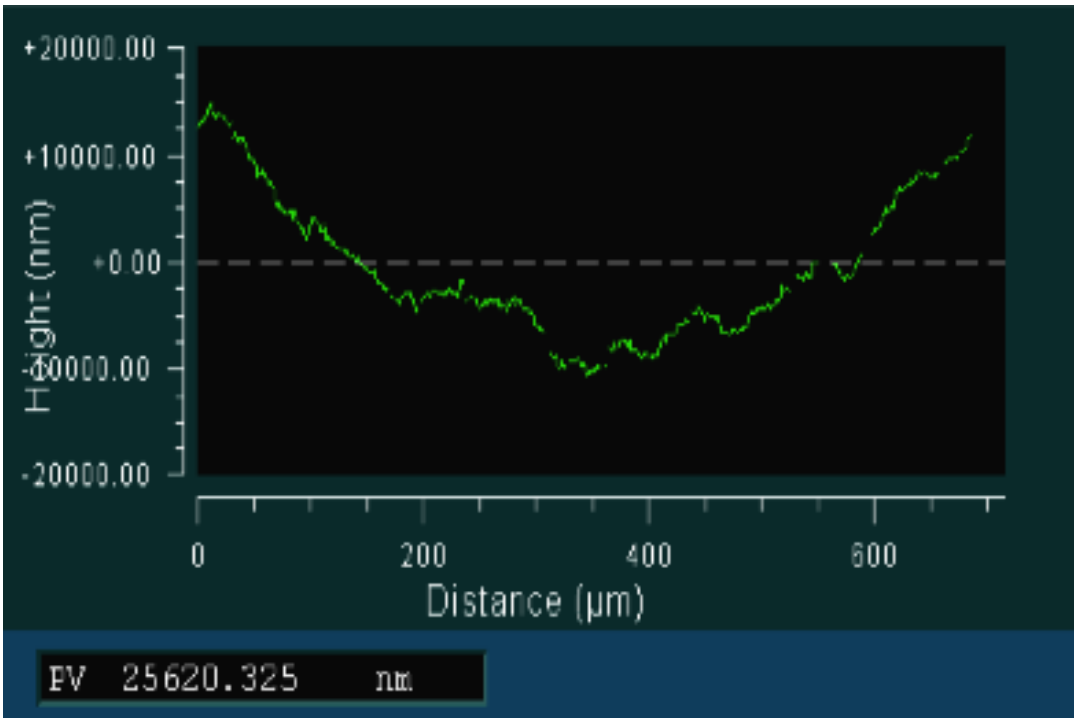

Figure 5.4: Two-dimensional surface profile of a flake of Swan River Chert.

The downside to using a contact profilometer is that is relies on precision made and moving parts. It is possible for the stylus to become damaged as a result of surface wear or an inattentive operator, meaning that it needs to be replaced. Another feature that needs to be kept in mind when using a contact profilometer is that the data you get will inherently be linear, since all that is being recorded is the path that the stylus takes across the object.

Optical profilometers work by using the properties of light to compare the optical path difference between the surface being tested and a reference surface located in the machine. A beam of collimated light is split, with half the beam passing through the focal plane of a microscope objective onto the test material; and the other half of the split beam directed onto the reference mirror. When the distance from the beam splitter to the reference mirror is the same distance as the beam splitter is from the test surface, the split beams are recombined. Constructive and destructive interference occurs in the combined beam wherever the length of the light beams vary. This property creates a series of light and dark bands known as interference fringes. Since the reference mirror is of a known flatness, the optical path differences are due to height variances in the test surface. This interference beam is focused into a digital camera, which sees the constructive interference areas as lighter, and the destructive interference areas as darker. In the interference image, each transition from light to dark represents one-half a wavelength of difference between the reference path and the test path. If the size of the wavelength is known, it is possible to calculate height differences across a surface, in fractions of a wave. From these height differences,

a surface measurement is obtained. For example, if the wavelength of a beam of light is 500 nm, each light and dark band would represent a distance of one half a wavelength, or 250 nm.

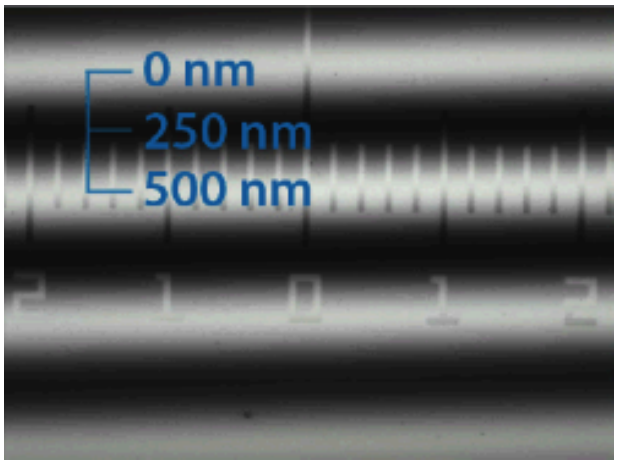

Figure 5.5: Interference fringes. Each light and dark band is equivalent to 250 nm.

The biggest advantage to using an optical profilometer is its resolution. The vertical resolution of an optical profilometer is usually around a single nanometer, while contact profilometers have a vertical resolution of only around 10 nm. Since light is being used instead of a stylus, the data that are acquired are inherently three-dimensional, with measurements being taken across the x, y and, z axes. This image creates a much more accurate representation of the surface being examined, and makes it easier to compare the surfaces of multiple objects. Speed is another advantage to using an optical profilometer. Each scan takes approximately 30-60 seconds to do, depending on the level of resolution that you are trying to achieve. This speed makes it possible to analyze a large number of items in a relatively short amount of time. Due to the speed with which objects can be analyzed, and its ability to generate three-dimensional images of a surface,

the optical profilometer was selected to characterize the flake surfaces of Swan River Chert.

Photo 5.2: Zygo Optical Profilometer located in the University of Alberta's NanoFab laboratory.

In order to maximize the effectiveness of the optical profilometer samples are typically given a coating of gold so that they are capable of reflecting more of the light back into the device. This procedure is accomplished by using a gold sputtering device. The Denton gold sputter unit at the University of Alberta uses a particular type of sputtering called "gas flow sputtering" to coat surfaces with a thin layer of gold. This layer of gold is extremely thin (15-20 nanometres), so one does not have to worry about affecting the final results by filling in any pits, or exaggerating any peaks.

After the scanning is complete, the machine will display four images: a surface map, a surface profile, an oblique plot, and an intensity map that provides

a visual representation of the surface. In addition to the images, there are three numbers that are also displayed: the PV value, R_a value, and the rms value. The PV value is the maximum peak to valley height of the surface profile within the assessment length. The R_a, or roughness average value is the arithmetic average of the absolute values above and below the centerline as calculated by the formula:

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$

Formula 5.1: Formula for calculating R_a.

where *n* is the number of ordered, equally spaced points being analyzed and y_i is the vertical distance from the mean line to the i^{th} data point. The rms value is the root mean squared value for the arithmetic average for each value of *n*, and is calculated using the formula:

$$R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{n}y_i^2}$$

Formula 5.2: Formula for calculating rms.

The rms is similar to the R_a, but is capable of handling negative numbers. This feature creates a kind of weighted average: rms values are always higher than R_a values.

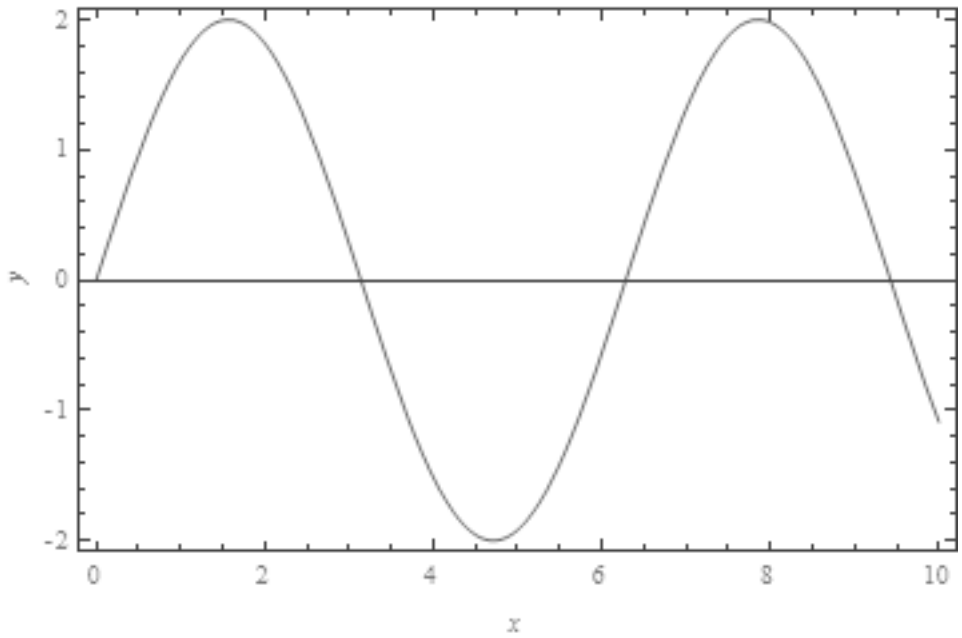

Figure 5.6: Hypothetical sinusoidal curve with a peak of 2 and a valley of -2. The curve theoretically continues on to infinity. Using the formula for R_a would give a roughness average of 0. If the formula for rms is used, then the average would be 2.

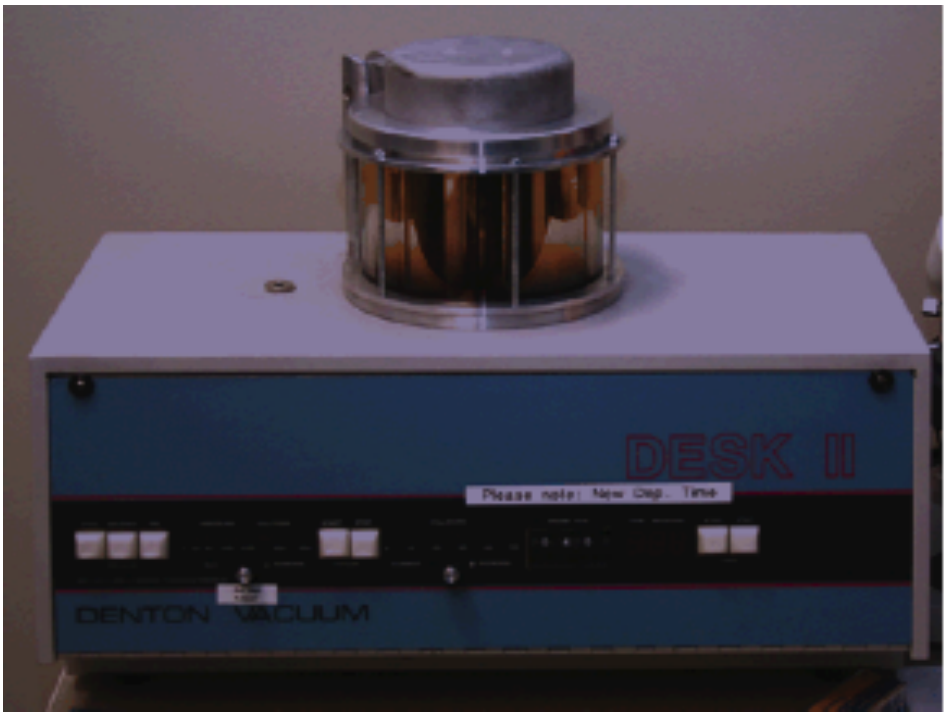

Photo 5.3: Denton Gold Sputter Unit.

The goal of this part of the study was to develop a kind of "baseline" from which it would be possible to determine whether or not flakes that have been found in archaeological contexts have been heat-treated. To that end, 102 flakes (51 heated, 51 unheated) were struck from the prepared cobbles and given a sputter coating of gold. Each flake was then placed under the Zygo optical profilometer (Zygo for short), which had been programmed to scan an area 0.717 mm long and 0.538 mm wide and check for variations in height up to 200 μm. Since this process involves incredibly fine measurements, some precautions were taken in order to minimize the chance that any imperfections would skew the results. First, only the ventral surface of each flake was scanned. This was done in order to eliminate the possibility of the scan being affected by any flake scars present on the dorsal surface. Second, care was taken to ensure that only chert was being scanned. Any vugs or other mineral inclusions were avoided so as to avoid creating a higher or lower roughness value than would be found in the chert itself. Third, only one scan was taken for each flake. Since some of the flakes examined are quite small and would not have enough room for multiple scans, the decision was made to scan all the flakes one time only. This was done in order to facilitate a more direct comparison between the flakes.

Results

The results of the scans on the unheated flakes are presented in Table 5.3:

Sample #	Heated/Unheated	R_a (μm)	rms (μm)
GP-10-013	Unheated	8.325	10.47
GP-10-013	Unheated	8.351	10.709
GP-10-013	Unheated	9.22	11.108
GP-10-013	Unheated	8.007	10.297
GP-10-013	Unheated	6.235	8.284
GP-10-013	Unheated	4.647	5.788
GP-10-013	Unheated	4.781	6.024
GP-10-013	Unheated	4.489	5.447
GP-10-013	Unheated	7.965	10.18
GP-10-013	Unheated	6.953	8.698
GP-10-018 & 019	Unheated	12.871	16.249
GP-10-018 & 019	Unheated	9.338	11.832
GP-10-018 & 019	Unheated	11.18	14.107
GP-10-018 & 019	Unheated	20.904	24.909
GP-10-018 & 019	Unheated	11.11	13.447
GP-10-018 & 019	Unheated	11.237	13.748
GP-10-018 & 019	Unheated	12.891	15.706
GP-10-018 & 019	Unheated	19.202	23.892
GP-10-018 & 019	Unheated	14.63	18.731

Sample #	Heated/Unheated	R_a (µm)	rms (µm)
GP-10-018 & 019	Unheated	13.688	18.549
GP-10-020	Unheated	17.829	22.998
GP-10-020	Unheated	8.549	10.396
GP-10-020	Unheated	9.342	11.599
M-10-005	Unheated	11.451	14.213
M-10-005	Unheated	9.241	12.679
M-10-005	Unheated	8.709	11.169
M-10-005	Unheated	25.519	25.519
M-10-005	Unheated	19.519	22.931
M-10-005	Unheated	16.893	21.579
M-10-005	Unheated	19.858	24.317
M-10-005	Unheated	11.005	13.894
M-10-005	Unheated	11.564	14.669
M-10-005	Unheated	12.293	16.743
M-10-005	Unheated	11.452	14.136
M-10-005	Unheated	10.391	15.188
M-10-006	Unheated	14.456	18.392
M-10-006	Unheated	9.505	12.156
M-10-006	Unheated	5.262	7.845
M-10-006	Unheated	9.6	11.872
M-10-006	Unheated	4.953	6.268

Sample #	Heated/Unheated	R_a (µm)	rms (µm)
M-10-006	Unheated	3.095	3.895
M-10-006	Unheated	8.698	10.235
M-10-006	Unheated	3.062	3.771
M-10-006	Unheated	4.311	5.254
M-10-008	Unheated	6.033	8.095
M-10-008	Unheated	7.395	9.35
M-10-008	Unheated	8.507	11.497
M-10-008	Unheated	6.386	6.386
M-10-008	Unheated	12.874	15.855
M-10-008	Unheated	9.945	11.726
M-10-008	Unheated	10.579	13.699

Table 5.3: R_a and rms values for unheated flakes of Swan River Chert.

In this study, the average R_a value for unheated flakes was 10.476 µm, the minimum value was 3.062, the maximum value was 25.519 µm, and the standard deviation was 4.841. The average rms value was 13.069 µm, the minimum value was 3.771 µm, and the maximum value was 25.519 µm, with a standard deviation of 5.658.

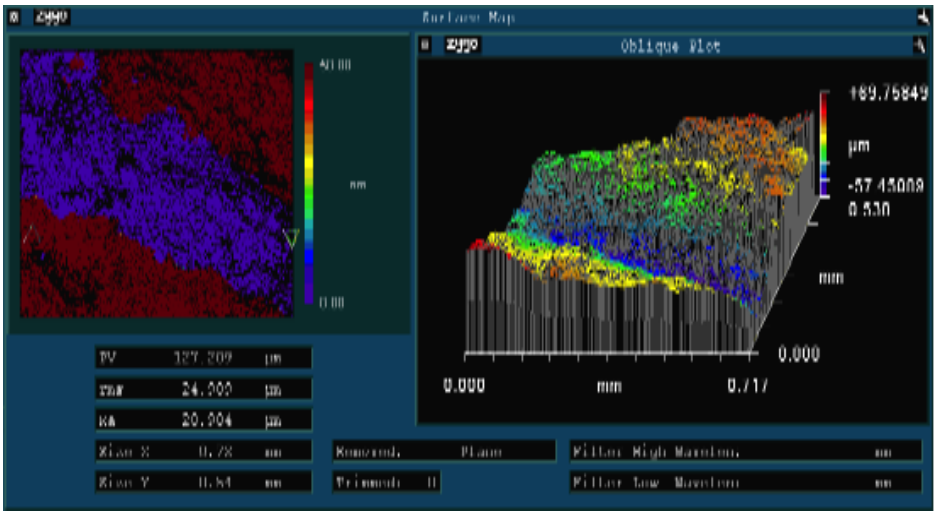

Figure 5.7: Optical profilometer image of an unheated SRC flake.

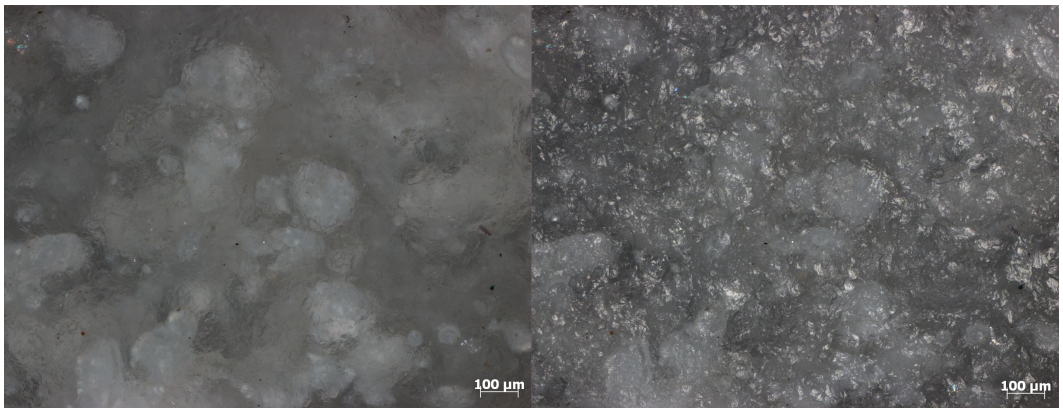

Photo 5.4: Stereomicroscopic image of untreated SRC at 10x magnification using polarized (left) and regular (right) light.

