Using Particle Size Analysis to Separate the Deposition of a Bonebed and Artifact at the Wenas Creek Mammoth Site

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USING PARTICLE SIZE ANALYSIS TO SEPARATE THE DEPOSITION OF A
BONEBED AND ARTIFACT AT THE WENAS CREEK MAMMOTH SITE

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ABSTRACT

USING PARTICLE SIZE ANALYSIS TO SEPARATE THE DEPOSITION OF A BONEBED AND ARTIFACT AT THE WENAS CREEK MAMMOTH SITE

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June 2015

The 2005 discovery of a 17,000 year old mammoth bonebed in close proximity to a possible artifact at the Wenas Creek Mammoth Site (WCMS) brought with it the question of whether the bones and artifact were actually deposited together. If the two are associated, the WCMS would qualify as a Pre-Clovis site, a title given to just a handful of proven archaeological sites in North America, though claimed for numerous more. A close interval particle size analysis was performed on 2 column samples from the WCMS with the intention of identifying microstratification that would separate the bonebed from the artifact. Although no conclusive evidence for microstratification was determined through this test, other processes could still explain the close proximity positioning of the artifact and the bonebed.
I would first like to thank Dr. Patrick Lubinski, my committee chair. His encouragement, patience and guidance deserve special recognition. I also would like to thank the remaining committee members, Dr. Karl Lillquist, and Dr. Patrick McCutcheon, for their support throughout my graduate school career and for serving on my committee. Additionally, I would like to thank my husband Rick, and my children Claira and Nick for their never ending encouragement and extreme patience as I attempted to balance thesis work with the daily happenings of being a wife and mother. Lastly, I would like to thank the rest of my family and friends who continued to gently encourage the completion of this thesis and helped give me the strength to continue no matter the circumstance.

I would also like to thank those who assisted during the various stages it took to complete this thesis: Katherine Krieger, Barbara Parsons, and Rose Fredericks, who assisted in the collection of my samples, and Lisa Ely, Patrick Johnston, and Caitlin Orem, who mentored me in the use of the Mastersizer 2000. Helpful and much appreciated insight and suggestion on pretreatment were provided by Vance Holliday, Brett Lenz, Peter Jacobs, Joe Mason, and Bill Reitze. Additionally, I’d like to thank Central Washington University’s Department of Biological Sciences who graciously lent me glassware and other supplies for lab work, as well as the Department of Geological Sciences who kindly shared lab space and equipment necessary for project completion. The Wenas Creek Mammoth Project to which this thesis contributes has received
generous contributions and support from landowners Doug and Bronwyn Mayo, Central Washington University, field school and laboratory students and volunteers, and private donors, and I thank all of these individuals as well for without their help and support we would not be able to investigate the implications this site has to offer
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CHAPTER I
INTRODUCTION

The initial human settlement of the Americas has been a controversial issue for decades (Grayson and Meltzer 2002; Roosevelt et al, 2002; Waguespack 2007). Scientists argue over when people first inhabited the Americas, how they got here, and how they subsisted (Dincauze 1984; Grayson and Meltzer 2002; Holiday 2000; Haynes 1969; Haynes 2002; Waguespeck and Surovell 2003). There is a large data gap in the archaeological record when looking for sites predating Clovis occupation (ca. 11,500 B.P.), specifically in eastern Washington (Lyman 2000). In particular, sites containing evidence of human-mammoth interaction are quite sparse in North America in general, but particularly in the Pacific Northwest (Grayson and Meltzer 2003; Fiedel and Haynes 2004; Kenady et al, 2011; Lawler 2011; Waters et al, 2011). The Wenas Creek Mammoth Site, which is the focus of the proposed research, may provide missing and important information about the peopling of the Americas with regard to its time framing as well as early human interaction with Pleistocene megafauna.

In 2005, a mammoth was inadvertently discovered in the Wenas Valley on a bench just above Wenas Creek, just outside of Selah, Washington (Figure 1). Excavations on the Wenas Creek Mammoth from 2005 to 2010 recovered a substantial number of bones from this animal, and the location of the mammoth is at an elevation too high and a distance too far away to have been deposited by Missoula floods (Lubinski et al, 2007, 2014a), and too far down valley to have been affected by direct glacial activity. In addition, an excavation unit (XU12) which contains some of the mammoth bonebed, also
contains some bison bones, and a small chert flake fragment (FS 261, Cat. 176), all within the same stratigraphic layer (Lubinski et al, 2009, 2014b; see Figure 2). The flake fragment lies 15 cm above the mammoth/bison bone bed and its depositional context relative to the bonebed is unclear.

In an attempt to clarify this depositional context, bone samples from both mammoth and bison were sent in for AMS radiocarbon dating and sediment samples were sent in for infrared-stimulated luminescence dating (IRSL). The eight bone samples yielded dates of approximately 13,000-14,000 B.P., or 15,500-17,000 cal B.P. (Lubinski et al, 2014a). Four of the IRSL samples were collected from sediment surrounding the flake and sent in for dating. Of the 94 resulting estimates from these 4 samples 80% dated at an average of 16.8 ± 0.9 Ka, and 20% averaged 5.1 ± 0.5 Ka (Lubinski et al,
This means that 80% of the dating results from around the flake match both the IRSL sediment dates from elsewhere in the stratum as well as the radiocarbon bone dates. This could signify contemporaneous Pre-Clovis deposition of both the flake and the bonebed, or that a disturbance occurred within the bonebed stratum during which the flake was deposited, such as a mass wasting event, or bioturbation. Thus, deciphering the depositional history of this layer will provide a better understanding of the relationship, if any, between the bonebed and the flake fragment.

Fig 2. Elevation backplot showing stratigraphy and association of flake (Cat 176) and bones (Lubinski, Terry & McCutcheon 2014: Figure 2). Graph shows all total station data for a 30 cm wide strip (500.70-501.00 m North) from 90.0-93.5 m East. Black polygons are all bones mapped within these coordinates. Wk-20117 is the location of a bone collagen radiocarbon sample assayed at 13,788±70 RCYBP.

Several different scenarios could account for an association between the artifact and bonebed, each with different levels of certainty about the contemporaneity of the artifact and bonebed deposits. A depositional association would indicate that the specimens were deposited during the same event, although both could be redeposited together in this event from separate earlier deposits. A chronological association would have temporal evidence (in our case, luminescence sediment dates) to support the
interpretation that the artifact and bonebed were deposited to this location at about the same time, although not necessarily in the same depositional event. A stronger association would be justified with the demonstration of both a depositional and a chronological association, but even then there would be no certainty that the artifact was used on or with the bonebed given the likelihood for redeposition and the coarse nature of the sediment dates. Nonetheless, if there is no evidence to suggest that the flake fragment has had a different depositional history than the bonebed, it is presumable that they were initially deposited simultaneously.

Contemporaneous deposition in and of itself does not mean that the flake fragment was used at the same time the animals, whose bones are in the bonebed, died. Work on dating the sediments that encase both the flake and the bonebed (Lubinski et al. 2014a) showed that most of sediments are the same age as the bonebed (i.e., $^{14}$C dates on the bone), although the flake fragment could be intrusive if it is derived from the $\sim$20% of sediments averaging deposition $\sim$5 Ka. For this study, I presume that the bonebed is a coherent, well dated unit and am seeking to discover whether the flake is associated with it depositionally. The research question here is whether there is any evidence in the sediment microstratigraphy surrounding the bone bed and flake fragment to suggest that they have different depositional histories.

The purpose of this thesis is to determine whether there is any evidence for microstratigraphy within the Stratum II sediment at the Wenas Creek Mammoth Site, particularly stratigraphy that would disassociate the bonebed from the chert flake fragment. Microstratification within Stratum II located between the bonebed and the flake would support and confirm their being deposited during different events thus
falsifying any hypothesis for contemporaneity of deposition. In order to determine microstratigraphy within the Stratum, I performed a close interval particle size analysis of the Stratum II sediment.

The particle size analysis may be able to help determine if there is any decipherable sorting and/or patterns of sorting within the Stratum II sediments, which could indicate multiple depositional events. If there are discernable substrata, the number and locations of the boundaries then become very important in disassociating the events that deposited the flake and the bonebed. In order to perform this close interval particle size analysis, I collected 2 column samples from Stratum II in 2 cm intervals. These samples were pretreated and analyzed in the Malvern Mastersizer 2000 for particle size distribution. The data from the Mastersizer was then assessed for evidence of microstratification signifying separate episodes of deposition. Depending on the character of a possible downslope depositional event (Postma 1986), sediment could be deposited in a regular graded, or reverse or inverse graded pattern which would leave the most dense particles of the top and the lightest on the bottom (Gray and Chugunov 2006; Major 1997; Naylor 1980; Rick 1976; Savage and Lun 1988).

Although a relative depositional association between this flake and the multi species bonebed would not in any way prove pre-Clovis occupation in the Pacific Northwest, a lack of discernable microstratification within Stratum II would indicate that the flake fragment and bones were either deposited during the same event, or the flake fragment was brought to its peculiar location by other means, most likely through bioturbation. Taking into account other factors like the post-depositional environment and the effects of bioturbation are only a few of the things that could be considered in
order to have full confidence in the nature of the association. Although pre-Clovis status is not a likely scenario for the Wenas Creek Mammoth site, the authenticity of other purported pre-Clovis sites is still a current issue being debated throughout North America (Grayson and Meltzer 2002; Kenady et al, 2011; Kitchen et al, 2008; Lawler 2011; Meltzer 2004; Morrow et al, 2012; Waguespeck 2007; Waters et al, 2011; Whitley and Dorn 1993). Deposition of the flake and bonebed during the same event could also indicate that the flake fragment and bones were initially deposited during different events upslope, and then redepited during a colluvial event bringing them all downslope at the same time.

This thesis is organized into five chapters. Chapter II contains a review of literature pertaining to important objectives of this thesis. First is a review of Pleistocene archaeology and geoarchaeology of North America, and specifically, the Wenas Valley and site location. This is followed by a review of site formation processes, followed by an indepth review of particle size analysis and its usefulness in deciphering depositional history of sediment. Chapter III presents the methods I used to perform the microstratigraphic analysis for this thesis and how I analyzed the results. Chapter IV discusses my findings, conclusions on the results and processes, and recommendations and implications for future studies. Finally, Chapter V contains the journal article manuscript for this journal-ready thesis option.
CHAPTER II

PRE-CLOVIS, SITE SETTING, AND GEOARCHAEOLOGY

The problem I intend to investigate at Wenas Creek requires an understanding of two distinct dimensions of New World archaeology: pre-Clovis human occupation and the prehistoric utilization of mammoths. It also requires an understanding of the geologic history of Wenas Valley and how particle size analysis may be useful in determining depositional sequence. The methods I employ for my analysis rely on an understanding of both large and small-scale geologic and geomorphic processes. As previously discussed, pre-Clovis archaeology and early human association with mammoths is surrounded by controversy in the New World primarily due to the fact that evidence is similarly sparse for both subjects. The literature on geologic history is more abundant and unambiguous.

