Bracketing the Age of the Great Gallery Rock Art Panel in Horseshoe Canyon, Utah by OSL Dating of Associated Alluvial Terraces

Melissa S. Jackson
Utah State University

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BRACKETING THE AGE OF THE GREAT GALLERY ROCK ART PANEL IN HORSESHOE CANYON, UTAH BY OSL DATING OF ASSOCIATED ALLUVIAL TERRACES

by

Melissa S. Jackson

Thesis submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Bracketing the age of the Great Gallery rock art panel in Horseshoe Canyon, Utah by OSL Dating of associated Alluvial Terraces

Barrier Canyon Style rock art (BCS) is a unique rock art style indigenous to the middle Colorado Plateau that is of an unknown age and formed by a combination of wall preparation, rock pecking, and application of multiple pigments. It is characterized by broad-shouldered, mummy-like figures that commonly lack limbs and facial details but are accompanied by animated and realistic representations of animals. The age of BCS art remains unknown in spite of attempts to radiocarbon date accessory brush fibers in the mineral-based pigment. Yet a range of age hypotheses exist, from as young as 1600 AD to as old as the initial peopling of the continent, all based on stylistic comparisons to other rock art and figurines. This study attempts to constrain the age of BCS art by optically stimulated luminescence dating (OSL) alluvial terraces that have demonstrable cross-cutting stratigraphic relations to the type BCS rock art panel, the Great Gallery.

Horseshoe Canyon, in Canyonlands National Park of southwestern Utah, contains a series of preserved alluvial terraces that record the burial and exposure of the alcove that now hosts the BCS Great Gallery, bracketing the window of time when it was physically possible to create the art. This type panel must be younger than the erosional time period between deposition of the T2 and T1 alluvial terraces when the alcove wall became exposed. Alluvial samples from the highest exposed and preserved T2 terrace in the drainage were collected in metal tubes and analyzed using the single-aliquot regenerative (SAR) protocol of Murray and Wintle (2000).
Dose-rates were calculated from bulk sediment samples using the methods of Aitken (1998) and adjusted for local shielding of cosmic radiation by bedrock overhangs.

Results from several of the alluvium samples exhibit partial bleaching issues common in ephemeral stream deposits, requiring a minimum age model analysis. Age estimates produced in this study suggest that it was not physically possible for the Great Gallery to have been created prior to 6 ka BP, rejecting several earlier hypotheses for its temporal association.
I would like to thank Joel Pederson and Tammy Rittenour for giving me endless advice and opportunities in pursuing undergraduate research. They have both been an integral part of my education at Utah State University and have provided me with the necessary tools and understanding to engage in quality scientific investigation. This thesis would not have been possible without them. Also, special thanks extend to Chris Tressler for his invaluable assistance in the field and with all things technological and to National Park Service Ranger Gary Cox for his support and encouragement of furthering research at the Great Gallery. I am also very appreciative of Canyonlands National Park for the permission to conduct this research and collect samples. Lastly, thanks to all the students, faculty, and family members who have shared in my journey and made a difference in my life.

Melissa Jackson
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INTRODUCTION

The archaeological record is fundamental to understanding human culture and society. It provides precedent for human reaction to climate change and reveals information about patterns of civilization. As a science, archaeology is limited to material records of culture. While most material preserved in the archaeological record relates to technology and economics, rock art provides unique insight into the social organization and ideology of the cultures that created it.

One of the best known rock art styles in the western United States is Barrier Canyon Style (BCS) rock art. The unique figures and panels of the style are astonishing, but interpretations of their meaning are stranded until the style can be associated with other material remains of the culture that created them. Such an association is dependent upon the spatial and temporal distribution of the style. While the spatial distribution of rock art panels can be obtained from simple archaeological survey, establishing temporal context is a much more exacting process. The intrigue of BCS rock art has inspired various attempts at dating, especially at its type location, the Great Gallery in Canyonlands National Park. Dating methods used include subjective attempts such as stylistic comparison, occupation site association, and diagnostic element identification. Quantitative efforts at dating the panel have included radiocarbon analyses. However, none of these studies have produced a definitive age that has been widely accepted.

In this study, a new technique for establishing age control is used that is not dependent on stylistic similarities or the presence of minute organic traces. This technique, optically stimulated luminescence (OSL), provides a numerical age estimate for the last exposure of mineral grains to sunlight before burial. While OSL may not be able to date the BCS rock art directly, demonstrable cross-cutting relationships between alluvial terraces and the Great Gallery rock art
panel enable us to constrain the time when it was physically possible for the rock art to have been created. This is likely to rule out some hypotheses on the age of BCS rock art and improve chances of identifying its associated material culture.

**BACKGROUND**

*Northern Colorado Plateau cultural history*

In order to appreciate the possible cultural context and interpretations of BCS rock art, a basic understanding of the regional cultural history is essential. The oldest artifacts in the Colorado Plateau region are Clovis spear points dating to about 13,500 years ago (Fiedel 1999), but it could have been populated before then. A number of early archaeological sites in North and South America are revealing that humans colonized the Americas over 15,000 years ago, and perhaps beyond 20,000 years ago (Feathers 2006, Goodyear 2001, Meltzer et al 1997, Adovasio 1990). It is probable that settlements lingered on the edges of archaeological visibility for millennia before population growth resulted in the continent-wide appearance of Clovis (Simms 2008). The style of projectile points that characterized Clovis culture persisted at most for a few hundred years before they were replaced by Folsom technology. Both cultures are thought to have been big-game hunters whose limited evidence of occupation consists of few scattered campfire hearths and butchering sites. Very little evidence of Clovis age occupation has been found in the canyons of the Colorado Plateau, possibly because big game animals were more easily hunted on wide-open plains (Elias 1997). More evidence of Folsom people has been found in this region, but the record is dominated by individual points found on the surface (Elias 1997).

The extinction of megafauna at the end of the Younger Dryas (~11,700 BP), coupled with increased human population, selected for populations with reduced mobility, increased intensity
of landscape exploitation, and a broadening of subsistence patterns (Simms 2008). The transition in lifestyle and subsistence patterns included a new investment in small seed exploitation and greater dependence on smaller game animals. The earliest milling stones on the Colorado Plateau date to 8,500 to 9,000 years ago in Valley Alcove and Sudden Shelter, tens of miles NW of Canyonlands National Park (Simms 2008). People of the early Archaic culture were probably the first to utilize the Canyonlands region widely as several early Archaic sites have been discovered and excavated in the region (Elias 1997, Jennings 1980).