Both the R_a and rms values for heat-treated flakes seem to show a noticeable improvement as shown in Table 5.4:

Nodule	Heated/Unheated	R_a (µm)	rms (µm)
GP-10-013	Heated	6.656	8.434
GP-10-013	Heated	6.744	8.23
GP-10-013	Heated	5.912	7.013
GP-10-013	Heated	5.401	6.917
GP-10-013	Heated	5.386	6.855

Nodule	Heated/Unheated	R_a (µm)	rms (µm)
GP-10-013	Heated	5.139	6.552
GP-10-013	Heated	4.85	6.437
GP-10-013	Heated	3.901	5.16
GP-10-013	Heated	3.624	4.729
GP-10-013	Heated	3.241	4.395
GP-10-013	Heated	2.806	3.695
GP-10-018	Heated	8.573	10.542
GP-10-018	Heated	5.857	7.394
GP-10-018	Heated	5.522	6.904
GP-10-018	Heated	5.268	6.786
GP-10-018	Heated	5.2	6.488
GP-10-018	Heated	4.67	5.933
GP-10-018	Heated	4.474	5.453
GP-10-018	Heated	4.386	5.316
GP-10-018	Heated	4.075	5.041
GP-10-018	Heated	2.618	3.792
GP-10-018	Heated	1.525	2.03
GP-10-019	Heated	6.144	8.189
GP-10-019	Heated	5.418	7.035
GP-10-019	Heated	5.222	6.404
GP-10-019	Heated	4.726	5.874

Nodule	Heated/Unheated	R_a (µm)	rms (µm)
GP-10-019	Heated	4.087	5.299
GP-10-019	Heated	3.977	5.289
GP-10-019	Heated	3.883	4.802
GP-10-019	Heated	3.561	4.701
GP-10-019	Heated	3.324	4.389
GP-10-019	Heated	3.436	4.225
GP-10-020	Heated	7.787	10.968
L-10-001	Heated	5.11	6.637
L-10-001	Heated	4.825	6.03
M-10-005	Heated	16.54	21.281
M-10-005	Heated	12.908	16.684
M-10-005	Heated	12.825	15.185
M-10-005	Heated	12.197	15.036
M-10-005	Heated	11.608	14.656
M-10-005	Heated	11.559	14.354
M-10-006	Heated	9.763	12.857
M-10-006	Heated	8.981	11.126
M-10-006	Heated	8.91	10.756
M-10-006	Heated	6.707	8.775
M-10-006	Heated	6.841	8.415
M-10-006	Heated	5.716	7.125

Nodule	Heated/Unheated	R_a (µm)	rms (µm)
M-10-006	Heated	4.359	5.784
M-10-006	Heated	4.506	5.711
M-10-006	Heated	4.312	5.663
M-10-006	Heated	3.273	4.246

Table 5.4: R_a and rms values for heat-treated Swan River Chert.

For heat-treated flakes of Swan River Chert, the average R_a value was 6.046 µm. The minimum value was 1.525 µm, the maximum value was 16.54 µm, and the standard deviation was 3.084. The average rms value was 7.678 µm, with a minimum value of 2.03 µm, a maximum value of 21.281, and a standard deviation of 3.848.

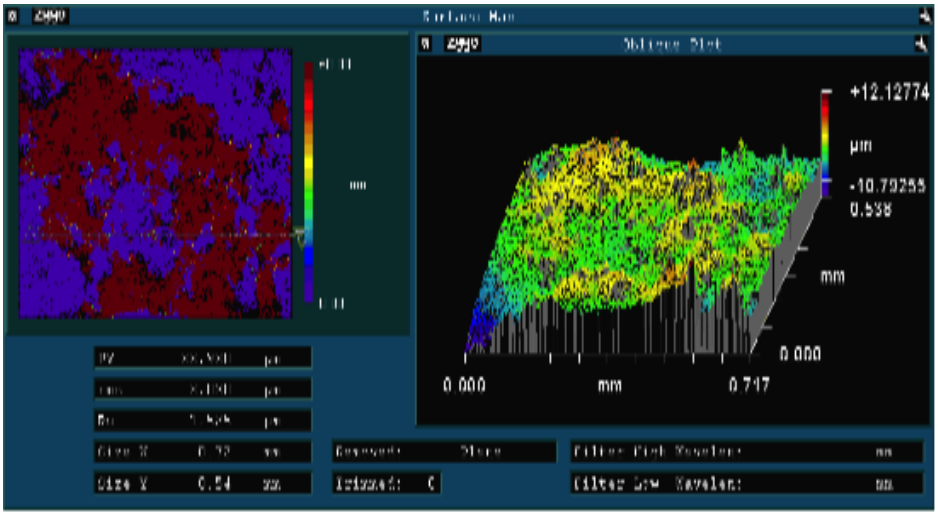

Figure 5.8: Optical profilometer image of a heated SRC flake.

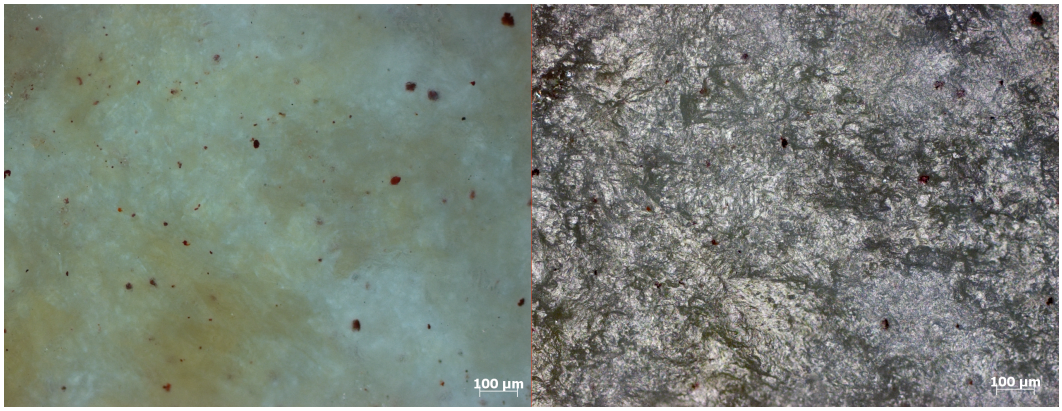

Photo 5.5: Stereomicroscopic image of heat-treated SRC at 10x magnification using polarized (left) and regular (right) light. Note how the surface has a much smoother appearance than the untreated SRC in Photo 5.4.

The data were put into a clustered column chart to see if it was possible to identify a point in the data below which it could be stated that a flake was likely to have been heat-treated and above which it was likely to be untreated. In Figures 5.8 and 5.9, one can clearly see that heat-treated flakes are concentrated at values that are at and below 5-7.5 µm.

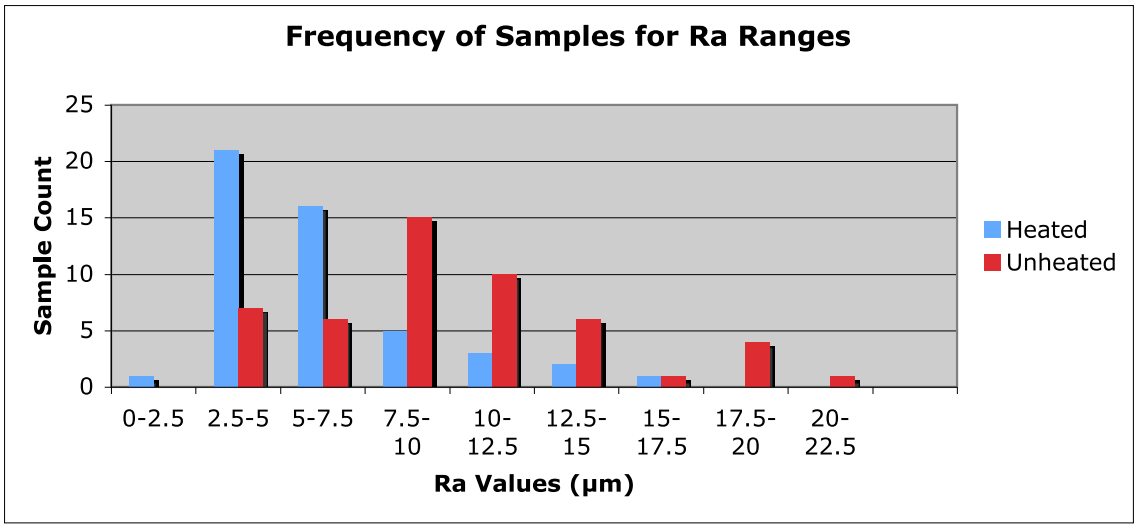

Figure 5.9: Frequency of samples for R_a ranges.

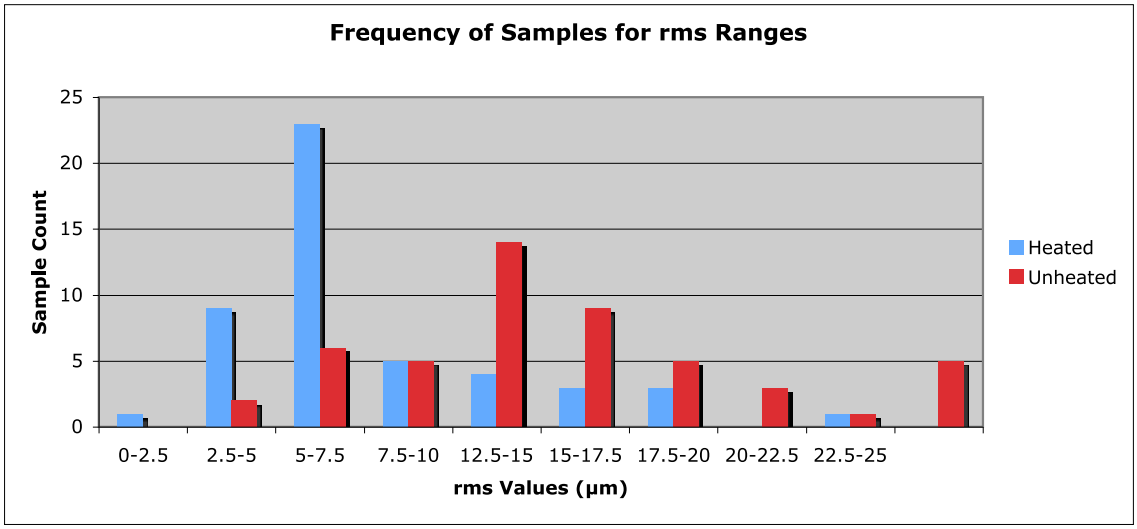

Figure 5.10: Frequency of samples for rms ranges.

While the difference between the two samples looks significant at a glance, some kind of statistical test is required in order for this observation to be confirmed. In order to demonstrate that the difference between the two samples is statistically significant, the data were run through the SOFA Statistics software package version 1.1.1. SOFA Statistics is an open source software program created by Paton-Simpson & Associates Ltd. of New Zealand that is capable of performing a variety of statistical tests for the end user. When the R_a and rms values for the heated and unheated flake types are subjected to a test for normality, the results do follow a distribution that is approximately (although not ideally) normal.

In order to confirm or reject the null hypothesis, the Mann-Whitney U test was used to determine if there were any statistically significant differences between the roughness values for heated and unheated SRC. The Mann-Whitney U is a non-parametric (i.e., doesn't rely on data belonging to any particular distribution) statistical test that is used to assess whether one of two samples of

independent observation tends to have larger values than the other. It is considered an ideal test when dealing with distributions that deviate from a normal distribution pattern and when dealing with large sample sizes (Conover 1980:225-226).

When the R_a and rms values of the heat-treated and unheated flakes were compared using the Mann-Whitney test, both sets of data returned a p-value that was less than 0.001. Since the p-values for both data sets is less than 0.001, the null hypothesis can be rejected; temperature does have a significant effect on the roughness values of Swan River Chert flakes.

Verifying The Results

In order to make sure that the results of this experiment were not unique and could be applied to a variety of lithic materials, a second experiment was run using silcrete. Silcrete is another type of siliceous material that bears a superficial resemblance to quartzite; however, it forms in a completely different way. Silcrete is formed by the silicification of soil profile material, or the unconsolidated products of rock weathering (Hughes, et al. 1973:220). By contrast, quartzite forms as a result of partial or complete silification of rock material by either metamorphic secondary cementation processes (Hughes, et al. 1973:220). These silcrete cobbles were collected by Eugene Gryba from the Swan River area, and had been heated in an oven to ~371°C (700°F). Half of each cobble was set aside to act as a control. 25 heated flakes and 25 unheated flakes were run through the Zygo, and the results are displayed in Figures 5.11 and 5.12 and Table 5.5:

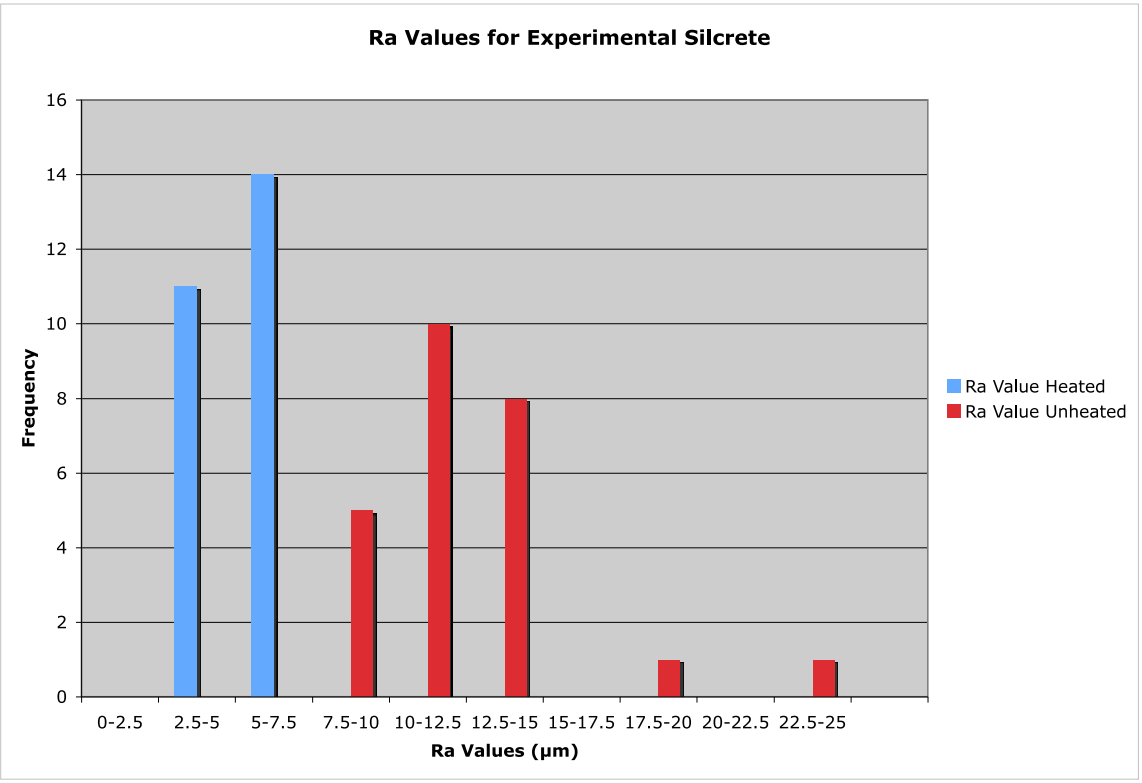

Figure 5.11: R_a values for heated and unheated silcrete.

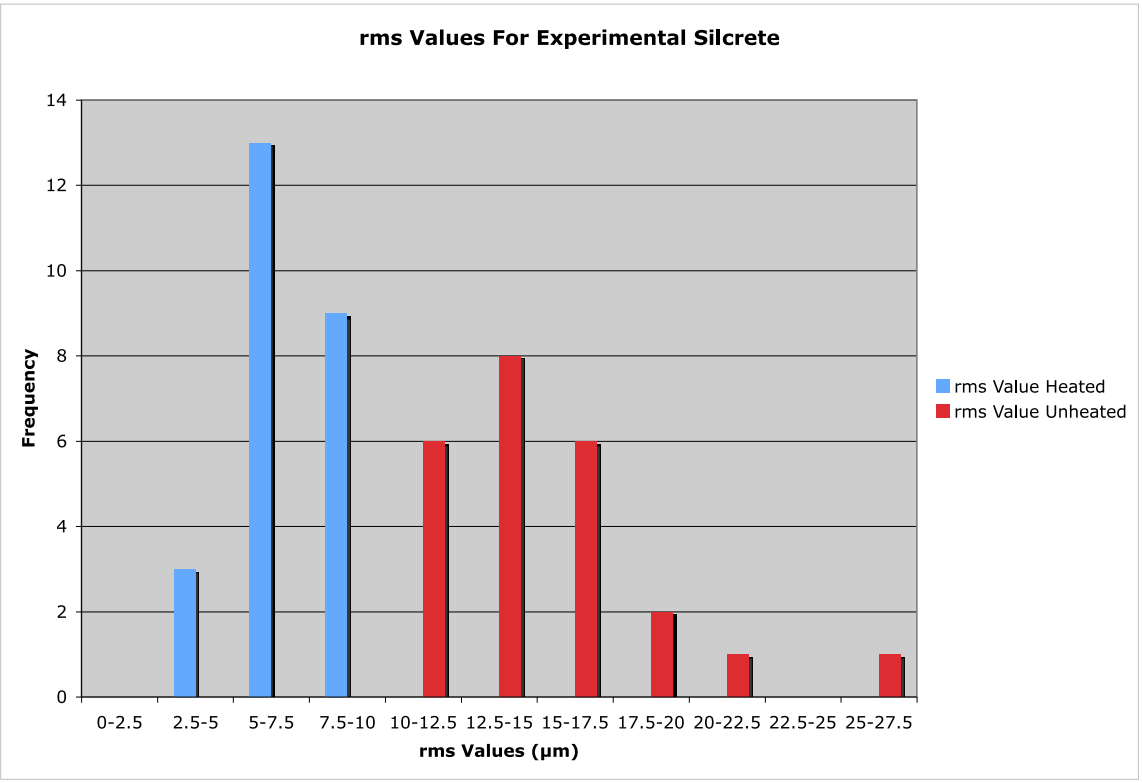

Figure 5.12: rms values for heated and unheated silcrete.