Pre-Clovis and Mammoths in New World Archaeology

The study of pre-Clovis archaeological assemblages in the New World is closely tied to a much larger and very significant research problem: determining when and by which route(s) people first came to the New World and ultimately arrived south of the Laurentide and Cordilleran ice sheets (Haynes 2002; Meltzer 1995; Whitley and Dorn 1993). There have been several competing theories proposed, from a single land-based immigration via the Bering Land Bridge, to multiple waves of immigration by both land and sea. Countless articles, papers and discussions have focused on this question over the last century (Haynes 2002; Kitchen et al, 2008; Meltzer 1995; Waguespack 2007).
To date, proposed New World pre-Clovis archaeological sites include Monte Verde, Chili (Dillehay 1997), Meadowcroft Rockshelter, Pennsylvania (Goldberg and Arpin 1999), Cactus Hill, South Carolina (McAvoy 2000), Hebior-Schaefer, Wisconsin (Overstreet and Kolb 2003; Johnson 2007; Waters et al, 2011) and many others. Interestingly, the Hebior and Schaefer sites presumably contain the only documented evidence to date of pre-Clovis human butchery of proboscideans; the sites date as early as 13,530–11,200 B.P. (Johnson 2007; Waters et al, 2011). If the flake and mammoth remains at Wenas Creek are found to be associated, another pre-Clovis site may be able to be added to the archaeological record, and more importantly one in the Pacific Northwest. Future taphonomic examination of the mammoth bones may also produce evidence for this site being one of the few sites exhibiting pre-Clovis human use of mammoths.

Many mammoth bone isolates have been discovered in the Pacific Northwest (Barton 1999; Gilbow 1981; Lillquist et al, 2005; Newcomb and Repenning 1970; Scott and Clem 1967), but they lack either the information of their original spatial contexts, or that information was lost as the bones were carried hundreds of miles in Missoula floods to their new location (Barton 1999). At this time, there are no confirmed instances of Pre-Clovis archaeological association with proboscideans in the Pacific Northwest. There are, however, some sites claiming this association. These sites include Ledgerwood in Washington (Gustafson et al, 1991), Manis in Washington (Gustafson et al, 1979; Waters et al, 2011), Owl Cave /Wasden in Idaho (Miller 1989), and Umatilla in Washington (Gilbow 1981). This lack of hard evidence could be because prehistoric people in the Pacific Northwest did not actually utilize proboscideans, or because Pacific Northwest
proboscidean sites have returned ambiguous evidence regarding their association with human interaction.

New World archaeological sites containing evidence for human utilization of proboscideans were first discovered in the southwestern United States and were associated technologically and temporally with distinctive Clovis artifacts, including Clovis points at a site outside of Clovis, New Mexico (Haynes 1966; Haynes 2002). Additional Clovis sites containing proboscideans are distributed across the southwestern U.S. (Naco and Murray Springs, Arizona and Gault, Texas), the Great Plains (Colby, Wyoming) through the Midwest (Kimmswick site, Missouri and Boaz Mastodon site in Richland County, Wisconsin) and into the East (Haynes 2002; Waters and Stafford 2007). Given the widespread distribution of proboscidean archaeological sites across Eurasia and the New World, it is curious that none have been found to date in the Pacific Northwest. This study could provide the first site in the Pacific Northwest exhibiting human use of proboscideans.

Geologic History of the Wenas Valley

Columbia River Basalts, dating back into the late Miocene (approximately 17 to 6 Ma), predominantly underlie the landscape in this area, and from the Cascades to Idaho (Bingham and Grolier 1966; Tolan et al, 2009). Since their deposition, the Columbia River Basalts have been altered tectonically to create fold and thrust belts which shape the landscape. At the end of the Miocene basalt depositions, a phase of continental pyroclastic and sedimentary materials accreted and often interfingered with these basalts and is known as the Ellensburg Formation. These materials are derived from ancient
river and lake systems, and tephras from local active Miocene volcanoes (Tolan et al., 2009) The Ellensburg Formation formed at the end of the Miocene and into the Pliocene (Tolan et al., 2009)

The final retreat of the Pleistocene glaciers and the outburst floods at about 13,500-13,000 B.P. marked the last of the major landscape-forming events in this study area (Benito and O’Connor 2003; Booth et al., 2004). Geology in the study area has changed since then through geomorphic processes such as weathering, mass-wasting, fluvial activity, and wind.

Mammoth Site Setting

The Wenas Valley, bounded by Umtanum Ridge to the north and Cleman Mountain to the south, is home to Wenas Creek, a tributary of the Yakima River and part of the Columbia River hydrographic basin. Ellensburg Formation volcanioclastic sediments are present on the well eroded surface of Cleman mountain (Bingham and Grollier 1966; Tolan et al., 2009). The mammoth excavation site is located in an area denoted as a Quaternary landslide deposit (Bentley and Campbell 1983). The site sits upon a bench approximately 21 m above the Wenas Valley floor (Lubinski et al., 2007), and approximately 170 m from the top of an interfluvial ridge separating Wenas Creek from the Naches River (Lubinski et al., 2014b). The site sits in a location unaffected by the Cordilleran Pleistocene ice sheet at its maximum extent, and more importantly, it sits at an elevation too high to have been affected by the outburst floods of glacial Lake Missoula (Baker and Bunker 1985; Booth et al., 2004; Lillquist et al., 2005; Waitt 1985).
The study area for examining the mammoth site includes the entire Wenas Creek drainage valley (see Figure 1 above). This study area was chosen because the valley provides natural geographic borders. Though many factors can be analyzed to reconstruct the depositional and historical context of the study area, for the purposes of this thesis I am solely examining the microstratigraphy in proximity to the flake and bonebed and looking for evidence to disassociate the events which placed the bones and the flake in their current locations. Here I describe the topography of the site location, and current soil and vegetation of the valley to provide some context for the microstratigraphic investigation.

Figure 3 shows the topographic location of the WCMS on a bench above Wenas Creek. The site bench is at a modest grade, while the hillslope above is much steeper. These slope angles were estimated using the 7.5’ topographic map for the site location (e.g., Lubinski et al, 2014b:Figure 2), measuring the distance between 20 foot contour lines, as about 5° on the bench and 26° on the slope between this bench and the hill crest. This slope angle is consistent with downslope mass wasting events in the form of debris slides and mudflows as opposed to rockfall events. Being that Stratum II (the stratum of interest) is colluvial, source material for the depositional events would be derived from upslope material, mainly the Ellensburg formation sediments discussed above.

In 1985, the Soil Conservation Service performed a soil survey of Yakima County with the intention of analyzing and defining each distinct variety of soil and listing the characteristics of each soil pertaining to land-use practices (Lenfesty and Reedy 1985). According to the soil survey, the Mammoth site lies mainly within what has been categorized as Roza clay loam (Zones 111-114, which differ only in degree of slope).
Fig 3: Topographic map showing site location on hillside. Created by Holly Eagleston, based on topographic field data collected by Ryan Murphy in 2005.

For the purpose of their 1985 study (Lenfesty and Reedy 1985:85) they describe this clay loam as follows:
Typically, the surface layer is grayish brown clay loam about 2 inches thick. The upper part of the subsoil is grayish brown clay loam about 9 inches thick, and the lower part is light brownish gray silty clay about 8 inches thick. The substratum to a depth of 60 inches or more is light brownish gray, pale brown, and light gray silty clay, silty clay loam, and clay loam. Vertical cracks 1/2- to 1-inch wide extend from the surface to a depth of 19 inches. In some areas the soil is underlain by sandstone, and in some areas the soil has an intermittent hardpan.

The study area is located in what is known as a shrub-steppe vegetation region. This region generally has an arid to semi-arid climate with hot, dry summers and cold winters, and little precipitation (Franklin and Dyrness 1988). According to Franklin and Dyrness, this site lies within the *Artemisia tridentata/Agropyron spicatum* zone where vegetation is sparse. Typical vegetation would include sagebrushes, bluebunch wheatgrass, bluegrass, and low pussytoes. Current on-site vegetation includes sagebrush, gray rabbitbrush, purple sage, yarrow, lupine, Mariposa lily, phlox, daisy, bunchgrasses, wheatgrass and some unidentified variants of these species, as well as some introduced species such as cheat grass, Russian thistle, tumble mustard, and Western salsify (Lubinski et al, 2009). In the time of the mammoth ~17,000 cal. B.P., the vegetation ratio would likely have been reversed from that of today, and the landscape would have been comprised of 2/3 grasses and 1/3 sagebrush and other shrubs (Barton 1999).

Geoarchaeology, Site Formation Processes, and Particle Size Analysis

In order to understand how humans lived in a landscape, the relationship between both material culture and environment needs to be investigated. The contribution of the
earth sciences, particularly geomorphology and sedimentary petrography, to the interpretation and environmental reconstruction of archaeological contexts is called ‘geoarchaeology’ (Gladfelter 1977, 1981; Waters 1992). The physical context provides a paleoenvironmental story subject to patterning and interpretation just as artifacts imply prehistoric cultural activity. Through field study and laboratory analysis the geoarchaeologist elaborates the environments of a site, and provides input for reconstructing prehistoric human activity patterns in time and space.

In the field, the geoarchaeologist studies the geomorphology, sediment properties, sedimentary contacts and bedding or stratigraphy at the site and then ties that information with the broader geomorphological context to create a complete picture. The second part of the geoarchaeologist’s job is to deal with data developed in the laboratory. This data can be gathered through dating sediments, analyzing grain characteristics, or by performing microanalysis, chemical analysis, or particle size distribution analysis (Gladfelter 1977, 1981; Holliday 2004; Shackley 1975; Waters 1992).

The data gathered from field and laboratory research can then be combined to fulfill the geoarchaeologist’s main objectives: First, to place sites and their contents in a relative and absolute temporal context (Waters 1992; Renfrew 1976); second, to understand the natural processes of site formation (Waters 1992; Renfrew 1976; Schiffer 1983, 1996), and third to understand the prehistoric landscape surrounding the site while it was occupied. Before human behavior can be meaningfully reconstructed, it is necessary to understand the natural transitions that have affected the systemic context of a site. ‘Geoarchaeology’ is employed as a means to classify the natural environment of
early human settlement and identify those processes which alter the cultural record (Huckleberry et al, 2003).

A key interest to geoarchaeology is site formation processes. Schiffer (1972, 1983, 1996) defined two processes that create a site and its associated context: cultural transformations and natural transformations. Cultural transformations are the human processes that created the intentional patterning of artifacts and features on a site. The realm of archaeology analyzes the spatial patterning and configuration of related sites (systemic context) which reflects human behavior. However, before human behavior can be meaningfully reconstructed, the natural transformations which have affected the systemic context of a site must be understood. The analysis of natural site formation processes is concerned with physical, chemical, and biological factors responsible for the burial, alteration, and destruction of the systemic context at a site. Natural transformation is then subdivided into the biological realm (plants and animals) and the geomorphologic realm (Waters 1992).