By the Middle Archaic (7,000 to 4,000 BP) regular residential use occurred in the desert uplands as well as the lowlands. Residential mobility was high, with sites that were far apart occupied for short periods for particular tasks (Simms 2008). The rich collection of Middle Archaic basketry from dry caves attests to continual occupation by the same indigenous peoples of the Early Archaic (Adovasio 1986). In the Late Archaic, 4,000 to 2,000 BP, the cultural organization and social system reflected an environment filled to capacity by foraging peoples (Simms 2008). Economies became oriented around food processing and storage, not just food acquisition and consumption. Eventually, population growth in surrounding areas led to the northward spread of farming.

The spread of maize agriculture and bow and arrow technology around 2,000 BP resulted in the creation of new cultures with both indigenous and foreign roots, namely the Ancestral Puebloan and Fremont cultures. Ancestral Puebloan culture is best known for the jacal, adobe and sandstone dwellings that they built along cliff walls. Fremont culture was reflective of its origins in its diversity of subsistence behaviors including full-time farmers, full-time foragers, and part-time farmer/foragers who seasonally switched modes of production (Madsen and Simms 1998). Fremont peoples were once known as the northern periphery of Ancestral
Puebloan culture and Canyonlands National Park lies on the frontier between the two related cultures. Rock art associated with Fremont and Ancestral Puebloan cultures has been well defined and described as a distinctive style (Schaafsma 1971). Fremont and Ancestral Puebloan rock art is characterized by the presence of circles and curvilinear meanders. Anthropomorphic elements are less dominant than in BCS rock art and commonly display triangular torsos and curved limbs (Schaafsma 1971). Fremont and Ancestral Puebloan cultures, as well as the associated farming lifestyle, collapsed about 1300 AD, possibly due to climate change and population dynamics (Simms 2008).

The relationship of Fremont and Ancestral Puebloan cultures to the peoples living in the Colorado Plateau in historic times is uncertain. Ancestral DNA, language, and basketry studies are contradictory and inconclusive as to whether population replacement, in-situ cultural change, or some combination thereof occurred at this time (Simms 2008). Ute culture occupied the area as early as 1300 AD. They foraged for food and lived without permanent dwellings, similar to the hunter-gatherers in the Archaic period. Ute, Navajo, and Paiute Indians all occupied southern Utah when Spanish explorers entered the area in the late 1700s, though their use of the canyons area appears to have been minimal (Elias 1997).

**Barrier Canyon Style rock art**

Barrier Canyon Style rock art was first described by Schaafsma (1971). She defined BCS and other styles from the Donald Scott collection of rock art photography, which consists of photographs and drawings of rock art assembled by Donald Scott through out his life-long career in the southwestern United States. Major stylistic categories were created by a rough sorting of photographs according to their general appearance and on the basis of an intuitive evaluation of
the elements present. Objective analysis and careful consideration of techniques and aesthetic qualities later refined these categories into distinct rock art styles (Schaafsma 1971).

Barrier Canyon Style rock art is variable and includes both polychrome and monochrome paintings made with liquid and dry pigments, petroglyphs that have been pecked, abraded, lightly incised, or scratched, and combination forms. Some rock surfaces were prepared by abrasion or smoothing prior to painting (Cole 2004). The style is defined by a dominant motif of frontal view anthropomorphic figures with elongate, tapering torsos and rounded, sloping shoulders (Fig. 1). In Schaafsma’s (1971) original study, these figures constituted 79% of the elements in BCS rock art. In addition to dominating the rock art panels numerically, these characteristic figures are life-size and can be more than 2 m in height.

Many of the anthropomorphs are depicted without limbs but have distinctive decorative detail (Fig. 1). Certain forms of headgear occur repeatedly and antenna or prong-like projections are portrayed on occasion (Schaafsma 1971). The torsos of most of the figures are plain but a few have intricate decorative treatment including white dots, vertical stripes, zigzags or combinations thereof. Naturalistic renderings of animal figures are visible in association with the anthropomorphs at over half the panels used to define the style. The small figures do not seem to
occur randomly, but rather are arranged in composed groups or directly associated with the
larger anthropomorphs.

Barrier Canyon Style rock art has a broad geographic distribution across much of the
northern Colorado Plateau, from the Escalante River of Utah to the White River of Colorado
(Cole 2004). The style has limited representation within major river corridors but frequently
occurs near or at the forks of canyons and close to springs and creeks. The art varies in its
landscape position, being depicted on prominent canyon walls and on relatively inconspicuous
and small rock outcrops or boulders, found high above canyon floors and at or just above present
ground level. The largest and best known type-site for BCS is the Great Gallery in Horseshoe
Canyon of Canyonlands National Park (CNP).

The Great Gallery in Barrier Canyon

The Great Gallery in Horseshoe Canyon consists of about a 30m long rock shelter wall
that is painted with detailed, life-sized figures (Fig. 1). One figure has animals painted in the
chest region and another has small mummy-like figures incorporated into one of the torso panels.
A seven-foot tall figure painted in brown by a spatter technique has a distinct ethereal
appearance and is known as “the Holy Ghost” (Schaafsma 1971; top photograph in Fig. 1). Many
mountain sheep and other animals are depicted in the panel in groups and associated with
anthropomorphs.

Potential meaning of BCS rock art

Interpretations of BCS rock art vary. While some researchers claim the visibility of the
art on prominent canyon walls suggest it was repeatedly viewed and visited, other researchers
posit that the remoteness of many panels from significant habitation sites suggests they were isolated ceremonial retreats (Schaafsma 1994, Cole 2004). Schaafsma (1971) observed that individual panels are relatively consistent in techniques and style suggesting that each was painted by a single individual. Many studies have hypothesized that the subject matter of the style is indicative of shamanism or ancestor worship (Schaafsma 1971, Schaafsma 1994, Cole 2004). Small animalistic figures associated with the prominent anthropomorphs are thought to be animal helpers, while the decorative details of the anthropomorphs themselves may suggest masks and ceremonial transformation (Schaafsma 1994). Cole (2004) uses ethnographic analogy with Australian Aborigines to suggest BCS art is associated with critical resource environments and may have marked social territory and affiliation. She suggests that the panels may have been ‘interactive’ and retained viability among successive generations through change and renewal to some of the elements and panels. Hypotheses such as these of the function and meaning of BCS art may be partly tested when the panels can be placed in temporal context. For example, this would enable association of the art with settlement sites and established patterns of cultural subsistence and mobility.