Catalogue #	Heated/ Unheated	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
1	Heated	Flake	6-11.99	n	0.2	5.636	7.122
2	Heated	Flake	6-11.99	n	0.2	4.759	5.943
3	Heated	Flake	12-24.99	n	1.9	6.737	8.815
4	Heated	Flake	12-24.99	n	0.5	4.24	5.385
5	Heated	Flake	12-24.99	n	0.3	4.355	5.474
6	Heated	Flake	25-50	n	6.0	5.095	6.273
7	Heated	Flake	6-11.99	n	0.2	3.721	4.811
8	Heated	Flake	6-11.99	n	0.3	4.507	3.5
9	Heated	Flake	6-11.99	n	0.2	6.866	8.392
10	Heated	Flake	6-11.99	n	0.3	6.922	8.409
11	Heated	Flake	6-11.99	n	0.2	7.16	9.537
12	Heated	Flake	6-11.99	n	0.1	5.93	7.343
13	Heated	Flake	6-11.99	n	0.2	6.606	7.957
14	Heated	Flake	6-11.99	n	0.3	6.316	7.953
15	Heated	Flake	6-11.99	n	0.2	4.593	5.977
16	Heated	Flake	6-11.99	n	0.1	3.109	4.112
17	Heated	Flake	6-11.99	n	0.1	6.249	7.537
18	Heated	Flake	2-5.99	n	<0.1	6.804	7.996
19	Heated	Flake	2-5.99	n	<0.1	5.813	7.076
20	Heated	Flake	2-5.99	n	<0.1	5.009	6.337
21	Heated	Flake	6-11.99	n	0.1	5.792	7.556
22	Heated	Flake	2-5.99	n	<0.1	4.985	6.395
23	Heated	Flake	6-11.99	n	0.1	4.228	5.612
24	Heated	Flake	6-11.99	n	0.1	4.39	5.599
25	Heated	Flake	6-11.99	n	0.1	3.749	5.103
1	Unheated	Flake	25-50	y	3.2	12.811	15.623
2	Unheated	Flake	25-50	y	7.5	13.997	17.669
3	Unheated	Flake	25-50	n	4.5	10.586	13.898
4	Unheated	Flake	25-50	n	1.1	14.28	17.548
5	Unheated	Flake	12-24.99	n	1.4	9.884	12.36
6	Unheated	Flake	12-24.99	n	0.1	19.58	23.861
7	Unheated	Flake	12-24.99	n	0.8	10.222	12.869
8	Unheated	Flake	12-24.99	n	0.3	12.673	15.444
9	Unheated	Flake	12-24.99	n	0.2	11.411	14.301
10	Unheated	Flake	6-11.99	n	0.2	13.217	16.034
11	Unheated	Flake	12-24.99	n	0.3	11.03	14.982
12	Unheated	Flake	6-11.99	n	0.1	9.911	12.33
13	Unheated	Flake	6-11.99	n	0.1	10.394	13.425
14	Unheated	Flake	6-11.99	n	0.1	9.388	11.868
15	Unheated	Flake	6-11.99	n	0.3	13.152	16.844
16	Unheated	Flake	6-11.99	n	0.1	22.895	28.914
17	Unheated	Flake	12-24.99	n	0.4	10.01	12.047

Catalogue #	Heated/ Unheated	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
18	Unheated	Flake	6-11.99	n	0.1	11.293	14.109
19	Unheated	Flake	6-11.99	n	0.1	8.836	11.881
20	Unheated	Flake	6-11.99	n	0.1	8.427	10.641
21	Unheated	Flake	2-5.99	n	<0.1	14.381	20.159
22	Unheated	Flake	6-11.99	n	0.2	10.555	13.388
23	Unheated	Flake	12-24.99	n	0.3	13.407	16.032
24	Unheated	Flake	6-11.99	n	0.1	11.435	14.709
25	Unheated	Flake	2-5.99	n	<0.1	12.386	15.678

Table 5.5: R_a and rms values for heated and unheated silcrete flakes.

The two charts show that there is a clear difference between the roughness values in heated and unheated silcrete flakes. The heated silcrete flakes all have an R_a value that is less than 7.5 µm, and an rms value that is less than 10 µm. The average R_a value for the heated silcrete flakes is 5.34 µm, and the average rms value is 6.65 µm. The unheated flakes had average R_a and rms values of 12.25 µm and 15.46 µm respectively. When a Mann-Whitney U test is applied to these data to determine if there is a statistically significant difference between the roughness values between the heated and unheated silcrete flakes, the p-value for both the R_a and rms is <0.001. From this result, it can be concluded that there is a statistically significant difference between the heated and unheated roughness values. These results lend further credence to the effectiveness of the Zygo as a means of detecting heat-treatment.

X-Ray Diffraction

In addition to the use of the optical profilometer to examine the effects of heat-treatment on SRC, some samples were sent to the X-Ray diffraction laboratory at the University of Alberta to see if the crystalline structure of SRC changes after heat-treatment. X-ray diffraction analysis is based on the principle

that x-rays undergo elastic collisions with atoms that change the direction of the X-ray without changing its energy (University of Alberta Office of Environmental Health and Safety 2003:2). The x-rays are generated in a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate the radiation, and then directed towards the sample (Dutrow & Clark 2011). The interaction of the waves with the sample produces constructive interference; and the diffracted X-rays are detected, processed, and counted. The diffractometer is constructed in such a way that the sample rotates in the path of the X-ray beam at an angle θ, while the X-ray detector is mounted on an arm to collect the diffracted X-rays and rotates at an angle of 2θ (Dutrow & Clark 2011). The instrument used to maintain the angle and rotate the sample is called a goniometer. The data are then compiled onto a chart, where they can be compared with standard reference patterns in order to determine the composition of the material.

Three samples of SRC were brought to the lab: one control (unheated), one that was properly heat-treated, and a third that was deliberately overheated and suffered from thermal fracturing. Each sample was ground into a fine powder (less than 10 μm), and 1-2 grams of each sample were run through the machine. Data were collected at 2θ from 10° to 110°, and the results can be seen in Figure 5.13.

With regard to the composition of SRC, the X-ray diffraction chart is not too surprising; and matches up quite well with the results described by Stephen Grasby and colleagues (2002). The mineralogy of SRC is >90% chert, with minor amounts of calcium, potassium, feldspar, and clay minerals. What was of

interest to the author was whether or not there was a change in the diffraction pattern between unheated, heated, and overheated SRC. The early use of X-ray diffraction by Purdy and Brooks (1971) to compare heated and unheated lithics was inconclusive; however, later research that focused on specific sections of the X-ray diffraction chart provided some interesting results. The 212 peak located at 67.74° has been identified by Domanski and Webb (1992) as being the site on the X-ray diffraction chart to look for evidence of heat-treatment. They noticed that the 212 peak changed between unheated and heated samples of flint and agate, with the heated samples showing a shift towards better ordered, equigranular crystals. A broadening of the 212 peak between the heated and unheated samples indicates that this shift has occurred.

By zooming in on the 212 peak of the SRC X-ray diffraction curve, one can see a distinct difference between the three samples (see Fig. 5.14). There is a definite broadening of the 212 peak between the heated and unheated samples, indicating a reduction in overall crystal size, and shift towards more ordered crystals (Domanski & Webb 1992:610). The area around the 212 peak of the overheated SRC is also particularly interesting. Rather than having a series of peaks like the other two samples, the area between ~67.5°-69° 2θ on the overheated sample appears to be more like a smooth curve. This curve shape is typically associated with objects that have a low crystallinity index (<1.0) (Murata & Norman 1976:1122). The poorly crystallized cryptocrystalline quartz in the overheated SRC may be one of the reasons that it flakes so poorly. As the SRC is heated, the silicon-oxygen bonds of the quartz interlock less strongly. In

overheated cherts, the bond might be so weak that when a force is applied to the stone, it simply shatters rather than allowing the force to pass through it (Domanski & Webb 1992:611).

UV Light

In instances when it is not cost effective or feasible to use X-ray diffraction to determine if a particular lithic has been heat-treated, it may be possible to use UV light to identify instances of heat-treatment. For this study 6 flakes of SRC (two unheated, two unheated and two overheated) were placed under a Black Ray® UV lamp and examined for differences in colour. The Black Ray® UV lamp is a long wave (365 nm) ultraviolet light with an intensity of 21,700 $\mu m/cm^2$ at 5 cm (Ted Pella Inc. 2013). It is commonly used for curing polymers and for staining microscope specimens.

When these flakes were exposed to the UV light, the untreated flakes exhibited almost no change in colour. In contrast, the heat-treated and overheated flakes changed from a light red colour to a mottled deep red. While the mechanism behind this colour change is not yet understood, and further research is necessary, this technique could prove to be an effective method for quickly identifying heat-treated lithics when examining a large number of samples and setting them aside for further analysis.

Photo 5.6: Visual comparison of unheated (left), heated (center) and overheated (right) samples of SRC under normal (bottom) and UV (top) light.

Summary

The temperatures generated by a standard fire are more than sufficient to generate the amount of heat necessary to successfully heat treat siliceous materials including SRC. At a depth of ~5 cm below the fire, lithics are sufficiently insulated from the heat that they do not suffer from thermal decomposition and become brittle. The results of the optical profilometer were also encouraging. The machine was able to demonstrate that there is a quantitative difference between the roughness values of heat-treated and unheated flakes of SRC, with heat-treated SRC having consistently lower R_a and rms values than untreated SRC. While the precise mechanism that causes the change is still very much up for debate, current evidence suggests that the temperature of the fire is sufficient to cause structural water to migrate into fluid inclusions that are

structurally comparable to the surrounding lepispheres. Since the SRC now has a more uniform structural density, when a force is applied it will now travel straight through the material, rather than preferentially around the lepispheres. This creates a smoother ventral surface and consequently, lower R_a and rms values.

To make sure that the results were not unique to SRC, a second test was run using flakes of silcrete. The data from this test also show a clear difference between the roughness values of heat-treated and unheated flakes. From these two tests, it can be concluded that the Zygo profilometer may be effectively used to detect heat-treatment in lithics. The use of X-ray diffraction also showed that there is a difference between heated, unheated, and overheated SRC with regard to their crystalline structure. This change is demonstrated by a broadening of the 212 peak in the heat-treated samples. While x-ray diffraction is useful for confirming that a structural change has occurred in the material, the destructive nature of this test does make it impractical for directly studying archaeological collections. Having established that the optical profilometer can be used to distinguish heated from unheated flakes, the next part of this research involved collecting archaeological specimens and submitting them to profilometric analysis to determine whether or not they had been heat treated.

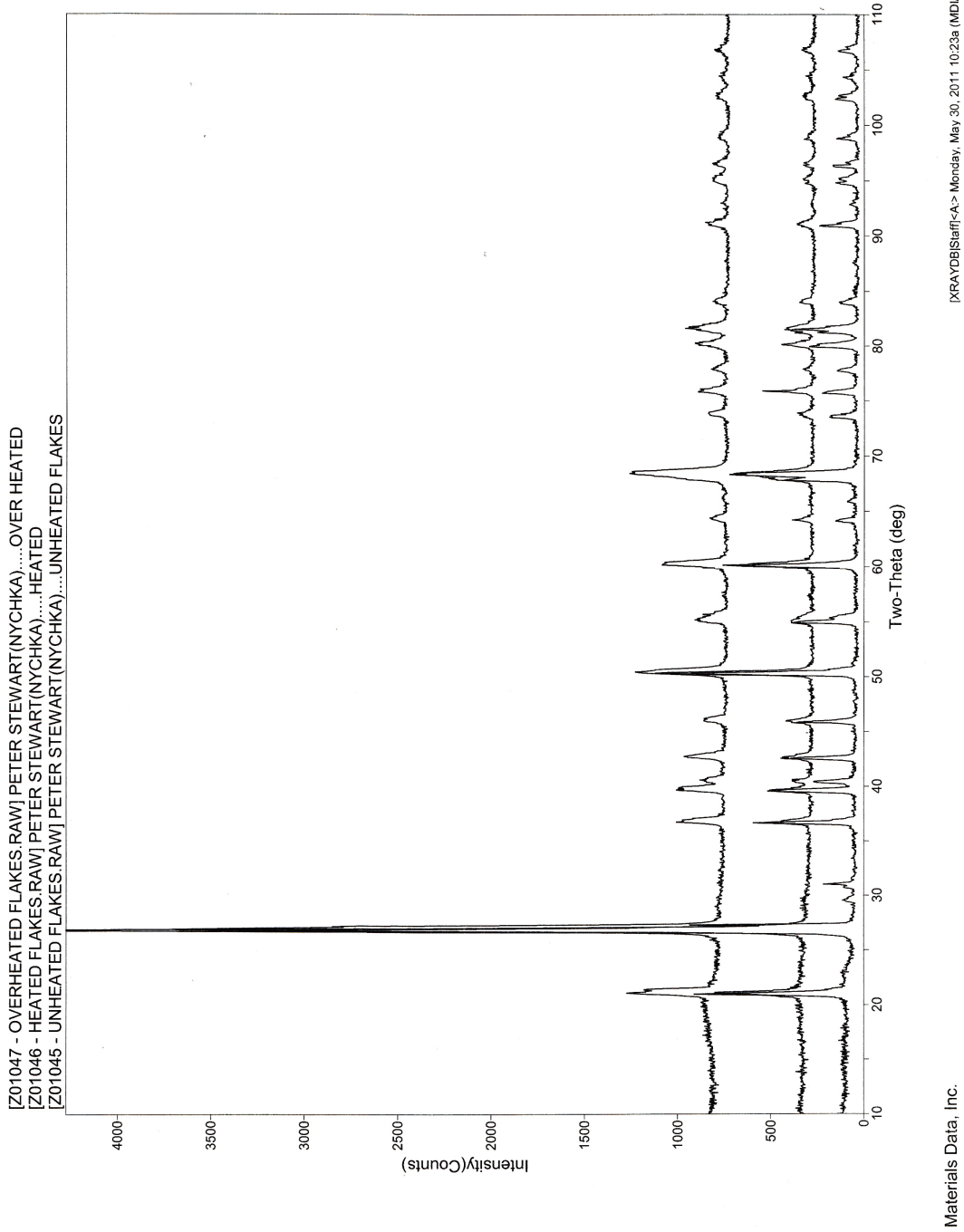

Figure 5.13: X-ray diffraction chart for overheated (top), heated (middle), and unheated (bottom) SRC.

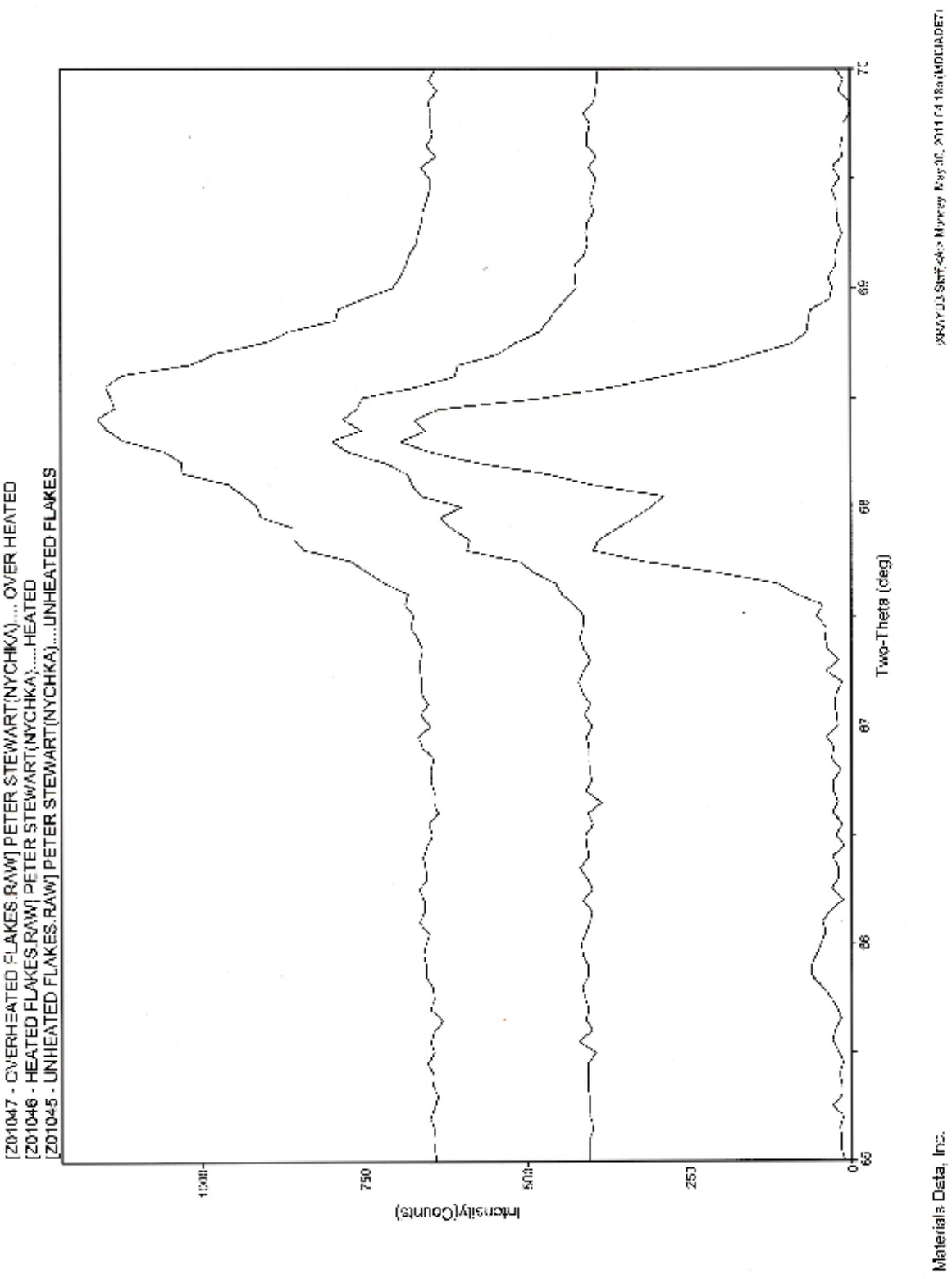

Figure 5.14: Close up of the 212 peak in overheated (top), heated (middle), and unheated (bottom) SRC.

Chapter 6

Site Descriptions

The archaeological sites chosen for this study are in Alberta and were investigated between 1980 and 2007. The Archaeological Survey of Alberta, located in Old St. Stephen's College at the University of Alberta, contains all the site reports, final reports, and the site database that were used for this study. The artifacts themselves are curated by the Royal Alberta Museum, and are currently being held in their warehouse.

I took several steps to mitigate the effects of certain environmental and anthropogenic factors on the artifacts. Some of the sites that had SRC in their lithic assemblage were excluded from this study based on the following criteria:

1) Surfaces finds were not selected for this study, because their exposure to the elements may have had deleterious effects on the flake surface that could cause misleading results. Private donations were also excluded from this study. The overwhelming majority of private collections consist of projectile points and other assorted tools. Since the use wear on tools has the potential to give a false positive (i.e., smoother surfaces created by use rather than heat treating), only unaltered flakes are examined in this study; these are uncommon in private collections.
2) In order to make sure that I obtained a sample of a reasonable size, no sites were selected that had less than 50 flakes of SRC.

According to the Archaeological Survey of Alberta's site database, there are 226 sites in Alberta in which SRC has been found. The majority of these sites are isolated scatters consisting of less than 10 artifacts. A total of 12 sites were found that had at least 50 flakes of SRC, and 8 of these sites were selected for analysis. These sites are: EgPr-2, DjPk-1, DkPi-2, DlPd-3, FaOm-1, FaOm-22, EgPt-28, EdPd-24, and EfPl-254 (Fig. 6.2). Flakes were selected from each site by identifying which box or boxes had SRC in them. Once this examination had been accomplished, level bags were pulled from each box at random and all the SRC flakes were removed from each bag. This procedure was repeated until 50 flakes had been collected from each site. It was decided to select 50 flakes from each site in order to facilitate a more direct comparison with the results from chapter 5.

In total, 400 flakes were analyzed using the optical profilometer. The results of this analysis were then compared to the results of the experimental work to determine if the optical profilometer is an effective tool for detecting heat-treatment in SRC. In order to determine whether or not there is a relationship between the use of heat-treatment and particular stages of the lithic reduction sequence, all flakes were assigned to one of four size categories: 2-5.99 mm, 6-11.99 mm, 12-24.99 mm, and 25-50 mm.

In order to determine whether or not the profilometer results from the experimentally heat-treated SRC flakes can be applied to archaeological collections, a statistical test must be used. A test for normality using SOFA Statistics v 1.1.1 indicates that the distribution of roughness values for the lithics

examined do not meet any of the criteria for a normal distribution, a situation which limits the kind of statistical tests applicable. One possible explanation for the lack of normality in the distribution of these roughness values is that prehistoric groups may have been more selective in which lithic raw materials they collected than I was. It is likely that prehistoric people would have had an understanding of what "good" and "bad" SRC looked like, and preferentially selected higher quality pieces of SRC. This choice would cause the roughness values to concentrate around a smaller range of numbers, creating a non-parametric distribution that skews heavily to the left hand side of the chart (see Fig 6.1). For performing statistical analysis on these flakes, the Mann-Whitney U test is used once again, since it is designed for use on large sample sizes and samples that do not have a normal distribution.

