UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

THE DEVELOPMENT OF PALEOINDIAN COMMUNAL BISON KILLS: A COMPARISON OF NORTHERN TO SOUTHERN PLAINS ARROYO TRAPS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

In partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

KRISTEN CARLSON
Norman, Oklahoma
2015

THE DEVELOPMENT OF PALEOINDIAN COMMUNAL BISON KILLS:
A COMPARISON OF NORTHERN TO SOUTHERN PLAINS ARROYO TRAPS

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF ANTHROPOLOGY

BY

Dr. Leland Bement, Chair

Dr. Bonnie Pitblado

Dr. Asa Randall

Dr. Diane Warren

Dr. Jeffrey Kelly

ACKNOWLEDGMENTS

I want to acknowledge the funders and participants who made this research possible. Thank you to NSF (grant #BCS-1419245), Harold Courson and Courson Oil and Gas, and the Oklahoma Archaeological Survey for providing funding. Thank you to my chair Dr. Leland Bement for his commitment to this work throughout the entire process. Thanks to the BLM Curation facility, Billings Mt. and BLM, Miles City Mt. In addition thanks go to my committee, Dr. Bonnie Pitblado, Dr. Asa Randall, Dr. Diane Warren, Dr. Jeff Kelly. My appreciation also extends to Dr. Frison, Dr. Danny Walker, Dr. Jody Clauter, Dr. Marcel Kornfeld, Dr. Mary Lou Larson, Dr. Bob Kelly, David Wade, and all previous researchers on whose work this study builds. Thanks also goes to Sue Selman, the entire crew of Time Team America, as well as the field crews that aided in recovery and processing of Badger Hole materials.

A very special thanks to my tireless field crew of 6 years, Justin and Saige Carlson Roach and my Dad for never teaching me the meaning of the word can’t. Remembering Mojave and all the friends that couldn’t finish this leg of the journey with me.

TABLE OF CONTENTS

TABLES

FIGURES

Abstract

This dissertation addresses the questions: Is there a link between environmental change, bison mobility behavior, and large-scale hunting? What were the mobility patterns of bison hunted in large kills during the Folsom and Goshen periods? What was the environment like? To investigate these questions I employ stable isotopes of bison bone from Paleoindian kill sites to reconstruct the grasslands. In addition I combine the isotopic analysis with trace element analysis of bison teeth to reconstruct the mobility patterns of these animals. These techniques are first applied to the robust and temporally continuous sample on the southern Plains providing a reference to create models to fill gaps in data on the northern Plains.

This project develops a framework to understand hunting through the analysis of prey behavior and the environment during the Paleoindian period on the Great Plains. The focus of this research is temporal fluctuation of bison mobility and grassland structure. Success in hunting is directly linked to an in depth understanding of prey behavior (Frison 2004). Concerning archaeological investigation, in order to understand the hunting systems of Paleoindians, we must first be intimately familiar with the species and environment in which they hunted.

The results of this research on the southern Plains demonstrate a change in hunting adaptation from the end of the Clovis period through the Folsom period that coincides with changes in grassland structure indicating environmental fluctuation. The northern Plains results provide data that define an

environmentally stable period where little change is observed in bison behavior and hunting adaptation.

Chapter 1: Introduction

This project develops a framework for furthering our understanding of Paleoindian people by gaining an understanding of the prey species and the environment in which they lived. As any hunter will tell you (Frison 2004) in order to be successful one must be intimately familiar with their prey. In the case of archaeological investigation in order to understand the hunting systems of Paleoindians we must be intimately familiar with the species in which they hunted, and the environment in which they lived. This basic groundwork seems obvious but until recent decades the technology has not been present to delve deeply into this issue. This dissertation does just that.

The southern Plains provide a clear trajectory of communal hunting development from the late Clovis period into the Folsom period. Initially I had hoped to trace this development on the northern Plains, however new dates provided by myself and the work of Waters and Stafford (2014) are drastically changing our ideas of chronology on the northern Plains during the Paleoindian period. This further demonstrates the key realization that we as researchers must step back and reevaluate what we thought we already knew about Paleoindian America.

This research aims to further our understanding of how people change their adaptations when faced with dramatic changes in their surrounds. In particular, the purpose of this research is to determine what environmental shifts instigated the switch from isolated hunting to large-scale cooperative hunting seen to occur during the Pleistocene/Holocene transition (Bement and Carter

2010; Frison and Stafford 1982; Frison 1996; Kornfeld et al. 2010). Furthermore the results of this research demonstrate a shift in human and animal behavioral patterns seen to occur in fluctuating environmental conditions. Though I do not presume that environment is the only factor leading to large-scale change during this period I will argue that it is a major contributor.

Through the theoretical framework of behavioral ecology this research compares and contrasts Paleoindian arroyo trap bison kill sites on the southern Plains to sites on the northern Plains to investigate the transition from opportunistic hunting to organized hunting under different environmental regimes. The Paleoindian period extends from 12,000 to 7,000 ^{14}C years before present (^{14}C BP; Frison 1991; Kornfeld et al. 2010), though new discoveries and analysis lead to an ever-deepening time range. The methods employed include: stable isotopes of bison bone to aid in environmental reconstruction, radiocarbon dates to determine the antiquity of the sites being compared, and trace element analysis of teeth to determine migration patterns in order to relate hunting organization to bison behavior.

In recent years a discussion has been broached concerning the application of the word communal to large kill events. When hunter-gatherer groups seek to find faunal resources they have two means of capturing their prey. The first is to go out in a small group or as individuals and kill a single animal, the second is to go out in larger groups and kill multiple animals at once (Frison 1978, 1994; Kelly 1995, 2013). Frison (1991) differentiated between communal kills being large-scale events and isolated kills being of the smaller variety. Bement (2003) defined large-scale kills as containing over 10 animals and isolated kills contained under 10 animals. Were these events communal or were they carried out by smaller groups of people? For the purpose of this research I refer to the killing of numerous bison in arroyo trap kills as communal events. I use the term communal because the discussion of such large-scale events has typically used the term and rewriting terminology for the purpose of discussion seems a waste of effort and risks each researcher speaking in their own language.

Bison Hunting Development

Significant adaptations in subsistence methods have often marked changes in the human condition. For example, the Broad Spectrum Revolution (15,000 ^{14}C BP in the Middle East and 12,000 ^{14}C BP in Europe) outlined by Kent Flannery (1969) or the later Neolithic Revolution (roughly 12,000 ^{14}C BP) outlined by V. Gordon Childe (1950) and Robert J. Braidwood (1975) provide cases in which dramatic adaptations in subsistence have drastically changed the way people inhabit the landscape. These drastic changes in human adaptation are often linked to changes in climate (Binford 1968; Henry 1989, 1995; Smith 1995). Scholars have argued that those most likely to adapt new means of subsistence are those struggling to maintain the old ways (Binford 1968; Flannery 1973; Wenke and Olsewski 2007). While the Neolithic revolution was taking place in Europe different adaptations were underway in North America. Early Paleoindian hunters (11,000 ^{14}C BP and before) developed opportunistic techniques or encounter hunting, taking advantage of single animals such as mammoths at predictable locations such as watering holes. Examples of encounter hunting sites include Murray Springs (Haynes and Huckell 2007) in southern Arizona and Blackwater Draw (Hester et al. 1972) in northeastern New Mexico. These sites are prime examples of Clovis hunters opportunistically hunting in locations likely to attract animals.

The focus of this research is the development from hunting of animals in opportunistic situations to the active manipulation of animals, in this case bison, into predetermined traps. The shift from opportunistic hunting to active organized hunting shows a change in hunting adaptation that coincides with environmental change. The changing environment favored the expansion of prey species' population numbers at least locally beyond a threshold that made animals susceptible to manipulation by human hunters. The focus of this dissertation research is on the Folsom (11,000 – 10,000 ^{14}C BP; Kornfeld at al. 2010; Meltzer 2006) and Goshen (10,450- 10,175 ^{14}C BP; Waters and Stafford 2014) time periods when communal bison hunting develops and becomes prevalent across the northern and southern Plains.

Folsom and Goshen era organized hunting evolved with the amalgamation of certain attributes necessary to conduct communal kills. These attributes include: bison in large herds, a favorable topographic setting, and hunters in adequate number with adequate understanding of bison behavior (Carlson and Bement 2013). Evidence of these attributes is consistently represented in numerous bison kill sites dating from Paleoindian to Late Prehistoric periods (Bamforth 2011; Bement 2003; Bement and Carter 2010; Brink 2008; Carlson 2011; Cooper 2008; Kornfeld et al. 2010; Meltzer 2006). I refer to this amalgamation of attributes as the *communal hunting system*. To test the hypothesis that the rise of organized hunting in different regions arose with the incorporation of increased herd size, favorable topographic setting, and a large number of available hunters, I compared six early communal hunting sites arrayed across the northern and southern Plains. The study of these attributes provides a model built on the southern Plains, expanded to the northern Plains, which can now be applied to other areas of the world to determine when conditions arise to support the development of organized communal hunting.

Environmental conditions must favor prey populations high enough for hunters to manipulate herds into traps. The focus prey animal in this study is bison. Bison expansion is postulated to have occurred in North America following the extinction of mammoths and other large grazing animals, thereby reducing competition for grazing resources (McDonald 1981). In North America this expansion of the bison population occurred during the Younger Dryas (10,900 – 10,000 ^{14}C BP; McDonald 1981; Martin 2005). Paleoenvironmental reconstructions for the Younger Dryas indicate extensive environmental changes on a global scale (Ballenger et al. 2011). Similar reconstructions are required to understand changes in the carrying capacity of the paleolandscape. Paleoenvironments can be reconstructed from pollen analysis where available (Bement et al. 2007; Cummings 1996; Holloway 1993), and from stable isotopes in bones from Paleoindian arroyo traps (Connin et al. 1998; Larson et al. 2001; Meltzer 2006). Stable isotopes indicate the diets of the animals prior to their time of death, and can be evaluated to reconstruct the paleoenvironment (DeNiro and Epstein 1978; Hoppe et al. 2006; Schoeninger and DeNiro 1984; Tieszen 1991).

Suitable topography is another necessary component of the system for a successful hunt (Brink 2008; Carlson 2011). Components of a favorable topographic situation include a drive lane along which the prey animal can be maneuvered from a milling area (e.g. grazing pasture) to a kill point (Carlson and Bement 2013). Reconstructing the paleotopography of arroyo trap systems can be difficult because the cut and fill cycles of arroyos often destroys much of the original channel used to trap the animals (Kornfeld et al. 2010). However even without clear reconstruction available all sites contained within this analysis are arroyo kills.

The accumulation of the necessary number of people was likely a factor in the successful execution of a communal bison kill and likely required aggregation of two or more groups. Extended family groups likely roamed the Plains throughout much of the year, with small bands reaching as many as 50 when resources provided a means to sustain such numbers. An aggregation of 50-80 people would have engaged in a large-scale kill event (Kelly 2013). Hunter-gatherers worldwide aggregate to exchange marriage partners, tools, materials, and ideas (Hollenbach 2009; Ingold et al. 1988; Kelly 2013; MacDonald et al. 1999; Pennington 2001). The question, as far as I am concerned, is not whether or not Paleoindian hunters aggregated; it is where. Paleoindian bison kill sites provide an ideal indicator that an aggregation site is nearby. Predictable migration routes during the late summer to early winter coupled with the proper landscape features provide a means for group scheduling and aggregations. Whether Paleoindian groups aggregated, or whether that aggregation is visible archaeologically has been debated in past publications (Conkey et al. 1980; Hofman 1994; Robinson et al. 2009).

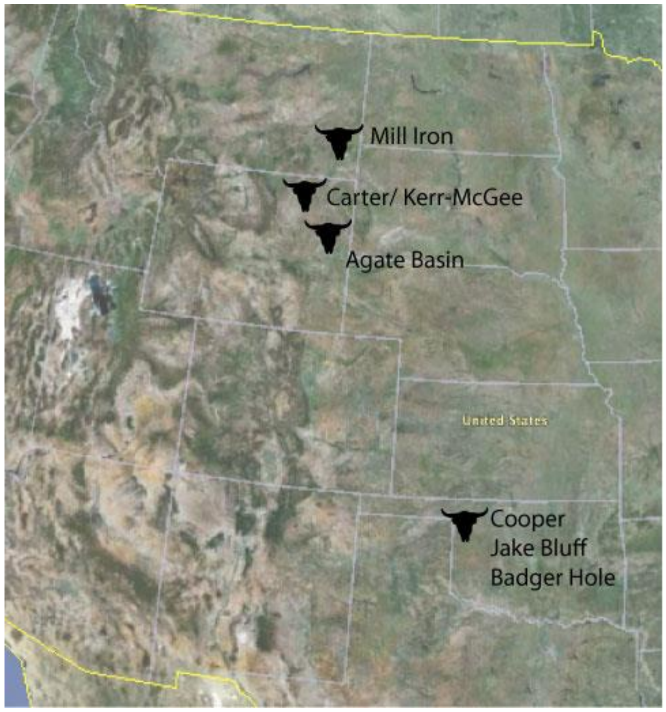
Scheduling is necessary to provide the components for repeated aggregation around a large-scale animal kill site. Aggregation at a particular node on the landscape requires a surplus of food to support participating groups for the duration of the aggregation, in this case the bison hunt and subsequent butchering of the animals. In considering the use of communal bison hunts as the subsistence intensification required for repeated, planned aggregation, the immovable bison kill site serves as the node around which the aggregations could be planned and executed.

Special landscape requirements necessary for a successful communal bison kill, include a bison milling area, drive path, and containment or kill structure (pound, jump, arroyo trap; Carlson 2011; Fawcett 1987; Frison 1991). Reuse of a successful kill site such as indicated at Head-Smashed-In (Brink 2008), Vore (Reher and Frison 1980), Kutoyis (Zedeño 2014) and Cooper (Bement 1999) meet such requirements. The special requirements of the kill site, especially the proximity to a bison population, anchor the system to areas where the requisite landform type (e.g. cliff or arroyo) are found where bison congregate or are concentrated such as along established migration paths. An example of the convergence of a topographically suitable kill opportunity along prey animals' migration route was identified at Trappers Point, Wyoming, where pronghorn antelope were communally harvested at a natural constriction along the migration route (Francis and Widman 1999; Miller and Sanders 2000). An example of bison kills distributed along a known bison migration path is found at the Bad Pass Trail, a segment of the Big Horn bison migration route that traverses western Wyoming, Montana and possibly extends into Alberta, Canada (Carlson 2011; Wisehart 2005).

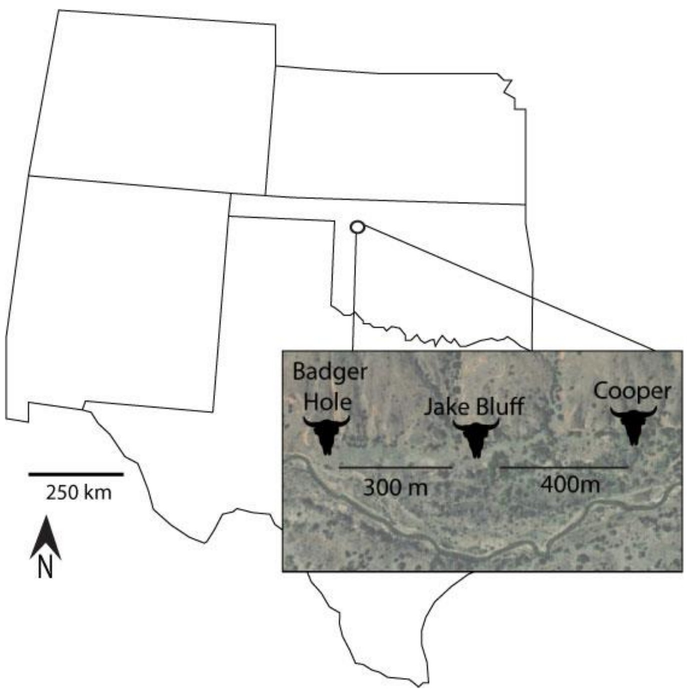
I operate under the assumption that on the Plains, arroyo traps served a similar role as a node of activity. For this to occur, a predictable bison presence must be demonstrated. Southern Plains bison experienced a behavior shift from isolated resident herds during the late Pleistocene to herds following an east-west migration pattern during the Younger Dryas first proposed by Graves (2010) and further supported in Chapters 6 and 7 of this dissertation. This restructuring of bison behavior and movement provided a predictable location and season for bison presence on the landscape. By Folsom times, large numbers of bison would predictably be along the Beaver River in northwestern Oklahoma during the late summer and early fall, setting the stage for aggregated social groups and communal hunting strategies. In this analysis I compare six sites (Figure 1.1). The three southern Plains sites are part of the Beaver River kill complex of northwestern Oklahoma which contains three arroyo trap kill sites; Cooper (34HP45; Bement 1999), Jake Buff (34HP60; Bement and Carter 2010), and Badger Hole (34HP194; Bement et al. 2012). The northern Plains sites are Mill Iron, Montana (24CT30; Frison 1996), Agate Basin, Wyoming (48NA201;

Frison and Stanford 1982; Hill 2008), and Carter/Kerr-McGee, Wyoming (48CA12; Frison 1984).

This project focused on the reanalysis of previously excavated materials through the application of new techniques in order to aid in furthering the understanding of Paleoindian hunting. Migrating herds are one key component of the kill system proposed above. They provide a predictable node on the landscape in which a large number of prey animals and a favorable topographic setting can provide a planned meeting place for people to carry out communal hunts resulting in the procurement of multiple animals and the resources they provide. The trace element portion of this analysis seeks to determine the extent to which Paleoindian bison hunters focused on migratory herds as opposed to resident herds in large-scale hunting.



A.



B.

Figure 1.1. Spatial relationship of sites A) across North America and B) in the Beaver River Complex.

Trace element analysis on bison teeth can be used to determine migration patterns of animals, based on variation of elements in teeth. The trace element analysis tested the 3rd molar or 4th premolar of bison found in bison kill sites in order to determine the territory of the bison hunted. In addition modern samples from isolated bison herds were also analyzed in order to gain a comparative dataset of trace elements. LA-ICP-MS is a high precision microscopic sampling technique (Speakman and Neff 2005) that allows minimally destructive sampling at the microscopic level. This precision allows sampling of individual enamel rows. For these purposes samples were collected at one location and then move to another location further down the tooth face (see Chapter 4). The separation between each down tooth sampling location represents a known time interval. In this fashion, it is possible to obtain an elemental signature at specific time intervals, representing the various places on the landscape visited by the bison in a yearly cycle of their lives.

Northern Plains kills generally occur later in the year than southern Plains kills in the Paleoindian period (Frison 1996; Frison and Stanford 1982; Hill 2008; Kornfeld et al. 2010). The seasonal disparity could indicate that dissimilar environmental zones offer different optimal periods for communal hunting. The herd demographics are also important to take into consideration in conjunction with seasonality. Bison aggregate during the summer rut but split into sexually segregated herds for the remainder of the year. Male bison in full rut are difficult to drive making summer an unlikely time to successfully manipulate herds interspersed with bulls (Brink 2008; Frison 2004). Cow/calf herds are easier to manipulate during non-calving seasons, especially during late summer through the winter when herds follow a lead cow. Seasonality and herd demographics were compared and contrasted between the three southern Plains and three northern Plains sites in order to fully understand the similarities and differences that occur between these distinctive geographic areas.

This chapter summarized the overall project outlined in this dissertation. Chapter 2 contains the theoretical background that structures this research. Chapter 3 provides the background of site history and environment, as well as a brief summary of the Paleoindian studies included in this study. Chapter 4 provides background for the methods. Chapter 5 describes the methods employed to address the research question, and Chapter 6 provides the analysis. Chapter 7 outlines the conclusions and results of this research. In brief the data collected provides evidence to support human aggregation for large-scale kill events taking advantage of largely migratory animals. The shift from small-scale isolated kills to large-scale organized kill events does seem to co-occur with drastic changes in environment and changes in prey species behavior.

Chapter 2:

Theoretical Perspectives and Models of Bison Hunting

In this chapter I outline the background of bison hunting, and discuss the history of the theoretical approaches applied to the study of large game hunting. This section provides the framework in which this study is grounded. This research falls under the broad category of Behavioral Ecology, which focuses on social adaptation in relation to fluctuations in environmental circumstances (Bird and O’Connell 2006; Kennett 2005; Kennett and Winterhalder 2006; Surovell 2012; Winterhalder 2001). I argue throughout this dissertation that in order to understand the hunting practices of Paleoindians we must first understand the prey species being hunted and the environment in which they lived.

Broader Theoretical Developments in Large Game Hunting

Here, I briefly outline the history of theoretical applications to large game hunting leading to Behavioral Ecology, which provides the framework for this analysis. The economies of pre-agricultural, hunter-gatherer societies were studied early in anthropology by 19th-century social evolutionists such as Tylor, Morgan, and Engels (Smith et al. 1983:625). The social evolutionists' early methods of constructing “stages” of cultural development were overturned by anthropologists’ later reaction against grand evolutionary schemes (Smith et al.1983:625). New approaches, proposed by Julian Steward’s works (1933, 1937, 1955) on hunter-gatherer subsistence and social organization, focused predominantly on ecological modes of adaptation. Supported by the cultural ecological framework proposed by Steward, studies of bison procurement progressed along with archaeological theories from a focus on collecting artifacts before the 1920s to a broader focus on bone beds, processing sites, and campsites in the 1960s through the 1980s and continuing today (Frison 2004).

Karl Butzer (1982) dedicated a chapter of *Human Ecology in Archaeology* to the study of faunal assemblages as they relate to large game hunting. He outlined the necessity to cross theories from biology and zoology in order to better understand the fossilized remains of archaeological faunal assemblages. In the 1980's zoo-archaeology was considered a new and rapidly expanding subfield of archaeology: "In the elucidation of prehistoric subsistence patterns, the higher aspiration of faunal analysis is to study the relationships between people and animals as they interact spatially and as their patterns change through time" (Butzer 1982:191).

Optimal Foraging Theory

In the 1970s the application of optimal foraging strategies to hunter-gathering societies developed within the theoretical framework of behavioral ecology (Winterhalder and Smith 1981). Optimal foraging theory assumes that people hunt game or forage for plant resources depending upon the expense of those activities; the least costly method of obtaining calories would be preferable, and most adaptive. If hunting requires more calories than what is obtained, then it is not an optimal method of obtaining calories. One critique of optimal foraging theory is the tendency of researchers to abandon theory altogether and focus only on empirical data (Smith et al. 1983:625). Most foraging models assume that foragers will maximize "*the net rate of return* (of energy or nutrients) *per unit* *foraging time*" (italics original; Smith et al. 1983:626). Optimal foraging models consider diet breadth, patch choice, time allocation, foraging-group size, and settlement pattern to address the variables of what to hunt, where to obtain it, how long to forage, with whom and where to live (Table 1; Smith et al. 1983). Such models could be applied to hunting as well as gathering subsistence strategies. However, when considering the !Kung in Africa, Lee and DeVore (1968, 1973) argued that plant resources were more easily accessible, provided more reliable nutrition, and had a lesser caloric cost than resources obtained by hunting. According to Lee (1968:3), hunting is a risky and unreliable means of obtaining nutrition and noted that the !Kung collect 60-80% of their diet from vegetable sources. Lee's work provides a classic example of "general models" which describe all hunter-gatherer cultures as if they share the same cultural attributes (Smith et al. 1983:625). General models overlook the diversity of adaptive responses available to cultures thereby providing an additional criticism of optimal foraging theory.

In contrast to Lee, Marvin Harris (1979), an American anthropologist well known for his work on cultural materialism, argued instead that hunter-gatherers world-wide chose plant resources only during times of large game scarcity because large game provides the better source of nutrition and greater return on expenditure. Archaeological findings on the Plains of North America show that hunter-gatherer communities hunted large game *and* foraged plants (Kornfeld et al. 2010; Waguespack and Surovell 2003). Later research suggests that bison scarcity does not appear to correlate with an increase in foraging

(Kornfeld et al. 2010; Waguespack and Surovell 2003). Bison meat enabled many groups to survive long winters with scarce plant resources.

Optimal foraging theory created a solid basis of study early in archaeology, and remains applicable to archaeological study today (Broughton 2012; Table 2.1). Optimal foraging theory has been criticized for simplifying a much more complex process of human behavior (Gurven and Hill 2009; Pierce et al. 1987; Sassaman and Randall 2012:22; Zeder 2012). Despite the adaptive strategy of foraging optimally, people routinely behave in sub-optimal, unpredictable patterns (Keene 1983). Optimal Foraging also assumes a complete understanding of the resources available to hunters and gatherers in the past, which is particularly problematic when dealing with a non-analogous environmental system like that found during the Paleoindian period in North America.

Although hunting has been criticized as being a costly method of obtaining calories (Speth 2010), no empirical data has been analyzed in North America that accurately measures the benefits of a communal large game hunt such as a communal bison kill. A communal bison hunt would require extensive human resources. However, it is argued (Bamforth 1988) that the amount of meat and resources obtained during a communal hunt outweighed the resources invested in the event assuming the kill is successful. Killing numerous animals the size of bison individually would cost far more in terms of human time and resources than the killing of many animals in a single event (Bamforth 1988).

This dissertation continues this research to include kill sites within North America, focusing on the Folsom and Goshen time periods, when adaptation to a changing environment changed the methods used by large game hunters to procure resources. Hunting shifted during this time from opportunistic hunting of mammoth to planned communal hunting of bison.

Table 2.1. Optimal foraging theory models, published by Smith et al. 1983.

TABLE 1

MAJOR DECISION CATEGORIES OF OPTIMAL FORAGING THEORY: STRATEGIC GOALS, DOMAINS OF CHOICE, COST-BENEFIT CRITERIA, AND MAJOR CONSTRAINING VARIABLES

DECISION CATEGORY	STRATEGIC GOAL	DOMAIN OF CHOICE	COST-BENEFIT CRITERIA	SOME MAJOR CONSTRAINING VARIABLES
Diet breadth	Optimal set of resource types to exploit	Which types to harvest, once encountered	Return per unit handling time for each type, overall return on foraging (including search time)	Search and pursuit abilities of forager, encounter rates with high-ranked types
Diet breadth with nutrient constraints	Same as above	Which and how many of each prey type to harvest	Minimum cost for meeting nutritional requirements	Nutrient requirements, abundance of prey types, procurement costs
Patch choice	Optimal array of habitats to exploit	Which set of patches to visit	Average rate of return with patch types and average over all patches (including travel time between patches)	Efficiency ranking of patch types, habitat richness, travel time between patches
Time allocation	Optimal pattern of time allocated to alternatives (patches, etc.)	Time spent foraging in each alternative	Marginal return rate for each alternative, average return rate for entire set	Resource richness, depletion rates for each alternative
Foraging-group size	Formation of optimal-sized groups for foraging	Size of groups to join for foraging under specified conditions	Average per capita rate of return at each group size, marginal cost and gain to joiner or group members	Return-rate curves for each group size under each condition, possibilities for group formation, rules governing division of harvest
Settlement pattern	Optimal location of home base for foraging efficiency	Settlement location of each foraging unit (individual or family)	Mean travel costs and/or search costs per unit harvest	Spatiotemporal dispersion and predictability of major resources, effects of cooperation and competition

Communal Bison Hunting

In this section I provide background on bison behavior and bison hunting to better clarify the system to which these theories are applied. Communal bison hunting was successfully conducted for thousands of years across the Plains of North America (Bamforth 2011; Bement 1999, 2003; Bement et al. 2012; Brink 2008; Frison 1976, 1978, 1973, 1984, 1991, 1996; Kehoe and Eyman 1973;

Reeves 1990; Verbicky-Todd 1984). Bison kill sites provide some of the oldest evidence for communal hunting in North America. Bison jumps, arroyo traps, and pounds (corrals) appear in the archaeological record as early as 11,000 ^{14}C BP (Frison 1978:147) and continue to the introduction of horses and subsequent overhunting of bison in the 1880s. During the early development of the kill technique large game hunters had to adapt to a rapidly changing environment (Frison 1978; Jodry 1999; Meltzer 2006).

Many factors are necessary for a successful bison hunt, and these factors had to be taken into consideration by prehistoric hunters and archaeologists to gain the most accurate understanding of how bison kills took place. Through generations of hunting, prehistoric people gained an extensive knowledge of their environment and prey behavior in order to successfully develop communal kill techniques. However, change does not typically occur slowly through time. Innovation requires a trigger. In the case of communal hunting I believe this trigger to have been a drastic environmental change and changes in prey species, from mammoth to bison because hunters had to adapt to the rapid change of b=prey species during the mass extinction of mega fauna. Researchers when studying a bison kill must therefore consider environment and bison behavior.

Hunting Behavior and Animal Behavior: Hunters and Prey

To understand bison kills in the deep past one must take time to address the first concern of many large game archaeologists. Are *Bison bison antiquus* anything like modern *Bison bison bison* roaming the Plains today? If they are we can begin to draw conclusions between the ways in which both species have been hunted. How can we determine if a species extinct for 5,000 years behaves similarly to the modern species hunted by later Native groups? Paleontologists turn to living descendants to determine behavior of extinct species (Guthrie 1970; Kurten and Anderson 1980; Martin 2005). Further, the archaeological record indicates that bison hunting has had similar components throughout prehistory (Bamforth 2011; Carlson and Bement 2013; Frison 1998; Kornfeld et al. 2010; Reeves 1990). These components are explained below. This provides the basis for my argument that bison behavior is ingrained in the species from deep prehistory to today, with much of that behavior being rooted in herd animals across species. This validates the use of bison observation throughout time as well as gives a means to understanding animal behavior from ethnographic accounts as well. In general most bison kills have three components; one a bison herd milling area (an area of wide open land, good water that can support a large herd), two a drive area typically marked by cairns in the case of jumps and pounds as discussed below, and three arroyo walls in the case of arroyo kills, and a kill area (Brink 2008; Carlson 2011; Carlson and Bement 2013). Frison (1987, 2004) argues that the key to understanding hunting behavior is to understand the prey being hunted. Frison (1987, 1991, 2004) outlines the use of sand dunes, arroyos, pounds, and snow drifts in hunting bison which all provide perfect traps that take advantage of the bison behavior I outline below.

In addition to similarities in hunting techniques of bison there are a wide range of similarities in hunting techniques of large game herd animals world-wide which also strengthens the argument that large game herd animals maintain certain behaviors that make them susceptible to human predation. Caribou hunted in the Old World and New World as early as the Upper Paleolithic and as recently as by modern reindeer herders share similarities to bison hunting (Jackson and Thacker 1997; Reeves 1990). These herd animals are run into preset traps, or rivers in order to trap and kill large numbers. Gazelle and sheep are also trapped by similar means archaeologically (Frison 1971).

Bison as Herd Animal

North American Great Plains humans hunted three subspecies of bison: *B. bison antiquus, B. bison occidentalis,* and *B. bison bison* (Frison 1987:183; Wilson 1974). The extinct *B. bison antiquus* and *B. bison occidentalis* evolved into the modern-day *B. bison bison* (Frison 1987; Wilson 1974, 1996). Compared to modern bison, the extinct subspecies had larger bodies, wider horn spans, and more massive horns (Frison 1987:190; Guthrie 1970:12; McDonald 1981). Bison are aggressive, agile, and fleet of foot. They have poor eyesight and a well developed sense of smell (Brink 2008; Frison 1987; McHugh 1958). Modern male bison can reach 1.8 meters tall and weigh more than 900 kg, making them the largest herbivore on the Plains of North America (Arthun and Holechek 1982:123). Bison agility enables quick response to threat. Their hostile nature and imposing size make bison difficult to hunt, particularly in herds.

Ethnographic studies indicate that the bison life cycle played a crucial role in the hunt (Brink 2008; Verbicky-Todd 1984), which I discuss further in the following section. Cows and bulls travel together only during rutting season. The rest of the year, bulls and cows split into male herds and female herds with calves. Bison cows typically become pregnant during the late July through early September rut, giving birth in April or May after a nine-month gestation period (Berger and Cunningham 1994). Females carry more fat throughout the year, making them the prime hunting target. Bulls carry more fat going into the rutting season, but in that season hormones render the meat undesirable, on the verge of being inedible (Audubon et al. 1846; Brink 2008; Speth 2010). Males were eaten only in dire situations (Ewers 1958:76).

Studies conducted at archaeological sites indicate that most successful bison kills occurred in the late summer/early fall on the southern Plains and late fall/early winter on the northern Plains (Bement 1999; Brink 2008; Frison 1996), when cows had formed their own large herds and bulls had separated into smaller herds. Through the study of herd demographics at archaeological sites archaeologists have been able to confirm that *Bison bison antiquus* group in cow/calf herds for most of the year as do modern bison (Bement 1999; Bement and Carter 2010; Bement et al. 2012; Frison 1991; Frison and Todd 1987). Birthing patterns are also consistent with modern bison herds, making tooth eruption a viable means of obtaining the season of the kill (Frison and Todd 1987).

Ethnographic Record of Bison Hunting

Understanding that bison herd dynamics and behavior has not changed dramatically through time I look to the ethnographic record of bison hunting on the Plains to inform the details of bison hunting. Keeping in mind the limiting factors of ethnography including ethnocentrism, and the incomplete nature of the ethnographic record, (Kelly 2013:167), what can we learn about Plains hunters during the fur trade years ranging from 1600's and climaxing in the late 1890's? We know that Native populations were greatly diminished with abundant accounts of sick and dying individuals (Cocking 1908). We also know that Native hunters commented repeatedly concerning the dwindling numbers of bison present on the Plains (Hendry 1907; Henry and Thompson 1897; Lehmer 1963; Lowie 1922).

Verbicky-Todd (1984) collected an exhaustive record of ethnographic data on the Canadian Plains, which indicated similarities in hunting techniques across the northern Plains during the Late Prehistoric. Tribes such as the Omaha, Blackfeet, and the Assiniboine carried out bison kills in the form of pounds. A bison pound is a human-made enclosure usually constructed with heavy wood and draped with hides or brush to cut off the view of the outside (Brink 2008; Frison 1998; Verbicky-Todd 1984) taking advantage of bison's poor eyesight. Pounds were often placed just over hills, or below shallow drops on the landscape where bison would not be able to see the structure until they were contained within it. Another less commonly ethnographically documented type of kill is the bison jump, which appears as a wide-ranging, highly successful kill technique throughout the archaeological record on the northern Plains for roughly 5,000 years (Brink 2008).

Although the use of pounds is well documented in the ethnographic record, the use of the jump technique is only mentioned by native hunters and seldom if ever witnessed by ethnographers (Brink 2008). Many factors of bison behavior are apparent when analyzing these kills. Bison have poor eye sight and modern bison can be contained in quite flimsy structures despite their strength, as long as they cannot perceive a means of escape. Ethnographic accounts of bison pounds indicate that bison often will not touch the walls of the enclosure unless they see a hole in which case they will smash through the enclosure, spoiling the kill (Ewers 1955; Henry and Thompson 1897).

A Bison Kill Beginning to End, Based on Ethnographic Data

The bison kill from beginning to end as we know it from ethnography, based on pounds and jumps, is outlined here. Based on numerous ethnographic accounts bison kills share certain similarities. One appears to be a high rate of failure. This may be due to the depleted number and size of herds, but more likely it indicates the delicate nature of a mass kill event, where large portions of a herd are killed. Groups join together to engage in kills although sometimes, individual bands would attempt to pound bison without the aid of neighboring groups (Hendry 1907; Verbicky-Todd 1984) with varying levels of success.

Numerous rituals are associated with the bison kill and many ritual observances were followed. One steadfast rule was that no man would hunt a bison during the period preceding a planned kill. This was a strictly adhered to rule in which offenders were severely punished by having their belongings burned or by severe whippings (Ewers 1958; McHugh 1972; Verbicky-Todd 1984). The practicality behind this social norm is clear; the killing of one bison may lead to disruption of the herd and ruin the success of the larger kill for the group. The pre-kill ceremonies observed varied widely across cultures, but extensive preparation was required by both men and woman (Verbicky-Todd 1984).

Buffalo runners, young, often unmarried, men were sent away from camp after meeting with the shaman, or head man running the hunt, often referred to as a chief in ethnographic accounts (Schaeffer 1978: 245-246). The buffalo runners were quick, skilled, revered men that ran sometimes for days to locate the bison herds (Brink 2008; McHugh 1972; Scheaffer 1978). Once they located the herd they would slowly push and maneuver the herd toward the pound or jump drive lanes.

The way the animals were manipulated was quite ingenious and demonstrates the intimate relationship the hunters had with the herds they hunted. Runners would often cloak themselves in a wolf's skin, and stalk the bison from behind, careful not to cause a stampede, but just enough to push the herd in the desired direction (Brink 2008). Another means of moving the herd involved runners dressing in the skin of calves and sounding distress calls at the front of the herd causing the herds to shift to investigate the calf in distress (Brink 2008; Quaife 1921:284). Small fires were also documented as being set just behind the herd, again to push the herds toward the drive lanes (Verbicky-Todd 1984; Weekes 1948). Once the herd was in range a runner would run back to camp and alert the group who would then move to the drive lanes (McDonnell 1889:279).

The drive lanes were preplanned routes, which were marked by small piles of rocks called cairns, or in some cases piles of brush. These drive lanes are still intact over many regions on the northern Plains (Brink 2008; Carlson 2011). According to the ethnographic accounts, men, women, and potentially even children would hide under robes or brush near these cairns (Ewers 1958; Verbicky-Todd 1984), but the real purpose and use of these cairns remains a mystery beyond the obvious need to mark a path to drive a stampeding herd to the kill point (Brink 2008; Brink and Rollans 1990). According to accounts the group would aid in keeping the bison within the drive lanes and continue their movement toward the jump or pound. Bison, again having poor eyesight, could be contained simply by flapping hides, making noise, or other means of deterring them. Also bison follow a lead animal; as long as the lead cow continued to stampede toward the pound or cliff the herd would follow (McHugh 1958).

A bison jump was a success when the bison were run through the drive lanes over the cliff, which usually was sufficiently high to kill or maim the majority of the lead bison (Brink 2008). Archaeologically we see bone beds containing hundreds of bison in one kill event at the base of a cliff (Brink 2008). Gathered hunters near the base of the cliff dispatched bison not killed in the fall. In the case of a pound the bison would mill, or run around in a circle, avoiding the walls of the pound until exhausted and killed (Coues 1897:519; Harmon 1911:286; McDougall 1896:281). The ethnographic record of how the animals were killed after they were contained is less consistent. Some accounts indicate ceremonies would be conducted while the animals were in the pound, others indicate that bison would be run to exhaustion and then shot with bows and arrows, interestingly, never rifles, even when they were available (McDonnell 1889:280; Skinner 1914:526; Verbicky-Todd 1984).

The activities following a mass kill event are also variable as recorded in the ethnographic record, which may indicate the chaos that would ensue as hunters raced to butcher animals. Also many value-laden accounts depicting Native groups in an uncivilized way indicate the political attitude toward Native people during the time the accounts were written (De Smet 1906, 1972:153). One such ethnographer indicated his disgust as Native people covered themselves with the blood of their kill (Henry 1901). Having butchered a bison myself, I can attest that it is not the cleanest job but the ethnographer's account was obviously saturated with ethnocentric opinions concerning the people involved in the butchering. Opinions aside, the animals were then butchered, the meat distributed, and the feasts would ensue. Often butchering would go for days especially when the weather was chilly and favorable for preserving the animals.

Some ethnographic accounts indicated that hunters had marks on each of their points indicating who would be credited with the kill of individual animals. Despite the mark everyone butchered the animals (Lehmer 1963). According to the accounts Verbicky-Todd (1984) collected butchering seems a fairly unorganized task, credited as being woman's work but in practice it appeared that all members of the community engaged in the butchering process (Hind 1971:358; Pallister 1863:11). Men apparently would move from butchering to celebration ceremonies while women moved to the arduous task of hide scraping (Verbicky-Todd 1984).

The Archaeological Record

Recurrent features of bison kill events are present in the archeological record. Communal kill events in which a large number of bison are killed do share many similarities. Bison pounds are poorly preserved because of the impermanent nature of the building materials in which the pounds are constructed. Bison jumps have a long, deep record on the northwestern plains (Brink 2008; Reeves 1990). Sites such as Head-Smashed-In-Buffalo-Jump were in use for 5500 years (Brink 2008). There is evidence for a potential bison jump in Texas dating back 10,000 years at Bonfire shelter (Bement 1986; Byerly et al. 2005; Dibble and Lorrain 1968). Jumps typically contain a drive lane of cairns and a bone bed or multiple bone beds below a cliff. Often a camp is located nearby. Arroyo traps typical of Paleoindian kills consist of an arroyo, bison bone beds, and the lithic materials used to dispatch the animals.

The earliest evidence we have for a bison pound is the Ruby site (Frison 1971). This site dates to 1670 ± 100 ^{14}C BP. This site contains a drive lane and corral still visible in the form of postholes around the bison bones. Frison and Todd's (1978) excavations at the Horner site contained two Cody-age (Late Paleoindian) bison kill events. The containment system used in this case is unclear but a consistent circular end to the bone bed indicates that a pound may have been employed at this site. The archaeological record correlates with the kill techniques seen in ethnographic accounts. The study of ethnographic accounts of bison kills coupled with the excavation of Paleoindian bison kills aids in furthering our understanding concerning the methods employed to kill large numbers of bison in a single event.

Bison-Specific Hunting Models on the Plains

Bison procurement specifically has been studied for decades on the Plains of North America. Many researchers have developed models based on excavated materials (Bement 1999; Bement and Carter 2010; Bement et al. 2012; Frison 1991; Frison and Todd 1987; Reher 1978; Reher and Frison 1980). These models, summarized by Judith Cooper (2008) in her dissertation, are outlined below. The models include are the Annual and Fall Procurement model, the Carrying Capacity Model, and the Social Model. These models are not mutually exclusive; they provide a framework for reference and understanding of bison hunting on the Plains and provide the background for ongoing research.

The Annual and Fall Procurement Model

The Annual and Fall Procurement model was developed on the northern Plains to explain the patterns seen in bison kill site assemblages, which tend to be dominated by fall season kills (Brink 2008; Frison 1970, 1971, 1973, 1991, 1996; Kehoe 1973; Reeves 1990; Reher and Frison 1980). This model is the most widely accepted and frequently used because it follows clear patterns apparent in northern Plains sites and is largely substantiated by ethnographic accounts of bison hunting. According to the model, bison were communally hunted annually during the fall when stores of cows rich in fat procured by hunters would enable human survival through the harsh winter months (Figure 2). The location for annual winter communal kills would move yearly in order to allow the stench of rotting carcasses from previous successful kills to dissipate (Frison 1970). This model also fits well with bison behavior and changing herd structure discussed earlier in this chapter. Communal drives were more likely to be successful when bison groups followed a lead cow and have separate cow/calf herds and bull herds.

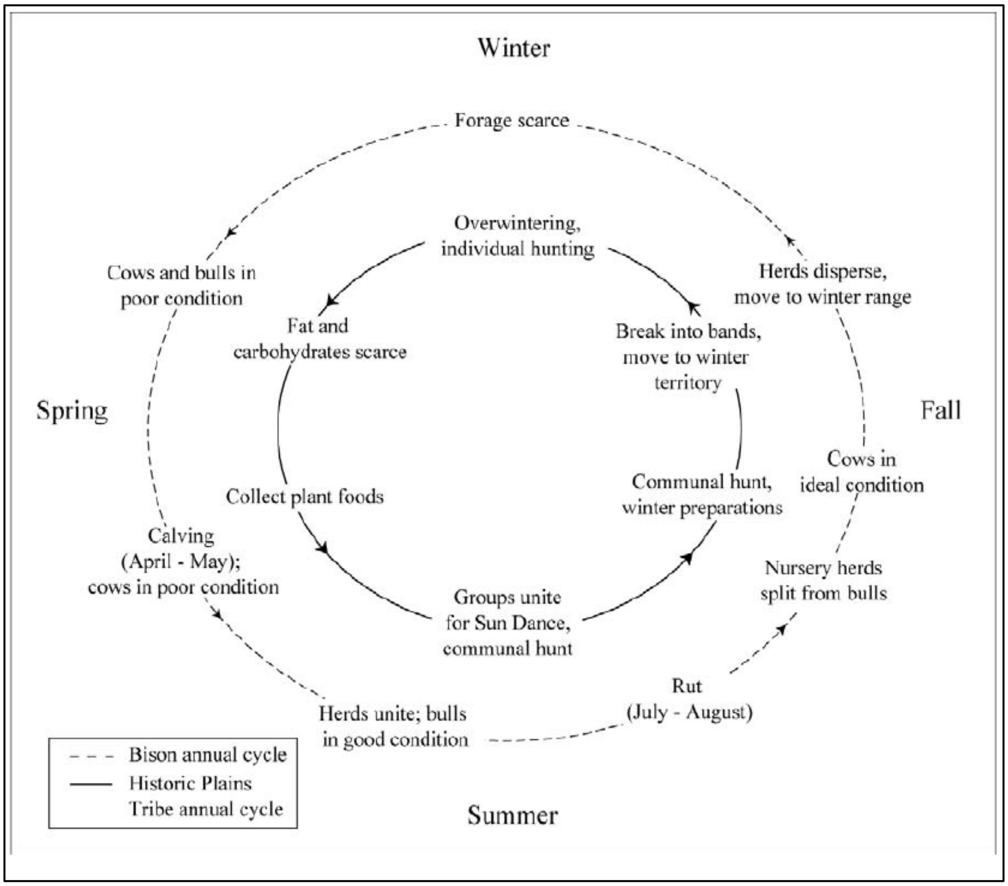


Figure 2.1. Historic Northern Plains hunting annual cycles and bison yearly round. Adapted from Brink (2008), Cooper (2008), and Oliver (1962).

The Annual and Fall Procurement model was questioned in light of ethnographic evidence, which indicated that bison were hunted throughout the winter months (Arthur 1975, 1978; Walker 1974). This led to the development of the Winter Bison Procurement Model (Walker 1974). None of the arguing parties dispute the Annual and Fall model; the Winter Bison Procurement Model merely extends the communal hunting season into the winter months. Cooper's (2008) expectations of winter kills include communal kills extending through the winter as well as a lack of intensive butchering during the fall, indicating animals were readily available throughout the winter season.

The Carrying Capacity Model

The Carrying Capacity model relates directly to the availability and condition of bison herds (Cooper 2008; Kelly 1995). In years of high precipitation and subsequent high grass quality bison herd size increases. Due to this increase in herd size human encounters with bison would also increase, leading to increased hunting. In years of scarcity bison procurement decreased. This model relies heavily on the diet breadth model, which determines how a hunter will select prey upon encounter (Bird and O'Connell 2006; Broughton 2012; Kelly 1995; Lupo 2007; MacArthur and Pianka 1966; Pianka 1974; Winterhalder 1981; Winterhalder and Smith 1981). Bison, as the largest prey animal on the landscape, would likely be killed upon encounter (Kelly 1995). Therefore an increase in encounter rates would lead to an increase in kill rates, whereas a decrease in encounters would lead to an increase in diet breadth (Winterhalder and Kennett 2006) as hunters widened their selection of prey varieties to compensate for scarcity. In this case the increase of bison hunting and the decrease of diet breadth applies as seen on the Plains during the Folsom and Goshen periods.

The Carrying Capacity model gains support from findings at the Vore site by Charles Reher and George Frison (1980). The Vore site in eastern Wyoming provided 22 kill events spanning a period from A.D. 1500 to 1800 resulting in the successful slaughter of over 20,000 animals (Reher 1978; Reher and Frison 1980). In addition to the temporal depth of information at this site sediment varves were used to detail precipitation history. A correlation of varve data and kill site data indicated that kills occurred at Vore every 25 years, following precipitation maximums by 3 to 7 years. Reher argues that in light of this evidence communal kills could not be supported annually in this region (Reher 1978).

The Social Model

The Social model proposed by William Fawcett (1987) argues that communal kills were carried out to aggregate and feed large groups of people. Kills provided a means to facilitate social interaction while consolidating power. Hunter-gatherer groups do not typically maintain groups over 25, one reason for this is that tensions and power struggles in groups over 25 typically splinter the group (Kelly 2013). Communal kills provide a time when the hosting group can take control and responsibility for a large group temporarily. These kills would occur independent of environmental conditions (Cooper 2008). An example of the social model emerges in theories such as costly signaling (Speth 2010) when kills are argued to have provided a means of increasing prestige rather than merely procuring resources.

A Setting for Aggregation

North American bison kill sites, once only thought to fulfill procurement and subsistence needs, are currently being re-evaluated from a decidedly social perspective (Speth 2010). Often the bison kill is only one component of a site complex also containing a processing area, camp, and ritual site (Zedeño 2014). These decidedly communal complexes incorporate cyclical nucleation (aggregation) with ritual observances with the execution of communal bison hunts that employ large bison jumps, pounds, or arroyo traps (Bement 1999; Carlson 2011). Addressing these questions transforms the basic subsistence function of communal bison kill sites into the realm of social constructs (Hayden and Dietler 2001). In the future the application of cyclical nucleation under the larger theoretical framework of behavioral ecology provides a transformative way to view Paleoindian bison hunting that generates new hypotheses and expectations, while acknowledging the substantial resource base these kill events produced.

Group Size and Paleoindians on the Landscape

Our understanding of demography outlined by Kelly (2013) comes from a small collection of hunter-gatherer ethnographic studies ranging from aboriginal Australians (Blurton Jones et al. 1992), the Ache (Hill and Hurtados 1996), the Dobe !Kung (Howell 1979, 2010), and the Hadza (Marlowe 2010). This range of ethnographic records is replete with limitations in accuracy due to colonial impacts such as disease bringing high mortality, and dramatic changes in culture, which predated the ethnographers. As Kelly aptly points out the data should be used with “healthy skepticism” (Kelly 2013:167). That being said, the following discussion provides a framework to understand what group dynamics may have looked like during the Paleoindian period.

Initial counts of minimum group size for mobile hunter-gatherers tended to be too high (Birdsell 1953) at 500 persons. More recent reanalysis of this issue has provided a count of roughly 25 people for an average foraging group (Binford 2001; Marlowe 2005), with an average of ten to seventeen people for nomadic, plant-dependent people. While 15 people for terrestrial hunters, and 18 for those dependent on aquatic resources seems a reasonable range. Hamilton et al. (2007) upon reanalysis of Binford’s 2001 dataset found that families consist of 4-5 people residential groups include 14-17 people. Social aggregations such as winter camps include 50-60 people, periodic aggregations of 150-180 people and ethnic populations reaching as high as 730-950 people. These numbers seem to remains consistent across differing environments. According to Kelly (2013:172) these groups reflect a consensus concerning how to efficiently move food, information, and mates without overt competition. Groups tend to function without a leader at 25 people; above 25 leaders are required for group management, which leads to fissioning of the groups (Kelly 2013:172). Wobst (1974) created a computer simulation, which indicated that a genetically viable group could not drop below 25 people. Lower numbers of hunter-gatherers can remain viable by interacting with other smaller neighboring groups (Kelly 2013).

Of particular importance to this study is the carrying capacity of bison and humans on the landscape during the prehistoric period (Epp and Dyke 2002).

Though the analysis carried out by Epp and Dyke (2002) focuses on the past 5,000 years, it is relevant to this research because it provides a basis to understand prey species mobility, and its effects on human demographics. The method applied by Epp and Dyke (2002) is based on the assumption that the number of people on the Plains can be estimated if the number of bison is known. It follows that if one person requires seven bison per year, then by knowing the number of bison on the landscape at any given of time, the non-human predation rate, and allowing for whether the herd is migratory or resident, the Epp and Dyke model provides a means to estimate an upper population level for people. According to Epp and Dyke (2002) by the late Historic period bison populations are estimated to have reached 30 million, 80% of those bison would have belonged to migratory herds at 24 million, while resident herds comprised the other 6 million. By applying the Epp and Dyke calculations, the migratory herd could support 315,000 people and the non-migratory herd a maximum of 43,000 people.

Potential for Aggregation and the Kill Site

Cyclical nucleation is the scheduled aggregation of multiple subsets of groups at a predetermined and repeatedly, often seasonally, visited node or location (Schaedel 1995; Turpin 2004). To avoid jargon I will discuss cyclical nucleation more simply as scheduled aggregation. The purposes of aggregation allow otherwise dispersed groups to perform acts outside their usual capabilities. These acts include communal activities such as hunting, feasting, and social networking, including information exchange, mate selection, trade relations, and social bond reinforcement (Hollenbach 2009; Kelly 2013). To be successful, the dispersed groups require a predetermined time and place or node to meet. A node is needed in a predictable location on the landscape in order to draw groups of people together at a set time during the year when a resource abundance is available to support the aggregation of a large number of people. A bison kill site provides this predictable node.

More recent kill/camp/ritual site complexes found at Late Prehistoric northern High Plains jump sites provide examples of scheduled aggregation around bison kills. These sites consist of one or more repeatedly used bison jumps, a processing site (generally at the base of the jump), a campsite (generally a fair distance from the jump) and evidence of ritual activity, which can be integrated into any of the aspects of the bison kill (Zedeño et al. 2014). The complex and extensive drive lanes associated with jumps reflect the social investment in these sites (Carlson 2011). Situational leadership is the hallmark of egalitarian society (Fawcett 1987; Johnson 1982; Kelly 2013).

Scheduled aggregation at a particular node on the landscape requires an abundance of food to support various groups for the duration of the aggregation, in this case the bison hunt and subsequent butchering of the animals. In considering the use of communal bison hunts as the subsistence intensification required for scheduled aggregation, the repeatedly used bison kill site is proposed to serve as a component of a node around which the system functions. Special landscape requirements must be met for a successful communal bison kill, including bison milling area, drive path, and containment or kill structure (pound, jump, arroyo trap; Carlson 2011; Fawcett 1987; Frison 1991). The node requirement is met by the reuse of a successful kill site such as indicated at Head-Smashed-In (Brink 2008), Vore (Reher and Frison 1980), and Kutoyis (Zedeño et al. 2014). The special requirements of the kill site, especially the proximity to a bison population, anchor the system to areas where the requisite landform type (e.g. cliff or arroyo) is found where bison congregate or are concentrated such as along established migration paths. This view of large-scale bison hunting builds on previous models of Plains bison hunting systems.

The above outlined models provide the background for our understanding of bison hunting as well as my research. My research relies on the Fall Procurement Model without the assumption that kills are carried out as a yearly event. The Winter Bison Procurement Model is not completely excluded however I do not see evidence that fully supports elaborate kills carried out throughout the winter months although winter kills do occur. The Carrying Capacity Model also features heavily in the research as evidence does support an increase in kills during seasons of increases in herd size. Lastly the Social Model acknowledges the social benefits a large-scale kill provides in addition to the caloric resources procured.

Theory Summary

In summary large game hunting has a long history of varying theoretical paradigms that have framed the research up to this point. Under Human Behavioral Ecology large game hunting can be analyzed to determine the extent to which large-scale kill events suddenly develop in North America at the

Younger Dryas shift. The Younger Dryas climatic reversal is discussed in the next chapter. This shift marked a period in which large game such as mammoths were dying off and bison were recovering from a near extinction event. The prey landscape was dramatically changing and human populations were on the rise. Using Human Behavioral Ecology we can analyze bison kill sites in two different region of North America and determine the extent to which the large scale hunting adaptation was dependent on dramatic ecological changes.

Chapter 3: Background

The following chapter provides the ecological and environmental setting for the regions containing the archaeological sites selected for my analysis. I then discuss the cultural historical context as it is currently understood for the Paleoindian period on the North American Great Plains. In addition to this discussion I summarize the data currently available from excavations of the six bison kill sites compared within this research.

Ecological Background of the Great Plains

The Great Plains span from Canada to the north, down to Mexico in the south, from the Rocky Mountains to the west and the Eastern Woodlands mark the eastern boundary (Wedel 1963). Though the Plains seem ubiquitous in flat grassland expanse, subtle changes in landscape and precipitation create ecosystems that vary slightly from east to west and north to south. The Plains change subtly across its great expanse. Relief of the landscape comes in the form of stream valleys, uplifts, and erosional remnants (Frison 1991; Kornfeld et al. 2010). The Plains provides a xeric landscape in which people and animals creatively adapted in order to survive.

Variation in Climate: From Global to Local

To understand the drastic changes in environment through time I focus the environmental discussion on the shift between the Pleistocene and Holocene on the Plains. First, I discuss how we know what we know concerning environmental change by discussing oxygen isotopes and the Greenland and Antarctic ice sheet record. This record provides a global perspective of changes in environmental conditions through time. Second, I discuss the pollen and phytolith records specific to the regions under study on the northern and southern Plains.

Global Climate Change

In order to better understand climate change on a global scale I include a brief discussion of oxygen isotopes and how they are used to determine glacial periods. An isotope is a variant of an element, which has the same number of protons but different numbers of neutrons (Macdougall 2013; Meltzer 2009: 28). Two forms of oxygen are ^{16}O and the heavier isotope ^{18}O, both of which bond with hydrogen to form water. Greater proportions of ^{16}O reach the clouds after evaporation because they are lighter, the ^{18}O isotopes are left behind in the oceans. In non-glacial periods the ratio of ^{18}O to ^{16}O is fairly constant in ocean water because rain and snow return to the ocean. When precipitation becomes locked in glaciers the ^{16}O molecules do not make it into the ocean thereby changing the ratio of ^{18}O to ^{16}O in the oceans (Alley 2000; Alley et al. 2005; Krajick 2002). Through the analysis of tiny planktonoic animals, which precipitate calcareous shells that record the ^{18}O to ^{16}O ratio, a record of glaciation can be reconstructed (Alley 2000; Meltzer 2009). Extensive ocean floor samples coupled with Greenland and Antarctic ice core records have been analyzed to provide the last million year record of global glacial periods (Alley et al. 2005; Krajick 2002; Macdougall 2004).

The Wisconsin glacial period is of particular relevance to this research since the focus is the Paleoindian record. The Wisconsin is broken into three periods. The Early Wisconsin (80,000-65,000 ^{14}C BP), which marks a colder period, began the glacial episode. The middle Wisconsin (65,000 – 35,000 ^{14}C BP) marks a warmer period with reduced glaciers on land. The Late Wisconsin (35,000- 10,000 ^{14}C BP) marks the Last Glacial Maximum (LGM) and the warming to the Holocene (10,000 ^{14}C BP to present; Martinson et al. 1987; Macdougall 2004). What is referred to as the Pleistocene/Holocene transition is of particular interest to this research since it coincides with the early Paleoindian Clovis and Folsom periods.

Local Climate Change on the Great Plains

Climate has varied drastically across the Plains from the late Pleistocene to the early Holocene. These changes affected prehistoric occupants by rapidly changing plant and animal resources. The most dramatic climatic shifts occurred at the end of the Pleistocene, starting with the warming conditions of the Bolling-Allerod (14,500 – 10,900 ^{14}C BP), abrupt cooling and then warm-up of the Younger Dryas (10,900 – 10,000 ^{14}C BP), followed by warming conditions of the Holocene (10,000 – 0 ^{14}C BP; Alley 2000; Figure 3.1).