**Subjective Hypotheses of the Age of BCS rock art**

Schaafsma (1971) originally suggested that BCS rock art is late Archaic, immediately preceding Fremont rock art based on the absence of bow and arrow elements in the panels, superimposition of Fremont-type elements on BCS art, and the existence of rock art panels seemingly transitional between the two styles. However, a number of other age hypotheses have been presented since that time. Tipps (1994) attempted to date BCS art through association with nearby archaeological excavations, but the technique proved unsuccessful due to multi-
component sites including both pre-ceramic and Fremont occupations. Still, the study revealed three cultural sites adjacent to BCS panels with a range of radiocarbon dates, suggesting that Barrier Canyon art may fall roughly in the late Archaic range of 4000-2000 B.P. In another study, Coulam and Schroedl (1996) suggested that figurines found at Cowboy Cave within Horseshoe Canyon may have been created by the same culture associated with BCS rock art. These “Horseshoe shouldered figurines” are formed by smoothing and rolling a single piece of clay. They are characterized by pronounced, rounded shoulders with compelling similarity to BCS art, and were found in sediments dating to the early Archaic (7,000 to 8,000 BP). An even older estimate of the age for BCS rock art suggests that the art may be Clovis or pre-Clovis in age based upon stylistic similarities to other rock art across the globe (Nancy Simon, pers. comm.).

Manning (1990) suggested a younger age for BCS rock art based on elements figured within the panels. He suggests that a bow and arrow actually is featured in at least one BCS panel and that Fox Pelt Pendants are found more frequently. Fox Pelt Pendants are an article of ceremonial adornment hypothesized to be associated almost exclusively with Kachina ceremonies (Manning 1990). Although Fox Pelt Pendants are known to exist in the southern Colorado Plateau, in the northern Colorado Plateau the only potential evidence for these pendants is BCS rock art. Manning suggests that since artifactual evidence of Kachina ceremonies and BCS rock art are found in the same geographic area, ideas and concepts could have easily been shared. Kachina ceremonies became a part of Puebloan culture as late as 1325 AD (Schaafsma 1974), suggesting that the BCS rock art could be post-Fremont in age. Previous claims by Schaafsma (1971) that Fremont rock art is superimposed on BCS art are dismissed by Manning (1990) as misinterpretations. Manning (1990) further supports his post-Fremont
hypothesis with the claim that several BCS panels have visibly deteriorated historically and that little of the art would remain unless it was of relatively recent origin. In contrast, Cole (2004) suggests that preparation of rock surfaces by smoothing may account for the longevity of pigments that are somewhat exposed to weather.

Attempts at Radiocarbon Dating

Beyond stylistic comparison and spatial associations, there have been two intensive attempts to directly date BCS rock art using radiocarbon analysis. The challenge with BCS art is the lack of organic binder in the pigment; it is dominated instead by kaolinite and feldspar matrix mixed with hematite coloring (Watchman, 2003). Thus, the target material for radiocarbon dating is limited to rare accessory brush fibers and other organic particles randomly included in the pigment. In the first attempts, it was thought that carbon from the underlying bedrock had contaminated all but one sample. The single resultant date of 3000-2800 calibrated years B.P. suggested a late Archaic association for Barrier Canyon rock art (Tipps, 1994). But ultimately this date was called into question along with subsequent analyses. They were all confounded by bedrock contamination, with instances of results being both too old and too young due to the addition of ancient hydrocarbons and modern aqueous carbon, respectively (Watchman, 2003). A more recent second attempt to directly date the art involved meticulous efforts to avoid this bedrock contamination, along with the use of a specialized mass-spectrometer facility designed for analysis of trace amounts of carbon (Watchman, 2003). Yet despite attempts to date three successive samples, this effort was also thwarted by a lack of carbon and laboratory mistakes.
OSL dating

This study employs optically stimulated luminescence (OSL) dating of alluvium to constrain the age of the Great Gallery. Optically stimulated luminescence provides a numerical age estimate for the last exposure of mineral grains to sunlight during transport. A luminescence signal held in defects in the crystal structure is released due to stimulation by sunlight, effectively re-setting the OSL signal (Aitken, 1998). After burial, the luminescence signal grows with time due to exposure to ambient radiation in the sediment matrix, which is calculated in the environmental dose rate for the sample. The total signal held by the grains and the radiation required to instill a signal of that intensity (the equivalent dose) are measured in the laboratory and these measurements, in combination with the environmental dose rate, is used to calculate the time since burial.

Optically stimulated luminescence dating has numerous applications in archaeology (Feathers 2003). It is unique among chronological techniques in that it provides data on the depositional integrity of sediments (and thus artifacts within them) in addition to estimating age. Many archaeological excavations incorporate OSL into their methods in order to establish both of these criteria for well-preserved cultural remains (Feathers 2006, Goodyear 2001, Pitblado 2008). Although the use of alluvial terraces to constrain rock art creation is unique to this study, previous attempts have used OSL to constrain rock art creation through stratigraphic relationships with wasp nests (Roberts 1997, Yoshida 2003). Mud-nesting wasps construct mud-dauber and potter nests that become petrified after abandonment. Quartz sand embedded in the mud of fossilized nests are effectively removed from sunlight and can be dated using OSL. When such nests overlie prehistoric rock paintings or petroglyphs, they can provide a minimum age constraint on the creation of the rock art (Roberts 1997).
In the case of this study, OSL is used to date an alluvial terrace that constrains the exposure of an alcove wall, providing a maximum age of when it was physically possible for the rock art to have been created. Unfortunately, the nature of ephemeral stream deposits, such as those in Horseshoe Canyon, is such that the OSL signal of some grains may not have been reset by solar radiation (Jain 2002). However, recent advances in measurement protocols, technology and statistical treatment of data have enabled more accurate age determinations of such samples. The single aliquot regenerative protocol (SAR) is a method for establishing the equivalent dose that monitors and corrects for changes in the mineral’s ability to accumulate a luminescence signal. This correction enables SAR to produce more reliable ages than previous methods.