The combination of natural and cultural site formation processes also destroy and modify each other and the landscape so the variability caused by these actions on one another also needs to be addressed and understood (Rick 1976). In addition, Schiffer (1983, 1996) mentions that identification of a formation process is merely an inference of what process has occurred. He also states that this inference can only be made by analyzing the evidence provided in the deposit. With each type of noncultural process having predictable physical effects on artifacts, such as wind and water velocity moving smaller size artifacts further and first, long axis alignment as an indicator of direction flow and/or energy, dip as an indicator of trampling, artifact size as a resistor of damage,
location and type of bone damage patterns linked to specific agents such as carnivores, weathering, and burial, and degree or type of patination as an indicator of environment and alkalinity. Other than the effects on artifacts, there are other analytical tools hidden in a site deposit that need to be looked at.

In order to determine how the flake got to its location, agents of transport and deposition must be considered, as well as postdepositional alterations following the example of Stein (1983) and Rick (1976). As stated previously, the Missoula floods did not reach this area, and neither did glaciers. The site lies on a hill that slopes down to the north and east so the source is from upslope. The modes of transport for the site sediments could include depositional and postdepositional accretion of aeolian, colluvial, and/or alluvial processes (Balek 2002) based on its location within the Wenas valley.

Regardless of how many events deposited the sediment in Stratum II, postdepositional processes most definitely need to be considered as a possibility for moving the flake to its position near the bonebed. There are a variety of ways that sediment may be altered post-depositionally. Bioturbation involves the mixing and transference of soil, rocks, and artifacts by faunae such as earthworms, ants and other burrowing creatures (Johnson 2002). The movement of the animals through the soil often transplants larger objects downward (Balek 2002; Wood and Johnson 1978), and smaller objects upward (Balek 2002). At the Wenas Creek Mammoth Site itself, cicada burrows and larger krovotina are visible in profile, so it stands to reason that other non-visible sediment altering biomechanical processes may also have been involved in churning the sediment during the last 17,000 years. Bioturbation is a natural and obvious process that may be accountable for the placement of the flake fragment and could explain the fact
that 20% of the IRSL dates in proximity to the flake averaged $5.1 \pm 0.5$ Ka. (Lubinski et al, 2014a). Another possible cause of postdepositional mixing is cryoturbation, although this seems an unlikely explanation for the downward movement of younger post-Pleistocene sediments into Stratum II.

While there are a number of ways to analyze sediment from an archaeological site including micromorphology, dating techniques, stratigraphic analysis, chemical analysis, and grain size analysis (Shackley 1975), for this thesis, I utilized the technique of particle size analysis to examine the sediment at the Wenas Creek Mammoth Site for signs of microstratification. There are a variety of methods that can perform a particle size analysis including hydrometer, pipette, sieving, and laser diffraction analysis (Gee and Bauder 1986; Loveland and Whalley 2001; Shackley 1975). All of these methods measure the size distribution of individual particles within a sample and evaluating the volume or weight percent of each size class of particles for that sample. The particle size distribution of sediment is a product of the properties of the sediment, the transport-depositional system, and energy of the sedimentary process (Gladfelter 1977, 1981; Postma 1985; Rick 1976). Analysis for the presence/absence of microstratification through particle size analysis is an important method in sediment analysis and site reconstruction because it helps the analyst decipher which processes aided in material deposition, and careful scrutiny can ascertain whether or not certain features, artifacts, or materials are related depositionally (Stein 1985). Particle size analysis has been used for many archaeological sites (Stein 1985), paleontological sites (Kelly et al, 2006; Overstreet and Kolb 2003), and general geoarchaeological and geographical investigations (Huckleberry et al, 2003; Lyman 2000; Naylor 1980; Postma 1985; Rick
Particle size analysis can be used to demonstrate whether artifacts and bones were deposited during the same event, thus associating them as in Overstreet and Kolb’s (2003) study in Wisconsin, and a similar study in Wyoming (Kelly et al., 2006), or whether they are not depositionally associated at all.

As stated above, in this thesis particle size analysis was used to look for signs of microstratification that would indicate that the flake and the bonebed were deposited during different events. The evidence for microstratification would be found in the form of repeated sequences of ungraded and normal and inversely graded sediment. Inverse grading is the opposite of normal grading. In normal deposition, such as in typical alluvial or aeolian environments, the sediments are distributed in a pattern grading from largest and heaviest pieces on the bottom to the smallest and lightest pieces on the top based on general gravity principles (Gray and Chugunov 1988; Major 1997; Naylor 1980; Savage and Lun 1988). Because of the nature of mass wasting events, it is possible that the sediment may be inversely graded due to the principle of kinetic sieving which asserts that in some instances as the particles move downslope due to gravity, the smallest particles will fall into the spaces that open up as the larger clasts move and settle out first leaving the larger clasts to grade out on top (Gray and Chugunov 2006; Naylor 1980; Postma 1986; Savage and Lun 1988). Figure 4 shows an example of how inverse grading may appear.
Major (1997) and Nemec and Kazanci (1999) found that debris flow deposits are commonly ungraded, but can occur with both sequences of inverse and inverse-to-normal grading. Additionally, these grading sequences cannot only occur together but often the inverse grading is of the largest clasts only (Major 1997; Costa and Jarrett 1981; Major and Voight 1986; Scott 1988; Vallance and Scott 1996). Despite these studies discussing the largest clasts in inverse graded colluvial sediments, there has been no subsequent work to set standards for particle size data evidence for the phenomenon. The grading patterns illustrated in the work by Nemec and Kazanci (1999) show sequences of normal and inverse grading occurring together or separately, which are quite visually discernable in the field by subsets of well-sorted microstrata within the larger colluvial strata. Major (1997) states that although the break in stratigraphy is sometimes obvious between separate depositional events by way of fluvial modification and textural changes which
may or may not be overtly obvious, he also asserts that units comprised of accumulation from several separate depositional events frequently present as a massive, homogeneous, matrix-supported unit. Despite being comprised of several separate depositional events, the massive unit will not necessarily exhibit any grading at all (Major 1997; Postma 1986).
CHAPTER III

METHODS

To analyze whether the mammoth bones and the chert flake could be depositionally associated (deposited together), I performed an analysis consisting of a close-interval particle size analysis of the colluvial layer in which the bones and flake are found. The analysis was approached with the hypothesis that the depositional histories of the bones and FS 261 lithic specimen are different; that is, the bonebed and flake are not depositionally associated, and in the absence of additional compelling evidence, Wenas Creek cannot be considered a pre-Clovis archaeological site demonstrating human use of proboscideans.

Through the particle size analysis, I was looking for evidence of discernable multiple episodes of deposition in Stratum II, which for the purposes of this study was assumed to be colluvial based on the work of Dr. Karl Lillquist. This was done to determine if the bonebed deposition and FS 261 flake fragment deposition in XU 12 can be attributed to separate events. More subtle reworking of the sediments such as by soil creep is probably not discernable under the scope of this study. Analysis resulting in a single depositional event could mean an association between the flake fragment and the bonebed, whereas multiple events that separate the flake fragment from the bonebed would indicate no association.

A particle size analysis was performed in an attempt to decipher whether the colluvial layer (Stratum II) is comprised of one or multiple depositional events. Using the Malvern Mastersizer 2000 and laser diffraction to perform particle size analysis, I
attempted to find evidence for stratification within this layer. I chose to examine only this Unit II because this is the only layer that contains both the bones and the most unambiguous human artifact. Only events relating to the deposition and reworking of the Unit II sediments that contain the bones and flake are pertinent to this study.

Sample Selection and Collection

Stratigraphic columns for particle size analysis were collected from the site, each containing material from approximately 10 cm above the Stratum II colluvial layer, through the colluvial layer, to 10 cm below the colluvial layer (as available). Collection was made by the author and one or two field school student assistants (Katherine Krieger, Barbara Parsons, Rose Fredericks) per day from August 10 through 14, 2009. The upper and lower boundaries of Stratum II were assessed by Dr. Karl Lillquist during the 2005-2009 field seasons and I used these boundaries in my study. These stratigraphic boundaries had been marked with nails in the excavation unit walls prior to my sample collection. Samples were collected from 9 column locations at the site traversing a north-south, and an east-west grid line. The locations selected were chosen to provide a maximum north-south and east-west spread across open areas of the main excavation block. Vertical columns 5 x 5 cm in size were removed in 2 cm increments with a 5 cm wide trowel, with each 2 cm vertical increment being a separate sample, following the protocol suggested by Brett Lentz (personal communication 2009). Each column extended from 10 cm above Stratum II’s upper boundary to 10 cm below the Stratum’s lower boundary. Because the thickness of Stratum II varies throughout the site, the number of samples in each column also varied. Upon extraction, each sample was
bagged and labeled. In addition, photos were taken and a total station reading was taken at the top and bottom of each column.

The locations of the columns removed are provided in Table 1 and Figure 5. I was careful to choose the location of each column so as to avoid column intersections with krotovinas that were visible on exposed walls of the excavation units. While this worked for what I could see, I cannot know for sure there were not filled burrows behind the exposed wall surface. The location of the top and bottom of each column was recorded with the project total station surveying instrument. From each column I collected between 15 and 33 samples, as follows: 25 from Column 1, 28 from Column 2, 33 from Column 3, 26 from Column 4, 22 from Column 5, 32 from Column 6, 29 from Column 7, 21 from Column 8, and 15 from Column 9.

### TABLE 1. PARTICLE SIZE COLUMN SAMPLE LOCATIONS

<table>
<thead>
<tr>
<th>Column</th>
<th>FS#</th>
<th>XU</th>
<th>Description</th>
<th>Top North (m)</th>
<th>Top East (m)</th>
<th>Top elevation (m)</th>
<th>Base elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1079</td>
<td>12</td>
<td>W wall ~50 cm N of flake</td>
<td>501.264</td>
<td>91.989</td>
<td>100.306</td>
<td>99.829</td>
</tr>
<tr>
<td>2</td>
<td>1080</td>
<td>12</td>
<td>W wall ~1 m S of flake</td>
<td>500.074</td>
<td>91.961</td>
<td>100.553</td>
<td>100.016</td>
</tr>
<tr>
<td>3</td>
<td>1081</td>
<td>14</td>
<td>W wall ~2 m S of Column 2</td>
<td>498.076</td>
<td>91.982</td>
<td>100.865</td>
<td>100.171</td>
</tr>
<tr>
<td>4</td>
<td>1082</td>
<td>18</td>
<td>W wall ~4 m S of Column 2</td>
<td>496.368</td>
<td>91.976</td>
<td>101.021</td>
<td>100.506</td>
</tr>
<tr>
<td>5</td>
<td>1083</td>
<td>21</td>
<td>W wall ~6 m S of Column 2</td>
<td>494.495</td>
<td>91.960</td>
<td>101.456</td>
<td>101.014</td>
</tr>
<tr>
<td>6</td>
<td>1084</td>
<td>27</td>
<td>S wall ~ 4 m W of NS line</td>
<td>497.972</td>
<td>88.287</td>
<td>101.220</td>
<td>100.556</td>
</tr>
<tr>
<td>7</td>
<td>1085</td>
<td>20</td>
<td>S wall ~ 2 m W of NS line</td>
<td>497.945</td>
<td>90.132</td>
<td>100.968</td>
<td>100.369</td>
</tr>
<tr>
<td>8</td>
<td>1086</td>
<td>29</td>
<td>N wall ~ 2 m E of NS line</td>
<td>497.526</td>
<td>94.305</td>
<td>100.752</td>
<td>100.320</td>
</tr>
<tr>
<td>9</td>
<td>1087</td>
<td>32</td>
<td>N wall ~ 4 m E of NS line</td>
<td>497.530</td>
<td>96.167</td>
<td>100.437</td>
<td>100.062</td>
</tr>
</tbody>
</table>
Fig 5. Map of excavated units with bone finds, artifact, and location of column samples. Blue triangles numbered 1-9 represent locations of columns collected for particle size analysis. Only Columns 1 and 2 were analyzed for this thesis. Map created by Tom Winter.
Although nine columns were collected for this thesis, particle size analyses were run exclusively on Columns 1 and 2; the two columns in closest proximity to the flake and bonebed (see Figures 5 and 6). Because of their location, these two columns were thought to be the most significant, and the individual samples from two columns were considered a reasonable size for a thesis project. The other columns are stored for possible future analysis.