For each lithic collection in this study, the Mann-Whitney U test is used to compare the roughness values of the archaeological flakes to the roughness values of the heated and unheated flakes that were analyzed in chapter 5. In each case we are testing two null hypotheses: 1) that the profilometer results from the experimentally heated flakes and those gathered from museum collections are similar; and 2) that the profilometer results from the unheated flakes from the experiments and the flakes from the museum are similar. Each null hypothesis will be rejected if its respective p-value is less than 0.01.

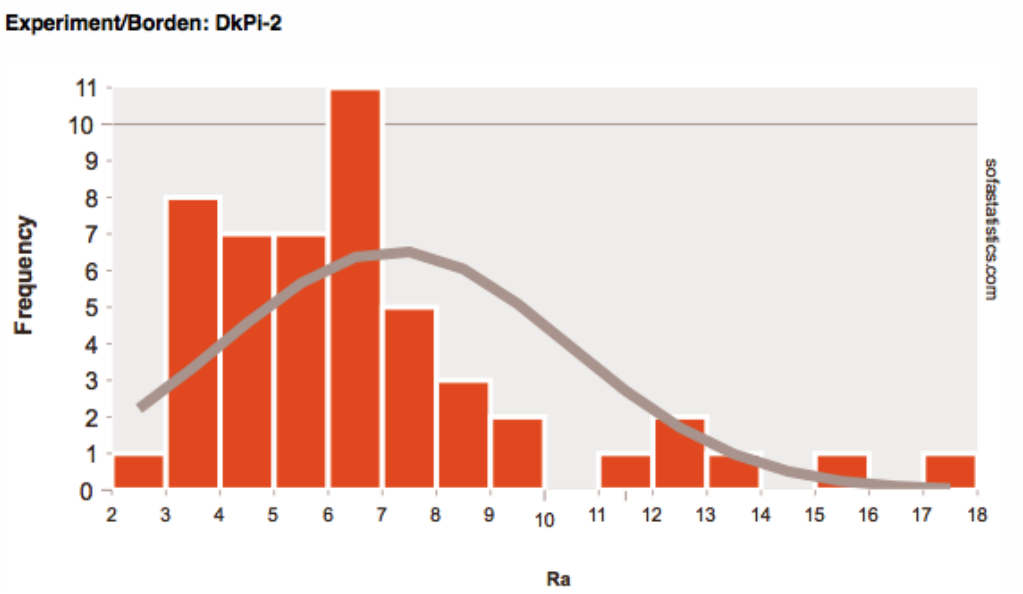

Figure 6.1: Distribution of R_a values for SRC flakes from DkPi-2 in comparison to a normal distribution curve.

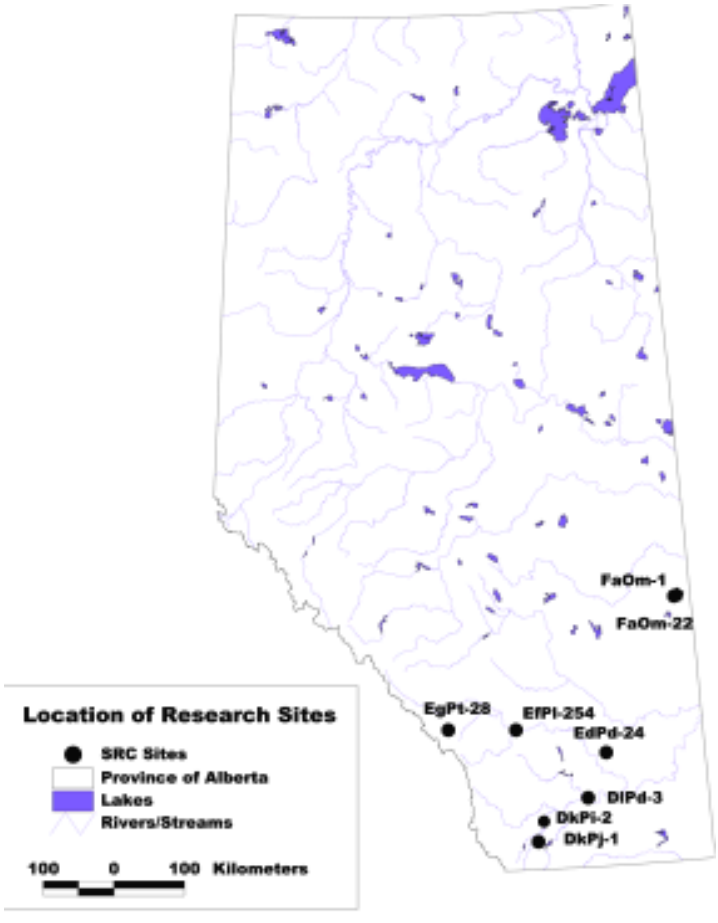

Figure 6.2: Location of sites studied for this thesis.

Site Collections Examined

DjPk-1

Commonly referred to as Head-Smashed-In Buffalo Jump (HSI), DjPk-1 is a bison kill site located in southwestern Alberta at the southern edge of the Porcupine Hills. To the east of the kill site, there is a shallowly buried blanket of cultural material that covers an estimated 500,000 m^2 (Brink and Dawe 1989:3). For this study, artifacts from the 1985-1986 field season were selected for study, as the site report specifically identifies and separates Swan River Chert from the other types of chert found at the site.

For the 1985-1986 field seasons, a total of six 2 m^2 x 2 m^2 units were excavated, all of which had cultural material. A total of 17,092 lithic artifacts were excavated, consisting of 15,523 pieces of debitage, 1,106 tools, 425 cores, and 38 ground and non-formed stone tools (Brink and Dawe 1989:183). Diagnostic projectile points include Old Women's, Avonlea, Besant, Pelican Lake, Bitterroot, and Oxbow, as well as some unnotched and shallow notched lanceolate points. Radiocarbon dates were also obtained, and seem to date occupation of this particular area to between 360 +/- 180 and 1,300 +/- 70 B.P. Of the 15,523 pieces of debitage that were collected, 2,734 of them were SRC. This represents 17.6% of the debitage that was collected.

The distribution of the R_a and rms values gathered from the profilometer are summarized in Figure 6.3 and Table 6.1.

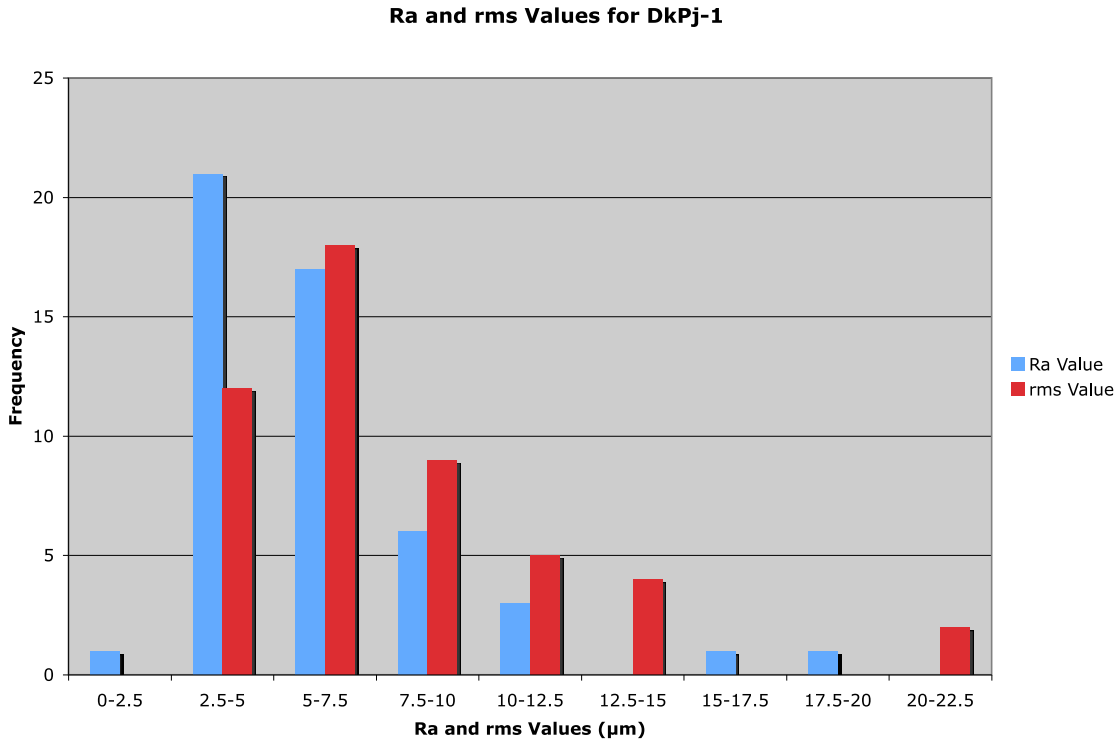

Figure 6.3: R_a and rms values for flakes from DkPj-1.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
DkPj-1	66456	Flake	6-11.99	n	0.2	5.324	8.12
DkPj-1	66551	Flake	6-11.99	y	0.3	6.259	7.609
DkPj-1	66552	Flake	12-24.99	y	1.7	10.205	12.583
DkPj-1	66553	Flake	6-11.99	n	0.1	8.76	11.298
DkPj-1	66554	Flake	6-11.99	n	<0.1	2.769	3.583
DkPj-1	66555	Flake	6-11.99	n	0.3	6.132	8.706
DkPj-1	66556	Flake	12-24.99	n	0.6	3.811	4.639
DkPj-1	66557	Flake	12-24.99	n	1.2	7.081	8.62
DkPj-1	66558	Flake	12-24.99	n	1.1	3.914	5.352
DkPj-1	66742	Flake	12-24.99	n	0.5	11.356	14.947
DkPj-1	66743	Flake	6-11.99	n	0.2	3.382	4.172
DkPj-1	66744	Flake	6-11.99	n	0.2	7.338	9.264
DkPj-1	66745	Flake	6-11.99	n	0.2	4.392	5.672
DkPj-1	66746	Flake	6-11.99	n	0.3	7.959	10.44
DkPj-1	66747	Flake	6-11.99	n	0.2	5.66	7.255
DkPj-1	67003	Flake	6-11.99	n	<0.1	3.337	4.145
DkPj-1	67004	Flake	6-11.99	n	0.3	6.578	8.024
DkPj-1	67005	Flake	6-11.99	n	0.2	4.622	6.732
DkPj-1	67006	Flake	12-24.99	n	1.3	5.148	6.487
DkPj-1	67250	Shatter	25-50	y	14.0	16.991	20.254

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
DkPj-1	67315	Flake	6-11.99	n	0.4	4.05	5.304
DkPj-1	67316	Flake	12-24.99	y	1.1	4.447	5.683
DkPj-1	67544	Flake	6-11.99	n	0.2	3.347	4.334
DkPj-1	67545	Flake	6-11.99	n	0.1	4.405	6.628
DkPj-1	68035	Flake	6-11.99	n	0.6	5.705	7.372
DkPj-1	68036	Shatter	12-24.99	n	1.0	5.748	7.352
DkPj-1	68129	Flake	25-50	n	4.6	2.502	3.296
DkPj-1	68343	Flake	6-11.99	n	0.3	9.744	12.932
DkPj-1	68344	Flake	6-11.99	n	0.3	6.072	7.262
DkPj-1	68345	Flake	6-11.99	n	0.2	17.801	21.06
DkPj-1	68346	Flake	6-11.99	n	0.1	4.793	6.127
DkPj-1	68347	Flake	6-11.99	n	0.2	5.282	6.398
DkPj-1	68348	Flake	6-11.99	n	0.3	9.53	11.771
DkPj-1	68349	Flake	6-11.99	n	0.1	3.754	4.918
DkPj-1	68350	Flake	6-11.99	n	0.1	10.655	12.734
DkPj-1	68425	Flake	6-11.99	n	0.2	6.471	7.832
DkPj-1	68426	Flake	6-11.99	n	0.2	4.001	4.958
DkPj-1	68489	Flake	12-24.99	n	1.1	2.709	3.486
DkPj-1	69657	Flake	6-11.99	n	0.1	3.686	4.616
DkPj-1	70122	Flake	12-24.99	n	0.5	4.513	5.775
DkPj-1	70123	Shatter	12-24.99	n	0.7	6.586	8.025
DkPj-1	70283	Flake	6-11.99	n	0.4	6.598	8.185
DkPj-1	70449	Flake	12-24.99	n	1.1	5.52	7.133
DkPj-1	70450	Shatter	6-11.99	n	0.2	4.922	6.005
DkPj-1	70451	Flake	6-11.99	n	0.2	2.607	3.287
DkPj-1	70452	Flake	6-11.99	n	0.1	8.124	10.195
DkPj-1	70635	Flake	12-24.99	n	0.4	8.631	10.851
DkPj-1	70636	Flake	12-24.99	n	0.4	2.049	2.547
DkPj-1	70811	Flake	12-24.99	n	0.8	5.688	7.177
DkPj-1	70812	Flake	12-24.99	n	3.1	4.685	5.595

Table 6.1: List of flakes analyzed from DkPj-1.

The average R_a and rms values for the flakes from DkPj-1 are 6.113 μm and 7.735 μm respectively. These values are very similar to the R_a average of 6.10 μm and the rms average of 7.75 μm from the experimental flakes. If the results from this test are compared to the results of the previous chapter, then we can determine that 39 out of 50 flakes meet the condition for being heat-treated, based on the R_a values. If the rms value is used to compare the two sets of data,

then the number drops to 30 out of 50 (heat-treated is defined in chapter 5 as having an R_a/rms value <7.5 μm). The Mann-Whitney U test compares the roughness values for flakes from DkPj-1 with the experimentally heated flakes, and provides a p-value of 0.962 for the R_a and 0.901 for the rms. In both instances the p-value is high enough that we can assume that the result is not statistically significant, so the first null hypothesis is not rejected. When the roughness values of the flakes from DkPj-1 are compared to the unheated flakes, the p-value for both the R_a and rms data is less than 0.001. This figure indicates that the result here is statistically significant, so the second null hypothesis is rejected.

FaOm-1 & FaOm-22

Located approximately 20 km southeast of the town of Provost and 1 km southwest of the town of Bodo, the Bodo Bison Skulls site (FaOm-1) and the Bodo Overlook site (FaOm-22) are located on the edge of a series of localized sand dunes. These sand dunes have been stabilized by a mixed vegetation community consisting of grasses, prickly rose, willow, aspen, and black poplar (Gibson 2007:9).

In 2002, the University of Alberta began conducting a field school on what was the western edge of FaOm-1. FaOm-22 was discovered in 2003, and in 2004 the eastern edge of this site was expanded and merged with FaOm-1 (Gibson 2007:9). Earliest occupation of these two sites seems to begin with Pelican Lake and continued into the protohistoric era.

These two sites were selected based on the large amounts of SRC that were collected during the 2006 Bodo Field School (Permit # 06-260) that was run by the University of Alberta. Unfortunately, a formal report has yet to be written for the excavations at FaOm-1 and FaOm-22 that were conducted under this permit, and only the artifacts from FaOm-1 have been given formal catalogue numbers. While this situation does not directly impact the flake analysis, the lack of a formal report makes it difficult to place any of the results within a larger context, as important pieces of information (e.g., total weight of SRC recovered, number of pieces of SRC debitage recovered, percentage of lithic assemblage that is SRC) are not available.

FaOm-22 Flake Data

The R_a and rms values of the SRC flakes from FaOm-22 are presented in Table 6.2 and summarized in Figure 6.3.

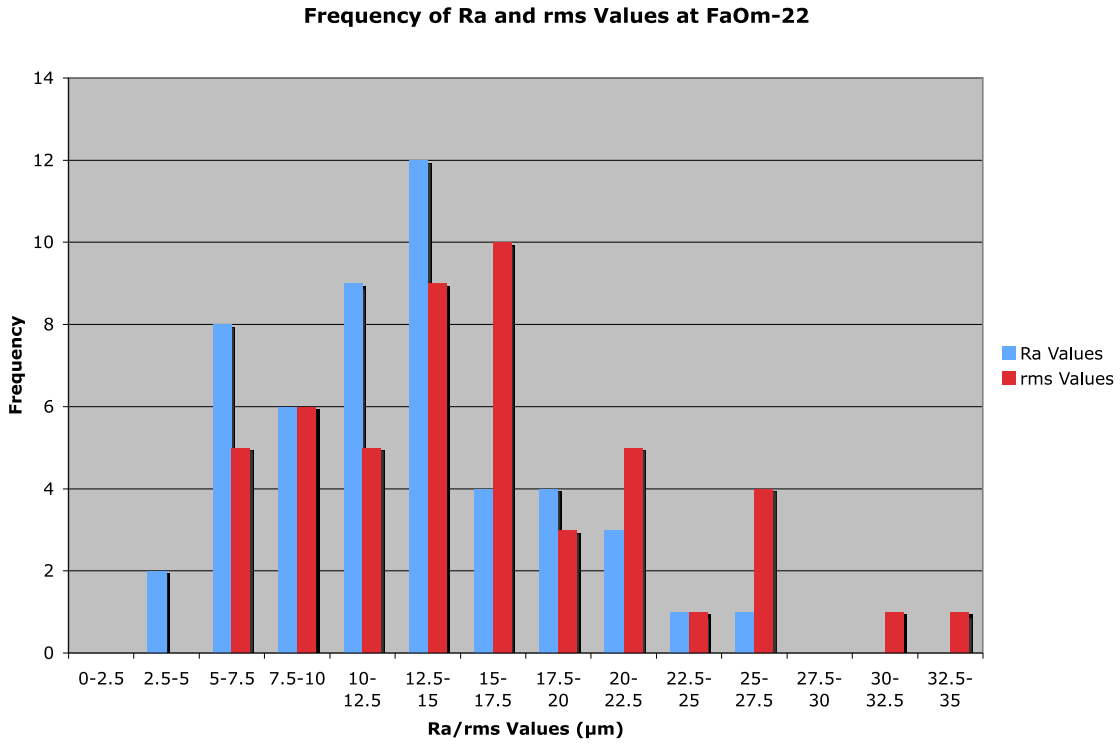

Figure 6.4: R_a and rms values for flakes from FaOm-22.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
FaOm-22	1	Flake	6-11.99	n	< 0.1	7.209	9.684
FaOm-22	2	Flake	12-24.99	n	0.4	16.828	20.596
FaOm-22	3	Flake	6-121.99	n	0.2	5.219	6.46
FaOm-22	4	Flake	12-24.99	n	2.2	17.589	21.999
FaOm-22	5	Flake	12-24.99	n	0.6	16.368	20.534
FaOm-22	6	Flake	12-24.99	n	1.4	7.254	9.296
FaOm-22	7	Flake	6-11.99	n	0.2	5.401	6.86
FaOm-22	8	Flake	25-50	y	6.5	13.617	17.246
FaOm-22	9	Flake	12-24.99	n	0.5	14.338	17.874
FaOm-22	10	Flake	25-50	n	23.4	10.307	13.575
FaOm-22	11	Flake	12-24.99	n	2.2	10.358	13.527
FaOm-22	12	Flake	25-50	n	17.8	8.243	10.093
FaOm-22	13	Flake	25-50	y	20.9	13.534	16.57
FaOm-22	14	Flake	25-50	n	4.7	18.311	21.5
FaOm-22	15	Flake	12-24.99	n	1.3	13.714	16.75
FaOm-22	16	Flake	6-11.99	n	0.1	11.427	13.722
FaOm-22	17	Flake	6-11.99	n	0.3	12.655	16.257
FaOm-22	18	Flake	12-24.99	n	1.3	20.77	27.324
FaOm-22	19	Flake	12-24.99	n	1.2	12.703	15.682
FaOm-22	20	Flake	6-11.99	n	0.3	24.526	31.757

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
FaOm-22	21	Flake	6-11.99	n	0.3	6.419	8.002
FaOm-22	22	Flake	6-11.99	n	0.2	13.241	16.128
FaOm-22	23	Flake	6-11.99	n	0.2	20.277	25.929
FaOm-22	24	Flake	6-11.99	n	0.3	8.854	11.074
FaOm-22	25	Flake	6-11.99	n	0.3	18.133	23.122
FaOm-22	26	Flake	12-24.99	n	0.4	6.381	8.809
FaOm-22	27	Flake	12-24.99	n	0.1	9.081	11.858
FaOm-22	28	Flake	12-24.99	n	0.4	15.104	19.497
FaOm-22	29	Flake	12-24.99	n	0.9	14.77	18.944
FaOm-22	30	Flake	25-50	y	5.1	5.101	6.617
FaOm-22	31	Flake	25-50	n	3.5	12.141	14.995
FaOm-22	32	Flake	12-24.99	n	2.6	9.9	12.318
FaOm-22	33	Flake	25-50	n	4.1	12.798	16.001
FaOm-22	34	Flake	25-50	n	4.6	12.42	14.938
FaOm-22	35	Flake	12-24.99	n	2.3	19.093	26.136
FaOm-22	36	Shatter	12-24.99	y	3.8	7.688	9.895
FaOm-22	37	Shatter	12-24.99	n	0.8	13.922	16.859
FaOm-22	38	Flake	12-24.99	y	2.3	4.248	5.206
FaOm-22	39	Flake	12-24.99	y	1.0	11.629	14.804
FaOm-22	40	Flake	25-50	n	4.6	15.835	20.37
FaOm-22	41	Flake	25-50	y	12.3	12.68	16.686
FaOm-22	42	Shatter	12-24.99	y	0.5	10.344	12.725
FaOm-22	43	Flake	25-50	y	11.6	8.316	10.641
FaOm-22	44	Flake	25-50	n	3.2	10.117	13.562
FaOm-22	45	Shatter	12-24.99	n	2.4	25.21	34.377
FaOm-22	46	Flake	6-11.99	n	< 0.1	7.386	9.256
FaOm-22	47	Flake	12-24.99	n	0.3	12.845	15.967
FaOm-22	48	Flake	6-11.99	n	0.1	4.228	5.32
FaOm-22	49	Flake	12-24.99	n	0.4	12.07	14.543
FaOm-22	50	Flake	12-24.99	n	2.1	21.169	25.63

Table 6.2: List of flakes analyzed from FaOm-22.