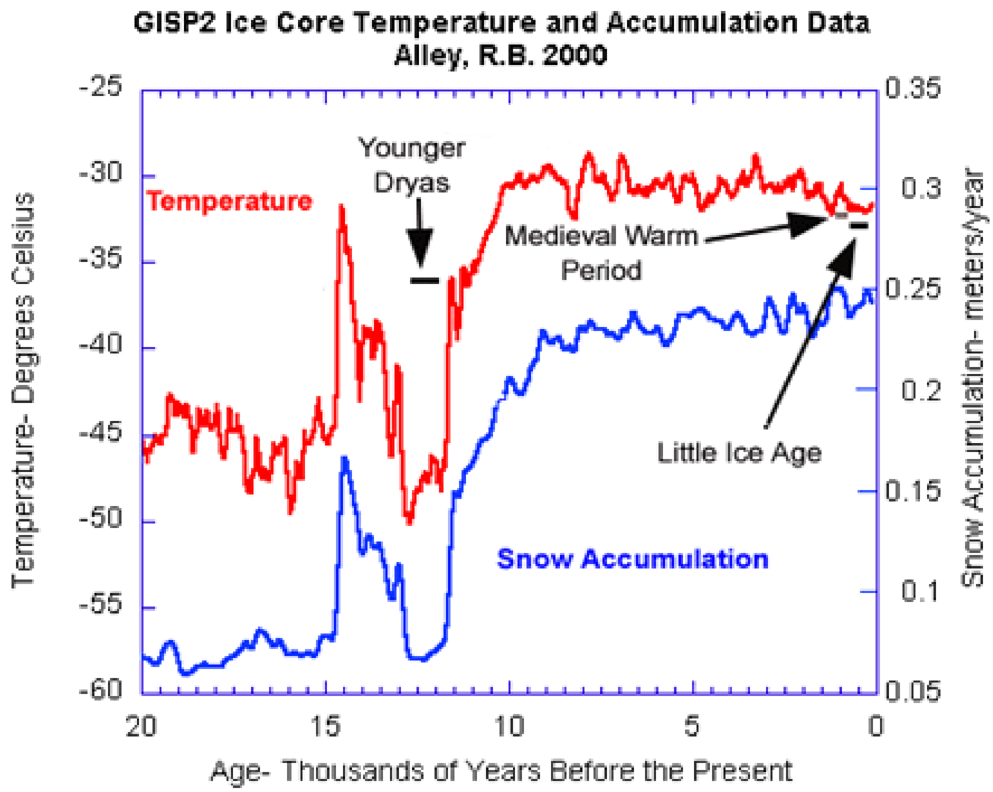


Figure 3.1. Alley (2000) image of the changes in temperature based on Greenland Ice Core data.

Warming at the end of the Wisconsin Glacial Maximum during the Pleistocene (11,500 – 10,000 ^{14}C BP) melted the Cordilleran and Laurentide ice sheets and created a world unlike anything prior (Blinnikov et al. 2002; Graham et al. 1994; Kornfeld et al. 2010). Vegetation shifted from a widly diverse flora to a homogenous steppe enviornment across the Great Plains by 11,000 ^{14}C BP followed by an expansive grassland by 10,000 ^{14}C BP (Fredlund and Tieszen 1994). Many large animals went extinct between 11,900 and 10,200 ^{14}C BP (Martin and Klein 1984). When the cooler, wetter Younger Dryas came about (10,900 ^{14}C BP) bison were the largest remaining prey animal on the landscape (Kornfeld et al. 2010). Bison arrived in North America sometime during the mid-

Pleistocene and, as a genus, did not become extinct during the late Pleistocene when other megamammals died out (Martin 2005). Instead, bison populations survived and later flourished as the largest-bodied, post-Pleistocene Plains herbivore. Bison did not, however, survive unscathed. In fact, mitochondrial DNA (mtDNA) of Beringian bison populations suggest that bison experienced a genetic bottleneck at the same time mammoths, horses, camels, and other North American large mammals were headed for extinction (Drummond et al. 2005; Shapiro et al. 2004). The extent of this stress is reflected in a mtDNA founder effect mutation that appears in all bison populations south of the Laurentide and Cordilleron ice sheets around 11,300 ^{14}C BP (Shapiro et al. 2004) and is still evident in living populations today (O'Shea 2012).

In the early Holocene winter and summer, temperature ranges were not synchronized on the Plains. Fluctuations in elevation caused drastically different precipitation levels, leading to xeric and mesic enviornments coexsisting in close proximity to each other (Fredlund and Tieszen 1994). By 10,600 ^{14}C BP the north still experienced near glacial conditions, leaving eastern Wyoming and the Colorado Rocky Mountains cool and wet while northwestern Wyoming to the west in Idaho experienced comparatively dry and warm climates. Summer temperatures also started to rise during this time while winters stayed relatvely consistent (Beiswenger 1991; Fall et al. 1995; Whitlock et al. 2002).

The northern Plains were still subject to glacial conditions during the Younger Dryas while summers began to gradually warm for longer periods (Beiswenger 1991, Kornfeld et al. 2010). Figure 3.2 demonstrated the Greenland ice core record commonly used to infer global environmental change. The lower line below the ice core record indicates the southern Plains soil isotopic record indicates that global climate shifts were occurring in the region. Soil isotopic evidence on the southern Plains indicates a significantly cooler temperature around the start of the Younger Dryas (11,000 ^{14}C BP) followed by a warming trend (Bement et al. 2007:44; Figure 3.2). This data is significant to demonstrate that global changes also occurred at a regional level during the Paleoindian period. These changes are reflected more specifically in the pollen and phytolith data discussed below.

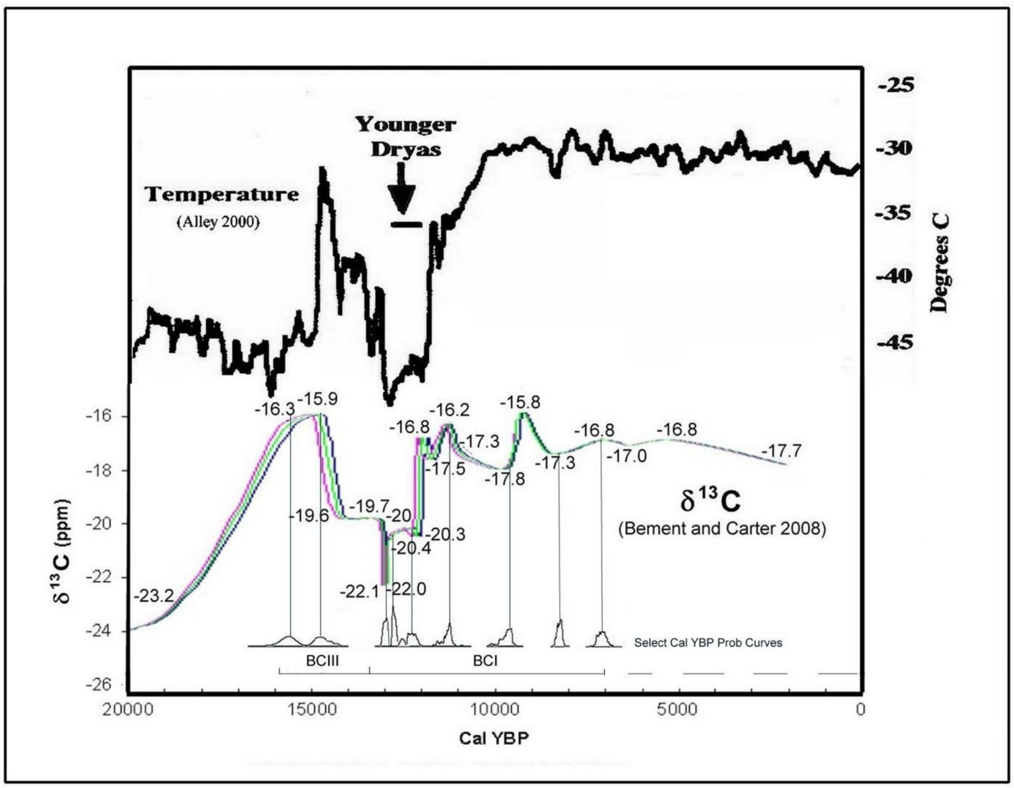


Figure 3.2. Greenland ice sheet core data (above) compared to soil isotope data on the southern Plains (below). Climate changes occurred regionally and locally on the southern Plains (after Bement and Carter 2010).

Pollen and Phytolith Records from the Site Regions

Pollen and phytoliths data are commonly used for environmental reconstruction archaeologically (Cummings 1996). Most abundant types of pollen preserved in the record are wind transported. This pollen category includes trees, shrubs, grasses, and forbs such as Cheno-ams (*Atriplex* – *saltbrush* and others), sagebrush (*Artemisia*), and sedges (*Cyperaceae*). Differences in pollen counts can be attributed to wind patterns and density of local vegetation. Pollen moved by insects and animals travel shorter distances than wind born pollen leading to smaller counts recovered in pollen analysis (Cummings 1996:177). Phytoliths are structures made of silica produced by plants, which preserve after the plant has decomposed. They can also be subject to degradation and decomposition through erosion and high pH soils (Cummings 1996:177). The Paleoindian period poses unique problems for pollen and phytolith analysis due to the extensive period of decomposition and remodeling. Pollen analysis specific to the Agate Basin site area, for example was deemed inconclusive due to high oxidation in the soil, (Beiswenger 1987). This is a common issue in pollen analysis of this time period on the Plains (Beiswenger 1987; Hall 1981; Tschudy 1969). Phytolith analysis has been plagued with many of the same preservation issues and a clear phytolith record is also not readily available on the Plains (Lewis 1979; Rovner 1975:130). The data provided below demonstrates what the pollen and phytolith record indicates.

The Southern Plains

Pollen data from Bull Creek (Bement et al. 2007:48) located in the Oklahoma panhandle provides the most complete pollen record for the southern Plains site region. The pollen indicates change from a mesic landscape of open sage scrubland mixed with hardwoods with an understory of mixed grasses and shrubs prior to 11,000 ^{14}C BP to one containing more oaks and grassy medows by 10,850 ^{14}C BP. Arboreal pollen from Black Mountain Colorado increseses from 32 percent to 45 percent between 11,600 and 11,000 ^{14}C BP. While after 11,000 ^{14}C BP arboreal pollen decreases from 45 percent to 30 percent (Jodry 1999:31). Grass pollen (*poacaea*) also increases during this time from 5 percent to 10 percent (Jodry 1999). This data further supports the abrubt switch from moist to dry conditions following 11,000 ^{14}C BP.

The Northern Plains

Changes in climate between 15,000 and 12,000 ^{14}C BP caused the receding of the Wisconsin ice sheet discussed above. These changes led to the decline in the boreal forests in regions south of the ice sheets, including North Dakota, South Dakota, Nebraska, and Kansas (Marlow 1984). Upland plant communities began to provide ideal bison range grasslands with an increase in nutrient rich C_3 grasses discussed further below. This region provided little in the way of edible plant remains for humans during the Folsom time period (Marlow 1984:349).

Pollen analysis of the region including South Dakota, North Dakota, Manitoba, Saskatchewan, and Minnesota (Wright 1970) indicate that spruce (*picea ssp*), fir (*Abies ssp*.), pine (*Pinus ssp.*), and other boreal trees occupied the region between 15,000 and 12,500 years ^{14}C BP. By 10,000 ^{14}C BP (Wright 1970) shows that Spruce began to retreat north.

The phytolith and pollen evidence on the northern Plains indicates fluctuations in Pine (*pinus*) and very high sagebrush (*artemisia*) with Pine (*pinus*) being at its lowest during the range of 11,000 ^{14}C BP to 8,000 ^{14}C BP. This pattern is consistent with regional patterns for the Late Pleistocene and the early Holocene Anathermal (Cummings 1996:177). Sagebrush dominates the landscape with grasses dispersed throughout the region. The region appears to increasingly warm and dry, and supports a grassland dominated by Chloridoid (short grasses), which grow well in warm dry conditions. Solar insolation models indicate that increased solar radiation during the summer resulted in warmer dryer summers but had little effect on winter temperatures (COHMAP Members 1988). Effective summer drought conditions increased during the early Holocene. The warming of the Anathermal is noted to be a summer occurrence (Kutzbach 1987). This array of pollen is not seen to reoccur after the Pleistocene (Cummings 1996).

Grasslands of the Plains

In this section I discuss the modern grassland distribution of the regions under study. The Paleoindian grasslands are reconstructed in later chapters through stable isotope analysis.

Grasslands change with changes in precipitation (Heisler-White et al. 2008). A brief discussion of modern grasslands provided here demonstrates how grassland environments are understood today. As I will explain in the following chapters modern grasslands do not provide a good proxy for Paleoindian grasslands because of dramatic changes in ecosystems since that time. However a map of modern grasses does provide a visual of the shift in changing environments from east to west and north to south, which are consistent through time (Fredlund and Tieszen 1994); Kucher 1975). The regional variation of today is similar to regional variation during the Paleoindian period, although the species are not the same during these periods. Grasslands on the Plains shift from east to west in step with increasing levels of precipitation (Figure 3.3 and 3.4). The eastern Plains are marked predominantly by tallgrass prairies rich in moist climate C_4 grasses. Mixed Prairies combine C_3 and C_4 grasses through the central Plains and dominate the northern landscapes. Shortgrass prairies dominate the southwestern Plains and are composed of xeric-adapted C_4 grasses. This grassland array coincides with changes in precipitation (Figure 3.3) creating slight variation in ecozones (Figure 3.4). A more thorough explanation of C_3 and C_4 grasses will be discussed in Chapter 4 in relation to stable isotopic analysis.

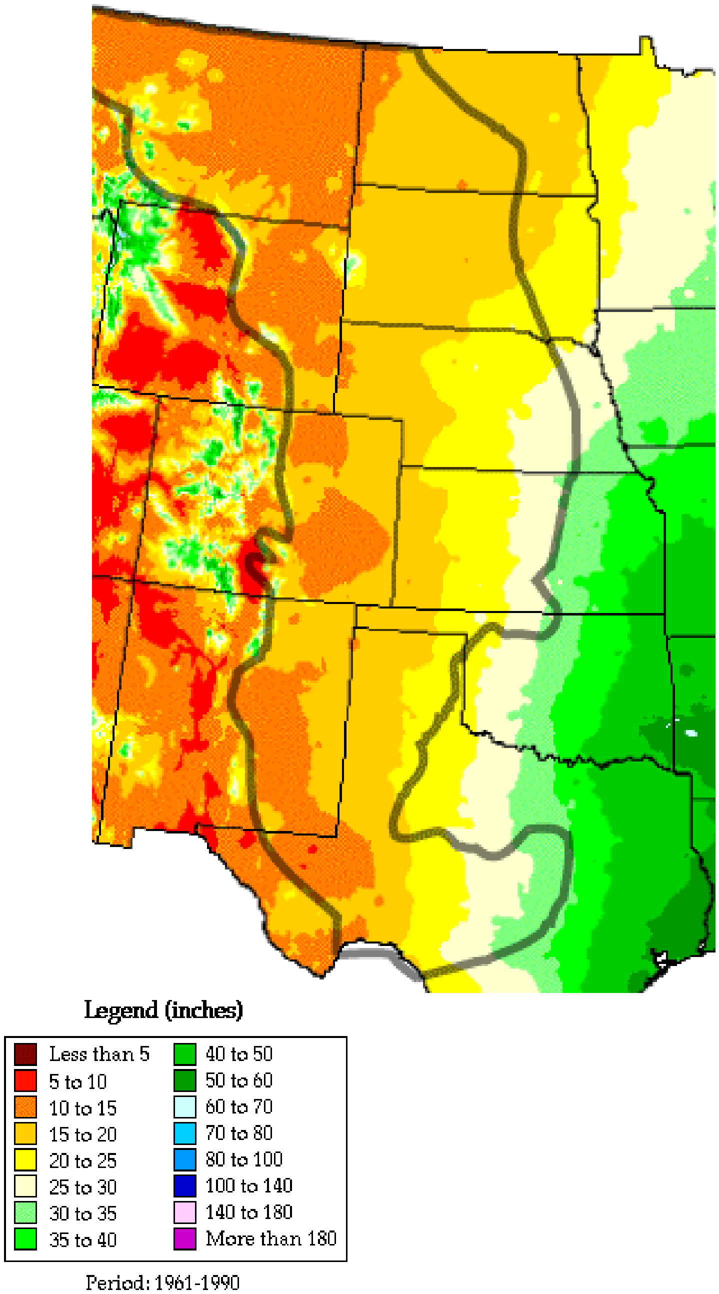


Figure 3.3. Modern variation in precipitation across North American Plains, (outlined in grey), note the bands of precipitation from west to east on the Plains (Christopher Daily PRISM model 1990).

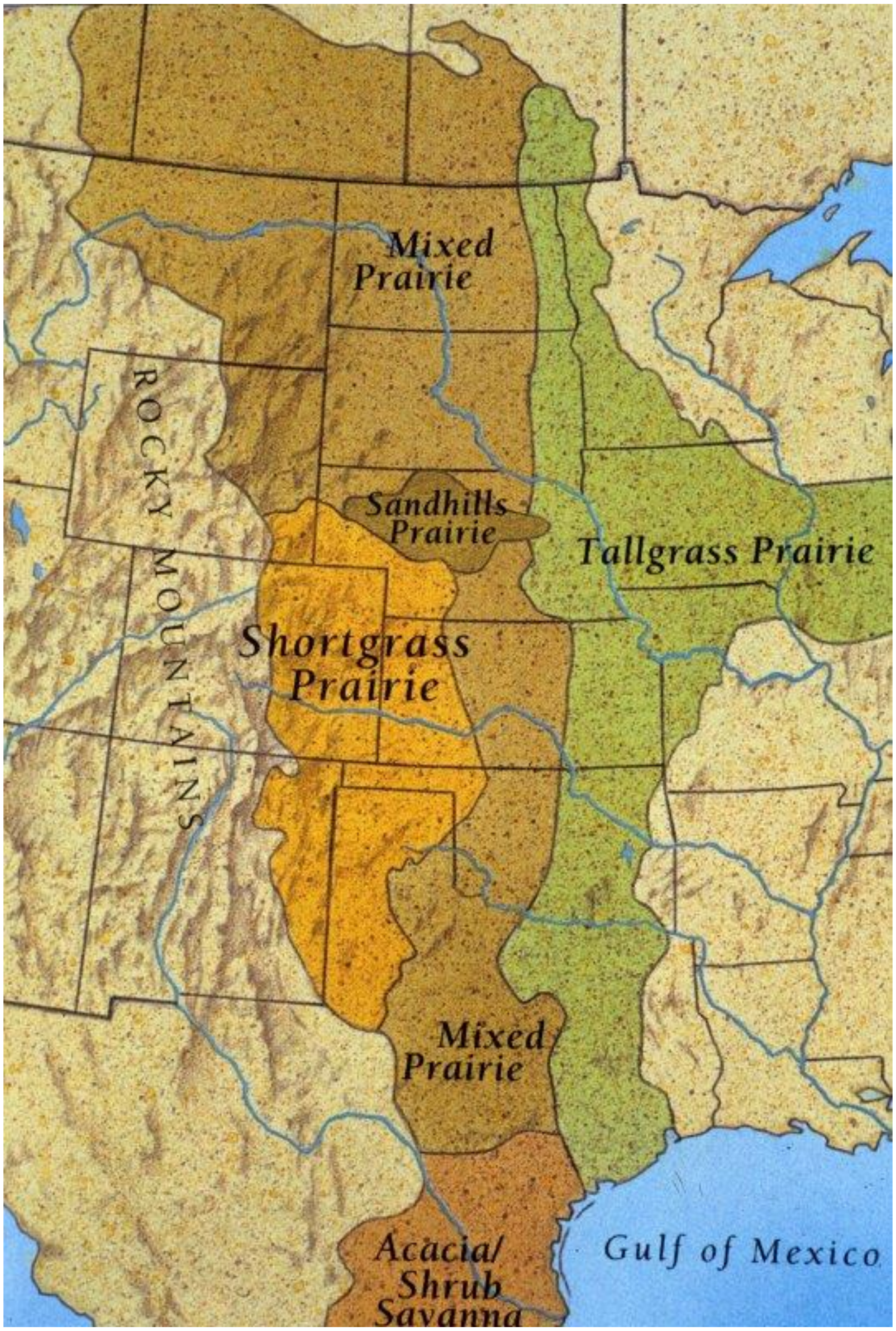


Figure 3.4. Changes in grassland composition across the Great Plains reflect changes in grassland composition outlined in studies such as Fredlund and Tieszen (1994) and Kucher (1975).

This concludes the environmental discussion of the Plains providing background for climate change and grassland composition, which, provide the basis for the research discussed in the following section. The following section will discuss the cultural history of the region and the sites analyzed.

Cultural Background of the Great Plains: The Paleoindian Period

The Paleoindian period spans from the peopling of the New World sometime prior to 12,000 ^{14}C BP (Pitblado 2011) to the end of the Late Paleoindian period roughly 7,500 ^{14}C BP (Frison 1976, 1978, 1988; Kornfeld et al. 2010). This time period spans the late Pleistocene to the early Holocene transition, culminating just prior to the Altithermal (9,000 to 5,000 ^{14}C BP). The terminal Pleistocene/early Holocene is a period in which the environment undergoes dramatic changes on a global scale.

Clovis sites, once thought to mark the cultural remains of the first Americans, are now being reevaluated with an earlier migration of Pre-Clovis people in mind (Anderson et al. 2015; Waters and Stafford 2014). Pre-Clovis does not appear to share a wide-spread lithic technology and site assemblages vary greatly between Pre-Clovis sites (Collins and Bradley 2008; Gilbert et al. 2008; Morrow et al. 2012; Waters et al. 2011a; Waters et al. 2011b). To date, none of the Pre-Clovis sites display characteristics attributed to large-scale hunting adaptations and thus are not discussed further here.

The Paleoindian time period is split into three periods: early, middle, and late (Frison 1991). The early Paleoindian is marked by entry into the New World sometime before 12,000 ^{14}C BP. Mounting evidence supports a Pre-Clovis entry followed by the Clovis period, which dates to 11,900-10,800 ^{14}C BP (Waters and Stafford 2007). On the Plains in particular, the waxing and waning of Paleoindian cultures is often conceived as changing projectile point styles. On the Plains Clovis technology changes into Goshen, Folsom, and Midland (Figure 3.5). Plainview replaces Goshen on the southern Plains (Knudson 1983). Agate Basin and Hell Gap develop in the middle Paleoindian period. Alberta and Cody are found at the beginning of the late Paleoindian period followed by Fredrick, James Allen, Lusk, and Blackwater Side Notched. Other varieties of points develop regionally during the mid Paleoindian through the late Paleoindian period, such as Angostura, in the Rockies and the west (Libe and Pitblado 1999).

The following section focuses on the Clovis, Folsom, and Goshen complexes on the Plains. These lithic technologies and associated cultural complexes provide the focus for this research. On the southern Plains the sites included span from the late Clovis period through the Folsom period. Northern Plains sites analyzed include the Folsom components of Agate Basin and CKM as well as the Goshen Mill Iron site.

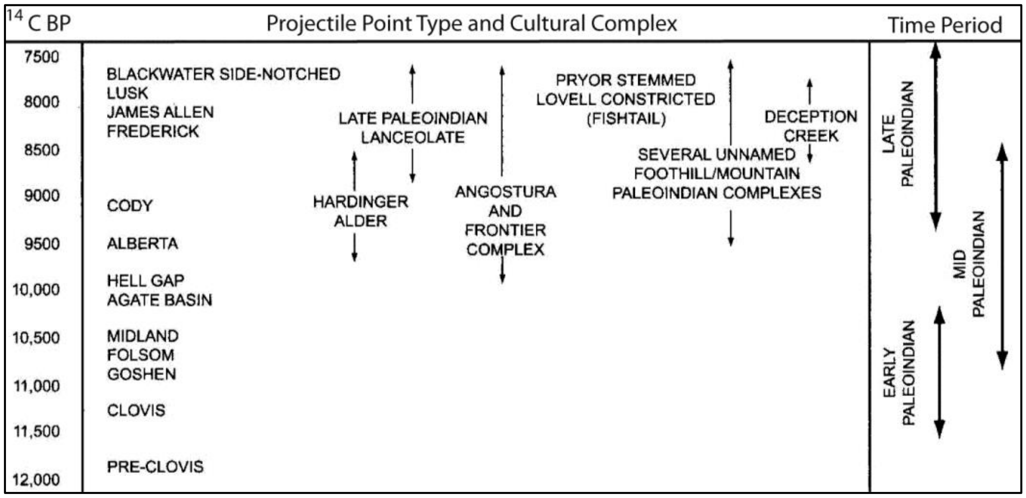


Figure 3.5. Chronology of Plains Paleoindian period adapted from Kornfeld et al. (2010).

Clovis

Clovis represents the oldest clearly archaeologically visible and well defined archaeological culture in North America (Miller et al. 2013; Smallwood and Jennings 2015) with sites ranging in age from 11,600 to 10,800 ^{14}C BP at the widest range (13.4k-12.7k cal yr BP; Grayson and Meltzer 2015; Miller et al. 2013) to the likely tighter range proposed by Waters and Stafford (2007) of 11,050-10,800 ^{14}C years ago. The Clovis technology is one of the most geographically extensive cultural expressions of North America spanning from coast to coast and from Canada to Central America (Anderson et al. 2010; Bradley et al. 2010; Collins 1999:35; Meltzer 2009:241; Miller et al. 2013:207; Waters and Stafford 2007). The Clovis type site is Blackwater Draw Locality No. 1 in eastern New Mexico (Hester et al. 1972). Clovis lithic technology is distinct (Bradley et al. 2010). Clovis lithic material provides a hallmark for Clovis site identification with distinctive lanceolate biface points often thinned by means of overshot flaking (Bradley et al. 2010). Prismatic blades are another diagnostic element of the lithic assemblage (Collins 1999).

Clovis sites fall into three main types: caches, animal kills, and camps. An example of a Clovis camp is found at the Gault site in Texas where extensive repeat occupation debris is associated with a nearby lithic source. Other sites include Clovis caches (Huckell and Kilby 2014), and megafaunal kill and/ or scavenging sites (Grayson and Meltzer 2002; 2015).

Sites containing Clovis type lithic material are extensive. Anderson et al. (2015) has complied an online database of the North American distribution of Paleoindian material, including Clovis points (www.pidba.utk.edu). Over 20,000 points are recognized as belonging to the Paleoindian period, however for the purpose of this discussion I will limit this discussion to the 2,060 Clovis points positively identified in 409 locations (Figure 3.6). According to Anderson and Faught (2000) the vast majority of Clovis materials are located in the southeastern United States. The high concentration of Clovis material in the southeast, rather than the northern Plains has implications for the hypothesis that Clovis people were the initial colonizers of the Americas. If Clovis were the initial colonizers coming across the Bering land bridge and descending through the ice free corridor, one would expect to see the highest concentration of Clovis material at the southern point of the ice free corridor and adjacent areas, not in southeastern US (Anderson and Gillam 2000; Anderson et al. 2010).

For the purpose of this discussion I simply note the distribution of artifacts to indicate the wide spread nature of Clovis artifacts, which likely took a substantial population to produce given the time range of Clovis. I believe this provides evidence that human populations had to have reached significant numbers prior to the development of the Clovis culture.

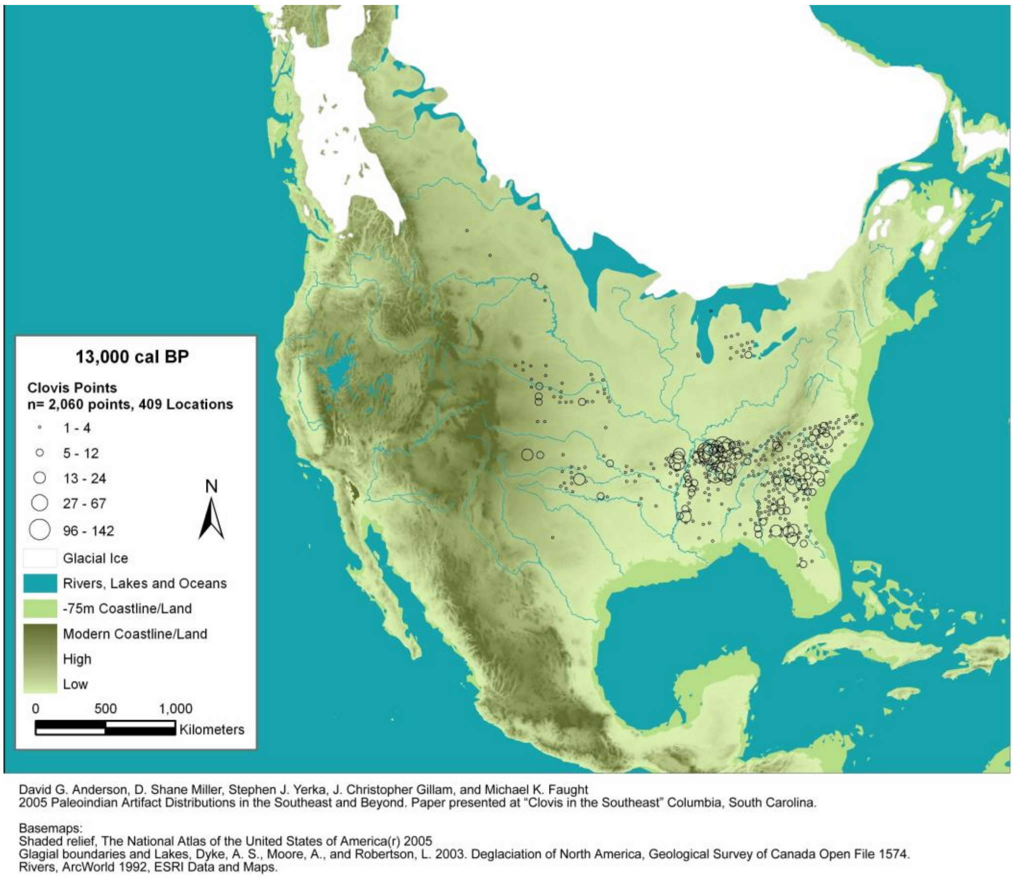


Figure 3.6. Distribution of Clovis materials across North America (Anderson et al. 2005).

Currently over 25 Clovis caches have been identified (Bamforth 2014; Huckell and Kilby 2014: 217). Though the exact purpose of caches is still a source for future study the increase in recognition of cached materials leads to avenues of research from lithic manufacture and maintenance, mobility and land use practices (Bement 2014; Condon et al. 2014; Holen 2014), and social organization and ritual behavior (Kilby 2008; Wilke et al. 1991). Clovis caches are unique archaeologically because they appear to be useful material, which has, in most cases, been set aside for later use (Huckell and Kilby 2014). The distribution of Clovis caches spans the Plains of North America (Figure 3.7). The Anzick cache (Lahren and Bonnichsen 1974; Wilke et al. 1991) located near Wilsall, Montana contains burial remains of a young male and 8 points, 62 bifaces, 1 blade, 9 flakes, and 6 shaped and carved bone rods (Huckell and Kilby 2014). The burial, recently the subject of genetic analysis, slightly post-dates Clovis at 10,705 ± 35 ^{14}C BP (approximately 12,707–12,556 cal yrs BP) and provides evidence of "gene flow from the Siberian Upper Palaeolithic Mal'ta population into Native American ancestors is also shared by the Anzick-1 individual and thus happened before 12,600 years BP" (Rasmussen et al. 2014:225).

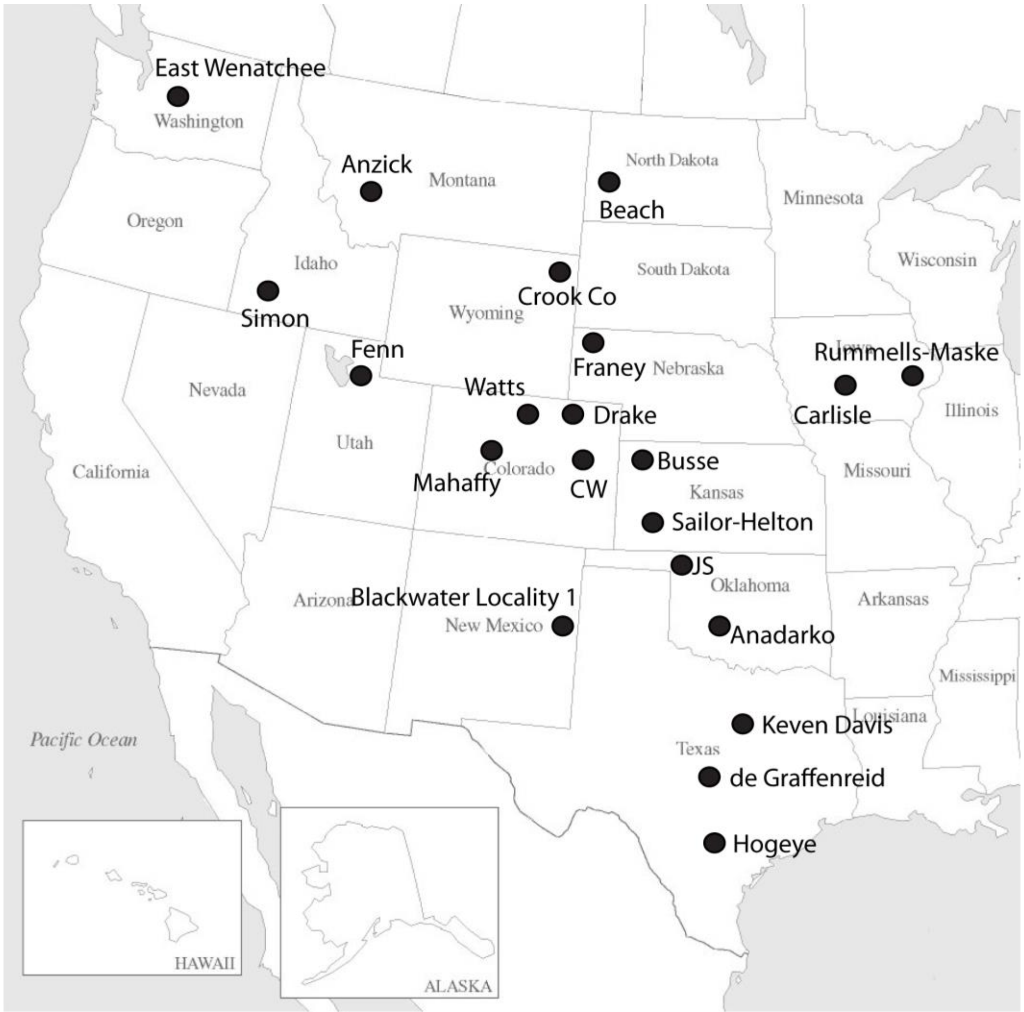


Figure 3.7. The distribution of Clovis caches across the Plains.

Clovis sites associated with Pleistocene animals are typically associated with Proboscidea, Mammoth (*Mammuthus*) and American Mastadon (*Mammut*; Meltzer 2009; Grayson and Meltzer 2015). In the analysis of Clovis sites in North America by Grayson and Meltzer (2015) the authors provide a strict association between human behavior and animal remains providing a very restrictive list of Clovis and potentially pre Clovis sites associated with mammoth and mastodon remains. These sites are briefly discussed here to demonstrate the extent by which our understanding of Clovis hunting is based. The association between animals and humans is difficult to strongly support. As Meltzer and Grayson point out when Clovis materials are strongly associated with Proboscideans it is difficult if not impossible to ascertain the cause of death of the animal. Therefore we can merely demonstrate that people exploited the animal resources, not necessarily that the animal was killed by people. Therefore associations between animals and people at this time period may demonstrate hunting of the animal, or scavenging of animal resources, or a combination of both. Grayson and Meltzer (2015) narrow the Clovis site array down to 15 sites, which they argue provide compelling evidence for an association between people and animals. These 15 sites include remains from *Camelops, Equus, Cuvieronius, Mammut,* and *Mammuthus*.

To the northwest the Manis Mastodon site in Washington, a potential bone point was located imbedded in the rib of the animal (Gustafson 1984, 1985; Gustafson et al. 1979; Waters et al. 2011). Grayson and Meltzer (2015) argued the bone to be the result of male bull mastodons fighting rather than human hunting. Waters (2011) concludes that the bone is a fashioned point and, therefore, is indicative of hunting. For the background discussion of Clovis this is included as a Clovis site.

On the northern Plains the Wally's Beach site, Alberta, Canada (Kooyman et al. 2006; McNeil et al. 2004, 2005, 2007) provides a Clovis-age (11,070 ± 80 ^{14}C BP) kill containing horse (*Equus*), camel (*Camelops*) and *Bootherium.* The Sheaman site in Wyoming (Frison and Stanford 1982) provides lithic material commonly found in Clovis deposits such as blades and a decorated carved antler object (Frison and Craig 1982).

To the southeast sites such as Page Ladson, Florida (Webb and Simons 2006) contain multiple late Pleistocene vertebrates. The researchers at the site indicate cut marks and butchering marks on multiple animals including a horse (*Equus*) and a tapir (*Tapirus)* and mastodon (Mammut). Coats-Hines Tennessee (Deter-Wolf et al. 2011) provides mastodon remains with lithic material and possible cutmarks on the bones (Breitburg and Broster 1995).

To the south other well-studied Clovis sites with clear human and animal associations include Murray Springs, Arizona (Haynes and Huckell 2007) where there is strong evidence for mammoth hunting. The Dent site, located in Colorado, provides strong evidence for mammoth hunting or scavenging (Brunswig 2007; Brunswig and Fisher 1993; Fisher and Fox 2007; Grayson and Meltzer 2015; Haynes et al. 1998; Hoppe 2004; Saunders 2007). The site contains the remains for multiple mammoths and three Clovis points (Kornfeld et al. 2010). Key Oklahoma Clovis sites include the mammoth kill at the Domebo site (Leonhardy 1966) and the bison kill at Jake Bluff (Bement and Carter 2010). Jake Bluff is discussed at length below. El Fin del Mundo, Sonora, Mexico (Sanchez et al. 2014) contains remains of gomphethere (*Cuvieronius sp*.) The lithic assemblage from the site includes 13 Clovis points and or fragments. Charcoal dates from the site yielded ages of 11,550 ± 60 ^{14}C BP and 11,880 ± 200 ^{14}C BP, making it potentially one of the oldest Clovis sites.

Clovis peoples, once thought to be the first inhabitants of North America, now appear to have developed out of cultures settled into the country for longer periods than initial interpretations indicated. Whether Clovis people inhabited North America for 900 years (Grayson and Meltzer 2015; Miller et al. 2013) or 300 years (Waters and Stafford 2007) theirs remains one of the widest cultural manifestations to cover North America. The Clovis culture also witnessed the extinction of the largest animals in North America, including mammoth, mastodon, horse, ground sloth, camel, and short faced bear (Martin 2005). The loss of many of the Plains grazing animals set the stage for the development of the subsequent culture, Folsom.

Folsom

Immediately following the Clovis period on the High Plains and Rocky Mountain provinces of North America is the Folsom period. The Folsom period ranges between 10,900 to 10,200 ^{14}C BP (Frison 1991; Kornfeld et al. 2010) and is marked by the exquisitely flaked and fluted Folsom projectile point. The most distinct difference between Folsom and Clovis is the preponderance of bison in Folsom sites, indicating that the species flourished during Folsom times. Folsom technology has been argued to be adapted specifically for bison (Frison 2004).

The highest density of Folsom sites are found on the Great Plains and Rockie Mountains (Figure 3.8). Wyoming sites include the Brewster site along Moss Agate arroyo in eastern Wyomings (Agogino 1972), the Folsom component of Agate Basin (Frison and Stanford 1982), several Folsom components at the Hell Gap site in southeastern Wyoming (Irwin- Williams et al.

1973; Larson et al. 2009), Hanson site in northern Wyoming (Frison and Bradley 1980), the Folsom component at Carter/Kerr-McGee (Frison 1984), and Two Moon Shelter in the Bighorn Muntains of Wyoming contains Folsom lithic material (Finely et al. 2005) and appears to be a camp near a lithic outcrop. Montana sites include the McHaffie site (Forbis and Sperry 1952) and the Indian Creek site (Davis 1984; Davis and Greiser 1992). A Folsom hearth-centered use area was located at the Barger Gulch camp (Surovell and Waguespack 2007).

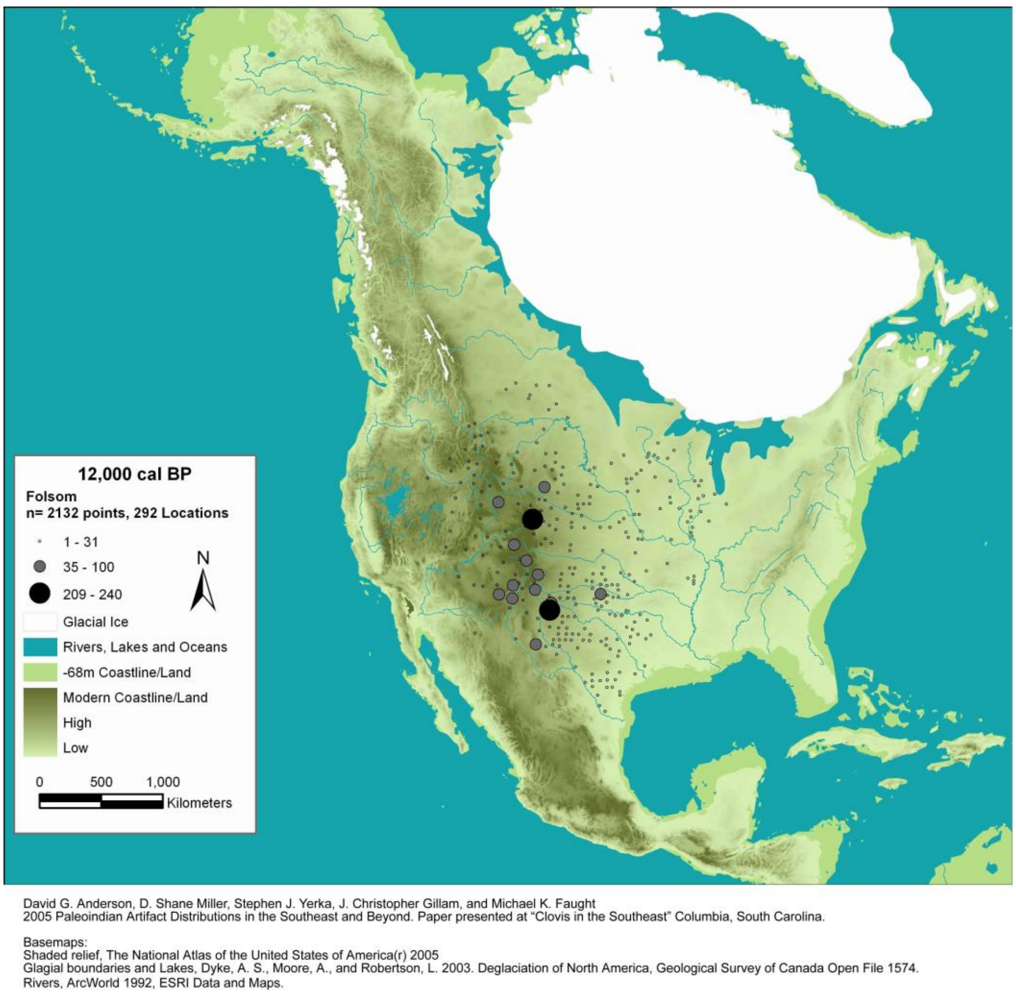


Figure 3.8. Distribution of Folsom projectile points across North America (Anderson 2005).

On the southern Plains the Folsom type site is located in New Mexico (Meltzer 2006). A Folsom component is also found at Blackwater Locality No. 1 (Hester 1972). Folsom camp sites in Colorado include Lindenmeier (Roberts 1935; Wilmsen and Roberts 1978), Barger Cultch a shallowly buried Folsom site in Middle Park Colorado (Surovell et al. 2005), and Stewart's Cattle Guard in the San Luis Valley of south central Colorado. Stewart's Cattle Guard also contains a bison kill (Jodry 1999). Oklahoma sites include the Beaver River Complex, including Cooper, Jake Bluff, and Badger Hole (Bement et al. 2012; Carlson and Bement 2013) and the Waugh site (Hill and Hofman 1997). Key Texas Folsom sites include Lubbock Lake, (Johnson 1987), Lake Theo (Harrison and Killen 1978); Adair-Steadman (Tunnell 1977), Hot Tubb (Meltzer et al. 2006), and Bonfire Shelter (Bement 1986; Dibble and Lorrain 1968).

The Folsom adaptation includes a similar suite of site types found during Clovis times on the Plains and includes camps, bison kill sites, and lithic quarries excluding caches. A full array of bison hunting techniques includes large-scale kills utilyzing arroyo traps, dune traps, and cliff jumps, as well as small-scale encounters at watering holes (Bement 2003).

Many Paleoindian researchers believe Folsom projectile points represent the finest quality pressure flaking seen across the world (Ahler 2000; Amick 1995; Kornfeld et al. 2010). Folsom fluting is an unexplained phenomena that has been postulated to represent artistic design more than function (Kornfeld et al. 2010; Speth 2010). The bone tools including needles (Frison and Craig 1982) and antler projectile points discovered at Agate Basin (Frison and Zeimens 1980) are indicative of the craftmanship common to Folsom materials.

Agate Basin's Folsom level contained what are interpreted as punches for removing channel flakes during the fluting process (Frison and Bradley 1980). Other items found among channel flakes, broken preforms, and deitage at other sites indicate various methods were likely employed to flute Folsom points (Kornfeld et al. 2010:81). One constant, however, is the selection of high-quality lithic material for Folsom point manufacture. The purpose of fluting remainas a topic of debate, including functional as well as ritual attributes.

The Folsom bison hunting focus is symptomatic of the "settling in" to the post-extinction situation seen during Clovis and the abrupt climate changes of the Younger Dryas. Similar regionally-specific adaptations are seen in other areas of North America and the process continues into late Paleoindian times and beyond as fluting technology is replaced by unfluted and eventually stemmed and notched projectile point forms (Kornfeld et al. 2010).

The emergence of unfluted bifacial projectile points during Folsom is seen with Midland points which may be unfluted Folsom points (Bradley 2009). More research is needed on this technology to determine the extent to which Midland represents its own knapping style (Amick 1995; Bamforth 1991; Holliday and Meltzer 1996; Irwin-Williams et al. 1973; Kornfeld et al. 2010).

Other unfluted technologies overlap with Folsom technology chronologically. The appearance of Plainview on the southern Plains and Goshen on the northern Plains illustrates this development. Similarities in lithic technology, site types, and adaptation suggests Plainview and Goshen are one and the same. For the purpose of this dissertation, I will focus on Goshen sites from the northern Plains.

Goshen

Goshen, the cultral complex associated with the Mill Iron site, included in my analysis, is discussed here. Goshen materials are only found on the northern Plains and adjacent Rocky Mountains (Frison 1996). Goshen points exhibit transvere pressure flaking, are basally thinned, and have a slight concavity at the base (Frison 1991). Points similar to Goshen are usually attributed to the Plainview culture when discovered on the southern Plains (Waters and Stafford 2014). The Goshen complex on the northern Plains was originally thought to date somewhere in the Clovis period or perhaps overlapping early Folsom in some cases (Frison 1996). Redating of site materials discussed in later chapters as part of the analysis carried out in this dissertation as well as recent work by Waters and Stafford (2014) provides a new chronology for Goshen. New dates obtained from this study as well as Waters and Stafford (2014) indicate that Goshen falls in between 10,450 ± 15 and 10,175 ± 40 ^{14}C yr BP.

Sites containing Goshen materials are listed below. At Hell Gap a Goshen level was defined below the Folsom level (Frison 1996). Mill Iron site proved to be a Goshen site (Frison 1996). Goshen projectile points also emerged from the Jim Pitts site in South Dakota (Sellet 2001; Sellet et al. 2009) and the Upper

Twin Mountain site in Colorado (Kornfeld et al 1999; Kornfeld and Frison 2000).

Archaeological Sites Analyzed

The following section outlines the background of the six Paleoindian sites included in this analysis (Figure 3.9). This research focuses on the early Paleoindian time period, 11,100-10,000 ^{14}C BP, when large-scale bison hunting is prevalent across the northern and southern Plains enabling an inter-regional comparison. Large-scale kill events may exist prior to this period, however, the archaeological record of such events is sparse (Frison 1978; Kornfeld et al. 2010). For this research I collected data from three southern Plains early Paleoindian sites and from comparable sites on the northern Plains. The southern Plains sites include the Beaver River kill complex of northwestern Oklahoma which contains three arroyo trap kill sites: Cooper (34HP45; Bement 1999), Jake Buff (34HP60; Bement and Carter 2010), and Badger Hole (34HP194; Bement et al. 2012). The northern Plains sites are Mill Iron, Montana (24CT30; Frison 1996), Agate Basin, Wyoming (48NA201; Frison and Stanford 1982; Hill 2008), and Carter/Kerr-McGee, Wyoming (48CA12; Frison 1984).

Figure 3.9. Sites included in this study.

Southern Plains Sites

Three arroyo trap bison kill sites located along the Beaver River in Harper County, Oklahoma constitute the Beaver River Complex (3.10). The Beaver River bison hunting complex consists of large (> 10 bison), late summer/early fall, arroyo trap kills manned by groups using lithics that originated in various southern Plains regions, including the western Oklahoma panhandle, Texas panhandle, and central Texas (Figure 3.11). Occasional inclusion of individuals or groups from the central Plains is suggested by the occasional occurrence of tools or points made from sources in northwestern

Kansas and eastern Colorado (Bement 1999). These sites provide the samples from the southern Plains research due to the 500 radiocarbon year hunting duration at the kill complex.

Pollen and phytolith analysis conducted at multiple sites along the Beaver River drainage provide an understanding of the ecosystem of the immediate region around the time the kill sites were in use (Cummings and Yost 2012a, 2012b). Soil samples taken from the Jake Bluff site provide the clearest record of environment along the Beaver River Complex.

Vegetation in the modern setting includes xeric species of sagebrush, yucca, short grasses, and various stunted shrub oak. The riparian zones include oaks, hickory, cottonwood, mid-story juniper and occasional tall grasses.

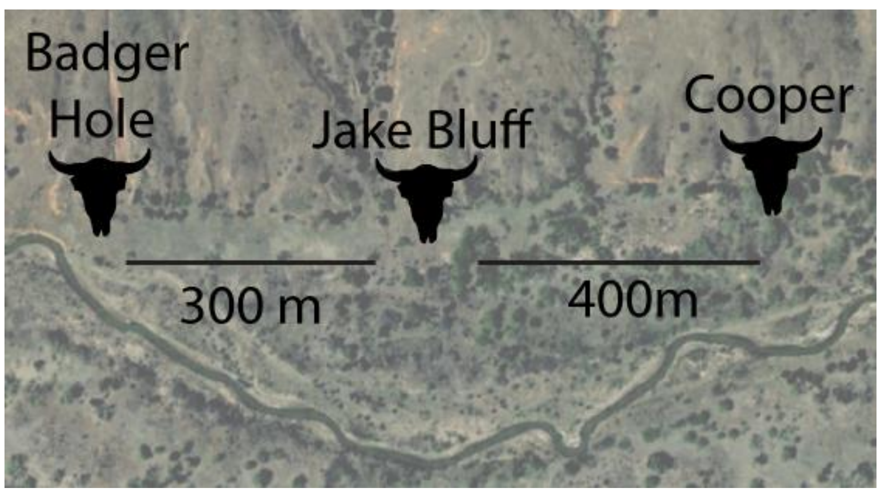


Figure 3.10. Beaver River Complex sites.

Jake Bluff

The earliest record of arroyo trap kills within the Beaver River drainage is found at the Clovis-age Jake Bluff Site (34HP60; Bement and Carter 2010). During excavations from 2001 to 2007 Dr. Leland Bement excavated 67 m^2

including 4 m^2 on the west bench of the paleo-arroyo, 25 m^2 of the east bench, and 38 m^2.

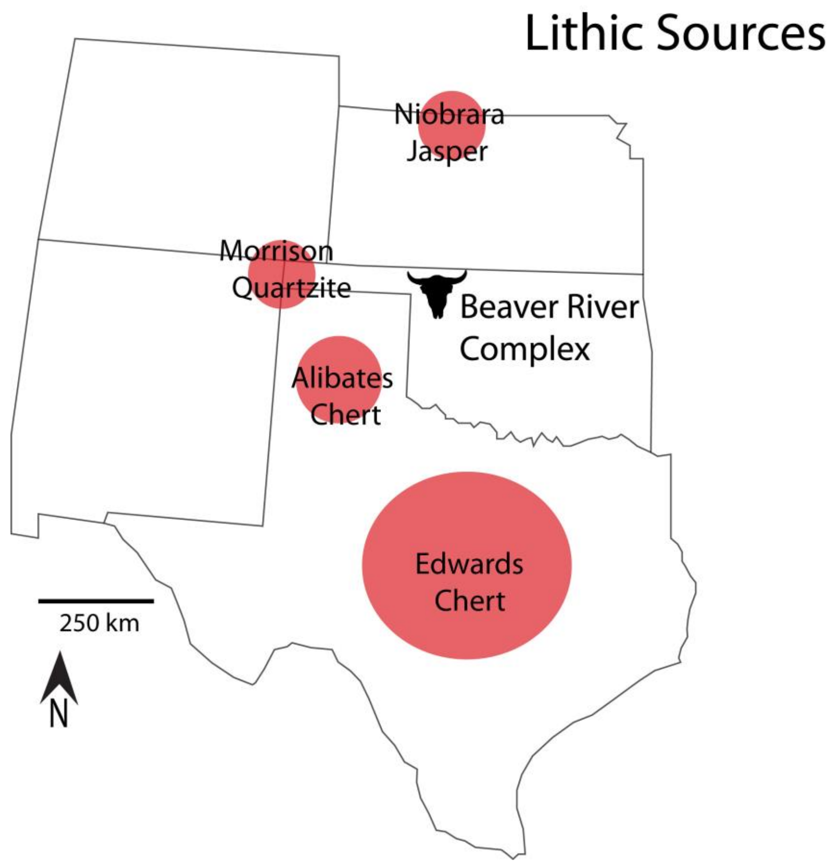


Figure 3.11. The map above shows the various lithic sources common to the southern Plains sites included in this analysis.

within the central paleo-arroyo leaving 30 m^2 unexcavated (Figure 3.12; Bement and Carter 2010). Two kill events were discovered at the site, one larger kill and butchering event dating to the Clovis period and a small remnant of a butchering event dating to the Folsom period. A Folsom point was located 1 m above the Clovis deposits and was made of Edwards chert from Central Texas. Due to the scant remains at the Folsom level the use of this site during this time period is unknown. Multiple caliche cobbles were found in association with the point and highly fractured bone.

The buried arroyo used to trap and kill the Clovis aged bison was roughly V shaped, it was a narrow 2 m wide and extended at least 20 meters (Bement and Carter 2010). As is often the case in arroyo systems more recent arroyo activity has truncated the paleo arroyo. The arroyo contains a mixture of in situ kill deposits as well as butcher piles (Figure 3.12). Gley deposits within the bone bed indicate undisturbed deposits (Hofman and Carter 1991; Hofman et al. 1991) under both the kill and butcher piles. Gley is caused when "large quantities of anaerobic bacteria from the killed animals' rumen and adjacent native soil rapidly expand and populate the sediment and consume organic remains on bones. . . During metabolism the Fe +3 iron oxides are reduced to Fe +2 iron oxides, changing the sediment from red to gray" (Bement and Carter 2010).

The kill event at Jake Bluff dates to 10,821 ± 17 ^{14}C BP (Bement and Carter 2010), post-dating all known Clovis mammoth kills and earning Jake Bluff a position as one of the latest Clovis sites in North America (Holliday and Meltzer 2010; Waters and Stafford 2007). The timing of this site is significant because it marks a period when mammoth are dying off and reflects methods by which Paleoindian hunters began to adapt to the next highest ranking species left on the landscape, bison.

Geologic coring along the north margin of the Beaver River floodplain terraces found that the requisite arroyos for bison traps formed by 11,200 ^{14}C BP

(Bement and Brosowske 1999) and began filling with sediment until full, shortly after 10,000 ^{14}C BP. This sequence parallels similar landscape histories identified in nearby regions (Holliday 1995). The development of the arroyo trap technique in this area was possible because of the existence of suitable short, steep-walled arroyos, large numbers of bison – at least seasonally – and the requisite number of hunters with the knowledge of bison trap hunting methods.

Lithic material recovered from Jake Bluff's Clovis level include four Clovis points, a 5th point reworked into a drill, one large flake knife, 23 pieces of debitage, and 12 possible hammer stones, and a possible anvil stone. Three of the Clovis points are Alibates chert, and the fourth is a gray quartzite, either Morrison or Dakota formation (Figure 3.13). The Clovis points have a single flute on each face. Residue analysis conducted before cleaning (Bement and Carter 2010) resulted in bison in addition to a single point containing the result of black bear. Black bear remains from a single individual were found butchered and scattered within the bison remains (Bement and Carter 2010).

The bone assemblage contains 1,915 identifiable specimens (NISP) and the minimum number of bison (*B. b. antiquus*) individuals (MNI) killed at Jake Bluff is 22 based on left proximal femora (Bement and Carter 2010). Based on tooth eruption patterns the kill took place during late summer/fall. If we assume calving occurred during April and May as it does currently then the kills occurred from August to September.