Until recently, all OSL measurements were performed on multi-grain aliquots of samples. Although these analyses produce accurate ages for most samples tested against independent age control, any variation in equivalent dose between quartz grains is averaged for each aliquot (Duller 2008). Advancements in technology have enabled the use of smaller aliquots and even single grain analyses that can better investigate these variations. Samples with incomplete resetting of the OSL signal during transport (partial bleaching) are expected to have grains with varying equivalent doses, where the higher doses have residual signals that were not removed during sunlight. In contrast, samples that have been mixed due to bioturbation and other processes may incorporate younger grains with equivalent doses less than those representing the depositional age of the unit (Duller 2000). In addition to the SAR protocol and SG technology, recently published statistical analyses can identify a minimum age from a population of grains or aliquots of grains (Galbraith et al 1999). It is interpreted that this minimum dose population represents the most accurate age for a partially bleached deposit. The reported ages for both the
analyses of small aliquots (SA) and single grains (SG) are the result of statistical analyses on multiple independently measured equivalent doses.

**GEOMORPHIC SETTING**

The Horseshoe Canyon catchment covers ~450 km² and is inset into the Hans Flat plateau and San Rafael desert. It is on the west flank of the Maze district of Canyonlands National Park (CNP). The drainage joins the Green River north of the park (Fig. 2). This area lies along the gentle north-dipping slope of the Laramide Monument Uplift, which the canyons of the Green and Colorado rivers are superimposed across (Pederson 2009). The entire catchment is cut into the Glen Canyon Group of Jurassic sandstones, including the Wingate, Kayenta, and Navajo.

![Figure 2 Map of the western United States depicting the location of Horseshoe Canyon. The catchment is portrayed by a white dashed outline. The Horseshoe Unit of CNP is a section along the drainage flowing north into the Green River.](image)
formations (Huntoon et al., 1982). The headwaters of the Horseshoe catchment are within a relatively broad mesa-and-valley landscape but as the drainage enters the study area it becomes increasingly entrenched into bedrock canyons.

The Great Gallery rock art panel resides in an alcove cut into Navajo formation bedrock. The reach of the canyon underlain by Navajo formation is sandwiched between two Kayenta reaches as the drainage cuts across a broad syncline (Pederson 2009). Three laterally traceable terrace landforms and deposits are preserved along the Navajo reach. These terraces are designated T1, T2, and T3 with increasing age and height above the present-day channel. The alluvial landform immediately adjacent to the Great Gallery is a T2 terrace and the alcove wall was exposed during the erosional event between deposition of the T2 and T1 terraces. Thus, the uppermost deposit of the T2 terrace can provide a maximum age constraint for when the alcove wall was exposed and it was physically possible for the rock art to have been created.

Chronostratigraphy of the terraces in the Navajo reach were published in a previous study (Pederson 2009), but this initial research did not include the stratigraphically highest sediments of the T2 terrace that are preserved and exposed in the deposit adjacent to the Great Gallery (Fig. 3). The chronostratigraphy of this key deposit is the focus of this study.

Figure 3 A generalized diagram of the stratigraphy in the Navajo reach of Horseshoe Canyon and at the Great Gallery. Ages for the general Navajo reach are from Pederson (2009), whereas the ages for the Great Gallery are from this study. Most of the ages are from OSL analyses with the exception of the italicized age in the Navajo reach which is from AMS radiocarbon analysis.
METHODS

Two sedimentary sections of the alluvium in the Great Gallery T2 deposit were measured. Distortion by overlapping rockfall talus and pinching out of units mask definite correlations in the field. Individual units within each section were systematically described and their depositional environments interpreted. Units from both of the sections were sampled for OSL dating.

Units sampled for OSL were selected based on the presence of sedimentary structures indicating depositional environments where sediment would have been exposed to sunlight and that bioturbation had been minimal. The samples were collected in steel tubes, with depth, elevation, and latitude/longitude noted for calculation of cosmic contribution (Prescott and Hutton 1994). This component of the dose rates has been adjusted for 49% local shielding by bedrock at the Great Gallery utilizing azimuth measurements of the horizon taken in the field. Representative samples for the determination of dose rate were collected from within 30 cm of the tubes. The bulk sediment concentration of K, Rb, U and Th was measured using ICP-MS and ICP-AES techniques at Chemex Laboratories in order to determine their beta and gamma contributions to dose rate. Moisture content was measured at the time of sampling, rounded to the next percent, and provided with 100% error to account for changes in the sample moisture history through time. Dose-rates incorporating estimated water-content history, chemistry and cosmic contribution were then determined (Adamiec and Aitken, 1998; Aitken, 1998) and errors were calculated using the methods of Aitken and Alldred (1972), Aitken (1976) and (Aitken, 1985).

Sample preparation at Utah State University’s Luminescence laboratory focused on extracting sand-sized pure quartz mineral grains. Sediment from the ends of the tubes was
removed before analysis because grains had been exposed to sunlight during sampling. The remaining sample was wet-sieved to either 75-150 μm or 90-150 μm and then treated with 10% HCl and bleach in order to remove carbonate and organic particles. Heavy minerals were separated using a solution of sodium polytungstate at a density of 2.72 g/ cm³. The samples were then treated with HF acid in order to remove feldspars and etch away the rind on grains that had been affected by alpha particle irradiation. Multigrain samples were mounted on stainless steel discs using 1mm diameter circle of silicon spray. Small aliquot sizes were used in order to enhance the estimated equivalent dose variability and therefore the detection of inadequate resetting of the OSL signal (Olley et al 1999). Single grain measurements were based on grains placed in tiny holes drilled as 10 by 10 arrays into specifically designed discs provided by RisØ National Laboratory. Due to the fine grain size, the technique was actually only pseudo-single grain as up to 5 grains may have been present in any hole. However, as only a small proportion of quartz grains luminesce, each signal produced was likely due to only one grain and the presence of multiple grains within a hole only increased the probability that any luminescence response would be measured.

Multigrain measurements were conducted using an automated RISO TL/OSL-DA-20 reader with blue-green light stimulation (470 nm, 7 mm Hoya U340 filter), while single grain measurements were stimulated with a green laser (532 nm, 7 mm Hoya U340 filter). Sequences were run following the single aliquot regenerative protocol (SAR) of Murray and Wintle (2000) with 240 C preheats and 160 C cutheats. At the end of the SAR sequence, potential feldspar contaminants were identified by infrared stimulation. Five regenerative doses were measured in order to construct a dose-response curve bracketing the luminescence of the natural signal. The first three regenerative doses each increased in irradiation dose with the second regenerative dose
being approximately equal to the expected natural signal. The fourth regenerative dose was zero, following the suggestion of Murray and Wintle (2000) in order to test for recuperation. The fifth and final regenerative dose was a repeat of the first to test reproducibility and sensitivity correction.