The average R_a value for these flakes is 12.44 μm, and the average rms is 15.75 μm. Out of all the flakes examined, only 10 out of 50 meet the requirement for being heat-treated. If the rms value is used, then only 5 of the flakes selected can be considered heat-treated. This result represents a significant departure from the average R_a and rms values of 6.10 μm and 7.75 μm respectively that the experimentally heat-treated flakes possess. When the R_a and rms values of the

flakes from FaOm-22 are compared to the experimentally heated flakes using the Mann-Whitney U test, the p-values for both sets of data is less than 0.001. With p-values that low, it can be assumed that the difference between the two data sets is statistically significant. When these flakes are compared to the unheated flakes from the experimental work, the p-value for the R_a values is 0.038 and for the rms values it is 0.032. Based on this result, the second null hypothesis cannot be rejected.

One possibility for this discrepancy may be found in the size of the flakes being analyzed. 76% (38/50) of the flakes selected from FaOm-22 fall anywhere between 12-50 mm in size. These large flakes may have come from an earlier stage of a reduction sequence, and may not have been subjected to heat-treatment. This idea that there is a possible relationship between flake size and heat-treatment will be discussed later in this chapter. Another possibility for these results may be the quality of the chert itself. The SRC recovered from this site is particularly vuggy; and many of the flakes have macroscopic, crystalline inclusions. These two factors make the flake surface much more uneven, and would have certainly contributed to the higher overall R_a and rms values.

FaOm-1 Flake Data

Despite their close proximity to each other, the roughness values for the flakes at FaOm-1 are radically different from those that were recovered from FaOm-22. The results of the flake analysis are summarized in Figure 6.5 and Table 6.3.

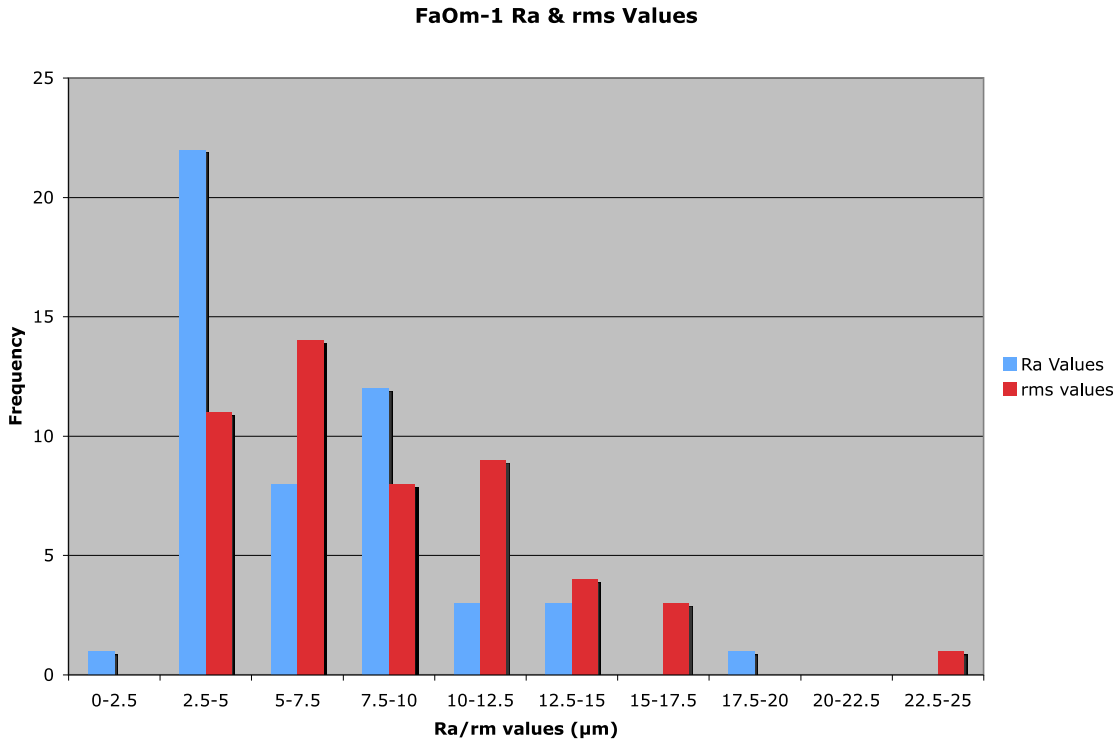

Figure 6.5: R_a and rms values for flakes from FaOm-1.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
FaOm-1	106228	Flake	12-24.99	n	0.6	11.85	14.92
FaOm-1	106229	Flake	12-24.99	n	0.2	10.164	12.754
FaOm-1	106230	Flake	12-24.99	n	0.2	7.749	9.421
FaOm-1	106240	Flake	6-11.99	n	0.1	2.855	3.915
FaOm-1	106241	Flake	6-11.99	n	0.1	3.423	4.291
FaOm-1	106242	Flake	6-11.99	n	0.2	8.288	11.076
FaOm-1	106243	Flake	6-11.99	n	0.1	3.462	4.687
FaOm-1	106244	Flake	6-11.99	n	0.1	3.389	4.13
FaOm-1	106245	Flake	6-11.99	n	0.1	3.735	5.06
FaOm-1	106246	Flake	6-11.99	n	0.2	9.006	10.784
FaOm-1	106247	Flake	6-11.99	n	0.2	13.415	16.216
FaOm-1	106248	Flake	6-11.99	n	0.1	5.845	7.6
FaOm-1	106249	Flake	6-11.99	n	0.2	6.037	7.181
FaOm-1	106264	Flake	2-5.99	n	< 0.1	9.254	11.295
FaOm-1	106265	Flake	2-5.99	n	< 0.1	11.483	14.116
FaOm-1	106266	Flake	2-5.99	n	< 0.1	8.289	10.237
FaOm-1	106499	Flake	6-11.99	n	0.1	7.149	9.337
FaOm-1	107996	Shatter	12-24.99	n	1.2	19.624	23.489
FaOm-1	107997	Shatter	12-24.99	n	1.8	7.067	8.51

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
FaOm-1	107998	Shatter	12-24.99	y	0.8	8.907	12.185
FaOm-1	107999	Flake	12-24.99	y	0.4	14.057	17.065
FaOm-1	108000	Flake	12-24.99	n	0.3	4.666	5.743
FaOm-1	108001	Flake	12-24.99	n	0.3	3.808	4.926
FaOm-1	108002	Flake	12-24.99	n	0.2	3.691	4.951
FaOm-1	108019	Flake	6-11.99	n	< 0.1	4.762	6.049
FaOm-1	108020	Flake	6-11.99	n	0.1	5.955	8.149
FaOm-1	108021	Flake	6-11.99	n	0.3	3.076	3.881
FaOm-1	108022	Flake	6-11.99	n	0.3	9.252	11.599
FaOm-1	108023	Flake	6-11.99	n	0.1	4.065	5.93
FaOm-1	108024	Flake	6-11.99	n	0.1	4.622	5.686
FaOm-1	108025	Flake	6-11.99	n	0.2	8.685	10.858
FaOm-1	108026	Flake	6-11.99	n	0.1	3.611	5.053
FaOm-1	108027	Flake	6-11.99	y	0.1	4.026	5.079
FaOm-1	108028	Flake	6-11.99	y	0.2	7.278	9.456
FaOm-1	108029	Flake	6-11.99	y	0.2	2.279	3.045
FaOm-1	108049	Flake	2-5.99	n	< 0.1	3.637	5.081
FaOm-1	108050	Flake	2-5.99	n	< 0.1	2.903	4.14
FaOm-1	108371	Flake	2-5.99	n	< 0.1	2.933	3.741
FaOm-1	110605	Flake	12-24.99	n	0.4	4.308	5.399
FaOm-1	112457	Shatter	25-50	y	3.6	4.411	5.424
FaOm-1	112458	Flake	25-50	n	3.2	4.175	5.41
FaOm-1	112477	Shatter	12-24.99	n	0.5	12.544	15.238
FaOm-1	112478	Shatter	12-24.99	n	0.3	7.767	10.141
FaOm-1	112479	Shatter	12-24.99	n	0.4	4.914	6.298
FaOm-1	112480	Shatter	12-24.99	n	0.5	3.627	4.659
FaOm-1	112481	Shatter	12-24.99	n	0.3	9.315	12.632
FaOm-1	114217	Flake	12-24.99	n	1.0	8.278	9.67
FaOm-1	114218	Shatter	12-24.99	n	0.5	7.43	9.281
FaOm-1	114219	Shatter	12-24.99	y	0.8	8.851	11.338
FaOm-1	114222	Shatter	6-11.99	n	0.2	5.394	6.743

Table 6.3: List of flakes analyzed from FaOm-1.

The average R_a value for the flakes analyzed from FaOm-1 is 6.71 μm, and the average rms value is 8.48 μm. These results seem to compare favourably with the experimental R_a and rms values. When the R_a value is used, 30 of 50 flakes can be defined as being heat-treated. If the rms value is used, then 25 out of 50 flakes can be considered heat-treated. The Mann-Whitney U test comparing

the R_a value of the flakes from FaOm-1 to the experimental flakes provides a p-value of 0.610; and when it is used to compare the rms values, it provides a p-value of 0.581. When the p-values are this high, we can assume that the results are not statistically significant; so the first null hypothesis is not rejected. Comparing the R_a and rms values of these flakes with the unheated flakes from the experimental work yields a p-value of less than 0.001 in both instances, indicating that there is a statistically significant difference between the two data sets. Based on this result, the null hypothesis that there is a relationship between the flakes from FaOm-1 and unheated flakes of SRC from the experimental work is rejected.

DlPd-3

Located 15 km northeast of Coaldale, Alberta, along a flood plain of the Oldman River, the Ross Site (DlPd-3) was first excavated under the direction of Dr. Richard Forbis in 1957 and again in 1980 by Rod Vickers. Dr. Forbis (1960) interpreted the Ross site as a winter campsite, based on the location of the site and ethnographic analogy. Cultural materials associated with the site may represent as many as six occupations that all occurred during the Old Women's Phase (~1400-1700 A.D.) (Vickers 1987:1). The site has yielded a diverse array of artifacts including stone and bone tools, shell and bone beads, pottery, and broken or comminuted animal bones. Activities that are believed to have occurred at this site include: tool and ornament manufacturing, animal butchering and roasting, as well as grease extraction.

A total of 782 pieces of debitage was recovered from this site during the 1980 excavation, and 201 of these pieces (25.7% of the assemblage) are SRC. Fifty of these flakes were removed from the collection to be analyzed with the optical profilometer. The results of the profilometer scans are summarized in Figure 6.6 and Table 6.4.

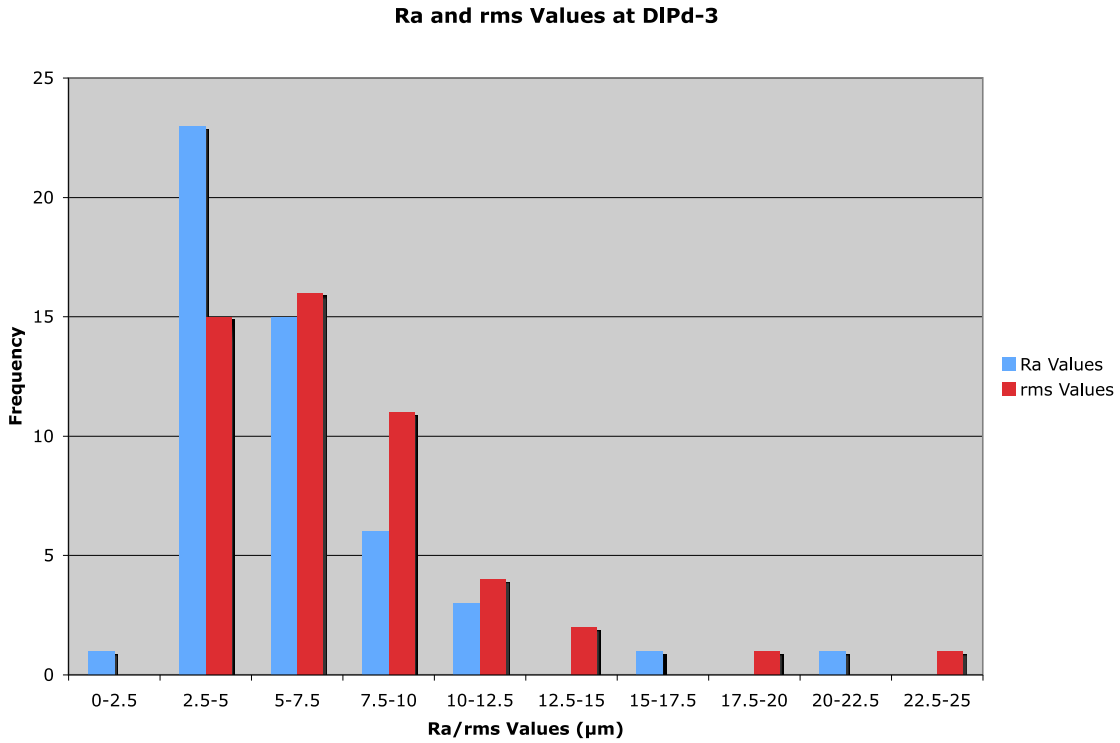

Figure 6.6: R_a and rms values for flakes from DlPd-3.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
DlPd-3	2147	Flake	12-24.99	n	0.7	3.815	5.099
DlPd-3	2149	Flake	2-5.99	n	< 0.1	20.27	23.22
DlPd-3	2152	Flake	12-24.99	n	4.1	4.033	6.743
DlPd-3	2155	Flake	12-24.99	y	0.6	6.527	8.409
DlPd-3	2157	Flake	12-24.99	n	1.7	10.067	14.156
DlPd-3	2166	Flake	12-24.99	n	0.6	10.332	12.342
DlPd-3	2175	Flake	6-11.99	n	0.1	2.674	3.703
DlPd-3	2176	Flake	2-5.99	n	< 0.1	3.391	4.283
DlPd-3	2177	Shatter	6-11.99	n	0.1	3.239	4.059
DlPd-3	2178.02	Flake	2-5.99	n	< 0.1	4.174	5.285
DlPd-3	2178.03	Flake	2-5.99	n	< 0.1	3.666	4.614

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
DlPd-3	2180	Flake	6-11.99	n	0.1	7.472	9.413
DlPd-3	2468.23	Flake	2-5.99	n	< 0.1	2.939	3.57
DlPd-3	2468.24	Flake	2-5.99	n	< 0.1	3.336	4.189
DlPd-3	2468.25	Flake	2-5.99	n	< 0.1	3.803	5.715
DlPd-3	2468.26	Flake	2-5.99	n	< 0.1	4.208	5.214
DlPd-3	2468.27	Flake	2-5.99	n	< 0.1	5.397	7.514
DlPd-3	2538.12	Flake	2-5.99	n	< 0.1	4.19	5.224
DlPd-3	2538.13	Flake	2-5.99	n	< 0.1	3.979	4.858
DlPd-3	2538.14	Flake	2-5.99	n	< 0.1	7.526	9.633
DlPd-3	2538.15	Flake	2-5.99	n	< 0.1	6.856	8.915
DlPd-3	2538.16	Flake	2-5.99	n	< 0.1	5.675	6.94
DlPd-3	2538.17	Flake	2-5.99	n	< 0.1	6.877	8.468
DlPd-3	2538.18	Flake	2-5.99	n	< 0.1	3.171	4.364
DlPd-3	2538.19	Flake	2-5.99	n	< 0.1	3.852	4.904
DlPd-3	2538.21	Flake	2-5.99	n	< 0.1	5.223	6.014
DlPd-3	2538.22	Flake	2-5.99	n	< 0.1	5.556	6.84
DlPd-3	2692.011	Flake	6-11.99	n	0.1	5.684	7.211
DlPd-3	2692.012	Flake	6-11.99	n	0.3	4.258	5.391
DlPd-3	2692.013	Flake	6-11.99	n	0.3	8.135	10.233
DlPd-3	2692.016	Flake	6-11.99	n	0.1	8.979	11.299
DlPd-3	2692.017	Flake	6-11.99	n	< 0.1	4.581	5.975
DlPd-3	2692.018	Flake	6-11.99	n	< 0.1	2.779	3.668
DlPd-3	2692.019	Flake	6-11.99	n	< 0.1	11.742	14.515
DlPd-3	2692.71	Flake	6-11.99	n	0.2	2.533	3.365
DlPd-3	2695.01	Flake	12-24.99	n	2.0	6.717	8.384
DlPd-3	2695.02	Flake	12-24.99	n	0.9	5.741	7.149
DlPd-3	2795	Shatter	6-11.99	n	0.4	7.748	9.353
DlPd-3	2796	Flake	12-24.99	n	0.9	5.788	7.327
DlPd-3	2797	Flake	12-24.99	n	1.0	3.839	4.878
DlPd-3	2849.01	Shatter	6-11.99	n	0.3	2.17	2.795
DlPd-3	2849.02	Shatter	6-11.99	n	0.1	9.358	11.671
DlPd-3	2906.01	Flake	6-11.99	n	0.2	5.143	6.249
DlPd-3	2906.04	Flake	6-11.99	n	0.1	3.426	4.239
DlPd-3	2914.02	Flake	6-11.99	n	0.5	6.094	7.825
DlPd-3	2914.06	Flake	12-24.99	n	0.3	15.464	19.165
DlPd-3	2914.07	Flake	2-5.99	n	< 0.1	4.199	5.112
DlPd-3	2914.11	Flake	6-11.99	n	0.1	6.236	8.063
DlPd-3	2538.20	Flake	2-5.99	n	< 0.1	7.998	9.969
DlPd-3	2692.010	Flake	12-24.99	n	0.5	3.708	4.592

Table 6.4: List of flakes analyzed from DlPd-3.

