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A Light in the Dark: Luminescence Dating Intermountain Ware Ceramics from Four Archaeological Sites in Northwestern Wyoming

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A LIGHT IN THE DARK: LUMINESCENCE DATING INTERMOUNTAIN WARE

CERAMICS FROM FOUR ARCHAEOLOGICAL SITES IN NORTHWESTERN

WYOMING

by

Carlie J. Ideker

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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ABSTRACT

A Light in the Dark: Luminescence Dating Intermountain Ware Ceramics from Four

Archaeological Sites in Northwestern Wyoming

by

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Late Period (<1500 years), high-altitude (>2600 m asl) archaeological sites in northwestern Wyoming prove difficult to date with traditional methods. The presence of Intermountain Ware ceramics at these sites presents an opportunity to use single-grain optically stimulated luminescence (OSL) to date vessel manufacture. These OSL ages also date site occupation as the vessels' use-life is encapsulated within the standard error of the technique. This thesis develops a protocol to date quartz temper of Intermountain Ware sherds. Additionally, it investigates potential post-depositional thermal resetting of luminescence signals by wildfires. Ceramic sherd samples were obtained from four sites in northwestern Wyoming: Boulder Ridge, High Rise Village, Caldwell Creek, and Platt.

Each site, except Caldwell Creek, has existing radiocarbon ages that provide independent age control. Additionally, all sites except Platt were impacted by past wildfires of varying intensity and consequently provide a test of the thermal resetting capabilities of wildfires. The Platt site is also the only site not located at high altitude and therefore, the sample from this site serves as a control in this study.

Luminescence results demonstrate single-grain OSL dating of quartz temper from Intermountain Ware ceramics can provide improved accuracy and precision over radiocarbon dating when sherds are not adversely affected by wildfires. These results underscore the need for cultural resource managers to sample from subsurface contexts when inventorying sites impacted by high-intensity wildfires or to locate and identify sites with strong potential for high-intensity wildfires and date them prior to eventual burning. These results also validate single-grain OSL dating of ceramic temper as a valuable chronometric tool for cultural resource managers and archaeologists seeking to build and refine existing site and regional chronologies.

(78 pages)

PUBLIC ABSTRACT

A Light in the Dark: Luminescence Dating Intermountain Ware Ceramics from Four

Archaeological Sites in Northwestern Wyoming

Carlie J. Ideker

The chronology of high-altitude archaeological sites in northwestern Wyoming is poorly understood due to limited reliable age constraints. While temporally diagnostic artifacts provide relative age control, fluctuations in atmospheric radiocarbon produce radiocarbon age results with multiple calibrated age-range intercepts that prove difficult to interpret. Age overestimates associated with the 'old wood' problem can be especially prominent at high-altitude sites where cold and semi-arid environments promote the presence of long-living trees and prolong the preservation of organic material. Moreover, regional droughts coupled with a pine beetle epidemic have resulted in increasing wildfire frequency and intensities that serve both as a benefit and hindrance to archaeological research and cultural resource management. While fires expose archaeological sites, they also limit contexts for radiocarbon dating through the destruction of prehistoric wooden structures and release modern charcoal on open-air sites. Needless to say, the convergence of these complications reduces confidence in radiocarbon results alone at many high elevation sites. Fortunately, the presence of prehistoric pottery, known as Intermountain Ware, at many of these sites provides an opportunity for direct dating with optically stimulated luminescence or OSL. Researchers can use OSL along with radiocarbon dating to strengthen resulting chronologies for these problematic geographical areas.

In general, luminescence dating provides an age estimate of the time since quartz or feldspar grains were last exposed to light, during sediment transport, or heat, during firing, which resets the luminescence signal. In regards to prehistoric ceramics, quartz and feldspar grains become reset during prolonged exposure to temperatures in excess of 450°C, common during the firing process. Grains then begin to accumulate a luminescence signal due to exposure to radiation from surrounding sediments and the sherd itself. The luminescence emitted from the grain is proportional to the annual dose of environmental radiation and the amount of time since the vessel was originally fired. Luminescence results are interpreted to provide direct ages for site occupation as vessel use-life is encapsulated within the standard error of the technique.

Single-grain OSL examines luminescence signals of individual grains, and provides a detailed look into the thermal resetting capabilities of wildfires on sherd luminescence signals. This is especially important as all sherds analyzed in this study, except one, come from post-wildfire inventories or excavations. Results demonstrate that single-grain OSL dating of quartz temper from Intermountain Ware ceramics can provide improved accuracy and precision over radiocarbon dating when sherds are not adversely affected by wildfires.

ACKNOWLEDGMENTS

the analysis of High Rise Village sherds and provided important information about the archaeological context of artifacts from the site. Dr. Laura Scheiber provided the Caldwell Creek sherds and contributed valuable archaeological information about the artifacts. Michelle Nelson, the USU Luminescence Lab Manager, spent countless hours analyzing data, generating figures, and discussing luminescence procedure options with me.

During the past three years, my fellow archaeological and geological graduate students provided much needed friendship and support. From informal conversations to actual edits, they gave me a fresh perspective when I needed it most. I hope that I am able to repay the favor.

Finally, I must thank those who provided personal support throughout the duration of this project. Mike Ellefson provided unwavering support and endured many archaeological and luminescence rants. He also provided aesthetic advice on countless presentations and posters. Additionally, my family has supported my educational endeavors since the day I asked for homework in kindergarten. When I expressed an interest in archaeology, my parents whole-heartedly encouraged my pursuit.

<div align="right">Carlie J. Ideker</div>

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CHAPTER ONE:

INTRODUCTION

The chronology of high-altitude (>2600 m asl) archaeological sites in northwestern Wyoming, USA is poorly understood due to limited reliable radiometric age constraints (Adams 2010; Eakin 2005; Scheiber and Finley 2010; Morgan et al. 2012). Temporally diagnostic artifacts yield relative site occupation ages and at best provide vague windows into the chronological past. Consequently, fundamental research questions reliant on precise radiometric ages remain unanswered and regional chronologies indistinct. Temporally diagnostic artifacts indicate occupation at many high-altitude sites occurred within the past 1500 years. However, fluctuations in atmospheric radiocarbon during this time period produce multiple, calibrated calendar age-range intercepts (Reimer et al. 2013), which make it difficult to interpret radiocarbon results. Moreover, age overestimates associated with the 'old wood problem' (Schiffer 1986) can be especially prominent at high elevations where cold and semi-arid environments promote the presence of long-living trees and prolong the preservation of organic material on the landscape (Dean 1978).

Current climatic regimes further obstruct the use of radiocarbon dating at archaeological sites within the Central Rocky Mountains. Regional droughts in combination with a mountain pine beetle epidemic have left dead and dying forests with decreased snowpack and increasing winter temperatures (Rocca et al. 2014). As a result, wildfire seasons are lengthening and annual areas burned by wildfires are expected to

increase up to six times regionally (National Resource Council 2011). The subsequent

increase in wildfire frequencies (Kulakowski and Jarvis 2011) proves both an advantage

and obstacle for archaeologists. While fires burn forest duff and vegetation revealing

obscured archaeological sites, they also limit contexts for radiocarbon dating through the

destruction of prehistoric wooden structures and release of modern charcoal at open-air

sites (Buenger 2003).

The presence of prehistoric ceramics, known as Intermountain Ware, at many

high-altitude archaeological sites provides an opportunity for directly dating site

occupations with optically stimulated luminescence (OSL). The technique yields

calendric ages and directly dates vessel manufacture, thus removing calibration concerns,

uncertainties regarding sample association, and 'old wood' problems (Feathers 2000). In

general, luminescence dating provides an age estimate of the time since the vessel was

fired. Quartz or feldspar grains within the temper and paste become sensitized during

prolonged exposure to temperatures in excess of 450°C, common during the firing

process (Aitken 1997; Feathers 2003:1495; Rhodes 2011:469). This thermal exposure

resets the dating clock for quartz and feldspar minerals. Due to exposure to ionizing

radiation, defects within the crystal lattice structures then begin to accumulate electrons,

which are released as the natural luminescence signal in the laboratory when exposed to

light or heat. The energy emitted from the grain is proportional to the annual dose of

environmental radiation and the length of time since the vessel was originally fired

(Aitken 1985; Feathers 2000). As Intermountain Ware ceramics had short use-lives at

high altitude, their associated firing age and entire lifespan are likely encapsulated within

the standard error range of the technique. Therefore, luminescence results can be interpreted as directly reflecting the age of site occupation.

As a relatively new dating technique, little is known about the impacts of wildfires on prehistoric sherd luminescence signals. Wildfires can potentially thermally reset sherd luminescence signals, although experimental research suggests low-to-moderate intensity[1] fires will not adversely affect sherd signals (Buenger 2003; Herbert et al. 2002). Additionally, Buenger (2003) suggests buried sherds are insulated from post-depositional thermal alteration. The impacts of high-intensity fires on sherd signals are not well studied. To further explore this issue, I dated Intermountain Ware sherds from sites impacted by wildfires of varying intensity with single-grain OSL. Single-grain OSL represents the most advanced luminescence technique available (Duller 2008, 2012). In regards to ceramics, single-grain OSL bolsters luminescence ages by creating a robust dataset from limited material and provides a detailed look into the thermal resetting capabilities of wildfires at the level of individual grains.

In this thesis, I develop a single-grain OSL protocol to date Intermountain Ware sherds from four Late Period archaeological sites within northwestern Wyoming (Figure 1). The resulting luminescence ages provide an improved chronology for a region where constructing chronologies has proven difficult (Adams 2010; Eakin 2005; Scheiber and Finley 2010; Morgan et al. 2012).

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[1] Fire intensity refers to the total energy output from fire as a function of temperature and heating duration (Keeley 2008).
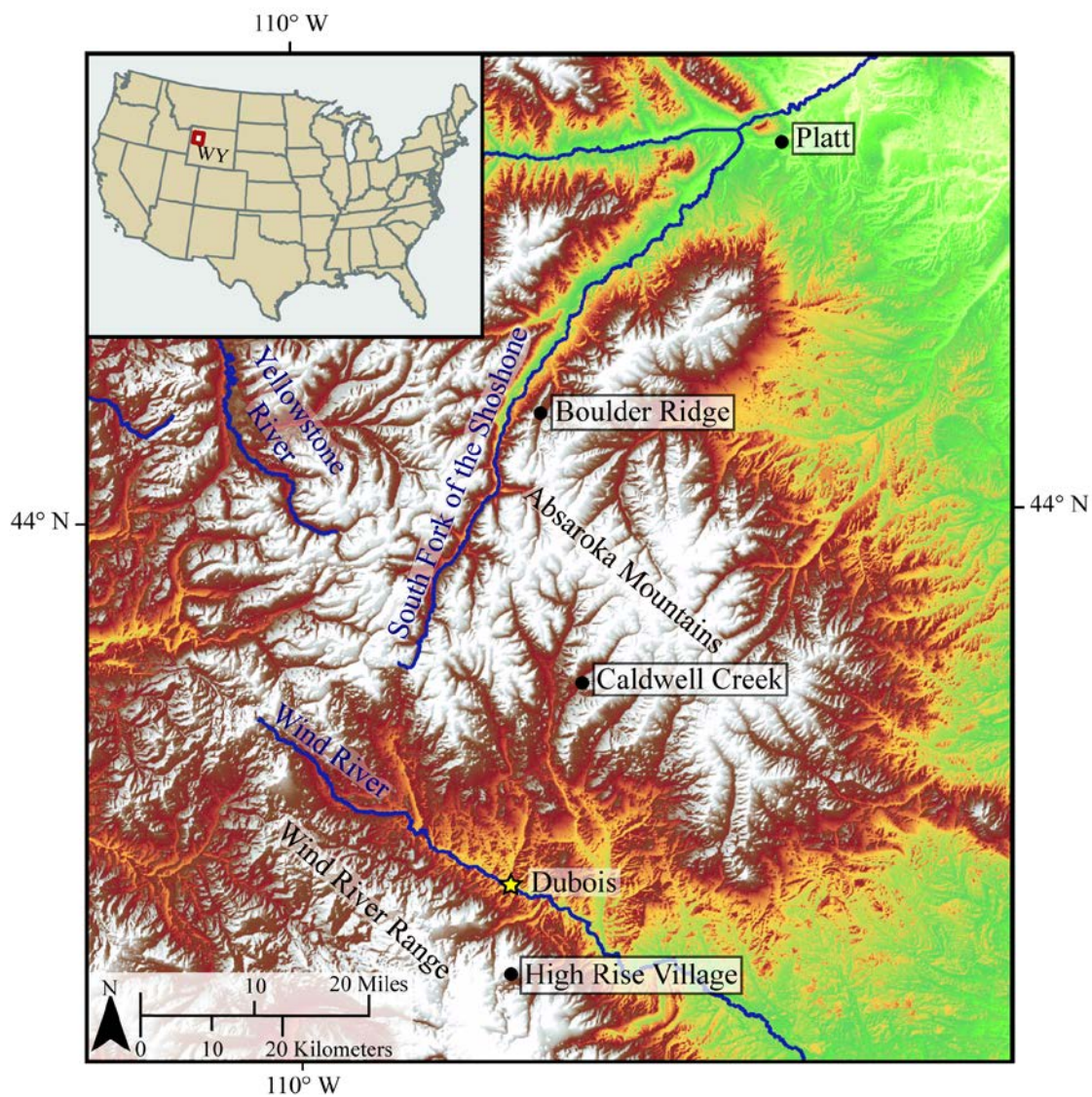
Figure 1. Northwestern Wyoming (WY) archaeological sites, Boulder Ridge (48PA2665), High Rise Village (48FR5891), Caldwell Creek (48FR7091), and Platt (48PA848).