In addition to using the SAR protocol to estimate equivalent dose, a preheat plateau dose-recovery and thermal transfer test was performed on one of the samples. This test investigates the behavior of quartz from the study area and determines the preheat temperature most likely to eliminate unstable signal components, minimize thermal transfer, and accurately recover a given dose. Forty-eight aliquots of sample USU-670 were used for this analysis. All of the aliquots were bleached by repeated exposure to blue-green light stimulation and 1000s pauses and then 24 of the aliquots were given a dose of 22.3 Gys. All of the samples were analyzed using the SAR technique as described above but with groups of 4 aliquots subject to different preheat temperatures ranging from 180-280 C. The resulting equivalent dose estimates were then used to assess ability of the quartz grains to recover the known dose.

After the initial results for the samples were obtained, some parameters were adjusted in order to accommodate the behavior of the samples. Specifically, regenerative doses were increased for samples whose natural signal consistently responded with greater luminescence than the highest laboratory dose given. Additionally, test dose preheats and test dose magnitudes were changed for several multigrain aliquots of samples that exhibited poor recycling ratios, as suggested by Ed Rhodes (pers. comm.)

Single grain analyses on USU-671 were performed using regenerative doses that did not extend the full range of equivalent doses in order to provide higher resolution dose-response curves for the lower equivalent doses, which are interpreted to represent the depositional age of
the sample. This regenerative dose selection gives the resulting equivalent dose distribution an apparent normal distribution. However, the multi-modal equivalent distribution of the small aliquot analyses for this sample (appendix A) clearly indicates partial bleaching and potential mixing.

RESULTS

The two adjacent measured sedimentary sections at the Great Gallery each had nine identifiable units. Both sections are capped by talus from different rockfall events (Fig 4). The correlation of the two units was tentative based on field observations alone. Only one OSL sample was collected from the downstream section A because many of the upper units were either bioturbated or deformed by a rockfall. Three OSL samples were collected from the upstream section B, including the stratigraphically highest alluvial bed preserved at the locality.

Stratigraphy of Section A

Measured section A is 3.3 m thick below the talus unit (Fig 5). The basal bed is a distinctive, cobble-pebble gravel with imbrication, and it is interpreted as the coarse alluvium at the base of the T2 gravel that is seen elsewhere in Horseshoe Canyon. Units 2-7 are all medium, lenticular to tabular beds of normally graded sand with laminations and common ripple marks. They are interpreted as individual stream flood deposits (Fig 6). Sample USU-668 was collected from one of the middle flood deposits, unit 4. The top of unit 7 is deformed by clasts from rock fall events that are intermixed with the unit 8 alluvium.
Figure 4. Photograph panorama depicting the relationship of sections A and B to each other and to the rock art panel. Although correlation between the two measured sections is tentative in the field, luminescence chronology results suggest that unit 2 of section B is the continuation of rock-fall events recorded in units 8 and 9 of section A.
1. Clast-supported cobble-pebble gravel, 0.70 m thick, clast-supported, wavy-tabular basal bed, bedding obscured but appears to fine slightly upwards (normal grading) to pebble gravel. Subrounded-subangular base is imbricated 32, 54 downstream. Very-fine lower, subrounded to rounded sand in matrix. Clasts are largely Navajo, few indurated jurassic limestones, trace Kayenta red chert and siltstone, sharp lower contact on strath. Interpreted as high energy channel deposit.

2. Sand, 1.1 m thick, lenticular, pinches out to left, overlain on the right by drapes of upper units, normal grading from medium lower to very fine upper, thin laminations, no effervescence, wavy lower contact. Interpreted as lower flow regime overbank or channel margin depositional event.

3. Sand, 0.20 m thick, tabular wavy, normal grading from medium lower to very fine lower, climbing ripples, thinly laminated No effervescence. Sharp lower contact. Interpreted as lower flow regime overbank or channel margin depositional event.

4. Sand, 0.21 m thick, lenticular, pinching out to left, drapes to the right, normal grading from very fine lower to very fine upper, climbing ripples with large wavelengths, super critical climbing on left, thin bedding, redder color, trace of insect turbation, no effervescence, sharp lower contact. Interpreted as rapid and high sediment load overbank or channel margin deposition.

5. Sand, 0.23 m thick, lenticular, thickens/ drapes to the right, normal grading from fine lower to very fine upper, thin laminations, thin layer of gypsum in swales of upper bed, no effervescence, sharp lower contact. Interpreted as low energy, lower flow regime deposition.

6. Sand, 0.12 m thick, lenticular, pinching out to left, normal grading from fine upper to very fine lower, thin laminations, no effervescence, wavy lower contact. Interpreted as low energy, lower flow regime deposition.

7. Sand, 0.26 m thick, lenticular, pinches out to left, deformed to right by fallen rocks, no grading with very fine upper and lower throughout, planar laminations with some ripples, gypsum nodules, thin bedding, no effervescence, sharp and wavy lower contact. Interpreted as low energy, lower flow regime deposition.

8. Clast-supported cobble-pebble gravel with sand matrix, 0-0.5m thick, angular Navajo sandstone cobbles and boulders mixed with deformed sand. Interpreted as the deformed base of the rockfall deposit.

9. Clast-supported boulder gravel, angular Navajo sandstone boulders, wavy and irregular lower contact. Interpreted as a rockfall.

Figure 5. Stratigraphy of alluvium and talus, lower section (A) at the Great Gallery. The location and MAM age for sample USU-668 is reported with one standard deviation of error.
Figure 6. Photograph showing strata of lower section (A) at the Great Gallery. Unit 1 is cutoff in the picture so the lowest visible unit is unit 2.
**Stratigraphy of Section B**

Measured section B is at least 3.0 m thick below the talus unit (Fig 7), but its entire thickness is indeterminable because the base of unit 1 is covered. Unit 2 is a distinctive rock fall talus deposit that thickens downstream (figure 8). Based partially on OSL results discussed below, this is interpreted to correlate with the main mass of talus at the top of section A in units 8 and 9. The section consists of packages of normally graded fluvial sand deposits and lower energy mud drape deposits intermixed with larger clasts from rock fall events. Sample USU-669 was collected from the middle of the exposed basal unit and sample USU-670 was collected from unit 5, a sandy unit underlain and covered by potential mud drape deposits. Unit 7 is unique in its extent of bioturbation and lack of sedimentary features and is interpreted as possibly of aeolian origin. The stratigraphically highest alluvial bed preserved in Horseshoe canyon, unit 8, lies directly above the bioturbated deposit, thickens to a depth of only 0.11 m, is not laterally continuous, and is capped by talus from multiple rock fall events. This top unit was sampled for USU-671, which was subject to both SAR and SG analysis.