![Profile map of west wall of Unit 12 including locations of column samples 1 and 2 and FS 261 flake fragment. Stratum boundaries were still being finalized at the time of sample extraction. The solid boundary between II and III represents the initial 2006 mapping while the dashed line represents the estimated boundary from 2009 data elsewhere in the unit. A finalized map will be provided in Chapter 5.](image_url)

**Fig 6.** Profile map of west wall of Unit 12 including locations of column samples 1 and 2 and FS 261 flake fragment. Stratum boundaries were still being finalized at the time of sample extraction. The solid boundary between II and III represents the initial 2006 mapping while the dashed line represents the estimated boundary from 2009 data elsewhere in the unit. A finalized map will be provided in Chapter 5.

**Pretreatment**

To begin pretreatments, all samples were air-dried for 9 months, then each sample was divided in half using a riffle box sample splitter to preserve an untreated portion of the original sample for possible future studies, as suggested by Shackley (1975). The riffle box was washed before each new sample was run through it to keep any stray or
leftover particles from contaminating the next samples. Peds (greater than 0.5 cm) within a sample were lightly broken up prior to their passing through the riffle box. Next, each sample was weighed and recorded to the nearest 0.01 g using an Ohaus Adventurer Pro digital scale and the riffle box was used to split the sample until a 10 g portion was separated out. This 10 g sample was subject to further pretreatment and was used for the particle size analysis; the remainder of the sample was held as a reserve. There were 53 of these 10 g samples extracted from the two initial sampling columns.

To determine whether the samples would require pretreatment for removal of carbonates, a visual test was performed by Dr. Patrick McCutcheon and I by applying a small amount of 10% hydrochloric acid (HCl) to each sample, following Natural Resources Conservation Service ([NRCS] 1996). The samples were then viewed under a microscope to look for a bubbling reaction which would indicate the presence of calcium carbonates. The fact that 26 of the 53 samples tested positive for carbonates necessitated the pretreatment for removal of carbonates on those 26 samples before any other pretreating could be done.

At this point, Dr. McCutcheon and I performed a pilot test on six samples to determine the most appropriate pretreatment method for carbonate removal. The six samples (3 positives from top, middle, and bottom of each positive section of the column) were treated in 3 different ways to see which pretreatment removed the carbonates best: 1) NaOAc to remove carbonates only, 2) just deflocculation with sodium hexametaphosphate, and 3) NaOAc followed by deflocculation. Details on these methods are provided below. Sub-samples from each of the six samples received each pretreatment. After pretreatment, each sample was again placed under the microscope
and tested with HCl. Deflocculated samples still produced a visible reaction, while samples treated with NaOAc produced very weak or no reactions. Since there was no reaction with HCl for any sample undergoing both pretreatments, it was determined that the combination of these methods produced good results and should be adopted for the remaining samples. Additionally, all of the carbonate in these pilot samples was apparently removed with a single NaOAc treatment; multiple washings were not needed.

The carbonate removal pretreatment was done using a 1N-sodium acetate (NaOAc) solution following the standard set by numerous authorities in this field (e.g., Catt 1990; Gee and Bauder 1986; Holliday 2004; Mason, personal communication 2010; Reitze, personal communication 2010; NRCS 1996). Batches of sodium acetate solution were made 5 L at a time by mixing 680 g of NaOAc powder into 4 L of distilled water using a magnetic stirrer, and then adding 230 ml of 5% acetic acid to buffer the solution to pH 5 using a calibrated Hanna Checker pH meter, following Gee & Bauder (1986) and NRCS (1996). To treat the samples, each of the 26 carbonate-containing 10 g samples was placed into a separate 600 ml beaker, and then 200 ml of the NaOAc solution was added to the sediment in each beaker, after NRCS (1996). In these samples, bubbling was minimal and ceased within the first minute of mixing, implying relatively little carbonate in the samples. The samples were mixed slowly with the NaOAc solution, covered with plastic film, and left mixing overnight on a magnetic stirrer. Each sample was then heated to 90 °C on a hot plate and the temperature was maintained for 2 minutes to thoroughly treat even though no bubbling reaction was noticed.

Since no reaction was observed more than one minute into the mixing process and the pilot test implied all carbonate was removed after one application of NaOAc, there
was no need to repeat the carbonate removal procedure on the samples. (In this way my method differed slightly from NRCS (1996), in which subsequent washings with NaOAc are advised until there is no further reaction.) After each sample solution had cooled and settled (approximately 16 h), the clear liquid was removed with a bulb siphon and each sample was rinsed once with 200 ml of distilled water and then was centrifuged for 5 minutes at 2500 rpm to settle the sample from the liquid. The clear liquid was siphoned out again, and the sample was placed in a separate beaker for the next pretreatment. The NRCS (1996) includes a step in their carbonate removal procedure involving the use of 30% hydrogen peroxide, which is generally otherwise used to remove organic material (Catt 1990; Gee & Bauder 1986; Holliday 2004; Shackley 1975; Singer & Janitzky 1986). Due to the toxicity and caustic nature of the chemical, in conjunction with time, money and lab constraints, and the fact that the arid climate conditions of the site setting is not conducive to organic material accumulation, along with the lack of support of this step in the carbonate removal process by other professionals (Catt 1990; Gee and Bauder 1986; Holliday 2004; Mason, personal communication 2010; Reitze, personal communication 2010), I chose to omit the organic matter removal step in my pretreatments.

Each of the 53 samples was then deflocculated regardless of whether or not they reacted with the HCl. After NRCS (1996), a solution of sodium hexametaphosphate ((NaPO₃)₆) was made by dissolving 37.5 g of powdered sodium hexametaphosphate and 7 g baking soda into 1 L of distilled water using a magnetic stirrer. To deflocculate each sample, the 10 g sample and 10 ml of the premixed sodium hexametaphosphate solution were mixed in a beaker, and distilled water was added to the sample to make a volume of
200 ml after the example of NRCS (1996). The sample was stoppered and mixed with a magnetic stirrer overnight at medium-high speed.

**Particle Size Analysis**

Dispersed within the hexametaphosphate solution, each sample was then wet sieved in the manner of numerous researchers (Shackley 1975; Singer and Janitzky 1986; NRCS 1996) to obtain the size fraction that could be run in the Mastersizer 2000. The dispersed samples were poured through 2 mm, and 62.5 µm nested, square-hole mesh, brass screen sieves and onto a bottom pan. To ensure reasonable sorting with the sieves, distilled water was poured on the sieves while a small brush was used to rub the samples through the mesh. The samples were then removed from the sieves and oven dried for approximately 36 h at 90 °F, and then each fraction was weighed and recorded to the nearest 0.01 g. The end result quantified the large fraction pebbles and cobbles (>2 mm) that the Mastersizer cannot analyze (Malvern Instruments 2007), the sand fraction (62.5 µm to 2 mm) and the clay/silt fraction (< 62.5 µm) according to the size classes delineated on the Wentworth scale. A summary of the samples and their size fractions is provided in Tables 2 and 3.

At this point, all pretreated samples were transported to the Mastersizer lab, located in the Department of Geological Sciences where the particle size analysis segment of this project would take place. Particle size analyses on the sand and clay/silt fractions (<2 mm) were performed using a Malvern Mastersizer 2000 following the methods outlined by Patrick Johnston, a graduate student in CWU’s Department of
<table>
<thead>
<tr>
<th>Sample (Bottom Depth)</th>
<th>Split Sample Weight (g)</th>
<th>Treated with NaOAc?</th>
<th>Sample weight after pretreating &amp; sieving (g)</th>
<th>% Sample loss during pretreatment</th>
<th>&gt;2mm portion (g)</th>
<th>&lt;62.5µm portion (g)</th>
<th>Total of both &lt;2mm portions (g)</th>
<th>% of total weight &lt;2mm</th>
<th>% of total sample weight &gt;2mm</th>
</tr>
</thead>
<tbody>
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<td>A (2)</td>
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<td>0.51</td>
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<td>0.67</td>
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<td>0.90</td>
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<td>2.12</td>
<td>6.74</td>
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<td>F (12)</td>
<td>53.36</td>
<td>Yes</td>
<td>9.26</td>
<td>0.74</td>
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<td>3.44</td>
<td>4.64</td>
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<td>61.77</td>
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<td>9.09</td>
<td>0.91</td>
<td>0.71</td>
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<td>1.83</td>
<td>1.11</td>
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<td>6.60</td>
<td>7.06</td>
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<td>1.00</td>
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<td>1.24</td>
<td>7.15</td>
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<td>1.92</td>
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<td>37.51</td>
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</table>
## TABLE 3. SUMMARY OF SAMPLES FROM COLUMN 2 (FS 1080)

<table>
<thead>
<tr>
<th>Sample (Bottom Depth)</th>
<th>Sample Weight (g)</th>
<th>Treated with NaOAc?</th>
<th>Sample weight after pretreating &amp; sieving (g)</th>
<th>Sample weight during pretreatment</th>
<th>&gt;2mm portion (g)</th>
<th>&lt;2mm portion (g)</th>
<th>Total of both &lt;2mm portions (g)</th>
<th>% of total weight &lt;2mm</th>
<th>% of total weight &gt;2mm</th>
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<tbody>
<tr>
<td>A (2)</td>
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<td>9.39</td>
<td>0.61</td>
<td>0.42</td>
<td>3.39</td>
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<td>8.97</td>
<td>95.5272</td>
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<td>B (4)</td>
<td>59.75</td>
<td>No</td>
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<td>0.77</td>
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<td>4.39</td>
<td>5.60</td>
<td>7.99</td>
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<td>E (10)</td>
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<td>0.96</td>
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<td>8.74</td>
<td>96.6814</td>
</tr>
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<td>1.21</td>
<td>7.40</td>
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<td>96.2011</td>
</tr>
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<td>T (40)</td>
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<td>0.44</td>
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<td>Treated with NaOAc?</td>
<td>Sample weight after pretreating &amp; sieving (g)</td>
<td>% Sample loss during pretreatment</td>
<td>&gt;2mm portion (g)</td>
<td>&lt;62.5µm portion (g)</td>
<td>Total of both &lt;2mm portions (g)</td>
<td>% of total weight &lt;2mm</td>
<td>% of total sample weight &gt;2mm</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------</td>
<td>--------------------</td>
<td>---------------------------------------------</td>
<td>----------------------------------</td>
<td>-----------------</td>
<td>------------------------</td>
<td>---------------------------------</td>
<td>----------------------</td>
<td>-------------------------</td>
</tr>
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<td>6.28</td>
<td>9.21</td>
<td>96.3389</td>
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<td>7.54</td>
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<td>2.60</td>
<td>5.72</td>
<td>8.32</td>
<td>91.3282</td>
<td>8.67</td>
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</table>
Geological Sciences, and guidance from Dr. Lisa Ely of CWU’s Department of Geological Sciences, in conjunction with methods delineated by Sperazza et al. (2002), and the Mastersizer’s own comprehensive manual (Malvern Instruments 2007). While both of the fractions which are < 2 mm could be analyzed in the Mastersizer, I decided to run them as separate fractions so as not to obscure the laser and confuse the machine with such vast size class differences, as suggested by the user’s manual (Malvern Instruments 2007). For each analysis, I extracted a 0.1 g portion of each dry sample (~0.1 g of 62.5 µm to 2 mm fraction, and ~0.1 g of < 62.5 µm fraction) from each sample bag. These dry sub-samples were then placed in 250 ml beakers, and each was topped off with 100 ml of a 0.5 g/L sodium hexametaphosphate solution and stirred by hand for 2 minutes to make sure that the sample was fully dispersed while being analyzed.