RESEARCH DESIGN SUMMARY

This thesis develops a single-grain OSL protocol to date ten Intermountain Ware ceramic sherds recovered from four archaeological sites in northwestern Wyoming. Resultant OSL ages are used to evaluate the reliability of radiocarbon results from each site, and single-grain results are also used to explore the thermal resetting capabilities of wildfires on sherd luminescence signals. In the course of this thesis, I explore several research questions. First, can single-grain OSL dating of Intermountain Ware ceramics accurately and precisely date vessel manufacture and therefore site occupation? If so, I expect OSL results to consistently post-date associated radiocarbon ages, which provide an upper limit or maximum boundary for prehistoric occupations. Secondly, do wildfires reset sherd luminescence signals, and can single-grain OSL identify impacted luminescence signals? Experimental results suggest low-to-moderate intensity fires do not impact sherd signals (Buenger 2003). These results also indicate buried sherds are insulated from any post-depositional thermal alteration and consequently, artifacts recovered from the surface of severely burned sites are more likely to exhibit thermal alteration. This thesis provides a test of these experimental results and further explores the effects of high-intensity fires on sherd luminescence signals through the lens of single-grain OSL analysis.

To answer these questions, I chose a total of ten sherds from four archaeological sites. Nine sherds came from three high-altitude sites impacted by varying wildfire intensities. The sherds were collected by previous site investigators and reflect both

surface and excavated contexts. For a control, I also analyzed a sherd covered in organic residue believed to reflect a cooking event. This sherd was excavated from the Platt site, located below the high-altitude cutoff (>2600 m asl) and unaffected by wildfires.

The single-grain OSL results from this study indicate the technique is an excellent choice for accurately and precisely dating high-altitude occupations that have not been impacted by high-intensity wildfires. Sherds recovered from site surfaces after high-intensity fires experienced extensive post-depositional thermal resetting as indicated by their near-modern apparent luminescence ages. In this case, single-grain analysis accurately identified reset grains and potentially identified a grain population with intact signals. However, sherds recovered from excavated contexts appear to have been insulated from recent thermal alteration regardless of fire intensity. Results also indicate low-to-moderate intensity fires do not impact luminescence signals of sherds recovered from site surfaces.

In all cases where sherds were not thermally reset by recent fires, luminescence results agreed with relative ages produced from temporally diagnostic artifacts and allowed problematic radiocarbon ages to be identified. Single-grain OSL sherd analysis also yielded precision greater than or equal to associated radiocarbon ages. Results from this study indicate single-grain OSL is as a reliable and precise dating technique, except when dating sherds recovered from site surfaces after high-intensity fires.

This thesis begins by outlining luminescence-dating fundamentals in regards to prehistoric ceramics, provides a general discussion of Intermountain Ware within the Central Rocky Mountain region, and introduces the reader to study sites. Chapters Three and Four detail the methods used in this thesis and discuss single-grain OSL results and

implications. Chapter Five compares luminescence, radiocarbon, and relative ages from each site and examines parameters of thermal resetting by wildfires. Finally, Chapter Six reorients the reader to the original research questions, provides recommendations for future use of the technique, and considers the contribution of this scholarship to academia and cultural resource management.

CHAPTER TWO:

RESEARCH CONTEXT

The application of luminescence dating Intermountain Ware sherds has potential for producing direct occupation ages of archaeological sites, especially those at high altitudes where traditional radiometric techniques yield greater uncertainties and have poorly resolved chronologies. Intermountain Ware ceramics are excellent candidates for OSL due to their short use-life, and abundance of quartz sand in vessel temper (Coale 1963; Finley and Boyle 2014; Middleton et al. 2007). Furthermore, relatively recent advances in luminescence dating have resulted in single-grain methods with increased accuracy and precision (Duller 2008, 2012). This thesis applies single-grain OSL to quartz temper from Intermountain Ware ceramics to produce manufacture ages that directly reflect occupation ages, clarify site chronologies, and explore the potential for thermal resetting of sherd luminescence signals. This chapter provides background on luminescence dating, Intermountain Ware ceramics, and introduces the study sites.

LUMINESCENCE DATING

Luminescence dating operates on the principle that natural minerals such as quartz or feldspar absorb and store energy in defects within their crystalline structure.

Exposure to sufficient light or heat will release all or part of the stored electrons (Aitken 1985, 1998; Feathers 2003; Huntley et al. 1985; Lian 2007; Rhodes 2011). Free electrons accumulate in defects within mineral crystalline lattice structures due to radiation exposure from radiogenic isotopes within the grain, the surrounding environment, and incoming cosmic radiation (Lian 2007; Rhodes 2011). These ionized electrons are attracted to the positively charged traps or defects within the crystalline lattice and will remain trapped until the grain is exposed to sufficient energy to evict electrons (Aitken 1985, 1998; Huntley et al. 1985). Once evicted, electrons are pulled into the conduction band of an atom missing an electron and drop into a lower energy state, although they can also return to the original defect (Aitken 1985, 1998; Huntley et al. 1985). As a result of the drop in energy, luminescence signals are produced as electrons emit a photon of light. The intensity of the natural luminescence signal is proportional to the length of time since the grain was last exposed to sufficient energy. Events responsible for resetting the natural signal are referred to as bleaching or zeroing events. After a grain is zeroed, electron accumulation begins again at a rate dependent on the environmental dose rate (Aitken 1998).

Quartz and feldspar can be dated using heat, known as thermoluminescence dating (TL; Aitken 1985), or light, known as optically stimulated luminescence dating (OSL; Huntley et al. 1985). The equivalent dose (D_E) represents the amount of absorbed radiation required to produce a luminescence signal equal to the natural signal. Luminescence ages are determined by dividing the D_E by the environmental dose rate (D_R), with the following equation:

$$D_E \text{ (Gy)} / D_R \text{ (Gy/ka)} = \text{Age (ka)}$$

The environmental dose rate is calculated from representative samples of the sherd and surrounding soil and includes internal, short-ranged alpha and beta radiation from within the sample, and environmental components from external, long-ranged gamma and cosmic radiation (Aitken 1985, 1998).

The single-aliquot regeneration (SAR) protocol represents the current standard for luminescence dating and was developed to alleviate problems associated with inter-aliquot variability common with multiple-aliquot techniques (Murray and Wintle 2000). SAR protocol applies the same steps to every aliquot, standardizes each aliquot with preheats and cutheats, and monitors induced sensitivity changes by measuring aliquot responses to given radiation doses. Continued exposure to ionizing radiation can induce sensitivity changes to the luminescence properties of sand. Repeated low-test doses are used track and correct for such changes. Luminescence signal responses to regenerative doses are used to produce a dose-response curve that brackets the natural signal. As a result, the equivalent dose is determined via interpolation. SAR protocol has been applied to quartz (Murray and Wintle 2000, 2003), feldspar (Wallinga et al. 2000), and polymineral fine (Banerjee et al. 2001) fractions. Table 1 outlines a complete SAR sequence

Table 1. SAR-OSL Sequence.

SAR Sequence Steps
1. Preheat between 160ºC-300ºC and hold for 10 s
2. Stimulate for 40 s at 125ºC (natural or regen. signal)
3. Test dose, D_t
4. Cutheat between 160ºC-300ºC and hold for 10 s
5. Stimulate for 40 s at 125 ºC (test dose signal)
6. Regenerative dose, D_i
7. Repeat steps 1-7 altering regenerative dose as follows: R1: regenerative dose lower than natural R2: regenerative dose approximate to natural R3: regenerative dose higher than natural R0: zero dose – recuperation check R1': repeat of first regenerative dose – recycling ratio check
8. IR stimulation to check for feldspar contamination

Single-Grain Optically Stimulated Luminescence

Murray and Roberts (1997) developed single-grain OSL methods to correct for a fundamental assumption of luminescence dating: grains are exposed to sufficient energy to completely evacuate all electron traps. In reality, variable depositional environments often produce partially reset grains that retain residual luminescence signals due to inadequate light or heat exposure (Duller 2008; Rittenour et al. 2015). Unchecked incompletely reset or partially bleached grains can cause age-overestimations (Duller 2008). Single-grain luminescence dating restricts aliquot size from traditional small aliquots (~10-1,000s grains) and examines the luminescence properties on a grain-by-grain basis (Duller 2008; Murray and Roberts 1997). Consequently, single-grain OSL can identify problematic grains and remove them from contributing to the final age, thereby increasing the accuracy and precision of the resulting age. Because of the improved

precision provided by the single-grain method, it has become widely used in settings where solar resetting can be problematic.

Luminescence Dating of Prehistoric Ceramics

The earliest applications of luminescence techniques involved dating prehistoric ceramics as heat, in addition to light, resets the luminescence signal in quartz and feldspar minerals (Aitken 1985, 1998). Traditional methods used thermoluminescence (TL) to date the polymineral very-fine-to-fine silt (4-11 μm) fraction of ceramic paste (Aitken 1985). Contemporary methods rely on optically stimulated luminescence (OSL) dating to determine ceramic firing ages (Barnett 2000; Brisson et al. 2015; Eerkens and Lipo 2011; Feathers and Rhode 1998; Rhode 1994). Advances in luminescence dating have allowed techniques to move from analysis of multiple large aliquots and polymineral fractions to mineral-specific fractions of ever smaller aliquots, culminating in the single aliquot regenerative dose (SAR) technique (Murray and Wintle 2000) applied to single-grain dating (Duller 2008, 2012; Duller et al. 2000). Single-grain OSL is widely recognized as the most advanced and refined luminescence method available (Duller 2008, 2012). The reduction in the number and size of aliquots allows greater accuracy and precision than analysis of large aliquots (Duller 2008, 2012) resulting in improved archaeological applications (Robert et al. 2015).

In regards to archaeological ceramics, single-grain OSL dating of quartz temper provides improved accuracy and precision over older TL and fine-grained OSL dating of ceramic paste as uncertainties regarding minerals analyzed and correction for anomalous

fading of feldspar signals are avoided. Additionally, single-grain OSL of ceramics

bolsters sample robustness as it yields more data points than would otherwise be achieved

through small aliquot SAR techniques on samples with limited material. Furthermore,

single-grain OSL explores the luminescence signals of individual grains and provides a

detailed look into the thermal resetting capabilities of wildfires on sherd luminescence

signals. This is especially important as all sherds analyzed in this study, except one, come

from post-wildfire inventories or excavations.

INTERMOUNTAIN WARE CERAMICS IN THE ROCKY MOUNTAINS

Ceramic sherds used in this study represent a pottery type known as

Intermountain Ware. The Intermountain Ware tradition was first identified by Mulloy

(1958) and is dispersed throughout the Central Rocky Mountains, Great Basin, and even

into the Northern Rocky Mountains (Coale 1963; Davis et al. 2010; Eerkens et al. 2002;

Finley and Boyle 2014; Frison 1971, 1976; Kornfeld et al. 2010; Middleton et al. 2007).