**Geochronology**

The ages obtained for the samples are presented in table 1 with dose rate information presented in table 2. Two ages are reported for every sample analyzed, using different statistical techniques on the accepted aliquots. The central age model (CAM) provides an age based on the weighted average of the equivalent doses of accepted aliquots (Galbraith 1999). Theoretically, samples analyzed with this technique should be completely bleached and have a Gaussian distribution of equivalent doses. In contrast, the samples for this study were taken from a setting where partial bleaching is expected and evidence for it is observed with equivalent dose
4. Sand, 0-0.11 m thick, wavy and discontinuous, normally graded from fine lower to very fine lower, planar thin beds, not bioturbated, pack rat midden material possibly from top units, distinct orange color similar to unit 7, effervescent. Interpreted as a low energy fluvial on-lapping.

7. Sand, 0.75 m thick, lenticular with wavy base, massive, heavily bioturbated, grain size is very fine upper – fine upper, Distinctive orangish color, no effervescence. Interpreted as a possible aeolian deposit

8. Sand, 0-0.11 m thick, wavy and discontinuous, normally graded from fine lower to very fine lower, planar thin beds, not bioturbated, pack rat midden material possibly from top units, distinct orange color similar to unit 7, effervescent. Interpreted as a low energy fluvial on-lapping.

9. Clast-supported boulder gravel, angular Navajo sandstone clasts, wavy and irregular lower contact. Interpreted as a rockfall.
Figure 8. Photograph depicting the units of section B. While unit 8 is the highest stratum, it is thin and not laterally extensive. Units 6 and 7 are not conducive to OSL sampling due to bioturbation and lack of sand. Thus, sample USU-670 may provide the most reliable maximum age constraint.
distributions for the samples being significantly skewed (see Appendix A). Thus, the ages accepted and discussed here are based on the minimum age model (MAM) of Galbraith (1999). This model expects equivalent dose distributions to reflect a mixed truncated normal distribution and gives high precision, low equivalent doses heavy weights in dose determination. Application of the MAM to a luminescence sample from Horseshoe Canyon with independent radiocarbon age control confirms that the technique provides accurate ages for sediment deposited by this drainage (Pederson 2009).

Table 1. Optically Stimulated Luminescence Age Information

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Location</th>
<th>depth (m)</th>
<th># aliquots</th>
<th>dose rate (Gy/ka)</th>
<th>Age, ka (1 SD) CAM</th>
<th>MAM-3</th>
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</thead>
<tbody>
<tr>
<td>USU-671 SG DATA</td>
<td>0.5</td>
<td>48(500)</td>
<td>3.08 ± 0.12</td>
<td>9.75 ± 3.33</td>
<td><strong>6.24 ± 2.13</strong></td>
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<td>USU-671 Sect. B unit 8</td>
<td>0.5</td>
<td>30 (47)</td>
<td>3.08 ± 0.12</td>
<td>15.91 ± 7.02</td>
<td><strong>9.06 ± 4.00</strong></td>
<td></td>
</tr>
<tr>
<td>USU-670 Sect. B unit 5</td>
<td>2.0</td>
<td>32 (39)</td>
<td>1.87 ± 0.08</td>
<td>12.14 ± 0.79</td>
<td><strong>9.64 ± 0.63</strong></td>
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<tr>
<td>USU-669 Sect. B unit 1</td>
<td>3.7</td>
<td>26 (39)</td>
<td>1.48 ± 0.06</td>
<td>19.80 ± 6.85</td>
<td><strong>12.88 ± 4.46</strong></td>
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<td>USU-668 Sect. A unit 4</td>
<td>1.9</td>
<td>22 (29)</td>
<td>1.78 ± 0.07</td>
<td>14.54 ± 1.85</td>
<td><strong>11.15 ± 1.42</strong></td>
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Table 2. Environmental Dose Rate Information

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Grain Size</th>
<th>H2O%</th>
<th>K2O%</th>
<th>Rb2O (ppm)</th>
<th>Th (ppm)</th>
<th>U (ppm)</th>
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<tr>
<td>USU-668 90-150</td>
<td>1.65</td>
<td>1.59 ± 0.04</td>
<td>46.9 ± 1.9</td>
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<td>1.10 ± 0.10</td>
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<tr>
<td>USU-669 75-150</td>
<td>1.72</td>
<td>1.51 ± 0.04</td>
<td>45.2 ± 1.8</td>
<td>1.3 ± 0.20</td>
<td>0.40 ± 0.10</td>
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<tr>
<td>USU-670 90-150</td>
<td>1.93</td>
<td>1.89 ± 0.05</td>
<td>55.8 ± 2.2</td>
<td>1.7 ± 0.20</td>
<td>0.50 ± 0.10</td>
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<tr>
<td>USU-671 75-150</td>
<td>1.67</td>
<td>3.07 ± 0.08</td>
<td>79.5 ± 3.20</td>
<td>3.7 ± 0.33</td>
<td>0.90 ± 0.10</td>
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</table>

One of the most common problems with luminescence samples is thermal transfer. This refers to uncorrected translocation of trapped charge during pre-heats, which can result in significant overestimates of equivalent dose. The samples in this study were tested for thermal transfer by the zero regenerative dose in the SAR protocol and by a thermal transfer pre-heat test.

* 2 ± 2% water content was used for all samples to accommodate for moisture content history
** Samples received ~50% shielding from cosmic radiation by canyon walls
Results of both of these assessments suggest that any thermal transfer occurring during the SAR protocol is only ~2% of the natural signal and is not sufficiently significant to affect equivalent dose estimation (Fig. 9).