The R_a and rms values for the flakes from DlPd-3 are 5.90 μm and 7.44 μm respectively. Based on the R_a value, 39 out of 50 flakes meet the criterion for being heat-treated; and using the rms value, 32 out of the 50 flakes meet the criterion for heat-treatment. These results also compare favourably with the experimental results. When the Mann-Whitney U test is used to compare the R_a values, a p-value of 0.499 results; and when it is used on the rms values, the p-value is 0.504. With p-values this high, it is assumed that the difference between the two sets of data is not statistically significant, so the first null hypothesis cannot be rejected. When the roughness values of the unheated, experimental flakes are compared to the roughness values of the flakes from DlPd-3, the p-values of both the R_a and rms are less than 0.001. This result indicates that there is a statistically significant difference between these two sets of data. Based on this result, the second null hypothesis, that there is a relationship between the unheated, experimental flakes and the flakes from DlPd-3, can be rejected.

DkPi-2

DkPi-2, also known as the Junction Site, is a bison kill and processing site located 2 km west of the town of Fort Macleod on the northwest corner of the intersection of Highways 2 and 3 (Unfreed 1993:3). The site is made up of a low river terrace and an upper prairie (Unfreed and Van Dyke 2005). Excavation at this site focused on the low terrace, where the bison kill and processing debris were located. The sediments at the site were divided into three components: Components I and II contained artifacts associated with the Old Women's phase, while Component III contained historic material (Unfreed 1992:138-139).

Samples sent off for radiocarbon dating yielded dates of 800 B.P. and 500 B.P. for Components I and II respectively (Unfreed 1992:139). Lithic artifacts recovered from this site include Cayley series projectile points, bifaces, scrapers, choppers, wedges, cores, and flakes. Examples of non-lithic artifacts recovered include: bone and antler tools as well as shell ornaments. Ceramics were also recovered from this site, and were identified as Late Variant pottery from the Saskatchewan Basin complex.

A total of 251 SRC flakes were recovered from the excavations at DkPi-2. This represents approximately 2.3% of the total amount of debitage recovered (Unfreed 1992:612). 50 of these flakes were removed for analysis, and the results are illustrated in Figure 6.7 and Table 6.5.

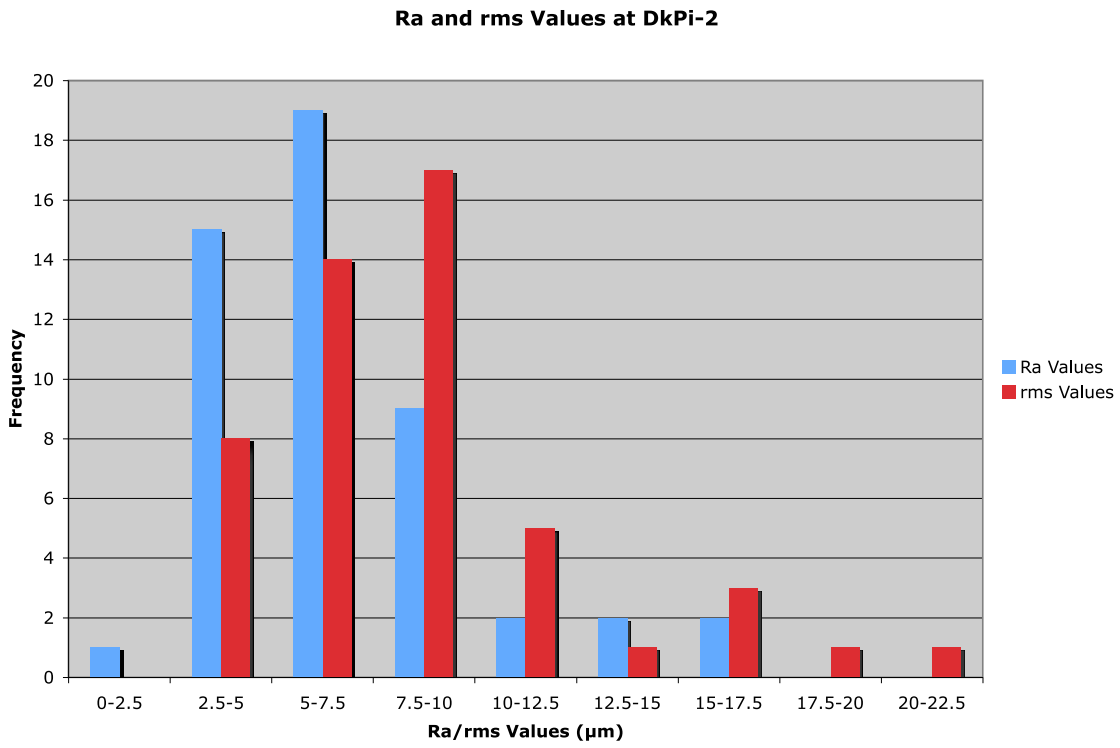

Figure 6.7: R_a and rms values for flakes from DkPi-2.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
DkPi-2	210888	Shatter	12-24.99	n	0.2	4.884	5.858
DkPi-2	210927	Flake	12-24.99	n	2.3	5.453	8.39
DkPi-2	212351	Flake	25-50	n	2.8	9.414	12.298
DkPi-2	212865	Flake	25-50	n	11.6	15.962	19.694
DkPi-2	212891	Flake	25-50	n	8.7	6.961	9.052
DkPi-2	212910	Flake	12-24.99	n	0.5	6.394	7.776
DkPi-2	212954	Shatter	25-50	y	9.5	11.932	15.84
DkPi-2	216196	Flake	25-50	n	5.4	17.427	20.442
DkPi-2	216267	Flake	12-24.99	n	1.7	6.673	8.382
DkPi-2	216285	Shatter	25-50	n	12.2	12.64	16.742
DkPi-2	216299	Flake	12-24.99	n	0.5	7.125	9.41
DkPi-2	216384	Flake	12-24.99	n	1.5	8.405	11.372
DkPi-2	216432	Flake	12-24.99	n	2.7	5.407	7.012
DkPi-2	216447	Flake	25-50	n	18.7	8.124	10.51
DkPi-2	216611	Flake	12-24.99	n	1.4	3.787	4.892
DkPi-2	216619	Shatter	12-24.99	n	0.5	6.844	9.202
DkPi-2	216708	Flake	12-24.99	n	1.1	2.018	2.586
DkPi-2	216713	Flake	12-24.99	n	2.2	3.202	4.489
DkPi-2	216714	Flake	12-24.99	n	0.3	5.337	6.447
DkPi-2	216715	Flake	6-11.99	n	0.2	3.671	4.648
DkPi-2	216756	Flake	6-11.99	n	0.2	3.404	4.226
DkPi-2	216764	Flake	12-24.99	n	0.8	3.392	4.374
DkPi-2	216772	Flake	25-50	y	11.9	7.598	9.501
DkPi-2	216798	Flake	12-24.99	n	4.1	6.225	8.23
DkPi-2	216799	Flake	2-5.99	n	< 0.1	4.076	5.015
DkPi-2	216800	Flake	6-11.99	n	< 0.1	4.149	5.066
DkPi-2	216801	Flake	2-5.99	n	< 0.1	9.328	12.181
DkPi-2	216902	Flake	6-11.99	n	< 0.1	7.554	9.158
DkPi-2	216998	Flake	2-5.99	n	< 0.1	5.941	7.29
DkPi-2	216999	Flake	2-5.99	n	0.1	5.888	7.622
DkPi-2	217006	Flake	6-11.99	n	0.4	4.735	5.828
DkPi-2	217009	Flake	12-24.99	n	0.6	13.06	15.607
DkPi-2	217010	Flake	6-11.99	n	0.1	6.107	7.388
DkPi-2	217011	Flake	2-5.99	n	< 0.1	3.31	4.048
DkPi-2	217012	Flake	2-5.99	n	< 0.1	5.413	6.752
DkPi-2	217013	Flake	2-5.99	n	< 0.1	4.615	5.584
DkPi-2	217014	Flake	2-5.99	n	< 0.1	4.843	6.385
DkPi-2	217025	Flake	25-50	n	3.4	8.149	10.51
DkPi-2	217198	Flake	12-24.99	n	3.5	12.132	14.724
DkPi-2	217211	Flake	25-50	n	4.7	5.105	6.655
DkPi-2	217342	Flake	12-24.99	n	0.8	7.757	9.373
DkPi-2	217369	Shatter	6-11.99	n	0.4	4.841	5.789
DkPi-2	217370	Flake	6-11.99	n	0.3	7.963	9.89

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
DkPi-2	217515	Flake	12-24.99	n	0.9	6.068	7.583
DkPi-2	217641	Flake	12-24.99	n	1.7	6.727	9.39
DkPi-2	218131	Flake	12-24.99	n	0.6	6.46	8.415
DkPi-2	218132	Flake	12-24.99	n	0.4	6.495	9.063
DkPi-2	219832	Flake	12-24.99	n	1.0	3.79	5.076
DkPi-2	219833	Flake	12-24.99	n	2.0	3.242	4.189
DkPi-2	220166	Flake	12-24.99	n	1.0	6.316	8.128

Table 6.5: List of flakes analyzed from DkPi-2.

The average R_a value for the flakes from DkPi-2 is 6.73 μm, and their average rms value is 8.56 μm. A Mann-Whitney U test yields a p-value of 0.324 for the R_a values, and a p-value of 0.300 for the rms values. These p-values indicate that the difference between the flakes from DkPi-2 and the experimentally heated flakes is not statistically significant. Based on this result, the null hypothesis that there is a relationship between these two sets of data cannot be rejected. When the R_a and rms values of the flakes from DkPi-2 and the unheated, experimental flakes are compared, the resulting p-values are both less than 0.001. This result indicates that the difference between the two sets of data is statistically significant, so the second null hypothesis is rejected in this instance.

EfPl-254

EfPl-254 is a prehistoric campsite located along the south rim of the Bow River Valley, southeast of Calgary, in 16-4-22-29-W4M; and was discovered during a Historical Resource Impact Assessment (HRIA) for Upper Lakes Group, Inc. (Gryba 2007:ii). A total of 180 m^2 was excavated, resulting in the recovery of archaeological material that spans approximately the last 5,000-6,000 years.

Based on the identification of projectile points, the earliest occupation of this site appears to take place during the Oxbow Phase, with the site also being used by successive Duncan/McKean, Pelican Lake, Besant, and Late Prehistoric groups of people (Gryba 2007:34-35). Charcoal samples taken from two hearth features at the site provided dates of 140 +/- 40 and 120 +/- 40 ^{14}C yr B.P., while a third radiocarbon sample from a piece of charred wood gave a 180 +/- 40 ^{14}C yr B.P. These dates, along with the absence of European trade goods, suggest that the site was last used during the late part of the Old Women's Phase (Gryba 2007:39).

A total of 7,051 pieces of lithic debitage were recovered from this site, with the majority (57.11%) being locally sourced siltstones and quartzites (Gryba 2007:51). One hundred and forty four of the flakes that were recovered were identified as SRC. This represents approximately 2.04% of the total amount of debitage recovered. The results of the analysis of the SRC flakes selected from this site are summarized in Figure 6.8 and Table 6.6.

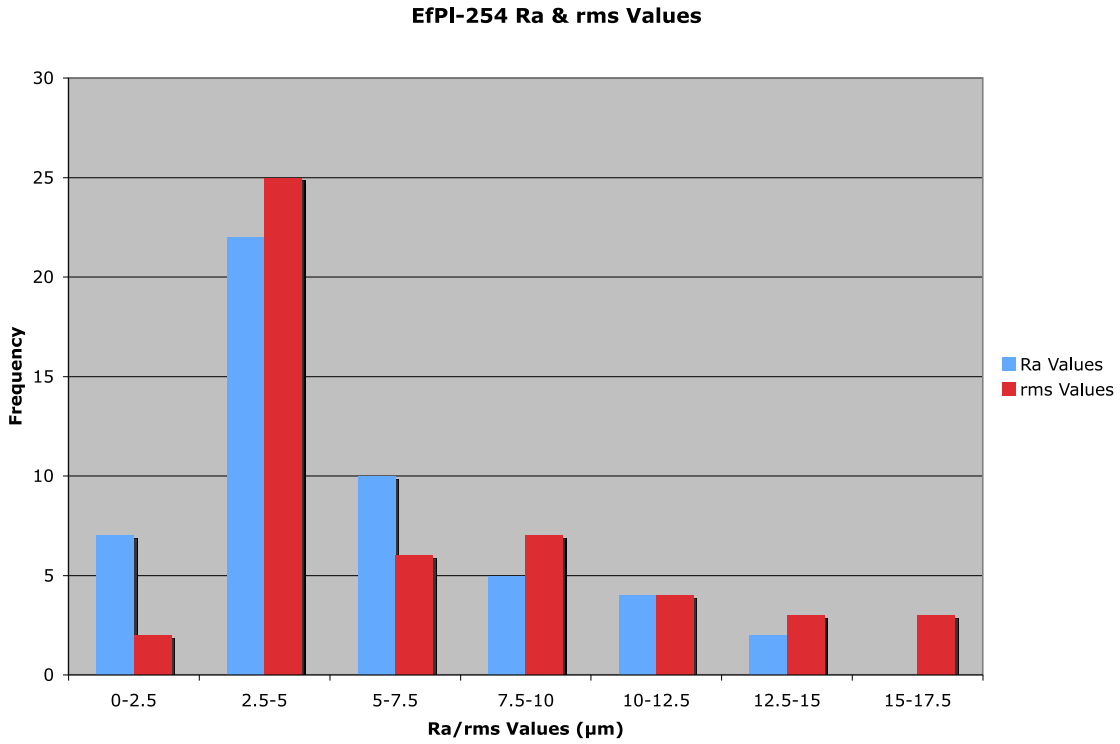

Figure 6.8: R_a and rms values for flakes from EfPl-254.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
EfPl-254	799	Flake	6-11.99	N	0.4	6.701	8.759
EfPl-254	800	Flake	6-11.99	n	0.2	8.321	10.693
EfPl-254	809	Flake	2-5.99	n	0.1	7.457	9.263
EfPl-254	810	Flake	2-5.99	n	0.1	10.88	13.673
EfPl-254	811	Flake	6-11.99	n	0.6	10.638	13.043
EfPl-254	812	Flake	2-5.99	n	0.2	9.694	11.336
EfPl-254	813	Flake	6-11.99	n	0.2	2.596	3.3
EfPl-254	816	Flake	2-5.99	n	0.1	2.985	3.736
EfPl-254	817	Flake	2-5.99	n	0.1	4.989	6.33
EfPl-254	825	Flake	6-11.99	n	0.5	2.214	2.92
EfPl-254	845	Flake	6-11.99	n	0.4	2.986	3.968
EfPl-254	846	Flake	12-24.99	n	1.4	12.352	16.823
EfPl-254	847	Flake	6-11.99	n	0.5	2.695	3.332
EfPl-254	848	Flake	6-11.99	n	0.5	5.714	7.354
EfPl-254	849	Flake	6-11.99	n	0.3	2.979	3.897
EfPl-254	880	Flake	6-11.99	n	0.3	4.008	4.899
EfPl-254	881	Flake	6-11.99	n	0.4	6.324	8.232
EfPl-254	882	Flake	2-5.99	n	0.1	6.36	7.778
EfPl-254	883	Flake	6-11.99	n	0.6	3.655	4.798

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
EfPl-254	884	Flake	2-5.99	n	0.3	3.428	4.79
EfPl-254	885	Flake	2-5.99	n	0.2	5.838	7.36
EfPl-254	909	Flake	6-11.99	n	0.2	6.71	8.618
EfPl-254	910	Flake	6-11.99	n	0.2	2.427	3.008
EfPl-254	947	Flake	12-24.99	n	0.3	1.731	2.188
EfPl-254	948	Flake	12-24.99	n	0.5	2.833	3.755
EfPl-254	958	Flake	6-11.99	n	0.2	1.72	2.161
EfPl-254	959	Flake	6-11.99	y	0.2	3.174	4.147
EfPl-254	1080	Flake	12-24.99	n	0.6	2.583	3.235
EfPl-254	1081	Flake	6-11.99	n	0.1	13.235	15.869
EfPl-254	3675	Flake	2-5.99	n	<0.1	3.277	4.243
EfPl-254	3740	Flake	6-11.99	n	0.1	3.36	4.193
EfPl-254	3741	Flake	6-11.99	n	0.1	2.069	2.597
EfPl-254	3742	Flake	2-5.99	n	0.1	2.528	3.29
EfPl-254	3743	Flake	2-5.99	n	<0.1	2.856	3.602
EfPl-254	3744	Flake	2-5.99	n	0.1	3.683	4.657
EfPl-254	3754	Flake	2-5.99	n	<0.1	2.317	3.057
EfPl-254	3755	Flake	6-11.99	n	0.1	8.738	10.902
EfPl-254	3803	Flake	6-11.99	n	0.1	2.833	3.529
EfPl-254	3809	Flake	2-5.99	n	0.1	1.994	2.537
EfPl-254	3810	Flake	2-5.99	n	0.1	2.96	3.645
EfPl-254	3811	Flake	6-11.99	n	0.1	3.175	4.01

Table 6.6: List of flakes analyzed from EfPl-254.

The flakes collected from EfPl-254 have an average R_a value of 5.276 μm, and an average rms value of 6.664 μm. The Mann-Whitney U test gives a p-value of 0.034 for the R_a values, and a p-value of 0.028 for the rms values. These p-values indicate that the difference between the flakes from EfPl-254 and the experimentally heated flakes is not statistically significant, so the first null hypothesis cannot be rejected. The p-values for the comparison of the R_a and rms values of the unheated, experimental flakes and the flakes from EfPl-254 are both less than 0.001, indicating that there is a statistically significant difference

between these two sets of data. Based on this result, the second null hypothesis is rejected.

EdPd-24

EdPd-24 was discovered during a Historical Resource Impact Assessment (HRIA) for ConocoPhillips Canada Resources Ltd. Of Calgary, AB. EdPd-24 is an artifact scatter that lies along a proposed pipeline tie-in route in 14-20-18-19 W4 of the Majorville locality of southern Alberta (Rollans 2002:22). During the 2005 field season, 15.4 m^2 were excavated, and while no datable material was recovered, based on the style of projectile points recovered, the site has been associated with a Besant occupation (Rollans 2005:67). A total of 390 pieces of lithic debitage were collected from this site, with the collection dominated by SRC. 154 pieces of the debitage recovered have been identified as SRC, representing 39.49% of all the lithics recovered (Rollans 2005:62). The other main material type recovered from this site is quartzite, which makes up 26.92% (105 pieces) of the lithic assemblage. The results of the analysis of the flakes from this site are illustrated in Figure 6.9 and Table 6.7.