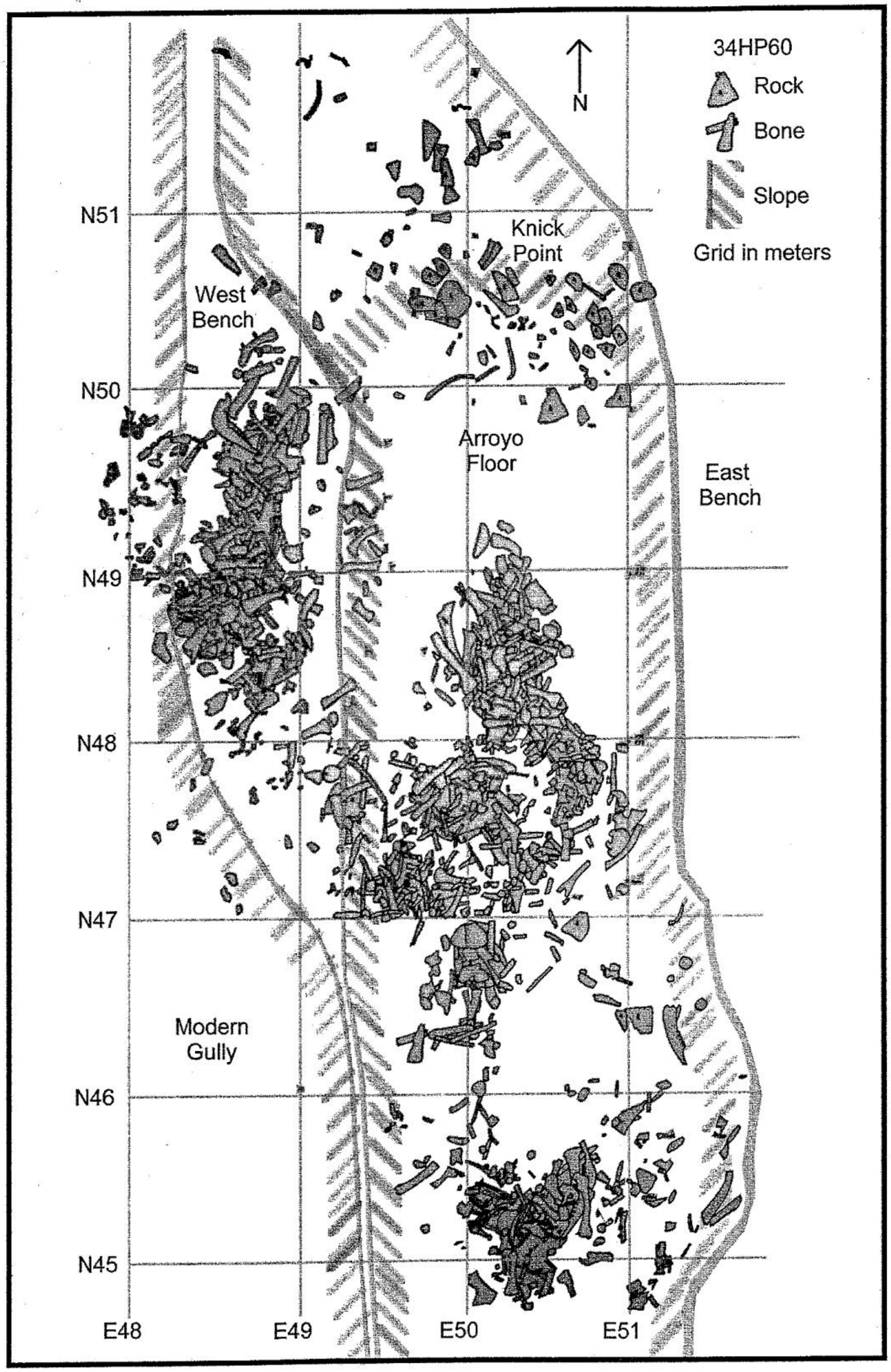


Figure 3.12. The portion of the Jake Bluff bone bed immediately below the knick point (Bement and Carter 2010).

Figure 3.13. Clovis points from the Jake Bluff site.

Cooper

Cooper (34HP45) consists of three separate kill events during a span of roughly 60 radiocarbon years. The state of Oklahoma purchased the property in 1992 and created the Cooper Wildlife Management Area. Excavations at Cooper began in 1993 after turkey hunters discovered a Folsom point eroding near bison bones (Bement 1999). The seasonality of all three kill sites based on tooth eruption and wear pattern analysis indicated the kills occurred during the late summer early fall. MNI's from each kill level are described below. The actual number of bison killed during this event is unknown due to excessive erosion occurring well before the discovery of the site.

The upper kill at Cooper, dated originally to 10,600 ± 40 ^{14}C BP (Johnson and Bement 2009), measured 6 m from east to west by 4 m from north to south (Figure 3.14). A total of 972 identifiable bones were excavated from the upper kill. MNI by age indicates 29 individuals including three claves, two yearlings, six two year-olds, five three year-olds, three six year-olds, and two animals age seven or older. No animals fit the ten and older category (Bement 1999). Five bones within the upper kill level have signs of cut marks. Spiral fractures were found on five elements (Bement 1999).

The lithic assemblage of the upper kill contains 13 complete or fragmented projectile points. The points are consistent with the Folsom technology. Five (38%) of the points were complete and ten (77%) are fluted on both surfaces. Ten of the 13 points were made from Alibates. Two were made from Edwards Chert. One point was made from Niobrara jasper (Figure 3.15). Flake tools include four flake knifes. A fifth knife was created from a channel flake (Bement 1999).

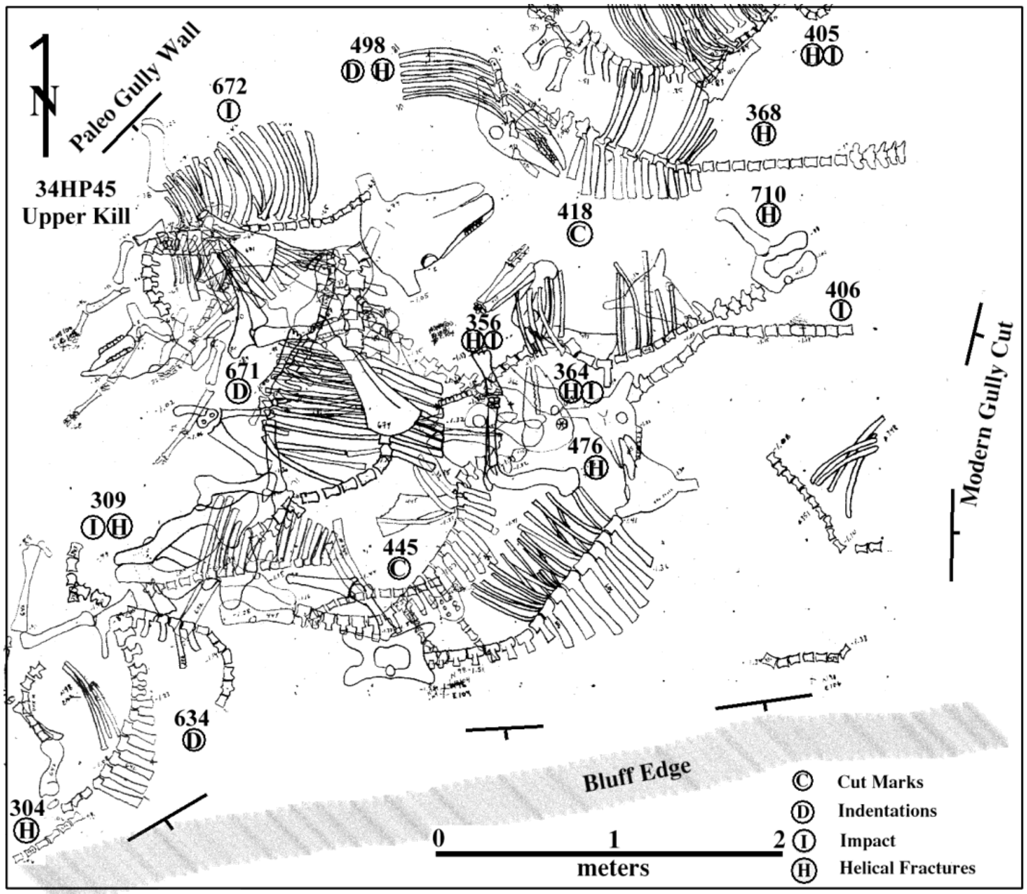


Figure 3.14. Upper Kill from Cooper (Johnson and Bement 2009).

Figure 3.15. Examples of Folsom points from each of the three Cooper kills. Top row, upper kill; middle row, middle kill; bottom row, lowest kill.

Located roughly 25 cm below the upper kill the middle kill was originally dated to 10,535 ± 40 ^{14}C BP (Johnson and Bement 2009). What remains of the kill episode covered an area 5.5 m from east to west and 4 m from north to south (Figure 3.16). The western edge of the middle kill intermingles with the upper kill due to erosion and soil movement. The bison of the upper kill trampled the bones contained on this western edge of the middle kill during the later kill event (Bement 1999).

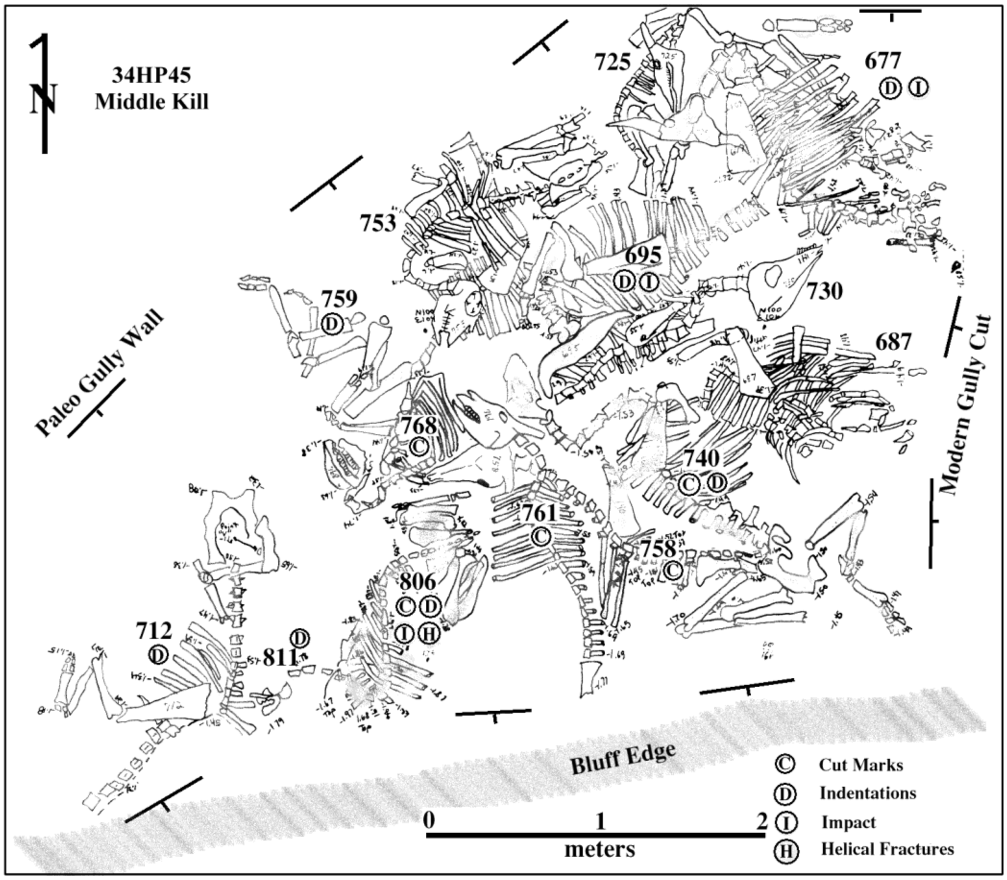


Figure 3.16. Middle Kill from Cooper (Johnson and Bement 2009).

A total of 707 elements were recovered from the middle kill excavation. Age distribution of the MNI of 29 includes, one calf, five yearlings, nine two year-olds, seven three year-olds, four four year-olds, and three five plus year-olds. No animals over seven years were present (Bement 1999). Fourteen cut marks were discovered during analysis predominantly located on ribs (10) and thoracic vertebrae (2). Only four elements displayed spiral fractures, predominantly metatarsals (Bement 1999).

The lithic assemblage included seven projectile points (Figure 3.15). Three points were made of Edwards chert of the grey brown variety, the remaining four points were made from an Edwards variety known as Owl Creek

(Figure 3.15). Six of the seven points were fluted on both sides. Two flake tools were located in the excavation. The first was a secondary flake made from Ogallala quartzite. Ogallala comes from Rocky Mountain gravel outwash deposits found throughout the southern Plains. The second tool was made from Owl Creek Edwards chert (Bement 1999).

The lowest kill was separated by a very thin layer of sediment between it and the middle kill. Trampling damage documented between the middle and upper kill is also evident between the middle and lowest kill. The lower kill contained a minimum of 20 mostly articulated individuals. The deposit spanned 4m from east to west and 3m from north to south (Figure 3.17; Bement 1999). The lowest kill was originally dated to 10,505 ± 40 ^{14}C BP (Johnson and Bement 2009).

A total of 444 identified elements were recovered from this kill level. The 20 individuals by age are one calf, one yearling, five two year olds, six three year olds, two four year olds, three five year olds, and two seven year old, no individuals older than six were recovered from this level (Bement 1999). Six specimens had cut marks and a single scapula had a spiral fracture. Seven Folsom points were recovered from the lower kill (Figure 3.15). Five of the points were fluted; two were not. The unfluted points were made from Alibates and Owl Creek. Two of the fluted points were made from Alibates, and one from the Owl Creek variety of Edwards; two were from the more common variety of Edwards (Bement 1999).

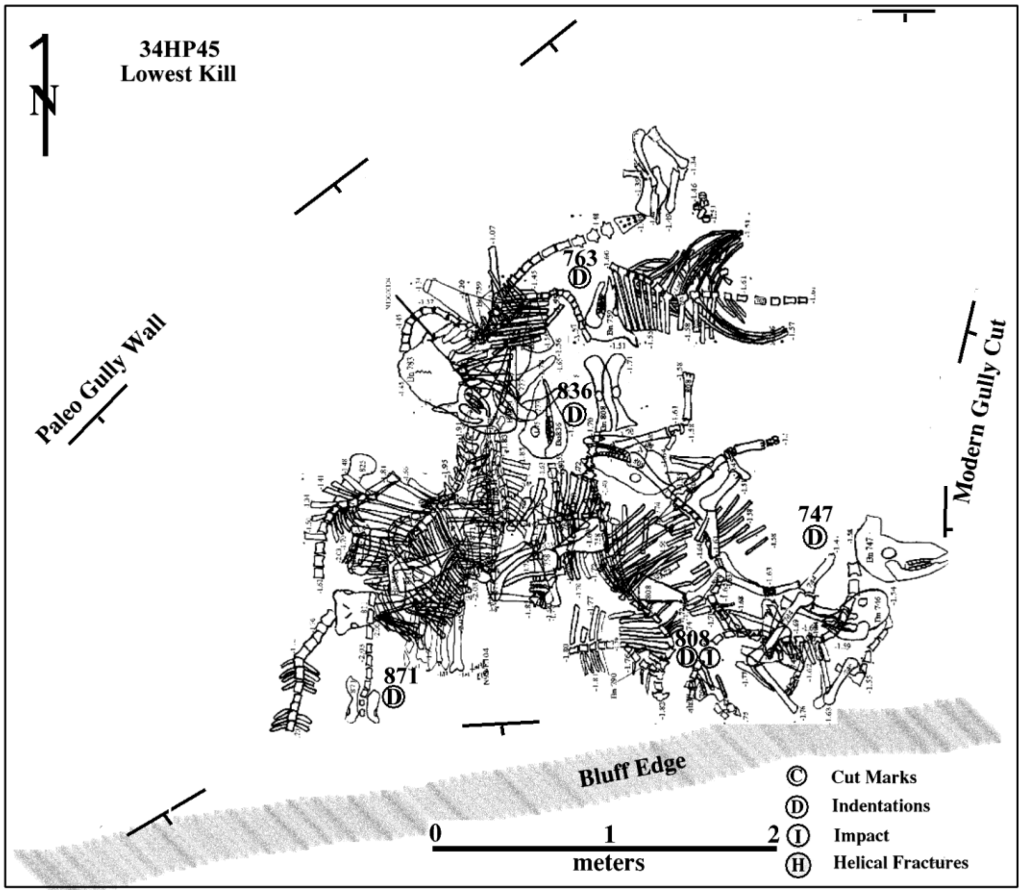


Figure 3.17. Bonebed map of the lowest kill at Cooper (Johnson and Bement 2009).

Badger Hole

Badger Hole (34HP194), the most recent bison kill site of the Beaver River Complex sites, was originally dated to 10,300 ± 30 ^{14}C BP (Bement et al. 2012). The site was discovered in 2010 after a brush fire cleared the vegetation, exposing the eroding bison bone bed. Excavations I carried out in 2011 and 2012 revealed a partially intact arroyo trap, with a section severely eroded and displaced to the west of the intact deposits. An MNI of 10 was determined from excavated remains. Seasonality follows the Beaver River Complex pattern of late summer/early fall gleaned from tooth eruption patterns of mandibular molars (Todd et al. 1996).

Prior to the 2011 excavation a 1 m x 2 m test unit was opened to determine the existence of an intact bone bed. The 2011 excavation opened a 4m x 6m block. Contained within this block were eight individuals including three calves, one yearly, one two-year-old, one four-year-old, once five-year old, and one seven plus year old. The articulated remains of the seven-plus year old and the four year old dominated the excavation block. The dentition analysis revealed an age of +0.3 years indicating a late summer/early fall kill as was seen within the other southern Plains sites.

The main excavation area was expanded in 2012 to a 3 x 8 m area (Figure 3.18). The 2012 excavation uncovered a butchering pile in the northeastern corner of the excavation unit. An articulated leg of a 3+ year old was uncovered at the south extent of the excavation unit.

Also during 2012 I opened a 1 m wide by 8 m long test trench to intercept the western edge of the kill arroyo. This trench revealed an extensive area of bison bone which had been displaced from the original bone bed sometime after the arroyo filled. The trench extended 6 meters below the modern surface and documented that this portion of the bone bed has washed away from the original in situ bones in a westerly direction. The force of displacement severely fragmented the bones. Two Folsom projectile points were also recovered within this secondary deposit.

Numerous flakes were recovered at Badger Hole and a single flake tool. Four Folsom points have been recovered, including an Alibates Folsom point found in situ under the neck of the seven-plus-year-old (Figure 3.19). The additional points were eroding out of the bone bed, including the two recovered from a test trench dug to the east of the site. The second Alibates Folsom point is a midsection that was found in the profile slump. The third and fourth Folsom points were originated in secondary deposits along the western edge of the site in 2012. The lithic assemblage was predominantly Alibates, though some Edwards chert and quartzite were also present.

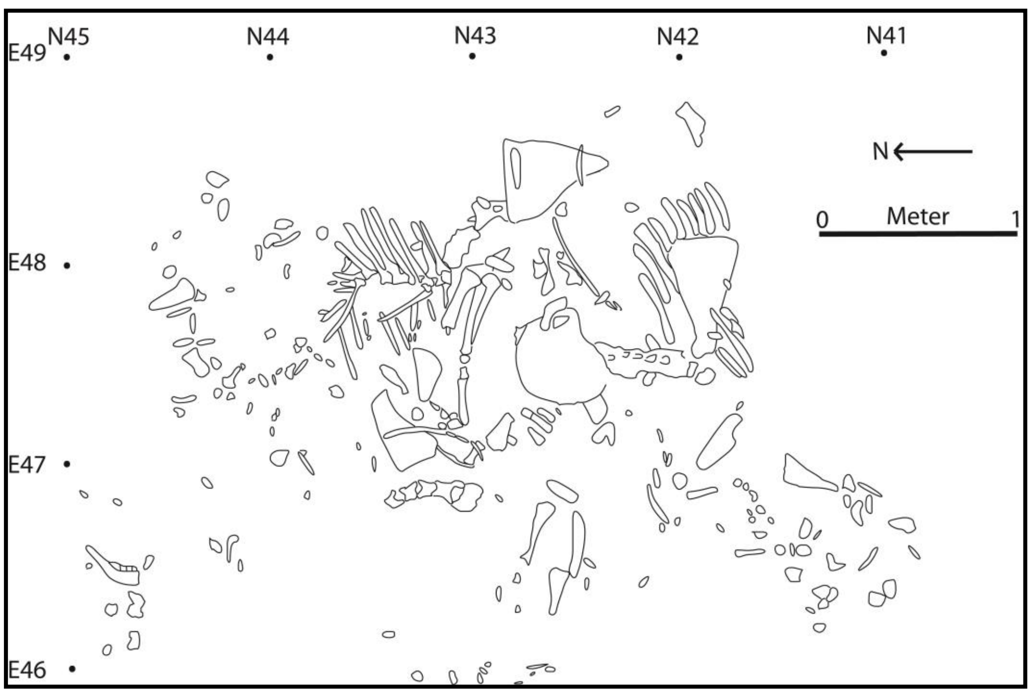


Figure 3.18. Bone bed at Badger Hole 2011 excavation.

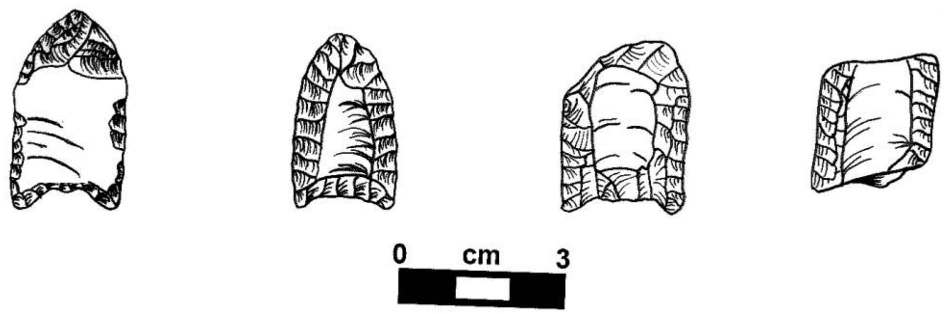


Figure 3.19. Folsom projectile points from the Badger Hole site.

Northern Plains Sites

The sites chosen for comparison on the northwestern Plains include Mill Iron, MT (Frison 1996), Agate Basin, WY (Frison and Stanford 1982), and Carter/Kerr-McGee, WY (Frison 1984). Mill Iron and Agate Basin have been extensively analyzed over the years. Less data is available on the Folsom level at Carter/Kerr-McGee. These sites were originally chosen for comparison because they contained enough samples for isotopic testing and the ages of the sites coincided with southern Plains sites, which provided a means to compare changes in environment and changes in herd mobility patterns in two areas across similar time periods (Figure 3.20). Early dating techniques at the three northwestern Plains sites produced dates with wide ranges of error, which have been reevaluated with radiocarbon dates from bone samples. Re-dating of site materials as part of this analysis however changed the chronology, which will be discussed in chapters 6 and 7.

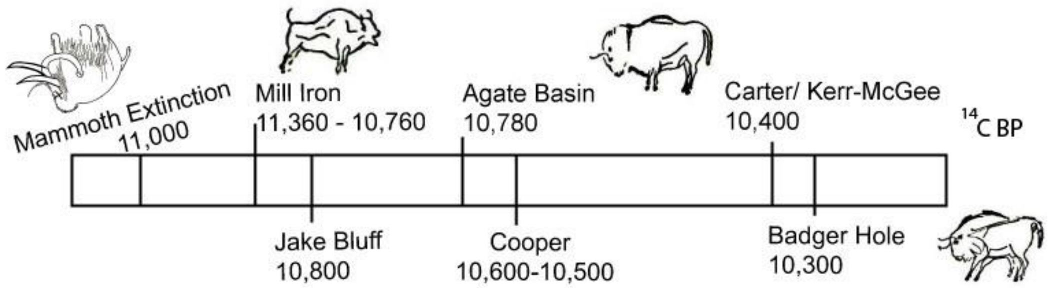


Figure 3.20. Original timeline of radiocarbon dates for the sites in the Beaver River Complex and corresponding northern Plains sites.

Mill Iron (24CT30), located in eastern Montana, was discovered in 1979 and excavated extensively from 1984 through 1988 by multiple academic and avocational groups. The principal investigator on the majority of the projects was Dr. George Frison who later produced a publication concerning the findings at Mill Iron, summarized below (Frison 1996). The Mill Iron site produced two clusters of dates ranging at both ends of the span from 11,360 to 10,760 ^{14}C BP (Frison 1996). The actual trap used to kill the bison at Mill Iron is missing but was interpreted as an arroyo trap due to the layout of the bones. The bone bed excavated at Mill Iron produced an MNI of 29 individuals, mostly cows, killed in a single event (Figure 3.21; Haynes et al. 1992). Seasonality was determined to be late spring/ early summer during or just after calving based on tooth eruption (Todd et al. 1996).

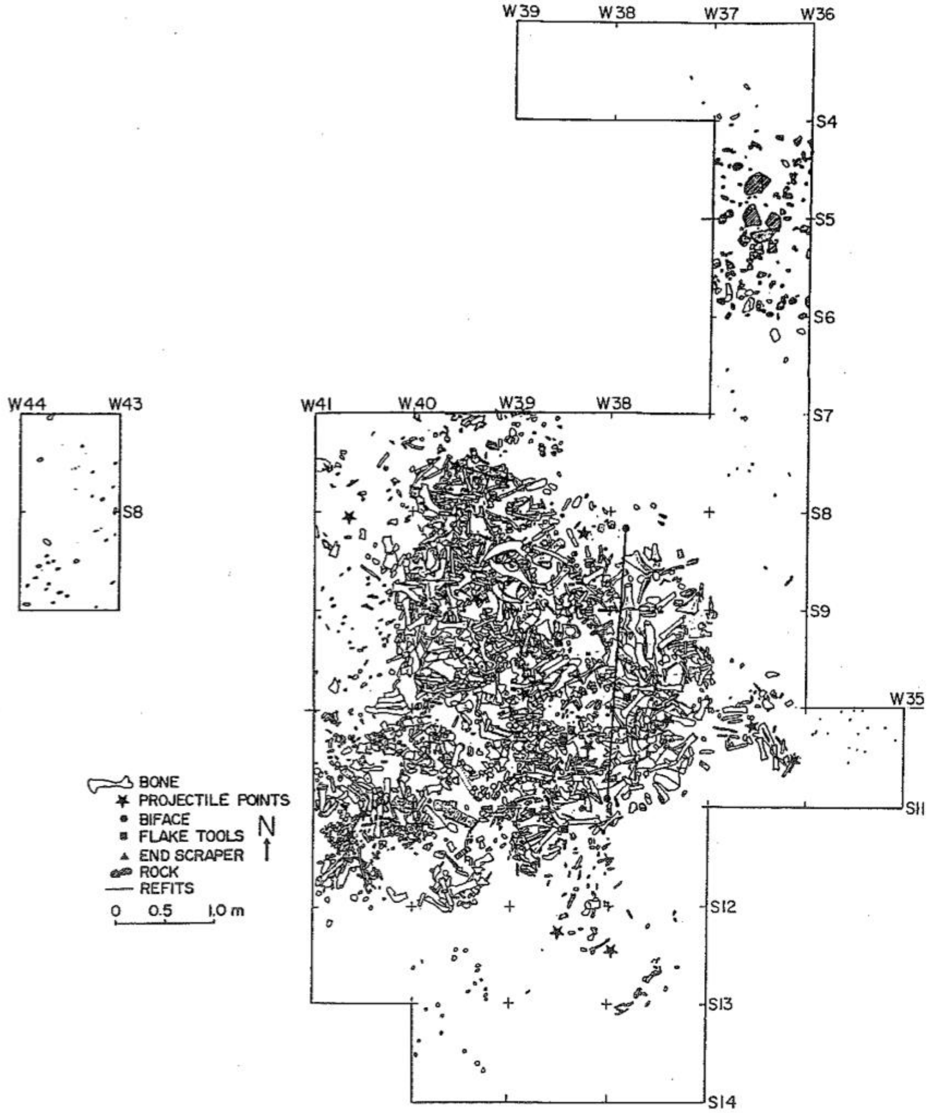


Figure 3.21. Mill Iron bison bone bed (Frison 1996).

Agate Basin (48NA201), a multi component kill site and camp located in Wyoming, was first excavated in 1942 by Smithsonian archaeologists and then in 1961 and 1975-1980 by University of Wyoming archaeologists. The Paleoindian use of Agate Basin spanned a period of significant climatic change from the Late Pleistocene to the early Holocene (Frison and Stanford 1982). Three kill levels are evident within the arroyo: a Folsom level with an MNI of 9 (Figure 3.22 and

3.23), an Agate Basin level, and a Hell Gap level. The Folsom level appears to be a winter kill based on tooth eruption patterns. Agate Basin's Folsom component was dated from a small amount of charcoal producing the date of 10,430 ± 570 ^{14}C BP (Frison and Stanford 1982). Freshwater snails located from Agate Basin indicate the trap was located near a consistent water source during the Folsom period (Evanoff 1982:359).

Carter/Kerr-McGee (48CA12) is also a multicomponent kill site located in Wyoming. Four cultural levels include Clovis, Folsom, Agate Basin-Hell Gap, and Alberta-Cody (Frison 1984). The site was discovered in 1975 and excavated in 1977 as part of a cultural resource management salvage project. Headward erosion destroyed the majority of the kill deposits within the arroyo prior to excavation. Frison (1984) published predominately on the more extensive Cody-Alberta level but makes little remark to the Folsom levels. It is likely that the remains excavated at Carter/Kerr-McGee were not in the location of the kill event but were removed from the nearby kill area to the excavated area for further butchering (Frison 1984). A hearth located at the Folsom level in addition to Folsom fluted points and channel flakes led to the dating of the Folsom level (Figure 3.24). Frison (1984) dated a charcoal sample from the Folsom hearth of Carter/Kerr-McGee produced a date of 10,400 ± 600 ^{14}C BP.

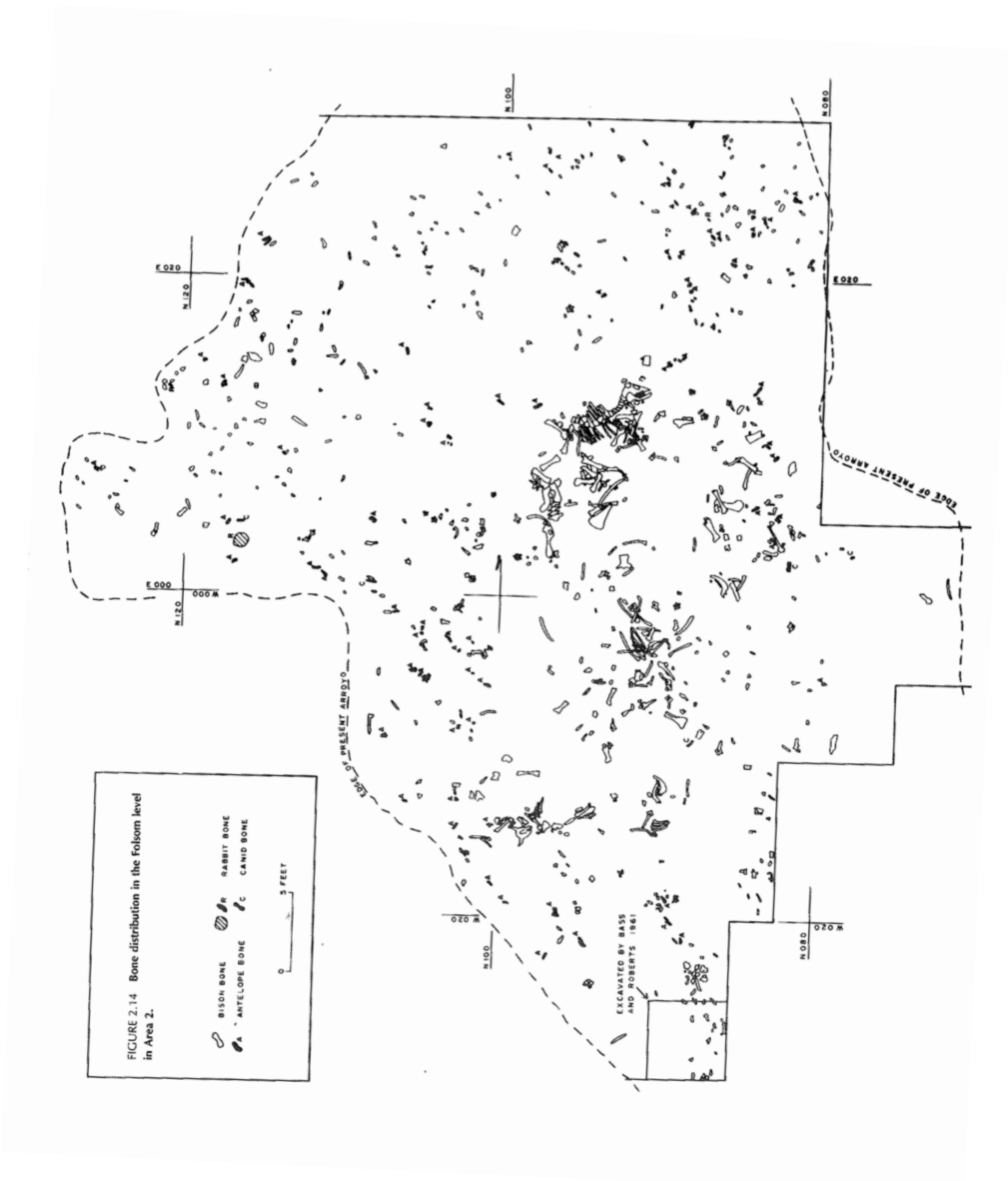


Figure 3.22. Agate Basin Folsom level area 2 (Frison and Stanford 1982).

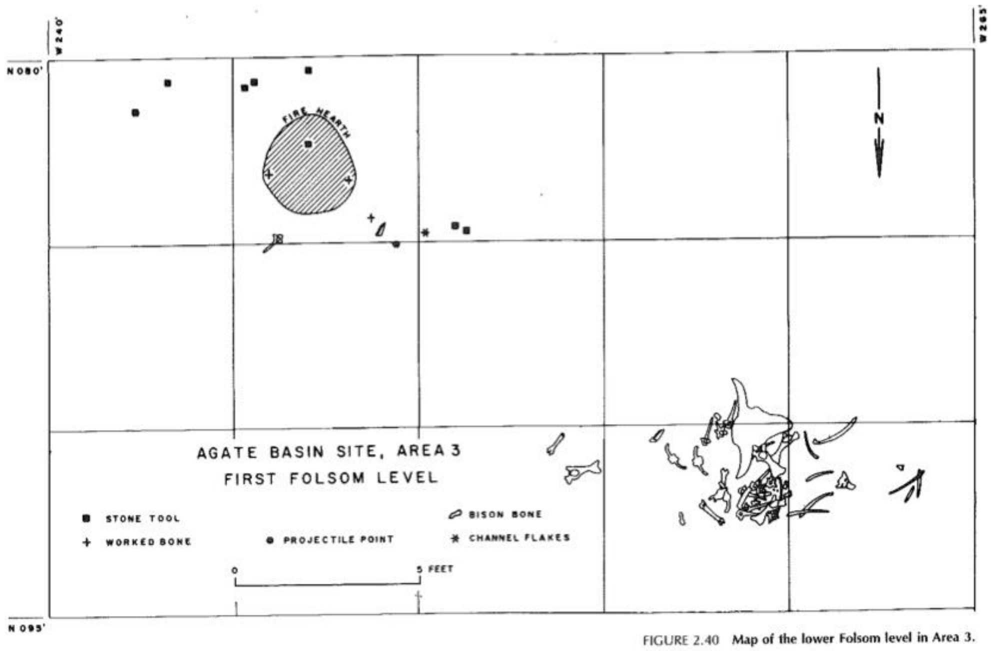


Figure 3.23. Folsom area 3 Agate Basin (Frison and Stanford 1982).

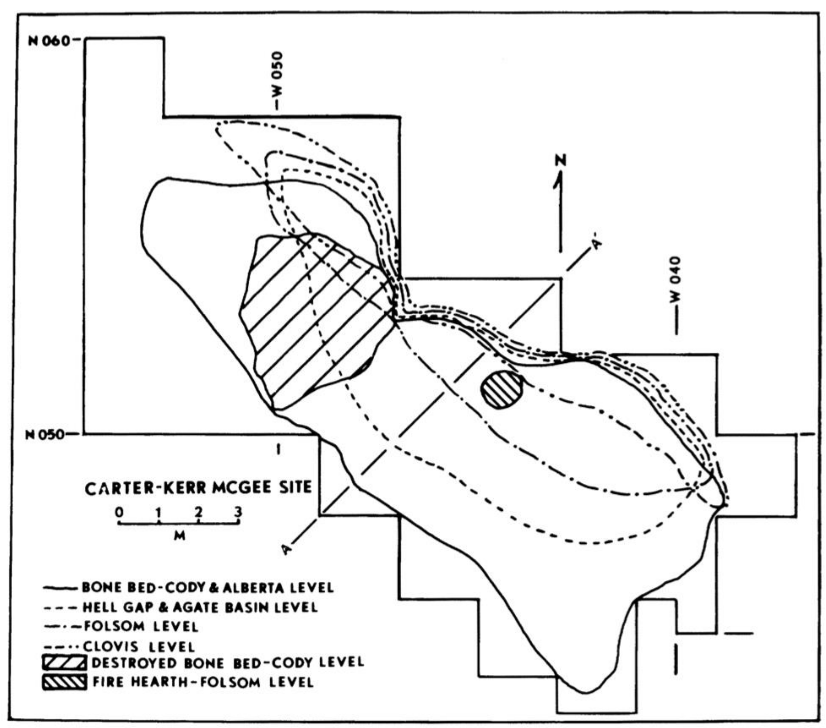


Figure 3.24. Outline of multiple kill levels at Carter/Kerr-McGee (Frison 1984).

A bison bone assemblage analysis is currently underway at the University of Wyoming for both the Folsom and Cody levels to determine MNI and seasonality.

Summary

The southern Plains sites contain 5 kill events in three sites along the same 700 m stretch of the Beaver River Complex. The northern Plains sites studied contain 3 kill sites. Mill Iron is a Goshen aged site. Carter/Kerr-McGee contains a Folsom kill level and a Cody kill level. Agate Basin contains three components, the Folsom component, the Agate Basin component and the Hell Gap component. For the purpose of this analysis I focused only on the Folsom levels at Carter/Kerr-McGee and Agate Basin. Further research when time and funds permit to further investigate the remains of the late Paleoindian period would be incredibly useful to gaining an understanding of change through time. For the purpose of this analysis I focused on the earliest events that may lead to an understanding of how the kill techniques were developed in the region. All sites were active during the Younger Dryas period.

Chapter 4: Methods Background

The research questions posed by this research are: Do changes in environment correlate with changes in hunting technique? Are changes in environment linked to changes in bison behavior? What were the mobility patterns of bison hunted in large kills during the Folsom and Goshen periods? We know that communal hunting develops at the end of the Clovis period on the southern Plains as discussed in previous chapters. To address the research questions requires the establishment of a firm site timeline, the reconstruction of environment during that time span, the structure of the grasslands, and bison mobility patterns. The methods selected to obtain this data are AMS radiocarbon dating of bison bone from southern and northern Plains bison kill sites; stable carbon and nitrogen isotope analysis of bison bone from these same kill sites; and trace element analysis of bison tooth enamel from these same kill sites and modern bison herds.

To tighten our understanding of the temporal context of these kills the sites are re-dated using XAD purified bison bone collagen and AMS techniques to provide error ranges around 25 years. Stable isotopes are used to determine the composition of the grasslands consumed by the bison thereby enabling the reconstruction of the paleoenvironment inhabited by the bison and their hunters. Lastly trace element analyses on bison teeth, in connection with stable isotopes from bone, were used to determine the extent to which bison migrated. This combination of data and analyses provides the means to further our understanding of the environments in which Paleoindians lived and the behavior and mobility patterns of the bison on which they depended.

Stable Carbon and Nitrogen Isotopes

The following section will discuss the basics of stable isotope research and the use of $\delta^{13}C$ and $\delta^{15}N$ in the reconstruction of grasslands. I will also discuss the use of coefficient of variance (CV) a statistic that provides a visual of variation in isotopes within a bison herd population, which provides a means to quantify relative mobility.

Bison are grazing animals whose trophic level is one step above the level of the grasses consumed (Figure 4.1). Grazers in particular are useful for reconstruction of paleoenvironments because they are eating either C_4 or C_3 grasses (Coppedge et al. 1998; Feranec 2004; Larson et al. 2001; Steuter et al. 1995; Tieszen 1991, 1994; Tieszen et al. 1998). C_4 and C_3 plants indicate two types of environmental signature, which will be discussed in detail below. These plants leave a $\delta^{13}C$ stable isotope signature in the bones, which provides a means to analyze environmental settings of extinct species (Hoppe et al. 2006; Larson et al. 2001; Tieszen 1991). Archaeologically this is a useful means of analysis because bison bones are often well preserved and can be studied to reconstruct environments that are difficult to understand by other means such as pollen or phytolith analyses. However, there are taphonomic factors that can affect the preservation of bone. The process in which stable isotopes find their way into bone collagen must also be understood to ensure that the samples under analysis contain information related directly to the animals and environment and not to the process of degradation which has occurred since the animal's death. This degradation process is known as diagenesis.

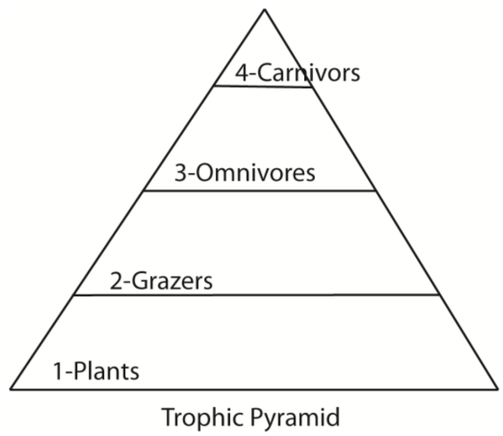


Figure 4.1. Demonstrates trophic level. The 1st trophic level is that of plants, the second of primary consumers of plants such as bison, trophic level increases as consumers move further away from subsistence of the main producer, plants. The 4th trophic level is that of carnivores.

Photosynthesis and Isotopes: Variation, Carbon, and CO_2

The following section provides a brief outline of the photosynthetic processing of CO_2 from the atmosphere and how it affects the carbon value of plants. Because there are only three categories of plants, and those categories have been consistent through time, isotopes provide a means to understand paleoenvironments through time and across trophic levels (Coppedge et al., 1998; Feranec 2004; Koch et al. 1998; Larson et al. 2001; Steuter et al. 1995; Tieszen 1994, 1998). However, the amount of CO_2 in the atmosphere has not been constant through time, which leads to variation in stable C isotopes (Friedli et al. 1986; Marino and McElroy 1991; Marino et al. 1992), which provides additional challenges for interpreting early sites.

Carbon (C) and nitrogen (N) have stable isotope forms often studied archaeologically in animal remains (DeNiro and Epstein 1978; Hoppe et al. 2006; Tieszen 1991). This section discusses the ^{13}C and ^{12}C content in plants and the process in which photosynthesis drives the variation between plants (Julien et al. 2012; Tieszen 1991, 1994). There are two classifications of grasses bison consume, C_3 and C_4 grasses, and each grass indicates a different kind of environment (Tieszen 1991, 1994). C_3 grasses generally grow in wet, cool environments where as C_4 grasses are hardier and grow in dryer hotter environments. But what drives the variation between C_3 and C_4 grasses?

CO_2 in the atmosphere is absorbed into plants differently dependent upon the plant (DeNiro and Epstein 1978; Larson et al. 2012). There are three groups of plants that process CO_2 through different photosynthetic pathways; these plants are C_3, C_4, and CAM. C_3 plants represent the most common plant type. They use a simple photosynthetic process that leads to a 3 carbon compound, giving these plants their classification. These plants typically are successful in a mesic environment. C_4 plant photosynthesis conserves water, is more energy efficient, and more complex. C_4 plants typically grow in xeric environments. Plants that employ the CAM pathway are typically cactus species (Stowe and Teeri 1978; Szarek and Ting 1977; Teeri et al. 1978) and can fluctuate between C_3 and C_4 pathways. CAM plants are not typically ingested by bison. They do however use photosynthesis similar in complexity to that of C_4. These photosynthetic pathways are influenced by climate thereby enabling environmental reconstruction (Koch et al. 1998).

Due to the increase in CO_2 in the atmosphere since the industrial revolution prehistoric samples are expected to be more negative than modern samples (Larson et al. 2012). These numbers fluctuate dependent on materials tested. Everything from hair, to bone collagen, tooth apatite, and feces can be analyzed for stable isotopes (DeNiro and Epstein 1978; Hoppe et al. 2006; Tieszen 1991). Bone and teeth are the most common organic remains preserved in archaeological context hence the most commonly analyzed.

Degradation of Samples

Degradation of sample quality is another issue that archaeologists need to consider when studying stable isotopes from prehistoric contexts. This process of degradation and change of a sample is called diagenesis. In the case of bone samples the element under study is the collagen in the bone and enamel in the teeth. The apatite is contained in the bones and tooth enamel. The dentine in teeth is rarely used because it has a greater risk of being altered by diagenetic processes (Tutken and Vennemann 2011a). Collagen in bone has a higher likelihood of being altered through diagenesis than the apatite component in either bones or teeth. Tooth enamel has a larger crystalline structure making it stronger and more likely to retain its original composition when compared to the crystalline structure of collagen (Tutken and Vennemann 2011a).

From the time an animal dies the remains are subject to alteration from the environment. This process is studied through taphonomy. When studying isotopes researchers hope to isolate the original stable isotopes from the bone or tooth, which indicate the grazing patterns of the animal while it was alive, (Hoppe et al. 2006; Julien et al. 2012; Tieszen 1994). This can aid in understanding past grazing range and be used to reconstruct past environments (Julien et al. 2012; Tieszen 1991). Diagenesis can alter those results by introducing or degrading the elements under study. The first stage of diagenesis can occur during decomposition and burial. Decomposition is a chemical process, which, under some conditions, changes or destroys collagen or tooth enamel. Understanding the environment of deposition is a key factor in being able to determine the degree to which diagenesis could be a possibility for the samples under study (Tieszen 1991). For example acidic environments rarely preserve viable samples for isotopic analysis. Also special factors such as distance from coal seams, which could increase the overall C composition of the bone or tooth must be taken into account (Kohn et al. 2013).

Many steps are involved in the process of CO_2 moving from the atmosphere and being processed by plants in the form of photosynthesis. These plants are then ingested by large herbivores and C is then laid down in the bones and teeth of the grazing animals. If diagenesis has not degraded the collagen and apatite of a sample, then they can be studied to gain an understanding of the C_3 or C_4 plants consumed by grazers. This information can then be used to reconstruct ranging patterns such as migration and paleoenvironmental reconstruction is areas such as the Plains where pollen and other means of paleoenvironmental reconstruction are often not preserved.

The isotopic composition of the nitrogen in an animal reflects the nitrogen isotopic composition of its diet. The $\delta^{15}N$ values of the whole bodies of animals are usually more positive that those of their diets, (DeNiro and Epstein 1981). Variation in the food sources $\delta^{15}N$ has to be present in order for the $\delta^{15}N$ to say anything about the diet of the animal. Typically $\delta^{15}N$ is used to determine if legumes, vs. non-legumes, or aquatic resources are present within a diet. Like carbon, nitrogen studies are analyzing a ratio of $^{15}N/^{14}N$. Plants which can fix molecular nitrogen (due to the presence of symbiotic bacteria) will have characteristically lower $^{15}N/^{14}N$ ratios than those which must assimilate other forms of inorganic nitrogen, such as ammonia or nitrate, (Delwiche and Styn 1970: Delwiche et al. 1979). Plants capable of nitrogen fixation in terrestrial ecosystems are almost exclusively legumes. Blue green algae are responsible for most of the molecular nitrogen fixation that occurs in aquatic systems (Burns and Hardy 1975). A fair amount of variation occurs in N ratio dependent on where the plants grow and at what time of year (Delwiche et al. 1979; Mankin et al. 2007). However, for the purposes of this analysis $\delta^{15}N$ is generally used to determine the extent of diagenesis affecting the samples. The $\delta^{15}N$ provides an indicator for moisture (Murphy and Bowman 2009) and when combined with the $\delta^{13}C$ can provide a clearer understanding of the landscape in which the bison moved.

Bison bone collagen when analyzed for stable isotopes particularly $\delta^{13}C$ and $\delta^{15}N$ can then provide a means to reconstruct the environments in which the bison ranged, which also provides a means to understand the landscape in which

Paleoindians hunted. In addition to paleoenvironmental reconstruction bison isotopes can also be used to determine the extent of migration within a group. Because bison are migratory animals the grasslands that they range across change structure between high C_4 and high C_3 grasses. In order to understand the amount of variation in herd diet the CV is used to determine the amount of variation present. The larger the mobility range of the animals the wider the CV in range of variation in isotopes. The application of CV will be discussed further in the context of the analysis in Chapter 6.

Stable isotope analysis has long been determined an acceptable means of analysis to determine diet and, in some cases, mobility among prehistoric species (Balasse 2002; Beard and Johnson 2000; Fricke and O'Neil 1996; Gadbury et al. 2000; Sharp and Cerling 1998; Wiedemann et al. 1999). Isotopic analysis provides an excellent means to analyze diet variation, but has limitations. The array of carbon and nitrogen isotopes cannot map an animal's exact movement across a landscape. Additional data is necessary to determine where exactly on a landscape an animal has traversed. Isotopes can enable an understanding of mobility, such as resident vs. migratory as seen above but the actual direction and distance of travel is unknown. In order to correct for these disadvantages I selected trace element analysis to provide a means to track animal movement across the landscape.

In the following section I describe the methods used for trace element analysis of bison teeth in determining the migration range of bison from kill site contexts. I discuss the common uses of trace element analysis and the relatively new method under development to trace migration of animals and potentially people on the landscape through this analysis.

Trace Element Analysis

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has been used in archaeology on ceramics, glass, metals, obsidian, and semi precious stones (Speakman and Neff 2005). Due to the ability to target specific areas the method has been used to analyze the temporal variation of element composition in human teeth (Budd et al. 1998; Cox et al. 1996; Cucina et al. 2007; Dolphin et al. 2005; Lee et al. 1999; Lochner et al 1999). It has also been used to estimate trophic levels of past humans and other hominids (Burton et al. 1999; Lee-Throp and Sponheimer 2006; Sillen 1992). Using trace elements to track bison migration was first attempted by Adam Graves in his 2010 dissertation. Many of his results will be summarized here to demonstrate how the method he proposed works. While trying to determine trophic levels in trace elements of teeth Kohn et al. (2013) came to the realization that grazers ingest a substantial amount of dirt, and thus elements, from grazing and water sources. This discovery further supports the potential for mapping animal movement through trace element analysis.

Surface and Bedrock Geology and Bison Teeth

Just as geologists collect hand samples while traveling across a region bison, too, collect trace elements in the water they drink and the grasses they consume. These trace elements can be tested for and analyzed to gain an understanding of the land bison traverse through a year of their lives. Required for the trace element analysis are bison tooth samples from either the mandibular fourth premolar or third molar (Graves 2010). Both of these teeth form after weaning, eliminating the possibility of trace element filtering through the mother's body (placental filtering and lactation). The laser ablation sampling technique removes any surface material through a pre-sampling ablation run that scours the surface, eliminating the need for special handling at the time of excavation (Speakman and Neff 2005). Modern bison are restricted in their range territory providing a proxy sample in which to compare prehistoric samples in order to map the movement of the animals across a landscape. Eruption and wear patterns of bison teeth enable seasonality to be assigned to the various segments of tooth formation, which enables the linking of seasonality to geographic location (Frison and Stafford 1982; Frison and Todd 1987).

Looking at a bison tooth from a prehistoric context alone is not sufficient to gain an understanding of migration. Since the geologic signature has been processed through a biological system to enter the tooth a similarly processed sample must be used for comparison. In this case modern residential bison teeth were used. A modern animal tooth will contain the geological signature of the restricted range in which it grew up. By using these samples as a baseline prehistoric samples can then be compared to the modern samples to accurately determine where an animal traveled during that year of tooth formation (Graves 2010).

Making Sense of the Data

While it is possible to analyze for all elements in the periodic table by this technique, elements selected are only those incorporated in tooth enamel (Graves 2010; Hillson 1986). The values for these elements are log transformed (Neff 2002; Speakman and Neff 2005) and then analyzed. The initial study conducted by Graves (2010) used Principle Component Analysis (PCA) to determine migration patterns. To understand how animals moved across the landscape the prehistoric samples plot against the first order principle component, which was a representation of the selected elements for several samples for several locations (Graves 2010:131). Averages of the samples taken from resident herds by Graves were then grouped together to mark regional areas. The prehistoric samples are then plotted with the region samples to track movement of prehistoric animals. By comparing this suite of data we can see the movement or lack of movement in prehistoric samples.

The real purpose of my analysis is to locate suites of elements and the presence or absence of certain elements to be able to determine if two samples, archaeological or modern, share the same elemental signature, or have different signatures. This is accomplished by running discriminant analysis in JMP where the statistical program groups clusters of elements using principle component analysis, which provide the most variability and provides an elemental signature from the landscape. Modern bison teeth from limited area herds (herds born and raised in small-area preserves) provide the geographic signatures for their respective places on the map. Since the surface geology of an area is fixed, the modern bison tooth elemental composition serves as an analog for that geographical area. In addition, any biological filtering that occurs in the bison physiology is held constant.

If necessary, all samples taken on one tooth can be averaged to provide a single overall signature, as is done for each modern tooth of known geographical provenance. However, even for modern samples the individual sampling lines are analyzed to provide an annual cycle of elemental uptake. This is vital to be able to determine if the animal was in fact raised at the range or if the animal was reared elsewhere and sold to the ranch as is common among modern herds. If this is the case a drastic change in individual sample lines is obvious in the results. The movement of the animal shows up as a change in elemental composition in the down tooth sample and provides cause for the tooth to be excluded from the analysis.

Elemental values vary seasonally due to changes in water turbidity or dust thickness on vegetation (two known sources of elemental ingestion). For the prehistoric samples it is necessary to separate signatures for each down tooth location separated by known time interval. In this way I can compare each of those results with the averaged results from the modern bison samples to create a mapping of the prehistoric bison on the elemental landscape.

Trace elements from teeth and bone can be correlated with elements associated with soil, water, and plants (Driessens and Verbeeck 1990:287; Harper and Reed 1964; Kohn et al. 2013; Schneider and Blakeslee 1990). For the purpose of trace element analysis changes in surface and bedrock geology are important to study the movement of animals. However, the complete mapping of elemental compositions of water, soils, and plants across a region as expansive as the Plains is cost prohibitive (Graves 2010:60). In addition to the monetary costs, such an analysis would take decades. In addition to being cost prohibitive this analysis would then have to be corrected for the biofilter of the bison who grazed across that landscape. To correct for these limitations the use of modern bison from ranches provides the elemental signature as well as the biofilter to recreate the necessary elements for trace element comparison with archaeological samples (Graves 2010).

A map of the surface geology is provided for both Oklahoma and the northern Plains to give a visual representation of the changes in surface geology across the region. The geology across the Plains is particularly diverse as landforms have weathered and changed through time. On the northern Plains (Figure 4.2) large sections of the northeastern regions are predominated by Upper Cretaceous Carlisle shale, while the central northern region is mostly Paleocene Fort Unions formation. Wyoming and Montana are particularly complex in geology, enabling a solid basis for interpreting trace elements and animal movement and migration. Oklahoma geology is equally complex (Figure 4.3) with Quaternary and Tertiary deposits common on the western half of the state, Jurassic deposits in the central portion of the state and Pennsylvanian aged deposits to the eastern portions of the state (US Geological Survey 2012).

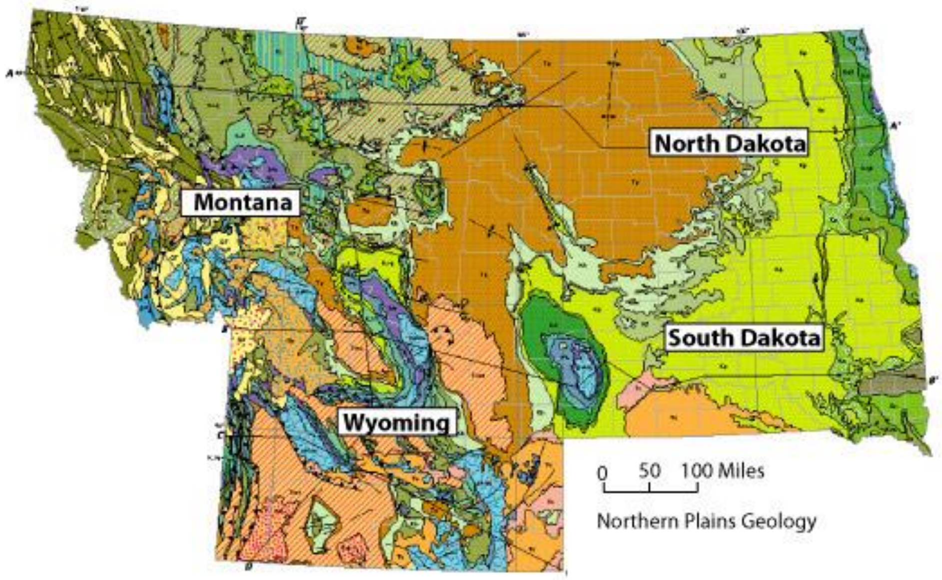


Figure 4.2. Northern Plains Geological distribution converted from Love and Christiansen (1985) U.S. Geologic survey map.

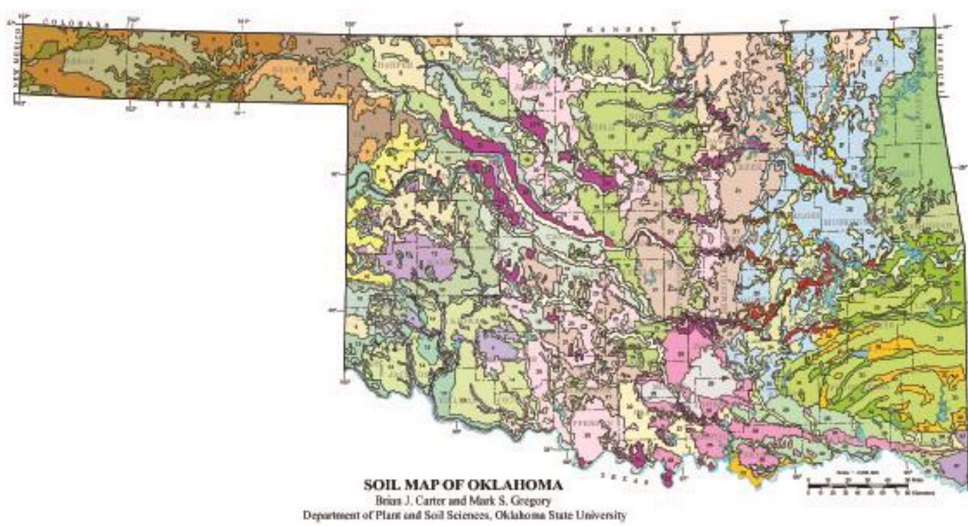


Figure 4.3. Oklahoma geological distribution from Carter and Gregory (2008) soil distribution.