Intermountain Ware ceramics bare a Shoshonean ethnicity (Mulloy 1958; Wedel 1954),

because they commonly occur in the archaeological record with suite of diagnostic

Shoshonean artifacts (Holmer 1994; Frison 1971; Larson and Kornfeld 1994; Scheiber

and Finley 2010). Radiocarbon age estimates suggest that most sites associated with

Intermountain Ware ceramics in the Rocky Mountains were occupied within the last 800

years (Davis et al. 2010). The oldest known age of an Intermountain Ware vessel in the

Central Rocky Mountains comes from the Myers-Hindman site near Livingston, Montana and has been dated to 800 ± 180 cal B.P.$_{2010}$[2] (790 ± 90 B.P., GAK-2631; Lahren 1976).

Intermountain Ware ceramics are often referred to as 'brown ware' (Pippin 1986) due to surface color likely obtained from a reducing atmosphere during the firing process (Coale 1963). However, as vessel color varies according to oxidation levels during firing or even cooking, color is not necessarily a reliable characteristic for type definition, let alone a type name (Finley and Boyle 2014). The ten sherds utilized in this thesis further illustrate this point as they range in color from brown to grey (Figure 2).

In general, Intermountain Ware ceramics are typed according to vessel form, surface treatment, and temper (Middleton et al. 2007). Vessels typically display a characteristic 'flower pot' or 'truncated cone' form with thick walls and thick, flat bases (Figure 3; Finley and Boyle 2014; Kornfeld et al. 2010). Intermountain Ware sherds generally have limited surface treatments including brushing or fingernail impressions and high temper-to-paste ratio (Coale 1963; Finley and Boyle 2014; Kornfeld et al. 2010; Mulloy 1958; Scheiber and Finley 2011; Wedel 1954). Vessel temper consists of poorly sorted quartz sand or grit (Middleton et al. 2007). Sherds exhibit extreme friability as a consequence of relatively coarse paste, an abundance of temper, and likely low firing temperatures (Coale 1963:2), further promoting a short use-life of Intermountain Ware vessels.

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[2] Ages noted as 'cal B.P.$_{2010}$' have been calibrated using the IntCAL13 (Reimer et al. 2013) calibration curve and have been standardized to A.D. 2010 by the addition of 60 years to allow for direct comparison with OSL results. All errors are reported at two-sigma standard error.

Boulder Ridge

High Rise Village

Caldwell Creek

Platt

1 cm

Figure 2. Ten Intermountain Ware sherds from four archaeological sites prior to analysis. Sherds are organized according to site and USU number. Going left to right, Boulder Ridge sherds are: USU-1571, USU-1586, USU-1769. High Rise Village sherds: USU-1780, USU-1781, USU-1782, USU-1783. Caldwell Creek: USU-1784, USU-1785. Platt: USU-1786.
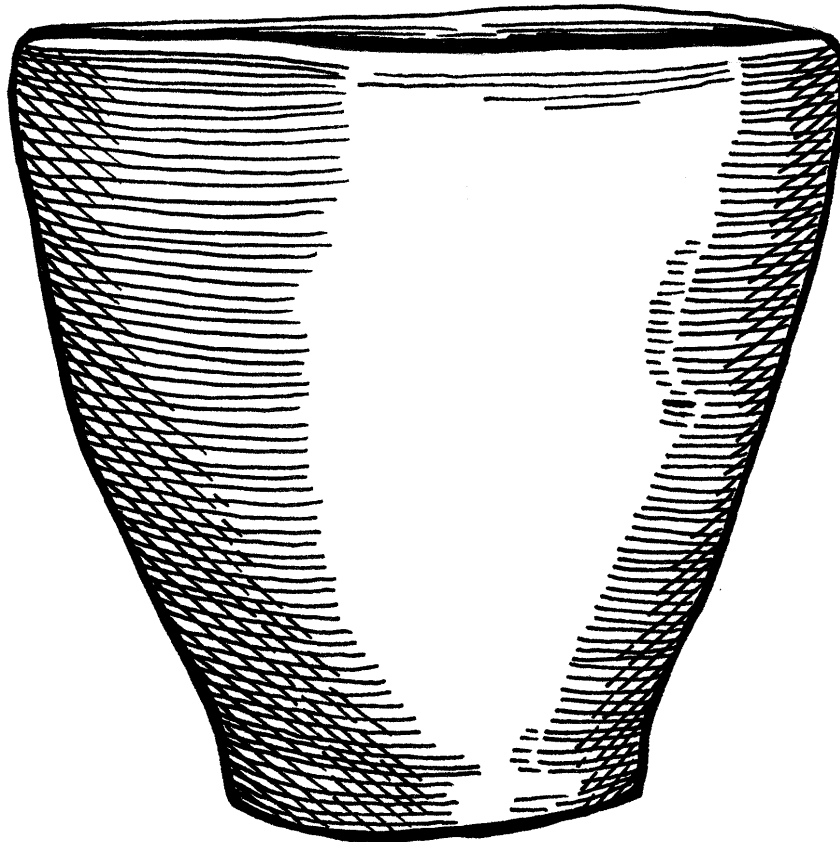
Figure 3. A typical Intermountain Ware vessel form. Illustration courtesy of Maureen Boyle, Utah State University Anthropology.

While Intermountain Ware have a broad distribution, sherds remain relatively rare in the Central Rocky Mountain region (Finley and Scheiber 2010). As a consequence, there is a general paucity of literature within the region regarding Intermountain Ware beyond basic descriptive analyses (Finley and Boyle 2014). Paradoxically, Intermountain Ware ceramics along the western Great Basin, more commonly referred to regionally as brownware, are associated with a growing body of rigorous scholarship. Studies focused on ceramic selection and investment (Eerkens 2003, 2004), provenance and conveyance

(Eerkens 2012; Eerkens et al. 2002; Simms et al.1997), and age (Eerkens and Lipo 2011, 2014; Feathers and Rhode 1998; Rhode 1994) yield insight into fundamental issues regarding prehistoric mobility patterns and technological diffusion. Similar studies need to be undertaken within the Central Rocky Mountain to gain insight into regional ceramic use, and consequently, tease out fundamental similarities and differences in Intermountain Ware between the two culture areas. Such comparisons will undoubtedly provide further insight into the significance of these often disregarded artifacts and larger inter-region mobility patterns, interactions, and technology diffusion.

STUDY SITES AND SAMPLE SELECTION

Four study sites located in northwestern Wyoming were selected for analysis (Figure 1). Boulder Ridge (48PA2665), Caldwell Creek (48FR7091), and Platt (48PA848) all lie within or on the periphery of the Absaroka Mountains. High Rise Village (HRV; 48FR5891) sits above 3,000 m asl in the Wind River Range, south of the Absarokas. Wildfires have impacted three of the four sites involved in this study. Boulder Ridge burned in A.D. 2003 during the Boulder Basin II wildfire (Scheiber and Finley 2010), while HRV also partially burned in a decades-old fire (Adams 2010; Koenig 2010). More recently, the A.D. 2011 Norton Point forest fire exposed the Caldwell Creek site. These fires have limited reliable contexts for radiocarbon dating by releasing modern carbon and destroying any associated prehistoric wooden structures in sites already

difficult to date. Previous archaeological investigations provide the context for each site's background.

Boulder Ridge (48PA2665)

Boulder Ridge is located at approximately 2800 m asl in northwestern Wyoming's Absaroka Mountains (Figure 1). Prior to A.D. 2003, the site was located within a dense mixed, subalpine forest of Engelmann spruce (*Picea engelmannii*), Douglas fir (*Pseudotsuga menziesii*), and lodgepole pine (*Pinus contorta*). In A.D. 2003, the Boulder Basin II wildfire swept through the area, burning over 11,000 acres, including Boulder Ridge (Eakin 2005). The site includes lodges, bighorn sheep (*Ovis canadensis*) hunting traps, and animal butchering areas with varying levels of time depth and cultural accumulation that represent multiple occupations. Occupation periods at Boulder Ridge have been identified on the basis of Late Prehistoric (1500-500 cal B.P.)[3] artifacts and a historic component that dates to the turn of the 19th century (Eakin 2005; Scheiber and Finley 2010). The Boulder Basin II wildfire uncovered artifacts like glass trade beads and rusted sheet-iron alongside traditional stone tools, Late Prehistoric projectile points, and Intermountain Ware ceramics (Eakin 2005; Scheiber and Finley 2010, 2011). Three radiocarbon ages obtained on charcoal fragments from an excavated hearth place occupation of an associated lodge within a broad range of 1030-590 cal B.P.[2010] (Table 2; Scheiber et al. 2009). The presence of historic and prehistoric artifacts together provide a rare view into social and material transitions from the pre-contact into

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[3] Time period divisions based on Kornfeld et al. 2010:49.

Table 2. Radiocarbon Age Information.

Site	Lab ID	Sample ID	Lodge	Context	δ13C	^{14}C age[a] (B.P.)	2σ calibrated age range [relative area][b]	Median age[c] (cal B.P.$_{2010}$)
Boulder Ridge	AA98838	48PA2665-38	I	Hearth/ Charcoal	-23.2	570 ± 30	527-566 cal B.P. [0.395] 585-646 cal B.P. [0.605]	650 ± 60
	AA98839	48PA2665-39	I	Hearth/ Charcoal	-23.6	960 ± 40	786-938 cal B.P. [0.992] 946-952 cal B.P. [0.008]	930 ± 80
	AA98840	48PA2665-40	I	Hearth/ Charcoal	-22.7	980 ± 30	796-875 cal B.P. [0.515] 892-956 cal B.P. [0.485]	950 ± 80
High Rise Village	Beta-245981[d]	FR5891 LODGE S	S	Hearth/ Charcoal	--	840 ± 40	680-800 cal B.P. [0.908] 814-826 cal B.P. [0.017] 866-901 cal B.P. [0.075]	850 ± 110
	Beta-248565[d]	FR5891 LODGE CC	CC	Structural timber/ Wood	--	420 ± 50	317-396 cal B.P. [0.264] 423-535 cal B.P. [0.736]	490 ± 110
	Beta-269156[d]	FR5891 LODGE CC-2	CC	Sherd residue	--	130 ± 40	7-47 cal B.P. [0.162] 55-152 cal B.P. [0.420] 171-280 cal B.P. [0.419]	205 ± 140
Platt	UCIAMS-147405	CSI-PS-30 burnt residue	--	Sherd residue	-110.9	945 ± 25	796-888 cal B.P. [0.754] 890-922 cal B.P. [0.246]	920 ± 60

[a] Conventional radiocarbon age (± 1σ error) reported in radiocarbon years before A.D. 1950 (B.P.).

[b] Using IntCal13 calibration curve Reimer et al. 2013.

[c] Calibrated ages rounded to the nearest decade and reported at two-sigma error in years before A.D. 2010 (B.P.$_{2010}$) by adding 60 years to calibrated age.

[d] Samples originally reported in Morgan et al. 2012.

the post-contact era, and while these temporally significant artifacts provide relative

chronological constraints, ongoing research at Boulder Ridge requires greater age control

to understand the palimpsest material record and timing of past occupations (Finley and

Scheiber 2010; Scheiber and Finley 2010, 2011).

Three Boulder Ridge sherds (Figure 2; Table 3) were selected for analysis and

likely represent a single vessel based on petrographic and chemical analyses (Finley and

Scheiber 2010). After the Boulder Basin II wildfire, the sherds were discovered on the

surface near a circular lodge (Eakins 2005; Scheiber and Finley 2010). Three radiocarbon

ages are from an excavated hearth, and both the lodge and ceramic scatter are assumed to

be contemporaneous. However, investigations have as of yet failed to resolve the age of

the occupations since it is unknown whether or not an 'old wood' problem is present in

the radiocarbon samples from the excavated hearth.

High Rise Village (48FR5891)

HRV (Figure 1) stretches across approximately 19 acres of subalpine forest and

alpine tundra above 3000 m asl in the Wind River Range (Losey 2013; Morgan et al.

2012). The site straddles modern treeline, with remnants of a Late Holocene (1800-800

cal B.P.) whitebark pine forest (*Pinus albicaulis*), or ghost forest, extending

approximately 100 m farther up the mountain slope (Morgan et al. 2014). The so-called

ghost forest reflects a period towards the end of the Late Holocene when warmer

temperatures resulted in higher upper tree lines throughout the Rocky Mountain ranges of

Wyoming, Montana, and Colorado (Benedict et al. 2009; Carrara and McGeehan 2015;

Table 3. Sherd Information.