For each sample run, the Mastersizer’s computer was initialized and calibrated as prompted by the screen on start-up. I also utilized the ultrasonic component of the pump while running each sample, which helped to keep the sample from settling out of suspension. Each sample was run for 45 seconds. During the course of sample analysis, the Mastersizer itself takes three separate readings and then averages those three for a fourth averaged set of data. The data sets are provided in both numerical form and as graphs by the Mastersizer software. Example graphic output is provided as Figure 7.

Additionally, I ran every 5th sample an additional two times to ensure machine consistency and check for accuracy. The averaged set of data for each sample was used for my analysis, which for both columns totaled 154 sets of data to work with. This
Fig 7. Sample Mastersizer output for Sample 1079e (Column 1 at 10 cm). The upper graph is for the fine fraction (< 62.5 µm) and the lower graph is for the sand fraction (> 62.5 µm).

breaks down to 77 sets of data containing ±50 size ranges each for the 62.5 µm – 2 mm range, and 77 sets of data containing ±40 size ranges for the < 62.5 µm range.

During the process of using the Malvern Mastersizer 2000 to perform the particle size analysis, I ran every 5th sample in triplicate in order to test the accuracy of the machine. This left me with 12 samples that have 3 sets of results. These ‘accuracy spot checks’ produced very similar findings per sample and I see no reason to doubt any of my results. In order to reduce this triplicate data into a single set of data that would be usable with the other samples that were not ‘spot checked,’ I averaged the three sets of raw data per sample, on the advice of Central Washington University’s Geography professor Dr.
John Bowen, and then proceeded with the subsequent calculations and analysis. This reduced the number of results from 154 to 130.

Data Analysis and Interpretation

For each of the 130 results sets, the averaged Mastersizer breakdown of size classes and measured percent volume of those size classes were transcribed to an Excel spreadsheet and the size classes were converted to the phi scale (Table 4). Next, for each sample, the percent volumes were added together by phi size so that any overlapping phi sizes measured by the Mastersizer within the two size classes < 2 mm would be combined. These combined percent volumes were then divided by two to calculate the total percent volume of particles < 2 mm. This volume was then multiplied by the original measured weight percent of each sample in the < 2 mm category to get the percent total volume of the total sample. For each sample, any Mastersizer data that resulted in sizes > 2 mm was added back to the original > 2 mm data withheld from being run in the machine and, as above, was multiplied it by the original weight percent in the > 2 mm category to produce complete data for that size class. Using these numbers, I calculated the cumulative percent total of all sizes per sample, per column.

After calculating the cumulative percent distribution for each combined sample, I then graphed those numbers to find the phi size of each sample at the 5th, 15th, 16th, 25th, 50th, 75th and 84th percentiles. These phi size values were used to calculate data statistics. I calculated the logarithmic geometric mean, standard deviation, skewness, and kurtosis in the manner of Blott and Pye (2001), Folk and Ward (1957). The formulae used for these statistics are provided in Table 5.
### TABLE 4. EXAMPLE MASTERSIZER DATA FOR <62.5 µm AVERAGES FROM FS 1079E CONVERTED TO PHI SCALE

<table>
<thead>
<tr>
<th>Size (µm)</th>
<th>Size (mm)</th>
<th>Phi scale</th>
<th>% volume</th>
<th>Size (µm)</th>
<th>Size (mm)</th>
<th>Phi scale</th>
<th>% volume</th>
</tr>
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<td>0.18</td>
<td>26.303</td>
<td>0.026303</td>
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<td>1.66</td>
<td>0.00166</td>
<td>9.23</td>
<td>0.35</td>
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<td>0.0302</td>
<td>5.05</td>
<td>4.01</td>
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<td>0.001905</td>
<td>9.04</td>
<td>0.50</td>
<td>34.674</td>
<td>0.034674</td>
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<td>0.039811</td>
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<td>4.52</td>
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<td>4.95</td>
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<td></td>
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</table>

The use of these statistics is described as follows: Geometric mean is a way of looking at particle size in the phi scale to determine the energy necessary to move those grains any distance. Standard deviation is a way of determining of how well sorted a sample is. In turn, the sorting reveals the method of transport and degree of reworking of the sediment (Waters 1992). Skewness is an examination of the size distribution to one side of the calculated average. According to Blott and Pye (2001), and Folk and Ward
TABLE 5. FORMULAE FOR GRAPHICAL STATISTICS USED FOR EACH SAMPLE, AFTER BLOTT & PYE (2001) AND FOLK & WARD (1957)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric mean</td>
<td>( M_7 = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3} )</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>( \sigma = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6} )</td>
</tr>
<tr>
<td>Skewness</td>
<td>( Sk_1 = \frac{\phi_{16} + \phi_{84} - 2(\phi_{50})}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{5} + \phi_{95} - 2(\phi_{50})}{2(\phi_{95} - \phi_{5})} )</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>( K_G = \frac{\phi_{95} - \phi_{5}}{2\times44(\phi_{75} - \phi_{25})} )</td>
</tr>
</tbody>
</table>

(1957), calculations of this statistic tells us if the sample is positive or fine-skewed (excess of fines in the sample), negative or coarse-skewed (excess of coarse particles in the sample), or symmetrical (even amounts of particles in the sample). Lastly, kurtosis is the degree of variation in particle size relative to the average. The sample can have a normal distribution of particle size (mesokurtic), less variation in particle size (leptokurtic, very leptokurtic, or extremely leptokurtic), or more variation in particle size (platykurtic or very platykurtic).  

The geometric mean, standard deviation, skewness, and kurtosis were examined and plotted with depth following the example of Blott and Pye (2001). Next, using phi sizes, I divided the cumulative percent data for each sample into classifications of gravel, sand, silt, and clay based on the Wentworth grain-size scale and that information was plotted with depth for each of the 2 columns. This graph was examined for evidence of ungraded, or normally or inversely graded sequences which would indicate the presence of stratification and multiple depositional events.

In order to directly compare the particle size analysis from each column with the actual placement of the flake and bonebed, I plotted the locations of the columns, the top of the excavated bones nearest each column, and the location of the flake on a unit profile...
map. Then I took the actual total station locations for these elements and interpolated their relationship to the columns based on the stratum boundaries delineated during the 2009 excavation season. More details on this procedure are provided in results below.
I performed a particle size analysis on samples of Stratum II sediment extracted from two columns in close proximity to the flake fragment. Although I am primarily interested in Stratum II sediment because that is the stratum that encompasses the flake fragment of interest, when extracting the samples I attempted to include 10 cm of sediment from both above and below Stratum II because the subjectivity of the boundary lines and because there is generally some level of interfingering and discontinuity at transitioning boundary lines. (Note that these boundaries were mapped as gradual at top and diffuse at bottom, following the Natural Resources Conservation Service (NRCS) naming conventions, which correspond with transitions 5 to < 15 cm and > 15 cm wide, respectively (Schoeneberger et al, 2012)). My samples were taken according to the marked 2006 boundaries set by Dr. Karl Lillquist, however, these boundaries were still being defined and were adjusted a bit deeper during the 2009 season, leaving the bottom of my columns just barely including sediment from Stratum III (See Figure 6). Based on the 2009 boundaries delineations, Column 1 contains about 7 cm of Stratum I, 40 cm of Stratum II, and 3 cm of Stratum III, and Column 2 contains about 9 cm of Stratum I, 43 cm of Stratum II, and 4 cm of Stratum III. However, these designations are based on the hard line boundaries and do not take into account the gradual/diffuse nature of the transitions between strata.

The results of the particle size analysis can be discussed in several ways. A simple initial description would be to use the textural classifications of the NRCS
(Schoeneberger et al, 2012). Another system for describing texture perhaps more common for sediments is based on Folk (1974), and this is also included in Table 6. Based on my particle size analysis and the textural classification chart the texture distributions from my columns are generally loams with silt and sand constituents under NRCS nomenclature, or slightly gravelly to gravelly sandy muds or muddy sands under Folk’s classification system (see Table 6). Loams are sediments that are comprised of roughly equivalent percentages of silt, sand, and clay. Of the 5 samples with the texture modifier preface of gravelly or very gravelly under NRCS, 4 are describing samples with 2 mm to 5 mm gravels and 1 sample (Column 1 at 50 cm) has gravels 2 mm to 5 mm and one clast that is 2.5 cm. Under Folk’s classification, only three of the samples have enough gravel percent to be classified as a gravel.