Bison Teeth and Trace Elements

Studies conducted by Graves (2010) for his dissertation work at the University of Oklahoma indicate that *Bison bison antiquus* and *Bison bison bison* teeth contain geological signatures laid down during tooth formation which can be analyzed using LA-ICP-MS and linked to the geological signature of a landscape thereby enabling a mapping of migration patterns. The significance of this research enables us to see where bison were moving on the landscape before falling prey to Paleoindian hunters. The archaeological significance in tracking migration is that people can intercept predictable migrating herds rather than following them. If we can determine where the bison were traveling we can begin to determine the means in which social organization of Paleoindian hunters could focus around the movement of the herds.

Mature bison teeth are made predominantly of hydroxyapatite, a crystalline compound composed of calcium and phosphate (Ca10(PO4)(OH)2). The enamel of a tooth consists of isotopes and trace elements incorporated during mineralization (Curzon and Cutress1983:33; Dreissens and Verbeeck 1990:237; Schneider and Blakeslee 1990). The trace elements in tooth enamel can be correlated with trace elements found in soil, plants, and water (Harper and Reed 1964). Because tooth enamel is not affected appreciably by diagenesis (Curzon and Cutress1983:33; Molleson 1988) the composition reflects that of the diet of the animal. The formation and mineralization of tooth enamel (amelogenesis) begins at the occlusal surface and proceeds downward to the cementum-enamel junction (CEJ) (Balasse 2002; Graves 2010). Diet drives variation in isotopic and elemental concentrations down the tooth.

Bison are born in the same season every year. Because of this their teeth grow in predictable patterns, which enables researchers to determine what season a portion of tooth represents. By using LA-ICP/MS, samples can be taken at intervals down the tooth, and can then link to seasonality. The season and location of the bison during that time can be determined (Figure 4.4). The teeth I analyzed are the P4 and M3 (Figure 4.5). These teeth only contain data for one year of life (P4) or 1.4 years (M3). If a bison changed migration patterns, or joined a different herd after the period of tooth development that information is not represented in the tooth. We are gaining a picture of one animal's migration during the first years of development when the animal still travels with its mother. As mentioned in previous chapters bison are herd animals and female/calf herds are the large herds targeted by Paleoindian hunters. So sampling the tooth and gaining the year of migration provides a reasonable picture of migration of the herd as represented in the juvenile/mother bond, juvenile/mother/mother's sisters bond, and juvenile/mother/mother's sisters/lead cow bond.

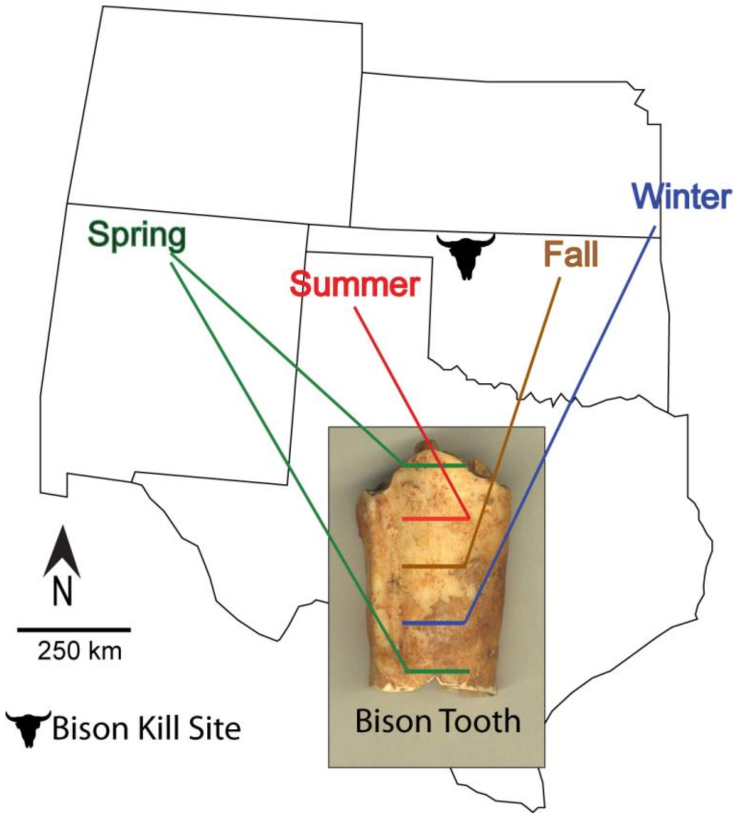


Figure 4.4. Markers on teeth indicate the sample area with lines reaching to the associated region indicated by trace elements at that sample area adopted from Graves (2010) results.

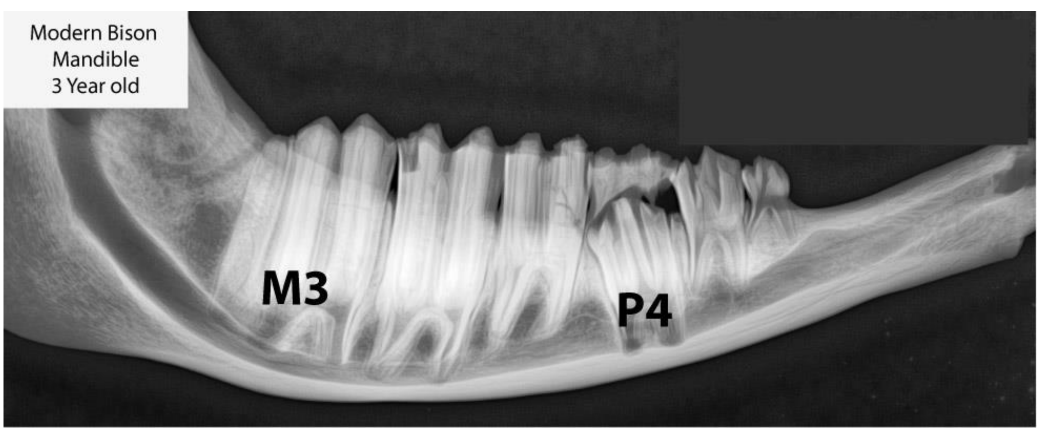


Figure 4.5. Modern bison mandible X-ray showing the M3 and P4 used in this analysis.

Methods Summary

To gain a clearer understanding of the ecosystem in which Paleoindian bison hunters ranged and the mobility of the bison they hunted the above outlined methods were employed. Re-dating bone material provides a strong chronological framework for the project. Stable isotope analysis provides a means to reconstruct environmental change though time and trace element analysis tracks bison movement across the landscape. Combined, all of these methods provide the information necessary to gain a fuller understanding of the setting in which large-scale bison kills in the Paleoindian period took place. When analyzed together this data provide a means to understand how bison and those who hunted them moved across a changing landscape. In the following chapter I present the results of the analytical methods on samples from the southern and northern Plains sites.

Chapter 5: Methods

In this chapter I outline the methods employed in this dissertation research. My work focuses on three main analysis, AMS dating, stable isotope analysis, and trace element analysis. The sites selected for this analysis are three southern and three northern Plains bison kill sites associated with an arroyo trap. When selecting sites for comparison I chose sites that were from the Folsom time period, or the transitional Clovis time period. Mill Iron was chosen because it dated to the same period as Jake Bluff the Clovis kill on the southern Plains. The dates and sites had to contain a high enough number of bison individuals to provide 5 separate individuals to sample for stable isotopes and 3 separate individuals to sample for radiocarbon dates. The reasoning behind these number is described below.

AMS Dating

In order to reevaluate bison kill sites in proper temporal context, re-dating of bone material was necessary. I collected a minimum of three samples per site from extant materials to date the bone material and determine if previous dates were accurate. Brendan Culleton and Douglas Kennett conducted the ^{14}C analysis in the Human Paleoecology and Isotope Geochemistry Lab, Department of Anthropology at Pennsylvania State University. They employed the AMS radiocarbon method of XAD purified collagen outlined by Stafford et al. (1988, 1991) to gain new assays with minimal error ranges.

The dates are then averaged to obtain a mean age of the site materials. Where more samples were available they are included to further strengthen the date. Radiocarbon years are used throughout my discussion due to inconsistencies in carbon in the environment during the Younger Dryas which cause problems for calibration of radiocarbon dates (Meltzer 2009).

I will discuss the results of this analysis further in the following chapter however the AMS dates changed our understanding of the temporal context of the northern Plains sites. Re-dating early excavated sites has become incredibly important in recent decades and has been taken on by archaeologists (e.g. Mike Waters and Thomas Stafford 2007, 2014). Re-dating of materials with AMS is crucial to furthering our understanding of the Paleoindian record, which anthropologists of recent years have been evaluating without a clear temporal context. If we, as researchers, are going to be able to say anything about cultural development in the Paleoindian period we must first back up and reexamine the basic temporal context of sites.

Southern Plains

Previous AMS samples for dating the sites on the southern Plains were combined with new dates to further tighten the chronology of the sites. The total sample number of previous dates from Jake Bluff was sufficiently dated with five radiocarbon dates on five different individuals. No further samples were dated from Jake Bluff. Cooper had a single AMS date for each kill level. This number was increased to three per kill site by dating an additional two samples per kill level. The Badger Hole site was unexcavated at the beginning of this analysis therefore three samples were dated as part of my study after excavation.

Northern Plains

Northern Plains sites were previously excavated in the 1980's, 1990's and earlier. Dates obtained from these early excavations produced results with large error ranges, typical of charcoal dates. Three additional bone samples were collected from all three sites in order to gain a clearer picture of northern Plains chronology. Mike Waters and Dennis Stafford were also working on re-dating materials from Mill Iron during the time of this research and their dates are included in the overall mean for Mill Iron, which will be discussed in the following chapters.

Stable Isotopes

To reconstruct paleoenvironments at the kill sites I obtained stable isotope data from bones from individuals at all six sites under analysis. To be considered for comparison the animals had to be 3 years old or older, past weaning, to gain a clear record of isotopes related to grasslands not the consumption of mother milk. As demonstrated by Hoppe (2006) five samples provide sufficient data to indicate environment. The Human Paleoecology and Isotope Geochemistry Lab, Department of Anthropology at Pennsylvania State University ran the stable carbon and nitrogen isotopes on collagen from bison bone for this study (table).

In order to make sense of C results archaeologists and biologists analyze the $\delta^{13}C$, which is obtained from the ratio of ^{13}C to ^{12}C (Ambrose 1990; Koch et al. 1998).

$$\delta^{13}C = [(^{13}C/^{12}C_{sample} \div {}^{13}C/^{12}C_{standard})-1]x1000 .$$

The international reference was V-PDB. The $\delta^{13}C$ of the sample will break into two groups if C_4 and C_3 plants are present. C_3 plants, which include all trees, most shrubs and herbs and grasses in cool regions and closed-canopy, tropical forests, have low $\delta^{13}C$ values (-27 ± 3 parts per mil (‰)), whereas C_4 plants, which include warm/ dry climate grasses, sedges and some herbs, have higher values (-13± 2 ‰) (O'Leary 1988; Tieszen and Boutton 1983). The mean $\delta^{13}C$ value for C_3 plants will be in the range of -26 ‰ to -28 ‰, while C_4 plants will usually group in -12 ‰ to -14 ‰ (Tieszen et al. 1998).

In order to interpolate $\delta^{13}C$ into percentage of C_4 grasslands following Chisolm et al. (1986) and others (Hart and Lovvorn 2002; Lovvorn et al. 2001; Leyden and Oetelaar 2001) two equations are used.

$$\% C_4 \text{ plants} = 1 - (\delta^{13}C_{OBS} - \delta^{13}C_{4mean}) / (\delta^{13}C_{3mean} - \delta^{13}C_{4mean}) \times 100$$

or from the equation describing the regression line:

$$\% C_4 \text{ plants} = (\delta^{13}C_{observed} + 21.5)/0.14$$

The results of this analysis are assumed to have an error range of 5% (Chisolm et al. 1986:197).

The $\delta^{15}N$ was also collected as a check for sample degradation and can be used to reconstruct the paleoenvironment to some extent. The same bone samples used for $\delta^{13}C$ analysis were used for $\delta^{15}N$. The isotopic ratio is expressed: $\delta^{15}N = [(^{15}N/^{14}N_{sample} \div {}^{15}N/^{14}N_{reference}) - 1] \times 1000$ ppm. The international reference was atmospheric nitrogen (AIR).

Techniques to determine the extent to which samples have been altered through diagenesis have been developed. Collagen can be assessed by taking the atomic C to N ratio of the prehistoric sample and comparing it to a modern sample (Ambrose 1990; DeNiro 1985; Tieszen 1991; Tutken and Venneman 2011). If the ratios are similar the collagen has preserved. If the ratios vary greatly from modern values then the sample is likely degraded and cannot be used for accurate analysis, the acceptable range is between 2.9 and 3.6 (Ambrose 1990).

The Coefficient of Variance (CV) can be used to compare samples from archaeological sites. The CV is defined by the ratio of the standard deviation to the mean. It is a means of measuring the magnitude of distribution. The CV is included as part of the stable isotope analysis to determine migration or residency in prey bison herds.

Table 5.1. The table of materials analyzed for dates and isotopes. The sites named without asterisks represent previously ran isotopes or dates included in the analysis. The yellow indicates samples thrown out due to low collagen yields.

Site Name	Site Number	Bone number	Element	Analysis	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N atomic
*Agate Basin	48NO201	1126	Humerus	Date & Isotopes	-18.03	5.50	23.75	8.41	3.29
*Agate Basin	48NO201	1152	Humerus	Date & Isotopes	-18.19	4.65	24.69	8.87	3.25
*Agate Basin	48NO201	349/ F1306	Tibia	Date & Isotopes	-18.37	5.33	29.10	10.48	3.24
*Agate Basin	48NO201	1149/ F1555	Humerus	Isotopes	-19.41	6.15	18.06	6.45	3.27
*Agate Basin	48NO201	1852/F1440	Femur	Isotopes	-17.04	4.92	23.79	8.50	3.26
*Agate Basin	48NO201	833/ F1718	Femur	Isotopes	-18.60	7.18	24.52	8.81	3.25
*CKM	48CA012	0G002	Femur	Date & Isotopes	-13.08	6.70	17.95	6.18	3.39
*CKM	48CA012	0G003	Tibia	Date & Isotopes	-18.54	7.21	17.00	6.07	3.27
*CKM	48CA012	0G023	Femur	Date & Isotopes	-16.38	4.92	25.57	9.13	3.27
*CKM	48CA012	UMF0125	petrous	Date & Isotopes	-16.93	7.99	24.29	8.54	3.32
*CKM	48CA012	0G008	2nd phalanx	Isotopes	-18.68	7.24	18.75	6.71	3.26
*Mill Iron	24CT30	24CT30-6787	Petrous	Date & Isotopes	-19.02	7.26	16.23	5.69	3.33
*Mill Iron	24CT30	24CT30-7477	Petrous	Date & Isotopes	-18.68	5.86	16.18	5.67	3.33
*Mill Iron	24CT30	24CT30-8030	Humerus	Isotopes					
*Mill Iron	24CT30	24CT30-7584	Femur	Isotopes	-19.15	6.68	23.43	8.36	3.27
*Mill Iron	24CT30	24CT30-7514	Humerus	Isotopes	-16.95	5.43	27.75	9.86	3.28
*Mill Iron	24CT30	24CT30-7309	Humerus	Isotopes					
*Jake Bluff	34HP60	BN136	L. Femur	Isotopes	-8.10	11.10	14.70	5.06	3.42
*Jake Bluff	34HP60	BN797	L. Tibia	Isotopes	-8.17	11.02			
*Jake Bluff	34HP60	686 #1	Femur	Isotopes	-17.12	-48.66	0.95	0.08	14.54
*Jake Bluff	34HP60	802 #1	Femur	Isotopes	-14.69	-2.10	1.62	0.29	6.63
*Jake Bluff	34HP60	838	Humerus	Isotopes	-12.89	6.48	5.62	1.68	3.91
*Cooper Upper	34HP45	494	R. Petrous	Date & Isotopes	-10.93	8.38	25.85	9.07	3.33
*Cooper Upper	34HP45	496	R. Petrous	Date & Isotopes	-9.86	8.05	23.43	8.55	3.20
Cooper Upper	34HP45	BN657		Isotopes	-9.48	6.71			3.52
Cooper Upper	34HP45	672	R. Femur	Isotopes	-14.80	7.70			
Cooper Upper	34HP45	BN674		Isotopes	-11.60	8.60			
*Cooper Middle	34HP45	695	L. Petrous	Date & Isotopes	-16.34	6.42	29.01	10.51	3.22
*Cooper Middle	34HP45	768	L. Petrous	Date & Isotopes	-11.40	9.04	29.12	10.66	3.19
Cooper Middle	34HP45	BN731		Isotopes	-10.18	9.06			3.34
Cooper Middle	34HP45	BN752		Isotopes	-10.40	8.70			
Cooper Middle	34HP45	BN740		Isotopes	-10.30	7.60			
*Cooper Lower	34HP45	774	R. Petrous	Date & Isotopes	-13.92	6.98	28.19	10.31	3.19
*Cooper Lower	34HP45	856	L. Petrous	Date & Isotopes	-9.18	10.10	28.34	10.37	3.19
*Cooper Lower	34HP45	836	L. Petrous	Date & Isotopes	-10.20	8.97	29.64	10.83	3.19
*Cooper Lower	34HP45	BN803		Isotopes	-11.53	7.94	9.44	3.21	3.43
Cooper Lower	34HP45	BN866		Isotopes	-11.74	9.83			4.15
Cooper Lower	34HP45	744		Isotopes	-13.80	6.70			
Cooper Lower	34HP45	BN800		Isotopes	-9.60	7.50			
*Badger	34HP194	341	L. Petrus frag	Date & Isotopes	-12.12	7.25	14.62	5.45	3.13
*Badger	34HP194	276-1	Petrous	Date & Isotopes	-19.39	6.09	28.30	10.11	3.27
*Badger	34HP194	593	R. Humerus	Date & Isotopes	-12.11	8.17	24.41	8.63	3.30
*Badger	34HP194	BN298	Radius	Isotopes	-15.06	8.88	11.01	3.58	3.58
*Badger	34HP194	BN266	Humerus	Isotopes	-15.23	4.95	14.40	4.85	3.46
*Badger	34HP194	BN363	Humerus	Isotopes	-12.82	4.79	8.43	2.70	3.64
*Badger	34HP194	266	Humerus	Isotopes	-14.01	5.80	15.07	5.63	3.12

Trace Elements

For the trace element analysis I collected archaeological tooth samples from the mandibular 4th premolar following the methods employed by Graves (2010). The fourth premolar as discussed in Chapter 4 forms after weaning and comes into wear when the animal reaches the age of 4 years old. The goal was to obtain teeth before they came into wear, though in some cases slight wear had occurred on the surface of the teeth.

LA-ICP-MS

LA-ICP-MS is a high precision microscopic sampling technique (Speakman and Neff 2005) that allows minimally destructive sampling at the microscopic level. Damage from the laser is not visible to the naked eye. However in order to fit the sample in the chamber it must be removed from the mandible which can be accomplished with a Dremel tool with great care so that the sample can be glued back into place when analysis is completed. Individual enamel rows were sampled every 5 mm. The number of sample areas per tooth depended on the condition and size of the tooth. The separation between each down-tooth sampling location represents a known time interval of enamel formation. The 5 mm wide strip down the middle of each tooth was lightly abraded to remove surface contaminants prior to analysis. Every 5 mm equals two months of tooth formations (Graves 2010). Because of this it is possible to obtain an elemental signature at specific time intervals, representing the various places on the landscape visited by the bison (Graves 2010).

The parameters set for the LA-ICP-MS are included in Table 5.2. The laser samples the tooth in 5 mm increments down the tooth from CEF to crown. Each ablation samples three passes in one line and these samples were averaged to determine the elemental composition of that portion of tooth. Glass blanks were used before and after each tooth sample to aid in calibration of the machine. After the LA-ICP-MS runs the trace element analysis the machine moves the data to a table, which then has to be calibrated using the glass blanks to compensate for instrument drift. Data were then calibrated to parts per million using the NIST glasses, with ^{43}Ca as an internal standard.

Trace Elements and the Periodic Table

Mapping a wide range of elements with LA-ICP-MS results in thousands of lines of data not necessarily useful for determining the movement of bison. However, the analysis of 26 elements, discussed below, provides the data necessary to discriminate regions within the Plains. In order to separate the useful elements from the background noise a few steps are necessary. First data were calibrated by the lab to parts per million using the NIST glasses, with ^{43}Ca as an internal standard. Then the elements eliminated from the study were removed and remaining elements were Log transformed. The regional modern samples were plotted in a discriminant analysis with prehistoric samples overlain on the regional results providing a map of movement of prehistoric animals through regionally known locals (Graves 2010).

Table 5.2. Settings used for LAICP MS analysis with experiment parameters.

Settings for Instrument Tune on NIST612

Ablation

Pattern		Laser	
Passes	10	Output (%)	60.0
Scan Speed (µm/sec)	10	Rep. Rate (Hz)	20
Depth/Pass (µm)	5	Spot Size (µm)	100

Experiment Settings

Pre-Ablation

Pattern		Laser	
Passes	3	Output (%)	80
Scan Speed (µm/sec)	100	Rep. Rate (Hz)	20
Depth/Pass (µm)	5	Spot Size (µm)	200

Ablation

Pattern		Laser	
Passes	10	Output (%)	60.0
Scan Speed (µm/sec)	10	Rep. Rate (Hz)	20
Depth/Pass (µm)	5	Spot Size (µm)	100

Pattern Type: Raster / Line / Spot

Number of main runs: (Plasmalab) 3

Standards included in ablation experiment: Glasses C, D, E and CAMAS Apatite Standards (Blank, Low, Medium, High)
Internal standard: 103Rh, 193Ir

I selected the elements for analysis through a series of steps. The first elements to be eliminated were Ca, P, C, and H. The high counts of these elements made them useless for analysis. According to Driessens and Verbeeck (1990) certain elements show up in high enough quantity over 100's of ppm in bison teeth, due to the elements passing through the intestinal walls in high enough quantity to pile up in the amelogenesis process and mineralize in enamel. The elements Na, and Mg have relatively high concentrations (1000s of ppm), followed by Al, Si, S, K, Fe, Zn, Sr, and Ba (10's to 100s of ppm), and B, Cu, Br, Rb, Mo, Sn and Pb (>1 ppm; Curzon and Cutress 1983: Kohn et al. 2013).

Other elements were eliminated because they are not retained in the tooth formation process or are too abundant in the environment to be useful. Also limitation of the LA-ICP-MS and the calibration process further limited the elements to be included in analysis. Statistical analysis finally was used on a larger suite of elements to determine which elements held the most weight in determining the clusters defined by JMP in the discriminant analysis. These elements (Figure 5.1) were selected to determine the regional location of bison. For the purpose of this research the following elements are the focus of analysis; boron (^{11}B), sodium (^{11}Na), magnesium (^{25}Mg), potassium (^{19}K), titanium (^{22}Ti), cobalt (^{27}Co), copper (^{65}Cu), zinc (^{66}Zn), gallium (^{31}Ga), arsenic (^{33}As), rubidium (^{37}Rb), strontium (^{88}Sr), yttrium (^{39}Y), zirconium (^{40}Zr), molybdenum (^{42}Mo), cesium (^{55}Cs), lanthanum (^{57}La), cerium (^{58}Ce), praseodymium (^{59}Pr), neodymium (^{60}Nd), samarium (^{62}Sm), europium (^{63}Eu), gadolinium (^{64}Gd), dysprosium (^{66}Dy), lead (^{208}Pb), uranium (^{92}U).

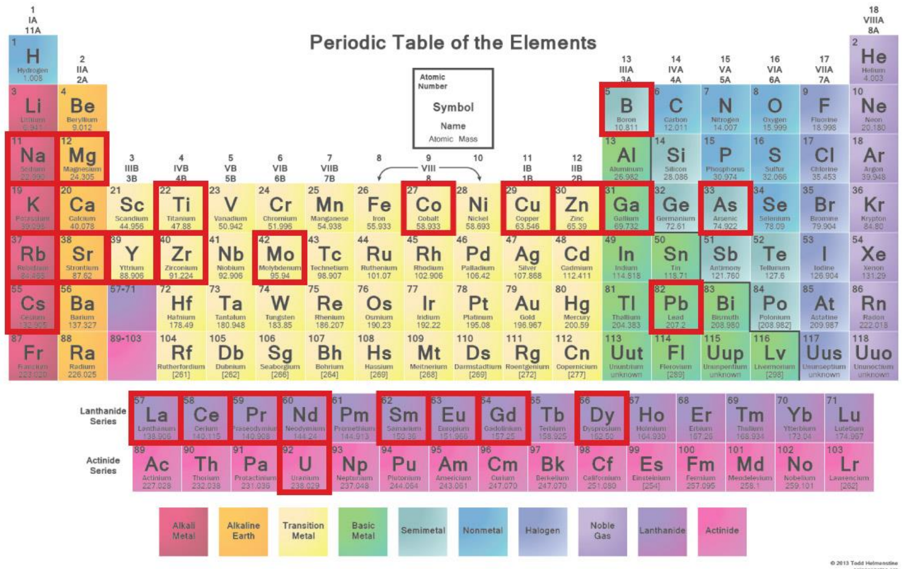


Figure 5.1. The elements selected for analysis are outlined in red.

Southern Plains

On the southern Plains modern samples were previously collected by Graves (2010). I collected further archaeological samples to compare to the modern samples previously run. Archaeological samples were collected from all three kill sites and run for trace elements (Appendix A).

Northern Plains

For the northern Plains sites where the geographical distribution of elements is unknown, I began the task of obtaining the local site distribution of trace elements by LA-ICP-MS analysis of teeth from resident bison ranging on local grasslands. I obtained four samples from modern herds on the Northern Plains. These proxy materials can be obtained from animals living in the area today. Since the ungulate sample employs a down-tooth sampling strategy that tracks the movement of the animal across distinct trace element landscapes (source areas) it should be possible to identify which season or seasons of the year the animal entered the region.

The samples size of four samples from the northern Plains was relatively small in comparison to the southern Plains samples. Part of this analysis was to determine the sample size necessary to determine migration ranges using trace elements. The results of that study will be discussed in Chapter 6.

Chapter 6:
Analysis: Dates, Stable Isotopes, and Trace Elements

This chapter applies the methods described in Chapter 5 to the various site materials for the three southern and three northern Plains sites with a focus on stable isotopes and trace elements. Extensive work has been published on the southern Plains and the northern Plains sites. Badger Hole is the newest site on the southern Plains excavated in 2011 and 2012. All six sites were the focus of the stable isotope analysis and trace element analysis, which is extensively described below. The southern Plains sites include the Beaver River kill complex of northwestern Oklahoma which contains three arroyo trap kill sites; Cooper (34HP45; Bement 1999), Jake Buff (34HP60; Bement and Carter 2010), and Badger Hole (34HP194; Bement et al. 2012). The northern Plains sites are Mill Iron, Montana (24CT30; Frison 1996), Agate Basin, Wyoming (48NA201; Frison and Stanford 1982; Hill 2008), and Carter/Kerr-McGee, Wyoming (48CA12; Frison 1984).

Southern Plains

The following section summarizes the analysis of the southern Plains materials including AMS dating, stable isotopes, and trace element analysis. This data will be further compared and discussed in Chapter 7.

AMS Dates

Though well dated at the time of excavation XAD purified collagen methods now available for bone sample purification were run using AMS techniques to improve the chronology of the sites. AMS dates on XAD purified collagen were already available for Jake Bluff (Bement and Carter 2010). However, additional samples were analyzed for and the three kill levels at Cooper and for Badger Hole to further tighten the age ranges at these sites.

The new dates from the XAD purified collagen techniques are outlined in Table 6.1 and discussed below. The averages of these dates are presented here. The use of the arroyo bison trap technique along the Beaver River began by 10,821 ± 17 ^{14}C BP (mean of 4 dates; Bement and Carter 2010) at Jake Bluff. Cooper kills date to 10,589 ± 16 ^{14}C BP at the lower kill, 10,563 ± 19 ^{14}C BP at the middle kill, and 10,532 ± 19 ^{14}C BP at the upper kill level (Johnson and Bement 2009). Badger Hole extends the arroyo bison trap-hunting complex along the Beaver River to at least 10,347 ± 16 ^{14}C BP.

The new radiocarbon dates for the three Cooper kills refine, yet uphold the stratigraphic ordering of the lower, middle, and upper kill episodes. The original dates (Johnson and Bement 2009) suggested a maximum span of 100 radiocarbon years (or 200 cal years BP) in which all three kills occurred. The inclusion of additional dates refines this time frame to the span of 57 radiocarbon years. The new dates indicate that all three kills could have occurred in the course of one or two generations (Bement 1999:182).

Table 6.1. New radiocarbon dates for southern Plains sites. Dates included from sources outside this analysis are included in the references column.

Site		14C Age BP*	1 Sig.	Lab Number	Reference
Jake bluff		10750	40	CAMS-79940	Bement and Carter 2010
		10840	45	CAMS-90968	
		10810	25	UCIAMS-61657	
		10885	35	PSU-4129/UCIAMS-59874	
	Mean**	10821	17	X2=6.87; df=3, T crit=7.81	
	Cal BP 2 Sig. (Prob)	12,590-12,833 (1)			
Cooper					
Lower		10600	40	CAMS-94850	Johnson and Bement 2009
		10560	30	PSU-6077/UCIAMS-140849	
		10570	30	PSU-6078/UCIAMS-140850	
		10630	30	PSU-6079/UCIAMS-140851	
	Mean	10589	16	X2=3.28; df=3, T crit=7.81	
	Cal BP 2 Sig. (Prob)	12,444-12,461 (0.02)			
		12,536-12,640 (0.98)			
Middle		10530	45	CAMS-82407	Johnson and Bement 2009
		10565	30	PSU-6075/UCIAMS-140847	
		10575	30	PSU-6076/UCIAMS-140848	
	Mean	10563	19	x2=0.70; df=2, T crit=5.99	
	Cal BP 2 Sig. (Prob)	12,428-12,490 (0.29)			
		12,522-12,616 (0.71)			
Upper		10505	45	CAMS-94849	Johnson and Bement 2009
		10550	30	PSU-6073/UCIAMS-140845	
		10525	30	PSU-6074/UCIAMS-140846	
	Mean	10532	19	X2=0.77; df=2, T crit=5.99	
	Cal BP 2 Sig. (Prob)	12,422-12,507 (0.56)			
		12,511-12,583 (0.34)			
Badger Hole		10300	25	UCIAMS-98369	Bement et al. 2012
		10395	35	PSU-5144/UCIAMS-111184	
		10370	25	PSU-5457/UCIAMS-122579	
	Mean	10347	16	X2=6.26; df=2, T crit=5.99	
	Cal BP 2 Sig. (Prob)	12,066-12,224 (0.70)			
		12,260-12,325 (0.17)			
		12,338-12,379 (0.13)			

*All dates on XAD purified bison bone.
**Weighted mean following Ward and Wilson (1978)

Stable Isotopes

The stable isotope analysis provides the basis to understand the environment during the time of each kill event as well as providing some information concerning the mobility of the bison herds targeted for the hunt. Overall this collection of sites provides a means to compare changes in bison herd diet through time on the northern and southern Plains. This section will discuss the southern Plains data and results. A comparison and evaluation of the data will be presented in Chapter 7. Table 6.2 provides the stable carbon results from the southern Plains.

I briefly outline the methods discussed in Chapter 5 here to enable clearer interpretation of the presented data. To obtain reliable stable isotope data the atomic carbon and nitrogen ratio of the samples were compared to modern C:N ratios to determine if the collagen had undergone diagenesis. This is a commonly used method of determining the extent to which diagenetic processes may have altered archaeological materials (DeNiro 1985; van Klinken 1999). The C:N ratio must result in a range between 2.9 and 3.6 (Julien et al. 2012; Tieszen et al. 1998) to be considered for comparison. $\delta^{13}C$ and $\delta^{15}N$ also provide two slightly different measures to determine environment and vegetation. $\delta^{13}C$ provides a proxy for temperature while $\delta^{15}N$ provides a means to reconstruct moisture (Tieszen et al. 1998). For paleoenvironmental reconstruction C_4 indicates a hot, dry short or tall grass prairie environment while C_3 indicates a cool, wet taller-grass prairie. The mean $\delta^{13}C$ value for C_3 plants will be in the range of -26 parts per mil to -28 parts per mil, while C_4 plants will usually group in -12 parts per mil to -14 parts per mil (Tieszen et al. 1998).

Southern Plains Stable Isotopes

The five kill episodes at the Beaver River Complex define one of the highest density Folsom site concentrations on the southern Plains. These sites provide the focus of my southern Plains research because of the long duration of hunting at the sites and the Clovis site Jake Bluff, which may mark the transition from Clovis to Folsom and the beginning of communal hunting of bison herds on the southern Plains.

Table 6.2. Stable isotope results from southern Plains sites.

Site Name	**δ13C**	**δ15N**	**Average**	**SD**	**CV**
Jake Bluff	-8.1	11.1			
Jake	-8.17	11.02			
		13C	-8.135	0.049497	0.608451
		15N	11.06	0.056569	0.51147
Cooper Lower	-9.6	7.5			
Cooper Lower	-9.17587	10.10241			
Cooper Lower	-10.2033	8.96962			
Cooper Lower	-11.53	7.94			
		13C	-10.1273	1.02577	10.12877
		15N	9.004012	1.159933	12.8824
Cooper Upper	-11.6	8.6			
Cooper Upper	-9.48	6.71			
Cooper Upper	-10.9292	8.380369			
Cooper Upper	-9.862	8.047061			
		13C	-10.4678	0.972541	9.290789
		15N	7.934357	0.847301	10.67889
Cooper Middle	-10.4	8.7			
Cooper Middle	-10.3	7.6			
Cooper Middle	-10.18	9.06			
Cooper Middle	-16.3359	6.420622			
Cooper Middle	-11.3961	9.035036			
		13C	-11.7224	2.62402	22.38468
		15N	8.163132	1.140863	13.9758
Badger	-15.06	8.88			
Badger	-15.23	4.95			
Badger	-12.82	4.79			
Badger	-12.1151	7.254537			
Badger	-14.0096	5.798257			
Badger	-19.3855	6.092308			
Badger	-12.113	8.16953			
		13C	-14.3904	2.55208	17.73454
		15N	6.56209	1.580049	24.07844

The stable isotope results (Figure 6.1) indicate a changing pattern from the Clovis kill at Jake Bluff, the three Folsom kills at Cooper, and the later Folsom kill at Badger Hole. These results indicate a shift from hot dry C_4 grasslands to a progressively cool and wet C_3. Due to the poor preservation of the majority of the bone remains from Jake Bluff only two samples provide sufficient preservation for analysis. Though five stable isotope samples are ideal for interpreting diet the tight error range of the two samples analyzed provide good evidence for environmental reconstruction. The Jake Bluff samples also fall outside the range of the later Cooper samples indicating environmental change through time. The three kill levels at Cooper are separated by approximately 50 radiocarbon years, explaining the close proximity of the stable isotope results. Lastly, the Badger Hole results, which are more dispersed, do not overlap the results from Cooper and Jake Bluff.

In order to clarify the change from C_3 to C_4 grasses the equation that converts $\delta^{13}C$ to % C_4 discussed in Chapter 4 set out by Chisolm et al. (1986) and others (Leyden and Oetelaar 2001; Lovvorn et al. 2001) was used to create Figure 5.2 demonstrating the percent C_4 and C_3 in the grasslands grazed by the animals under study. The overall trend depicted here indicates a shift over time from hot and dry C_4 grasses at Jake Bluff to increasingly wetter and cooler C_3

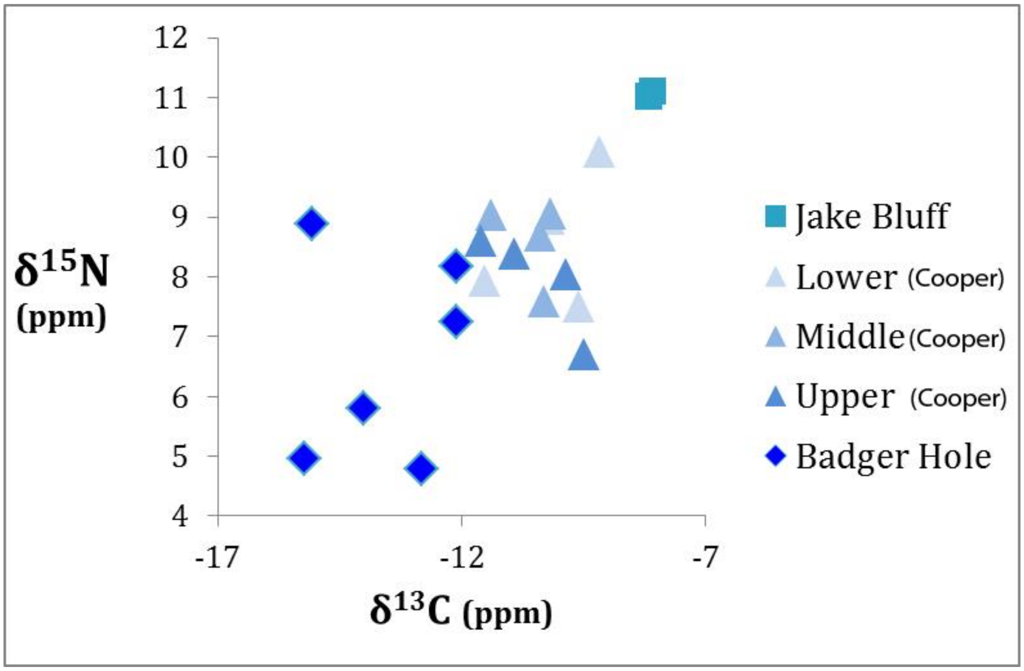


Figure 6.1. Stable isotope results from the southern Plains sites indicating a change in bison diet variety through time. Jake Bluff being the oldest site, then the Cooper lower, middle, and upper kills, followed by the youngest site Badger Hole.

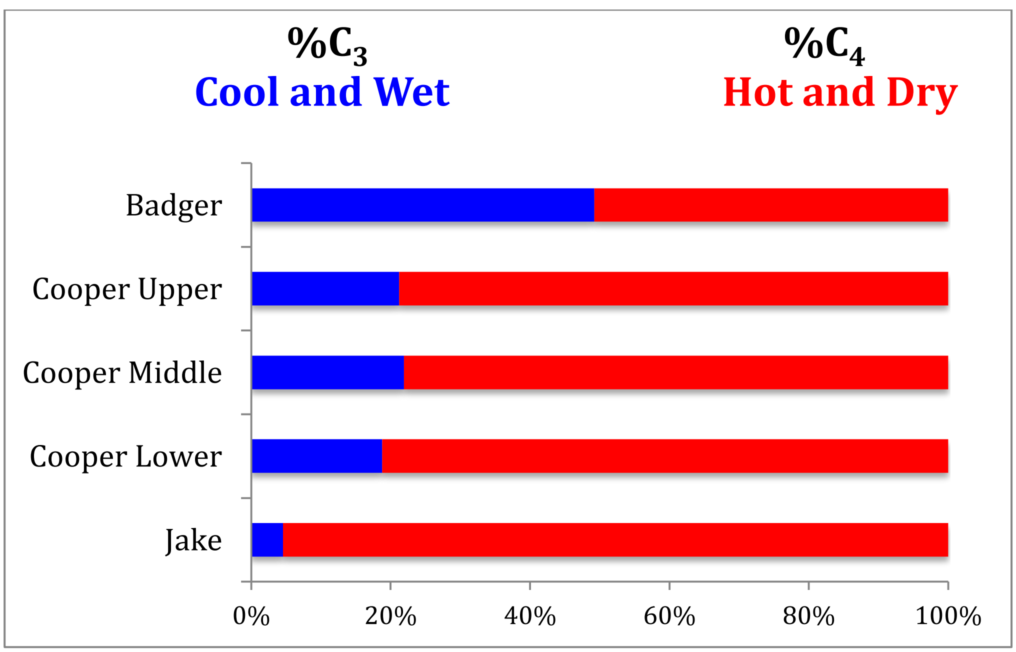


Figure 6.2. This graph depicts the percentage of C_3 and C_4 grasses and how that change from the youngest site, Badger Hole to the Oldest site Jake Bluff. A change from hot and dry climate to a cooler wetter climate is indicated.

conditions seen in the Badger Hole results, with the three Cooper kills in intermediate positions.

The coefficient of variance can be used to demonstrate both the changes in climate through time but also an increase in diet variety among the animals analyzed (Figure 6.3). The smaller circles indicate a low range of variation, or in this case minimal migration while the larger circles indicate a wider range of variation, or a larger migration range. Based on the work of Chisolm et al. (1986), a resident herd is indicated when all animals consume the same grasses. Greater herd mobility or migration is indicated as grassland composition increases to include greater varieties of C_3 and C_4 grasses as bison move into different environmental settings. When comparing the southern Plains carbon isotope variance in relation to time a shift is apparent from resident (predominantly only C_4 grasses) at Jake Bluff to more wide ranging migratory herds at the three kills at Cooper where both C3 and C4 grasslands are grazed and at Badger Hole where increasing amounts of C3 grasses are grazed. This change in diet demonstrates that these animals go from a restricted, resident diet at Jake Bluff with minimal variation to more variation indicating increased migration of the animals during the time of Badger Hole.

On the southern Plains, CV analysis supports the visual dispersion of $\delta^{13}C$ and $\delta^{15}N$ ratios (Figure 6.3). In particular, the limited distribution of Jake Bluff data points is accompanied by the lowest CV values of any kill sites in the analysis. This pattern suggests the Jake Bluff bison are indeed residential with low mobility. The Cooper data represented in Figure 6.3 indicates a decrease in mobility in the middle kill period, with similar ranges of mobility in the upper and lower kills. The Badger Hole animals display far and above the highest level of mobility of any kill within the Beaver River Complex.

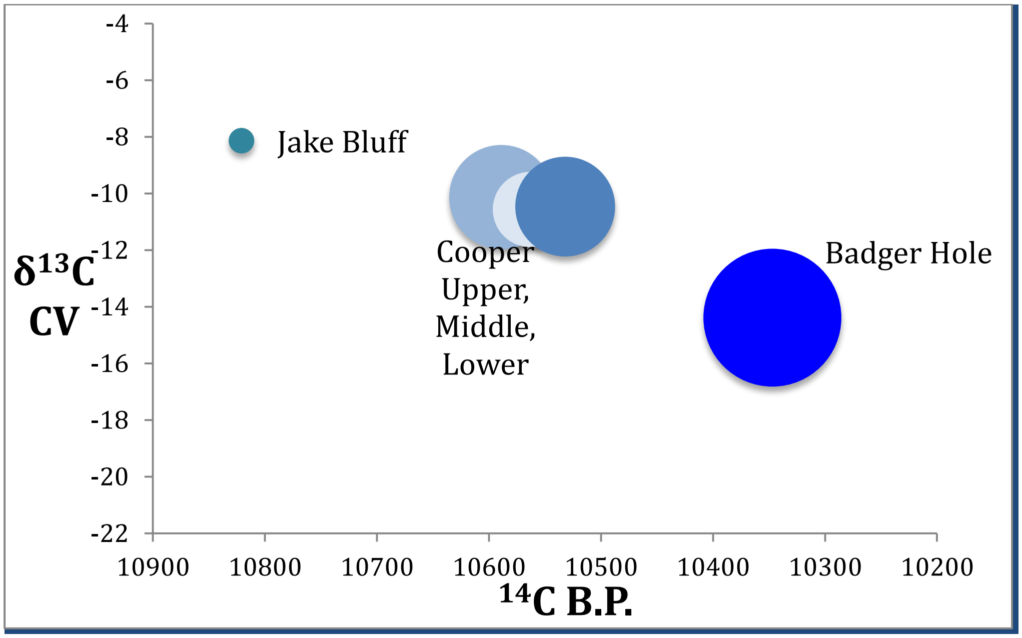


Figure 6.3. The coefficient of variance or CV indicates an increase in bison range area through time with a decrease occurring during the middle kill at Cooper.

An implication of this pattern for bison behavior is seen in the instance where animals under pressure will often pack together and minimize their range area to stay close to predictable necessary resources such as water and nutritious grasslands (Gadbury et al. 2000; Haynes 2002; Niven et al. 2004). The bison at Jake Bluff are clearly a species under stress, the isotopes indicate that the animals were grazing in a hot dry environment relative to the other late Folsom Kills analyzed. The skeletal remains also indicate animals under duress (Bement and Carter 2010). When compared to the skeletal remains of the later Folsom bison kills in the same arroyo trap complex the bison at Jake Bluff are gracile and thin. (Figure 6.4). Jake Bluff, currently the earliest communal bison kill site on the Plains, marks a period of extreme environmental duress near the beginning of the Younger Dryas at 10,800 ^{14}C BP as is indicated by the gracile bones of the bison and the high value of δ^{15}N and C_4 grasses indicated from the isotope analysis.

Figure 6.4. Comparison between A. Jake Bluff and B. Cooper metacarpals.

Trace Element Analysis

When I set out to conduct this portion of analysis I did so knowing that trace element analysis to determine bison migrations is a developmental technique. Debate circled many aspects of the technique and my intention was to clarify a methodology while increasing the sample size and adding new data to previous analysis. Progress was made in the development of this technique and the premise by which it works does hold. However, some critical problems arose that required initial investigations to be abandoned. Below I outline the steps and stages used to determine the migration of animals on the southern Plains as well as indicate problem areas within the research and lay out a moving forward section in which future researchers can take this method and further develop it.

The initial purpose of running the trace element analysis for this study was to compare the modern data set on the southern Plains previously compiled by Adam Graves (2010) to a larger prehistoric set of teeth. Graves (2010) had created a substantial modern database and originally tested a single bison tooth from multiple prehistoric samples in order to determine migration. The result of his analysis was a map of residential animals that prehistoric samples could be compared to in order to determine movement of prehistoric animals. But larger samples of archaeological teeth were necessary to begin to understand the full extent of animal migration among various animals in Paleoindian prey herds. The southern Plains sites contain large numbers of skulls and the teeth are well preserved, additionally the curation facilities were willing to have samples taken for this analysis. With numerous teeth to samples, the main purpose of the trace element analysis was to determine how many archaeological teeth were necessary to account for differing ranges between animals in a herd. The second step in this analysis was to begin to create a modern sample data set on the northern Plains where bison teeth are not well represented in the Folsom level of the sites analyzed. The goal of this research was to determine if any useful data could be gained from smaller samples more typical of early Paleoindian kill sites.

A problem led to setbacks for the purposes of the original research I had intended. Variation between machines and calibration techniques led to difficulties in comparing data sets, in this case the data set of Adam Graves (2010), and the data gained from the current analysis were not comparable. Data previously collected by Graves (2010) was not comparable to data collected nearly a decade later with a different machine in a different lab. Regrettably further work is necessary to solve this problem that is not the case by the time of this writing. For the purposes of future research the only solution to this problem to date is to run all samples together using the same machine and the same lab. This is not ideal when creating a modern database, which one would hope to add to over time.

Below I will walk through the discriminate analysis used on both data sets together and separately to indicate the split in samples from various labs. Samples run from the same lab are comparable and will be discussed at the end of the chapter. The outcome of this research does corroborate Graves' findings that modern samples can be used to create suits of elements comparable to prehistoric samples in order to reconstruct movement and demonstrates that the use of a different statistical technique provides the same results. Graves (2010) employed principle component analysis while I applied discriminate analysis. Both statistical method work on the same basic principles.

Problems of Comparison

In order to determine which prehistoric samples matched with the modern samples collected by myself and Graves (2012) I used discriminant analysis. Discriminant analysis determines a categorical dependent variable and works under the same principles as principle component analysis. Since the modern bison teeth provide a known category for what a certain elements in a region should look like discriminant analysis predicts with varying levels of certainty the region in which prehistoric teeth should fall. However, the level of certainty is also represented and a mis-assigned tooth will have a lower certainty percentage level than that of a tooth that is a better match to the region. Problems of diagenetic properties also come into play, which are not fully understood at the time of this analysis but appear to be corrected for by using the large suite of elements which do predict the animals' range.

The initial purpose of the trace elements analysis was to take a suite of new archaeological data in which to compare to previously sampled modern data (Graves 2010). After running the initial discriminate analysis on the log transformed data the conical graph representing the suite of modern data showed interesting results that did not make sense (Figure 6.5).

What is represented in this graph is the entire data set of northern and southern Plains data, both the analysis I ran at the lab in Pocatello, Idaho and the analysis Graves (2010) ran in his dissertation analysis. The data should cluster by region with northern and southern Plains samples splitting apart the farthest. However, the most obvious break in samples is between Graves (2010) data on the left and my data on the right. This split is indication of a calibration error, or errors created by using two different machines. The data is not currently comparable. The stars label the modern samples while the dots label the archaeological samples. At the time of this writing the calibration issue has yet to be resolved.

This poses clear problems if researchers using different labs, machines, and techniques cannot reach similar calibrations to make data comparable. I do not think this is a critical problem long term but for the purpose of this analysis it requires a different sort of comparison than what was initially planned. Since the complete data set is not currently comparable I split the data sets into Dr. Graves original set (2010) with the addition of later Badger Hole trace element data that was gained from the same lab. I ran this analysis separately to determine the extent of migration at Badger Hole a previously unanalyzed dataset excavated during the summer of 2011.

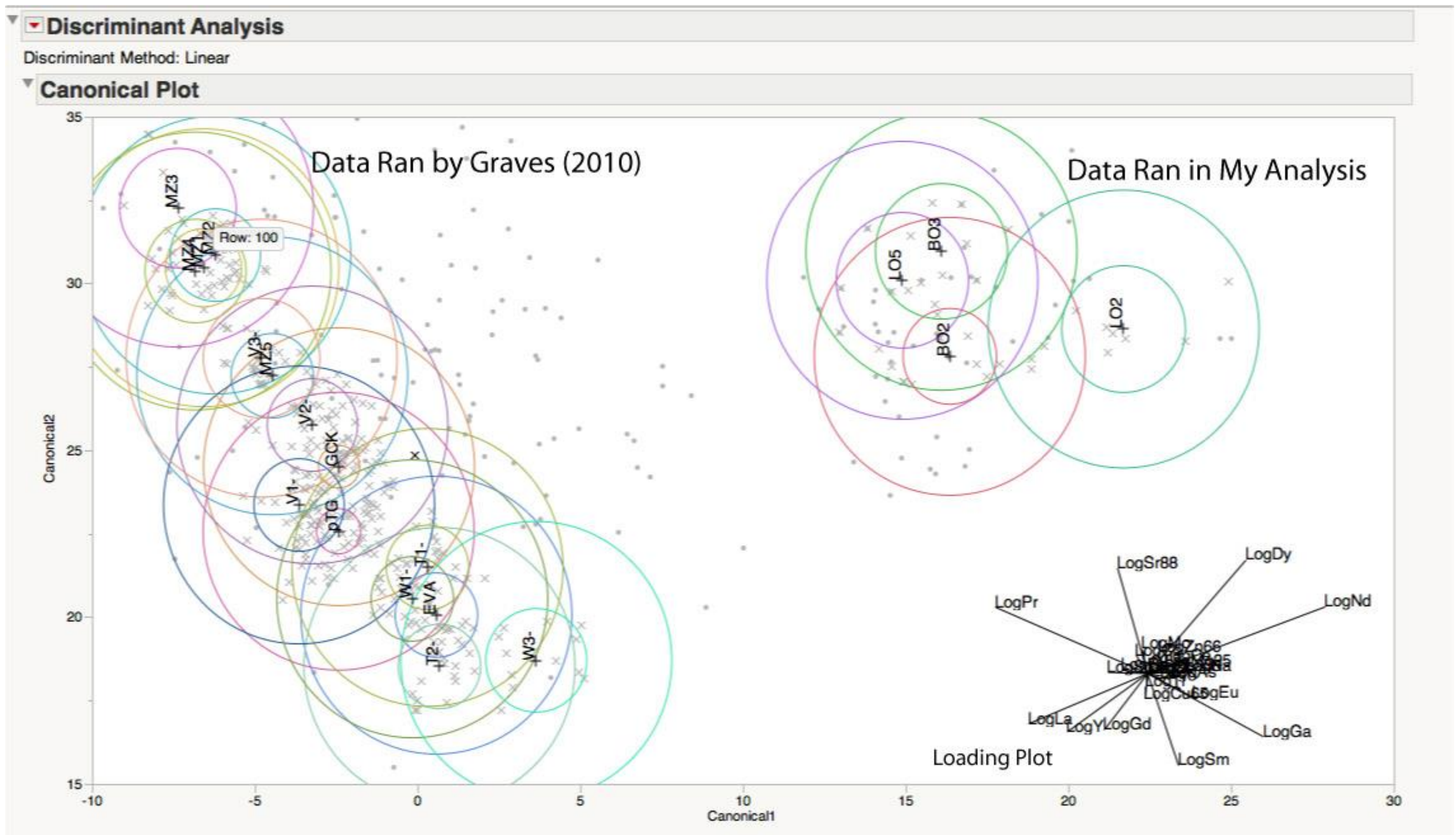


Figure 6.5. Canonical graph of discriminant analysis of both Graves (2010) modern data and data run for this analysis.

When removing my data from Graves (2010) data the conical graph demonstrates real clusters of regions across the southern Plains (Figure 6.6). The colored circles are indicative of a modern sample area. The dots are archaeological samples that fall into the modern samples area. The star plot in the center of the graph simply demonstrated which elements are pulling the categories set by the discriminant analysis. This analysis provides a 5% misclassification rate, when looking over the data the majority of the error occurred in one modern tooth sample which indicates that this tooth likely came from an individual which was moved and did not grow up and stay on the ranch during the entire period of tooth formation. Once this sample was removed (Figure 6.7). The percent of misclassified teeth dropped to 3%, an acceptable error range.

At this point in the analysis I had to abandon the idea of adding additional samples to an already complete modern data set on the southern Plains. The data is not comparable, for future research Graves (2010) modern samples will have to be run again through the new machine at the new lab in order be used with the new archaeological samples.

So what can be done with the samples run for trace elements at this point? While excavating Badger Hole in 2012 I came across a bison tooth sample, which I sent to the same lab that had run Grave's samples in 2010. Those data are comparable to the modern data set created by Graves and the results are presented below.

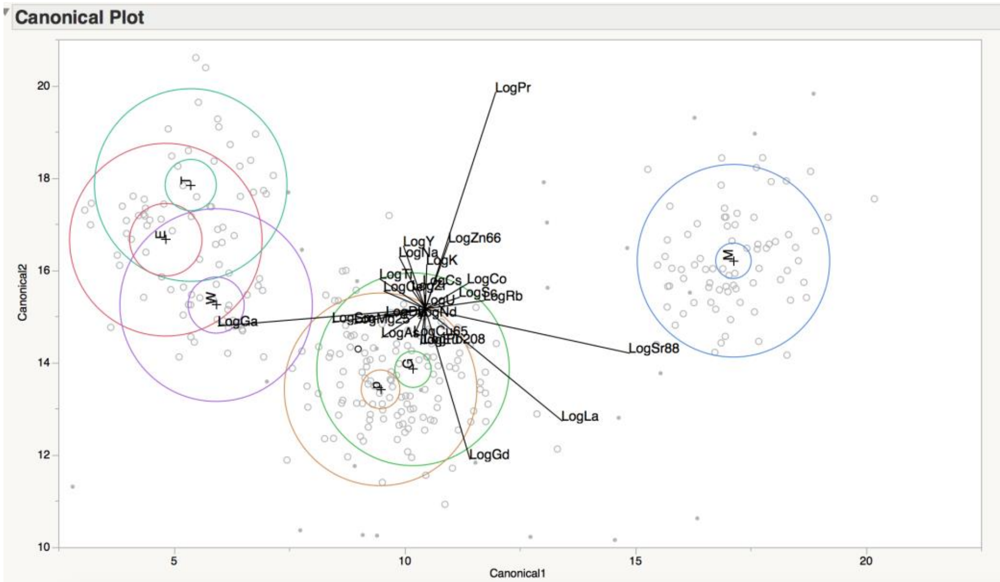


Figure 6.6 Graves (2010) data canonical plot prior to the removal of problematic tooth that likely resulted from an animal transferred from one ranch to another while enamel was forming, giving two distinct geographic signatures.

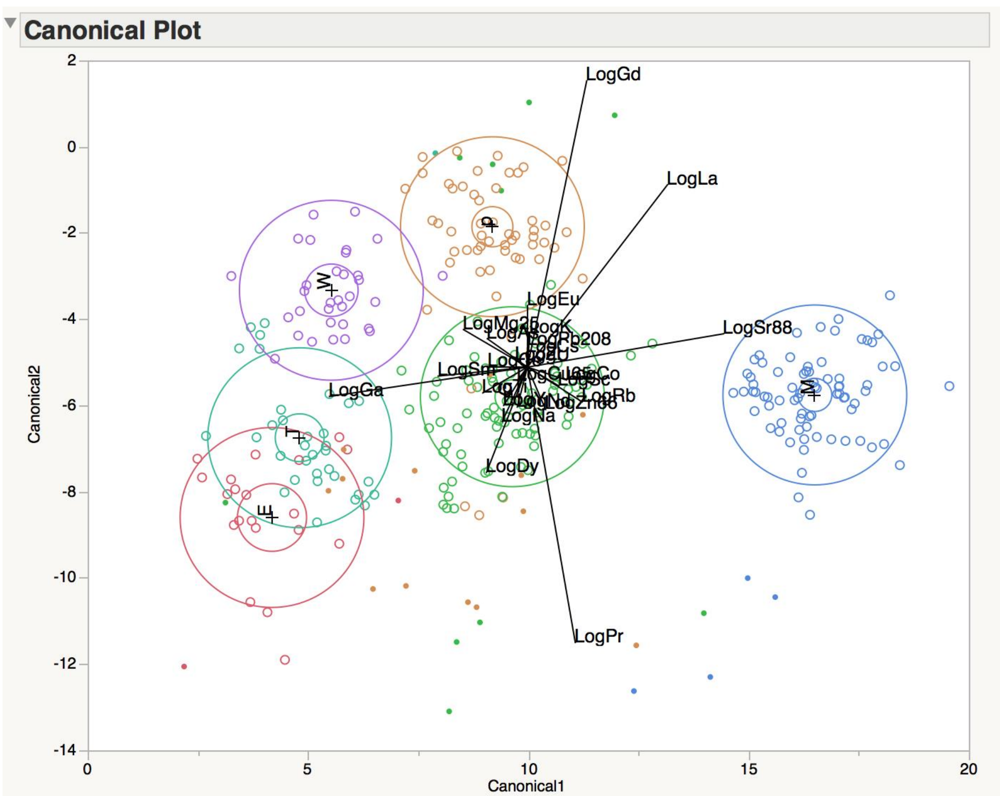


Figure 6.7. Conical plot of Graves (2010) data with problematic modern sample removed.

After correcting the above data set by removing the problematic modern sample. I highlighted the sources assigned to the archaeological materials by the discriminate function then created a mean line for the regional area in which to map the canonical or principle component of the range of the archaeological animal at Badger Hole. The results for the Badger Hole data are below (Figure 6.8).