Another common problem in OSL is incomplete sensitivity correction by the test dose. The recycling ratio tests for this problem in every aliquot analyzed. It is calculated by dividing the sensitivity corrected response to a given dose by the sensitivity corrected response to the same dose given at a different time in the protocol. Recycling ratios in the range of 0.9-1.10 are generally considered acceptable; however, the ratios for these samples were excessively high (Fig. 10). It is possible that this is the result of an insufficient cutheat or an excessive test dose magnitude. If this is the case, then increasing the cutheat and lowering the test dose magnitude may improve the results (Rhodes, pers. comm.).

Figure 9 Plot showing recuperation as % of natural signal for samples treated with different preheat temperatures.

Figure 10 Plot of Recycling ratios obtained for different preheat temperatures. Ideally the ratio should be at or within 10% of 1.0
In order to test whether this was the source for poor recycling ratios in these samples, 10 additional aliquots for three of the samples were analyzed with the SAR protocol using a 10s 220°C cutheat and a 50% reduced test dose. The recycling ratios calculated from these aliquots were significantly improved for the samples that had excessively high mean recycling ratios with the previous parameters (Fig 11). Additionally, the equivalent dose estimates of these analyses were consistent with the estimates of the previous analyses, suggesting that the cause for the high recycling ratios was not affecting dose recovery. This is confirmed by the results of the dose recovery preheat plateau test, which demonstrate that aliquots with preheats ranging from 200 to 260 C can recover a given dose within one standard deviation of error in spite of high recycling ratios (Fig. 12).

**Figure 11** Plot of recycling ratios for samples prepared with different SAR protocol parameters for sample USU-669. Parameters type 1 refers to aliquots given a 0s 160 C cutheat and a test dose of 100s. Parameters type 2 refers to aliquots treated with a 10s 220 C cutheat and a 50s test dose.

**Figure 12** Plot of dose recovery preheat plateau test depicting the ability of sample USU-670 to recover a given dose in spite of high recycling ratios.
Chronostratigraphy

The sediments that underlay the T2 terrace adjacent to the Great Gallery are a mixture of talus and flood deposits. Although the buried rock fall and mud drape events are not conducive to OSL dating, ages can be obtained for the sandy, lower flow regime stream deposits. The combined chronostratigraphy of the measured sections confirms that unit 8 of section B is indeed the highest preserved and exposed unit, and earlier studies suggest it is the highest preserved and exposed unit of T2 anywhere in the drainage (Pederson 2009). Sample USU-671 is therefore the best (youngest) maximum age constraint for the exposure of the alcove wall that can be obtained by dating alluvial terraces. In addition to correlating the measured sections, the three OSL samples taken from stratigraphically lower in the T2 landform provide context for sample USU-671, confirming that the MAM age of the SG SAR analysis is the most accurate age determination.

However, this sample has potential problems to address due its proximity to a heavily bioturbated unit and a rock fall unit. Any bioturbation from the underlying unit that extended into the sample could have introduced younger grains, whereas rock fall events could have introduced older, saturated grains. Even still, use of the MAM statistical technique should remove any grains with a residual signal regardless of whether it is due to partial bleaching or emplacement by rockfall events and the presence of fine planar laminations on the outcrop face where the sample was taken suggests that any bioturbation was probably minor. The next youngest OSL sample, USU-670, has the greatest precision and best supporting equivalent dose distribution of any of the samples. Its MAM age of 9.63 +/- 0.89 ka BP does not agree well with SA age estimates for USU-671 or the CAM SG age estimate. Additionally, the depositional age of the T2 terrace is ultimately older than the exposure of the alcove because the stream had to erode
back through its sediments before the alcove wall was revealed. Therefore, even if minor bioturbation has resulted in a slight age underestimation, 6 ka BP is a reasonable estimation of when it became physically possible for the Great Gallery to have been created.

**DISCUSSION**

The full exposed T2 deposit investigated in this study provides a record of sedimentation history at the Great Gallery that can be correlated to regional paleoclimate and local archaeological records. Optically stimulated luminescence ages presented here suggest deposition of T2 alluvium began prior to the Pleistocene-Holocene transition, by ~13 ka BP. This timing is consistent with MAM OSL ages obtained from basal exposures of the T2 deposits throughout the Navajo reach indicating deposition ~13-9 ka BP (Pederson 2009). Regional paleoclimate records suggest that 12-8.5 ka BP corresponds to a wet period associated with the peak of summer monsoonal influence (Reheis et al 2005). The correlation of alluvial terraces to wet episodes may be a response to storms increasing erosive runoff, thus leading to increased fluvial sediment load. This wet, summer monsoon dominated period of alluvial deposition was the setting for any Paleoindians occupying the northern Colorado Plateau region. Capping the early Holocene is at least one rockfall event near the Great Gallery alcove ~11-9 ka BP that is represented by units 8-9 in section A and unit 2 in Section B.

After ~8.5 ka BP, the summer monsoon is interpreted to have weakened and climate became much drier (Reheis et al 2005). This seems to correspond to a time of relative stability with some eolian deposition in the region. This climatic interpretation agrees well with the interpretation of unit 7 of section B as being of eolian origin and general tapering off of deposition in the upper T2 alluvium. It was during this time that late Archaic cultures began to
process small seeds and that Cowboy Cave in the upper Horseshoe Canyon was occupied. Rehais et al. (2005) suggest that at ~6 ka BP a cooler, wetter period began. This may coincide with deposition of unit 8 of section B and is likely when the river began to incise into the T2 terrace, exposing the Great Gallery alcove wall. At some unknown time after 6 ka, a second major rockfall buried the unit 8 deposit.

OSL MAM ages for the T1 terrace reported by Pederson (2009) indicate that alluvial deposition in the canyon renewed ~3 ka BP. The wall of the Great Gallery alcove would have been completely exposed incision between ~6-3 ka BP. Changing paleolake levels in Lake Canyon, Utah and stream activity on Black Mesa, just south of the study area, suggest that a subtle increase in precipitation and flooding is also associated with this period of T1 alluvial deposition (Karlstrom 1988, Pederson 2000). This late Archaic rise in moisture may have led to the success of farming cultures such as the Ancestral Puebloan and Fremont.