**TABLE 6. SEDIMENT TEXTURE DESCRIPTIONS OF THE SAMPLE COLUMNS BY DEPTH**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NRCS</td>
<td>Folk</td>
</tr>
<tr>
<td>-2.0</td>
<td>loam</td>
<td>gravelly mud</td>
</tr>
<tr>
<td>-4.0</td>
<td>loam</td>
<td>slightly gravelly sandy mud</td>
</tr>
<tr>
<td>-6.0</td>
<td>silt loam</td>
<td>slightly gravelly sandy mud</td>
</tr>
<tr>
<td>-8.0</td>
<td>silt loam</td>
<td>slightly gravelly sandy mud</td>
</tr>
<tr>
<td>-10.0</td>
<td>sandy loam</td>
<td>slightly gravelly muddy sand</td>
</tr>
<tr>
<td>-12.0</td>
<td>loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>Depth</td>
<td>NRCS</td>
<td>Folk</td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>-14.0</td>
<td>loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>-16.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-18.0</td>
<td>loam</td>
<td>slightly gravelly sandy mud</td>
</tr>
<tr>
<td>-20.0</td>
<td>loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>-22.0</td>
<td>sandy loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-24.0</td>
<td>loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>-26.0</td>
<td>loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>-28.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-30.0</td>
<td>loam</td>
<td>slightly gravelly sandy mud</td>
</tr>
<tr>
<td>-32.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-34.0</td>
<td>loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>-36.0</td>
<td>loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>-38.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-40.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-42.0</td>
<td>gravelly sandy loam</td>
<td>gravelly muddy sand</td>
</tr>
<tr>
<td>-44.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-46.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-48.0</td>
<td>loam</td>
<td>gravelly sandy mud</td>
</tr>
<tr>
<td>-50.0</td>
<td>very gravelly loamy sand</td>
<td>muddy sandy gravel</td>
</tr>
<tr>
<td>-52.0</td>
<td>gravelly mud</td>
<td>loam</td>
</tr>
<tr>
<td>-54.0</td>
<td>slightly gravelly sandy mud</td>
<td>loam</td>
</tr>
<tr>
<td>-56.0</td>
<td>sandy loam</td>
<td>gravelly muddy sand</td>
</tr>
</tbody>
</table>
The cumulative percent distribution has been plotted with depth for each column in Figure 8. These graphs show the percentage of gravel, sand, silt, and clay in each sample. In both columns, sand and silt make up most of the sediment. Excepting the 50 cm deep sample in Column 1 (discussed below), gravel makes up only 2-28% of the total in each sample, and clay-sized particles make up 2-12% of the total in all samples.

Fig 8. Cumulative proportions (%) of gravel, sand, silt and clay in each sample for Columns 1 (left) and Column 2 (right). Y-axis represents depth below top of column sample in cm. Samples are at 2 cm intervals.
Visually examining Figure 8, there are some trends of note. In both columns aside from a few slightly anomalous data points, the only significantly noticeable boundary change is in Column 1 at 50 cm in depth. At this point, the consistency changes to a much heavier gravelled sediment, which I would identify unequivocally as Stratum III. It must be remembered that the stratum boundaries are transitional zones; gradual before and diffuse after the delineated lines on Figure 6 when addressing the data in Figure 8 as well as Table 6. Likewise, this must be remembered when addressing the slightly anomalous data points. The spike in cumulative percent of gravel in Column 1 (Figure 8, left) at 42 cm, in conjunction with the texture change in Table 6 at that depth, could indicate an area of transitioning between Stratum II and Stratum III just 6 cm before the irrefutable boundary change after 48 cm. The rise in cumulative percent of gravel in Column 2 at 34 cm and again at 50 cm along with the gravelly textures at these depths on Table 6 may also be indicative of the transition zones between Stratum II and Stratum III. However, I do not see any other clear evidence for stratum boundaries based on the texture distribution (Table 6) or the cumulative percent distribution (Figure 8) other than after 48 cm in Column 1.

Once the data was transcribed and manipulated into the statistical data and graphed, I examined that data to look for any trends, discontinuities, or unconformities. For each sample I calculated geometric mean, standard deviation, skewness and kurtosis as noted in Chapter 3. These values are plotted by depth in Figures 9 and 10. The unit for all of the X-axes in these graphs is phi size. Phi sizes -1.0 and less are classified as gravel, 4.0 to -1.0 is classified as sand, 4.0 to 8.0 is silt, and phi sizes greater than 8.0 are classified as clay (Waters 1992).
The first thing I looked at was the geometric mean. In my two columns, the geometric mean was relatively constant staying mostly in the 3 and 4 Φ sizes (sand and silt) with just a few 5 Φ sizes in Column 2. A small grain size mean indicates movement...
by a low energy event (Waters 1992). The only anomalies were in Column 1 at 42 cm and 50 cm (which were \(~1.6 \Phi\), and \(~-10 \Phi\), respectively), and Column 2 sample at 34 cm (-0.25 \Phi) which were all abnormally low. For the purposes of this study, however, it must be noted that the anomalous samples from Column 1 are actually from the 10 cm that were to be extracted from the top of Stratum III, or more likely the transition into it, and probably fall outside of the boundaries of the stratum of interest.

Based on the statistical calculation for standard deviation, the entirety of both columns range from poorly sorted to extremely poorly sorted (Folk 1974; Folk and Ward 1957; Waters 1992). These results are entirely consistent with the interpretation of Stratum II as colluvium. In Column 1, the highest standard deviation was 17.871 \Phi (50 cm) and the lowest standard deviation was 1.967 \Phi (6 cm). However, both of those samples once again are located in the 10 cm of samples collected from transitional zones between Stratum II and the strata below and above it, respectively. The majority of samples within the delineated stratum boundary for Column 1 calculated in the 3 \Phi and 4 \Phi ranges, very poorly to extremely poorly sorted. In Figure 10 showing results for Column 2, all but 3 samples calculated in the 2 \Phi and 3 \Phi range classifying them as very poorly sorted, and those anomalous 3 have just a slightly higher standard deviation putting them in the extremely poorly sorted group. Again, one sample within Stratum II boundaries (34 cm) had a more obscure standard deviation of 6.857\Phi, but that is still classified as extremely poorly sorted. Poor sorting, as is the case with both columns is indicative of colluvial transport (Waters 1992)

Based on the calculated skewness, samples in Column 1 are classified as very finely skewed except for samples at 42 cm and 50 cm (which again are most likely in the
transition zone between Stratum II and Stratum III) which classify as very coarsely skewed. Samples in Column 2 are very finely skewed with just 2 samples (30 cm and 50 cm) classifying as finely skewed. Conversely, the sample at 34 cm is classified as coarsely skewed. Overall, both columns are very finely skewed meaning that there is an excess of fines in the samples. This supports the findings above for geometric mean (predominantly fine sand and silt sized particles) which is indicative of movement by an event with low sorting efficiency (Folk and Ward 1957:25-26), and corroborates the standard deviation findings for poor sorting as there is an excess of one size class, but a range of size classes are present.

The last statistic that I examined was kurtosis. Column 1 samples ended up as 30% platykurtic, 30% mesokurtic, and 30% leptokurtic, but in no particular pattern with depth. Samples at 22 cm and 46 cm were anomalous both classifying as very leptokurtic at 1.73 and 2.7 respectively, while the rest of the column ranged from 0.70 to 1.47. Column 2 samples ended up as 36% platykurtic, 43% mesokurtic, and 21% leptokurtic also in no particular pattern with depth. The only anomalous sample was at 54 cm which classified as very leptokurtic at 2.49 while the rest of the column ranged from 0.73 to 1.37. Overall with depth, the samples simply vary slightly back and forth between being normally distributed, and having slightly more or less variation in particle size distribution.

Overall, there does not appear to be any trend with depth that would separate the sediment in the columns into multiple depositional events. The cumulative percents do not vary with depth to the degree that would indicate any subsequences fining upwards or downward and thus substrata or multiple depositional events within Stratum II. The only
clear change in composition is in Column 1 at 50 cm which I believe unmistakably marks the entry into Stratum III. Both columns display similar statistical results despite their location over 1 meter apart. Throughout the columns, the geometric mean remains at 3-5 \( \Phi \), standard deviation ranges from poorly to very poorly sorted, skewness indicates an excess of fine particle sizes in the columns, and kurtosis is equally platykurtic, mesokurtic, and leptokurtic throughout the columns. The statistical results are consistent with colluvial transport, but the values stay fairly constant, with only minor inflections, and provide no clear evidence of a multiple episodes of transport.

Though there is no evidence for microstratification within Stratum II in the form of subsequences fining upwards or downward, there are inflections of the cumulative particle size percentages and statistical data within the columns which could just be noise or could represent episodes of variation within the same depositional event like distinct sheetwash events. If this is the case, it would be important to decipher whether the placement of the variation(s) occurs in a location within Stratum II which would separate the upper section which contains the flake, from the lower section which contains the bonebed. In order to address this matter, I used the total station data to estimate the stratigraphic locations of the flake and the top of the bonebed on each particle size column, as described in the methods section above and shown in Table 7 below.
<table>
<thead>
<tr>
<th>Description</th>
<th>Shot #</th>
<th>Northing (m)</th>
<th>Elevation (m)</th>
<th>Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flake</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coordinates of top of Strat II nearest Flake</td>
<td>1086</td>
<td>500.703</td>
<td>100.321</td>
<td></td>
</tr>
<tr>
<td>Coordinates of top of Strat II nearest Flake</td>
<td>1087</td>
<td>500.937</td>
<td>100.292</td>
<td></td>
</tr>
</tbody>
</table>
| Mean of top of Strat II                         |        |              | (100.321+100.29
|                                                 |        |              | 2)/2= 100.307 |
| Coordinates of Flake FS261                      | 43     | 500.874      | 100.147       |            |
| **Depth from top of Strat II to Flake**          |        |              | **100.307-**  | **16**     |
|                                                 |        |              | **100.147=**  | **.16**    |
| **Column 1**                                    |        |              |               |            |
| Coordinates of top of Strat II nearest Column 1 North of flake | 1089   | 501.185      | 100.24        |            |
|                                                 | 1090   | 501.433      | 100.193       |            |
| Mean top of Strat II                            |        |              | 100.2165      |            |
| Estimated flake elevation at Column 1           |        |              | 100.2165-.16= | 100.0565   |
| Top of FS1285 NW of Column 1                    | 52533  | 501.5255     | 100.0263      |            |
| Top of FS269 SE of Column 1                     | 56     | 501.288      | 100.049       |            |
| Mean depth for top of bonebed near Column 1     |        |              | 100.03765     |            |
| Top elevation of Column 1                       | e4931  | 501.264      | 100.306       |            |
| **Depth from top of Column 1 to top of Flake**  |        |              | **100.306-**  | **25**     |
|                                                 |        |              | **100.0565**  |            |
| **Distance from top of Column 1 to top of Bonebed** |        |              | **100.306-**  | **27**     |
|                                                 |        |              | **100.03765** |            |
### TABLE 7. TOTAL STATION LOCATIONS OF FLAKE, BONEBED, AND COLUMNS (Continued)

<table>
<thead>
<tr>
<th>Description</th>
<th>Shot #</th>
<th>Northing (m)</th>
<th>Elevation (m)</th>
<th>Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coordinates of top of Strat II</td>
<td>1083</td>
<td>500.035</td>
<td>100.471</td>
<td></td>
</tr>
<tr>
<td>nearest Column 2 South of flake</td>
<td>1084</td>
<td>500.204</td>
<td>100.385</td>
<td></td>
</tr>
<tr>
<td>Mean top of Strat II</td>
<td></td>
<td></td>
<td>100.428</td>
<td></td>
</tr>
<tr>
<td>Estimated flake elevation at Column 2</td>
<td></td>
<td></td>
<td>100.428-.16=</td>
<td>100.268</td>
</tr>
<tr>
<td>Top of FS1337 NW of Column 2</td>
<td>™2920</td>
<td>500.3119</td>
<td>100.1454</td>
<td></td>
</tr>
<tr>
<td>Top of FS918 SE of Column 2</td>
<td>™2183</td>
<td>499.786</td>
<td>100.173</td>
<td></td>
</tr>
<tr>
<td>Mean depth for top of bonebed near Column 2</td>
<td></td>
<td></td>
<td>100.1592</td>
<td></td>
</tr>
<tr>
<td>Top elevation of Column 2</td>
<td>™5168</td>
<td>500.074</td>
<td>100.553</td>
<td></td>
</tr>
<tr>
<td><strong>Depth from top of Column 2 to top of Flake</strong></td>
<td></td>
<td></td>
<td><strong>100.553-100.268</strong></td>
<td><strong>28.5</strong></td>
</tr>
<tr>
<td><strong>Distance from top of Column 2 to top of bonebed</strong></td>
<td></td>
<td></td>
<td><strong>100.553-</strong></td>
<td><strong>39</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>100.1592</strong></td>
<td></td>
</tr>
</tbody>
</table>

The flake and bonebed locations are illustrated on a revised unit profile map of the excavation area containing them both (Figure 11). The information calculated in Table 7 and depicted in Figure 11 tells us that the distance between the flake and bonebed in Column 1 is 2 cm, with the flake at 25 cm below the top of the column and the bonebed at 27 cm below the top of the column. For Column 2 the distance is a much larger 10.5 cm, with the flake at 28.5 cm below the top of the column, and the bonebed at 39 cm below the top of the column. This means that in both columns the flake sits stratigraphically above the bonebed, even if just by a couple of centimeters. In both cases the distance between stratigraphic positioning of the flake and bonebed separates them
enough that it cannot be concluded they were deposited during the same event and that further investigation is necessary.