What this graph shows is a highly magnified picture of movement for this particular animal. The entire tooth represent a full year of growth with each sample showing two weeks of movement as opposed to the two months collected in previous analysis (Graves 2010). A straight line would indicate limited mobility while a high degree of variation in the line indicates substantial mobility. Interpretations of this graph indicate that the animal ranged widely including regions not yet mapped by the modern tooth dataset. There are a few ways to interpret this graph. One, which is supported by Graves (2010) dissertation, in that the pattern of increased migration occurs through time and this was a highly mobile animal. Additionally this tooth was analyzed at a higher sample level than any other sample run by Graves or myself. Which may indicate problems with specific samples such as 17 (Figure 6.8), which may show movement that did not occur, or and more likely, may indicate a closer sampling strategy is necessary to actually capture the wider range of motion of prehistoric animals particularly when animals are wide ranging as in the case with Badger Hole.

When compared with Grave's (2010) data from the Jake Bluff site (Figure 6.9) two things are apparent, the animal analyzed from the Clovis kill was far less mobile, a pattern confirmed by the stable isotope analysis which indicates that other animals in the herd also demonstrated less variation indicating a resident herd. This tooth also has a wider spacing of samples every 5mm thought to best catch the movement of an animal at predictable two-month intervals. Given the data at hand, both isotopic and elemental, this sample represents a fair assessment of the animal's movement.

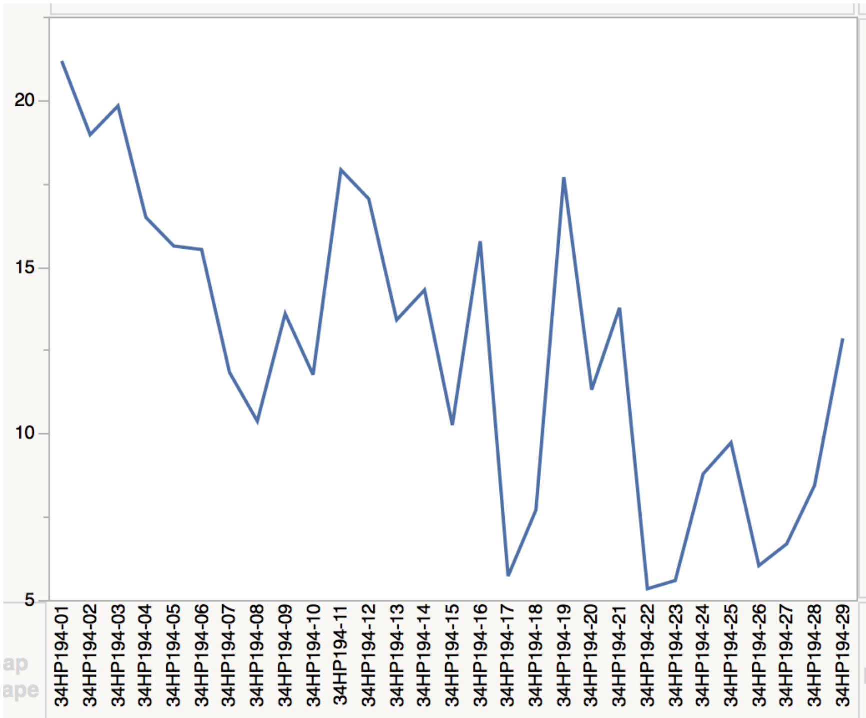


Figure 6.8. Badger Hole data at two-week intervals showing one full year of high mobility.

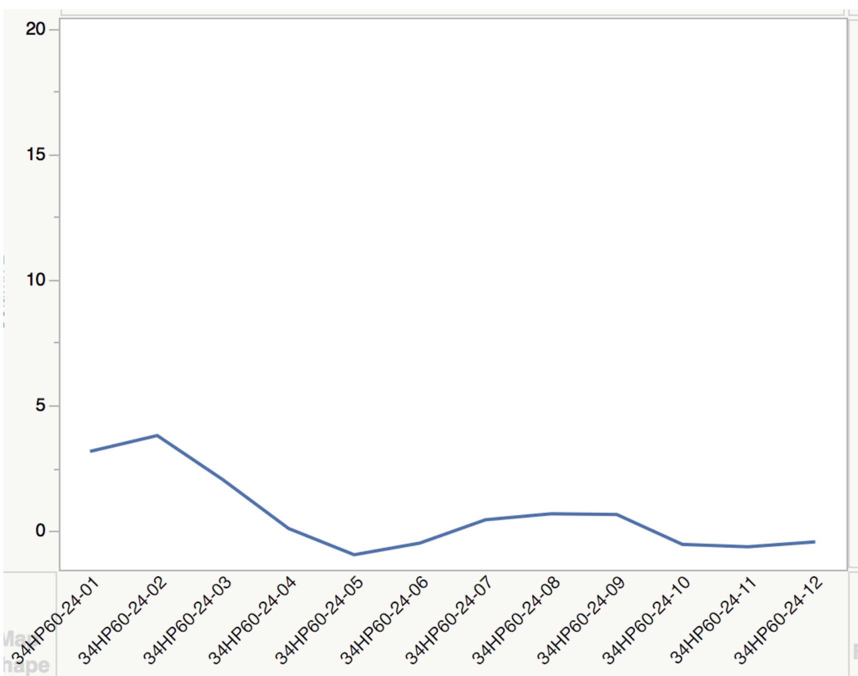


Figure 6.9. This image indicates the movement of Jake Bluff animals, which appear to have ranged very little when compared to the Badger Hole results. Each sample represents two months of the animal's life.

Northern Plains Sites

AMS dating enables tighter error ranges of materials to better clarify the temporal context of the sites under analysis. A charcoal sample from the Folsom hearth of Carter/Kerr-McGee produced a date of 10,400 ± 600 ^{14}C BP. Agate Basin's Folsom component was dated from a small amount of charcoal producing the original date of 10,430 ± 570 ^{14}C BP (Frison and Stanford 1982). Mill Iron is a Goshen site with charcoal dates ranging from 11,360 to 10,760 ^{14}C BP (Table 6.3; Frison 1996).

I obtained new dates for the northern Plains (Table 6.4) put the Folsom level of CKM as the oldest site at 10,560 ± 18 ^{14}C BP. Mill Iron dates discussed extensively by Waters and Stanford (2014) change our understanding of Goshen dates to more clearly overlap Folsom dates dismissing the validity of an older Goshen culture. Mill Iron materials dated by Waters and Stafford included in Table 6.4 complement the dates I ran for this analysis, the mean of both Waters and Stafford's (2014) and my assays provide a mean of 10.452 ± 11 ^{14}C BP. Agate Basin materials from the Folsom level are 10,283 ± 18 ^{14}C BP. These new dates provide a clear chronology for studying the change in stable isotopes through time on the northern Plains during the Paleoindian period.

Table 6.3. Original radiocarbon ages for the northern Plains sites in this study.

Site Name	^{14}C BP	+/-	Lab Number	Material	Publication
Agate Basin	9750	130	SI-4431	charcoal	
Agate Basin	10200	2000	RL-738	charcoal	
Agate Basin	10430	570	RL-557	charcoal	Frison & Stanford 1982
Agate Basin	10445	110	SI-4430	charcoal	Frison & Stanford 1982
Agate Basin	10575	90	SI-3730	charcoal	
Agate Basin	11450	110	SI-3734	charcoal	Frison & Stanford 1982
Agate Basin	11700	95	SI-3731	charcoal	Frison & Stanford 1982
Agate Basin	11840	130	I-10899	charcoal	Frison & Stanford 1982
Agate Basin	10780	120	SI-3733	charcoal	Frison & Stanford 1982
Agate Basin	10665	85	SI-3732	charcoal	Frison & Stanford 1982
CKM	10400	600	RL-917	charcoal	Frison 1984
Mill Iron	7480	240	RL-1530A	bone	CARD database
Mill Iron	9670	720	RL-1530	bone	CARD database
Mill Iron	10760	130	Beta-20110	charcoal	CARD database
Mill Iron	10770	85	AA-3669	charcoal	CARD database
Mill Iron	10990	170	NZA-623	charcoal	CARD database
Mill Iron	11010	140	Beta-16178	charcoal	CARD database
Mill Iron	11320	130	Beta-16179	charcoal	CARD database
Mill Iron	11340	120	Beta-13026	charcoal	CARD database
Mill Iron	11360	130	Beta-20111	charcoal	CARD database
Mill Iron	11560	920	NZA-624	charcoal	CARD database
Mill Iron	11570	170	NZA-625	charcoal	CARD database

Table 6.4. New radiocarbon dates completed as part of this analysis. Dates included from sources outside this analysis are included in the references column.

Site		14C Age BP*	1 Sig.	Lab Number	Reference
Carter/Kerr-McGee		10600	25	UCIAMS-122572	
		10520	25	UCIAMS-122573	
	Mean	10560	18	X2=3.84; df=1, Tcrit=5.12	
	Cal BP 2 Sig. (Prob)	12,428-12,491 (0.31)			
		12,522-12,613 (0.69)			
Mill Iron		10450	25	UCIAMS-61659	Waters and Stafford 2014
		10465	20	UCIAMS-98370	Waters and Stafford 2014
		10435	25	UCIAMS-98371	Waters and Stafford 2014
		10440	25	UCIAMS-122577	
		10465	25	UCIAMS-122578	
	Mean	10452	11	X2=9.49; df=4, Tcrit=1.39	
	Cal BP 2 Sig. (Prob)	12,219-12,282 (0.15)			
		12,379-12,436 (0.50)			
		12,458-12,525 (0.33)			
		12,547-12,571 (0.02)			
Agate Basin		10430	25	UCIAMS-122570	
		10135	25	UCIAMS-122571	
	Mean	10283	18	X2=3.84; df=1, Tcrit=69.62	
	Cal BP 2 Sig. (Prob)	11,983-12,125 (1)			

*All dates on XAD purified bison bone.
**Weighted mean following Ward and Wilson (1978)

Northern Plains Stable Isotopes

The stable isotopes at the northern Plains sites (Table 6.5) are not as clearly separated or easily interpreted (Figure 6.10) as the southern Plains sites. The oldest remains analyzed come from CKM at 10,560 ± 18 ^{14}C BP. Mill Iron, a Goshen kill site, produced a mean age of 10,452 ± 18 ^{14}C BP. The most recent Folsom kill event occurred at Agate Basin at 10,283 ± 18 ^{14}C BP. The isotopes indicate a relatively stable environment of cool/moist adapted prairie through all three kill events. When the δ^{13}C is converted to %C_4 the graph (Figure 6.11) further indicates a relatively stable environment.

There appears to be a trend from a wider ranging migratory herd at Carter/ Kerr-McGee to less mobile herds at Mill Iron and Agate Basin. But overall the environment appears to support C_3 rich grasses throughout this 400 year time period.

Table 6.5. Full results for the isotopes from the northern Plains sites.

Site Name	δ13C	δ15N	Average	SD	CV
Agate Basin	-18.0313	5.496118			
Agate Basin	-18.1894	4.653536			
Agate Basin	-18.3686	5.334375			
Agate Basin	-19.4112	6.149945			
Agate Basin	-17.0379	4.921575			
Agate Basin	-18.5981	7.183929			
		13C	-18.2728	0.774768	4.240015
		15N	5.623246	0.921459	16.3866
CKM	-13.0771	6.695726			
CKM	-18.5366	7.208015			
CKM	-18.6761	7.235724			
		13C	-16.7633	3.193104	19.0482
		15N	7.046488	0.304085	4.315411
Mill Iron	-19.0247	7.261388			
Mill Iron	-18.682	5.86482			
Mill Iron	-19.1502	6.679776			
Mill Iron	-16.9479	5.429137			
		13C	-18.4512	1.021558	5.536545
		15N	6.30878	0.81975	12.9938

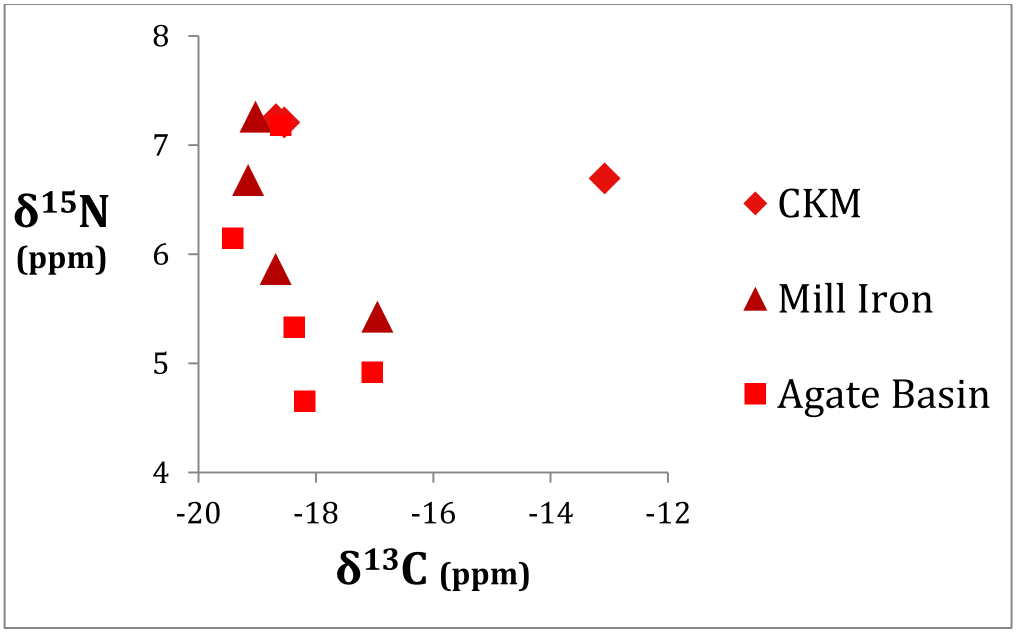


Figure 6.10. Stable isotopes results for northern Plains sites show a more consistent diet through time on the northern Plains than on the southern Plains.

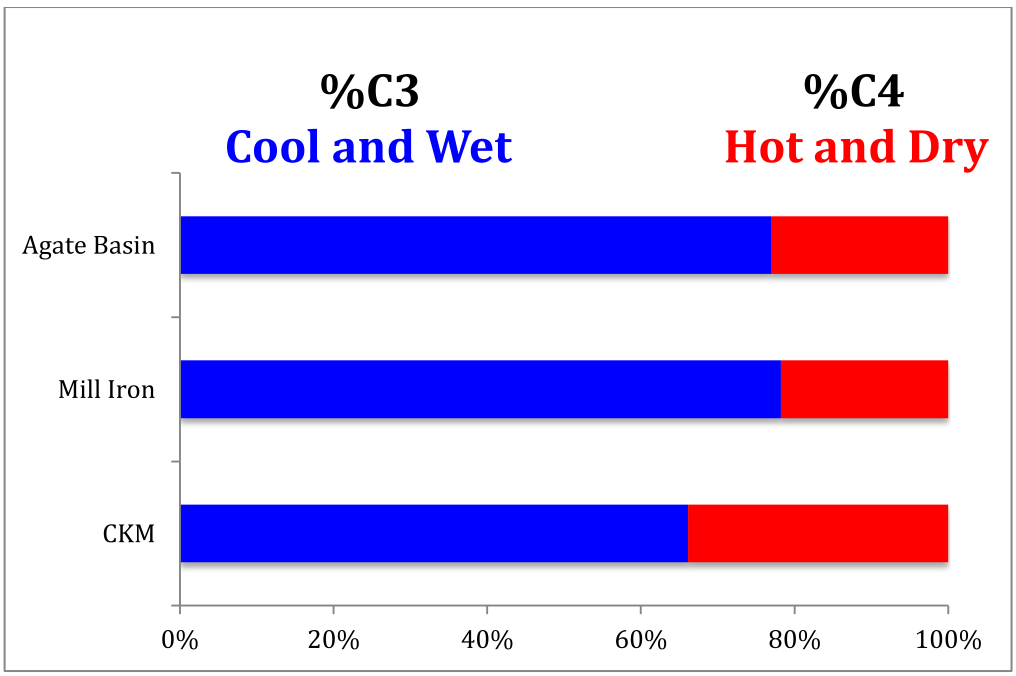


Figure 6.11. This graph represents the %C_4 and % C_3 in the diets of the animals studied. The data come from the mean results of the $\delta^{13}C$ isotope data.

The northern Plains bison kills CV results suggest the opposite pattern of mobility level through time compared to that seen on the southern Plains (Figure 6.12). The oldest bison kill is at CKM and has a $\delta^{13}C$ CV value that is the highest level for the three kill sites, suggesting the animals at 10,540 ^{14}C BP were mobile. By 10,452 ^{14}C BP, the bison mobility level reduced to that seen at the temporally roughly contemporaneous middle kill at the Cooper site. The lowest CV and hence lowest mobility level is expressed at the Agate Basin site (10,283 ^{14}C BP) which is when bison on the southern Plains were the most mobile. Unlike the situation on the southern Plains where $\delta^{15}N$ CV values varied in step with $\delta^{13}C$ values, on the northern Plains there is very little variation in $\delta^{15}N$ values between the three time periods. These values, however, are intermediate between those at Cooper and Badger Hole, suggesting the grassland structure on the northern Plains maintained a constant level of high nitrogen variability. Such high levels of variability in nitrogen may be the result of sustained drought conditions or possibly the common occurrence of fire on the southern Plains. Both drought and fire use are known to produce heterogeneous nitrogen patterns (Johnson et al. 2011; Murphy and Bowman 2009).

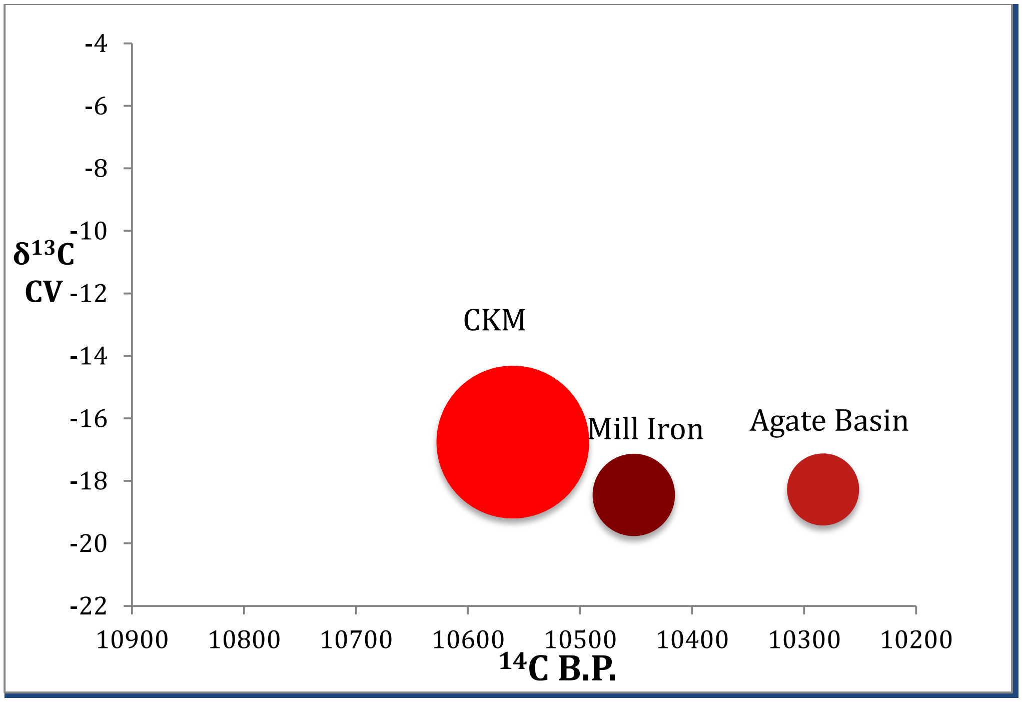


Figure 6.12. The Coefficient of variance (CV) indicates a greater range area followed by lesser ranging herds at Mill Iron and Agate Basin.

Trace Element Analysis

As mentioned above the northern Plains preservation did not allow for a full sampling of bison teeth for trace element analysis, though future research will aid in adding to the sampling size of the analysis. Four modern teeth and two prehistoric teeth were analyzed. One modern tooth matched the region for the prehistoric teeth while the other seems to indicate an area outside of the prehistoric bison range. A further collection of modern samples needs to be collected from modern ranch animals living on contained ranches on the northern Plains to create the equivalent modern sample Graves (2010) created in his dissertation for the southern Plains in order to be able to accurately map movement across the northern Range. These teeth will allow for a modern analog to the trace elements of the prehistoric teeth. Additional prehistoric teeth also need to be analyzed in future research. The next stage in mapping migration of prehistoric animals should focus on more recent kill activity on the northern Plains in order to avoid the background noise that comes from diagenetic processes. Once more modern baselines are obtained and sufficient prehistoric animals are tested then older samples will provide more accurate results through time.

On the northern Plains the samples of three modern bison were run along with two prehistoric bison teeth one from Agate Basin, and the other from Mill Iron (Figures 6.13; 6.14). The small sample size does not allow for very accurate results however they are presented here for the general discussion of bison movement. The discussion of bison mobility on the northern Plains must still rely heavily on isotopic analysis. The following section focuses more on adding a component to the overall method of trace element analysis than on the data that can be gained from the analysis itself. The same discriminate function was run with the smaller suite of data collected only for the northern Plains sites. The results seen below indicate that a larger sample of modern animals is necessary to determine the range of these particular animals. Both teeth appear to match the

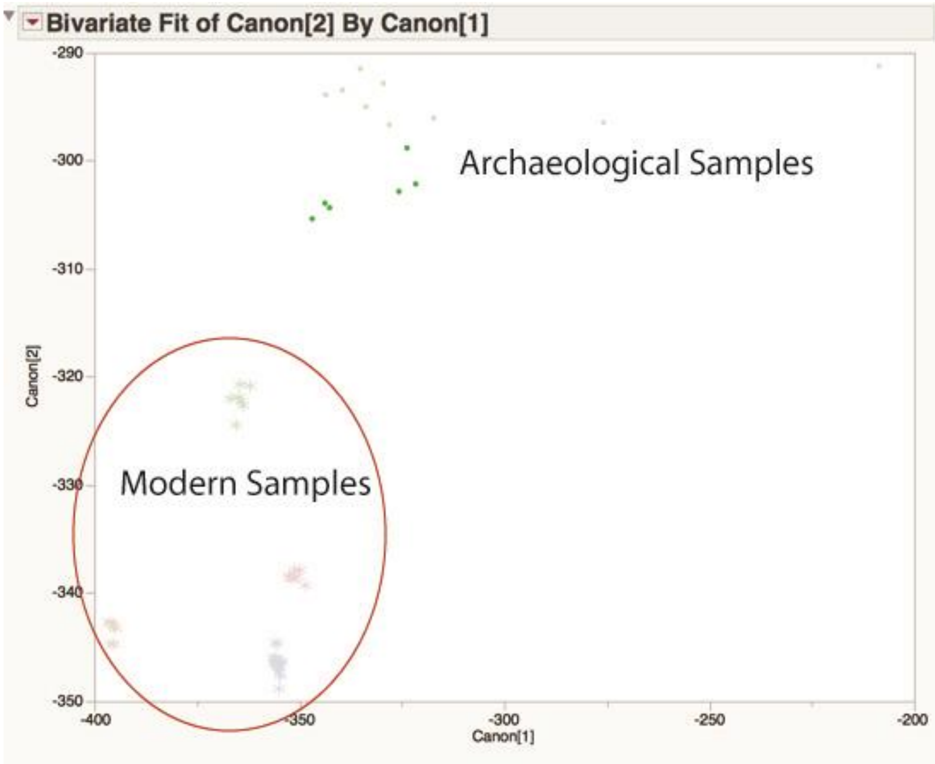


Figure 6.13. Conical plots of northern Plains data. Agate Basin sample highlighted in green.

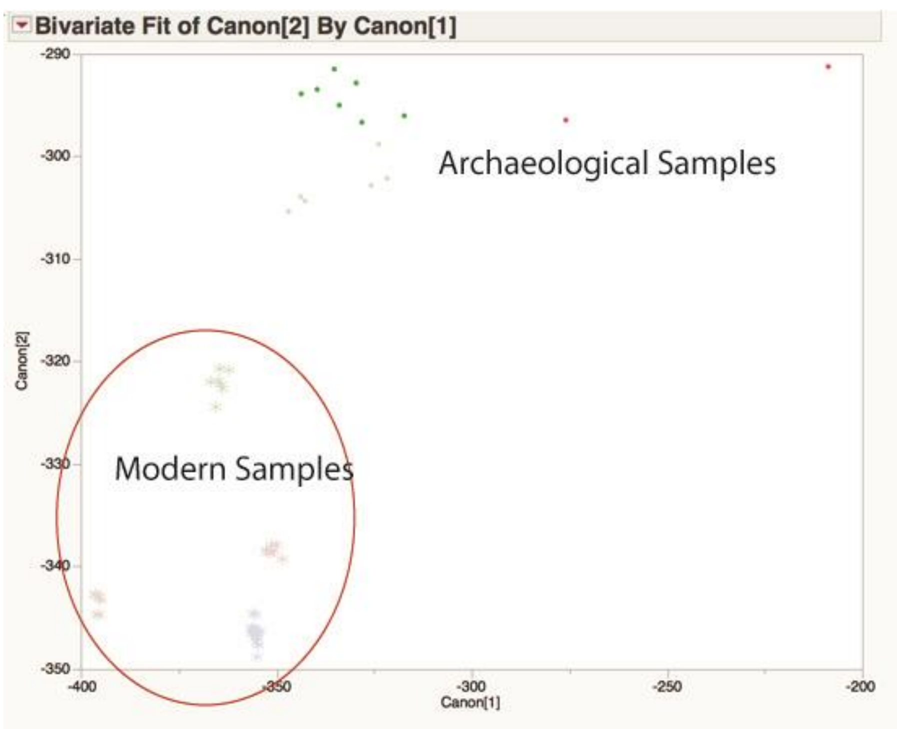


Figure 6.14. Mill Iron samples indicate a further migratory range of animals.

modern sample B0224 with 100% certainty (Figures 6.13 and 6.14). 24CT30, Mill Iron appears to have a wider migration range than the Agate Basin bison. However with so little to create the discriminate analysis this cannot be stated for certain and the stable isotope analysis would indicate that the animals are from a herd that migrates roughly the same distance.

Summary and Conclusion

In conclusion re-dating of materials was necessary to clear up the disparity created by antiquated dating techniques. Though the dates were sound for the time of excavation new techniques aid in focusing the dates of these early archaeological sites. Initially I had hoped to compare two early Paleoindian kill sites on the northern and southern plains but the new dates shifted the time period of focus to a more stable time period on the northern Plains as evident in stable isotope results. Stable isotopes were run to gain a clearer understanding of both environmental change at the sites as well as the degree to which animals migrated. The trace element technique, still relatively new to the study of bison migration, provided a means to begin mapping animals to specific regions on the landscape in determining migration routes. Further refinement of this technique is required before migration routes can be confirmed through trace element analysis.

Chapter 7: Discussion and Conclusion

The following chapter outlines the conclusions of this research. The questions I set out to address at the beginning of this project were: Is there a link between environmental change, bison mobility behavior, and large-scale hunting? What were the mobility patterns of bison hunted in large kills during the Folsom and Goshen periods? I begin by summarizing the setting in which communal kills develop, then I describe the prehistoric development and extended use of the Beaver River Complex on the southern Plains. This data set is the most complete and provides a clear example of communal hunting development on the southern Plains. I then review the northern Plains data, which provides a picture of bison hunting in a stable and settled environmental setting in the early Paleoindian period. This data demonstrates that communal bison hunting developed quickly and was maintained as a successful hunting adaptation throughout the Younger Dryas when the environment settled into a moist cool landscape. After providing a comparison of results from the northern and southern Plains I propose a model created from southern plains data to better understand the extent of bison migration and movement.

Trace element analysis though a viable means to determine migration distance and patterns is still in the developmental stages. To compensate for the limitations of trace elements I demonstrate a model developed from the southern Plains to determine the range of migration of bison utilizing stable isotopic variance (CV) when trace element analysis is not yet fully developed or cost efficient. Prey range size is significant in communal bison hunting to understand if hunters are targeting groups of migratory or residential animals, which speaks to the necessity to plan interception of migratory herds or take advantage of residential animals. Large migration routes of bison killed in arroyo traps in the Paleoindian period provide a predictable resource that aggregations can be planned to intercept. Group aggregation predetermined by predictable migratory routes enables hunters to engage in a social and subsistence activity. Bison trap systems based on bison behavior were so successful they were employed for over 10,000 years (Brink 2008; Frison 1994), by multiple cultures across North America. This research focuses on the developmental period of this adaptation during the Younger Dryas.

At the outset of this project I ascertained that re-dating previously excavated materials was necessary for a clear temporal picture of the sites under analysis (Figure 7.1). Though the excavations and analysis were carefully conducted at every site included in this project the dating methods at the time of analysis have been replaced with more accurate dating techniques. A clear temporal understanding of the sites was necessary to determine the initial development and continued use of kill sites across both the northern and southern Plains. Figure 7.2 places the sites on a timeline allowing a quick representation of how the sites included in this study are temporally related.

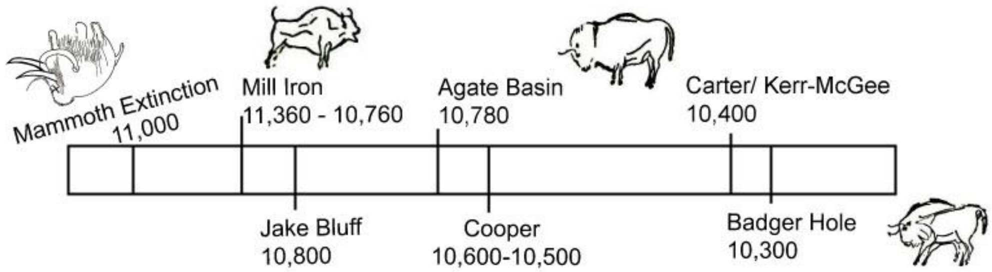


Figure 7.1. This timeline demonstrates the original dates in radiocarbon years for the northern and southern Plains.

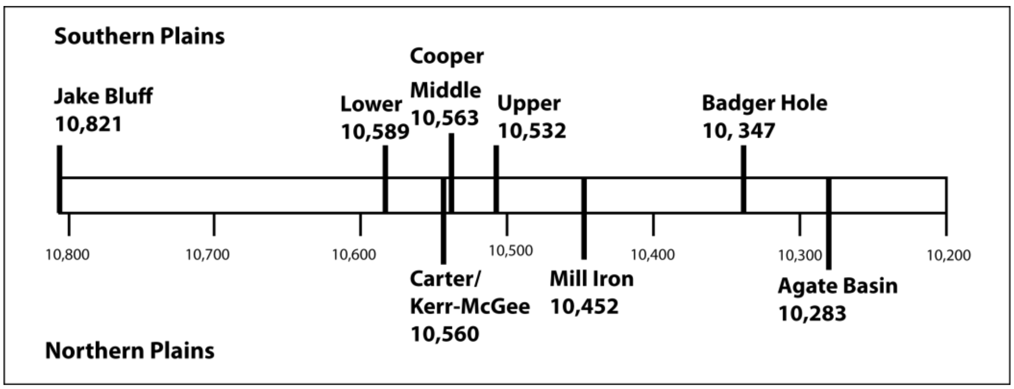


Figure 7.2. Radiocarbon year approximate range demonstrating the reordering of chronology of the sites included in this analysis.

The Setting for Communal Kill Development

At the end of the Clovis Period (~10,850 ^{14}C BP; Waters and Stafford 2007) mammoth were becoming scarce on the landscape as the megafauna of the period died out (Grayson 2007; Meltzer 2009). Bison were not immune to this event and narrowly escaped extinction themselves, as is evident from DNA data (O'Shea 2012). A bison population crash indicated in the DNA of Beringia bison (Drummond et al. 2005) and represented on the southern Plains by a single-allele founder affect mutation at ~11,300 ^{14}C BP suggests bison were scarce at the time of Clovis development. The scarcity of bison during the late Pleistocene is further supported by the paucity of bison remains in paleontological sites for that period (Wyckoff and Dalquest 1997). Archaeological discoveries to date indicate that Clovis people did not target large numbers of bison on the Plains until after mammoth extirpation and bison population levels rebounded (Frison 1994; Kornfeld et al. 2010; Meltzer 2009). Communal bison hunting develops at the beginning of the Younger Dryas (Figure 7.3).

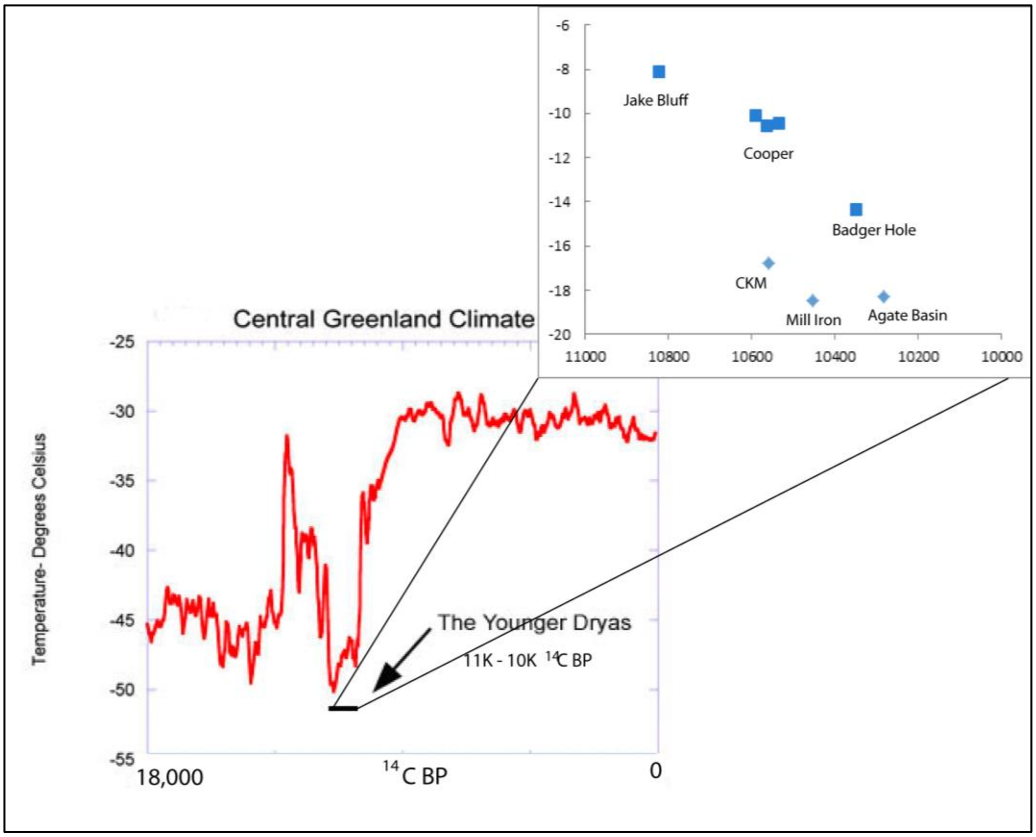


Figure 7.3. The stable isotope means from all sites mapped to time period to demonstrate the Younger Dryas and its relationship to early bison hunting.

Bison hunting in communal events is a difficult task. Bison are agile, aggressive, large, and respond quickly to threat. Bison were likely hunted individually by any group of hunters that could make use of the animal, if they were cunning enough to kill it. The ability to run a herd of bison into a trap to kill a large number (>10) of individuals is a remarkably successful means of attaining resources in a single event. In order to successfully manipulate a herd of bison the group had to be familiar with bison behavior. Bison herd mentality makes them particularly susceptible to arroyo trap hunting techniques. Where other animals such as deer scatter to avoid a predator, bison move together and flee in a group, an effective strategy when evading a wolf or other wild predator, but not when trying to evade humans.

This herd response to threat is ideal for humans to manipulate herds into arroyo traps where they were then killed. But certain factors must be present before this kill technique could develop. These factors are a thorough understanding of bison behavior, a sufficiently large number of people to warrant the communal kill of multiple animals, and a trap system in which bison can be driven. Additional requirements includes the availability of resources necessary to support large groups of hunters occupied with the organization, implementation, and subsequent butchering that surrounds a hunt of this magnitude.

Southern Plains

The southern Plains provided a unique opportunity to study an area in which Paleoindian hunters used the same 700 m stretch of river for a total of at least 500 years in five kill events: Jake Bluff, the oldest site and the earliest bison kill site yet analyzed in North America, Cooper, which contained three separate kill events of Folsom age, and Badger Hole, which was the most recent bison kill at the complex. All of the events contained within the Beaver River Complex sites transpired during the late summer/early fall. This season of the year provides an ideal time to kill bison as the rut is over, the males disperse, and the females pack together. This suite of sites provides an opportunity to look at the development and continued use of a large-scale kill adaptation through time.

Jake Bluff contains the earliest bison kill on record at 10,821 ± 17 ^{14}C BP (Bement and Carter 2010). This site represents the earliest time period on the southern Plains in which bison are present on the landscape in the required numbers to which they can be manipulated and killed in the arroyo trap method. The people must have a resource requirement to warrant a communal hunt. A single *Bison bison antiquus* could weigh over 2,000 pounds (900 kilograms) and stand over 2 m tall. A single animal provided a substantial amount of resources. I argue that to warrant the killing of 10 or more animals a large group has to be present to make use of the kill. This comes from the observation that the 22 animals killed at Jake Bluff were completely disarticulated; which only occurs when the majority of the meat is being used.

Jake Bluff contains the remains of 22 *Bison bison antiquus*. The bison at Jake Bluff are gracile and the isotopes indicate they are grazing in a xeric, high C_4 grassland. The animals were barely surviving the mass extinction event that killed over 36 species by the Younger Dryas (Grayson 2007; Martin and Klien 1989; Meltzer 2009) and they are living on an extremely arid landscape with grasses with high δ^{15}N values. In summary these animals were under duress. In addition to the physical state of the animals, though the sample size is small, both stable isotope and trace element analyses indicate that these animals are living in a restricted area. They are not migrating far if at all. Large animal populations under stress pack together near water resources and do not risk moving to find additional resources (G. Haynes 2002). This behavior is evident in the animals killed at Jake Bluff.

The hunters at Jake Bluff develop this large-scale kill technique because resident bison grazed near the arroyos for an extended period of time, providing hunters with the necessary components to develop this communal kill technique. People on the Plains hunted mammoth and bison before the environment changed dramatically and bison numbers increased across the landscape. Bison behavior would be a known element to Paleoindian hunters long before bison numbers increased during the Younger Dryas.

While inhabitants roamed the area and made use of individual bison their close proximity would allow the hunters to gain an understanding of the herd behavior of the species and develop the strategy necessary to run bison into the nearby land features. The animals were run into arroyos and killed then butchered fairly completely at this Clovis kill. As a rough estimate a single modern bison weighing 1000 pounds (453 kilograms) provides roughly 400 pounds (180 kilograms) of meat. Using this rather low estimate of resources 22 bison would provide 8,000 pounds (3600 kilograms) of meat, not including the sinew, bones for tools, and other resources gained from the animals. This kill technique once developed and carried out successfully provided a wealth of resources to the hunters and family groups.

The fact that only five kill events are present (one at Jake Bluff, three at Cooper, and one at Badger Hole) in a 500 year-period along the Beaver River indicates that these kills were not yearly events. Additional bison kill preservation across the Plains leads to the similar conclusions (Frison 2006; Kornfeld et al. 2010; Reher and Frison 1980). These early kills may only have been carried out once in a generation, or once every couple of generations when the herds were large, people could aggregate, and resources were plentiful to support large groups usually dispersed on the landscape.

Roughly 250 years after the successful arroyo kill at Jake Bluff additional kill events occur 400 m to the east at Cooper. The lowest, middle, and upper kills date to 10,589 ± 16 ^{14}C BP, 10,563 ± 19 ^{14}C BP, and 10,532 ± 19 ^{14}C BP, respectively. All three events occurred in less than 60 years. Arroyo traps used more than once throughout prehistory are not uncommon. Other Paleoindian examples include Agate Basin (Frison 1982) and Carter/Kerr-McGee (Frison 1984). What is unique concerning the sites analyzed is that these three kill events occur very close together in time, potentially within one person's lifetime and certainly within a couple of generations. The reuse of this site is significant. Why carry out such a large-scale kill so close together? Also a significant switch at this time is that the animals are no longer resident herds. They are migratory, as was indicated by the coefficient of variance of stable isotopes. So the hunters would have to time their use of the area with the migration of the herds to take advantage of the moving resource. This also must occur at the proper season to be able to carry out large-scale kills, in this case late summer/early fall. The same season the Jake Bluff kill was used.

What is also significant about Cooper is that the animals' migration route is not the same throughout the three kill events. The animals expand their range size through time, beginning as a relatively restricted herd and migrating further by the time of the next event (Carlson 2013; Graves 2010; Figure 7.4). The estimated migration range the southern plains animals are; 400 km for Jake, 800 km for the lower level at Cooper, 1000 km for the middle, 1000 km for the upper (Graves 2010) and 2000 km for Badger Hole. This is evident in both the isotopes and the trace elements in the teeth. Despite their widening migration routes they repeatedly travel through the Beaver River Complex area. This increase in migration and continued travel through the Beaver River area necessitated preplanning on the part of the hunters to place people in the same location as the bison and the arroyos at the proper time of year to engage in a successful large scale kill event. A significant amount of planning would be necessary to gather groups together to take advantage of the migrating resource.

Badger Hole is the most recent Folsom kill at the Beaver River Complex dating to 10,347 ± 16 ^{14}C BP. This site marks the last communal kill event preserved at the Beaver River Complex. The isotopes and trace elements at Badger Hole show a continued trend in widening migration patterns of the bison. Following the pattern set out by hunters less than 200 years prior, the people at Badger Hole maneuvered bison into an arroyo trap and killed over 10 animals, and likely substantially more given the size of the arroyo and the amount

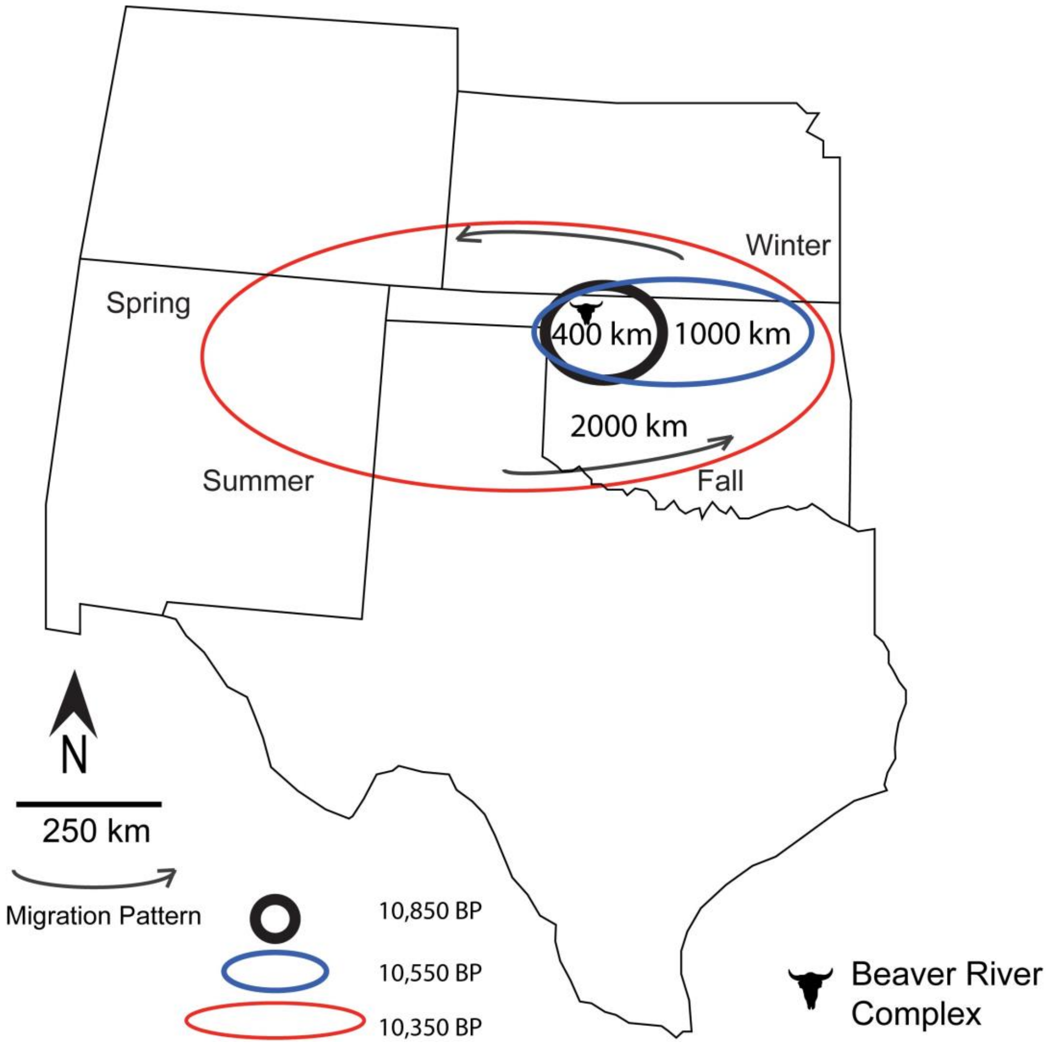


Figure 7.4. Map demonstrates increasing migration range through time with round trip distance in kilometers.

of bison remains discovered out of context in the trench to the west of the intact portion of the kill site.

While studying the stable isotopes on the southern Plains an increase in migration is seen to occur through time (Figure 7.5). The bison tooth trace element analysis confirms this with a widening range of migration. The data outlined above provides a picture of a developing kill technique that extends from the last years of Clovis to the end of the Folsom period. Hunters developed a kill technique from a resident herd arguably held in refugium that enabled the successful hunting of a substantial number of animals. Later hunters adapted to the widening migration routes of their prey species by planning kill events that took advantage of a predictable resource and landscape feature at the proper time of year to carry out a successful large scale kill at these sites that was late summer/early fall.

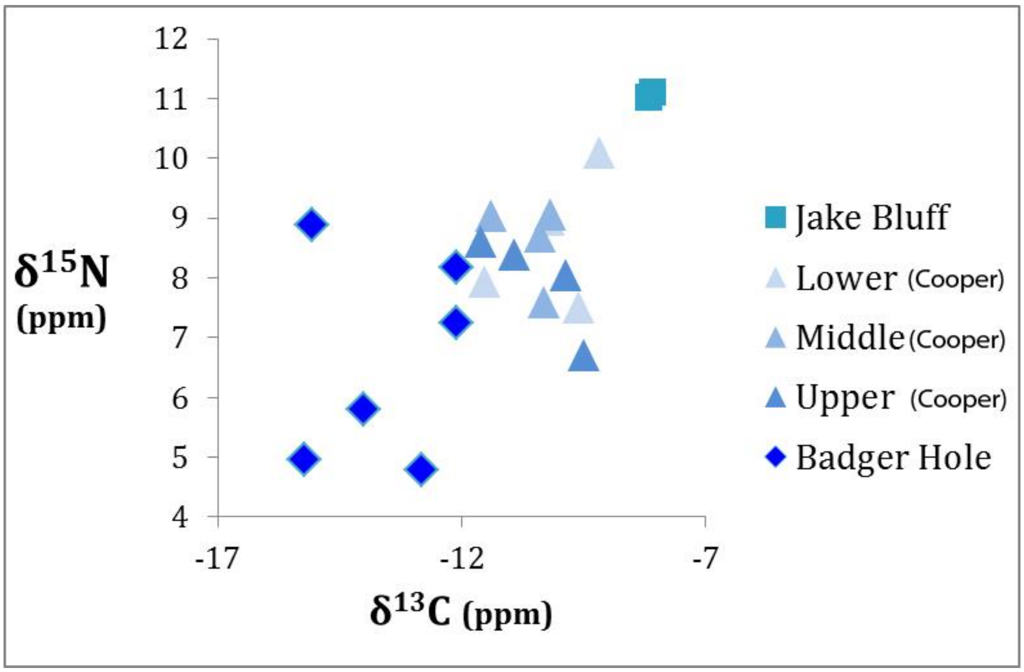


Figure 7.5. This graph depicts the stable isotope data for all southern Plains sites analyzed.

Expanding bison numbers led to ever-increasing migration ranges that Folsom hunters had to consider when scheduling hunts. During this time, the archaeological record shows that communal Folsom bison kills only occur in late summer/early fall on the southern Plains, to the exclusion of the other seasons and regardless of the size of bison migration territory. This suggests that Folsom hunters did not perform communal kills at other seasons of the year on the southern Plains, highlighting the singularity or uniqueness of the seasonality of these large-scale kills. The implication is that Folsom hunters did not plan communal hunts for the remaining seasons or along the rest of the migration routes of these animals. Leaving the rest of the year and territory open for encounter hunts by dispersed small groups as evident at the Waugh site's late spring kill of 6 animals (Hill and Hofman 1997) and Lubbock Lake winter kills of 2 to 3 animals at a time (Johnson 1987). The trace element results provide a means to approximate the size of bison ranges to be considered in this Folsom adaptation. The stable isotopes provide a measure of the structure of the grasslands across the migration range.

Northern Plains

The northern Plains provides a view of Folsom to Goshen time periods in which the environment has stabilized during the Younger Dryas and the adaptation to communal kills has already been established. The re-dated sites once thought to mark the earliest communal kill sites on the northern Plains now fall into a more established period of hunting adaptation. The environment on the northern Plains is more stable through this period and the earliest kill sites comparable to Jake Bluff on the southern Plains are absent from this study. The samples also come from three various regions on the northern Plains rather than representing one kill complex as kill complexes like the Beaver River Complex are archaeologically rare. The new dates for the three northern Plains sites place the earliest site at Carter/Kerr-McGee's Folsom level 10,560 ± 18 ^{14}C BP, nearly the same time as the middle kill at Cooper.

Looking at the stable isotope results for the northern Plains (Figure 7.6) The Folsom level at Agate Basin and Mill Iron appear to contain a more resident herd than the bison at Carter/Kerr-McGee. However the outlier at Carter/ Kerr/McGee is a young individual under 2-years-old and the isotope results are consistent with a nursing calf. After re-dating the materials at Carter/Kerr-McGee the bone assemblage was likely mixed with the Cody assemblage. Since landscape deflation is not uncommon in the region, the two dates correspond with two separate kill events. Since Carter/Kerr-McGee did not have teeth preserved with reliable provenience it is difficult to say if the migration of animals can ever be determined at the Folsom level. Further analysis at the Cody level however would likely result in interesting data and should be considered for future research. The Agate Basin Folsom material and the Mill Iron Goshen material appear to be the more resident of the northern Plains reflecting a migration pattern similar to that of Cooper.

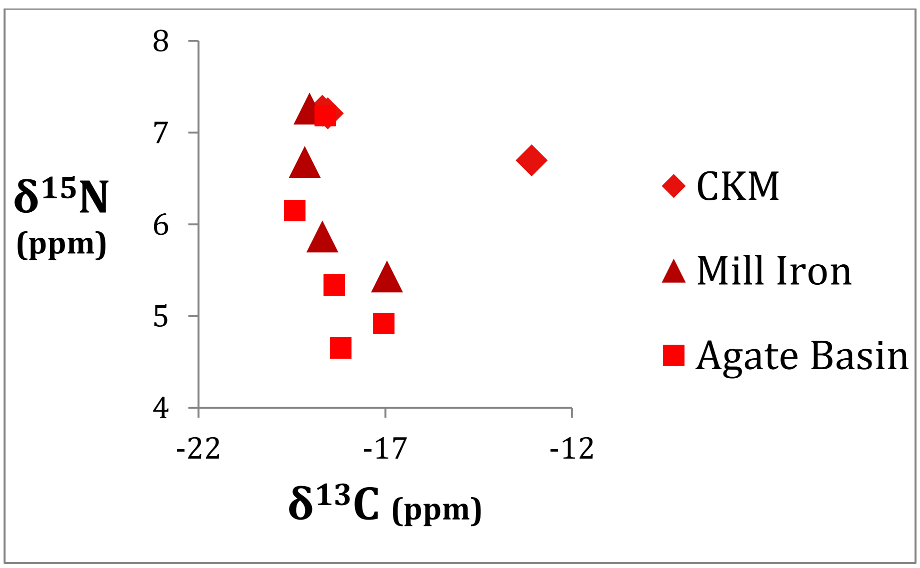


Figure 7.6. Northern Plains stable isotope results.

Comparing South to North

In order to gain a clearer understanding of the differences of the northern and southern Plains I will compare the two in this section. Figures 7.7 and 7.8 provides the entire data set of both northern and southern Plains data analyzed. As the graph depicts Northern Plains data indicate a stable cool, wet environment during the period analyzed. While southern Plains sites begin with dry, hot, high C_4 grasslands, which gradually become cooler and wetter over time. The bison also increase their migration patterns on the southern Plains.

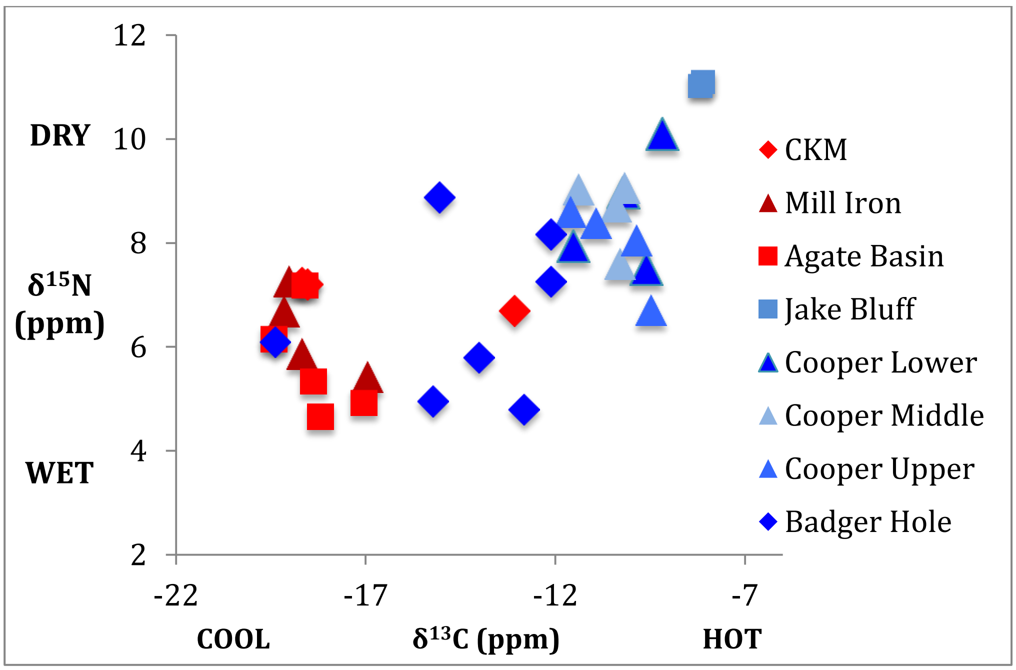


Figure 7.7. The isotopic results of the Northern and Southern Plains sites shown to increase in a hot dry climate as we move south and back in time.

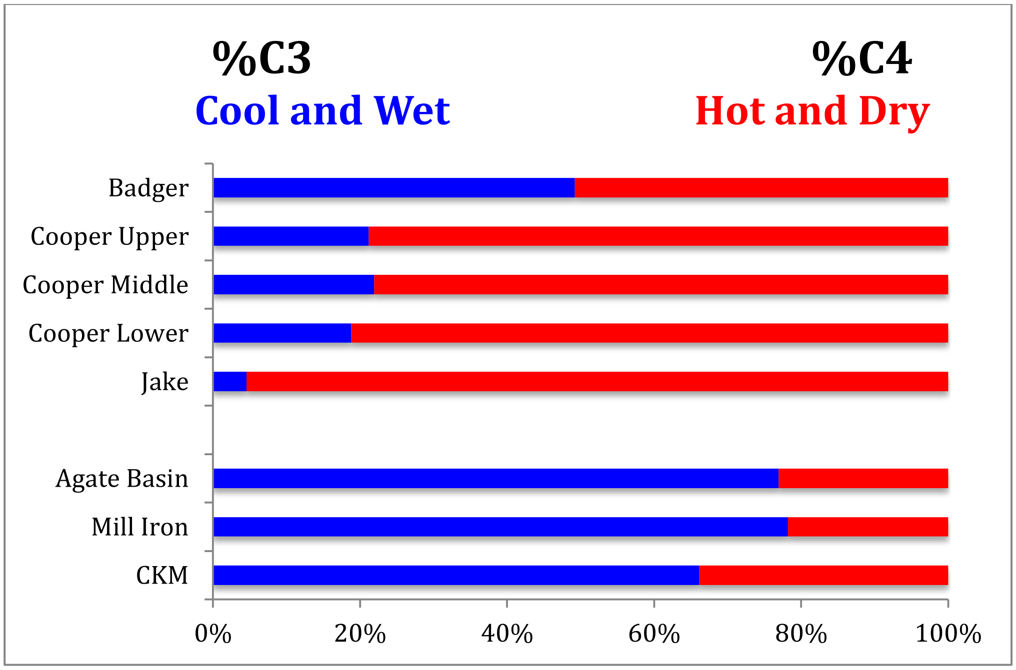


Figure 7.8. The southern Plains sites on the top from youngest to oldest at the bottom, and the northern Plains sites on the bottom also listed from youngest with Agate Basin to oldest with CKM. This graph depicts the increasing cool wet environmental grasslands on the southern Plains compared to the stable cool moist conditions seen on the northern Plains.

Bison Migration Distances

Given the unclear trace element results of the northern Plains samples, further analysis is necessary to try to determine migration extents in that area. Since scant preservation is common in the Paleoindian record I use the data presented in the southern Plains to create a model for estimating migration magnitude on the northern Plains where trace element data is incomplete. Bison herd mobility increases through time on the southern Plains. Bison movement decreases from CKM and then appears to be remain the same between the herds at Mill Iron and Agate Basin (Figure 7.9).