CONCLUSIONS

Based on the chronostratigraphy presented here, the alcove wall at the Great Gallery became exposed sometime after ~6 ka BP. Therefore, BCS rock art here must have been created sometime after ~6 ka also. This means the Early Archaic, Clovis and pre-Clovis hypotheses for the age of the BCS rock art can be rejected. Similarly, if there is a relationship between Horseshoe shouldered figurines at Cowboy Cave and BCS rock art, it is one where the figurines predate the rock art panels. However, these ages do not reject the hypothesis that BCS rock art is Late Archaic (4,000-2,000 BP). This hypothesis is supported by the age of some components at occupation sites in the region and a questionable 3000 cal BP radiocarbon date for BCS rock art (Tipps 1994). Late Archaic is also the age that Schaafsma (1971) first proposed for BCS art
based on interpreted relationships with Fremont rock art. The younger, post-Fremont hypothesis of Manning (1990) is also not rejected by these new data. However, future work obtaining a minimum age to accompany the maximum age provided here may later rule out this younger hypothesis.
REFERENCES CITED:


Coulam, N.J. and Schroedl, A.R., 1996, Early Archaic clay figurines from Cowboy and Walters caves in southeastern Utah


Goodyear, A. 2001 The Topper Site: Beyond Clovis at Allendale. *Mammoth Trumpet* 16:4


USU-668  Horseshoe Canyon

Individual Aliquot Data

<table>
<thead>
<tr>
<th>De (Gy) ± Age (ka) ± %disks within 2σ</th>
<th>De (Gy) ± Age (ka) ±</th>
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<tr>
<td>MAM (sd)</td>
<td>19.83 ± 2.19 ± 11.13 ± 1.42 ± 41%</td>
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<td>25.85 ± 7.25 ± 14.51 ± 1.85 ± 95%</td>
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n = 22/29 Aliquots

Random Errors= 11.26 %
Systematic Error= 5.94 %
Total Error= 12.73 %

overdispersion= 34 %

dose rate= 1.78 ± 0.07 Gy/ka

U = 1.10 ± 0.1 ppm
Th = 1.90 ± 0.2 ppm
K2O = 1.59 ± 0.04 wt. %
Rb2O= 46.9 ± 1.9 ppm
H2O= 2.0 ± 2.0 wt. %

Cosmic= 0.10 Gy/ka
depth = 1.9 m
latitude= 38 degrees (north positive)
longitude= -110 degrees (east positive)
elevation= 1.48 km asl

Notes: Quartz SAR OSL age (Murray and Wintle 2000), 10s 240 preheat, 0s 160 cutheat, 100s test dose
### Horseshoe Canyon

#### Individual Aliquot Data

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<tr>
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**Notes:**
- Quartz SAR OSL age (Murray and Wintle 2000)
- 10s 240 and 10 s 260 preheats, 0s 160 and 10s 220 cutheats, 50s and 100s testdoses
USU-670  Horseshoe Canyon

Individual Aliquot Data

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<tr>
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n = 32/39 Aliquots

Random Errors= 6.89 %
Systematic Error= 6.11 %
Total Error= 9.21 %
overdispersion= 31 %

dose rate= 1.87 0.08 Gy/ka
U = 0.50 0.1 ppm
Th = 1.70 0.2 ppm
K2O = 1.89 0.05 wt. %
Rb2O= 55.8 2.2 ppm
H2O= 2.0 2.0 wt. %
Cosmic= 0.11 Gy/ka
depth = 2.0 m
latitude= 38 degrees (north positive)
longitude= -110 degrees (east positive)
elevation= 1.48 km asl

Notes: Quartz SAR OSL age (following Murray and Wintle, 2000) 27.32 1.81 14.63 1.35
10s 240 and 10s 260 preheat, 0s 160 and 10s 220 cutheat,
50s and 100s test dose

De vs. Sensitivity

Cumulative Probability Curve

De Histogram

De vs. Sensitivity

Sensitivity (Pk-Bkgd Counts for 22.28 Gy)

Cosmic= 0.11 Gy/ka
depth = 2.0 m
latitude= 38 degrees (north positive)
longitude= -110 degrees (east positive)
elevation= 1.48 km asl

Notes: Quartz SAR OSL age (following Murray and Wintle, 2000) 27.32 1.81 14.63 1.35
10s 240 and 10s 260 preheat, 0s 160 and 10s 220 cutheat,
50s and 100s test dose
USU-671 SAR  Horseshoe Canyon

Individual Aliquot Data

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<td>48.97 ± 12.98</td>
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Random Errors= 43.70 %
Systematic Error= 6.09 %
Total Error= 44.12 %

overdispersion= 39 %

dose rate= 3.08 ± 0.12 Gy/ka
U = 0.90 ± 0.1 ppm
Th = 3.70 ± 0.3 ppm
K₂O = 3.07 ± 0.08 wt. %
Rb₂O= 79.5 ± 3.2 ppm
H₂O= 2.0 ± 2.0 wt. %

Cosmic= 0.13 Gy/ka
depth = 0.5 m
latitude= 38 degrees (north positive)
longitude= -110 degrees (east positive)
elevation= 1.48 km asl

Notes: Quartz SAR OSL age (following Murray and Wintle, 2000)
10s 240 and 10s 260 preheat, 0s 160 and 10s 220 cutheat,
50s and 100s test dose
## USU-671 SG  Horseshoe Canyon

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### Notes:
- Quartz SG SAR OSL age, 10s 240 preheat, 0s 160 cutheat, 100s test dose

## Individual Aliquot Data

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USU-671 SG  Horseshoe Canyon

Individual Aliquot Data

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De vs. Sensitivity

Cumulative Probability Curve

De vs. Sensitivity

MAM (19.23 Gy)
CAM (30.02 Gy)
Melissa Jackson was born June 8, 1988 in Provo, Utah to Paul and Kalualani Jackson. After a unique education at 10 different institutions, she graduated from Cottonwood High School in June 2006. A Presidential Scholar and Undergraduate Research Fellow, she entered Utah State University fall 2006 as a geology major with a geoarchaeology emphasis and an anthropology minor. She began a successful research career during her freshman year working with her faculty mentor, Joel Pederson. She has worked as a laboratory technician at USU’s Luminescence Laboratory since before its Grand Opening in January 2007 and has engaged in several research projects applying OSL dating in geoarchaeological studies. Throughout her undergraduate career she has served as secretary of the Geology Club, treasurer of the Geology Club, Vice-President for Community Service of USU National Society of Collegiate Scholars Chapter, Ambassador for the College of Science, and College of Science student representative on the Undergraduate Research Advisory Board. She has represented the university while disseminating research at domestic and international conferences and as a strong competitor on the USU Soils Team. After graduating valedictorian in May 2010, Melissa will continue her education as a NSF Graduate Research Fellow and PhD candidate at Aberystwyth University in Wales.