Lab Number	Site	Field Number	Size (length x width x thickness) (mm)	Context	Burial Depth (cm)
USU-1571	Boulder Ridge	BR-1-36	42.00 x 18.60 x 6.82	Surface	0
USU-1586	Boulder Ridge	BR-2-38	31.97 x 28.77 x 7.01	Surface	0
USU-1769	Boulder Ridge	BR-3-37	21.19 x 22.76 x 6.87	Surface	0
USU-1780	High Rise Village	HRV-488-1	11.35 x 7.75 x 6.05	Excavated	0-10
USU-1781	High Rise Village	HRV-488-2	17.62 x 14.45 x 7.92	Excavated	0-10
USU-1782	High Rise Village	HRV-1098-1	26.21 x 26.65 x 8.60	Excavated	0-10
USU-1783	High Rise Village	HRV-1098-2	27.27 x 18.60 x 7.29	Excavated	0-10
USU-1784	Caldwell Creek	CC-331	16.12 x 12.84 x 4.83	Excavated	0-30
USU-1785	Caldwell Creek	CC-438	18.18 x 15.52 x 9.38	Excavated	20-25
USU-1786	Platt	PS-30	63.96 x 46.45 x 8.18	Excavated	>15

Fall et al. 1995). These remnant stands have persisted for millennia in the semi-arid alpine conditions of the Wind River Range and would have been available as both construction timber and fuel wood for subsequent archaeological occupations.

The site was discovered in A.D. 2006 in a region affected by a previous wildfire (Adams 2010), although the fire did not affect portions of the site beyond modern treeline (Koenig 2010:12). HRV is a residential site consisting of approximately 52 lodge pads (rock-ringed, cut-and-fill lodges) near a region of known bighorn sheep habitat (Morgan et al. 2012:36). Radiocarbon ages place HRV occupations from the Middle or Late Archaic (5000-1500 cal B.P.) to the Late Prehistoric (1500-500 cal B.P.), although the

diagnostic projectile point assemblage indicates a predominantly Late Archaic and Late

Prehistoric occupation (see Morgan et al. (2012) for complete list of ages). The presence

of the Late Holocene ghost forest suggests that some of the oldest radiocarbon ages may

be due to incorporation of old wood into structures and hearths (Morgan et al. 2014).

HRV sherds (Figure 2; Table 3) came from two excavated lodges, Lodge S and

Lodge CC. Lodge S lies just beyond modern treeline and the boundary of the historic

wildfire. A radiocarbon age from an excavated hearth indicates lodge occupation between

960-740 cal B.P.$_{2010}$ (Table 2; Morgan et al. 2012). Lodge S sherds were not discovered

in situ and their exact burial depth is estimated to have been between 0-10 cm (Bryon

Schroeder, personal communication, 2015). Lodge CC has two associated radiocarbon

ages (Table 2) and sits within the boundary of the historic burn. The oldest radiocarbon

age range (600-380 cal B.P.$_{2010}$) comes from what researchers have interpreted as the

lodge's wooden superstructure, while the youngest age range (345-65 cal B.P.$_{2010}$) is

from organic residue scraped from the inner surface of a ceramic sherd (Losey 2013;

Morgan et al. 2012). Losey (2013:96) and Morgan et al. (2012) flagged Lodge CC

radiocarbon ages as problematic due to perceived issues with the sample. Problems with

dating organic residue from sherds are well known as humic substances and bacteria can

alter remaining food residue and contribute different sources of carbon (Berstan et al.

2008; Hedges et al. 1992; Stott et al. 2001; Yates et al. 2015).

Caldwell Creek (48FR7091)

The Caldwell Creek site was recorded in A.D. 2012 as part of a post-fire archaeological inventory north of Dubois, Wyoming (Scheiber et al. 2014). The site encompasses approximately seven acres of subalpine forest, including Engelmann spruce (*Picea engelmannii*), Douglas fir (*Pseudotsuga menziesii*), and lodgepole pine (*Pinus contorta*), and is located on the edge of a subalpine meadow at 2600 m asl. The site burned in the A.D. 2011 Norton Point wildfire that removed the thick vegetation and duff layer that previously obscured the diverse assemblage of surface artifacts (Scheiber et al. 2014). Cultural material indicates a sustained Mountain Shoshone occupation and includes over 2,000 Intermountain Ware sherds from at least six different vessels, tri-notched projectile points, bi-beveled knives, and steatite pipe fragments (Burtt et al. 2015; Scheiber et al. 2013; Scheiber et al. 2013). Features include a rock-ringed lodge, and preliminary excavations have revealed an extensive time depth and a continuous material record (Scheiber et al. 2014; Scheiber et al. 2014).

Two sherds were collected *in situ* from Caldwell Creek (Figure 2; Table 3), along with representative samples of external dose rates. Based on location and physical appearances, the sherds likely represent two different vessels with potentially differing manufacture ages. The presence of diagnostic artifacts at the site and in association with the sherds provide the only relative independent ages, which place ceramic manufacture within the past 1500 years (Scheiber et al. 2014; Scheiber et al. 2014).

Platt (48PA484)

The Platt site lies in a sagebrush steppe at the base the Absaroka Range at approximately 1600 m asl (Platt and Hughes 1986). The site was excavated in A.D. 1985 by the North Bighorn Basin Chapter of the Wyoming Archaeological Society and produced diagnostic projectile points from the Middle Archaic (5000-3500 cal B.P.) and Late Prehistoric (1500-500 cal B.P.) periods. On the surface, historic glass was recovered along with Intermountain Ware sherds (Platt and Hughes 1986). Sherds also came from undated excavated contexts.

Less is known about the Platt sherd (Figure 2; Table 3), as it comes from a relatively old excavation and has been curated for nearly 30 years. The sherd chosen came from a depth greater than 15 centimeters below surface (Chris Finley, personal communication, 2015) and had a considerable amount of organic residue on the inside from a cooking event. I carefully removed the residue and submitted it to the Earth System Science Department at University of California Irvine for radiocarbon analysis. The organic food residue produced an age of 920 ± 60 cal B.P.$_{2010}$ (Table 2). This radiocarbon age is currently the oldest radiometric age for Intermountain Ware in the Central Rocky Mountains and provides an interesting test for subsequent single-grain OSL analysis. Collectively, these 10 ceramic samples form the core of the subsequent study and proof of concept for single-grain OSL analysis as applied to prehistoric ceramics that has far-reaching implications for archaeological studies.

CHAPTER THREE:

METHODS

SINGLE-GRAIN OSL ANALYSIS

Sample Extraction

Sherds were collected during investigations at each site and were analyzed at the

Utah State University (USU) Luminescence Laboratory in Logan, Utah. Once at the lab,

each sherd was cataloged and photographed. Notes were taken regarding the type of

sherd, its size and thickness and temper composition. Working under dim amber light

conditions (~590 nm), the outer ~2 millimeters of each sherd was removed with a small

low-speed drill to eliminate the outer material that was exposed to light during collection.

Removal of the outer portion of the sherd also simplified calculation of the environmental

dose rate as grains exposed to beta radiation from the surrounding sediments were

removed. The remaining inner portion of the sherd was carefully disaggregated in a

mortar and pestle and subsequently wet sieved to acquire the target very fine to fine

grained quartz sand temper. The disaggregated sherd material was sieved to 63-250 μm

(90-250 μm for USU-1571) and treated with 10% hydrochloric acid and chlorine bleach

to dissolve carbonates and remove organic material. Quartz grains were isolated using a

sodium polytungstate (2.7 cm/g^3) float to remove heavy minerals. These isolated samples

were then treated in concentrated hydrofluoric and hydrochloric acids to remove

feldspars, etch quartz surfaces, and prevent formation of fluorite precipitates (see

Rittenour et al. 2005 and 2015 for details).

Dose Rate (D_R) Determination

Luminescence ages are calculated by dividing the dose of laboratory radiation

required to induce a luminescence signal similar to the natural signal, termed the

equivalent dose (D_E), by the rate of radiation exposure from the environment, termed the

dose rate (D_R) (Aitken 1998; Rhodes 2011). With ceramics, the dose rate contribution

from the internal radioactivity of the sherd also needs to be determined (Aitken 1985;

Feathers 2000; Wintle 2008). Dose rate calculation included internal beta and gamma

radiation contribution from radioisotopes of uranium, thorium and potassium from within

the sherd and gamma radiation from the surrounding sediments that was scaled based on

sherd thickness and burial depth. The contribution from cosmic radiation (Prescott and

Hutton 1995) and attenuation by water content were also included in dose rate

calculation. See Appendix for Supplemental Data details.

Optical Measurements

Quartz temper from the sherds was analyzed using the SAR technique (Murray

and Wintle 2000) on a Risø TL/OSL Model DA-20 reader with single-grain attachment.

Grains were stimulated with a green laser (532 nm) at 90% power (135 mW/cm^2) for 1 s

(0.1 s pause before and after stimulation) and the luminescence signal was detected

through a 7.5 mm UV filter (U-340). OSL measurements were carried out at 125°C.

Preheat temperatures followed natural and regenerative doses at 200°C (held for 10s),

and cutheat treatments were 160°C (held for 10s). Preheat and cutheat temperatures were

chosen based on the results of a preheat plateau dose recovery test (see Appendix for

Supplemental Figure S1 and caption for details).

Equivalent Dose (D_E) and Error Calculation

Resultant D_E distributions from each sample are presented in Figure 3.

Representative D_E values for age calculation were based on the mean of at least 77 grains

that passed rejection criteria (see Appendix Supplemental Table S3). Grains were rejected

if they had evidence of feldspar contamination (Duller 2003), recycling ratios >30% of

unity, recuperation >10% of the test dose signal, or D_E values greater than the highest

regenerative dose given (similar to criteria outlined in Rittenour et al. 2015). Errors on D_E

and age estimates are reported at two-sigma standard error and include errors related to

instrument calibration, and dose rate and equivalent dose calculations. All errors were

calculated in quadrature using the methods of Aitken (1985) and Aitken and Alldred

(1972).
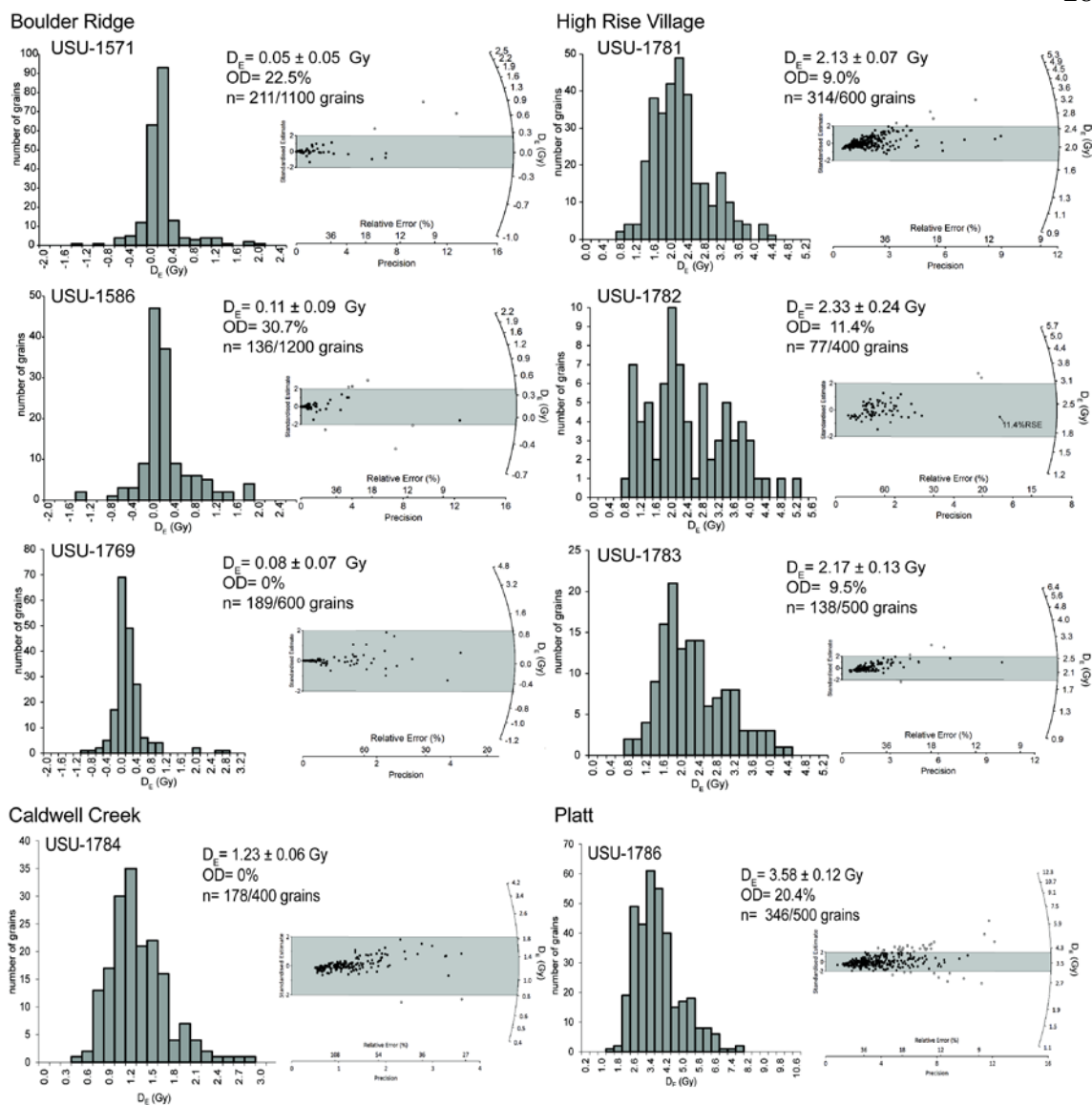
Figure 4. Equivalent dose (D$_E$) distributions from ceramic OSL samples collected from the four study sites. D$_E$'s and errors plotted on the left and radial plots of the same data are presented on the right. OD = overdispersion within the data or scatter beyond instrumental error, values greater than 30% represent significant scatter.