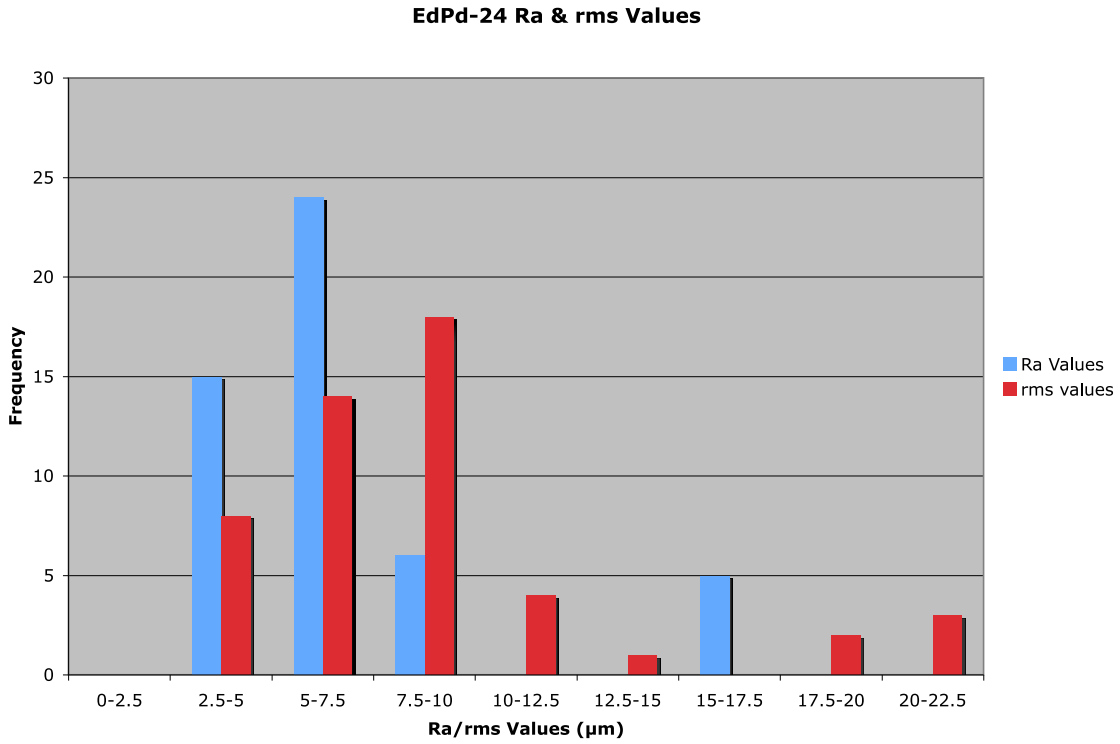

Figure 6.9: R_a and rms values for flakes from EdPd-24.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
EdPd-24	6	Flake	2-5.99	n	<0.1	6.644	8.672
EdPd-24	12	Flake	6-11.99	n	0.2	5.603	7.095
EdPd-24	14	Flake	2-5.99	n	<0.1	4.978	6.552
EdPd-24	21	Flake	6-11.99	n	0.6	5.84	7.5
EdPd-24	22	Flake	25-50	n	6.1	6.903	8.408
EdPd-24	24	Flake	6-11.99	n	0.3	7.719	9.844
EdPd-24	28	Flake	12-24.99	n	0.3	7.306	9.068
EdPd-24	32	Flake	12-24.99	n	3.8	7.067	8.727
EdPd-24	38	Flake	12-24.99	n	3.8	5.805	7.135
EdPd-24	42	Flake	6-11.99	n	0.8	4.248	5.397
EdPd-24	48	Flake	6-11.99	n	0.1	9.033	11.421
EdPd-24	67	Flake	12-24.99	n	1.1	3.453	4.391
EdPd-24	83	Flake	6-11.99	n	0.5	6.728	8.882
EdPd-24	85	Shatter	6-11.99	n	0.3	15.389	20.633
EdPd-24	86	Flake	6-11.99	n	0.3	9.459	11.965
EdPd-24	98	Flake	6-11.99	n	0.1	3.666	4.606
EdPd-24	100	Shatter	12-24.99	n	2.4	16.422	19.657
EdPd-24	101	Flake	6-11.99	n	0.3	5.264	6.426
EdPd-24	103	Flake	12-24.99	n	0.8	6.96	9.175
EdPd-24	107	Flake	6-11.99	n	0.1	3.433	4.551

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
EdPd-24	110	Flake	2-5.99	n	0.1	7.205	9.408
EdPd-24	113	Flake	12-24.99	n	2.2	6.863	9.061
EdPd-24	114	Flake	6-11.99	n	0.2	9.733	12.586
EdPd-24	207	Flake	6-11.99	n	0.1	16.742	20.317
EdPd-24	209	Shatter	6-11.99	n	0.3	5.217	7.016
EdPd-24	214	Flake	6-11.99	n	0.2	3.547	5.277
EdPd-24	220	Flake	6-11.99	n	<0.1	6.861	8.191
EdPd-24	271	Flake	12-24.99	n	1.2	4.907	6.48
EdPd-24	274	Flake	25-50	n	7.0	3.674	4.789
EdPd-24	283	Flake	6-11.99	n	0.2	8.59	10.636
EdPd-24	284	Flake	12-24.99	n	0.8	2.785	3.573
EdPd-24	286	Flake	12-24.99	n	0.6	5.254	6.235
EdPd-24	291	Flake	6-11.99	n	0.3	6.899	8.987
EdPd-24	294	Flake	6-11.99	n	0.1	15.836	18.961
EdPd-24	297	Flake	12-24.99	n	1.1	4.706	5.94
EdPd-24	300	Flake	6-11.99	n	0.6	7.456	9.457
EdPd-24	303	Flake	6-11.99	n	0.8	2.701	3.429
EdPd-24	304	Flake	6-11.99	n	0.3	5.052	7.674
EdPd-24	362	Flake	12-24.99	n	0.9	5.056	6.307
EdPd-24	363	Flake	6-11.99	n	0.4	7.218	8.714
EdPd-24	378	Flake	6-11.99	n	0.4	4.349	5.653
EdPd-24	379	Flake	6-11.99	n	0.2	3.139	3.953
EdPd-24	382	Flake	6-11.99	n	0.1	6.702	8.055
EdPd-24	384	Flake	6-11.99	n	0.4	6.099	8.06
EdPd-24	385	Flake	6-11.99	n	0.4	4.333	6.301
EdPd-24	397	Flake	6-11.99	n	0.3	5.724	7.305
EdPd-24	400	Flake	6-11.99	n	0.1	8.331	10.603
EdPd-24	401	Flake	6-11.99	n	0.2	7.333	9.995
EdPd-24	402	Flake	6-11.99	n	0.1	3.397	4.233
EdPd-24	403	Flake	6-11.99	n	0.1	16.579	20.339

Table 6.7: List of flakes analyzed from EdPd-24.

The average R_a value of the flakes from EdPd-24 is 6.884 μm, and the average rms value is 8.753 μm. Using the Mann-Whitney U test to compare these values with those from the experimental flakes yields p-values of 0.140 for the R_a values, and 0.111 for the rms values. These p-values indicate that the difference between the roughness values for the experimental flakes and the flakes from EdPd-24 is not significant, so the first null hypothesis is not rejected. When

comparing the R_a and rms values of the flakes from EdPd-24 and the unheated, experimental flakes, the p-value in both instances is less than 0.001. This result indicates that there is a statistically significant difference between the two sets of data; and as a result, the second null hypothesis is rejected.

EgPt-28

EgPt-28, also known as the Pigeon Mountain site, is a prehistoric occupation site located south of the Bow River and on the north side of the Trans Canada Highway, at the base of Pigeon Mountain in 7-18-24-9-W5M (Balcom, et al 1996: 40). The site was discovered during an HRIA completed for Canadian Western Natural Gas, in which regulatory clearance was sought for a natural gas pipeline west from Calgary, through the Bow Valley Corridor to Banff.

The site itself is comprised of two components separated by as much as 80 cm of fluvial sands and gravels, indicating that the Bow River had changed its course between the occupations (Clarke, et al 1998:ii). The upper component appears to be Late Prehistoric, based on the presence of small side-notched arrowheads. The lower component has been identified as Besant, based on the presence of Besant style projectile points and one Sandy Creek projectile point. Based on this observation, the authors of this report felt that the earliest occupation of the site happened some time around 2,400 and 1,400 B.P. (Balcom, et al 1996:45).

A total of 6,157 pieces of lithic debitage were recovered from the excavations at EgPt-28. The upper component is dominated by shale and SRC, which make up 38% (240 pieces) and 41% (256 pieces) of the assemblage

respectively (Clarke, et al. 1998: 92). Exotic materials, particularly Knife River Flint and obsidian, dominate the lower component of EgPt-28. These two material types together make up 78% of the lower occupation's lithic assemblage (Clarke, et al. 1998:117). Only two flakes of SRC were recovered from the lower occupation. This represents 0.04% of the lithic assemblage of the lower occupation.

The roughness values for the flakes from EgPt-28 are shown in Figure 6.10 and Table 6.8.

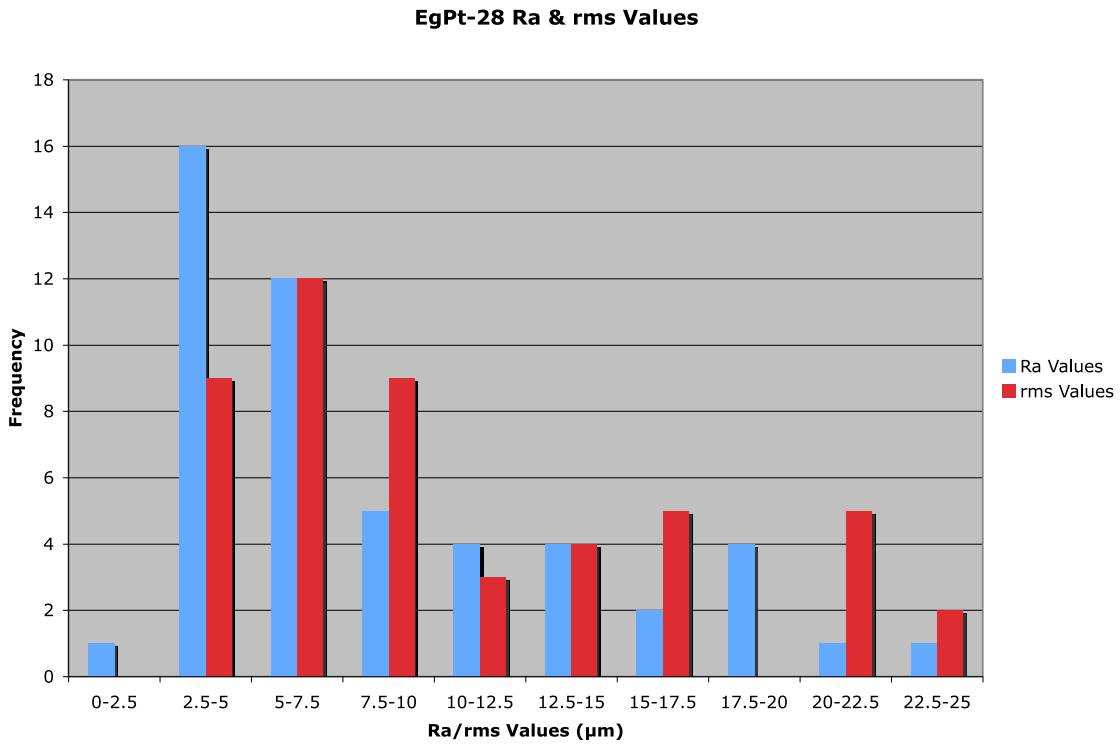

Figure 6.10: R_a and rms values for flakes from EgPt-28.

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
EgPt-28	7717	Flake	12-24.99	n	6.3	4.283	5.726
EgPt-28	7736	Flake	25-50	n	7.2	7.056	8.783
EgPt-28	7737	Flake	12-24.99	n	0.8	12.6	15.139
EgPt-28	7740	Flake	12-24.99	n	1.6	12.052	17.429

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
EgPt-28	7743	Flake	12-24.99	n	1.5	3.942	4.935
EgPt-28	7744	Flake	12-24.99	y	2.6	9.793	13.317
EgPt-28	7745	Flake	12-24.99	n	0.7	3.762	4.623
EgPt-28	7746	Flake	12-24.99	n	0.8	5.804	7.109
EgPt-28	7747	Flake	2-5.99	n	0.3	4.319	5.661
EgPt-28	7748	Flake	6-11.99	n	0.4	5.403	6.753
EgPt-28	7757	Flake	25-50	n	11.5	5.724	7.425
EgPt-28	7758	Flake	2-5.99	n	<0.1	7.064	9.35
EgPt-28	7759	Flake	12-24.99	n	2.1	11.854	15.233
EgPt-28	7760	Flake	12-24.99	n	0.6	3.891	4.912
EgPt-28	7761	Flake	6-11.99	n	0.4	4.438	5.62
EgPt-28	7762	Flake	12-24.99	n	1.1	4.471	5.868
EgPt-28	7763	Flake	6-11.99	n	0.2	4.839	6.202
EgPt-28	7764	Flake	6-11.99	n	0.3	8.419	10.947
EgPt-28	7765	Flake	12-24.99	n	0.8	2.827	3.785
EgPt-28	7766	Flake	6-11.99	n	0.2	4.732	6.41
EgPt-28	7767	Flake	6-11.99	n	0.2	6.89	8.337
EgPt-28	7768	Flake	6-11.99	n	0.3	2.516	3.154
EgPt-28	7769	Flake	6-11.99	n	0.3	3.755	4.738
EgPt-28	7770	Flake	6-11.99	n	0.3	3.127	3.93
EgPt-28	7771	Flake	6-11.99	n	0.1	2.316	2.859
EgPt-28	7772	Flake	6-11.99	n	0.4	2.589	3.29
EgPt-28	7847	Flake	12-24.99	n	5.6	6.641	8.753
EgPt-28	7848	Flake	25-50	y	11.7	4.805	6.023
EgPt-28	7849	Flake	25-50	n	6.6	5.973	7.94
EgPt-28	7850	Flake	25-50	n	5.1	6.375	8.039
EgPt-28	7851	Flake	12-24.99	n	2.3	6.026	7.633
EgPt-28	7852	Flake	12-24.99	n	3.3	5.934	8.134
EgPt-28	7853	Flake	12-24.99	n	3.9	4.095	5.278
EgPt-28	7854	Flake	6-11.99	n	0.3	5.129	6.586
EgPt-28	7855	Flake	12-24.99	n	0.6	8.559	10.937
EgPt-28	8040	Flake	25-50	n	5.5	17.808	21.775
EgPt-28	8041	Flake	12-24.99	n	2.6	17.114	22.208
EgPt-28	8042	Flake	12-24.99	n	2.1	12.528	16.379
EgPt-28	8044	Flake	12-24.99	n	3.2	11.702	14.289
EgPt-28	8045	Flake	12-24.99	n	2.6	23.108	28.109
EgPt-28	8046	Flake	12-24.99	n	2.1	12.542	14.887
EgPt-28	8047	Flake	12-24.99	n	1.7	17.912	22.226
EgPt-28	8048	Flake	12-24.99	n	1.6	7.65	9.489
EgPt-28	8049	Flake	12-24.99	n	1.7	11.177	14.008
EgPt-28	8050	Flake	12-24.99	n	1.1	20.392	24.392
EgPt-28	8051	Flake	12-24.99	n	2.1	8.102	10.84
EgPt-28	8052	Flake	12-24.99	n	0.7	15.256	20.033

Borden #	Catalogue #	Artifact Type	Size (mm)	Cortex (Y/N)	Weight (g)	R_a Value	rms Value
EgPt-28	8053	Flake	12-24.99	n	1.2	18.351	21.769
EgPt-28	8054	Flake	12-24.99	n	0.6	19.161	23.436
EgPt-28	8117	Flake	25-50	y	9.9	13.076	15.456

Table 6.8: List of flakes analyzed from EgPt-28.

The flakes from EgPt-28 have an average R_a value of 8.558 μm, and an average rms value of 10.803 μm. When these values are compared to the roughness values of the experimentally heated flakes using the Mann-Whitney U test, p-values of 0.035 and 0.031 are generated for the R_a and rms values respectively. These p-values indicate that the difference between the two sets of data cannot be considered statistically significant, so the first null hypothesis is not rejected. Comparing the roughness values of these flakes to those from the unheated, experimental flakes provides a p-value of 0.013 for the R_a value, and 0.019 for the rms value. The minimum threshold for rejecting the null hypothesis is a p-value that is 0.01, so the null hypothesis that there is a statistically significant relationship between the unheated, experimental flakes and the flakes from EgPt-28 also cannot be rejected.

A reason for both null hypotheses being rejected at this site may be related to the size of the flakes that were selected. Out of the 50 flakes that were selected for analysis, 29 of them fell into the 12-25 mm size category. Flakes that fall into this size range may include examples of both heat-treated and unheated flakes, so the strong bias towards this size category may be unintentionally skewing the results of this study. The next section explores the relationship between flake size and heat-treatment in more detail. In addition, further research at this site,

including an analysis of all of the SRC debitage from this site may help to determine what kind of reduction strategies were being employed on at this site.

Flake Size and Heat-Treatment

In order to examine the relationship between heat-treatment and flake size more closely, all the flakes were categorized by size (2-5.99, 6-11.99, 12-24.99 and 25-50 mm); and then compared to the experimentally heated flakes using the Mann-Whitney U test. The p-values for the R_a and rms values of the 2-5.99 mm and 6-11.99 mm flake sizes were 0.130 and 0.905 respectively. Based on these p-values, the first null hypothesis is not rejected for heated flakes and flakes that fall within the 2-5.99 mm and 6-11.99 mm size ranges. When the roughness values for the flakes in the 12-24.99 mm and 25-50 mm size ranges were run through the Mann-Whitney U test, we see a very different result. In both cases the p-value is less than 0.001. This result indicates that there is a statistically significant difference between the experimental data and the larger flake sizes, so the first null hypothesis is rejected for these two size categories.

The archaeological flakes were also compared to the unheated, experimental flakes, in an effort to determine what kinds of relationships exist there. In this instance the p-values for the R_a and rms flakes in the 2-5.99 and 6-11.99 mm size ranges were all less than 0.001. This result demonstrates that there is a statistically significant difference between these data sets, so the second null hypothesis can be rejected.

With the 12-24.99 mm size range, the p-values for the R_a and rms data are 0.007 and 0.011 respectively. This result suggests that there is likely also a

statistically significant difference between the archaeological flakes and the unheated, experimental flakes. A possible explanation for this size range rejecting both of the null hypotheses is that this particular size range might be common to both heat-treated and unheated flakes. With both varieties of flakes in this data set, there might be too much ambiguity in the data for the statistical analysis to allow any kind of conclusions.

The 25-50 mm size range yields p-values of 0.642 and 0.698 when its R_a and rms values are compared to those from the unheated, experimental flakes. Based on these p-values, the difference between the data sets is not considered statistically significant; and the second null hypothesis is not rejected.