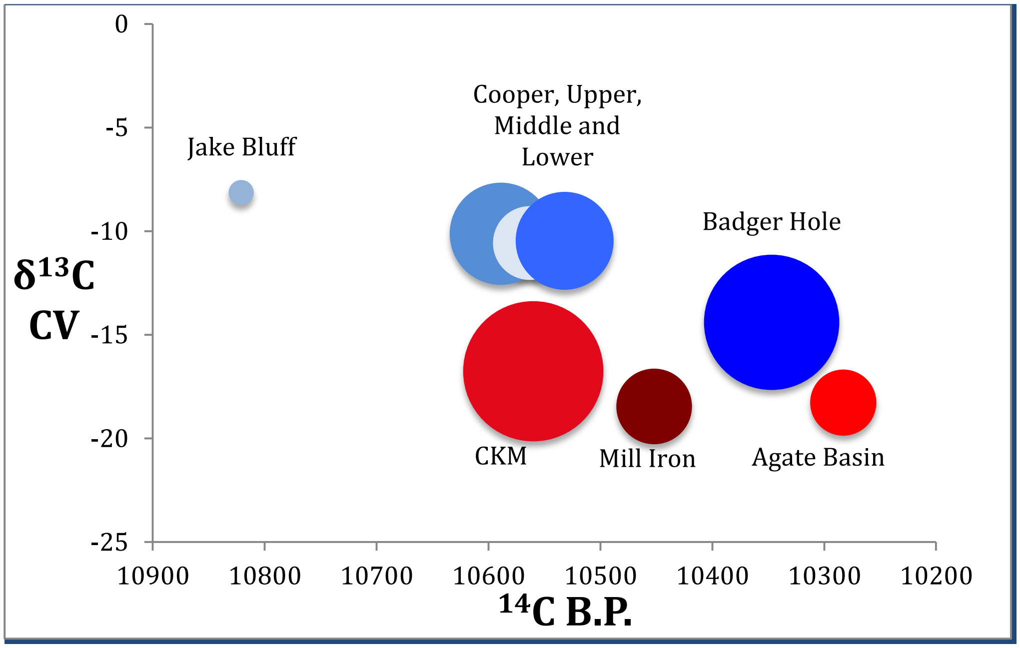


Figure 7.9. Coefficient of variance of northern and southern Plains sites combined.

A cross plot of southern Plains stable C isotopic CV (Figure 7.10) by the round trip migration distance determined by trace element analysis (Graves 2010) including Badger Hole data added in Chapter 6, produces a regression line and equation with an R^2 of .7955 (Figure 7.10). The southern Plains data indicates that CV and migration round trip distance co-vary to such an extent that if the CV is known, the migration round trip distance can be estimated. Applying the linear regression equation from the southern Plains Beaver River Complex sites to the northern Plains CV's suggest that the animals at the Carter/Kerr-McGee, Mill Iron, and Agate Basin sites followed migration routes with round trip distances of 1905 km, 690 km, and 800 km, respectively. Carter/Kerr-McGee's wide range territory could be accounted for if the outlying isotopes are from a bull with an idiosyncratic migration pattern different from the typical herd. A larger sample size would aid in clarification of this issue. However, Carter/Kerr-McGee's Folsom level does not contain a large suite of bones to sample. None of the northern Plains herd data implies that the animals were residential. Although the exact route of migration cannot be determined at this time, the predicted size of migration is sufficiently large to have prompted Paleoindian hunters to plan in advance the interception of these herds.

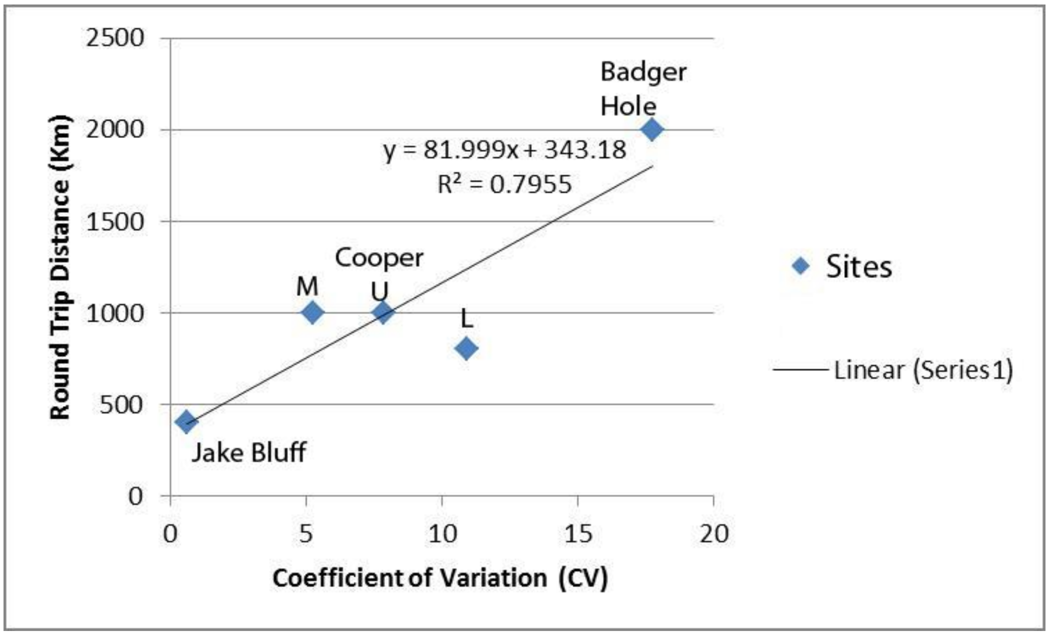


Figure 7.10. Plot of CV of southern Plains sites to the round-trip migration distance estimate of those herds based on geo-mapping from trace elements (Graves 2010), creating a linear regression equation to estimate northern Plains migration round trip distances.

Future Research

Future research needs to include further development of the methods concerning trace elements. This method has proven difficult to develop from the Paleoindian period where samples are scarce and quality often questionable.

Samples from modern and Late Prehistoric period sites need to be analyzed to better develop trace element methods. Trace element analysis has a great deal of potential in the study of migratory and prey animals and their interactions with people, but a great deal more research needs to be conducted to further hone our understanding of trace elements in bovid teeth and more recent samples would be a better place to start.

Redefining the chronology of Paleoindian Plains' sites is a crucial next step in understanding the development of bison hunting through time. The chronology we have used for decades to understand hunting needs to be reassessed. When the temporal context of sites can be clarified only then can we look to understanding the development of early bison hunting by analyzing the earliest sites to determine what factors trigger changes in the hunting system. Additional studies necessary in the Paleoindian period to help increase out understanding of bison hunting development include further analysis of sites that overlap transitional environmental periods such as the Younger Dryas, the Bolling/Allerod and the later Anathermal. A study of sites, which overlap these time periods would enable an even clearer understanding of environmental changes linked to hunting adaptation.

Studies similar to the study laid out here would also be useful in more recent sites to compare changes through time and reactions to changes in environment. Additionally a complete analysis of all kill levels on the northern Plains would provide ample information on the changes seen to occur on the northern Plains through time with the same resolution as the southern Plains results provided here. Agate Basin and Carter/Kerr-McGee have multiple kill levels from different time periods that should be further analyzed to demonstrate the extent to which people were exploiting migratory resources and how those migrations played into the development of the large scale kill system. This study set out to understand the development of these hunting techniques and therefor focused on the earliest kill deposits at the sites. Unfortunately the earliest deposits are often the most incomplete and subject to diagenetic alterations. Later kill deposits though still Paleoindian, are more complete with more samples suitable for both trace element and stable isotopic analysis.

Summary and Conclusions

On the southern Plains in a kill complex used for over 500 radiocarbon years (300-600 cal years) we see a communal kill system develop from resident herds of bison to migratory herds. This kill technique developed out of a period of environmental stress and continued into a more stable time period. Hunters adapted hunting strategies around the changing herd sizes and migratory behavior as well as the rapidly changing environment. The butchering program on the later southern Plains sites are focused on choice cuts of meat during the Folsom period and would have resulted in other elements being left behind. This indicates that the hunters were not necessarily pressed for resources.

On the northern Plains the clear picture of development is absent and the later seasonality (late fall/ winter kills) indicate that the same system developed but perhaps for different reasons. The need to prepare for near glacial winters on the northern Plains may have been more of a driving force in the development of this large-scale kill technique. This is also evident in the complete disarticulation of animals seen in all cases on the northern Plains. More of the animal resources were being exploited at these kills. The kill itself still contains all necessary elements to bring people together to reach a common, though perhaps more dire, goal. Obtain resources for the winter, while meeting the social needs of group aggregation.

Animal migration routes can only be estimated through model application on the northern Plains. However, the isotopic results indicate animals were migrating similar distances to those at Cooper, though not to the extent of the animals at Badger Hole on the southern Plains.

In conclusion suitable topographic settings with arroyos in grasslands in which bison migrate through yearly provide all of the necessary factors to enable communal hunting of bison. Aggregations must have occurred in the Paleoindian period to meet the multiple social needs of the group. A bison kill provides all necessary qualification to meet the needs of a large group of people. Under the theoretical framework of behavioral ecology environment plays a crucial role in the development and change of hunting techniques through the early Paleoindian period. Drastic environmental changes lead to new adaptations to increase herds of bison on the landscape. Bison hunters shifting from Clovis to Folsom on the southern Plains indicate a decrease in point size as they adapt their hunting toolkit to shifting prey from mammoth to bison. Folsom and Goshen point styles are ideal for the hunting of bison on the Plains. The Folsom period marks the beginning of this adaptation, which develops and continues until the near extinction of the bison with the encroachment of European settlers during the early historic periods. The communal kill adaptation, which begins in the Folsom period marks one of the most successful hunting techniques ever to be employed by human hunters and it revolves around bison herd behavior and landscape adaptation.

BIBLIOGRAPHY

Agogino, George A.
1972 Excavations at a Paleo-Indan site (Brewster) in Moss Agate Arroyo, eastern Wyoming. *National Geographic Research Reports 1955-1960*:1-6.

Ahler, Stanely A.
2000 Why Flute? Folsom Point Design and Adaptation. *Journal of Archaeological Science* 27:799-820.

Alley, Richard B.
2000 Ice-core evidence of abrupt climate changes. *Proceedings of the National Academy of Sciences* 97(4):1331-1334.

Alley, Richard B., Peter U Clark, Philippe Huybrechts and Ian Joughin
2005 Ice-Sheet and Sea-Level Changes. *Science* 310(5747):456-460.

Ambrose, Stanely H.
1990 Preparation and Characterization of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science* 17:431-451.

Amick, Daniel S.
1995 Patterns of technological variation among Folsom and Midland projectile points in the American Southwest. *Plains Anthropologist*:23-38.

Anderson, David G., and Michael K. Faught
2000 Palaeoindian artefact distributions: Evidence and implications. *Antiquity* 74(285):507-513.

Anderson, David G, Ashley M. Smallwood and Shane D. Miller
2015 Pleistocene Human Settlement in the Southeastern United States: Current Evidence and Future Directions. *PaleoAmerica* 1(1):7-51.

Anderson, David G. and J. Christopher Gillam
2000 Paleoindian Colonization of the Americas: Implications from an Examination of Physiology, Demography, and Artifact Distribution. *American Antiquity* 65(1):43-66.

Anderson, David G., Shane D. Miller, Stephen J. Yerka, J. Christopher Gillam, Erik N. Johanson, Derek T. Anderson, Albert C. Goodyear and Ashley M. Smallwood
2010 PIDBA (Paleoindian Database of the Americas) 2010: Current Status and Findings. *Archaeology of Eastern North America* 38:63-89.

Arthun, Dave and Jerry Holechek
1982 The Norther American Bison. *Rangelands* 4(3):123-125.

Arthur, George W
1975 An Introduction to the Ecology of Early Historic Communal Bison Hunting: Among the Northern Plains Indians. Archaeological Survey of Canadian Paper (No. 37) National Museums of Canada.

1978 A Re-Analysis of the Early Historic Plains Indian Bison Drives. *Plains Anthropologist* 14(23):236-242.

Audubon, John James, John Bachman and John Woodhouse Audubon
1846 *The Viviparous Quadrupeds of North America* 1. JJ Audubon.

Balasse, Marie
2002 Reconstructing dietary and environmental history from enamel isotopic analysis: time resolution of intra-tooth sequential sampling. *International Journal of Osteoarchaeology* 12(3):155-165.

Ballenger, Jesse A.M., Vance T. Holliday, Andrew L. Kowler, William T. Reitze, Mary M. Prasciunas, Shane D. Miller and Jason D. Windingstad
2011 Evidence for Younger Dryas Global Climate Oscillation and Human Response in the American Southwest. *Quaternary International* 242(2):502-519.

Bamforth, Douglas
1988 *Ecology and Human Organization on the Great Plains*. Plenum Press, New York.

1991 Flintknapping skill, Communal Hunting, and Paleoindian Projectile Point Typology. *Plains Anthropologist*:309-322.

2011 Origin Stories, Archaeological Evidence, and Post-Clovis Paleoindian Bison Hunting on the Great Plains. *American Antiquity* 76(1):24-40.

2014 Clovis Caches and Clovis Knowledge of the North American Landscape: The Mahaffy Cache, Colorado. In *Covis Caches Recent Discoveries and New Research*, edited by B. B. Huckell and J. D. Kilby. University of New Mexico Press, Albuquerque.

Beard, Brian L. and Clark M. Johnson
2000 Strontium Isotope Composition of Skeletal Material Can Determine the Birth Place and Geographic Mobility of Humans and Animals. *Journal of Forensic Sciences* 45(5):1049-1061.

Beiswenger, Jane M.
1987 *Late Quaternary Vegetational History of Grays Lake, Idaho and the Ice Slough, Wyoming*. University of Wyoming, Laramie.

1991 Late Quaternary Vegetational History of Grays Lake, Idaho. *Ecological Monographs*:165-182.

Bement, Leland C.
1986 Excavation of the Late Pleistocene Deposits of Bonfire Shelter Val Verde County, Texas. Texas Archeological Survey *Archeology Series* 1. University of Texas, Austin.

1999 *Bison Hunting at Cooper Site: Where Lightning Bolts Drew Thundering Herds*. University of Oklahoma Press, Norman.

2003 Constructing the Cooper Model of Folsom Bison Kills on the Southern Plains. *Great Plains Research: A Journal of Natural and Social Sciences* 13(645):27-41.

2014 The JS Cache: Clovis Provisioning the Southern Plains Late Pleistocene Landscape. . In *Clovis Cache Recent Discoveries and New Research*, edited by B. B. Huckell and J. D. Kilby. The University of New Mexico Press, Albuquerque.

Bement, Leland C. and Scott Browsowske
1999 *Paleoindian Bison Hunting Along the Beaver River Harper County, Oklahoma*. Archaeological Resource Survey Report No. 40. University of Oklahoma.

Bement, Leland C. and Brian J. Carter
2010 Jake Bluff: Clovis Bison Hunting on the Southern Plains of North America. *American Antiquity* 75(4):907-933.

Bement, Leland C., Brian J. Carter, PollyAnna Jelley, Kristen Carlson and Soctt Fine
2012 Badger Hole: Towards Defining a Folsom Bison Hunting Complex along the Beaver River Oklahoma. *Plains Anthropologist* 57(221):53-62.

Bement, Leland C., Brian J. Carter, RA Varney, Linda S. Cummings and J. Byron Sudbury
2007 Paleo-environmental reconstruction and bio-stratigraphy, Oklahoma Panhandle, USA. *Quaternary International* 169:39-50.

Berger, Joel and Carol Cunningham
1994 *Bison Mating and Conservation in Small Populations*. Columbia University, New York.

Binford, Lewis R.
1968 Post-Pliestocene Adaptation. In *New Perspectives in Archaeology*, edited by S. R. Binford and L. R. Binford, pp. 313-341. Aldine, Chicago.

2001 *Constructing frames of reference: an analytical method for archaeological theory building using hunter-gatherer and environmental data sets*. University of California Press.

Binford, Sally R. and Lewis R. Binford (editors)
1968 *New Perspectives in Archeology* Aldine, Chicago.

Bird, Douglas W. and James F. O'Connell
2006 Behavioral Ecology and Archaeology. *Journal of Archaeological Research* 14(2):143-188.

Birdsell, Joseph
1953 Some Enviornmental and Cultural Factors Influencing the Structuring of Australian Aboriginal Populations. *American Naturalist* 87:171-207.

Blinnikov, Mikhail, Alan Busacca and Cathy Whitlock
2002 Reconstruction of the late Pleistocene grassland of the Columbia basin, Washington, USA, based on phytolith records in loess. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177(1):77-101.

Blurton Jones, Nicholas G., Lars C Smith, James F O'Connell, Kristen Hawkes and Chrysanth L Kamuzora
1992 Demography of the Hadza, an increasing and high density population of savanna foragers. *American Journal of Physical Anthropology* 89(2):159-181.

Bradley, Bruce
2009 Bifacial Technology and Paleoindian projectile points. In *Hell Gap: A Stratefied Paleoindian Compsite at the Edge of the Rockies*, edited by M. L. Larson, M. Kornfeld and G. C. Frison. University of Utah Press, Salt Lake City.

Bradley, B. A., M.B. Collins and A. Hemmings
2010 Clovis Technology In *International Monographs in Prehistory*. Archaeological Series 17 vols.

Braidwood, Robert J.
1975 *Prehistoric Men*. Scott Foresman, Glenview Il.

Breitburg, E. and J B. Broster
1995 A hunt for big game: does Coats-Hines site confirm human/mastodon contact? *Tennesee Conservationist* 61(4):18-26.

Brink, Jack
2008 *Imagining Head-Smashed-In: Aboriginal buffalo hunting on the northern plains*. Athabasca University Press.

Brink, Jack and Maureen Rollans
1990 Thoughts on the Structure and Function of Drive Lane Systems at Communal Buffalo Jumps. In *Hunters of the Recent Past*, edited by L. B. Davis and B. O. K. Reeves, pp. 152-167. Unwin Hyman, London.

Broughton, Jack M.
2012 Prey spatial structure and behavior affect archaeological tests of optimal foraging models: Examples from the Emeryville Shellmound vertebrate fauna. *World Archaeology* 34(1):60-83.

Brunswig, R.H. and D. C. Fisher
1993 Research on the Dent Mammoth Site. *Current Research in the Pleistocene* 10:63-65.

Brunswig, R.H. Jr.
2007 New interpretations of the Dent Mammoth Site: a synthesis of recent multidisciplinary evidence. . In *Frontiers in Colorado Paleoindian Archaeology*, edited by R. H. Brunswig and B. L. Pitblado, pp. 87-121. University Press of Colorado, Boulder.

Budd, P., J. Montgomery, A. Cox, P. Krause, B. Barreiro and R.G. Thomas
1998 The distribution of lead within ancient and modern human teeth: implications for long-term and historical exposure monitoring. *The Science of the Total Environment* 220:121-136.

Burns, Richard C. and Ralph W.F. Hardy
1975 *Nitrogen fixation in bacteria and higher plants* 21. Springer Verlag.

Burton, J.H., T.D. Price and W.D. Middleton
1999 Correlation of bone Ba/Ca and Sr/Ca due to biological purification of calcium. *Journal of Archaeological Science* 26:609-616.

Butzer, Karl W
1982 *Archaeology as human ecology: method and theory for a contextual approach*. Cambridge University Press.

Byerly, Ryan M, Judith R Cooper, David J Meltzer, Matthew E Hill and Jason M LaBelle
2005 On Bonfire Shelter (Texas) as a Paleoindian bison jump: an assessment using GIS and zooarchaeology. *American Antiquity*:595-629.

Byers, David A. and Andrew Ugan
2005 Should we expect large game specialization in the late Pleistocene? An optimal foraging perspective on early Paleoindian prey choice. *Journal of Archaeological Science* 32(11):1624-1640.

Carlson, Krisen A.
2011 Prehistoric bison procurement: human agency and drive lane topography on the northwestern Plains. MA Thesis Northern Arizona University, Flagstaff.

Carlson, Kristen and Leland Bement
2013 Organization of Bison Hunting at the Pleistocene/Holocene Transition on the Plains of North America. *Quaternary International* 297:93-99.

Childe, V. Gordon
1950 The Urban Revolution. *Town Planning Review* 21(1):3.

Chisholm, Brian, Jonathan Driver, Sylvain Dube and Henry P. Schwarcz
1986 Assessment of Prehistoric Bison Foraging and Movment Patterns Via Stable- Carbon Isotopic Analysis. *Plains Anthropologist* 31(113):193-205.

Cocking, Mathew
1908 An Adventurer from Hudson Bay. *Proceedings and Transactions of the Royal Society of Canada* 2(2):89-121.

Collins, MB and BB Bradley
2008 Evidence for pre-Clovis occupation at the Gault site (41BL323), central Texas. *Current Research in the Pleistocene* 25:70-72.

Collins, Michael B.
1999 *Clovis Blade Technology: A comparison Study of the Keven Davis Cache, Texas*. University of Texas Press Austin.

Condon, Peter C., George Crawford, Vance T. Holliday, C. Vance Haynes Jr. and Jill Onken

2014 A Contextual and Technological Reevaluation of the Dickenson Blade Cache, Blackwater Locality No. 1, Roosevelt County, New Mexico. In *Clovis Cache Recent Discoveries and New Research*, edited by B. B. Huckell and J. D. Kilby. University of New Mexico Press, Albuquerque.

Conkey, Margaret, Antonio Beltran, G.A. Clark, J. Gonzalez Echegaray, M.G. Guenther, Joachim Hahn, Brian Hayden, K. Paddayya, Lawrence G. Straus and Karel Valoch

1980 The Indentification of Prehistoric Hunter-Gatherer Aggregation Sites: The Case of Altamira. *Current Anthropology* 21(5):609-630.

Connin, Sean L., Julio Betancourt and Jay Quade

1998 Late Pleistocene C4 Plant Dominance and Summer Rainfall in the Southwestern United States from Isotopic Study of Herbivore Teeth. *Quaternary Research* 50:179-193.

Cooper, Judith

2008 *Bison Hunting and Late Prehistoric Human Subsistence Economies in the Great Plains*. Unpublished Dissertation. Southern Methodist University, Dallas Texas.

Coppedge, Bryan R., David M. Leslie Jr. and James H. Shaw

1998 Botanical composition of bison diets on tallgrass prairie in Oklahoma. *Journal of Range Management*:379-382.

Coues, Elliot

1897 *New Light on the Early History of the Greater Northwest. The manuscript Journals of Alexander Henry, Fur Trader, and David Thompson, Official Geographer and Explorer of the North West Company* 3. Francis P. Harper, New York.

Cox, A., F. Kennan, M. Cooke and J. Appleton

1996 Trace element profiling of dental tissues using laser ablation-inductively coupled plasma-mass spectrometry. *Fresenius J. Anal. Chem* 354:254-258.

Cucina, Andrea, John Dudgeon and Hector Neff

2007 Methodological strategy for the analysis of human dental enamel by LA-ICP-MS. *Journal of Archaeological Science* 34(11):1884-1888.

Cummings, Linda S.

1996 Paleoenvironmental Interpretations for the Mill Iron site: Stratigraphic pollen and phytolith analysis. In *The Mill Iron Site*, edited by G. C. Frison, pp. 177-193. University of New Mexico Press, Albuquerque.

Cummings, Linda Scott and Chad Yost

2012a *Pollen and Phytolith Analyses and AMS Radiocarbon Dating of Stratigraphic Sediment Samples from the Badger Hole Site, 34HP194, Harper County, Oklahoma*. PaleoResearch.

Curzon, M.E.J. and T.W. Cutress

1983 *Trace Elements and Dental Disease*. John Wright PSG Inc, London.

Davis, Leslie B and Sally T Greiser

1992 Indian Creek paleoindians: early occupation of the Elkhorn Mountains' southeast flank, west-central Montana. *Ice Age hunters of the Rockies*:225-283.

Davis, Leslie B.

1984 Late Plistocene to Mid-Holocene adaptations at Indian Creek, west central Montana. *Current Research in the Pleistocene* 1:9-10.

De Smet, Pierre-Jean

1906 *Letters and Sketches: With a narrative of a Year's Residence Among the Indian Tribes of the Rocky Mountains*. Early Western Travels: 1748-1846 27. Arthur H. Clark, Cleveland.

1972 *Western Missions & Missionaries: A Series of Letters*. University Press, Shannon, Ireland.

Delwiche, CC, PJ Zinke, CM Johnson and RA Virginia

1979 Nitrogen Isotope Distribution as a Presumptive Indicator of Nitrogen Fixation. *Botanical Gazette*:S65-S69.

Delwiche, Constant C. and Pieter L. Steyn

1970 Nitrogen Isotope Fractionation in Soils and Microbial Reactions. *Environmental Science & Technology* 4(11):929-935.

DeNiro, Michael J.

1985 Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* (317) 806-809

DeNiro, Michael J. and Samuel Epstein
1978 Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42:495-506.

1981 Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* 45(3):341-351.

Deter-Wolf, Aaron, Jesse W Tune and John B Broster
2011 Excavations and dating of late Pleistocene and Paleoindian deposits at the Coats-Hines site, Williamson County, Tennessee. *Tennessee Archaeology* 5(2):142-156.

Dibble, David and Dessamae Lorrain
1968 Bonfire Shelter: A Stratified Bison Kill Site, Val Verde County, Texas. *Miscellaneous Papers No.* 1. Texas Memorial Museum, Austin.

Dolphin, A.E., A.H. Goodman and D.D. Amarasiriwardena
2005 Variation in enamel intensities among teeth and between pre- and postnatal regions of enamel. *American Jounral of Physical Anthropology* 128:878-888.

Douglas H. MacDonald and Barry S. Hewlett
1999 Reproductive Interests and Forager Mobility. *Current Anthropology* 40(4):501-524.

Driessens, F.C.M. and R.M.H. Verbeeck
1990 *Biominerals*. CRC Press, Boston.

Drummond, Alexei J, Andrew Rambaut, Beth Shapiro and Oliver G Pybus
2005 Bayesian coalescent inference of past population dynamics from molecular sequences. *Molecular Biology and Evolution* 22(5):1185-1192.

Epp, Henry and Ian Dyck
2002 Early Human-Bison Population Interdependence in the Plains Ecosystem *Great Plains Research* 12(Fall 2002):232-237.

Evanoff, Emmett
1982 Fossil Nonmarine Gastropods. In *The Agate Basin Site: A Record of the Paleoindian Occupation of the Northwestern High Plains*, edited by G. C. Frison and D. J. Stanford. Academic Press, New York.

Ewers, John C.
1955 The Horse and the Blackfeet. *Smithsonian Institution Bureau of Ethnology* 159.

1958 *The Blackfeet: Raiders of the Northwestern Plains*. University of Oklahoma Press, Norman.

Fall, Patricia L, Thompson Davis and Gregory Zielinski
1995 Late quaternary vegetation and climate of the Wind River Range, Wyoming. *Quaternary Research* 43(3):393-404.

Fawcett, William B.
1987 *Communal Hunts, Human Aggregations, Social Variation, and Climactic Change: Bison Utilization by Prehistoric Inhabitants of the Great Plains (Paleoecology)* University of Massachusetts, Amherst.

Feranec, R.S.
2004 Ecological consequences of the evolution of key adaptations, and niche partitioning in C3-dominated environments [Ph. D thesis]: Berkeley. California, University of California.

Finley, Judson B., Marcel Kornfeld, Brian N. Andrews, George C. Frison, Chris C. Finley and Michael T. Bies
2005 Rockshelter Archaeology and Geoarchaeology in the Bighorn Mountains, Wyoming. *Plains Anthropologist* 50(195):227-248.

Fisher, D.C. and D.L. Fox
2007 Season of death of the Dent mammoths: distinguishing single from multiple mortality events. *Frontiers in Colorado Paleoindian archaeology: From the Dent site to the Rocky Mountains. University Press of Colorado, Boulder, CO*:123-153.

Flannery, Kent V.
1969 Origins and Ecological Effects of Early Domestication in Iran and the Near East. In *The Domestication and Exploitation of Plants and Animals* edited by P. J. Ucko and G. W. Dimbleby, pp. 73-100. Chicago, Aldine.

1973 The Origins of Agriculture. *Annual Review of Anthropology* 2:271-310.

Forbis, Richard and J. D. Sperry
1952 An Early Man Site in Montana. *American Antiquity* 18(2):127-133.

Francis, Julie E. and Yvette Widman
1999 Variability in the Archaic: Projectile Points from Trappers Point. In *The Trappers Point Site (48SU1006): Early Archaic Adaptations and Pronghorn Procurement in the Upper Green River Basin, Wyoming*, edited by M. E. Miller, P. H. Sanders and J. E. Francis, pp. 139-170. Office of the Wyoming State Archaeologist, Laramie.

Fredlund, Glen G. and Larry T. Tieszen
1994 Modern Phytolith Assemblages from the North American Great Plains. *Journal of Biogeography* 21(3):321-335.

Fricke, Henry C. and James R O'Neil
1996 Inter-and intra-tooth variation in the oxygen isotope composition of mammalian tooth enamel phosphate: implications for palaeoclimatological and palaeobiological research. *Palaeogeography, Palaeoclimatology, Palaeoecology* 126(1):91-99.

Friedli, H, H Lötscher, Hj Oeschger, U Siegenthaler and B Stauffer
1986 Ice core record of the 13C/12C ratio of atmospheric CO2 in the past two centuries. *Nature* 324(6094):237-238.

Frison, George C.
1970 The Kobald Site, 24BH406: A Post-Altithermal record of buffalo-jumping for the Northwestern Plains. *Plains Anthropologist* 15(47):1-35.

1971 The Buffalo Pound in North-Western Plains Prehistory: Site 48 CA 302, Wyoming. *American Antiquity*:77-91.
1973 The Wardell Buffalo Trap 48SU301: Communal Procurement in the Upper Green River Basin, Wyoming. In *Anthropological Papers of the Museum of Anthropology*, edited by U. o. Michigan. vol. 48, Ann Arbor.

1976 The chronology of Paleo-Indian and Altithermal Period groups in the Bighorn Basin, Wyoming. In *Cultural Change and Continnuity: Essays in Honor of James Bennett Griffin*, edited by C. E. Cleland, pp. 147-173. Academic Press, New York.

1978 *Prehistoric Hunters of the High Plains*. Academic Press, New York.

1984 The Carter/ Kerr-McGee Paleoindian site: Cultural resource management and archaeological research. *American Antiquity* 49(2):288-314.

1987 Prehistoric, Plains-Mountain, large-mammal, communal hunting strategies. In *The Evolution of Human Hunting*, edited by M. H. Nitecki and D. V. Nitecki, pp. 177-211. Plenum Press, New York.

1988 Paleoindian subsistence and settlement during post-Clovis times on the Northwestern Plains, the adjacent mountain ranges, and intermontane basins. . In *Indians Before Columbus: Ice-Age Origins*, edited by R. C. Carlisle, pp. 83-106. University of Pittsburgh, Pittsburgh.

1991a The Goshen Paleoindian complex: new data for Paleoindian research. *Clovis: Origins and adaptations.* Corvallis, Oregon: Center for the Study of the First Americans:133-151.

1991b *Prehistoric Hunters of the High Plains*. Academic Press, San Diego.

1996 *The Mill Iron Site*. The University of New Mexico Press, Albuquerque.

1998 Paleoindian large mammal hunters on the plains of North America. *The National Academy of Sciences* 95:14576–14583.

2004 *Survivial by Hunting*. University of of California Press, Berkeley.

Frison, George and Bruce Bradley
1980 *Folsom tools and Technology at the Hanson site, Wyoming*. University of New Mexico Press

Frison, George C. and Carolyn Craig
1982 Bone, antler, and ivory artifacts and manufacture technology. *The Agate Basin Site: A Record of the Paleoindian Occupation of the Northwestern High Plains, Academic Press, New York*:157-173.

Frison, George C, Michael Wilson and Diane J Wilson
1976 Fossil bison and artifacts from an early Altithermal period arroyo trap in Wyoming. *American Antiquity*:28-57.

Frison, George C. and George M Zeimens
1980 Bone projectile points: an addition to the Folsom cultural complex. *American Antiquity*:231-237.

Frison, George C. and Dennis J. Stanford
1982 *The Agate Basin Site: A Record of the Paleoindian Occupation of the Northwestern High Plains*. Academic Press, New York, London.

Frison, George C. and Lawrence C. Todd
1987 *The Horner Site: The Type Site of the Cody Complex*. Academic Press, Orlando.

Gadbury, Carol, Lawrence Todd, A Hope Jahren and Ronald Amundson
2000 Spatial and temporal variations in the isotopic composition of bison tooth enamel from the Early Holocene Hudson–Meng Bone Bed, Nebraska. *Palaeogeography, Palaeoclimatology, Palaeoecology* 157(1):79-93.

Gilbert, M Thomas P, Dennis L Jenkins, Anders Götherstrom, Nuria Naveran, Juan J Sanchez, Michael Hofreiter, Philip Francis Thomsen, Jonas Binladen, Thomas FG Higham and Robert M Yohe
2008 DNA from pre-Clovis human coprolites in Oregon, North America. *Science* 320(5877):786-789.

Graham, Russell W, Ernest L Lundelius and Erich Schroeder
1994 *Faunmap: A Database for the Late Quaternary Distribution of Mammal Species in the United States*. Illinois State Museum.

Graves, Adam
2010 *Investigation Resource Structure and Human Mobility: an Example from Folsom-aged Bison Kill Sites on the U.S. Southern Great Plains*. Unpublished Dissertation. Department of Anthropology, University of Oklahoma.

Grayson, D.K
2007 Deciphering North America Pleistocene Extinctions. *Journal of Anthropological Research* 63:185-213.

Grayson, Donald K. and David J. Meltzer
2002 Clovis Hunting and Large Mammal Extinction: A Critical Review of the Evidence. *Journal of World Prehistory* 16(4):313-359.

2003 North American overkill continued? *Journal of Archaeological Science* 31:133-136.

2015 Revisiting Paleoindian Exploitation of Extinct North American Mammals. *Journal of Archaeological Science*.

Grimstead, Deanna N.
2010 Ethnographic and Modeled Costs of Long-Distance, Big-Game Hunting. *American Antiquity* 75(1):61-80.

Gurven, Michael and Kim Hill
2009 Why do men hunt? *Current Anthropology* 50(1):51-74.

Gustafson, C.E.
1984 *The Manis Mastodon Site: An Adventure in Prehistory*. Manis Enterprises, Sequim, WA.

1985 The Manis Mastodon site. *National Geographic Society Res. Rept.* :283-295.

Gustafson, C.E., D. Gilbow and R.D. Daugherty
1979 The Manis Mastodon Site: early man on the Olympic Peninsula. *Canadian Journal of Archaeology* 3:157-164.

Guthrie, Dale R.
1970 Bison Evolution and Zoogeography in North America during the Pleistocene. *The Quarterly Review of Biology* 45(1):1-15.

Hall, Stephen A
1981 Deteriorated pollen grains and the interpretation of Quaternary pollen diagrams. *Review of Palaeobotany and Palynology* 32(2):193-206.

Hamilton, Marcus J, Bruce T Milne, Robert S Walker, Oskar Burger and James H Brown
2007 The complex structure of hunter–gatherer social networks. *Proceedings of the Royal Society B: Biological Sciences* 274(1622):2195-2203.

Harmon, Daniel W.
1911 *A Journal of Woyages and Travels in the Interior of North America*. Courier Press, Toronto.

Harper, H. J. and L. W. Reed
1964 *Effect of Chemical Composition of Soil on Micronutrients and Other Elements in Oklahoma Forage Plants*. Processed Series P-486. Agric. Expt. Sta. Oklahoma State University, Stillwater.

Harris, Marvin
1979 *Cultural Materialism: The Struggle for a science of culture*. Random House, New York.

1985 *Good to Eat: Riddles of Food and Culture*. Simon and Schuster, New York.

Hart, E Andrew and James R Lovvorn
2002 Interpreting stable isotopes from macroinvertebrate foodwebs in saline wetlands. *Limnology and Oceanography* 47(2):580-584.

Haynes, C Vance, Michael McFaul, Robert H Brunswig and Kenneth D Hopkins
1998 Kersey–Kuner terrace investigations at the Dent and Bernhardt sites, Colorado. *Geoarchaeology* 13(2):201-218.

Haynes, Gary
2002 *The early settlement of North America: the Clovis era*. Cambridge University Press.

Haynes Jr, C. Vance
1964 Fluted Projectile Points: their age and distribution. *Science* 145:1408-1413.

1992 Contributions of radiocarbon dating to the geochronology of the peopling of the New World. In *Radiocarbon after four decades*, pp. 355-374. Springer.

Haynes, Vance C. and Bruce B. Huckell
2007 *Murray Springs: A Clovis site with multiple activity areas in the San Pedro Valley, Arizona*. University of Arizona Press.

Heisler-White, Jana L, Alan K Knapp and Eugene F Kelly
2008 Increasing precipitation event size increases aboveground net primary productivity in a semi-arid grassland. *Oecologia* 158(1):129-140.

Hendry, Anthony
1907 York Factory to the Blackfeet Country The Journals of Anthony Hendry 1754-1755. *Transactions of the Royal Society of Canada* 3(1).

Henry, Alexander
1901 (1776) *Travels and Adventures In Canada and the Indian Territories Between the Years 1760 and 1776*. George N. Morang, Toronto.

Henry, Alexander and David Thompson
1897 *New Light on the Early History of the Greater Northwest: The Manuscript Journals of Alexander Henry and David Thompson 1799-*1814, edited by E. Cues. 2 vols. Reprinted by Ross and Haines, Minneapolis, Minnesota.

Henry, D.O.
1989 *From Foraging to Agriculture: the Levant at the End of the Ice Age*. University of Pennsylvania Press, Philaelphia.

1995 *Prehistoric Cultural Ecology and Evolution: Insights from Southern Jordan*. Plenum Press, New York.

Hester, James J., Ernest L. Lundelius and Roals Fryxell
1972 *Blackwater locality no. 1: a stratified early man site in eastern New Mexico* 8. Southern Methodist University, Fort Burgwin Research Center.

Hill, Kim Ronald and A Magdalena Hurtado
1996 *Ache life history: The ecology and demography of a foraging people*. Transaction Publishers.

Hill, Mathew E.
2007 A Moveable Feast: Variation in Faunal Resource Use Among Central and Western North American Paleoindian Sites. *American Antiquity* 72(3):417-438.

Hill, Matthew Glenn
2008 *Paleoindian subsistence dynamics on the Northwestern Great Plains: zooarchaeology of the Agate Basin and Clary Ranch sites* 1756. British Archaeological Reports Ltd.

Hillson, Simon
1986 *Teeth*. Cambridge University Press, Cambridge.

Hind, Henry Youle
1971 *Narrative of the Canadian Red River exploring expedition of 1857 and of the Assinioine and Saskatchewan exploring expedition of 1858,* Hurtig, Edmonton.

Hinz, Emily A. and Matthew J. Kohn
2010 The effect of tissue structure and soil chemistry on trace element uptake in fossils. *Geochimica et Cosmochimica Acta* 74:3213-3231.

Hofman, Jack
1994 Paleoindian Aggregations on the Great Plains. *Journal of Anthropological Archaeology* 13:341-370.

Hofman, Jack, Brian Carter and Matt hill
1992 Folsom Occupation at the Waugh Site in Northwestern Oklahoma. *Current Research in the Pleistocene* 9:22-25.

Hofman, Jack L, Lawrence C Todd and Michael B Collins
1991 Identification of central Texas Edwards chert at the Folsom and Lindenmeier sites. *Plains Anthropologist*:297-308.

Holen, Steven
2014 Clovis Lithic Procurement, Caching, and Mobility in the Central Great Plains of North America. In *Clovis Caches Recent Discoveries and New Research*, edited by B. B. Huckell and J. D. Kilby. University of New Mexico, Albuquerque.

Hollenbach, Kandace D.
2009 *Foraging the Tennessee River Valley: 12,500 to 8,000 Years Ago*. University of Alabama Press.

Holliday, Vance T. and David J. Meltzer
1996 Geoarchaeology of the Midland (Paleoindian) site, Texas. *American Antiquity*:755-771.

Holliday, Vance T.
1995 Stratigraphy and Paleoenvironments of Late Quaternary Valley Fills on the Souhtern High Plains. *Geological Society of America Memoir* 186.

Holloway, Richard
1993 Pollen Analysis of Ferndale Bog, Oklahoma. In *Report to the Institute of Applied Sciences (49)*. University of North Texas, Denton, Texas.

Hoppe, Kathryn A.
2004 Late Pleistocene mammoth herd structure, migration patterns, and Clovis hunting strategies inferred from isotopic analyses of multiple death assemblages. *Paleobiology* 30(1).

Hoppe, Kathryn A., Adina Paytan and Page Chamberlain
2006 Reconstructing grassland vegetation and paleotemperatures using carbon isotope ratios of bison tooth enamel. *Geology* 34(8):649.

Howell, Nancy
1979 *Demography of the Dobe! kung*. University of California Press Berkeley, CA and Los Angeles, CA.

2010 *Life histories of the Dobe! Kung*. University of California Press Berkeley, CA and Los Angeles, CA.

Huckell, Bruce B. and J. David Kilby
2014 Clovis Caches: Discoveries, Identification, Lithic Technology, and Land Use. In *Clovis Cache: Recent Discoveries and New Research*, edited by B. B. Huckell and J. D. Kilby. University of New Mexico Press, Albuquerque

Ingbar, Eric E. and Jack L. Hofman
1999 Folsom Fluting Fallacies. In *Folsom and Lithic Technology: Explorations In Structure and Variation*, edited by D. Amick. International Monographs in Prehistory.

Ingold, Tim, David Riches and James Woodburn
1988 *Hunters and Gatherers.* 2, Berg, New York.

Irwin-Williams, Cynthia, Henry Irwin, George Agogino and C Vance Haynes
1973 Hell gap: Paleo-Indian occupation on the high plains. *Plains Anthropologist*:40-53.

Jackson, Lawrence J and Paul T Thacker
1997 *Caribou and Reindeer Hunters of the Northern Hemisphere* 6. Aldershot, Hampshire, Great Britain: Avebury.

Jodry, Margaret Ann Brierty
1999 *Folsom Technological and Socioeconomic Strategies: views from Stewart's Cattle Gaurd and the Upper Rio Grande Basin, Colorado*. American University, Washington D.C. .

Johnson, Eileen and Leland C Bement
2009 Bison butchery at Cooper, a Folsom site on the Southern Plains. *Journal of Archaeological Science* 36(7):1430-1446.

Johnson, Eileen and Curtis Tunnell
1977 Fluted projectile point production as revealed by lithic specimens from the Adair-Steadman site in northwest Texas.

Johnson, Gregory A
1982 Organizational structure and scalar stress. *Theory and Explanation in Archaeology*:389-421.

Julien, Marie-Anne, Hervé Bocherens, Ariane Burke, Dorothée G. Drucker, Marylène Patou-Mathis, Oleksandra Krotova and Stéphane Péan
2012 Were European steppe bison migratory? 18O, 13C and Sr intra-tooth isotopic variations applied to a palaeoethological reconstruction. *Quaternary International* 271:106-119.

Keene, Arthur
1983 Biology, behavior, and borrowing: a critical examination of optimal foraging theory in archaeology. *Archaeological hammers and theories*:137-155.

Kehoe, Thomas F and Frances Eyman
1973 *The Gull Lake site: a prehistoric bison drive site in southwestern Saskatchewan* 1. Milwaukee Public Museum.

Kelly, Robert L.
1995 *The foraging spectrum: Diversity in hunter-gatherer lifeways*. Smithsonian Institution Press Washington, DC.

2013 *The Lifeways of Hunter-Gatherers*. Cambridge University Press, Cambridge.

Kennett, Douglas J
2005 *The Island Chumash: Behavioral ecology of a maritime society*. Univ of California Press.

Kennett, Douglas J and Bruce Winterhalder
2006 *Behavioral ecology and the transition to agriculture* 1. Univ of California Press.

Kilby, J. David
2008 *An Investigation of Clovis Caches: Content, Function, and Technological Organization*. University of New Mexico, Albuquerque.

Knudson, Ruthann
1983 *Organizational variability in late Paleo-Indian assemblages*. Washington State University Laboratory of Anthropology.

Koch, Paul L., Katheryn A. Hoppe and S. David Webb
1998 The Isotopic Ecology of Late Pleistocene Mammals in North America: Part 1. Florida. *Chemical Geology* 152:119-138.

Kohn, Matthew J., Jennifer Morris and Paul Olin
2013 Trace element concentrations in teeth – a modern Idaho baseline with implications for archeometry, forensics, and palaeontology. *Journal of Archaeological Science* 40(4):1689-1699.

Kooyman, Brian, LV Hills, Paul McNeil and Shayne Tolman
2006 Late Pleistocene horse hunting at the Wally's Beach site (DhPg-8), Canada. *American Antiquity*:101-121.

Kornfeld, Marcel and George C. Frison
2000 Paleoindian occupation of the high country: the case of Middle Park, Colorado. *Plains Anthropologist*:129-153.

Kornfeld, Marcel, George C. Frison and Mary Lou Larson
2010 *Prehistoric Hunter-Gatherers of the High Plains and Rockies*. Left Coast Press, Walnut Creek, California.

Kornfeld, Marcel, George C. Frison, Mary Lou Larson, James C. Miller and Jan Saysette
1999 Paleoindian bison procurement and paleoenvironments in Middle Park of Colorado. *Geoarchaeology* 14(7):655-674.

Krajick, Kevin
2002 Melting glaciers release ancient relics. *Science* 296(5567):454-456.

Kuchler, A.W.
1975 Potential natural vegetation of the conterminous United States American Geographic Society, New York, NY.

Kurten, Bjorn and Elaine Anderson
1980 *Pleistocene Mammals of North America*. Columbia University Press, New York.

Kutzbach, John E
1987 Model simulations of the climatic patterns during the deglaciation of North America. *North America and adjacent oceans during the last deglaciation* 3:425-446.

L.Tieszen, Larry
1997 Stable Isotopic determination of seasonal dietary patterns in bison at four preserves across the Great Plains. *International Symposium on Bison Ecology and Management in North America*:130-140.

Lahren, L. and R. Bonnichsen
1974 R. Bone foreshafts from a Clovis burial in southwestern Montana. *Science* 186:147-150.

Larson, Mary Lou, Marcel Kornfeld and George C. Frison
2009 *Hell Gap: A Stratefied Paleoindian Campsite at the Edge of the Rockies*. University of Utah Press, Salt Lake City.

Larson, R. Mark, Lawrence C. Todd, Eugene F. Kelly and Jeffrey M. Welker
2001 Carbon Stable Isotope Analysis of Bison Dentition. *Great Plains Research: A Journal of Natural and Social Sciences* 545(11):25-64.

Lee, K.M., J. Appleton, M. Cooke, F. Kennan and K. Sawicka-Kapusta
1999 Use of laser ablation inductively coupled plasma mass spectrometry to pro- vide element versus time profiles in teeth. . *Anal. Chim. Acta* 395:179-185.

Lee, Richard B and Irven DeVore
1968 Problems in the study of hunters and gatherers. In *Man the Hunter,* ed. R.B. Lee and I. Devore, Chicago: Aldine.

Lee, Richard B.
1997 What Hunters Do for a Living, or, How to Make Out of Scarce Resources. In *Limited Wants, Unlimited Means: A Reader On Hunter-Gatherer Economics And The Environment*, edited by J. Gowdy. Island Press, Washington D.C. .

Lee, Richard Barry and Irven DeVore
1973 *Man the Hunter*. Transaction Publishers.

Lee-Thorp, J.A. and M. Sponheimer
1995 Contributions of biogeochemistry to understanding hominin dietary ecology. *Yearbook of Physical Anthropology* 49:131-148.

2006 Contributions of biogeochemistry to understanding hominin dietary ecology. *Yearbook of Physical Anthropology* 49:131-148.

Lehmer, Donald J.
1963 The Plains Bison Hunt- Prehistoric and Historic. *Plains Anthropologist* 8(22):211-217.

Leonhardy, Frank C
1966 *Domebo: A Paleo-Indian mammoth kill in the prairie-plains*. Great Plains Historical Association.

Lewis, Patrick J., Eileen Johnson, Briggs Buchanan and Steven E. Churchill
2010 The impact of changing grasslands on Late Quaternary bison of the Southern Plains. *Quaternary International* 217:117-130.

Lewis, Rhoda Owen
1979 *Use of Opal Phytoliths in Paleo-Environmental Reconstruction*. University of Wyoming, Laramie.

Leyden, Jeremy J and Gerald Oetelaar
2001 Carbon and nitrogen isotopes in archeological bison remains as indicators of paleoenvironmental change in southern Alberta. *Great Plains Research: A Journal of Natural and Social Sciences*. Paper 546.

Lipe, William D. and Bonnie L. Pitblado
1999 Paleoindian and Archaic Periods. In *Colorado Prehistory: A Context for the Southern Colorado River Basin*, edited by W. D. Lipe, M. Varien and R. H. Wilshusen. Colorado Council of Professional Archaeologists.

Lochner, F., J. Appleton, F. Keenan and M. Cooke
1999 Multi-element profiling of human deciduous teeth by laser ablation-inductively coupled plasma-mass spectrometry. *Anal. Chim. Acta* 401:299-306.

Love, John David and Ann Coe Christiansen
1985 *Geologic map of Wyoming*. US Geological Survey.

Lovvorn, Marjorie Brooks, George C Frison and Larry L Tieszen
2001 Paleoclimate and Amerindians: Evidence from stable isotopes and atmospheric circulation. *Proceedings of the National Academy of Sciences* 98(5):2485-2490.

Lowie, Robert H.
1922 The Material Culture of the Crow Indians. *Anthropological Papers of the American Museum of Natural History* 21(3):203-269.

Lupo, Karen D
2007 Evolutionary foraging models in zooarchaeological analysis: recent applications and future challenges. *Journal of Archaeological Research* 15(2):143-189.

MacArthur, Robert H and Eric R Pianka
1966 On optimal use of a patchy environment. *American Naturalist*:603-609.

MacDonald, Douglas H.
1999 Modeling Folsom Mobility, Mating Strategies, and Technological Organization in the Northern Plains. *Plains Anthropologist* 44(168):141-161.

Macdougall, Douglas
2013 *Frozen earth: the once and future story of Ice Ages*. Univ of California Press.

Mankin, Kyle R, Daniel M Ngandu, Charles J Barden, Stacy L Hutchinson and Wayne A Geyer
2007 Grass-Shrub Riparian Buffer Removal of Sediment, Phosphorus, and Nitrogen From Simulated Runoff1. *JAWRA Journal of the American Water Resources Association* 43(5):1108-1116.

Marino, B.D. , M.B. McElroy, R.J. Salawitch and W.G. Spaulding
1992 Glacial-to-interglacial variations in the carbon isotopic composition of atmospheric CO2. *Nature* 357:461-466.

Marino, B.D. and M.B. McElroy
1991 Isotopic composition of atmospheric CO2 inferred from carbon in C4 plant cellulose. *Nature* 249:127-131.

Marlow, C.F.
1978 *Plant Resources of the Powder River Basin: Archaeological Survey of the Western Powder River Basin* 3. Wyoming Recreation Commission, Cheyenne

Marlowe, F.
2005 Hunter-Gatherers and Human Evolution. *Evolutionary Anthropology* 14:54-67.

Marlowe, Frank
2010 *The Hadza: hunter-gatherers of Tanzania* 3. Univ of California Press.

Martin, Paul S and Richard G Klein
1989 *Quaternary Extinctions: a prehistoric revolution*. University of Arizona Press.

Martin, Paul Schultz
2005 *Twilight of the Mammoths: ice age extinctions and the rewilding of America*. University of California Press, Berkeley.

Martinson, Douglas G, Nicklas G Pisias, James D Hays, John Imbrie, Theodore C Moore and Nicholas J Shackleton
1987 Age dating and the orbital theory of the ice ages: development of a high-resolution 0 to 300,000-year chronostratigraphy. *Quaternary Research* 27(1):1-29.

Mason, Joseph A., Xiaodong Miao, Paul R. Hanson, Willian C. Johnson, Peter M. Jacobs and Ronald J. Goble
2008 Loess record of the Pleistocene–Holocene transition on the northern and central Great Plains, USA. *Quaternary Science Reviews* 27:1772-1783.

Matthew E. Hill, Jr. , Matthew G. Hill and Christopher C. Widga
2008 Late Quaternary Bison diminution on the Great Plains of North America: evaluating the role of human hunting versus climate change. *Quaternary Science Reviews* 27:1752-1771.

Matthew E. Hill, Jr. and Jack L. Hofman

1997 The Waugh Site: A Folsom-age Bison Bonebed in Northwestern Oklahoma. *Plains Anthropologist Memior* 29:63-83.

McDonald, Jerry N.

1981 *North American Bison Their Classification and Evolution*. University of California Press, Berkeley.

McDonnell, John

1889 Some Accounts of the Red Deer River (About 1797) With Extracts from His Journal 1793-1795. In *Les Bourgeois de la Compagnie du Nord-Quest*, edited by L. Masson. vol. 1. L'Imprimerie Generale A Cote et Cie, Quebec.

McDougall, John

1896 *Saddle, Sled, and Snowshoe*. William Briggs, Toronto.

1971 *Parsons on the Plains*. Don Mills, Ontario.

McHugh, T.

1958 Social Behavior of the American Buffalo (Bison bison bison). *Zoologica* 43:1-40.

McNeil, P., L.V. Hills, B. Kooyman and M.S. Tolman

2005 Mammoth tracks indicate a declining Late Pleistocene population in southwestern Alberta, Canada. *Quaternary Science Review* 24:1253-1259.

McNeil, P., L.V. Hills, B. Kooyman and M.S. Tolman

2004 Late Pleistocene geology and fauna of the Wally's Beach site (DhPg-8) Alberta, Canada. In *Archaeology on the Edge: New Perspectives from the Northern Plains.* , edited by B. Kooyman and J. H. Kelley, pp. 79-94, Canadian Archaeological Association Occasional Paper 4.

McNeil, P., L.V. Hills, M.S. Tolman and Kooyman B.

2007 Significance of latest Pleistocene tracks, trackways, and trample grounds from Southern Alberta, Canada. In *Cenozoic Vertebrate Tracks and Traces*, edited by S. G. Lucas, J. A. Spielmann and M. G. Lockley, pp. 209-224, New Mexico Museum of Natural History and Science Bulletin 42.

Meltzer, David J and Vance T Holliday

2010 Would North American Paleoindians have Noticed Younger Dryas Age Climate Changes? *Journal of World Prehistory* 23(1):1-41.

Meltzer, David J.
2006 *Folsom: New Archaeological Investigations of a Classic Paleoindian Bison Kill*. University of California Press, Berkely.

2009 *First Peoples in a New World: Colonizing Ice Age America* University of California Press, Berkeley.

COHMAP Members
1988 Climactic Changes of the Last 18,000 years: Observations and Model Smulations. *Science* 241:1043-1052.

Miller, D. Shane, Vance T. Holliday and Jordon Bright
2013 Clovis across the Continent. In *Paleoamerican Odyssey*, edited by K. Graft, C. V. Ketron and M. R. Waters. Center for the Study of the First Americans.

Miller, Mark E, Paul Hugh Sanders and Richard Adams
1999 *The trappers point site (48SU1006): early archaic adaptations in the Upper Green River Basin, Wyoming* 2. Office of the Wyoming State Archaeologist, Dept. of Anthropology, University of Wyoming.

Miller, Mark E. and Paul H. Sanders
2000 The Tappers Point Site (48SU1006): Early Archaic Adaptations and Pronghorn Procurement in the Upper Green River Basin, Wyoming. *Plains Anthropologist* 45(174):39-52.

Molleson, T.
1988 Trace elements in human teeth. In *Trace Elements in Environmental History* edited by G. G. a. B. Herrmann, pp. 67-82. Springer, New York.

Morrow, Juliet E, Stuart J Fiedel, Donald L Johnson, Marcel Kornfeld, Moye Rutledge and W Raymond Wood
2012 Pre-Clovis in Texas? A critical assessment of the “Buttermilk Creek Complex”. *Journal of Archaeological Science* 39(12):3677-3682.

Murphy, Brett P and David MJS Bowman
2009 The carbon and nitrogen isotope composition of Australian grasses in relation to climate. *Functional Ecology* 23(6):1040-1049.

Oliver, Symmes C.
1962 Ecology and Cultural Continuity as Contributing Factors in the Social Organization of the Plains Indians. *University of California Publications in American Archaeology and Ethnology* 48(1):1-90.

Palliser, John
1863 *The Journals, Detailed Reports and Observations Relating to the Exploration by Captian Palliser 1857-1860*. Eyre and Spottiswoode, London.

Pennington, R.
2001 Hunter-Gatherer Demography. In *Hunter-Gatherers: An Interdisciplinary Perspective*, edited by C. Panter-Brick, R. H. Layton and P. Rowley-Conwy, pp. 170-204. Cambridge University Press, Cambridge.

Pianka, Eric R.
1974 *Evolutionary Ecology*. Harper and Row Publishers, New York.

Pierce, GJ and JG Ollason
1987 Eight reasons why optimal foraging theory is a complete waste of time. *Oikos*:111-118.

Pinson, Ariane O.
2011 The Clovis Occupation Of The Dietz Site (35LK1529), Lake County, Oregon, and its Bearing on the Adaptive Diversity Of Clovis Foragers. *American Antiquity* 76(2):285-313.

Pitblado, Bonnie L.
2011 A Tale of Two Migrations: Reconciling Recent Biological and Archaeological Evidence for the Pleistocene Peopling of the Americas. *Journal of Archaeological Research* 19(4):327-375.

Quaife, Milo Mitton
1921 *Alexander Henry's Travels and Adventures in the Years 1760-1776*. R.R. Donnelley and Sons, Chicago.

Rasmussen, Morten, Sarah L Anzick, Michael R Waters, Pontus Skoglund, Michael DeGiorgio, Thomas W Stafford Jr, Simon Rasmussen, Ida Moltke, Anders Albrechtsen and Shane M Doyle
2014 The genome of a Late Pleistocene human from a Clovis burial site in western Montana. *Nature* 506(7487):225-229.

Reeves, Brian OK
1990 Communal bison hunters of the Northern Plains. *Hunters of the Recent Past*:168-194.

Reher, Charles A
1978 Buffalo population and other deterministic factors in a model of adaptive process on the shortgrass plains. *Plains Anthropologist*:23-39.

Reher, Charles A. and George C. Frison
1980 The Vore site, 48CK302, a stratified buffalo jump in the Wyoming Black Hills. *Plains Anthropologist*. 25(88) p. xvi-xxxi.

Roberts, Frank Harold Hanna
1935 *A Folsom complex: preliminary report on investigations at the Lindenmeier site on northern Colorado (with 16 plates)* 3333. The Smithsonian institution.

Robinson, Briann S., Jennifer C. Ort, Willaim A. Eldridge, Adrian L. Burke and Bertrand G. Pelletier
2009 Paleoindian Aggregation and Social Context at Bull Brook. *American Antiquity* 74(3):423-447.

Sanchez, Guadalupe, Vance T Holliday, Edmund P Gaines, Joaquín Arroyo-Cabrales, Natalia Martínez-Tagüeña, Andrew Kowler, Todd Lange, Gregory WL Hodgins, Susan M Mentzer and Ismael Sanchez-Morales
2014 Human (Clovis)–gomphothere (Cuvieronius sp.) association∼ 13,390 calibrated yBP in Sonora, Mexico. *Proceedings of the National Academy of Sciences* 111(30):10972-10977.