CHAPTER FOUR:

RESULTS

LUMINESCENCE AGES

Luminescence age estimates for vessel manufacture, or the last thermal exposure above 450°C, are reported in Table 4, and sample equivalent dose (D_E) distributions are shown in Figure 4. Additionally, Figures 5 and 6 provide a graphic comparison between luminescence ages and associated radiocarbon ages at each site, except Caldwell Creek, as there are no radiocarbon ages at this time. Overall, the quartz temper produced bright luminescence signals in response to given doses (10-1000 counts/Gy) and analysis resulted in high acceptance rates (10-70%) based on data quality criteria (see Table S3 in Appendix). Only eight of the ten sherds analyzed produced enough quartz grains to successfully date.

Boulder Ridge Sherd Luminescence Ages

The Boulder Ridge sherds were found at the site surface following the A.D. 2003 Boulder Basin II wildfire, and single-grain OSL results from the analysis are consistent with recent thermal resetting. Thermal resetting is apparent in the large number of near-zero D_E values (52-58%). Results suggest the latest thermal resetting occurred at 18 ± 16

Table 4. OSL Results from Quartz Temper.

USU lab number	Site	Number of grains[a]	Equivalent dose[b] (Gy)	Dose rate[c] (Gy/ka)	OSL age[d] (yr) $\pm$ 2 se
USU-1571	Boulder Ridge	152 (1100)	0.056 ± 0.051	3.14 ± 0.13	18 ± 16
USU-1586	Boulder Ridge	136 (1200)	0.10 ± 0.08	2.98 ± 0.12	34 ± 27
USU-1769	Boulder Ridge	183 (600)	0.08 ± 0.07	3.49 ± 0.20	23 ± 19
USU-1781	HRV Lodge S	314 (600)	1.94 ± 0.07	3.11 ± 0.13	620 ± 50
USU-1782	HRV Lodge CC	77 (400)	2.10 ± 0.21	4.27 ± 0.29	490 ± 70
USU-1783	HRV Lodge CC	138 (500)	1.97 ± 0.12	4.38 ± 0.34	450 ± 50
USU-1785	Caldwell Creek	178 (400)	1.11 ± 0.05	4.13 ± 0.42	270 ± 40
USU-1786	Platt	346 (500)	3.24 ± 0.11	4.21 ± 0.24	770 ± 70

[a] Number of grains used in age calculation and number of grain analyzed in parentheses.
[b] Equivalent dose (D_E) calculated as the mean of the individual grain D_E values.
[c] See Table S1 and S2 for data and Supplemental data for description of dose-rate calculation in the Appendix.
[d] Datum for OSL ages is A.D. 2010. Age reported at two-sigma standard error.

yr. (USU-1571), 34 ± 27 yr. (USU-1586), and 23 ± 19 yr. (USU-1769). These results are inconsistent with the associated cultural material record and radiocarbon ages that indicate Protohistoric and Late Prehistoric occupations (1030-590 cal B.P.[2010]; Table 2; Scheiber and Finley 2010, 2011). In this context, radiocarbon ages provide maximum ages for the cultural component associated with Intermountain Ware sherds and cannot be directly compared against luminescence results (Figure 5). The radiocarbon ages may reflect either a buried cultural horizon different from the later occupation responsible for depositing the Intermountain Ware vessel or result from wood that predates the occupation. Regardless, the near-modern results from these sherds suggest the luminescence signals in the quartz temper were reset during the high-intensity Boulder Basin II fire.
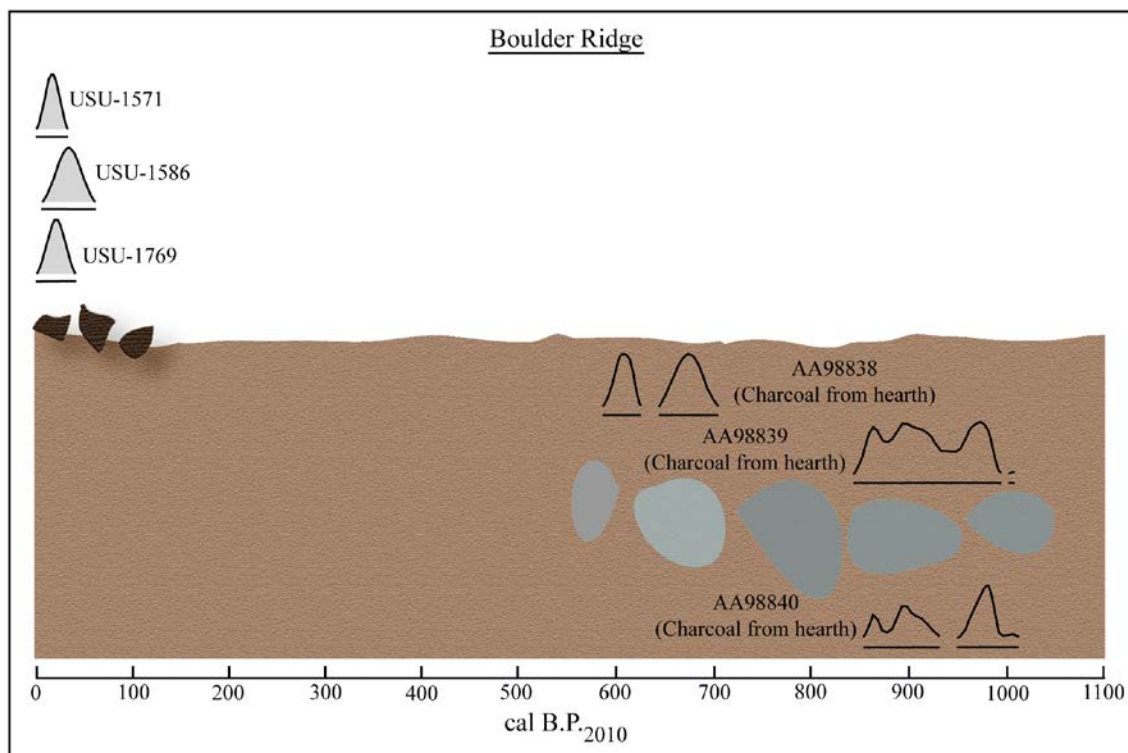
Figure 5. Boulder Ridge OSL (grey-shaded normal distributions) and radiocarbon age distributions imposed on a hypothetical site profile. Despite recent thermal resetting apparent in OSL results, spatiotemporal relationships suggest the buried hearth and surficial sherds reflect two different occupations.

The near-zero ages produced at the USU Luminescence Laboratory are at odds with fine-grain polymineral OSL ages on sherds from the same site analyzed at the University of Washington Luminescence Laboratory (Jim Feathers, personal communication, 2015). The UW ages are likely in error since they predate the known appearance of Intermountain Ware ceramics in western North America by nearly a millennium (Rhode and Feathers 1998). Work is currently underway at the USU lab to develop fine-grain dating protocol and rectify the potential discrepancies between the two lab analyses.
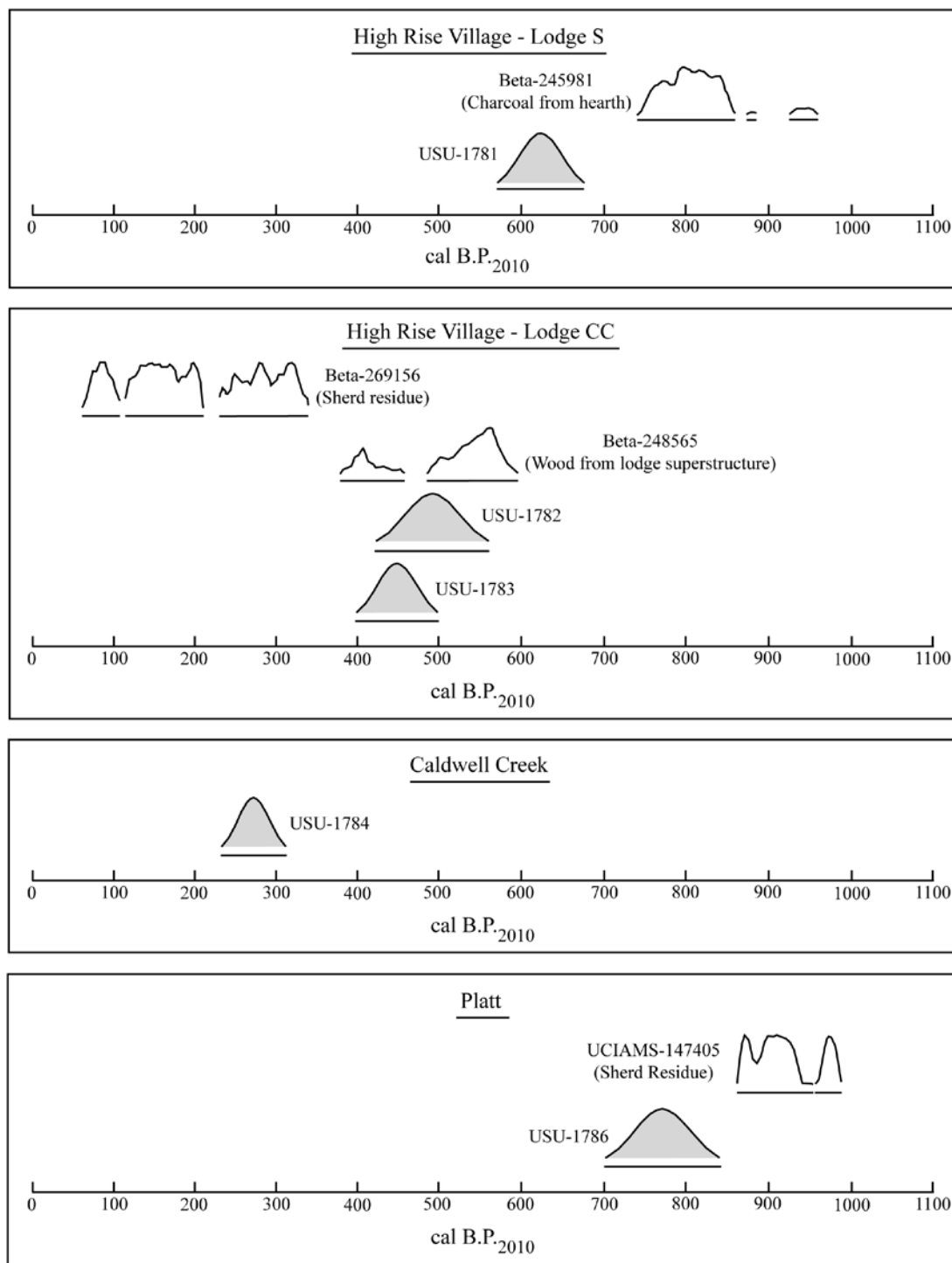
Figure 6. Two-sigma OSL (grey-shaded normal distributions) and radiocarbon age ranges from study sites. Two-sigma calibrated ^{14}C ages based on INTCAL (Reimer et al. 2013) and corrected to report ages in B.P.$_{2010}$ by adding 60 years to calibrated age range to allow for comparisons between dating techniques. Calibrated ages rounded to the nearest decade.