A plausible way to interpret these data would be to suggest that large flakes are struck off first, in order to shape the stone roughly into the desired shape (e.g.- biface preform, prepared core). Once a rough shape has been achieved, the stone is then heated and final shaping can commence. This method of lithic reduction may have been carried out for two reasons: 1.) The final stages of tool production often rely on soft hammer and/or pressure flaking for the final shaping. The use of heat-treatment before these final stages would help to ensure that flakes come off in a consistent and predictable manner. 2.) By thinning out the stone as much as possible before heating, the knapper would also be able to reduce the chance that the stone is damaged as a result of differential expansion.

Discussion

In order to see if the roughness values of the experimentally heated SRC reflected the roughness values of SRC from known archaeological sites, a total of

400 flakes from 8 sites were selected for analysis. With the exception of EgPt-28, the R_a and rms values generated by the optical profilometer for all of the site assemblages examined corresponded well with the model from chapter 5. This result is a strong indication that the optical profilometer can be used successfully to develop objective criteria for determining whether or not a flake has been heat-treated.

By using the Mann-Whitney U statistical test to compare the roughness values of flakes from archaeological sites in Alberta with those examined in chapter 5, some unexpected results were observed. Flakes in the 12-24.99 mm size range generated some statistical ambiguity, as both null hypotheses could be rejected. It may be that unheated and heat-treated flakes both fall into this size category, so the statistical test may not be able to determine whether or not these flakes were likely to have been heat-treated. Further research into flakes in the 12-24.99 mm size range is necessary to address this ambiguity in the data.

Flakes larger than 25 mm were less likely to have been heat-treated than flakes that were in the 2-5.99 and 6-11.99 mm size ranges, suggesting that pieces of SRC were roughly worked before being heat-treated. Not only can the optical profilometer can be used successfully to determine whether or not a flake has been heat-treated: as a secondary benefit, it may also be possible to determine at what point in the lithic reduction sequence heat-treatment was used. This goal can be accomplished by comparing the experimentally derived roughness values to the roughness values of flakes in various size categories.

While previous investigations at these sites did recognize that heat-treatment was likely applied to the flakes of SRC, no further analysis was undertaken or suggested. By applying my methodology to these collections, 261 (65%) of the flakes selected for this study met the criterion for being heat-treated. There also seems to be a preference for heat-treating SRC in the later stages of the lithic reduction sequence. This conclusion is based on the fact that 173 of the 223 flakes (78%) that fell into the 2-5.99 and 6-11.99 mm size categories met the criteria for being heat-treated, while only 13 of the 36 (36%) flakes in the 25-50 mm size did so. Flakes that fall into the 12-24.99 mm size range are more problematic because both null hypotheses were rejected using the Mann-Whitney U test. There are 141 flakes that fall into this size category, and only 77 flakes can be considered to have been heat-treated. With slightly more than half of the 12-24.99 mm flakes meeting the requirement for being heat-treated, it is not unreasonable to suggest that this size range might be representative of flakes that are both unheated and heat-treated.

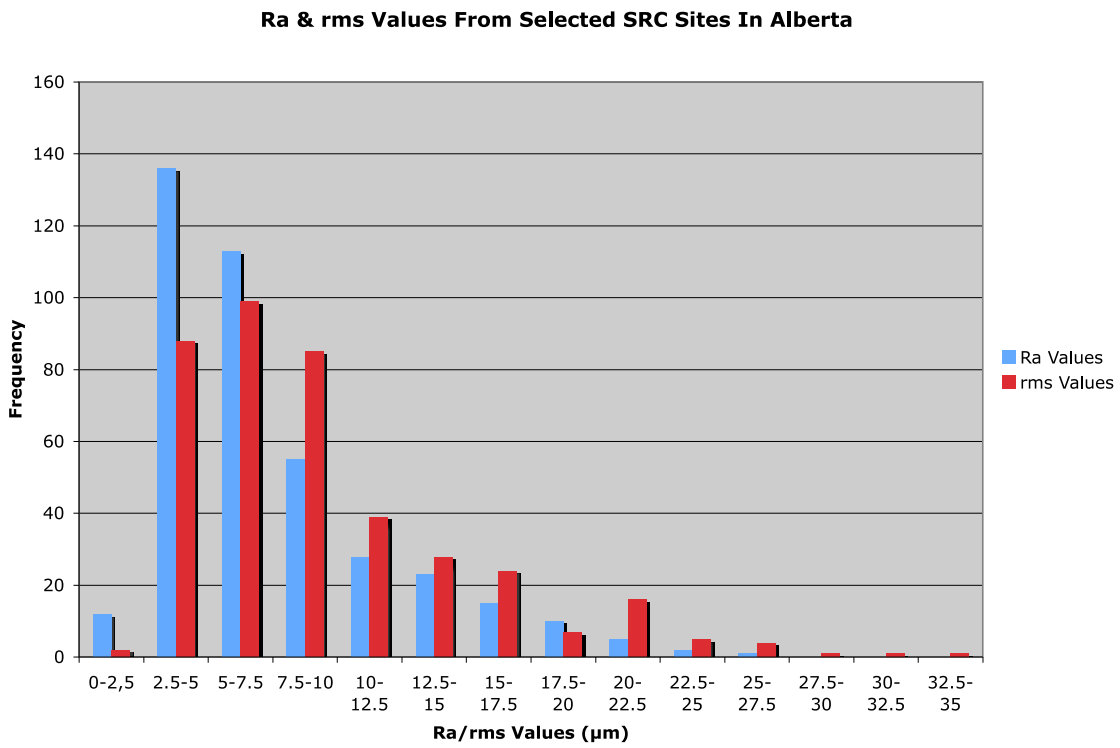

Figure 6.11: R_a and rms values for all the archaeological flakes examined in this study.

There is evidence to support this hypothesis at other sites in North America. Michael Collins and Jason Fenwick's (1974) examination of the Bland Cave site (15HD41) showed that the people there were preferentially heating biface preforms and flakes that had been removed from cores. At a group of sites along the Cedar Creek Reservoir in Tennessee, the pattern of debitage indicates that heat-treatment was employed on bifaces and preforms to enhance thinning (Futato 1983:122).

In addition to reducing the likelihood that the material would break during the heat-treatment process, there may have been another reason for preferentially heat-treating bifaces, flakes, and preforms. If the site is located some distance from a source of quality lithics, then individuals would want to maximize the amount of usable material that they are bringing back to the site with each trip

(Anderson 1979: 232). As a result, most of the cortex and other unwanted parts of the stone would be removed when it is picked up.

While some archaeological data appear to show that heat-treatment was being used during the later stages of the lithic reduction sequence, it would be premature to say that this was the only way heat-treatment was applied. A recent publication by Eren and Andrews (2013) challenges the assumption that bifaces were used as a kind of "mobile core" that would have allowed prehistoric people to produce tool blanks quickly, even if they are a considerable distance away from a known raw material source. Their examination of the maximum flake thickness from six Clovis sites in the Lower Great Lakes region suggests that unifacial tool blanks and not bifaces would have been the preferred method for transporting stone over long distances (Eren and Andrews 2013:175). This is certainly an interesting theory and one that is worth further exploration. Unfortunately the data from the Cedar Creek Reservoir, Bland Cave, and the SRC sites in Alberta do not include maximum flake thickness, so it is not possible at this time to see if Eren and Andrew's ideas about lithic transportation by Clovis-era people can be applied to other prehistoric groups. One potential problem with applying Eren and Andrew's methodology to SRC is that it assumes that the lithics are being collected from a fixed procurement site (Eren and Andrews 2013:174). Since the SRC in Alberta does not come from a fixed point, but is found scattered all over the prairies in lag deposits, their methodology may be of limited use.

In addition to Eren and Andrew's ideas on lithic transportation by Clovis hunter-gatherers, Eugene Gryba (personal communication 2010) has his own

method of heat-treatment that seems to work quite well. Gryba heats all of his SRC before attempting to remove any flakes and has not experienced any problems with thermal shock (Eugene Gryba, personal communication 2010). He carries out this procedure so that he can work with the best quality material from the beginning of the manufacturing process; thus he reduces the chance of the material breaking while he is making a tool. A possible explanation for why Gryba has not experienced any problems with thermal shock is that he heats all of his SRC using as oven. The oven gives him much greater control over how long and at what temperature the SRC is heated than he would have if he were to use a fire.

This method of heat-treatment from the start has also been documented in the archaeological literature, with at least two sites known in North America that have evidence that large, unworked pieces of chert were being heat-treated. The McKeithen site (8CO17) in northern Florida is a mound-village complex that was occupied from ~250-700 A.D. based on radiocarbon dates (Johnson 1987:30). The most common material type at this site is a locally available chert that makes up 93.7% of the lithic assemblage (Johnson 1987:31). The presence of heat-treated cores, cortical flakes, and core reduction flakes of chert suggest that at least some of the chert was being heat-treated before the material was worked on (Johnson: 1987:33).

Along the Nine Mile Creek in Kansas, there is a group of 36 sites, with occupation dates ranging from 2,500 B.C.-1,000 A.D, based on the presence of diagnostic artifacts such as projectile points and pottery (Johnson, et al. 1972:309-

311). At all of these sites the overwhelming majority of the lithic debitage is derived from locally available cherts. Much like at the McKeithen site, there were a number of cores that showed evidence of heat-treatment, suggesting that chert was not prepared or only minimally prepared prior to being heat-treated.

The likely reason for the chert at these sites being heated with little or no preparation may be their proximity to lithic quarries. All the Nine Mile Creek sites and the McKeithen site are located close to chert quarries. Since the inhabitants of these sites did not have to travel far to acquire quality stone, they may not have concerned themselves with maximizing the amount of usable stone they could carry in one trip, and may have just collected what was needed to produce a particular tool.

Chapter 7

Conclusions

This study was initiated in an attempt to devise a reliable and cost effective means for objectively determining whether or not lithics from an archaeological assemblage have been heat-treated. An experimental protocol was developed that combines experimental archaeology and materials engineering equipment in an effort to better understand the changes that SRC undergoes when it has been heat-treated, and to develop an objective way of determining when those changes have occurred.

The current archaeological data indicate that the heat-treatment of lithics was practiced by prehistoric groups all over the world and may have been developed as far back as 250,000-50,000 B.P. in Africa. The archaeological data are supported by numerous ethnographic accounts of heat-treatment that describe the techniques employed by various groups to improve the flaking properties of the stone they were working with. When reading these ethnographic accounts, a certain amount of caution should be exercised, as several of them do describe certain flint knapping techniques that we now know to be impossible. One such technique is water-chipping, whereby flakes are detached from a larger piece of stone by heating it in a fire and placing a couple of drops of water along the edge.

The first serious attempts at examining the effects of heat-treatment on lithics began in the 1960s with Don Crabtree, whose experimental work examined the relationship between heat and the flaking properties of lithics. In the

numerous experiments that have been run since Crabtree's work was published, some common indicators of heat-treatment have been identified. At the macroscopic level, changes in colour, lustre, texture; and the presence of ripples, are considered indicative of heat-treatment. While these indicators can serve as a good starting point for further investigations into heat-treatment, they are highly subjective and should not be used as the sole source of evidence that a particular lithic was heat-treated.

At the microscopic level, recrystallization of silica, eutectic melting, fluid migration, and microcrack formation are the four principal theories that have been put forth to describe the changes that siliceous lithics undergo when they are heated. Of these four theories, the only one that seems to make sense based on the current evidence is fluid migration. The recrystallization of silica and eutectic melting can occur only at temperatures that are higher than those that are generated in a normal campfire and the formation of microcracks within the material may actually increase its toughness.

Based on my conversations with Eugene Gryba, a heating period of approximately 6 hours, followed by a further 6-8 hours of cooling was deemed to be the ideal amount of time. If the SRC is heated for less than 6 hours it does not have an opportunity to undergo all of the physical changes that improve its flaking properties. SRC can be heated for longer periods of time, but there is no appreciable benefit to be gained (Eugene Gryba, personal communication 2010). The long cooling period is necessary to prevent thermal stresses as a result of being exposed to the (comparatively) cool air causing undesirable fractures in the

material. This amount of time also comes up frequently in the ethnographic literature, where heat-treatment is often described as being a day long, or overnight process.

While many studies have demonstrated the efficacy of heat-treatment on improving the flaking properties of numerous lithic types, there have been very few attempts to replicate the conditions under which prehistoric groups may have actually heat-treated the lithics that they had. The construction of a fire pit and the subsequent heating of SRC demonstrated that the temperatures required to heat-treat lithics successfully can be achieved using an ordinary campfire, as indicated by numerous ethnographic accounts. By burying the SRC ~4 cm underneath the campfire, it is sufficiently insulated from the direct heat of the fire and thermal fracturing is avoided.

In the experimental studies, all of the macroscopic changes described in chapter 3 were observed in all of the heated SRC; however, they are not necessarily as reliable an indicator of heat-treatment as the existing literature would seem to indicate. This observation is particularly true if colour is being used as the main criterion for determining whether or not a lithic has been heat-treated. The SRC samples that were placed at the bottom of the fire pit and the 16 cm and 20 cm depths developed a slight reddish colour, but no appreciable improvement in the flaking properties was noticed. Conversely, some of the SRC that was heated at the top of the pit did not develop any reddish tint at all; and remained a grey colour, as with source samples GP-10-016 and M-10-004. In light of this finding, it is my recommendation that a positive identification of heat-

treatment should not be made based on colour alone. Other, more objective techniques should also be employed. There may have been other factors, both natural and anthropogenic, that could have caused those colour changes to occur.

The use of the Zygo optical profilometer to compare the microtopography of heat-treated and untreated flakes proved to be successful in experimental studies. The results of this analysis indicate that heat-treated flakes of SRC tend to have R_a and rms values that are less than 7.5 μm. A second set of flakes from a different lithic material (silcrete) was also analyzed to demonstrate that the results of the SRC analysis were not just coincidental, and that the profilometer has the potential to be used on a variety of lithic materials. The heat-treated silcrete flakes also had R_a and rms values that are less than 7.5 μm. The results of this analysis show that there is a quantitative difference between heat-treated and unheated flakes. While the precise cause of this difference is still not fully understood, X-ray diffraction analysis does suggest that the silica crystals in the SRC undergo some kind of structural change.

Based upon the success of the experimental studies, the experimental methodology was subsequently applied to lithic collections from several archaeological sites in Alberta. The results of the analysis of flakes from these archaeological sites also shows that prehistoric groups in Alberta may have had a preference for using heat-treatment in the later stages of the lithic reduction sequence, as evidenced by the fact that the smaller flake sizes show an increased frequency of heat-treatment.

The ability of the Zygo to accurately identify heat-treated SRC is important, because it has the potential to help us reconstruct past behaviours regarding lithic reduction. While the results of this thesis should still be considered tentative, they do suggest that cobbles of SRC were roughly worked before being heat-treated. This procedure was most likely done in order to reduce the likelihood of the material breaking as a result of thermal shock, and to prepare the material for soft hammer and pressure flaking techniques.

Further Research

Having demonstrated the efficacy of the Zygo in identifying heat-treated lithics, there are a number of exciting avenues of research that can be pursued that will greatly enhance our understanding of the kinds of lithic acquisition and reduction strategies that were employed by prehistoric peoples. To conclude, I briefly discuss some future research topics of particular interest.

It will be helpful to conduct a thorough examination of all the SRC flakes in a site's assemblage. Based on the existing archaeological data, it appears that prehistoric groups heated bifaces or cores depending on their proximity to the source of the lithic material that was to be heat-treated. By using the Zygo to analyze the flakes, and combining that data with a count of the number of decortification flakes, cores, tools, and performs at a site, it may be possible to say a bit more about the lithic acquisition strategies used by the inhabitants of a particular site. While Eren and Andrews (2013) describe a Paleoindian era exception, one would ordinarily expect the frequency of bifacial thinning and other smaller flakes to be higher for sites situated at a greater distance from the

source. Most of the cortex and other undesirable parts would be removed where the stone was found in an effort to maximize the amount of workable material that can be brought back to the site in a single trip. When a site is close to a source of quality stone, we would expect to find a greater number of decortification flakes and cores, since the people collecting the material may not be as concerned with transport costs with each trip.

Another interesting avenue of research would be to apply this methodology to other varieties of stone, especially those that do not seem to experience a radical colour change as a result of heat-treatment. One example of this type of stone is Beaver River Sandstone (BRS), a bimodal, silica-cemented, quartz sandstone of medium to fine grain that is found near the Athabasca River in the Fort MacKay area (Fenton and Ives 1990:128,132). Beaver River Sandstone is generally light grey to dark grey in colour, although some coarser varieties are almost black in colour due to being impregnated with hydrocarbons (Fenton and Ives 1990:128; Gryba 2013). BRS exhibits considerable textural variation, and the grain sizes can range from macro- to micro- to cryptocrystalline (Robertson and Blyth 2009:42; Tsang 1998:17). Some archaeological examples of BRS flakes recovered from sites clustered around the Quarry of the Ancestors have reddened exteriors, and it has been hypothesized that BRS was heat-treated by prehistoric people to improve the quality of the material.

Heat-treatment experiments conducted on BRS by Eugene Gryba (2013) and E.C. Robertson and R. Blyth (2008) successfully recreated the red colour that was found on the archaeological specimens, and also demonstrated that its flaking

properties improve after being heated. Heated pieces of BRS also developed a lustrous appearance and waxy texture (Gryba 2013). Based on this experimental work and Eugene Gryba's (2013) observation that unheated BRS is extremely difficult to flake using hard hammer percussion, it seems likely that prehistoric people were heat-treating BRS to transform it into a more workable form. One interesting feature that was noticed about heat-treated BRS was that the red colour penetrated the stone only to a depth of 3 mm (Robertson and Blyth 2009:42). In light of this observation, it is possible that the frequency of heat-treatment for BRS is currently being underestimated, as many of the flakes may not have the reddish colour that is currently being used to characterize heat-treated BRS.

By applying my experimental methodology to BRS it would be possible to develop an objective set of criteria for identifying heat-treated BRS. Once those criteria have been established, it is just a matter of comparing the flakes from archaeological sites to the experimental data. BRS may also be an ideal material type to consider for examining the validity of Eren and Andrews (2013) methodology. Since BRS comes from a primary source, it should be possible to compare the distance that an archaeological site is from a known BRS quarry (e.g.; the Quarry of the Ancestors) to the thickness of the BRS flakes at that site. A study like this would certainly help to shed more light on whether or not prehistoric groups in different time ranges used bifaces as "mobile cores" or employed a different strategy for transporting lithics over large distances.

The experimental methodology described in this thesis may also be of interest to researchers in Africa who are looking at the origins of "cultural

modernity." The ability to heat-treat lithics successfully represents the first serious attempts by humans to deliberately alter an inorganic substance in order to make it easier to work, and as such may be indicative of the development of more complex cognitive processes. As mentioned in chapter 3, there has been some work done in Africa to consider the origins of heat-treatment. The work conducted at Pinnacle Point in South Africa suggests that heat-treatment was being used ~164,000 years ago. This age predates the appearance of symbolic behaviour in the area, which is only began ~71,000 years ago (Brown, et al 2009: 861).

Obviously claims such as this require a great deal of evidence to support them. The use of a glossmeter to measure the reflectivity of heated and unheated flakes of silcrete represents an important step in the development of an objective approach for ascertaining whether or not certain flakes have been heat-treated. The experimental methodology outlined in this thesis would provide an excellent means for efforts to verify the work of Brown et al. (2009) and Mourre et al. (2010), both of whom suggest that heat-treatment developed quite early in Africa.

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Appendix A

R_a and rms data for experimental flakes and flakes from sites in Alberta.

See attached CD.