Sassaman, KE and AR Randall
2012 Shell mounds of the middle St. Johns Basin, northeast Florida. *Early New World Monumentality*:53-77.

Saunders, JJ
2007 Processing marks on remains of Mammuthus columbi from the Dent site, Colorado, in light of those from Clovis, New Mexico: Fresh carcass butchery versus scavenging. *Paleoindian Archaeology: From the Dent Site to the Rocky Mountains*:155-184.

Schaedel, R.P.
1995 The temporal variants of proto-state societies. In *Alternative Pathways to Early States*, edited by N. N. Kradin and V. A. Lynsha, pp. 47-53, Dal'nauka, Vladivostok.

Schaeffer, Claude E.
1978 The Bison Drive of the Blackfoot Indians. *Plains Anthropologist, Memoir* 14:243-248.

Schneider, Kim N and Donald J Blakeslee
1990 Evaluating residence patterns among prehistoric populations: clues from dental enamel composition. *Human biology*:71-83.

Schoeller, Dale A.
1999 Isotope Fractioation: Why Aren't We What We Eat? *Journal of Archaeological Science* 26:667-673.

Schoeninger, Margaret J. and Michael J. DeNiro
1984 Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48:625-639.

Sellet, Frederic
2001 A changing perspective on Paleoindian chronology and typology: a view from the northwestern Plains. *Arctic Anthropology*:48-63.

Sellet, Frederic, James Donohue and Matthew G Hill
2009 The Jim Pitts site: a stratified Paleoindian site in the Black Hills of South Dakota. *American Antiquity*:735-758.

Shapiro, Beth, Alexei J Drummond, Andrew Rambaut, Michael C Wilson, Paul E Matheus, Andrei V Sher, Oliver G Pybus, M Thomas P Gilbert, Ian Barnes and Jonas Binladen
2004 Rise and fall of the Beringian steppe bison. *Science* 306(5701):1561-1565.

Sharp, Z.D. and T.E. Cerling
1998 Fossil isotope records of seasonal climate and ecology: straight from the horse's mouth. *Geology* 26(3):219-222.

Sillen, A.
1992 Strontium-calcium ratios (Sr/Ca) of Australopithecus robustus and associated fauna from Swartkrans. . *Journal of Human Evolution* 23:495-516.

Skinner, Alanson
1914 Political Organization, Cults and Ceremonies of the Plains-Cree. *Anthropological Papers of the American Museum of Natural History* 11(6):482-499.

Smallwood, Ashley M. and Thomas A. Jennings (editors)
2015 *Clovis: On the Edge of a New Understanding*. Texas A&M University Press, College Station.

Smith, B. D.
1995 *The Emergence of Agriculture*. Scienctific America Library, New York.

Smith, Eric Alden, Robert L Bettinger, Charles A Bishop, Valda Blundell, Elizabeth Cashdan, Michael J Casimir, Andrew L Christenson, Bruce Cox, Rada Dyson-Hudson and Brian Hayden

1983 Anthropological Applications of Optimal Foraging Theory: A Critical Review [and Comments and Reply]. *Current Anthropology*:625-651.

Speakman, Robert J and Hector Neff

2005 *Laser ablation ICP-MS in archaeological research*. UNM Press.

Speth, John D.

2010 *The Paleoanthropology and Archaeology of Big-Game Hunting*. Interdisiplinary Contributions to Archaeology. Springer, New York.

Stafford, Thomas W, K. Brendel and R. C. Duhamel

1988 Radiocarbon, 13C and 15N Analysis of Fossil Bone: Re- moval of Humates with XAD-2 Resin. *Geochimica et Cosmochimica Acta* 52:2257-2267.

Stafford, Thomas W, P Edgar Hare, Lloyd Currie, AJ Timothy Jull and Douglas J Donahue

1991 Accelerator radiocarbon dating at the molecular level. *Journal of Archaeological Science* 18(1):35-72.

Steuter, AA, EM Steinauer, GL Hill, PA Bowers and LL Tieszen

1995 Distribution and diet of bison and pocket gophers in a sandhills prairie. *Ecological Applications*:756-766.

Steward, Julian H

1937 Ecological aspects of Southwestern society. *Anthropos*:87-104.

Steward, Julian Haynes

1933 *Ethnography of the Owens Valley Paiute* 33. University of California Press Berkely.

1955 *Theory of culture change: The methodology of multilinear evolution*. University of Illinois Press.

Stewart, Andrew M., Darren Keith and Joan Scottie

2004 Caribou Crossings and Cultural Meanings: Placing Traditional Knowledge and Archaeology in Context in an Inuit Landscape. *Journal of Archaeological Method and Theory* 11(2):183-211.

Stowe, L.G. and J.A. Teeri

1978 The geographic distribution of C4 species of the Dicotyledonae in relation to climate. *American Naturalist* 112:609-623.

Surovell, Todd A.
2012 *Toward a behavioral ecology of lithic technology: cases from Paleoindian archaeology*. University of Arizona Press.

Surovell, Todd A. and Nicole M. Waguespack
2007 *Folsom hearth-centered use of space at Barger Gulch, Locality B. Emerging frontiers in Colorado Paleoindian archaeology.* University of Colorado Press, Boulder, CO:219-259.

Surovell, Todd A., Nicole M. Waguespack, James H. Mayer, Marcel Kornfeld and George C. Frison
2005 Shallow site archaeology: Artifact dispersal, stratigraphy, and radiocarbon dating at the Barger Gulch locality B Folsom Site, Middle Park, Colorado. *Geoarchaeology* 20(6):627-649.

Szarek, S.R. and I.P. Ting
1977 The occurrence of Crassulacean Acid Metabolism among plants. *Photosynthetica* 11:330-342.

Teeri, J.A.
1979 The Climatology of the C4 photosynthetic pathway. In *Topics in Plant Population Biology*, edited by O. T. Solbrig, S. Jain, G. B. Johnson and P. H. Raven, pp. 356-374. Univ. Press, New York, Columbia.

Tieszen, L.L., T.W. Boutton, K.G. Tesdahl and N.A. Slade
1983 Fractionation and turnover of stable carbon isotopes in animal tissues: Implications for d13C analysis of diet. *Oecologia* 57:32-37.

Tieszen, Larry L.
1991 Natural Variations in the Carbon Isotope Values of Plants: Implications for Archaeology, Ecology and Paleoecology. *Journal of Archaeological Science* 18:227-248.

1994 Stable Isotopes on the Plains: Vegetation Analysis and Diet Determinations. In *Subsistence Strategies and Dietary Assessments*.

Tieszen, Larry L., Dennis Hein, Svend A Qvortrup, John H. Troughton and Simeon K. Imbamba
1979 Use of d13C Values to Determine Vegetation Selectivity in East African Herbivores. *Oecologia* 37:351-359.

Tieszen, Larry L., Laura Stretch and Joel Vander Kooi
1998 *Stable Isotopic Determination of Seasonal Dietary Patterns in Bison at Four Preserves Across the Great Plains*. Bison Ecology and Management in North America. Montana State University Bozeman, Montana.

Todd, Lawrence C, David J Rapson and Jack L Hofman
1996 Dentition studies of the Mill Iron and other early Paleoindian bison bonebed sites. *The Mill Iron Site*:145-176. University of New Mexico Press. Albuquerque NM.

Tschudy, Robert H. and Richard A. Scott
1969 Aspects of palynology.

Turpin, Solveig A.
2004 Cyclical Nucleation and Sacred Space: Rock Art at the Center. In *New Perspectives on Prehistoric Art*, edited by G. Berghaus. Praeger, Wesport, Connecticut.

Tütken, Thomas and Torsten W. Vennemann
2011 Fossil bones and teeth: Preservation or alteration of biogenic compositions? *Palaeogeography, Palaeoclimatology, Palaeoecology* 310(1-2):1-8.

Tütken, Thomas, Torsten W. Vennemann and Hans- U. Pfretzschner
2011 Nd and Sr isotope compositions in modern and fossil bones – Proxies for vertebrate provenance and taphonomy. *Geochimica et Cosmochimica Acta* 75(20):5951-5970.

Van Klinken, Gert J
1999 Bone collagen quality indicators for palaeodietary and radiocarbon measurements. *Journal of Archaeological Science* 26(6):687-695.

Verbicky-Todd, Eleanor
1984a *Communal Buffalo Hunting Among Plains Indians*. Archaeological Survey of Alberta 24. Alberta Culture Historical Resource Division Alberta.

1984b *Communal buffalo hunting among the Plains Indians: an ethnographic and historic review*. Alberta Culture, Historical Resources Division.

Waguespack, Nicole M.
2005 The organization of male and female labor in foraging societies: Implications for early Paleoindian archaeology. *American Anthropologist* 107(4):666-676.

Waguespack, Nicole M. and Todd A. Surovell
2003 Clovis Hunting Strategies, or How to Make Out on Plentiful Resources. *American Antiquity* 68(2):333-352.

Walker, Ernest
1974 The Seasonal Nature of Post-Altithermal Communal Bison Procurement on the Northwestern Plains. *Na'Pao* 4(2):1-6.

Waters, Michael R and Thomas W Stafford
2007 Redefining the age of Clovis: implications for the peopling of the Americas. *Science* 315(5815):1122-1126.

Waters, Michael and Thomas Stafford Jr.
2014 Redating the Mill Iron Site, Montana: A Reexamination of Goshen Complex Chronology. *American Antiquity* 79(3):541-548.

Waters, Michael R, Steven L Forman, Thomas A Jennings, Lee C Nordt, Steven G Driese, Joshua M Feinberg, Joshua L Keene, Jessi Halligan, Anna Lindquist and James Pierson
2011 The Buttermilk Creek complex and the origins of Clovis at the Debra L. Friedkin site, Texas. *Science* 331(6024):1599-1603.

Waters, Michael R, Thomas W Stafford, H Gregory McDonald, Carl Gustafson, Morten Rasmussen, Enrico Cappellini, Jesper V Olsen, Damian Szklarczyk, Lars Juhl Jensen and M Thomas P Gilbert
2011 Pre-Clovis mastodon hunting 13,800 years ago at the Manis site, Washington. *Science* 334(6054):351-353.

Webb, S.D. and E. Simons
2006 Vertebrate paleontology. In *First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River*, edited by S. D. Webb, pp. 215-246. Springer, Dordrecht.

Wedel, Waldo
1963 The High Plains and their Utilization by the Indians. *American Antiquity* 29(1):1-16.

Weekes, Mary
1948 An Indian's Description of the Making of a Buffalo Pound. *Saskatchewan History* 1(3):14-17.

Wenke, R. J. and D.I. Olszewski

2007 *Patterns in Prehistory: Mankind's First Three Million Years*. Oxford University Press, New York.

Whitlock, Cathy, Mel A Reasoner and Carl H Key

2002 Paleoenvironmental History of the Rocky Mountain Region during the past 20,000 years. In *Rocky Mountain futures: an ecological perspective*, edited by J. S. Baron, pp. 41-57. Island Press, Washington D.C.

Wiedemann, Felicitas B, Hervé Bocherens, André Mariotti, Angela von den Driesch and Gisela Grupe

1999 Methodological and archaeological implications of intra-tooth isotopic variations (δ 13 C, δ 18 O) in herbivores from Ain Ghazal (Jordan, Neolithic). *Journal of Archaeological Science* 26(6):697-704.

Wilke, Philip J., J. Jeffery Flenniken and Terry L. Ozburn

1991 Clovis Technology at the Anzick Site Montana. *Journal of California and and Great Basin Archaeology* 13:242-272.

Wilmsen, Edwin N and Frank Harold Hanna Roberts

1978 *Lindenmeier, 1934-1974: Concluding report on investigations* 24. Smithsonian Institution Press.

Wilson, Michael

1974 The Casper local fauna and its fossil bison. *The Casper Site: A Hell Gap Bison Kill on the High Plains, Academic Press, New York*:125-171.

Wilson, Michael C

1996 Late quaternary vertebrates and the opening of the ice-free corridor, with special reference to the genusbison. *Quaternary International* 32:97-105.

Winterhalder, Bruce

1981 Optimal foraging strategies and hunter-gatherer research in anthropology: theory and models. In *Hunter-gatherer foraging strategies: Ethnographic and archaeological analyses* ed. Winterhalder, Bruce, and Eric Alden Smith. *University of Chicago, Illinois*.13-35.

2001 The Behavioural Ecology of Hunter Gatherers. In *Hunter-Gatherers: An Interdisciplinary Perspective*, edited by C. Panter-Brick, R. H. Layton and P. Rowley-Conwy. Cambridge University Press.

Winterhalder, Bruce and Douglas Kennett
2006 Behavioral Ecology and the Transition from Hunting and Gathering to Agriculture In *Behavioral Ecology and the Transition to Agriculture*, edited by D. Kennett and B. Winterhalder, pp. 1-21. University of California, Berkeley.

Winterhalder, Bruce and Eric Alden Smith
1981 Hunter-gatherer foraging strategies. *Ethnographic and Archaeologist Analyses. University of Chicago, Illinois*.

2000 Analyzing adaptive strategies: Human behavioral ecology at twenty-five. *Evolutionary Anthropology Issues News and Reviews* 9(2):51-72.

Wisehart, A. W.
2005 A Cultural Study of the Bad Pass Trail in the Pryor Mountains, Montana and Wyoming. MA Thesis Missoula Montana.

Wobst, H. Martin
1978 The Archaeo-Ethnology of Hunter-Gatherers or the Tyranny of the Ethnographic Record in Archaeology. *American Antiquity* 43:303-309.

Wright, H.E. Jr.
1970 Vegetational history of the Central Plains. Pleistocene and recent environments of the central Great Plains, University of Kansas Press, Lawrence.157-172.

Wycoff, D.G. and W.W Dalquest
1997 From Whence They Came: The Paleontology of the Southern Plains Bison. *Plains Anthropologist Memior* 29:5-32.

Youle, Henry
1971 *Narrative of the Canadian Red River Exploring Expedition of 1857 and of the Assiniboine and Saskatchewan exploring Expedition of 1858* 2. Hurtig, Edmonton.

Zedeño, Maria Nieves, Jesse A.M. Ballenger and John R. Murray
2014 Landscape engineering and organizational complexity among Late Prehistoric bison hunters of the northwestern plains. *Current Anthropology* 55(1):23-58.

Zeder, Melinda A
2012 The broad spectrum revolution at 40: resource diversity, intensification, and an alternative to optimal foraging explanations. *Journal of Anthropological Archaeology* 31(3):241-264.

APPENDIX A

TRACE ELEMENT DATA

Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	LO2-1	Modern	0.9931	3.7808	3.3702	2.7395	0.0000
Carlson	LO2-2	Modern	0.9922	3.7177	3.1962	2.1761	0.0000
Carlson	LO2-3	Modern	0.9477	3.7313	3.1787	2.3003	0.0000
Carlson	LO2-4	Modern	0.9278	3.6819	3.2174	1.9096	0.0000
Carlson	LO2-5	Modern	0.7973	3.7692	3.5672	2.6711	0.0000
Carlson	LO2-6	Modern	0.7354	3.7115	3.4219	2.3987	0.0000
Carlson	LO2-7	Modern	0.7959	3.7001	3.5425	1.7944	0.0000
Carlson	LO2-8	Modern	0.8161	3.7613	3.3746	2.2273	0.0000
Carlson	LO5-1	Modern	0.9094	3.7297	3.0317	2.7016	0.2610
Carlson	LO5-2	Modern	0.9291	3.7407	3.0906	2.7491	0.0000
Carlson	LO5-3	Modern	0.8697	3.7667	3.1088	2.9085	0.0335
Carlson	LO5-4	Modern	0.8563	3.7846	3.1194	3.0826	0.0312
Carlson	LO5-5	Modern	0.8289	3.7521	3.1852	2.7236	0.1746
Carlson	LO5-6	Modern	0.7198	3.6759	3.3620	2.5388	0.1709
Carlson	LO5-7	Modern	0.7720	3.6863	3.5776	2.6459	0.1557
Carlson	NBO224-1	Modern	0.8072	3.8160	3.1803	2.7268	0.2831
Carlson	NBO224-2	Modern	0.7478	3.7333	3.3916	2.5485	0.0000
Carlson	NBO224-3	Modern	0.7479	3.7211	3.2044	2.8729	0.0000
Carlson	NBO224-4	Modern	0.7353	3.7476	3.2808	2.8120	0.0000

Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	NBO224-5	Modern	0.7287	3.7678	3.2356	2.8546	0.0000
Carlson	NBO224-6	Modern	0.7114	3.8232	3.5737	2.9964	0.0000
Carlson	NBO224-7	Modern	0.7425	3.8886	3.5277	3.2539	0.0000
Carlson	BO229-1	Modern	0.7970	3.7867	3.1712	3.1255	0.0000
Carlson	BO229-2	Modern	0.7292	3.6936	3.2917	2.8513	0.0000
Carlson	BO229-3	Modern	0.7141	3.7034	3.3269	2.9726	0.0000
Carlson	BO229-4	Modern	0.6465	3.7316	3.0338	3.0739	0.0000
Carlson	BO229-5	Modern	0.6987	3.7279	3.0993	3.1077	0.0000
Carlson	BO229-6	Modern	0.7591	3.7610	3.2634	3.0062	0.0000
Carlson	BO229-7	Modern	0.6816	3.7776	3.2683	2.9982	0.0000
Carlson	1BO364-1	Modern	1.3296	3.8957	3.3970	2.9552	0.0000
Carlson	1BO364-2	Modern	0.8847	3.8218	3.5468	2.9406	0.0000
Carlson	1BO364-3	Modern	1.0041	3.8198	3.6961	3.0310	0.0000
Carlson	1BO364-4	Modern	1.2932	3.8547	3.7161	3.0879	0.0000
Carlson	1BO364-5	Modern	1.3066	3.8620	3.6107	3.1761	0.0000
Carlson	1BO364-6	Modern	1.0144	3.8450	3.7752	3.2637	0.0000
Carlson	1BO364-7	Modern	0.9062	3.7794	3.7168	3.0940	0.0000
Carlson	34HP45-494-1	Prehistoric	1.1936	2.2702	2.9421	3.4999	0.3937
Carlson	34HP45-494-2	Prehistoric	1.2002	2.1351	2.7813	3.2591	0.2522
Carlson	34HP45-494-3	Prehistoric	1.2923	2.0566	3.0448	3.2063	0.3610
Carlson	34HP45-494-4	Prehistoric	1.1325	1.3643	3.9727	3.1807	0.4096
Carlson	34HP45-494-5	Prehistoric	1.0176	1.4570	3.8531	2.7586	0.2952
Carlson	34HP45-494-6	Prehistoric	1.0252	1.3108	3.8745	2.8329	0.2485
Carlson	34HP45-494-7	Prehistoric	0.9956	1.5986	3.8601	3.0771	0.1907
Carlson	34HP45-494-8	Prehistoric	1.1018	1.3912	3.9742	3.2656	0.2578
Carlson	34HP45-494-9	Prehistoric	1.1441	1.4067	3.9245	3.1741	0.1712
Carlson	34HP45-494-10	Prehistoric	1.7185	1.6427	3.5958	3.1122	0.4684
Carlson	34HP45-494-11	Prehistoric	1.7060	1.6999	3.3780	2.9065	0.3906
Carlson	34HP45-494-12	Prehistoric	1.8156	1.6859	3.5624	3.0616	0.4190
Carlson	34HP45-494-13	Prehistoric	1.2458	1.4631	3.6115	2.9500	0.2704
Carlson	34HP45-494-14	Prehistoric	1.3058	1.5090	3.6355	2.9490	0.2931

Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
LO2-1	2.5321	0.5942	0.6659	2.5119	1.0587	0.8259	0.3889
LO2-2	2.5263	0.7169	0.7408	2.6418	0.9363	0.4157	0.1621
LO2-3	2.5304	0.5674	0.5578	2.6212	0.9253	0.5682	0.1339
LO2-4	2.5050	0.6270	0.5869	2.6123	0.9157	0.5189	0.0976
LO2-5	2.5364	0.2627	0.4621	2.4933	0.8816	0.5806	0.3036
LO2-6	2.4733	0.2454	0.6698	2.5350	0.8561	0.3532	0.0935
LO2-7	2.4931	0.2422	0.3908	2.6076	0.9434	0.6750	0.0614
LO2-8	2.4603	0.2397	0.3148	2.3414	0.8788	0.5339	0.0733
LO5-1	2.5925	0.3739	0.9348	2.5456	0.7633	0.1624	0.0600
LO5-2	2.6324	0.8379	0.6161	2.5372	0.7781	0.2539	0.0550
LO5-3	2.6309	0.5643	0.5363	2.5161	0.7748	0.0304	0.0591
LO5-4	2.6243	0.3960	0.7216	2.5219	0.7822	0.2574	0.1069
LO5-5	2.6172	0.2405	0.4252	2.4587	0.8374	0.1251	0.0482
LO5-6	2.5881	0.1602	0.3155	2.4531	0.7961	0.0332	0.0317
LO5-7	2.5704	0.1454	0.3220	2.6121	0.9208	0.0166	0.0365
NBO224-1	2.4445	0.1558	0.3250	2.4427	0.7550	0.2857	0.0653
NBO224-2	2.4540	0.1796	0.2542	2.4444	0.6521	0.1696	0.0324
NBO224-3	2.4458	0.1365	0.4706	2.4700	0.6364	0.0869	0.0501
NBO224-4	2.4394	0.1354	0.4376	2.3734	0.7474	0.1859	0.0356
Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
NBO224-5	2.4406	0.1465	0.3983	2.2447	0.7223	0.2358	0.0510
NBO224-6	2.4357	0.1325	0.4721	2.2563	0.6890	0.1338	0.0404
NBO224-7	2.4277	0.1347	0.5273	2.1464	0.6993	0.1925	0.0714
BO229-1	2.5005	0.1935	0.2854	2.3833	0.8088	0.1910	0.0691
BO229-2	2.4976	0.1438	0.2725	2.4785	0.7870	0.0289	0.0293
BO229-3	2.4710	0.1555	0.2344	2.4252	0.8282	0.0000	0.0354
BO229-4	2.4631	0.1588	0.2264	2.2350	0.6937	0.0027	0.0287
BO229-5	2.4497	0.1536	0.2744	2.1447	0.6867	0.0457	0.0298
BO229-6	2.4585	0.1457	0.3471	2.1148	0.7119	0.0000	0.0203
BO229-7	2.4470	0.1551	0.3396	2.0598	0.7404	0.0000	0.0200
1BO364-1	2.5815	0.2049	0.2457	2.4073	0.6831	0.0079	0.0992
1BO364-2	2.6573	0.1578	0.2119	2.4932	0.6054	0.2006	0.0524
1BO364-3	2.4756	0.1412	0.2646	2.5200	0.5985	0.2542	0.0421
1BO364-4	2.4979	0.1339	0.1979	2.5160	0.6524	0.0620	0.0691
1BO364-5	2.5462	0.1466	0.2969	2.4311	0.5713	0.2125	0.0846
1BO364-6	2.6298	0.1395	0.2188	2.4691	0.7741	0.0098	0.0851
1BO364-7	2.6353	0.1323	0.2388	2.4726	0.7572	0.2161	0.0537
34HP45-494-1	2.6914	0.4165	0.7245	1.5371	0.6903	0.3967	0.2455
34HP45-494-2	2.6604	0.4323	0.5633	1.6096	0.6720	0.4081	0.1604
34HP45-494-3	2.7036	0.5252	0.5851	1.6581	0.7278	0.4912	0.2826
34HP45-494-4	2.3778	0.3515	0.8427	1.2603	1.1018	0.2854	0.3940
34HP45-494-5	2.2537	0.2936	0.4967	1.3638	0.9836	0.2628	0.2054
34HP45-494-6	2.2779	0.3097	0.6351	1.3124	1.1080	0.2442	0.2853
34HP45-494-7	2.3705	0.3546	0.7540	1.4850	0.9425	0.2902	0.3032
34HP45-494-8	2.4374	0.4121	0.9907	1.4165	1.4176	0.2887	0.4394
34HP45-494-9	2.4181	0.4016	0.8612	1.4464	1.4216	0.2898	0.3938
34HP45-494-10	2.5913	0.8063	0.9428	1.8115	1.0658	0.6361	0.3541
34HP45-494-11	2.5342	0.7454	0.7986	1.8093	1.2415	0.5866	0.2189
34HP45-494-12	2.5350	0.7972	0.9865	1.8459	1.1374	0.6343	0.2520
34HP45-494-13	2.4973	0.5626	0.5834	1.7800	0.8425	0.3947	0.3101
34HP45-494-14	2.5196	0.5677	0.6032	1.7961	0.8273	0.4153	0.3194

Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
LO2-1	2.5159	0.2338	0.1663	0.1472	0.3277	0.4479	0.5686	0.3744
LO2-2	2.4928	0.2627	0.1409	0.0429	0.1031	0.3768	0.4762	0.1432
LO2-3	2.4935	0.2572	0.2070	0.0300	0.0234	0.3729	0.4730	0.0994
LO2-4	2.4773	0.1775	0.0855	0.0291	0.0182	0.2687	0.2812	0.0638
LO2-5	2.5178	0.2263	0.2309	0.0253	0.0286	0.3186	0.4639	0.1013
LO2-6	2.4857	0.0701	0.1135	0.0232	0.0116	0.0936	0.1307	0.0334
LO2-7	2.5037	0.0202	0.0170	0.0240	0.0022	0.0416	0.0625	0.0150
LO2-8	2.5051	0.0323	0.0328	0.0272	0.0040	0.0737	0.0643	0.0107
LO5-1	2.5103	0.2042	0.7211	0.8466	0.0311	0.2492	0.2972	0.0897
LO5-2	2.5001	0.1496	0.6040	0.7640	0.0182	0.2015	0.2491	0.0759
LO5-3	2.4623	0.0730	0.5852	0.7189	0.0103	0.1096	0.1341	0.0360
LO5-4	2.4694	0.1228	0.6785	0.7560	0.0046	0.1755	0.2158	0.0417
LO5-5	2.4624	0.0771	0.5193	0.6114	0.0043	0.1121	0.1464	0.0305
LO5-6	2.4045	0.0168	0.3190	0.3019	0.0033	0.0324	0.0382	0.0145
LO5-7	2.4194	0.0278	0.3221	0.1821	0.0028	0.0365	0.0426	0.0183
NBO224-1	2.1445	0.0539	0.2694	1.3221	0.0351	0.0900	0.1208	0.0628
NBO224-2	2.2415	0.0390	0.1892	0.7494	0.0236	0.0613	0.0941	0.0600
NBO224-3	2.2814	0.0730	0.4473	0.5853	0.0075	0.1054	0.0922	0.0336
NBO224-4	2.3011	0.0555	0.4838	0.4189	0.0068	0.0331	0.0485	0.0248
Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
NBO224-5	2.3563	0.0293	0.3012	0.2994	0.0129	0.0439	0.0597	0.0414
NBO224-6	2.3528	0.0093	0.3307	0.1854	0.0056	0.0178	0.0251	0.0174
NBO224-7	2.3932	0.0109	0.2713	0.1533	0.0035	0.0140	0.0198	0.0158
BO229-1	2.1780	0.0373	0.0527	1.5548	0.0388	0.0853	0.1115	0.0569
BO229-2	2.1844	0.0167	0.0000	1.4842	0.0122	0.0317	0.0430	0.0289
BO229-3	2.2726	0.0187	0.0162	1.1703	0.0105	0.0457	0.0507	0.0237
BO229-4	2.2175	0.0131	0.0000	0.9519	0.0041	0.0233	0.0274	0.0182
BO229-5	2.2184	0.0121	0.0221	0.7719	0.0065	0.0269	0.0347	0.0180
BO229-6	2.2370	0.0076	0.0848	0.7099	0.0025	0.0153	0.0183	0.0114
BO229-7	2.2826	0.0109	0.1283	0.5839	0.0092	0.0180	0.0251	0.0137
1BO364-1	2.2468	0.0758	0.3541	1.1543	0.0658	0.1200	0.1499	0.1273
1BO364-2	2.2934	0.0385	0.1610	1.2064	0.0111	0.0552	0.0695	0.0532
1BO364-3	2.2892	0.0243	0.1734	1.3041	0.0076	0.0291	0.0387	0.0310
1BO364-4	2.3025	0.0094	0.0027	1.2726	0.0020	0.0128	0.0222	0.0138
1BO364-5	2.2746	0.0234	0.1809	1.1502	0.0073	0.0477	0.0799	0.0444
1BO364-6	2.5149	0.0099	0.2455	1.0489	0.0047	0.0145	0.0198	0.0108
1BO364-7	2.4822	0.0079	0.2009	1.1187	0.0010	0.0096	0.0146	0.0069
34HP45-494-1	2.4874	1.6189	0.7488	0.3666	0.1011	1.4753	1.5770	0.9097
34HP45-494-2	2.4618	1.4758	0.5649	0.3771	0.0758	1.3260	1.4130	0.7779
34HP45-494-3	2.5310	1.6913	0.6831	0.3901	0.1807	1.5268	1.5799	0.9076
34HP45-494-4	2.9085	1.2209	1.1056	0.1006	0.3324	1.2072	1.1951	0.5695
34HP45-494-5	2.9236	1.4920	0.5913	0.1615	0.1790	1.4122	1.3817	0.7368
34HP45-494-6	2.8840	1.3948	0.6133	0.1226	0.2208	1.3493	1.3369	0.6955
34HP45-494-7	2.8639	1.4959	0.9876	0.2245	0.2162	1.3751	1.4430	0.7641
34HP45-494-8	2.8488	1.2677	1.0423	0.1782	0.3720	1.3412	1.2540	0.6307
34HP45-494-9	2.8118	1.3535	0.9623	0.2132	0.3350	1.4133	1.3568	0.7088
34HP45-494-10	2.9686	1.9554	1.3225	0.3737	0.2671	1.9180	2.0219	1.2067
34HP45-494-11	2.9529	1.8719	1.2696	0.3999	0.1737	1.8019	1.8668	1.0740
34HP45-494-12	3.0428	1.9313	1.2955	0.2597	0.1849	1.8513	1.9350	1.1181
34HP45-494-13	2.7614	1.4051	1.0130	0.4820	0.2704	1.4142	1.5541	0.7798
34HP45-494-14	2.8615	1.3752	1.0085	0.4803	0.2724	1.3792	1.5174	0.7446

Full ID	LogNd	LogSm	LogEu	LogGd	LogDy	LogPb208	LogU
LO2-1	0.4334	0.3071	0.3410	0.3455	0.2554	1.4651	0.4720
LO2-2	0.3597	0.1458	0.1421	0.1537	0.1097	1.5219	0.1800
LO2-3	0.3366	0.1115	0.0613	0.1184	0.0762	2.0606	0.1213
LO2-4	0.2457	0.0617	0.0403	0.0650	0.0432	1.4048	0.0618
LO2-5	0.3314	0.1063	0.0654	0.0986	0.0641	1.1003	0.0705
LO2-6	0.0993	0.0244	0.0322	0.0322	0.0189	0.6731	0.0228
LO2-7	0.0274	0.0055	0.0267	0.0158	0.0073	0.5812	0.0267
LO2-8	0.0481	0.0113	0.0227	0.0162	0.0075	0.5805	0.0171
LO5-1	0.2618	0.1066	0.0897	0.1103	0.0776	1.8411	0.1006
LO5-2	0.1932	0.0809	0.0759	0.0878	0.0591	1.6340	0.1089
LO5-3	0.1001	0.0349	0.0434	0.0459	0.0288	1.2094	0.0527
LO5-4	0.1718	0.0463	0.0362	0.0500	0.0320	1.6772	0.0405
LO5-5	0.1143	0.0368	0.0350	0.0355	0.0247	1.1771	0.0280
LO5-6	0.0269	0.0216	0.0289	0.0151	0.0116	0.5937	0.0195
LO5-7	0.0525	0.0218	0.0378	0.0229	0.0164	0.5814	0.0282
NBO224-1	0.1012	0.0608	0.0764	0.0728	0.0434	0.9872	0.0594
NBO224-2	0.0745	0.0576	0.0712	0.0589	0.0344	1.0065	0.0640
NBO224-3	0.1070	0.0379	0.0389	0.0437	0.0325	1.1738	0.0287
NBO224-4	0.0608	0.0274	0.0386	0.0296	0.0237	1.4764	0.0293
Full ID	LogNd	LogSm	LogEu	LogGd	LogDy	LogPb208	LogU
NBO224-5	0.0552	0.0388	0.0469	0.0369	0.0269	0.7815	0.0365
NBO224-6	0.0285	0.0167	0.0286	0.0181	0.0111	0.9835	0.0162
NBO224-7	0.0185	0.0182	0.0287	0.0168	0.0126	0.9070	0.0184
BO229-1	0.0861	0.0602	0.0773	0.0730	0.0379	1.0512	0.0954
BO229-2	0.0327	0.0222	0.0365	0.0264	0.0168	1.2394	0.0517
BO229-3	0.0296	0.0239	0.0381	0.0260	0.0171	1.1202	0.0333
BO229-4	0.0210	0.0136	0.0298	0.0193	0.0101	0.4235	0.0194
BO229-5	0.0228	0.0188	0.0373	0.0278	0.0145	0.1888	0.0394
BO229-6	0.0159	0.0128	0.0237	0.0148	0.0087	0.2328	0.0280
BO229-7	0.0118	0.0127	0.0272	0.0177	0.0105	0.4195	0.0197
1BO364-1	0.1292	0.1135	0.1270	0.1140	0.0830	0.6395	0.1374
1BO364-2	0.0559	0.0435	0.0651	0.0574	0.0323	0.6460	0.0620
1BO364-3	0.0272	0.0231	0.0371	0.0278	0.0198	0.8427	0.0398
1BO364-4	0.0119	0.0052	0.0262	0.0155	0.0066	0.9321	0.0184
1BO364-5	0.0381	0.0388	0.0457	0.0445	0.0247	0.7005	0.0575
1BO364-6	0.0136	0.0057	0.0336	0.0111	0.0068	0.7751	0.0139
1BO364-7	0.0085	0.0037	0.0311	0.0054	0.0034	0.7919	0.0124
34HP45-494-1	1.5182	0.9380	0.4247	1.1675	0.9474	0.9266	0.3771
34HP45-494-2	1.3601	0.7983	0.3450	0.9998	0.7999	0.8895	0.3901
34HP45-494-3	1.4984	0.8945	0.4152	1.1444	0.9299	1.0221	0.4706
34HP45-494-4	1.0860	0.5678	0.2220	0.7351	0.5468	0.7505	0.2961
34HP45-494-5	1.3128	0.7216	0.2996	0.9174	0.7467	0.7053	0.3065
34HP45-494-6	1.2559	0.6846	0.2750	0.8596	0.7031	0.6499	0.3280
34HP45-494-7	1.3575	0.7781	0.3261	0.9539	0.7949	0.8746	0.3776
34HP45-494-8	1.1469	0.6145	0.2589	0.7336	0.5869	0.8789	0.3251
34HP45-494-9	1.2521	0.6934	0.2927	0.8451	0.6654	0.8639	0.3508
34HP45-494-10	1.8182	1.1847	0.6077	1.3645	1.1783	1.4419	0.8941
34HP45-494-11	1.6726	1.0446	0.5148	1.2409	1.0733	1.3732	0.9235
34HP45-494-12	1.7200	1.0815	0.5393	1.2749	1.1039	1.3636	1.0357
34HP45-494-13	1.3653	0.7718	0.3158	0.9332	0.7193	1.1284	0.5927
34HP45-494-14	1.3140	0.7250	0.2860	0.8860	0.6918	1.1050	0.5916

Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	34HP45-494-16	Prehistoric	0.9442	1.3934	3.7233	2.5381	0.0000
Carlson	34HP45-494-17	Prehistoric	0.8898	1.1122	3.8727	2.7511	0.0446
Carlson	34HP45-494-18	Prehistoric	0.8099	1.1334	3.8115	2.5349	0.0730
Carlson	34HP45-671-1	Prehistoric	0.6470	1.7254	2.8941	1.6039	0.3986
Carlson	34HP45-671-2	Prehistoric	0.5683	1.7812	2.7087	1.6053	0.3450
Carlson	34HP45-671-3	Prehistoric	0.6060	1.7436	2.6925	1.5464	0.2469
Carlson	34HP45-671-4	Prehistoric	0.7738	1.8564	3.0111	1.8916	0.2809
Carlson	34HP45-671-5	Prehistoric	0.6170	1.8085	2.6849	1.5952	0.1915
Carlson	34HP45-671-6	Prehistoric	0.6550	1.7139	2.8935	1.8311	0.0986
Carlson	34HP45-671-7	Prehistoric	0.7034	1.7446	2.8693	1.8049	0.2567
Carlson	34HP45-671-8	Prehistoric	0.5803	1.7660	2.5903	1.4361	0.1986
Carlson	34HP45-671-9	Prehistoric	0.6507	1.7822	2.6803	1.4847	0.2007
Carlson	34HP45-671-10	Prehistoric	0.7851	1.7745	2.9447	1.9396	0.4461
Carlson	34HP45-671-11	Prehistoric	0.6785	1.6986	2.6532	1.5191	0.1382
Carlson	34HP45-671-12	Prehistoric	0.6953	1.6884	2.7583	1.6912	0.1239
Carlson	34HP45-671-13	Prehistoric	0.5950	1.6295	3.0725	1.9041	0.0000
Carlson	34HP45-671-14	Prehistoric	0.3799	1.2968	2.8662	1.3892	0.0000
Carlson	34HP45-671-15	Prehistoric	0.2414	1.4654	2.9459	1.4197	0.0000
Carlson	34HP45-671-16	Prehistoric	0.0722	1.1204	2.9086	1.5860	0.0000
Carlson	34HP45-671-17	Prehistoric	0.0000	1.4411	2.7245	1.0948	0.0000
Carlson	34HP45-671-18	Prehistoric	0.0577	1.5012	2.8107	1.3720	0.0000
Carlson	34HP45-695-1	Prehistoric	0.7402	2.0488	3.0810	1.6750	0.2410
Carlson	34HP45-695-2	Prehistoric	0.7322	1.9072	3.0923	1.4367	0.0946
Carlson	34HP45-695-3	Prehistoric	0.7779	2.0865	3.1376	1.5069	0.0971
Carlson	34HP45-695-4	Prehistoric	1.1566	1.9450	4.6980	2.2202	0.3666
Carlson	34HP45-695-5	Prehistoric	1.0980	1.8893	4.7001	2.2198	0.3322
Carlson	34HP45-695-6	Prehistoric	1.1521	1.8758	4.7508	2.5965	0.3640
Carlson	34HP45-695-7	Prehistoric	0.9196	1.7849	4.3832	2.0984	0.2738
Carlson	34HP45-695-8	Prehistoric	0.9291	1.7430	4.3858	2.0412	0.2737
Carlson	34HP45-695-9	Prehistoric	0.9386	1.7186	4.4649	2.0545	0.3123
Carlson	34HP45-695-10	Prehistoric	0.8378	1.7250	4.1674	2.2248	0.2265
Carlson	34HP45-695-11	Prehistoric	0.7683	1.6513	3.9982	1.8966	0.1815
Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	34HP45-695-12	Prehistoric	0.7952	1.8138	3.9737	2.3048	0.1853
Carlson	34HP45-695-13	Prehistoric	0.7859	1.7714	4.1367	2.2642	0.2313
Carlson	34HP45-695-14	Prehistoric	0.6394	1.5921	3.7949	1.5451	0.1129
Carlson	34HP45-695-15	Prehistoric	0.7651	1.6879	4.2528	2.0312	0.1461
Carlson	34HP45-695-16	Prehistoric	0.5113	1.7099	3.3472	1.6629	0.0806
Carlson	34HP45-695-17	Prehistoric	0.3814	1.7673	3.1304	0.0000	0.0000
Carlson	34HP45-695-18	Prehistoric	0.4192	1.7439	3.1667	0.7470	0.0287
Carlson	34HP45-718-1	Prehistoric	1.0418	1.9252	3.5308	3.1938	0.0000
Carlson	34HP45-718-2	Prehistoric	1.0052	1.9900	3.2069	2.1501	0.1082
Carlson	34HP45-718-3	Prehistoric	1.0399	1.9332	3.5357	2.5829	0.3652
Carlson	34HP45-718-4	Prehistoric	1.3692	2.0509	3.1757	1.6317	0.6826
Carlson	34HP45-718-5	Prehistoric	1.3266	2.0875	3.1335	1.6106	0.4644
Carlson	34HP45-718-6	Prehistoric	1.3124	2.0827	3.1705	1.8480	0.3760
Carlson	34HP45-718-7	Prehistoric	1.1458	2.0224	3.2519	1.8813	0.3870
Carlson	34HP45-718-8	Prehistoric	1.1452	1.9981	3.2265	1.8064	0.4434
Carlson	34HP45-718-9	Prehistoric	1.1397	2.0138	3.2555	1.9691	0.5479
Carlson	34HP45-718-10	Prehistoric	1.1484	1.9002	3.3798	2.3001	0.2717
Carlson	34HP45-718-11	Prehistoric	1.1572	1.9361	3.2273	1.8039	0.1435
Carlson	34HP45-718-12	Prehistoric	1.1583	1.8684	3.1801	1.5609	0.0602
Carlson	34HP45-718-13	Prehistoric	1.0734	1.7048	3.9597	3.0060	0.3556
Carlson	34HP45-718-14	Prehistoric	1.0769	1.6934	3.9855	3.0672	0.3413
Carlson	34HP45-718-15	Prehistoric	1.0855	1.6956	3.8597	2.8600	0.0893
Carlson	34HP45-718-16	Prehistoric	1.2522	1.8088	3.1004	1.7204	0.0000
Carlson	34HP45-718-17	Prehistoric	1.2437	1.8011	3.0655	0.0296	0.0000
Carlson	34HP45-718-18	Prehistoric	1.2233	1.8067	3.0737	0.0000	0.0000
Carlson	34HP45-837-1	Prehistoric	0.6026	1.8284	2.8761	1.6477	0.0000
Carlson	34HP45-837-2	Prehistoric	0.5551	1.9112	2.9436	1.7882	0.0000
Carlson	34HP45-837-3	Prehistoric	0.4680	2.0168	2.9887	1.6205	0.0000
Carlson	34HP45-837-4	Prehistoric	0.7238	1.7134	2.8852	1.1050	0.0000
Carlson	34HP45-837-5	Prehistoric	0.6068	1.8235	2.8561	0.0000	0.0000
Carlson	34HP45-837-6	Prehistoric	0.5922	1.8351	2.8662	1.5592	0.0000
Carlson	34HP45-837-7	Prehistoric	0.6861	1.9113	3.1720	2.3045	0.0000

Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
34HP45-494-16	2.3471	0.5509	0.6718	1.6077	1.2311	0.3063	0.1515
34HP45-494-17	2.3287	0.6083	0.7026	1.5776	1.2743	0.2877	0.2085
34HP45-494-18	2.2987	0.3217	0.5799	1.5648	1.0490	0.2653	0.1451
34HP45-671-1	2.6235	0.5163	0.8907	1.5541	0.8614	0.3907	0.1262
34HP45-671-2	2.6316	0.5203	0.7941	1.6335	0.7973	0.4039	0.1013
34HP45-671-3	2.6113	0.5129	0.7945	1.4291	0.7554	0.3727	0.0838
34HP45-671-4	2.7094	0.8160	1.0246	1.7091	0.9030	0.4522	0.1809
34HP45-671-5	2.6460	0.6908	0.5781	1.5302	0.7402	0.4427	0.0600
34HP45-671-6	2.5921	0.5961	0.7827	1.5630	0.7678	0.4018	0.1535
34HP45-671-7	2.6450	0.6827	1.0193	1.8340	0.8554	0.4600	0.1723
34HP45-671-8	2.5762	0.5782	0.4309	1.5618	0.6676	0.4588	0.0393
34HP45-671-9	2.5663	0.5350	0.6930	1.5230	0.6754	0.4326	0.0895
34HP45-671-10	2.5978	0.6019	1.2589	1.9059	0.8645	0.4730	0.2540
34HP45-671-11	2.5145	0.4593	0.7403	1.6488	0.6626	0.4062	0.0854
34HP45-671-12	2.5210	0.4793	0.8449	1.7334	0.7322	0.4249	0.1222
34HP45-671-13	2.5319	0.6126	0.6356	1.8219	0.8486	0.3457	0.2499
34HP45-671-14	2.4362	0.5038	0.3384	1.7687	0.7620	0.2763	0.0704
34HP45-671-15	2.4572	0.4914	0.3066	1.7933	0.7286	0.2490	0.0552
34HP45-671-16	2.4242	0.5129	0.5670	1.7287	0.7250	0.2490	0.0977
34HP45-671-17	2.3988	0.4125	0.2836	1.7168	0.5724	0.2132	0.0308
34HP45-671-18	2.4160	0.4261	0.3137	1.7144	0.5902	0.2354	0.0430
34HP45-695-1	2.6469	0.1936	0.5312	2.0521	0.6429	0.2685	0.0814
34HP45-695-2	2.6081	0.2355	0.5752	2.1247	0.7063	0.2601	0.0769
34HP45-695-3	2.5588	0.2090	0.4715	2.1107	0.7153	0.2541	0.0990
34HP45-695-4	2.0423	0.2353	0.7281	1.5196	1.0900	0.3002	0.3064
34HP45-695-5	2.0132	0.1908	0.7299	1.4428	1.0993	0.3015	0.3088
34HP45-695-6	2.3057	0.2785	0.8712	1.4256	1.1514	0.4337	0.5165
34HP45-695-7	2.2848	0.3563	0.6412	1.7542	1.0249	0.2867	0.2237
34HP45-695-8	2.3098	0.3748	0.5911	1.7338	0.9888	0.2745	0.3341
34HP45-695-9	2.2043	0.1981	0.6607	1.6193	0.9792	0.2633	0.2280
34HP45-695-10	2.3175	0.1602	0.6163	1.7578	0.8931	0.3460	0.2426
34HP45-695-11	2.3773	0.2887	0.5238	1.8133	0.7163	0.4282	0.1737
Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
34HP45-695-12	2.4547	0.2398	0.5594	1.8613	0.7375	0.3920	0.3628
34HP45-695-13	2.3992	0.3029	0.7309	1.8103	0.8321	0.2532	0.3110
34HP45-695-14	2.3604	0.1558	0.4897	1.8094	0.7173	0.1954	0.1077
34HP45-695-15	2.3338	0.2453	0.6333	1.7349	0.8084	0.2279	0.2471
34HP45-695-16	2.3959	0.2510	0.5857	1.8359	1.3739	0.2521	0.1555
34HP45-695-17	2.3695	0.1973	0.4586	1.8499	1.0706	0.2428	0.0544
34HP45-695-18	2.3809	0.2037	0.4049	1.8581	1.0870	0.2477	0.0740
34HP45-718-1	2.6150	0.5735	0.6270	1.8301	1.1496	0.4165	0.5766
34HP45-718-2	2.6200	0.4830	0.3515	1.8421	0.9136	0.4090	0.1446
34HP45-718-3	2.5871	0.5355	0.4705	1.7818	0.9899	0.3718	0.3115
34HP45-718-4	2.5703	0.9760	0.5380	1.7483	1.3576	0.7945	0.0591
34HP45-718-5	2.5319	0.9775	0.5383	1.8243	1.3017	0.8197	0.0465
34HP45-718-6	2.5230	1.0337	0.6379	1.8880	1.3250	0.8696	0.0997
34HP45-718-7	2.4872	0.8845	0.5936	1.7805	1.5634	0.7720	0.1087
34HP45-718-8	2.4652	0.8365	0.5505	1.7826	1.5926	0.7855	0.0696
34HP45-718-9	2.4515	0.8579	0.5939	1.8166	1.7449	0.8179	0.0954
34HP45-718-10	2.4552	0.9460	0.7850	1.9881	1.9417	0.7684	0.2275
34HP45-718-11	2.4272	0.8902	0.6687	1.9832	1.9928	0.7543	0.0972
34HP45-718-12	2.4115	0.9089	0.6868	2.0101	1.6449	0.7160	0.0866
34HP45-718-13	2.2397	0.9721	1.3777	1.7453	3.0200	0.4993	0.6665
34HP45-718-14	2.3434	0.7300	1.1147	1.5553	2.8634	0.4499	0.6157
34HP45-718-15	2.2908	0.6424	0.8610	1.4725	2.3881	0.3939	0.4439
34HP45-718-16	2.3319	0.6260	0.5764	1.9018	1.1322	0.5524	0.0818
34HP45-718-17	2.3347	0.5991	0.4523	1.8777	1.0533	0.5490	0.0181
34HP45-718-18	2.2967	0.5257	0.5019	1.9246	1.0470	0.5158	0.0219
34HP45-837-1	2.6723	0.2252	0.2842	1.8562	0.5638	0.4239	0.0443
34HP45-837-2	2.6533	0.2493	0.3651	1.8899	0.5920	0.4777	0.0439
34HP45-837-3	2.6297	0.3032	0.4296	1.9387	0.5946	0.4715	0.0740
34HP45-837-4	2.5656	0.2443	0.3467	1.9284	0.5218	0.4084	0.0327
34HP45-837-5	2.5379	0.2687	0.3243	1.8880	0.5078	0.4523	0.0235
34HP45-837-6	2.5275	0.2643	0.3685	1.9072	0.5069	0.4469	0.0392
34HP45-837-7	2.5414	0.3694	0.5379	2.1043	0.7439	0.4631	0.1028

Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
34HP45-494-16	2.9599	0.4932	0.6530	0.2231	0.1375	0.8246	0.6600	0.2168
34HP45-494-17	2.9498	0.5005	0.6679	0.2222	0.1990	0.8715	0.6728	0.2370
34HP45-494-18	2.9404	0.4340	0.5479	0.2319	0.1277	0.6747	0.5299	0.1634
34HP45-671-1	2.6239	1.8892	0.5270	0.4140	0.0940	1.7825	1.4938	1.1034
34HP45-671-2	2.4673	2.0248	0.5180	0.4524	0.0797	1.9020	1.4868	1.1955
34HP45-671-3	2.4632	1.4890	0.4284	0.3773	0.0603	1.1490	0.9151	0.5479
34HP45-671-4	2.6386	0.9165	0.5493	0.3758	0.1208	0.9080	0.9369	0.3950
34HP45-671-5	2.5483	0.8309	0.5033	0.3715	0.0358	0.6831	0.7571	0.2613
34HP45-671-6	2.4891	0.8160	0.5059	0.3922	0.1086	0.7692	0.7990	0.2764
34HP45-671-7	2.5340	1.3066	0.5052	0.6268	0.1253	1.1950	1.1496	0.5750
34HP45-671-8	2.4567	1.2592	0.5359	0.6064	0.0284	1.0053	0.9006	0.4061
34HP45-671-9	2.4322	1.2304	0.4712	0.5313	0.0580	0.9918	0.8887	0.3725
34HP45-671-10	2.5676	1.9191	3.0022	0.7087	0.1797	1.9017	1.8372	1.1784
34HP45-671-11	2.4729	1.8292	0.7565	0.5979	0.0654	1.8112	1.7142	1.0674
34HP45-671-12	2.4866	1.8908	0.6716	0.6246	0.0842	1.8984	1.7827	1.1651
34HP45-671-13	2.4572	0.5441	0.3594	0.5616	0.2071	0.7586	0.9780	0.3129
34HP45-671-14	2.3305	0.3416	0.2959	0.5329	0.0846	0.4736	0.5204	0.1324
34HP45-671-15	2.2963	0.2298	0.2381	0.5308	0.0503	0.3457	0.3445	0.0806
34HP45-671-16	2.3162	0.3092	0.3418	0.6134	0.0794	0.4672	0.5744	0.1444
34HP45-671-17	2.2590	0.2348	0.2627	0.6102	0.0130	0.2948	0.3156	0.0720
34HP45-671-18	2.2823	0.2791	0.2813	0.6069	0.0349	0.3246	0.3229	0.0772
34HP45-695-1	2.4474	0.4380	0.5864	0.7391	0.0848	0.4195	0.4736	0.1098
34HP45-695-2	2.4196	0.4445	0.4945	0.8474	0.1030	0.4508	0.5110	0.1165
34HP45-695-3	2.4344	0.4629	0.5455	0.8466	0.0998	0.4872	0.7343	0.1370
34HP45-695-4	2.9797	0.4789	0.6013	0.0535	0.2336	0.6518	0.6622	0.1972
34HP45-695-5	2.9992	0.5348	0.6135	0.1058	0.2288	0.6466	0.6340	0.1876
34HP45-695-6	3.0000	0.5426	0.7406	0.0421	0.3808	0.7536	0.7540	0.2426
34HP45-695-7	2.9472	0.4834	0.5976	0.7511	0.1544	0.6162	0.5779	0.1802
34HP45-695-8	2.9748	0.4933	0.6762	0.6934	0.3416	0.5749	0.5310	0.1514
34HP45-695-9	2.9696	0.5849	0.5987	0.6846	0.1765	0.6116	0.6056	0.1838
34HP45-695-10	2.7580	0.4213	0.4572	0.9345	0.1776	0.5826	0.5516	0.1474
34HP45-695-11	2.6313	0.4042	0.4714	0.9612	0.1323	0.4982	0.5761	0.1455
Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
34HP45-695-12	2.5782	0.4677	0.5415	0.9957	0.2597	0.6059	0.7041	0.2065
34HP45-695-13	2.7288	0.4182	0.6834	0.7158	0.2414	0.6129	0.6526	0.1736
34HP45-695-14	2.6684	0.3449	0.4664	0.7544	0.0910	0.4534	0.4855	0.1105
34HP45-695-15	2.7748	0.3924	0.5000	0.6473	0.2174	0.5338	0.5951	0.1566
34HP45-695-16	2.7106	0.4082	0.4675	0.6457	0.1424	1.2087	0.7607	0.2651
34HP45-695-17	2.6894	0.3834	0.4016	0.6610	0.0600	0.8869	0.5969	0.1709
34HP45-695-18	2.7009	0.3626	0.4162	0.6585	0.0775	0.9197	0.6255	0.1860
34HP45-718-1	2.5707	0.9599	0.5759	0.6570	0.4041	1.0964	0.9720	0.4666
34HP45-718-2	2.5128	1.1870	0.6018	0.6782	0.1715	1.1133	1.0976	0.5858
34HP45-718-3	2.5863	1.0344	0.6780	0.6105	0.3364	1.1658	1.1748	0.5678
34HP45-718-4	3.1396	1.5126	1.2206	0.1049	0.1226	1.5768	1.6997	0.9080
34HP45-718-5	3.1014	1.4144	1.1750	0.1157	0.1056	1.4915	1.5634	0.8297
34HP45-718-6	3.0932	1.3966	1.1560	0.1411	0.2075	1.4888	1.5906	0.8333
34HP45-718-7	3.1164	1.3627	1.0350	0.0961	0.2424	1.5773	1.5793	0.8553
34HP45-718-8	3.1204	1.4003	1.0424	0.0829	0.1541	1.6204	1.5811	0.8601
34HP45-718-9	3.1471	1.5416	1.0792	0.0870	0.2165	1.7938	1.7363	1.0374
34HP45-718-10	3.1408	1.1741	1.0848	0.1048	0.3662	1.9103	1.5000	0.8516
34HP45-718-11	3.1563	1.0875	1.1092	0.1026	0.2590	1.9495	1.4933	0.8203
34HP45-718-12	3.1232	1.0374	1.0688	0.1153	0.2629	1.6038	1.3301	0.6589
34HP45-718-13	3.3377	1.0693	0.9548	0.3273	1.0921	3.0869	2.3592	1.6528
34HP45-718-14	3.2398	0.9581	1.0174	0.1799	0.9441	2.9259	2.1543	1.4721
34HP45-718-15	2.9967	0.7390	0.8483	0.1151	0.6212	2.1922	1.5524	0.9692
34HP45-718-16	2.9958	0.6055	0.7722	0.2847	0.2257	0.9399	0.8313	0.2984
34HP45-718-17	2.9767	0.4910	0.7110	0.2637	0.0486	0.7213	0.5930	0.1996
34HP45-718-18	2.9550	0.5091	0.7128	0.4138	0.0530	0.7412	0.6747	0.2205
34HP45-837-1	2.3868	1.2093	0.5764	0.4621	0.0834	1.0948	1.4237	0.6347
34HP45-837-2	2.4390	1.3069	0.6442	0.4579	0.0623	1.1977	1.5044	0.7150
34HP45-837-3	2.4304	1.3523	0.6607	0.4751	0.0869	1.2101	1.5712	0.7693
34HP45-837-4	2.4691	1.2053	0.7423	0.4344	0.0415	1.1113	1.5502	0.6747
34HP45-837-5	2.4794	1.0574	0.7748	0.4084	0.0283	0.9777	1.3535	0.5375
34HP45-837-6	2.4511	1.1217	0.7881	0.4674	0.0536	1.0265	1.3973	0.5917
34HP45-837-7	2.6568	1.2858	0.8050	0.6376	0.0825	1.1618	1.4704	0.6897