**Fig 11.** Unit profile map showing locations of columns, strata, flake, and bonebed. Flake location is indicated as FS 261. The black rectangles indicate the range between the stratigraphic locations of the flake and top of the bonebed.

The zones in Column 1 and Column 2 between inferred flake and bonebed locations differ in thickness for two main reasons. First, the bones in the bonebed are located at uneven depths (see Figure 2), with some near the Stratum II/III boundary and some several centimeters above the boundary. Second, the bones are of uneven size, with many less than 5 cm thick, and some 20 cm or more. Since the bonebed stratigraphic location was estimated from the top of the two bones nearest the column, variation is likely to occur for these reasons.
As part of this investigation I looked at the particle size data in the cumulative percent distribution graphs specifically between the locations of the flake and bonebed (Figure 12). In Column 1’s cumulative percent distribution graph there is no distinct change in distribution in the 2 cm between the stratigraphic levels of the flake and bonebed. In Column 2, however, there is a spike in the distribution at 34 cm increasing the percent of gravel present, while the rest of the components remain about the same. This spike does not represent an isolated large clast, but instead is an increase in the amount of the same size fraction as previous and subsequent samples. Neither graph shows any micro-trends of sediment fining up nor down between the levels of the flake and bonebed, indicating that even though there is a gravel spike, there is nothing that indicates separate depositional histories of the flake and the bonebed.

Revised graphs of the statistical data for both columns, indicating the depths of the flake and bonebed, were also created. The revised graph for Column 1 is provided as Figure 13. Figure 13 shows no change in the statistical data between the stratigraphic positions of the flake and bonebed except for a very small spike in the kurtosis meaning that between the flake and the bonebed the sediment had slightly more variation in particle size distribution. Compared with the graph as a whole, however, the spike provides no significant information.

The revised graph for Column 2 is provided as Figure 14. The area between the stratigraphic positions of the flake and bonebed in Figure 14 is a bit more interesting. Within the range separating the flake and the bonebed, the geometric mean has a negative
Fig 12. Revised cumulative proportions (%) of gravel, sand, silt and clay in each sample for Columns 1 (left) and Column 2 (right). Horizontal lines represent approximate stratigraphic position of flake (upper line) and top of bonebed (lower line). Y-axis represents depth below top of column sample in cm.

spike and the standard deviation has a positive spike (both at 34 cm) and the skewness spikes to the negative twice. The kurtosis only has minor inflections within this range. These data require additional discussion.
Fig 13. Revised summary statistics for Column 1. Shows approximate stratigraphic position of flake (upper horizontal lines) and top of bonebed (lower horizontal lines). Y-axis represents depth below top of column sample in cm.

Fig 14. Revised summary statistics for Column 2. Shows approximate stratigraphic position of flake (upper horizontal lines) and top of bonebed (lower horizontal lines). Y-axis represents depth below top of column sample in cm.

The negative spike in geometric mean at 34 cm depth in Column 2 is anomalous as it was abnormally low, reflecting a sudden increase in particle size in this sample (phi size is more negative for larger particles) compared to the surrounding samples. This could imply higher energy for sediment transport in this sample than surrounding
samples, although some variation in particle size of colluvial deposits is typical (Waters 1992). The standard deviation between the flake and bonebed spiked positively at 34 cm. This is also anomalous, indicating extremely poorly sorted sediment. Both of these statistics support colluvial transport as suggested above, and that there was variation within this transport, but not a stratigraphic break. Although the spike in geometric mean could indicate a stratigraphic break, the sorting which continues to be poor does not support a stratigraphic break as better sorting would be evident if the sediment was grading either normally or reversely.

The skewness in Column 2 spiked twice negatively (at 30 cm and 34 cm) and twice positively (at 32 cm and 38 cm), shifting the samples from very finely skewed at 28 cm, to finely skewed, to very finely skewed, to coarsely skewed to very finely skewed at 38 cm. This means that in general the sediment had an excess of fines but changed at 34 cm to have an excess of coarse material in the sample and then returned to its previous composition. This anomaly only occurred in Column 2, and indicates an increase of coarse gravelly material as shown on both the statistical graphs and cumulative percent distribution. The change did not last for more than one 2 cm sample and does not coincide with any other significant trends.

Are the Figure 14 anomalies in mean, standard deviation, and skewness consistent with a stratigraphic break between 28 and 39 cm depth in Column 2? This would be simplest to demonstrate if there were distinctly different sediment characters above and below, or if there were graded or reverse-graded sequences that terminated/initiated in this depth range. Although there was a sudden increase in particle size which could support the theory of a stratigraphic break, the other statistics do not provide evidence for
a break. The sediment around the anomalies would need to show better sorting so that a trend of grading normally or inversely could be identified, like it was by Nemec and Kazanci (1999) and Major (1997). Additionally, the excess of coarse material would have to be preceded or followed by a trending excess of fines which would also indicate a grading sequence. Neither of these are present.

Additionally, looking back at the soil texture descriptions in Table 6 above for Column 2, the texture stays within varying degrees of the loamy texture classification and gravelly sandy mud, or gravelly muddy sand as the samples continue to have roughly equivalent percentages of silt, sand, and clay with a few samples having small percentages of gravels mixed in. In itself this does not serve as evidence for a stratigraphic break. This assertion is supported by the cumulative percent graph (Figure 12) which shows that there is no real texture change around the 34 cm gravel spike except for the addition of gravel. In a sequence of normal or inverse grading, there would need to be an obvious increase or decrease in particle size distribution indicating the beginning and end of a graded sequence. Additionally, the gravel spike itself should more prominent comprising the majority of the percent distribution such as in Figure 8, Column 1 at the 50 cm mark, and not just a portion as it is in Column 2. Though there is an increase in percent distribution of gravel at 34 cm in the Wenas Creek sediment, it is not a large enough increase in percentage to illicit that it is the top or bottom of a graded sequence. Additionally, the gravel spike is not followed or preceded by a decrease in the other size classes which would indicate predominantly finer grained sediments. This sediment is simply a matrix-supported colluvial deposit with no evidence of any type of grading.
After examining all the data produced by performing a particle size analysis on the sediment at the Wenas Creek Mammoth Site, there is no conclusive microstratigraphic evidence that would suggest that the flake and bonebed were deposited during separate events. As stated previously, other reasons could still explain the close location of the flake to the bonebed such as bioturbation, or that the flake and bonebed were initially deposited during different events, and then redeposited to this location together, but that is beyond the scope of this study.

The remaining seven columns that were collected are being retained by the CWU Department of Anthropology and Museum Studies for possible future studies that may or may not coincide with this thesis. Certainly, additional comparative data from the other seven columns could yield interesting information about the trend of the sediment as it covers the entire site, as opposed to information collected in the immediate location of the flake. Comparisons over the broad scale of the nine total columns together may provide more insight to the nature of the event(s) that deposited the flake and bonebed and give a broader understanding of the history of the site.
CHAPTER V

JOURNAL ARTICLE

The manuscript composing this chapter will be submitted to the *Journal of Northwest Anthropology*. It is coauthored with the student and one of the committee members that provided significant assistance on the project. The manuscript begins on the next page. This is a draft of the manuscript to be submitted; the final manuscript (assuming it is accepted) may be somewhat different in response to external peer review.
USING PARTICLE SIZE ANALYSIS TO SEPARATE THE DEPOSITION OF A BONEBED AND ARTIFACT AT THE WENAS CREEK MAMMOTH SITE, WASHINGTON

Genevieve A. Brown and Patrick M. Lubinski

ABSTRACT

The 2005 discovery of a 14,000 B.P. mammoth bonebed in close proximity to a possible artifact at the Wenas Creek Mammoth Site (WCMS) brought with it the question of whether the bones and artifact were actually deposited together. If the two are associated, the WCMS would qualify as a Pre-Clovis site, a title given to just a handful of proven archaeological sites in North America, though claimed for numerous more. A close interval particle size analysis was performed on 2 column samples from the WCMS with the intention of identifying microstratification that would separate the bonebed from the artifact. Although no conclusive evidence for microstratification was determined through this test, other processes could still explain the close proximity positioning of the artifact and the bonebed.
Introduction

As of the time of this paper, the earliest well-accepted establishment of humans in North America dates ca. 11,500 B.P. with Clovis artifacts (Holliday 2000; Meltzer 2004; Waters and Stafford 2007). Though there are claims of sites in North America dating to pre-Clovis times, these assertions are not as yet widely accepted (Haynes 1969; Dincauze 1984; Meltzer 2004). The Wenas Creek Mammoth site in Washington State, with mammoth and bison bones dated to about 14,000 B.P. (Lubinski et al. 2007; 2014a), could qualify as a pre-Clovis site if these dated bones were strongly associated with artifacts unambiguously made by humans. There are two possible artifacts at the site, one recovered in place (Lubinski et al. 2014b). In this paper, we attempt to separate the deposition of the purported in situ artifact from the deposition of the bonebed, and thus demonstrate that the two are not associated.

The purported artifact (a flake fragment) was found just 15 cm above the bonebed within the same colluvial stratum, which means that the bones and flake could have been deposited simultaneously. However, it could also mean either (1) that the bones and flake were deposited in discrete events not separable using sediment characteristics in the field, or (2) that post depositional processes or disturbances re-deposited these items from their original locations to locations in close proximity. Here we test the first possibility by searching for multiple microstratigraphic layers within this stratum; layers which would separate the bones and the flake. In order to determine the presence or lack of microstratigraphy within the stratum, a close-interval particle size analysis was performed on the sediment from the stratum of interest. The results were examined for
any patterns of sorting or grading (regular or inverse) with depth which could indicate separate depositional events.