High Rise Village Sherd Luminescence Ages

Samples from buried contexts at HRV produced finite older results. Quartz temper in sherds from Lodge CC produced age estimates of 450 ± 50 yr. and 490 ± 70 yr. (Table 4). While Lodge CC burned during a historic wildfire of unknown exact age (Koenig 2010; Morgan et al. 2012), neither sample exhibits a population of zero D_E values that might indicate thermal resetting. These results likely represent the vessel production age. Furthermore, the sample ages match the radiocarbon age of a structural timber from the same lodge (490 ± 110 yr., Table 2 and Figure 6).

Two sherds were collected from Lodge S at HRV. One of these sherds could not be analyzed because it did not yield enough material to date once the outer 2 mm of sherd was removed during processing. This sherd measured only 11.35 x 7.75 x 6.05 mm and provides a limit on the minimal sherd size that can be dated with this technique. The second sherd from Lodge S was datable and produced an age of 620 ± 50 yr. (Table 4 and Figure 6). The luminescence age is younger than the associated probability distribution of the radiocarbon age of 850 ± 110 cal B.P.$_{2010}$ taken from the lodge's hearth.

Caldwell Creek Sherd Luminescence Ages

Both of the sherds collected from Caldwell Creek came from buried contexts that likely insulated the sherds from thermal alteration in the A.D. 2011 Norton Point wildfire, although only one was successfully dated (USU-1784) with OSL. USU-1785 did not produce enough quartz material to date, despite its size of 16.12 x 12.84 x 4.83 mm. This

particular sherd had a lower temper-to-paste ratio than the rest of the samples, possibly

indicative of variation in mineral source material. The other sherd produced a

luminescence age of 270 ± 40 yr. (Table 4). While no other independent absolute ages

from an associated context exist for comparison at this time, the OSL age is consistent

with the relative age of the diagnostic artifacts recovered from the site.

Platt Sherd Luminescence Ages

The Platt sherd also came from an excavated setting and produced the oldest

luminescence age estimate out of all the study samples. The sherd yielded a manufacture

age of 770 ± 70 yr. (Table 4). At two-sigma standard error, the luminescence results for

the Platt sherd (USU-1786) slightly post-date the radiocarbon age taken from sherd

residue of 920 ± 60 cal B.P.$_{2010}$ (Table 2). While the luminescence results are not

statistically indistinguishable from the associated radiocarbon age, there is not an equal

probability that the true age lies in the periphery of the standard error. Based on this, the

luminescence age is likely more accurate and the radiocarbon age is potentially

compromised.

CHAPTER FIVE:

DISCUSSION

While luminescence results provide an age estimate of vessel manufacture and not necessarily vessel use, it is a reasonable assumption that the relatively short use-life of the vessel is encapsulated within the technique's two-sigma standard error. Ceramics utilized by mobile hunter-gatherer groups likely did not endure long, especially at high-altitudes (Shott 1996). Taphonomic processes operate on cached pots and prevalent high-altitude conditions such as cryoturbation would prove destructive potentially within one season (Reid 1984). Therefore, I argue that single-grain luminescence ages of Intermountain Ware ceramics provide direct ages for site occupations.

The A.D. 2003 Boulder Basin II wildfire thermally reset the three sherds sampled from the surface at Boulder Ridge based on their apparent age estimates of 18 ± 16 yr. (USU-1571), 34 ± 27 yr. (USU-1586), and 23 ± 19 yr. (USU-1769). The substantial population of near-zero D_E values (52-58%) indicates recent thermal resetting and is supported by the lack of correspondence between the luminescence ages and other age controls from Boulder Ridge. However, there appears to be a relationship between sherd thickness, apparent age estimate, and D_E distribution (Figure 7). For example, USU-1586 was the thickest of the three sherds analyzed (Table 3) and produced the oldest apparent age of 34 ± 27 yr. USU-1571 was the thinnest and produced the youngest apparent age, 18 ± 16 yr. This relationship suggests a correlation between sherd thickness and the degree to which luminescence signals are thermally altered by wildfire.

USU-1571 USU-1769 USU-1586
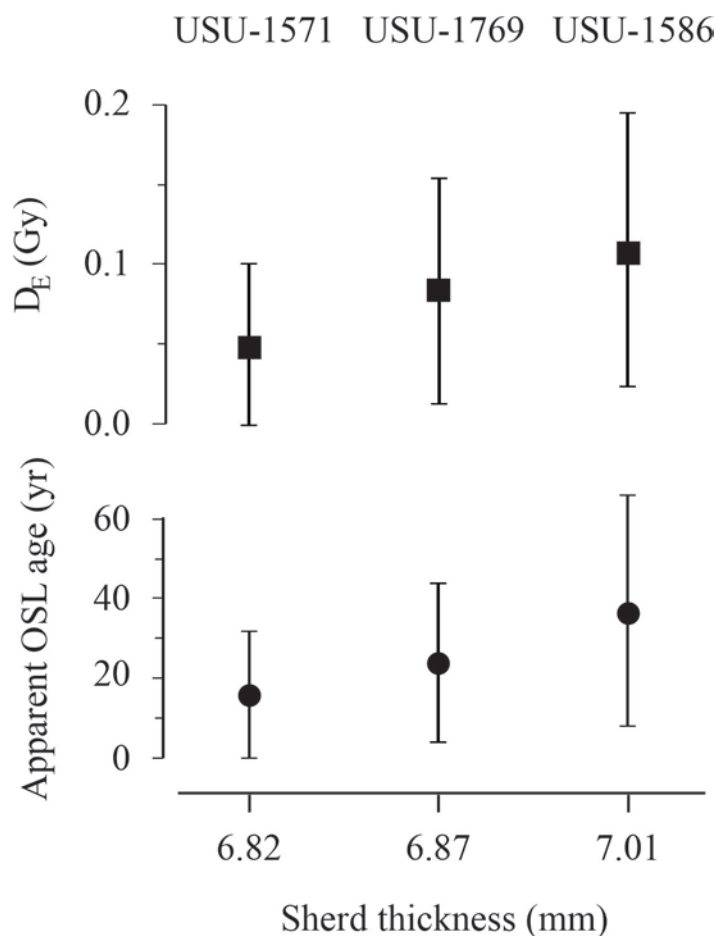
Figure 7. Comparison of D_E distributions and apparent age range from Boulder Ridge sherds with associated sherd thickness.

Historic artifacts at Boulder Ridge were recovered from the surface of the site and indicate a late 18th or early 19th century A.D. occupation, although the surface assemblage may be a complex palimpsest of multiple occupations including several centuries prior to European contact (Eakin 2005; Scheiber and Finley 2010, 2011). The Intermountain Ware sherds analyzed in this study were also recovered from the surface, so their association with the historic component is unknown. Based on this relationship, the sherds could have originated approximately 200 years ago, as part of a mixed-era

technological toolkit. While luminescence results cannot corroborate this hypothesis, a buried hearth has greater potential time depth than historic surface artifacts (Figure 5). Given the uncertainties of old wood in the hearth, I am still unable to conclude whether the hearth, lodge, and ceramic artifacts represent an earlier pre-contact occupation or part of the contact-era occupation associated with the historic artifacts. However, given the luminescence ages of ceramics from HRV and the Platt Site, ceramic ages of 400-840 years could be possible.

At present, three luminescence ages from HRV are not sufficient to determine if Lodge S and Lodge CC represent concurrent or isolated occupations (Figure 6). Sherds from both lodges were recovered from excavated contexts, up to 10 cm below the surface (Bryon Schroeder, personal communication, 2015). A sherd from Lodge S (USU-1781) produced an age of 620 ± 50 yr., which is younger than the radiocarbon age of a slab-lined hearth from the same lodge of 850 ± 110 cal B.P.$_{2010}$. The older and less precise radiocarbon age supports an 'old wood' problem hypothesized by previous researchers. The presence of a ghost whitebark pine forest dating to 1800-800 cal B.P. at HRV has been interpreted as the source of erroneously old radiocarbon ages (Losey 2013; Morgan et. 2012; Morgan et al. 2014). Lodge S represents at least one occupation, although the investment associated with a slab-lined hearth and cut-and-fill lodge indicates anticipated reuse (Koenig 2010). Lodge S luminescence and radiocarbon results potentially identify two different occupations, however, the presence of 'old wood' throughout the site makes it difficult to verify.

OSL results from Lodge CC sherds yielded consistent ages of 490 ± 70 yr. (USU-1782) and 450 ± 50 yr. (USU-1783) and agree with a radiocarbon age of 490 ± 110 cal

B.P.$_{2010}$ (Figure 6) from the wooden superstructure. The two sherds likely represent a single vessel based on their location, physical characteristics, and age agreement. Based on the luminescence ages, I propose that the radiocarbon age of 205 ± 140 cal B.P.$_{2010}$, which was taken from organic residue scraped off another sherd recovered from the same context is inaccurate. While previous investigators identified radiocarbon contexts from Lodge CC as questionable (Losey 2013:97; Morgan et al. 2012:42), my results only highlight the sherd residue age as problematic. The radiocarbon age estimate for sherd residue is too young and was likely contaminated by young carbon (Hedges et al. 1992; Stott et al. 2001). Alternatively, and assuming the two sherds are from the same vessel, the luminescence and residue ages might represent the vessel's initial manufacture and last use, potentially identifying an heirloomed vessel. However as previously discussed, Intermountain Ware vessels had a short use-life (Wedel 1954) and would not have survived intact at high elevations for the several centuries suggested by the sherd residue age (Figure 6). While Lodge CC might have hosted repeated site visits, the current dating resolution is not fine enough to identify the existence of a palimpsest. In general, chronometric ages from Lodge S and CC agree with relative age constraints identified by their material record that emphasize a Late Prehistoric (1500-500 cal B.P.) occupation at HRV. At the site level, OSL ages support radiocarbon results that indicate intensified site use during the past 1500 years (Figure 8).

Only one sherd recovered from the Caldwell Creek site yielded enough quartz sand to date with OSL. The resulting age, 270 ± 40 yr. (USU-1784; Table 4; Figure 6), can only be compared against relative ages provided by Late Prehistoric diagnostic
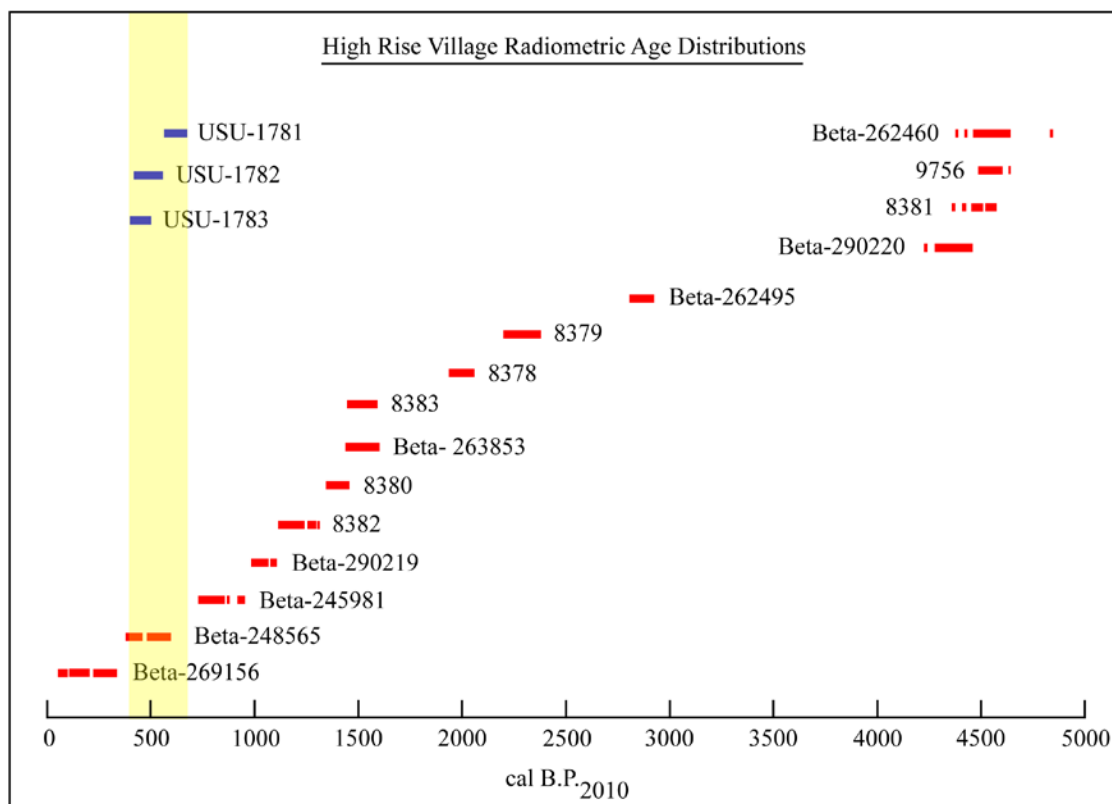
Figure 8. All available luminescence (blue) and radiocarbon (red) results from High Rise Village. Radiocarbon results have been standardized to A.D. 2010 by adding 60 years to report ages in cal B.P.$_{2010}$ and allow for comparisons between the dating techniques. ^{14}C ages based on INTCAL (Reimer et al. 2013), and calibrated ages rounded to the nearest decade. All ages calculated at two-sigma standard error ranges. Radiocarbon ages from Morgan et al. 2012.

artifacts (Scheiber et al. 2013; Scheiber et al. 2013; Scheiber et al. 2014; Scheiber et al. 2014). The absence of historic trade items corroborates the image of a relatively large residential site prior to contact.