Full ID	LogNd	LogSm	LogEu	LogGd	LogDy	LogPb208	LogU
34HP45-494-16	0.4242	0.1583	0.0608	0.1693	0.0985	0.4517	1.2148
34HP45-494-17	0.4110	0.1762	0.0646	0.1582	0.1068	0.4041	1.1481
34HP45-494-18	0.3279	0.1125	0.0467	0.1122	0.0744	0.3737	1.1139
34HP45-671-1	1.7579	1.1421	0.5669	1.3139	1.1799	0.7345	0.3685
34HP45-671-2	1.8534	1.2179	0.6338	1.3966	1.2834	0.7559	0.3163
34HP45-671-3	1.1242	0.5973	0.2446	0.7760	0.7251	0.6179	0.3666
34HP45-671-4	0.7989	0.3667	0.1482	0.5040	0.3518	0.8337	0.4385
34HP45-671-5	0.6103	0.2688	0.0991	0.4067	0.2939	0.6540	0.3718
34HP45-671-6	0.6431	0.2642	0.0973	0.3984	0.2690	0.7152	0.3759
34HP45-671-7	1.0994	0.5588	0.2147	0.7389	0.5851	0.9552	0.4183
34HP45-671-8	0.8989	0.4094	0.1407	0.5761	0.4946	0.8245	0.3812
34HP45-671-9	0.8518	0.3603	0.1204	0.5223	0.4379	0.8108	0.3575
34HP45-671-10	1.7905	1.1379	0.5585	1.3227	1.1381	1.1735	0.5442
34HP45-671-11	1.6910	1.0394	0.4738	1.2352	1.0468	0.9703	0.4077
34HP45-671-12	1.7824	1.1269	0.5482	1.2982	1.1255	1.0015	0.4139
34HP45-671-13	0.5864	0.2444	0.0946	0.3682	0.1704	0.6081	0.4597
34HP45-671-14	0.3003	0.1449	0.0494	0.1542	0.0774	0.4199	0.4338
34HP45-671-15	0.1620	0.0744	0.0356	0.0641	0.0287	0.3518	0.3638
34HP45-671-16	0.2842	0.1202	0.0415	0.1362	0.0737	0.4496	0.5182
34HP45-671-17	0.1888	0.0762	0.0297	0.0824	0.0319	0.3284	0.4814
34HP45-671-18	0.1836	0.0599	0.0272	0.0848	0.0287	0.3471	0.4920
34HP45-695-1	0.3139	0.1150	0.0429	0.2333	0.0760	0.8091	0.4010
34HP45-695-2	0.3300	0.1176	0.0454	0.2441	0.0974	0.6985	0.3824
34HP45-695-3	0.4169	0.1559	0.0580	0.3579	0.1176	0.6711	0.3755
34HP45-695-4	0.4267	0.2017	0.0980	0.2475	0.0866	0.4196	0.4467
34HP45-695-5	0.4173	0.2118	0.0925	0.2435	0.1197	0.3183	0.4690
34HP45-695-6	0.5062	0.2283	0.1069	0.2823	0.1041	0.4524	0.4194
34HP45-695-7	0.4109	0.1733	0.0716	0.2170	0.1025	0.3719	0.6745
34HP45-695-8	0.3451	0.1556	0.0674	0.2000	0.0773	0.3440	0.7230
34HP45-695-9	0.4277	0.1812	0.0766	0.2304	0.1429	0.2988	0.6388
34HP45-695-10	0.3429	0.1547	0.0601	0.1776	0.0820	0.3316	0.5082
34HP45-695-11	0.3851	0.1351	0.0438	0.2137	0.0995	0.3159	0.4849
Full ID	LogNd	LogSm	LogEu	LogGd	LogDy	LogPb208	LogU
34HP45-695-12	0.5088	0.1931	0.0599	0.3011	0.1422	0.3617	0.4662
34HP45-695-13	0.4030	0.1509	0.0595	0.2113	0.1066	0.3813	0.5807
34HP45-695-14	0.2896	0.0951	0.0388	0.1433	0.0623	0.3266	0.5831
34HP45-695-15	0.3674	0.1383	0.0542	0.1890	0.0903	0.3698	0.5613
34HP45-695-16	0.3709	0.2008	0.1110	0.1569	0.0726	0.3993	0.7496
34HP45-695-17	0.2826	0.1261	0.0580	0.1455	0.0758	0.3404	0.7558
34HP45-695-18	0.3212	0.1424	0.0675	0.1449	0.0722	0.3765	0.7692
34HP45-718-1	0.9206	0.5331	0.2929	0.6982	0.4008	0.8237	0.5235
34HP45-718-2	1.1077	0.6307	0.2694	0.8478	0.5547	0.7963	0.5968
34HP45-718-3	1.0656	0.5801	0.2606	0.8225	0.4366	0.7798	0.5031
34HP45-718-4	1.4684	0.9643	0.5387	1.2282	0.8394	1.2137	1.2264
34HP45-718-5	1.3771	0.8708	0.4596	1.1322	0.7470	1.2670	1.2368
34HP45-718-6	1.3881	0.8948	0.4692	1.1409	0.7684	1.3986	1.2280
34HP45-718-7	1.3951	0.9357	0.5492	1.1078	0.7647	1.0716	1.2932
34HP45-718-8	1.3901	0.9421	0.5506	1.0911	0.7839	1.0598	1.3071
34HP45-718-9	1.5804	1.0886	0.6678	1.2312	0.9156	1.0769	1.3095
34HP45-718-10	1.2105	0.9579	0.6639	0.8647	0.5996	1.1042	1.3727
34HP45-718-11	1.0979	0.9380	0.6785	0.7639	0.5409	1.1149	1.3932
34HP45-718-12	1.0368	0.7351	0.4417	0.7237	0.4892	1.1291	1.4182
34HP45-718-13	1.4425	1.6634	1.4421	0.5748	0.4104	0.5717	0.8891
34HP45-718-14	1.3004	1.5011	1.2794	0.5458	0.3470	0.4847	0.9582
34HP45-718-15	0.9416	1.0471	0.8236	0.4045	0.2479	0.5092	1.0217
34HP45-718-16	0.5514	0.4365	0.2429	0.3277	0.1717	0.6771	1.4879
34HP45-718-17	0.3523	0.3058	0.1768	0.1834	0.0905	0.5824	1.4923
34HP45-718-18	0.4139	0.2933	0.1584	0.2114	0.1240	0.6431	1.4625
34HP45-837-1	1.2162	0.7218	0.3114	1.1948	0.6753	0.9154	0.3185
34HP45-837-2	1.3264	0.7947	0.3499	1.2461	0.7459	0.9585	0.3573
34HP45-837-3	1.3860	0.8624	0.3886	1.2974	0.8335	0.9418	0.3650
34HP45-837-4	1.2579	0.7356	0.3048	1.1690	0.6762	0.9601	0.3267
34HP45-837-5	1.0996	0.6001	0.2283	0.9753	0.5458	0.9700	0.3570
34HP45-837-6	1.1447	0.6354	0.2592	1.0212	0.5893	0.9932	0.3594
34HP45-837-7	1.2947	0.7676	0.3450	1.1108	0.7469	0.9144	0.4908

Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	34HP45-837-8	Prehistoric	0.6573	1.8134	3.0085	1.4950	0.0000
Carlson	34HP45-837-9	Prehistoric	0.6781	1.7208	3.0199	1.1025	0.0000
Carlson	34HP45-837-10	Prehistoric	0.6087	1.6589	3.0800	0.0000	0.0000
Carlson	34HP45-837-11	Prehistoric	0.5879	1.6308	2.9972	0.0000	0.0000
Carlson	34HP45-837-12	Prehistoric	0.6256	1.7228	3.0316	0.0000	0.0000
Carlson	34HP45-837-13	Prehistoric	0.5441	1.7168	3.5400	2.9874	0.0000
Carlson	34HP45-837-14	Prehistoric	0.3382	1.4856	3.3110	2.0633	0.0000
Carlson	34HP45-837-15	Prehistoric	0.4276	1.2812	3.2807	2.0034	0.0000
Carlson	34HP45-856-1	Prehistoric	1.1679	1.8891	3.4174	1.3696	0.0932
Carlson	34HP45-856-2	Prehistoric	1.1343	1.8424	3.4408	1.1661	0.0000
Carlson	34HP45-856-3	Prehistoric	1.1316	1.7674	3.5284	1.1886	0.0000
Carlson	34HP45-856-4	Prehistoric	1.0404	1.9078	3.9567	2.0870	0.2283
Carlson	34HP45-856-5	Prehistoric	1.0332	1.8298	3.9945	2.0806	0.3659
Carlson	34HP45-856-6	Prehistoric	0.9969	1.7766	3.9984	2.0357	0.1513
Carlson	34HP45-856-7	Prehistoric	1.0462	1.7569	4.2562	2.3454	0.1954
Carlson	34HP45-856-8	Prehistoric	1.0619	1.8643	4.2330	2.5573	0.2893
Carlson	34HP45-856-9	Prehistoric	1.0469	2.0582	4.2713	2.3111	0.1532
Carlson	34HP45-856-10	Prehistoric	1.0036	1.7845	3.4896	1.3369	0.0000
Carlson	34HP45-856-11	Prehistoric	1.0147	1.8089	3.4411	1.2124	0.0000
Carlson	34HP45-856-12	Prehistoric	1.0476	1.8071	3.5785	1.5887	0.0000
Carlson	34HP45-856-13	Prehistoric	1.0538	1.7754	3.7565	1.1432	0.0000
Carlson	34HP45-856-14	Prehistoric	1.0333	1.7857	3.8638	1.2548	0.0000
Carlson	34HP45-856-15	Prehistoric	0.9761	1.7851	3.8985	0.6526	0.0000
Carlson	34HP45-856-16	Prehistoric	0.7699	1.7286	3.3944	1.3610	0.0000
Carlson	34HP45-856-17	Prehistoric	0.6123	1.6443	3.1559	0.6311	0.0000
Carlson	34HP45-856-18	Prehistoric	0.5177	1.4349	3.2295	0.8337	0.0000
Carlson	34HP60-102-1	Prehistoric	0.8958	1.7931	2.6577	1.8480	0.4132
Carlson	34HP60-102-2	Prehistoric	0.8989	1.8584	2.5961	1.5807	0.3462
Carlson	34HP60-102-3	Prehistoric	0.9630	1.6806	2.6159	1.5940	0.2344
Carlson	34HP60-102-4	Prehistoric	0.5776	0.8797	2.8079	1.4502	0.1610
Carlson	34HP60-102-5	Prehistoric	0.7680	1.3060	2.6958	1.6020	0.2054
Carlson	34HP60-102-6	Prehistoric	0.9201	1.7963	2.7616	1.6411	0.3492
Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	34HP60-102-7	Prehistoric	0.6857	0.0000	2.8413	1.3561	0.0901
Carlson	34HP60-102-8	Prehistoric	0.9739	1.5571	2.8725	1.9924	0.2434
Carlson	34HP60-102-9	Prehistoric	1.0163	1.3065	2.9290	1.8452	0.3287
Carlson	34HP60-102-10	Prehistoric	0.9269	1.6743	2.8465	1.5003	0.3249
Carlson	34HP60-102-11	Prehistoric	0.8888	1.5428	2.8402	1.4369	0.3024
Carlson	34HP60-102-12	Prehistoric	0.9357	1.6338	2.8638	1.5765	0.3333
Carlson	34HP60-102-13	Prehistoric	0.7207	1.5500	2.6880	1.7711	0.3290
Carlson	34HP60-102-14	Prehistoric	0.6606	1.4700	2.6793	1.7628	0.3170
Carlson	34HP60-102-15	Prehistoric	0.6765	1.5709	2.6755	1.8199	0.2871
Carlson	34HP60-102-16	Prehistoric	0.5415	0.6535	2.7503	1.7809	0.2107
Carlson	34HP60-102-17	Prehistoric	0.5053	1.0734	2.6893	1.5919	0.1954
Carlson	34HP60-102-18	Prehistoric	0.4765	0.9515	2.6794	1.2112	0.0206
Carlson	34HP60-24-1	Prehistoric	0.6877	1.9759	2.6138	1.2424	0.0000
Carlson	34HP60-24-2	Prehistoric	0.7768	1.9384	2.4676	1.2174	0.0000
Carlson	34HP60-24-3	Prehistoric	0.4115	1.7831	2.3822	1.2368	0.0000
Carlson	34HP60-24-4	Prehistoric	0.7844	1.7024	2.4712	0.9850	0.0345
Carlson	34HP60-24-5	Prehistoric	1.0655	1.5792	2.5717	0.8295	0.3018
Carlson	34HP60-24-6	Prehistoric	1.0590	1.5153	2.5717	0.9453	0.3076
Carlson	34HP60-24-7	Prehistoric	0.6404	1.5422	2.5666	0.4294	0.0855
Carlson	34HP60-24-8	Prehistoric	0.5505	1.4859	2.5708	0.2370	0.0434
Carlson	34HP60-24-9	Prehistoric	0.6413	1.5780	2.5097	0.6891	0.0818
Carlson	34HP60-24-10	Prehistoric	0.5211	1.0759	2.5782	0.0000	0.2616
Carlson	34HP60-24-11	Prehistoric	0.5823	1.3283	2.5487	0.0000	0.2670
Carlson	34HP60-24-12	Prehistoric	0.5906	1.3190	2.5726	0.0000	0.3250
Carlson	34HP45-369-1	Prehistoric	0.8644	3.8979	3.8679	2.5104	0.1697
Carlson	34HP45-369-2	Prehistoric	0.8871	3.7906	3.7962	2.4812	0.2084
Carlson	34HP45-369-3	Prehistoric	0.8685	3.7922	3.8431	2.8688	0.3964
Carlson	34HP45-369-4	Prehistoric	0.7915	3.7897	3.3233	2.3358	0.1703
Carlson	34HP45-369-5	Prehistoric	0.7420	3.7441	3.4249	2.3409	0.1590
Carlson	34HP45-369-6	Prehistoric	0.7039	3.7588	3.4605	2.3217	0.1644
Carlson	34HP45-369-7	Prehistoric	0.7097	3.7097	3.3496	2.3121	0.1557
Carlson	34HP45-369-8	Prehistoric	0.8776	3.7011	3.3147	2.3085	0.1714

Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
34HP45-837-8	2.5057	0.3245	0.4216	2.0387	0.6654	0.4311	0.0396
34HP45-837-9	2.4587	0.3366	0.4965	1.9689	0.6685	0.4407	0.0604
34HP45-837-10	2.4348	0.4035	0.4451	2.1233	0.7553	0.3997	0.0889
34HP45-837-11	2.4376	0.3819	0.4076	2.1540	0.7234	0.3628	0.0087
34HP45-837-12	2.4262	0.3555	0.4115	2.1595	0.7464	0.3734	0.0256
34HP45-837-13	2.4916	0.6363	0.8270	2.3466	0.9964	0.8489	0.3804
34HP45-837-14	2.4038	0.5199	0.6001	2.2148	0.8482	0.6137	0.1825
34HP45-837-15	2.3783	0.4774	0.5684	2.1962	0.8417	0.6297	0.1640
34HP45-856-1	2.6058	0.2041	0.6588	1.9053	1.2270	0.4278	0.0768
34HP45-856-2	2.5630	0.2069	0.5154	1.9085	1.3296	0.4369	0.0674
34HP45-856-3	2.5149	0.2896	0.5608	1.8673	1.5847	0.4153	0.0793
34HP45-856-4	2.4862	0.4414	0.8372	1.8829	1.2709	0.3882	0.3749
34HP45-856-5	2.4831	0.3336	0.8288	1.8520	1.1526	0.3702	0.3767
34HP45-856-6	2.4028	0.5878	0.7547	1.7987	1.5520	0.3580	0.3088
34HP45-856-7	2.3759	0.3424	0.7788	1.6525	1.2517	0.3426	0.5369
34HP45-856-8	2.3563	0.5805	0.8643	1.7033	1.1623	0.3573	0.6475
34HP45-856-9	2.3594	0.6599	0.8471	1.6992	1.2808	0.3672	0.5023
34HP45-856-10	2.3295	0.2126	0.5155	1.6659	1.0588	0.4027	0.1006
34HP45-856-11	2.3227	0.2910	0.4508	1.6581	1.0584	0.3878	0.0974
34HP45-856-12	2.3230	0.3212	0.5278	1.7034	1.0694	0.4122	0.2001
34HP45-856-13	2.2767	0.1865	0.6922	1.7393	0.9738	0.3606	0.0749
34HP45-856-14	2.2320	0.1808	0.7670	1.7677	0.9532	0.3274	0.0988
34HP45-856-15	2.1976	0.1768	0.7742	1.7440	0.8687	0.2913	0.0517
34HP45-856-16	2.2577	0.1827	0.6759	1.7289	0.6266	0.2089	0.1547
34HP45-856-17	2.2477	0.1709	0.4729	1.7463	0.5665	0.1720	0.0723
34HP45-856-18	2.2556	0.2237	0.4990	1.7540	0.5858	0.1999	0.0981
34HP60-102-1	2.4540	0.4781	0.2309	0.7241	0.7025	0.4181	0.0861
34HP60-102-2	2.4810	0.5558	0.1553	0.9066	0.5297	0.3899	0.0229
34HP60-102-3	2.4520	0.5329	0.1533	1.0700	0.5804	0.3185	0.0327
34HP60-102-4	2.4608	0.4623	0.0960	1.4817	0.4220	0.1249	0.0517
34HP60-102-5	2.4353	0.4861	0.1806	1.4393	0.4989	0.3298	0.0512
34HP60-102-6	2.4823	0.7197	0.2121	1.2245	0.5233	0.5473	0.0810
Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
34HP60-102-7	2.3826	0.5391	0.1534	1.4347	0.4888	0.3098	0.0362
34HP60-102-8	2.4343	0.7338	0.2896	1.4572	0.5859	0.6242	0.0693
34HP60-102-9	2.4136	0.7256	0.3074	1.4680	0.6039	0.7127	0.0914
34HP60-102-10	2.3200	0.6956	0.2094	1.3490	0.6493	0.8118	0.0514
34HP60-102-11	2.3016	0.6264	0.1912	1.4007	0.6371	0.7064	0.0528
34HP60-102-12	2.3166	0.7202	0.2264	1.4260	0.7122	0.7984	0.0679
34HP60-102-13	2.2698	0.7085	0.2613	1.6485	0.6910	0.9908	0.0409
34HP60-102-14	2.2518	0.6849	0.2498	1.6435	0.6757	0.9983	0.0355
34HP60-102-15	2.2437	0.6650	0.2595	1.6193	0.6529	0.9800	0.0368
34HP60-102-16	2.2942	0.6780	0.3049	1.5883	0.6225	0.8800	0.0859
34HP60-102-17	2.2467	0.5992	0.2500	1.5714	0.5898	0.8659	0.0367
34HP60-102-18	2.2436	0.6001	0.2174	1.5751	0.4993	0.5782	0.0284
34HP60-24-1	2.4814	0.6611	0.2841	1.5022	0.6959	0.3916	0.0688
34HP60-24-2	2.4602	0.5814	0.1866	1.4961	0.6607	0.3298	0.0485
34HP60-24-3	2.4096	0.4450	0.2531	1.4459	0.6226	0.2788	0.0538
34HP60-24-4	2.3642	0.5767	0.2253	1.5970	0.8543	0.5083	0.0350
34HP60-24-5	2.3345	0.6898	0.2486	1.6647	1.0362	0.7101	0.0219
34HP60-24-6	2.3094	0.6843	0.2665	1.6527	1.0421	0.7378	0.0249
34HP60-24-7	2.3071	0.7132	0.1937	1.5293	0.9058	0.5237	0.0257
34HP60-24-8	2.3209	0.7720	0.1845	1.4520	0.8523	0.4976	0.0187
34HP60-24-9	2.3159	0.8233	0.1931	1.4337	0.9227	0.5728	0.0186
34HP60-24-10	2.2471	0.6387	0.3081	1.7011	1.0764	0.7051	0.0157
34HP60-24-11	2.2368	0.6242	0.2801	1.6824	1.0568	0.7198	0.0103
34HP60-24-12	2.2062	0.5427	0.2836	1.6249	1.0863	0.7220	0.0117
34HP45-369-1	2.4996	0.1981	0.6240	1.9203	1.1331	0.4591	0.0907
34HP45-369-2	2.5546	0.3458	0.8051	1.8445	1.8674	0.5336	0.0364
34HP45-369-3	2.5542	0.2078	0.7988	1.9653	2.9113	0.4701	0.4806
34HP45-369-4	2.5960	0.1962	0.6993	1.8426	2.8062	0.4395	0.0314
34HP45-369-5	2.5650	0.1700	0.5891	2.0664	2.0518	0.3781	0.0223
34HP45-369-6	2.6020	0.1752	0.5608	2.2030	1.1293	0.3808	0.0099
34HP45-369-7	2.5990	0.1739	0.6102	2.3011	0.9572	0.3633	0.0125
34HP45-369-8	2.5932	0.2073	0.7516	2.4818	1.0128	0.3200	0.0135

Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
34HP45-837-8	2.5849	1.4721	0.7303	0.6633	0.0389	1.2766	1.6152	0.8163
34HP45-837-9	2.5819	1.6673	0.7358	0.7199	0.0593	1.4538	1.8385	1.0275
34HP45-837-10	2.4896	0.4320	0.5069	1.0361	0.0797	0.4781	0.5440	0.1492
34HP45-837-11	2.4832	0.4096	0.4965	1.0119	0.0284	0.4348	0.3807	0.1070
34HP45-837-12	2.5124	0.4435	0.5095	0.9386	0.0358	0.4636	0.4311	0.1208
34HP45-837-13	2.7396	0.4283	0.5392	0.7994	0.2935	0.7029	1.0009	0.2794
34HP45-837-14	2.5668	0.2858	0.3082	0.8346	0.1237	0.4596	0.6201	0.1302
34HP45-837-15	2.5730	0.3059	0.3474	0.8284	0.1407	0.4391	0.5731	0.1377
34HP45-856-1	3.0938	0.7007	0.6817	0.1099	0.0868	0.8480	0.6324	0.2230
34HP45-856-2	3.0914	0.6601	0.6996	0.1044	0.0872	0.9475	0.6603	0.2483
34HP45-856-3	3.0825	0.5965	0.6852	0.1252	0.1133	1.1275	0.6752	0.2938
34HP45-856-4	3.0434	0.6195	0.8742	0.1285	0.2951	0.8659	0.7152	0.2577
34HP45-856-5	3.0508	0.6325	0.8817	0.0996	0.2891	0.7934	0.7615	0.2582
34HP45-856-6	3.0499	0.6226	0.8561	0.1384	0.2600	1.1824	0.8102	0.3359
34HP45-856-7	2.9887	0.6518	0.9355	0.0994	0.3792	0.9171	0.7855	0.2876
34HP45-856-8	3.0116	0.7178	1.0245	0.1433	0.3776	0.8655	0.8609	0.3121
34HP45-856-9	3.0178	0.6606	0.9212	0.1293	0.3852	0.9815	0.9173	0.3455
34HP45-856-10	3.0510	0.5013	0.6547	0.1435	0.0909	0.6507	0.4393	0.1406
34HP45-856-11	3.0621	0.5059	0.6732	0.1433	0.0748	0.6643	0.4338	0.1570
34HP45-856-12	3.0739	0.5792	0.7159	0.1507	0.1866	0.7171	0.6079	0.2056
34HP45-856-13	2.9967	0.4899	0.6161	0.5221	0.0716	0.5461	0.4008	0.1359
34HP45-856-14	2.9381	0.4656	0.5901	0.6993	0.0717	0.5790	0.4331	0.1363
34HP45-856-15	2.8705	0.4322	0.5105	0.8140	0.0326	0.4933	0.3928	0.1082
34HP45-856-16	2.4690	0.5884	0.4438	1.0782	0.1208	0.6460	0.8555	0.2582
34HP45-856-17	2.4240	0.4026	0.2841	1.0957	0.0407	0.4592	0.6073	0.1499
34HP45-856-18	2.4266	0.4978	0.3571	1.1122	0.0759	0.5501	0.6679	0.1939
34HP60-102-1	2.2755	1.2619	0.2409	0.1018	0.0449	1.1961	0.9502	0.6097
34HP60-102-2	2.1552	1.0765	0.1377	0.1035	0.0230	1.0305	0.9632	0.5888
34HP60-102-3	2.0920	0.7593	0.1231	0.0961	0.0246	0.7557	0.7771	0.3795
34HP60-102-4	1.9152	0.4761	0.0717	0.5697	0.0391	0.6644	0.5657	0.3422
34HP60-102-5	2.1496	1.0855	0.2667	0.5246	0.0389	1.1314	0.7107	0.6324
34HP60-102-6	2.3355	1.2892	0.3758	0.3289	0.0425	1.2606	0.7662	0.6572

Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
34HP60-102-7	2.0886	0.9945	0.2026	0.5540	0.0244	0.9788	0.5742	0.5080
34HP60-102-8	2.3536	1.4022	0.5197	0.4678	0.0320	1.3845	0.9375	0.8260
34HP60-102-9	2.3912	1.5063	0.5735	0.4462	0.0487	1.5048	1.0535	0.9205
34HP60-102-10	2.5017	1.0995	0.6564	0.2600	0.0272	1.0923	0.6062	0.4566
34HP60-102-11	2.4491	1.0262	0.6009	0.3102	0.0200	1.0107	0.5251	0.3861
34HP60-102-12	2.5395	1.1145	0.7032	0.1891	0.0262	1.0924	0.6216	0.4444
34HP60-102-13	2.5860	1.1703	0.5674	0.1279	0.0148	1.3286	0.8286	0.6098
34HP60-102-14	2.5657	1.0955	0.5255	0.1881	0.0241	1.2461	0.7872	0.5508
34HP60-102-15	2.5310	1.0215	0.4903	0.2021	0.0099	1.1617	0.7144	0.4940
34HP60-102-16	2.3921	0.6541	0.3548	0.3542	0.0425	0.7102	0.7208	0.2979
34HP60-102-17	2.3832	0.6132	0.3327	0.3641	0.0046	0.6300	0.6587	0.2454
34HP60-102-18	2.1326	0.3105	0.1429	0.5646	0.0029	0.3656	0.4024	0.1166
34HP60-24-1	2.1063	0.8725	0.2044	0.7118	0.0924	0.8296	0.7702	0.4093
34HP60-24-2	2.1373	0.6807	0.2011	0.6833	0.0319	0.6466	0.5793	0.2721
34HP60-24-3	2.1383	0.7956	0.2386	0.7042	0.0336	0.7291	0.7249	0.3377
34HP60-24-4	2.4242	1.1707	0.5007	0.4428	0.0306	1.0867	0.8534	0.5124
34HP60-24-5	2.6349	1.4521	0.6934	0.2612	0.0490	1.3827	1.1321	0.7218
34HP60-24-6	2.6472	1.5028	0.7104	0.2596	0.0324	1.4543	1.1792	0.7710
34HP60-24-7	2.4958	0.9998	0.6206	0.3061	0.0336	0.9145	0.7032	0.3699
34HP60-24-8	2.4592	0.7736	0.5628	0.3042	0.0393	0.6608	0.3824	0.1598
34HP60-24-9	2.5539	0.8922	0.6722	0.2063	0.0237	0.7855	0.4884	0.2285
34HP60-24-10	2.6729	1.2332	0.8758	0.1618	0.0284	1.2293	0.9825	0.5764
34HP60-24-11	2.6709	1.2384	0.8648	0.1398	0.0199	1.2333	1.0020	0.5832
34HP60-24-12	2.7103	1.2681	0.9148	0.1453	0.0216	1.2942	1.0623	0.6219
34HP45-369-1	2.6608	0.1226	1.4304	0.2237	0.0045	0.1140	0.2103	0.0289
34HP45-369-2	2.7952	0.1219	1.3148	0.2696	0.0018	0.1913	0.2232	0.0309
34HP45-369-3	2.9893	0.2896	1.4112	0.4292	0.0416	0.5115	0.5915	0.1224
34HP45-369-4	2.8850	0.0972	0.9727	0.3747	0.0026	0.2624	0.1040	0.0128
34HP45-369-5	2.6137	0.0814	0.7982	0.3760	0.0021	0.1225	0.1387	0.0166
34HP45-369-6	2.5909	0.1614	0.8706	0.5449	0.0000	0.2209	0.3851	0.0588
34HP45-369-7	2.5387	0.1853	1.1644	0.8500	0.0002	0.1635	0.2947	0.0393
34HP45-369-8	2.5712	0.2309	1.1842	0.9125	0.0004	0.2630	0.3852	0.0676

Full ID	LogNd	LogSm	LogEu	LogGd	LogDy	LogPb208	LogU
34HP45-837-8	1.4428	0.9187	0.4303	1.2466	0.9027	0.8824	0.4489
34HP45-837-9	1.6785	1.1259	0.5758	1.4480	1.1439	0.9341	0.4284
34HP45-837-10	0.3160	0.1517	0.0925	0.2466	0.1000	0.6664	0.3226
34HP45-837-11	0.2988	0.1546	0.0793	0.1674	0.0774	0.6354	0.3003
34HP45-837-12	0.3030	0.1728	0.0816	0.2008	0.0983	0.6316	0.3297
34HP45-837-13	0.4655	0.2273	0.1475	0.3960	0.1017	0.8658	0.6140
34HP45-837-14	0.2213	0.1360	0.0676	0.1801	0.0245	0.6403	0.4342
34HP45-837-15	0.2224	0.1200	0.0767	0.1417	0.0492	0.6315	0.4501
34HP45-856-1	0.4628	0.4419	0.2677	0.3675	0.1619	0.5292	0.9118
34HP45-856-2	0.4608	0.4476	0.2911	0.3407	0.1475	0.4521	0.9113
34HP45-856-3	0.4160	0.5610	0.3904	0.2631	0.1024	0.4083	0.9000
34HP45-856-4	0.5259	0.4089	0.2417	0.3852	0.1438	0.3859	0.8476
34HP45-856-5	0.5788	0.3728	0.1935	0.4251	0.1758	0.3052	0.8569
34HP45-856-6	0.5552	0.4910	0.3107	0.3436	0.1623	0.3403	0.8456
34HP45-856-7	0.5806	0.3974	0.2109	0.4118	0.1871	0.2810	0.7524
34HP45-856-8	0.6716	0.3808	0.1836	0.4704	0.2284	0.3268	0.7920
34HP45-856-9	0.7086	0.4256	0.2060	0.4628	0.2278	0.3835	0.7947
34HP45-856-10	0.2921	0.2175	0.1183	0.1408	0.0683	0.2138	0.8883
34HP45-856-11	0.3129	0.2169	0.1083	0.1621	0.0768	0.1960	0.9003
34HP45-856-12	0.4390	0.2481	0.1255	0.2514	0.1307	0.2178	0.9075
34HP45-856-13	0.2552	0.1707	0.0943	0.1304	0.0795	0.2714	0.7580
34HP45-856-14	0.3025	0.1678	0.0801	0.1487	0.0751	0.2872	0.6962
34HP45-856-15	0.2454	0.1311	0.0648	0.1347	0.0668	0.2889	0.6085
34HP45-856-16	0.6450	0.2820	0.0895	0.4297	0.2220	0.3733	0.3112
34HP45-856-17	0.4269	0.1611	0.0496	0.2602	0.1110	0.3428	0.3015
34HP45-856-18	0.5390	0.2280	0.0672	0.3006	0.1689	0.3583	0.3715
34HP60-102-1	1.1840	0.6061	0.2398	0.7780	0.5821	0.2133	0.6839
34HP60-102-2	1.1613	0.6064	0.2409	0.7946	0.5358	0.1774	0.6405
34HP60-102-3	0.8724	0.4207	0.1528	0.5500	0.3360	0.2028	0.5774
34HP60-102-4	0.7583	0.3162	0.0910	0.4254	0.1779	0.3566	0.2484
34HP60-102-5	1.2249	0.6558	0.2420	0.7062	0.5471	0.3960	0.5259
34HP60-102-6	1.2291	0.6061	0.2344	0.7269	0.5899	0.3820	0.7285
Full ID	LogNd	LogSm	LogEu	LogGd	LogDy	LogPb208	LogU
34HP60-102-7	1.0626	0.5442	0.1842	0.6069	0.4630	0.4003	0.6266
34HP60-102-8	1.4153	0.8232	0.3439	0.9086	0.7678	0.4381	1.0662
34HP60-102-9	1.5478	0.9287	0.4134	1.0041	0.8708	0.4635	1.1731
34HP60-102-10	0.9837	0.4431	0.1442	0.5317	0.4498	0.3605	1.3783
34HP60-102-11	0.8833	0.3770	0.1222	0.4541	0.3802	0.3375	1.3265
34HP60-102-12	0.9715	0.4401	0.1416	0.5197	0.4482	0.4384	1.4529
34HP60-102-13	1.1783	0.5771	0.1936	0.6747	0.5111	0.6157	1.5316
34HP60-102-14	1.0991	0.5184	0.1778	0.6095	0.4637	0.5945	1.5107
34HP60-102-15	1.0209	0.4741	0.1453	0.5393	0.4142	0.5357	1.4766
34HP60-102-16	0.6977	0.2868	0.0903	0.3726	0.2450	0.4653	1.4049
34HP60-102-17	0.6249	0.2366	0.0724	0.3267	0.2043	0.4121	1.4060
34HP60-102-18	0.3184	0.0975	0.0348	0.1583	0.0793	0.3276	0.9836
34HP60-24-1	0.8551	0.4164	0.1610	0.5924	0.3592	0.4354	0.3876
34HP60-24-2	0.6709	0.3110	0.1095	0.4124	0.2666	0.3926	0.3645
34HP60-24-3	0.8021	0.3910	0.1374	0.5343	0.3276	0.4279	0.3627
34HP60-24-4	1.0430	0.5376	0.2149	0.6852	0.5244	0.6997	0.7946
34HP60-24-5	1.3051	0.7262	0.3106	0.8963	0.7303	0.7985	1.0458
34HP60-24-6	1.3501	0.7582	0.3275	0.9265	0.7755	0.8346	1.0297
34HP60-24-7	0.8249	0.3969	0.1535	0.4827	0.3787	0.7393	0.8272
34HP60-24-8	0.4135	0.1699	0.0806	0.2116	0.1668	0.7630	0.7674
34HP60-24-9	0.5378	0.2281	0.1007	0.2891	0.2238	0.8225	0.8581
34HP60-24-10	1.1081	0.5632	0.2260	0.6718	0.5703	0.8180	1.1490
34HP60-24-11	1.1109	0.5738	0.2219	0.6900	0.5729	0.7902	1.1471
34HP60-24-12	1.1508	0.6105	0.2434	0.7089	0.6019	0.8032	1.1865
34HP45-369-1	0.0947	0.0173	0.2022	0.0388	0.0162	0.3191	0.9330
34HP45-369-2	0.1731	0.0361	0.7184	0.0352	0.0211	0.3017	0.9053
34HP45-369-3	0.4869	0.1325	1.3114	0.1392	0.0639	0.3482	0.8373
34HP45-369-4	0.2472	0.0302	1.2017	0.0271	0.0128	0.2043	0.7859
34HP45-369-5	0.1183	0.0191	0.6284	0.0199	0.0136	0.1747	0.7572
34HP45-369-6	0.2105	0.0496	0.1892	0.0580	0.0341	0.2342	0.6938
34HP45-369-7	0.1587	0.0347	0.1268	0.0439	0.0370	0.2662	0.5800
34HP45-369-8	0.2266	0.0557	0.1505	0.0684	0.0419	0.5675	0.5299

Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	34HP45-494-1	Prehistoric	0.7628	3.7411	3.2548	2.2470	0.1435
Carlson	34HP45-494-2	Prehistoric	0.7535	3.6459	3.5881	2.2079	0.1708
Carlson	34HP45-494-3	Prehistoric	0.8384	3.6470	3.5792	2.2912	0.1770
Carlson	34HP45-494-4	Prehistoric	1.1270	3.6596	3.4810	2.2968	0.1701
Carlson	34HP45-494-5	Prehistoric	1.0364	3.7190	3.5074	2.2647	0.1594
Carlson	34HP45-494-6	Prehistoric	1.0191	3.7259	3.5355	2.2360	0.1467
Carlson	34HP45-494-7	Prehistoric	2.1139	3.6429	3.8635	1.9987	0.2395
Carlson	34HP45-740-1	Prehistoric	0.9333		3.7909	2.1967	0.1443
Carlson	34HP45-740-2	Prehistoric	0.8240		3.5473	2.2896	0.1523
Carlson	34HP45-740-3	Prehistoric	0.8256		3.7053	2.1802	0.1479
Carlson	34HP45-740-4	Prehistoric	0.7888		3.5362	2.2074	0.1513
Carlson	34HP45-740-5	Prehistoric	0.7860		3.5655	2.2626	0.1467
Carlson	34HP45-740-6	Prehistoric	0.7874		3.6747	2.2394	0.1432
Carlson	34HP45-740-7	Prehistoric	0.7691		3.5590	2.2530	0.1429
Carlson	34HP45-740-8	Prehistoric	0.8011		3.5823	2.1735	0.1406
Carlson	34HP45-811-1	Prehistoric	1.1540		3.7757	2.4365	0.1987
Carlson	34HP45-811-2	Prehistoric	1.0917		4.0316	2.3001	0.1926
Carlson	34HP45-811-3	Prehistoric	0.9923		4.1085	2.3296	0.1827
Carlson	34HP45-811-4	Prehistoric	0.9283		3.9596	2.2684	0.1763
Carlson	34HP45-811-5	Prehistoric	0.8980		3.8997	2.2317	0.1786
Carlson	34HP45-811-6	Prehistoric	0.8611		3.6271	2.2265	0.1526
Carlson	34HP45-774-1	Prehistoric	0.8946	3.6845	3.4703	2.3048	0.1850
Carlson	34HP45-774-2	Prehistoric	0.8102	3.6429	3.4823	2.1817	0.2114
Carlson	34HP45-774-3	Prehistoric	0.9085	3.6569	3.4236	2.1554	0.2062
Carlson	34HP45-774-4	Prehistoric	0.9834	3.6344	3.3702	2.1610	0.1943
Carlson	34HP45-774-5	Prehistoric	1.0548	3.6611	3.3701	2.2155	0.1973
Carlson	34HP45-774-6	Prehistoric	0.9823	3.7159	3.5771	2.3138	0.2113
Carlson	34HP45-746-1	Prehistoric	1.0492	3.8068	3.3353	2.3123	0.1547
Carlson	34HP45-746-2	Prehistoric	0.7893	3.6616	3.2360	2.1504	0.1586
Carlson	34HP45-746-3	Prehistoric	0.8569	3.6674	3.3836	2.1953	0.1569
Carlson	34HP45-746-4	Prehistoric	0.9145	3.6783	3.3724	2.1606	0.1525
Carlson	34HP45-746-5	Prehistoric	0.8653	3.6889	3.3492	2.2477	0.1651
Data Run by	Full ID	Era	LogB	LogNa	LogMg25	LogK	LogSc
Carlson	34HP45-746-6	Prehistoric	0.9944	3.7074	3.3605	2.2433	0.1531
Carlson	34HP45-746-7	Prehistoric	0.9741	3.6897	3.4308	2.1672	0.1532
Carlson	34HP194-775-1	Prehistoric	0.9094	3.7297	3.0317	2.7016	0.2610
Carlson	34HP194-775-2	Prehistoric	0.9291	3.7407	3.0906	2.7491	0.0000
Carlson	34HP194-775-3	Prehistoric	0.8697	3.7667	3.1088	2.9085	0.0335
Carlson	34HP194-775-4	Prehistoric	0.8563	3.7846	3.1194	3.0826	0.0312
Carlson	34HP194-775-5	Prehistoric	0.8289	3.7521	3.1852	2.7236	0.1746
Carlson	34HP194-775-6	Prehistoric	0.7198	3.6759	3.3620	2.5388	0.1709
Carlson	34HP194-775-7	Prehistoric	0.7720	3.6863	3.5776	2.6459	0.1557
Carlson	48NO201-5924-1	Prehistoric	1.3534	3.9337	3.4849	2.3597	0.1477
Carlson	48NO201-5924-2	Prehistoric	1.3569	3.9257	3.4831	2.4448	0.1664
Carlson	48NO201-5924-3	Prehistoric	1.3743	3.9548	3.5118	2.4025	0.1662
Carlson	48NO201-5924-4	Prehistoric	1.4478	3.9755	3.4952	2.3913	0.1626
Carlson	48NO201-5924-5	Prehistoric	1.4329	3.9945	3.5210	2.3934	0.1590
Carlson	48NO201-5924-6	Prehistoric	1.4282	3.9877	3.5202	2.4453	0.1664
Carlson	24CT30-6754-1	Prehistoric	1.2362	3.9935	3.8661	2.2174	0.1652
Carlson	24CT30-6754-2	Prehistoric	1.0487	3.9531	3.6338	2.2778	0.1639
Carlson	24CT30-6754-3	Prehistoric	0.9579	3.9480	3.4588	2.3252	0.1557
Carlson	24CT30-6754-4	Prehistoric	0.9403	3.9404	3.4388	2.3943	0.1703
Carlson	24CT30-6754-5	Prehistoric	0.9129	3.9339	3.4831	2.4316	0.1736
Carlson	24CT30-6754-6	Prehistoric	0.9303	3.9663	3.4996	2.4190	0.1739
Carlson	24CT30-6754-7	Prehistoric	0.9251	4.0036	3.4708	2.4283	0.1734
Carlson	24CT30-6754-8	Prehistoric	0.9002	3.9753	3.4683	2.3912	0.1635
Carlson	24CT30-6754-9	Prehistoric	1.0686	3.9884	3.4597	2.4255	0.1708

Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
34HP45-494-1	2.6178	0.1826	0.5457	2.1335	0.8716	0.1720	0.0116
34HP45-494-2	2.6219	0.1845	0.6684	2.5149	0.7966	0.1277	0.0086
34HP45-494-3	2.6406	0.1857	0.7464	2.4783	0.8251	0.1808	0.0126
34HP45-494-4	2.6467	0.1895	0.7551	2.4437	0.8987	0.1840	0.0192
34HP45-494-5	2.6766	0.1858	0.6376	2.4389	0.6300	0.0688	0.0097
34HP45-494-6	2.6734	0.1810	0.5533	2.4494	0.6607	0.0708	0.0067
34HP45-494-7	2.5993	0.3519	0.7987	2.3241	1.5464	0.7054	0.0069
34HP45-740-1	2.6101	0.1843	0.6637	2.4648	1.1686	0.3733	0.0126
34HP45-740-2	2.6465	0.1808	0.4715	2.3082	0.6577	0.1402	0.0096
34HP45-740-3	2.6150	0.1818	0.5084	2.5047	0.6276	0.1988	0.0092
34HP45-740-4	2.6377	0.1832	0.5087	2.5125	0.7116	0.1714	0.0122
34HP45-740-5	2.6115	0.1770	0.5025	2.3930	0.5957	0.1167	0.0147
34HP45-740-6	2.6639	0.1848	0.4894	2.5321	0.6299	0.1733	0.0176
34HP45-740-7	2.6427	0.1773	0.5802	2.4455	0.6350	0.1669	0.0222
34HP45-740-8	2.6352	0.1804	0.5494	2.5155	0.7144	0.1772	0.0129
34HP45-811-1	2.6472	0.2067	0.8087	2.1664	1.1084	0.6946	0.1462
34HP45-811-2	2.6599	0.2243	0.9268	2.3159	1.1036	0.5909	0.0757
34HP45-811-3	2.6444	0.1959	0.8433	2.2953	1.0731	0.6321	0.0521
34HP45-811-4	2.6523	0.1898	0.7601	2.3711	1.0578	0.5452	0.0169
34HP45-811-5	2.6812	0.1943	0.7662	2.5044	1.0868	0.4534	0.0174
34HP45-811-6	2.6631	0.1867	0.6673	2.5900	0.6982	0.1922	0.0245
34HP45-774-1	2.5890	0.1820	0.3086	2.4615	1.0267	0.2483	0.0661
34HP45-774-2	2.6318	0.1888	0.5212	2.4040	0.9907	0.2537	0.0092
34HP45-774-3	2.6740	0.1984	0.3238	2.4462	0.9726	0.3301	0.0029
34HP45-774-4	2.6427	0.2023	0.2410	2.4895	0.8280	0.2330	0.0108
34HP45-774-5	2.6159	0.1982	0.4605	2.4477	0.6466	0.1660	0.0133
34HP45-774-6	2.5851	0.1984	0.2929	2.5007	0.7164	0.1347	0.0113
34HP45-746-1	2.5418	0.1783	0.3836	2.3128	0.9455	0.1383	0.0295
34HP45-746-2	2.6068	0.1855	0.4565	2.4400	0.8413	0.1571	0.0077
34HP45-746-3	2.6373	0.1853	0.2112	2.4068	0.6371	0.0710	0.0028
34HP45-746-4	2.6068	0.1756	0.3475	2.4491	0.8880	0.1576	0.0092
34HP45-746-5	2.6329	0.1895	0.2587	2.4420	0.6013	0.0792	0.0156

Full ID	LogTi	LogCo	LogCu65	LogZn66	LogGa	LogAs	LogRb
34HP45-746-6	2.6385	0.1880	0.2516	2.3738	0.6821	0.0903	0.0139
34HP45-746-7	2.6654	0.1782	0.2247	2.3829	0.6857	0.0840	0.0139
34HP194-775-1	2.5925	0.3739	0.9348	2.5456	0.7633	0.1624	0.0600
34HP194-775-2	2.6324	0.8379	0.6161	2.5372	0.7781	0.2539	0.0550
34HP194-775-3	2.6309	0.5643	0.5363	2.5161	0.7748	0.0304	0.0591
34HP194-775-4	2.6243	0.3960	0.7216	2.5219	0.7822	0.2574	0.1069
34HP194-775-5	2.6172	0.2405	0.4252	2.4587	0.8374	0.1251	0.0482
34HP194-775-6	2.5881	0.1602	0.3155	2.4531	0.7961	0.0332	0.0317
34HP194-775-7	2.5704	0.1454	0.3220	2.6121	0.9208	0.0166	0.0365
48NO201-5924-1	2.6231	0.1798	0.1859	1.3711	0.7782	0.0332	0.0174
48NO201-5924-2	2.6463	0.1894	0.2006	1.3239	0.7907	0.0340	0.0210
48NO201-5924-3	2.6356	0.1889	0.2968	1.3984	0.8343	0.0415	0.0474
48NO201-5924-4	2.6593	0.1884	0.2462	1.3353	0.8719	0.0357	0.0169
48NO201-5924-5	2.6534	0.1838	0.2896	1.3563	0.8156	0.0412	0.0188
48NO201-5924-6	2.6952	0.1935	0.2508	1.2722	0.7977	0.0409	0.0220
24CT30-6754-1	2.5767	0.2048	0.4920	1.8619	1.0554	0.1227	0.0199
24CT30-6754-2	2.6253	0.1973	0.3014	1.5678	0.9119	0.0573	0.0105
24CT30-6754-3	2.6036	0.1841	0.2266	1.2984	0.8571	0.0410	0.0105
24CT30-6754-4	2.6153	0.1932	0.2328	1.2319	0.8262	0.0275	0.0123
24CT30-6754-5	2.6587	0.1903	0.2164	1.1508	0.7984	0.0261	0.0192
24CT30-6754-6	2.6743	0.1939	0.2241	1.1832	0.8675	0.0377	0.0129
24CT30-6754-7	2.6995	0.1913	0.2146	1.2587	0.9083	0.0399	0.0117
24CT30-6754-8	2.6926	0.1859	0.1787	1.2064	0.8521	0.0302	0.0072
24CT30-6754-9	2.6664	0.2000	0.2143	1.2455	0.8961	0.0453	0.0103

Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
34HP45-494-1	2.6346	0.1110	0.9703	0.6206	0.0125	0.0947	0.1809	0.0246
34HP45-494-2	2.4278	0.0045	0.1349	0.7119	0.0014	0.0091	0.0051	0.0021
34HP45-494-3	2.4662	0.0517	0.7472	0.7934	0.0032	0.0424	0.0332	0.0074
34HP45-494-4	2.5182	0.0179	0.7877	0.6155	0.0012	0.0230	0.0299	0.0043
34HP45-494-5	2.2518	0.0044	0.1384	0.6646	0.0000	0.0056	0.0030	0.0009
34HP45-494-6	2.2199	0.0053	0.1084	0.5595	0.0046	0.0086	0.0127	0.0015
34HP45-494-7	3.2256	1.6845	2.4331	0.1409	0.0006	1.5140	1.3644	0.7756
34HP45-740-1	2.8679	0.0706	0.3835	0.2942	0.0022	0.0836	0.1748	0.0215
34HP45-740-2	2.3422	0.0024	0.0203	0.2557	0.0002	0.0049	0.0041	0.0007
34HP45-740-3	2.3587	0.0072	0.0402	0.3665	0.0003	0.0084	0.0092	0.0006
34HP45-740-4	2.3691	0.0124	0.2493	0.3426	0.0003	0.0135	0.0252	0.0022
34HP45-740-5	2.2231	0.0046	0.0382	0.3285	0.0005	0.0066	0.0606	0.0021
34HP45-740-6	2.2634	0.0054	0.0415	0.3403	0.0006	0.0070	0.0219	0.0022
34HP45-740-7	2.2741	0.0030	0.0361	0.3825	0.0005	0.0049	0.0050	0.0007
34HP45-740-8	2.3660	0.0032	0.0225	0.6463	0.0009	0.0079	0.0070	0.0018
34HP45-811-1	2.7902	0.0239	0.1586	0.2253	0.0191	0.0561	0.1164	0.0235
34HP45-811-2	2.8278	0.2305	0.1767	0.4709	0.0077	0.2340	0.4452	0.0888
34HP45-811-3	2.8087	0.1428	0.1501	0.6354	0.0017	0.1197	0.2968	0.0425
34HP45-811-4	2.7543	0.2348	0.1996	0.6000	0.0007	0.2240	0.4962	0.0894
34HP45-811-5	2.7010	0.1472	0.2590	0.7934	0.0005	0.1393	0.3043	0.0463
34HP45-811-6	2.2082	0.0460	0.0216	1.1059	0.0006	0.0624	0.1814	0.0186
34HP45-774-1	2.6150	0.0625	0.3834	1.2761	0.0046	0.0889	0.2250	0.0356
34HP45-774-2	2.6658	0.1390	1.1089	1.0744	0.0012	0.1990	0.3834	0.0568
34HP45-774-3	2.5752	0.0421	0.4778	1.1730	0.0007	0.1102	0.1833	0.0256
34HP45-774-4	2.4660	0.0214	0.3930	1.2004	0.0015	0.0384	0.0884	0.0139
34HP45-774-5	2.3058	0.0188	0.3460	1.2881	0.0095	0.0305	0.1250	0.0322
34HP45-774-6	2.3179	0.0139	0.4309	0.9574	0.0059	0.0208	0.0385	0.0113
34HP45-746-1	2.5452	0.0753	0.6138	0.4677	0.0026	0.0766	0.1471	0.0230
34HP45-746-2	2.5292	0.0485	0.8198	0.7542	0.0001	0.0389	0.0771	0.0098
34HP45-746-3	2.3186	0.0027	0.0741	0.5617	0.0013	0.0017	0.0006	0.0002
34HP45-746-4	2.5438	0.0051	0.1187	0.6706	0.0003	0.0060	0.0023	0.0017
34HP45-746-5	2.2997	0.0027	0.0595	0.7855	0.0000	0.0008	0.0000	0.0000
Full ID	LogSr88	LogY	LogZr	LogMo	LogCs	LogLa	LogCe	LogPr
34HP45-746-6	2.3522	0.0021	0.0855	0.6804	0.0008	0.0033	0.0015	0.0000
34HP45-746-7	2.3104	0.0029	0.0760	0.8033	0.0005	0.0054	0.0070	0.0010
34HP194-775-1	2.5103	0.2042	0.7211	0.8466	0.0311	0.2492	0.2972	0.0897
34HP194-775-2	2.5001	0.1496	0.6040	0.7640	0.0182	0.2015	0.2491	0.0759
34HP194-775-3	2.4623	0.0730	0.5852	0.7189	0.0103	0.1096	0.1341	0.0360
34HP194-775-4	2.4694	0.1228	0.6785	0.7560	0.0046	0.1755	0.2158	0.0417
34HP194-775-5	2.4624	0.0771	0.5193	0.6114	0.0043	0.1121	0.1464	0.0305
34HP194-775-6	2.4045	0.0168	0.3190	0.3019	0.0033	0.0324	0.0382	0.0145
34HP194-775-7	2.4194	0.0278	0.3221	0.1821	0.0028	0.0365	0.0426	0.0183
48NO201-5924-1	2.4921	0.0035	0.1740	0.3860	0.0006	0.0060	0.0073	0.0008
48NO201-5924-2	2.5186	0.0043	0.1606	0.2391	0.0010	0.0054	0.0093	0.0014
48NO201-5924-3	2.5898	0.0054	0.1610	0.3515	0.0018	0.0059	0.0163	0.0020
48NO201-5924-4	2.6290	0.0106	0.4076	0.4310	0.0005	0.0245	0.0206	0.0017
48NO201-5924-5	2.6335	0.0033	0.2175	0.4034	0.0008	0.0053	0.0021	0.0002
48NO201-5924-6	2.6243	0.0076	0.3731	0.5096	0.0005	0.0061	0.0059	0.0004
24CT30-6754-1	2.7662	0.0080	0.5824	0.0847	0.0038	0.0160	0.0161	0.0021
24CT30-6754-2	2.6039	0.0035	0.2800	0.0808	0.0001	0.0072	0.0157	0.0002
24CT30-6754-3	2.5082	0.0030	0.1325	0.0991	0.0001	0.0069	0.0004	0.0011
24CT30-6754-4	2.4752	0.0022	0.1410	0.0865	0.0002	0.0067	0.0010	0.0004
24CT30-6754-5	2.3998	0.0031	0.0462	0.0947	0.0005	0.0057	0.0004	0.0001
24CT30-6754-6	2.4714	0.0030	0.0306	0.2224	0.0002	0.0061	0.0007	0.0012
24CT30-6754-7	2.5236	0.0030	0.0681	0.3547	0.0002	0.0073	0.0004	0.0004
24CT30-6754-8	2.4527	0.0026	0.0266	0.3237	0.0002	0.0055	0.0004	0.0002
24CT30-6754-9	2.4699	0.0026	0.2784	0.3072	0.0005	0.0074	0.0036	0.0008

Full ID	LogNd	LogSm	LogEu	LogGd	LogDy	LogPb208	LogU
34HP45-494-1	0.0890	0.0157	0.1023	0.0240	0.0166	0.3888	0.2753
34HP45-494-2	0.0090	0.0012	0.0817	0.0021	0.0009	0.4206	0.0188
34HP45-494-3	0.0239	0.0025	0.0897	0.0055	0.0042	0.4489	0.2060
34HP45-494-4	0.0253	0.0061	0.0990	0.0065	0.0013	0.2907	0.2392
34HP45-494-5	0.0073	0.0012	0.0546	0.0006	0.0089	0.1786	0.0069
34HP45-494-6	0.0101	0.0016	0.0607	0.0021	0.0009	0.1970	0.0038
34HP45-494-7	1.3381	0.6797	0.5162	0.7634	0.7335	1.1592	0.9009
34HP45-740-1	0.0761	0.0172	0.2074	0.0213	0.0113	0.5036	0.5036
34HP45-740-2	0.0053	0.0011	0.0702	0.0006	0.0007	0.0779	0.0278
34HP45-740-3	0.0085	0.0015	0.0583	0.0008	0.0010	0.2634	0.0333
34HP45-740-4	0.0153	0.0018	0.0744	0.0019	0.0015	0.2597	0.0406
34HP45-740-5	0.0093	0.0029	0.0561	0.0020	0.0016	0.0993	0.0124
34HP45-740-6	0.0102	0.0008	0.0622	0.0013	0.0003	0.2252	0.0174
34HP45-740-7	0.0244	0.0011	0.0606	0.0007	0.0007	0.2051	0.0160
34HP45-740-8	0.0038	0.0034	0.0750	0.0009	0.0005	0.3554	0.0172
34HP45-811-1	0.0376	0.0082	0.1724	0.0142	0.0089	0.1187	0.7136
34HP45-811-2	0.2851	0.0729	0.1901	0.0824	0.0582	0.2242	0.6544
34HP45-811-3	0.1579	0.0412	0.1726	0.0418	0.0330	0.2383	0.7127
34HP45-811-4	0.2822	0.0752	0.1595	0.0812	0.0564	0.3680	0.7114
34HP45-811-5	0.1515	0.0337	0.1679	0.0406	0.0294	0.3584	0.6301
34HP45-811-6	0.0654	0.0111	0.0657	0.0191	0.0108	0.4660	0.0722
34HP45-774-1	0.0865	0.0276	0.1424	0.0243	0.0169	0.3808	0.2856
34HP45-774-2	0.1724	0.0405	0.1394	0.0531	0.0295	0.3847	0.6305
34HP45-774-3	0.0797	0.0145	0.1306	0.0206	0.0066	0.2918	0.5077
34HP45-774-4	0.0361	0.0067	0.0990	0.0188	0.0042	0.4268	0.1895
34HP45-774-5	0.0289	0.0094	0.0698	0.0293	0.0050	0.3344	0.1077
34HP45-774-6	0.0141	0.0033	0.0671	0.0071	0.0031	0.3447	0.0446
34HP45-746-1	0.0833	0.0176	0.1220	0.0223	0.0151	0.3123	0.1340
34HP45-746-2	0.0472	0.0088	0.0950	0.0112	0.0073	0.4091	0.2040
34HP45-746-3	0.0027	0.0000	0.0499	0.0002	0.0003	0.1260	0.0144
34HP45-746-4	0.0076	0.0015	0.0983	0.0005	0.0001	0.3661	0.1961
34HP45-746-5	0.0038	0.0006	0.0445	0.0006	0.0000	0.2172	0.0093
34HP45-746-6	0.0034	0.0008	0.0594	0.0003	0.0002	0.1955	0.0325
34HP45-746-7	0.0070	0.0011	0.0582	0.0010	0.0005	0.1513	0.0097
34HP194-775-1	0.2618	0.1066	0.0897	0.1103	0.0776	1.8411	0.1006
34HP194-775-2	0.1932	0.0809	0.0759	0.0878	0.0591	1.6340	0.1089
34HP194-775-3	0.1001	0.0349	0.0434	0.0459	0.0288	1.2094	0.0527
34HP194-775-4	0.1718	0.0463	0.0362	0.0500	0.0320	1.6772	0.0405
34HP194-775-5	0.1143	0.0368	0.0350	0.0355	0.0247	1.1771	0.0280
34HP194-775-6	0.0269	0.0216	0.0289	0.0151	0.0116	0.5937	0.0195
34HP194-775-7	0.0525	0.0218	0.0378	0.0229	0.0164	0.5814	0.0282
48NO201-5924-1	0.0060	0.0013	0.0773	0.0014	0.0019	0.0210	0.0901
48NO201-5924-2	0.0066	0.0015	0.0831	0.0016	0.0001	0.0256	0.0605
48NO201-5924-3	0.0065	0.0020	0.0914	0.0011	0.0001	0.0402	0.1441
48NO201-5924-4	0.0134	0.0017	0.0975	0.0015	0.0011	0.0294	0.1832
48NO201-5924-5	0.0030	0.0005	0.0932	0.0005	0.0003	0.0161	0.2007
48NO201-5924-6	0.0066	0.0002	0.0928	0.0012	0.0008	0.0202	0.1065
24CT30-6754-1	0.0121	0.0046	0.1491	0.0054	0.0012	0.0336	0.6340
24CT30-6754-2	0.0037	0.0012	0.1124	0.0017	0.0004	0.0221	0.3141
24CT30-6754-3	0.0081	0.0005	0.0973	0.0007	0.0006	0.0178	0.0887
24CT30-6754-4	0.0041	0.0006	0.0903	0.0004	0.0000	0.0119	0.0437
24CT30-6754-5	0.0036	0.0004	0.0858	0.0002	0.0005	0.0098	0.0102
24CT30-6754-6	0.0062	0.0004	0.1022	0.0005	0.0003	0.0086	0.0289
24CT30-6754-7	0.0072	0.0004	0.1158	0.0008	0.0009	0.0097	0.0504
24CT30-6754-8	0.0028	0.0002	0.0981	0.0003	0.0003	0.0083	0.0086
24CT30-6754-9	0.0065	0.0011	0.1068	0.0003	0.0001	0.0153	0.0420