The theory behind this approach is that separate depositing events within colluvium may be expressed as sequences of normal graded, inverse graded, or ungraded strata or substrata (Major 1997; Nemec and Kazanci 1999). Normal graded deposits are a product of gravity principles which result in the heaviest pieces on the bottom and smallest on top, whereas inverse graded deposits are the product of kinetic sieving in which the downslope motion of these colluvial events causes the smaller particles to fill in the empty spaces around the larger clasts and settle out on the bottom (Gray and Chugunov 2006; Major 1997; Savage and Lun 1988). For either normal or inverse grading in colluvial sediments, it is common that only the largest clasts are graded (Major 1997; Costa and Jarrett 1981; Scott 1988; Vallance and Scott 1997), although there has been no work to set standards for particle size data evidence for the phenomenon. In some cases deposits from multiple colluvial events could exhibit a massive, homogenous, matrix-supported texture without any grading (Major 1997). With this in mind, the particle size data was examined for evidence of normal, inverse, and ungraded sequences between the flake and bonebed, which could then be used to separate the events that deposited them.
The Study Site

The Wenas Creek Mammoth site was discovered in 2005, uncovered by the construction of a private road, and excavated by Central Washington University from 2005 to 2010 (Lubinski et al. 2007; 2014a). The site yielded the remains of mammoth and bison as well as two possible lithic artifacts, one in situ, and one in a screen, all from a single observed stratum named Stratum II (Lubinski et al. 2009, 2014b). Stratum II is a ~20-50 cm thick, matrix-supported gravelly loam diamicton interpreted in the field as colluvium, overlain by a ~60-80 cm thick layer of loess (Stratum I), and underlain by over 180 cm of bedded sands and gravels (Stratum III) which were interpreted to be side stream alluvium (Lubinski et al. 2014a). The site lies in a locality mapped as a Quaternary landslide deposit modifying a ridge composed of Ellensburg Formation (Bentley and Campbell 1983) sediments of Miocene age (Tolan 2009).

Radiocarbon dating of eight bone samples yielded a mean pooled age of 13,874 ± 24 B. P. (Lubinski et al. 2014a). An attempt to date the possible in situ artifact by dating its surrounding Stratum II sediment using infrared-stimulated luminescence dating yielded 94 single-grain estimates (Lubinski et al. 2014a). When pooled, these estimates resolve into a component consistent with the age of the bonebed (80% of samples) and a mid-Holocene component (20% of samples). These age estimates for the Stratum II sediment imply some mixing of younger sediment into the stratum, possibly by bioturbation. A comparison of the two possible artifacts with theoretical expectations of flakes, natural rock in the site matrix, and modern flintknapped samples indicated that these two specimens are not easily dismissed as geofacts, but cannot be definitively
considered anthropogenic either (Lubinski et al. 2014b). Since neither the sediment
dating nor the technological examination of the possible artifacts provided sufficient
evidence to dismiss the possible association of the Pleistocene bonebed with human
activity, the site remains ambiguous. An attempt to separate the deposition of the
purported artifact from the bonebed might allow a clearer dismissal of the pre-Clovis
possibility.

Methods

A close interval particle size analysis was performed on two columns of sediment
collected from Stratum II, the stratum containing the bonebed and possible artifact (called
flake hereafter). Column 1 was collected from the west wall of the unit containing the
flake, 50 cm north and 9 cm west of the flake’s location. Column 2 was collected from
the west wall, 1 m south and 9 cm west of the flake. The column samples were collected
exclusively from Stratum II based on the boundaries delineated in the field, with a small
sampling from above and below the stratum boundaries to account for gradual
transitioning in and out of the stratum (Figures 1 and 2). Column collection involved
removing 5 cm x 5 cm samples in 2 cm increments. Column 1 yielded 25 samples, and
Column 2 yielded 28 samples, for a total of 53 samples. The locations of the flake and
bonebed were approximated within each column by interpolating flake location below
Stratum II top, and bonebed location by averaging the top of the nearest two bones to
each column. With these location parameters, the particle size analysis results could be
examined for evidence of stratification between the flake and the bonebed for each column.

Note that the zones between inferred flake and bonebed locations in Column 1 and Column 2 (see Figure 1) differ in thickness. This is because the bones in the bonebed are located at uneven depths within the stratum, and the bones are of different sizes (see Figure 2). Since the bonebed stratigraphic location was estimated from the top of the two bones nearest the column, variation is likely to occur.
A 10 g subsample was removed from each of the 53 samples for pretreatment and particle size analysis. Pretreatment was intended to remove carbonates and deflocculate the samples. Samples that tested positive in 10% hydrochloric acid solution were treated with 1N-sodium acetate solution for removal of carbonates, following the examples of Gee and Bauder (1986), Holliday (2004), and NRCS (1996). The samples were then rinsed and centrifuged to separate the liquid from the sample. All 53 samples were then deflocculated using sodium hexametaphosphate solution after NRCS (1996).

While dispersed within the hexametaphosphate solution, each sample was then wet sieved into 3 size classes: > 2 mm, 62.5 μm - 2 mm, and < 62.5 μm, oven dried for 36 hours, then weighed. The resulting size groupings were: the large fraction pebbles and cobbles (>2 mm), the sand fraction (62.5 μm to 2 mm), and the clay/silt fraction (< 62.5 μm).
The fractions below 2 mm were analyzed with a Malvern Mastersizer 2000 laser diffraction particle size analyzer. A 0.1 g portion of each sample was extracted and dispersed with hexametaphosphate solution before being run in the Mastersizer, and each sample was run while using the Mastersizer’s ultrasonic pump to help keep the samples suspended during analysis. To check the accuracy of the Mastersizer, every 5th sample was analyzed in triplicate, and each analysis produced comparable results.

The raw data were transcribed, size classes were converted to the phi scale, and calculations of percent total volume and cumulative percent by size class were made for each sample. These data were used to characterize sediment texture as proportions of gravel, sand, silt, and clay size classes using the Wentworth scale. Cumulative percents and their corresponding phi values for each sample were used to calculate geometric mean, standard deviation, skewness, and kurtosis in the manner of Blott and Pye (2001), and Folk and Ward (1957).

Results

The results of the particle size analysis can be discussed in several ways, including textural classifications, proportions of gravel, sand, silt, and clay, and sediment statistics. Using Natural Resources Conservation Service textural classifications (Schoeneberger et al. 2012), individual samples from within Stratum II vary from very gravelly loam to silt loam. Using Folk (1974) sediment classifications, the samples were slightly gravelly to gravelly sandy muds or muddy sands. The cumulative percent distributions of gravel, sand, silt, and clay by depth for each column (Figure 3) show that
sand and silt are the main components in both columns with the remaining material being comprised of only 2-28% gravels, and 2-12% clays except for the 50 cm sample in Column 1. This sample has a noticeable jump in cumulative percent gravel, representing the top of Stratum III.

Figure 3. Cumulative proportions (%) of gravel, sand, silt and clay in each sample for Columns 1 (left) and Column 2 (right). Horizontal lines represent approximate stratigraphic position of flake (upper line) and top of bonebed (lower line). Y-axis represents depth below top of column sample in cm.
The space between the horizontal lines in Figure 3 illustrates the stratigraphic locations of the flake and the top of the bonebed. This is the area where stratification would need to be observed in order to separate the flake and bonebed depositionally. This area in Column 1 appears no different than samples from surrounding depths, providing no evidence for substrata boundaries in this column. In Column 2, there is a spike in the amount of gravel present within the zone of interest, but all other components remain about the same. In and of itself, this anomaly does not provide any sort of evidence for stratification, it simply indicates that the amount of gravels increased slightly at this depth.

The statistical data plotted with depth is presented in Figures 4 and 5. For both columns the geometric mean remained in the 3 and 4 Φ range for the majority of the samples indicating movement by a low energy event (Waters 1992). The standard deviation calculations for both columns indicate a state of poorly to extremely poorly sorted sediment (Folk 1974; Blott and Pye 2001; Waters 1992). This finding supports the initial interpretation of Stratum II as colluvial. Overall, both columns are very finely skewed, which indicates an excess of fines in the samples, as expected for low energy, poorly sorted sediments (Folk and Ward 1957). Kurtosis for both columns varied between platykurtic, mesokurtic, and leptokurtic. Such variation is typical for low energy modes of transport (Folk and Ward 1957).
In Figure 4, there are no obvious trends in size grading with depth, and few anomalies except near the bottom of Column 1. There are no significant patterns within the narrow depth range between the flake and bonebed locations. The most striking pattern is in the shared anomaly at 50 cm depth in mean, standard deviation, and skew...
statistics, and a less striking pattern at 42 cm depth. These are most likely indicative of the sediment transitioning into the underlying Stratum III, a stratum with bedded sands and gravels interpreted as alluvium.

In Figure 5, there are no obvious trends in size grading with depth, but the most significant peaks in geometric mean, standard deviation and skewness all occur at 34 cm depth, within the elevation range between the flake and bonebed locations in Column 2. The 34 cm sample represents a much larger mean grain size, poorer sorting, and skew towards larger particles than any adjacent sample. However, the statistical data are not consistent with a stratigraphic break between the flake and bonebed elevations, because there are no distinctly different sediment characters above and below, nor are there any graded or inverse-graded sequences that terminate/initiate in this depth range. In order to demonstrate a trend of grading normally or inversely as was done by Nemec and Kazanci (1999) and Major (1997), the sediment around the anomaly would need to show better sorting. Additionally, the excess of coarse material at 34 cm shown in the skewness data would have to be preceded or followed by a trending excess of fines which would also indicate a grading sequence. Neither of these are present.

After examining all of the data, we do not see any clear evidence for strata boundaries in the form of normal or reverse grading sequences or changes in cumulative percent distribution that indicates anything other than one homogenous colluvial unit. There is no evidence in Figures 3, 4, or 5 for substratification of Stratum II into multiple depositional events, particularly between the location of the flake and the top of the bonebed. The only visible composition change is in Column 1 at 50 cm which indicates the boundary into Stratum III. Through the statistical analysis, both columns provide
evidence for a single episode of low energy transport which supports the initial theory that the sediment was transported through a downslope colluvial event.

Conclusions

Using particle size analysis, we were unable to find evidence for substratification within Stratum II that would definitively disassociate the flake (possible artifact) from the bonebed. Lacking evidence of multiple episodes of deposition within Stratum II, several alternative processes may be responsible for the juxtaposition of the flake and bonebed. First, the flake and bones may have been deposited to this particular location during the same event (even if it was an event subsequent to their initial, separate depositions). Second, there may have been several episodes of colluvial deposition that did not leave clearly separable substrata and so appear as a homogenous unit, as observed by Major (1997) in other sediments. Third, the flake may have been brought to its location by intrusive means, such as bioturbation (see Lubinski et al. 2014a). In any case, information from this study provides important details about how the bonebed and flake got to their final locations.

Since there is no clear evidence separating the deposition of the flake and bonebed, it remains possible that they are in fact associated. Of course, even if they are associated, it is possible that the purported artifact is not anthropogenic. The site does not have compelling evidence for pre-Clovis age human activity, but it remains an open question whether there is a human role or if it is merely a paleontological locality with a few interesting, angular rocks.
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