The Platt sherd yielded a surprisingly old luminescence age of 770 ± 70 yr. (USU-1786; Table 4; Figure 6). This age falls near the upper limit of the oldest previously known associated ages for Intermountain Ware in the Central Rocky Mountains (Davis et

al. 2010). The oldest known age of an Intermountain Ware vessel in the region comes

from the Myers-Hindman site near Livingston, Montana and has been dated to 800 ± 180

cal B.P.$_{2010}$ (790 ± 90 B.P., GAK-2631; Lahren 1976). While the Platt sherd residue age

is statistically indistinguishable from luminescence results, the radiocarbon age is slightly

older, 920 ± 60 cal B.P.$_{2010}$ (Figure 6). As previously discussed, the luminescence age

dates vessel manufacture and radiocarbon dating reflects vessel use; therefore,

radiocarbon results should post-date luminescence ages. There is no evidence in the

sherd's D_E distribution of exposure to post-depositional thermal reheating, such as with

the Boulder Ridge sherds (Figure 4), indicating the discrepancy between the two dating

techniques likely stems from issues inherent in dating sherd residue (Hedges et al. 1992;

Stott et al. 2001; Yates et al. 2015). Regardless, the general agreement between

luminescence and radiocarbon results identify the Platt sherd as one of the earliest

examples of Intermountain Ware within the region.

 In addition to providing an alternative method for determining the age of high-

elevation sites, single-grain OSL dating can provide valuable insight into thermal

resetting of luminescence signals by wildfires. Buenger (2003:6) suggested that the most

significant thermal alterations to archaeological materials occur at the surface of severely

burned sites. Boulder Ridge experienced a high-intensity fire, as evident in post-fire

photographs (Figure 9). Sherds from this site (Figure 2) did not exhibit any of the

physical effects common in intense burning, such as thermal spalling or increased

friability, but the substantial population of grains containing near-zero D_E values

indicates that these sherds were thermally reset by the Boulder Basin II wildfire (Figure
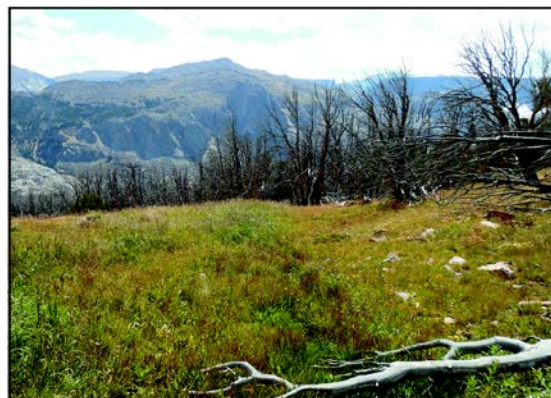
Boulder Ridge (Eakin 2005)   High Rise Village (Ideker 2013)

Caldwell Creek (Scheiber et al. 2013)

Figure 9. Post-fire photographs from Boulder Ridge, High Rise Village, and Caldwell Creek sites. Boulder Ridge and Caldwell Creek burned in high-intensity wildfires compared to High Rise Village, which experienced a low-to-moderate intensity fire evident by standing, partially-burnt trees with intact limbs.

5). In contrast, Caldwell Creek sherds were also recovered after a high-intensity fire, once again evident by post-fire photographs (Figure 9). While one sherd had insufficient quartz to date, the other came from an excavated context and consequently retained an intact luminescence signal. This is apparent by the lack of near-zero equivalent dose values (Figure 4) and further supports Buenger's (2003) results that buried artifacts are insulated from thermal alteration. Additionally, Lodge CC at HRV also burned in a

historic wildfire and sherds recovered from excavated contexts do not exhibit any effects consistent with thermal resetting. Moreover, the presence of standing, burned trees with intact limbs at HRV (Figure 9) demonstrate that the fire at this site was lower temperature and had a relatively short residence time, which could also have reduced potential thermal resetting.

Single-grain OSL ages were successfully produced for eight of ten ceramic sherds recovered from Boulder Ridge, High Rise Village, Caldwell Creek, and Platt. Radiocarbon ages from associated contexts, such as hearths, structural timbers, or sherd residue, provide independent age control for lodge occupations (Table 2). Luminescence ages generally indicate excellent agreement with associated radiocarbon ages at HRV and Platt where recent thermal resetting by wildfire was not an issue. These luminescence results have precision equal to or better than that of calibrated radiocarbon ages over the last ~1,000 years (Figure 6). Additionally, the radiocarbon ages used in this study, with the exception of sherd residue from Lodge CC and Platt, all predate the actual site occupations by necessity as the trees incorporated in structures or hearths existed prior to the occupations. Consequently, I interpret ceramic OSL ages as the most accurate representations for site occupations.

CHAPTER SIX:

CONCLUSIONS

This thesis provides the first demonstration and proof of concept for the application of single-grain OSL dating of quartz temper in prehistoric ceramics and therefore, provides a critical contribution to luminescence and archaeological dating methods. Eight Intermountain Ware sherds were dated from four northwestern Wyoming archaeological sites. Results indicate that single-grain OSL dating of prehistoric ceramic temper can yield ages that have equal or greater accuracy and precision than calibrated radiocarbon ages from the same sites (Figure 6). I argue that luminescence results provide age estimates for the last thermal resetting of the sherd, typically firing during manufacture, and because vessel use-life is encapsulated within the standard error of the technique, single-grain OSL results directly date prehistoric occupations. Use of single-grain OSL dating of ceramic temper can help identify problematic indirect ages, such as the incorporation of old wood or young carbon in HRV and Platt radiocarbon ages, and refine existing site chronologies. These traits in a dating technique are especially desirable at high-altitude sites where preservation of ghost forests and other organic material is more likely and can lead to a pronounced 'old wood' problem.

Based on the results of this study, the earliest Intermountain Ware luminescence age comes from the Platt site, 770 ± 70 yr. (USU-1786), and the latest is from Caldwell Creek, 270 ± 40 yr. (USU-1784). Boulder Ridge sherds potentially represent a vessel manufactured during the 18th or 19th century; however, the Boulder Basin II wildfire

thermally reset their luminescence signals. Luminescence results at HRV indicate Lodge S was likely occupied between 670-570 years ago and Lodge CC between 560-400 years ago. While these results suggest two separate occupations, the dating resolution is not sufficient to verify previous interpretations that view HRV as a palimpsest of repeated occupations by small family groups through time instead of a sustained high-altitude village (Figure 8; Morgan et al. 2012).

Results regarding sherd thermal resetting by wildfires suggest cultural resource managers should locate and identify open-air sites with strong likelihood for high-intensity wildfires (Figure 4 and 5) to mitigate data loss in eventual burning. Cultural resource managers need to date prehistoric occupations at such sites prior to burning or at the very least, collect samples for radiometric dating as insurance against such an event. The results in this thesis validate the utility of single-grain OSL on sherds from buried contexts, like Caldwell Creek, and potentially surface sherds recovered after low-to-moderate intensity wildfires, such as HRV, but the technique does not have the capacity to tease out the original firing age of sherds reset in a high-intensity fire. Boulder Ridge sherds are proof of this limitation.

Luminescence results from Boulder Ridge, HRV, and Caldwell Creek indicate sherds from subsurface contexts are insulated from thermal alteration. However, experimental results also suggest low-to-moderate intensity wildfires, such as at HRV, will not affect luminescence signals of sherds on the surface (Buenger 2003). While no sherds in this thesis came from the surface of HRV, future research should explore the direct effects of lower intensity wildfires on surface sherds in order to improve OSL sampling parameters.

The successful single-grain OSL dating of ceramic temper protocol presented here promotes its utility as a valuable chronometric tool for archaeologists seeking to build and refine existing site and regional chronologies. The technique also has potential to cultural resource managers faced with mitigating data loss associated with low-to-moderate intensity wildfires. Perhaps future research will further refine the method and potentially result in maximum age models capable of dating even sherds exposed to high-intensity wildfires by identifying quartz grain populations with intact luminescence signals. The current limitations of single-grain OSL dating of prehistoric ceramics do not detract from its ability to produce accurate and precise ages capable of rivaling calibrated radiocarbon results, but without the uncertainty associated with indirect dating methods.

Single-grain OSL ages from prehistoric ceramics in this study have greater accuracy and precision than ages achieved by the use of radiocarbon dating alone. Results suggest that single-grain OSL dating should be applied to other sites with ceramics containing quartz-rich temper in tandem with radiocarbon dating, a combination for surface assemblages that is seeing wider applications in archaeological practice (Janz et al. 2015). Recommendations for application are discussed below.

When selecting sherds for dating, size matters. Larger and thicker sherds with a minimum sherd size of approximately 15 mm x 15 mm x 5 mm should be selected for processing, based on the dimensions of the smallest sherd successfully dated in this study. Additionally, when investigating sites that have been exposed to high-intensity fires, sherds from buried contexts should be selected. Results from three Boulder Ridge sherds collected from the surface all display near-modern apparent luminescence ages that suggest they were reset in the A.D. 2003 Boulder Basin II wildfire. In contrast, the

sherds from HRV, Caldwell Creek, and the Platt site all produced ages consistent with the associated material record or radiocarbon ages. These results indicate sherds recovered from buried contexts are more likely to have an intact luminescence signal.

Given that wildfire frequency and intensity is expected to increase as a result of current climatic conditions in the Rocky Mountains (Kulakoski and Jarvis 2011), archaeological sites will continue to be impacted and researchers must be aware of the best circumstances from which to sample sherds for luminescence dating. In addition to assessing size and thermal history when selecting ceramics for luminescence dating, researchers should be cognizant of D_R conditions. Burial depths should be carefully noted and a sediment sample from directly around the sherds should be collected in order to accurately calculate environmental dose rate (see Nelson et al. (2015) for sampling guidelines). However, while the exact burial depths and soil samples are required for the most accurate calculation of D_R and age, (Aitken 1985; Feathers 2000), curated sherds without an environmental D_R can still be dated with OSL, albeit with lower precision. Finally, an abundance of quartz sand in the ceramic temper is required in order to utilize single-grain OSL dating.

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APPENDICES

Dose Rate (D_R) Calculation

Dose rate calculation included radioactive contribution from internal and external sources, contribution from cosmic radiation (Prescott and Hutton 1995) and attenuation by water content (Aitken 1998) (see Tables S1 and S2). Representative subsamples of the outer 2 mm removed from each sherd were analyzed for potassium, uranium and thorium content using ICP-MS and ICP-AES methods (Table S2 and S3). Environmental dose rate (D_R) from sediment associated with the sherds collected from the Boulder Ridge site was analyzed using alpha counting and flame photometry techniques at the University of Washington (Jim Feathers, personal communication, 2014). Associated environmental sediment from High Rise Village (HRV) was obtained during excavation of Lodge CC and was used to calculate the external D_R for sherds at both Lodge CC and Lodge S. Radioelemental concentrations from this sample were analyzed on duplicate splits using ICP-MS and ICP-AES methods. Environmental D_R values were calculated on representative sediment samples collected directly around each Caldwell Creek sherd. At the Platt Site, associated sediment was collected from the site surface to estimate sherd external D_R. D_R values for Caldwell Creek and Platt samples were also analyzed with ICP-MS and ICP-AES methods. Elemental concentrations from the sherds and associated sediment are presented in Table S1.

Relative dose rate contribution from the sherd and surrounding sediment followed gradients published by Aitken (1985) and assumed that all beta radiation originated from radioisotopes within the sherd (internal dose rate) and the contribution of gamma radiation was modulated by sherd thickness, with thicker sherds having a great proportion of gamma radiation originating from within the sherd. Gamma radiation derived from the surrounding soil was modified by burial depth with sherds at the surface or from burial depths less than 30 cm receiving proportionally less gamma dose, assuming the atmosphere contributed no gamma radiation. Contribution of beta and gamma radiation from radio-isotopes within the sherd and surrounding soil was based on conversion factors of Guérin et al. (2011), attenuation factors of Brennan (2004) and scaled based on attenuation from water content (Aitken 1985). Total dose rates were calculated based on water content, cosmic contribution (Prescott and Hutton 1995) and radioisotope concentration. See Table S1 and S2 and footnotes for details.

Preheat Plateau Test

A preheat-plateau (PP) test was performed on USU-1571 to determine the proper preheat temperature following the SAR protocol as suggested by Murray and Wintle (2003). First, each non-heated and non-irradiated aliquot was optically bleached twice at room temperature by blue-green LEDs (470 ± 30 nm) at 90% power (35 mW/cm^2) for 40 seconds. Each optical bleach was followed by a 1000-second pause to let the thermally transferred charges decay (Li and Li 2006). Five small aliquots (2-mm mask) were used at each temperature step on regenerative doses from 180°C to 260°C in 20°C increments,

each held for 10 seconds. The aliquots were irradiated with a Strontium-90 beta source to

13.52 Gy. The recovered doses for each aliquot were measured using the SAR protocol

(Murray and Wintle 2003). The preheat temperature for all test doses was 160°C, held for

10 seconds. The PP test shows no dependency of dose recovery and recycling ratio on

preheat temperature (Figure S1). An increase in recuperation follows an increase in

preheat temperature at the zero dose step in the protocol, though results are below 10% of

the given dose. Based on these PP results a 200°C preheat (10s) was chosen for these

samples.

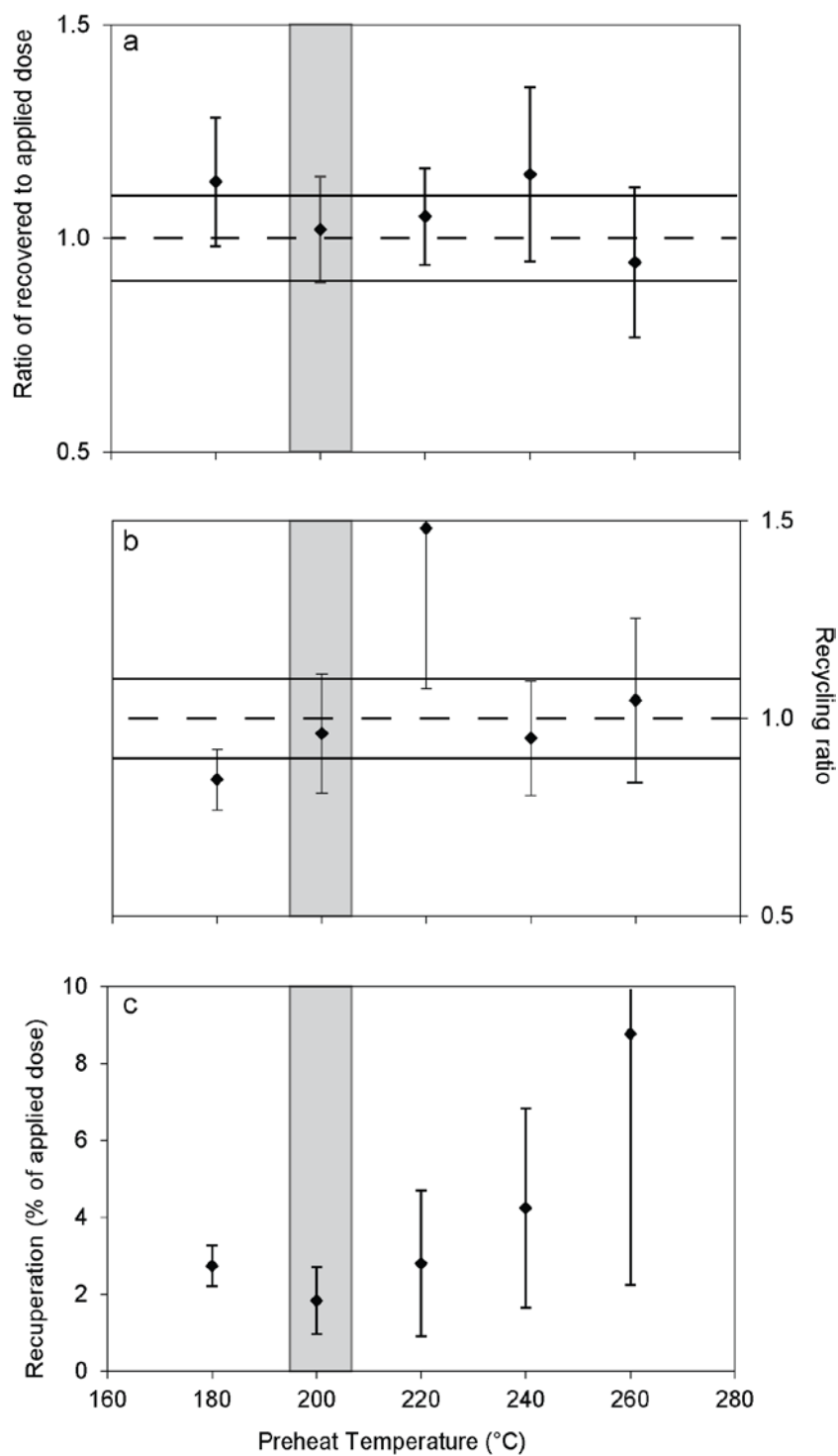Figure S1. Preheat plateau test results for USU-1571. (a) Dose recovery results plotted as a ratio of recovered to applied dose for preheat temperatures 180-260°C. (b) Recycling ratio results for repeated dose at the end of the SAR protocol. (c) Recuperation (% of applied dose) of luminescence signal when no dose was given to the sample. Results show that a 200°C preheat (10s) works best for these ceramic samples.

Table S1. Radioelemental Concentrations and Other Variables Related to Dose Rate Calculation.

USU lab number	Site	Depth (m)	Sherd thickness (mm)	Grain size analyzed (µm)	H₂O (wt%)[a]	K (%)[b]	Th (ppm)[b]	U (ppm)[b]
USU-1571 - sherd	Boulder Ridge	0	6.82	90-250	7.7	2.51	9.6	2.4
USU-1586 - sherd	Boulder Ridge	0	7.01	63-250	7.7	2.45	6.8	1.5
USU-1769 - sherd	Boulder Ridge	0	6.87	63-250	13.0	3.12	8.6	1.9
USU-1781 - sherd	HRV Lodge S	0.05 [c]	7.92	63-250	9.8	1.85	12.4	1.4
USU-1782 - sherd	HRV Lodge CC	0.05 [c]	8.60	63-250	7.2	2.75	25.7	2.2
USU-1783 - sherd	HRV Lodge CC	0.05 [c]	7.29	63-250	6.5	2.77	29.0	2.2
USU-1784 - sherd	Caldwell Basin	0.15	4.83	63-250	10.6	2.48	34.1	3.5
USU-1786 - sherd	Platt Site	0.30	0.82	63-250	6.4	2.56	18.5	5.7
Soil	Boulder Ridge	-	-	-	15.0	1.36	9.2	1.8
Soil	HRV Lodge CC	-	-	-	15.0	1.76	17.1	2.2
Soil	Caldwell Creek	-	-	-	2.9	1.52	9.0	1.8
Soil	Platt Site	-	-	-	5.0	1.08	5.8	3.0

[a] Saturated water content. For age calculation the water content was assumed to be 50% of the saturated state.

[b] Radioelemental concentrations determined by ICP-MS and ICP-AES techniques except for the soil sample from Boulder Ridge, which was calculated using alpha counting, and flame photometry techniques.

[c] Assumed depth of burial based on 10 cm depth of test pit from which sherds were collected.

Table S2. Dose Rate Calculation for Sampled Sherds.

USU lab number	Site	Beta[a] (sherd) (Gy/ka)	Gamma[b] (sherd) (Gy/ka)	Gamma[c] (soil) (Gy/ka)	Cosmic[d] (Gy/ka)	Total dose rate (Gy/ka)
USU-1571	Boulder Ridge	2.29	0.13	0.41	0.37	3.20 ± 0.13
USU-1586	Boulder Ridge	2.09	0.11	0.41	0.37	2.98 ± 0.12
USU-1769	Boulder Ridge	2.58	0.13	0.41	0.37	3.49 ± 0.20
USU-1781	HRV Lodge S	1.75	0.13	0.83	0.40	3.11 ± 0.13
USU-1782	HRV Lodge CC	2.81	0.24	0.82	0.40	4.27 ± 0.29
USU-1783	HRV Lodge CC	2.91	0.24	0.83	0.40	4.38 ± 0.34
USU-1784	Caldwell Creek	2.90	0.22	0.67	0.34	4.13 ± 0.42
USU-1786	Platt Site	2.96	0.23	0.74	0.28	4.21± 0.24

[a] Contribution of beta radiation from radio-isotopes within the sherd is based on conversion factors of Guerin et al. (2011) and scaled for beta attenuation based on mean analyzed grain-size (following Brennan (2003) and 50% of saturated water content of the sherd following Aitken (1985). See Table S1 for contributing data.
[b] Contribution of gamma radiation from radio-isotopes within the sherd is based on conversion factors of Guerin et al. (2011) and scaled based on attenuation from water content and the proportion of gamma contribution based on sherd thickness and sample depth following attenuation factors and gradients of Aitken (1985). See Table S1 for data.
[c] Contribution of gamma radiation from radio-isotopes from the associated soil sample is based on conversion factors of Guerin et al. (2011) and scaled based on attenuation from water content and the remaining proportion of gamma contribution based on sherd thickness and sample depth following attenuation factors and gradients of Aitken (1985). See Table S1 for contributing data.
[d] Contribution of cosmic radiation to the dose rate was calculated using sample depth, assumed sediment and ceramic density of 1.5 g/cm^3, and the elevation and latitude/longitude for the sites following Prescott and Hutton (1994). For Boulder Ridge: 2.83 km elevation, 44.1° N latitude and 109.6° W longitude. For High Rise Village: 3.27 km elevation, 43.4° N latitude and 109.6° W longitude. See Table S1 for contributing data.

Table S3. Single-Grain Rejection Criteria and Tally.

USU lab number	USU-1571	USU-1586	USU-1769	USU-1781	USU-1782	USU-1783	USU-1784	USU-1786
Grains analyzed	1100	1200	600	600	400	500	400	500
Rejection criteria[a]								
1. Low signal[b]	610	427	131	10	13	7	14	5
2. IR depletion (feldspar contamination)[c]	0	0	0	0	0	0	7	0
3. Recycling ratio > 30%[d]	199	369	215	205	227	260	140	98
4. Recuperation > 10%[e]	14	23	10	0	1	1	2	0
5. De > highest regenerative dose	2	0	0	0	1	0	0	0
6. Poor fit to dose-response curve	123	245	615	71	81	94	59	78
Total number of rejected grains	948	1064	417	286	323	362	222	181
Number of accepted grains	152	136	183	314	77	138	178	319
% acceptance	13.8%	11.3%	30.5%	52.3%	19.3%	27.6%	44.5%	63.8%

[a] Rejection criteria follow the order listed here. While many grains may have multiple causes for rejection, they are only tallied once based on the first rejection criteria encountered in the order listed here.

[b] Low signal = peak to background ratio < 3 (using 0.1-0.13s as signal and 0.67-0.92s as background) for given doses.

[c] Following test for feldspar detection of Duller (2003).

[d] Ratio between repeat doses at beginning and end of the SAR cycle.

[e] Percent of 11 Gy test dose signal generated during the zero-dose step of the SAR cycle.

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