12-2023

Did Arroyo Formation Impact the Occupation of Snake Rock Village, a Fremont Dryland Agricultural Community in Central Utah, ca. AD 1000–1200?

Alexandra Wolberg
Utah State University, alexandra.wolberg@usu.edu

Recommended Citation

Wolberg, Alexandra, "Did Arroyo Formation Impact the Occupation of Snake Rock Village, a Fremont Dryland Agricultural Community in Central Utah, ca. AD 1000–1200?" (2023). *All Graduate Theses and Dissertations, Fall 2023 to Present*. 57.
https://digitalcommons.usu.edu/etd2023/57

DID ARROYO FORMATION IMPACT THE OCCUPATION OF SNAKE ROCK VILLAGE, A FREMONT DRYLAND AGRICULTURAL COMMUNITY IN CENTRAL UTAH ca. AD 1000–1200?

by

Alexandra Wolberg

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

of

MASTER OF SCIENCE

in

Anthropology

Judson Byrd Finley, Ph.D.
Major Professor

Tammy Rittenour, Ph.D.
Committee Member

Jacob Freeman, Ph.D.
Committee Member

D. Richard Cutler, Ph.D.
Vice Provost for Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2023

ABSTRACT

Did Arroyo Formation Impact the Occupation of Snake Rock Village, A Fremont Dryland Agricultural Community in Central Utah ca. AD 1000 through 1200?

by

Alexandra Wolberg, Master of Science

Utah State University, 2023

Major Professor: Dr. Judson Byrd Finley

Department: Sociology, Social Work, and Anthropology

Snake Rock Village is a Fremont village site located in an alluvial valley at the base of the high Wasatch Mountains in east-central Utah. The Fremont culture occupied the northern Colorado Plateau and the eastern Great Basin for approximately 1,000 years from AD 300–1300. Seven radiocarbon ages from alluvial deposits exposed in a modern eroded channel near Snake Rock Village provide evidence for past episodes of valley entrenchment by Ivie Creek, a source of year round water in the margin of central Utah’s San Rafael Desert. This study builds an alluvial chronology that details the local history of floodplain deposition and erosion and examines the geoarchaeological context at Snake Rock Village. New contextual information in the form of dated sediment deposits, analysis of sediment type, and a Bayesian age model tests whether the incision of the floodplain adjacent to Snake Rock Village corresponded with the timing of its abandonment by early Indigenous agriculturalists. Alluvial cycles on small basin drainages would have affected Fremont dryland farming by locally lowering water tables and reducing farmable areas during phases of entrenchment. The results indicated that the abandonment of Snake Rock Village does not correspond with an incision of the adjacent floodplain. Instead, the floodplain was still aggrading when Snake Rock Village was abandoned, and the incision did not happen until either 330 or 485 years later (AD 1570 or AD 1725). This information helped us understand the relationship between past alluvial cycles and the development of agriculture in the northern Colorado Plateau.

(61 pages)

PUBLIC ABSTRACT

Did Arroyo Formation Impact the Occupation of Snake Rock Village, A Fremont Dryland Agricultural Community in Central Utah ca. AD 1000 through 1200?

Alexandra Wolberg

Fremont farmers of the northern Colorado Plateau grew maize at the limits for cultivation in western North America between AD 300–1300. Like other Indigenous farmers throughout the American Southwest, Fremont farmers used bundled agricultural niches where alluvial floodplains were the largest available site for cultivation. But dryland floodplains are a risk to the persistence of farming communities because the development of steep-sided arroyos lowers floodplain surfaces and water tables, rendering them unusable for growing maize. This study tests the relationship between the occupational timing of Snake Rock Village between AD 970–1240 and the formation of a 4.5m deep arroyo on Ivie Creek adjacent to the site. I present a high-precision AMS radiocarbon chronology of the village occupation paired with an AMS radiocarbon reconstruction of the Ivie Creek floodplain 400m upstream from the site. The results of this study provide a direct test of arroyo formation as a cause for the abandonment of Fremont agriculture by AD 1300. The results indicated that the abandonment of Snake Rock Village does not correspond with an incision of the adjacent floodplain. Instead, the floodplain was still aggrading when Snake Rock Village was abandoned, and the incision did not happen until AD 1570 or AD 1725. Thus, while some evidence implicates arroyo formation as one factor contributing to the abandonment of early agricultural villages in other parts of the northern

Colorado Plateau, arroyo formation did not appear to constrain the persistence of floodplain farming on Ivie Creek.

DEDICATION

This thesis is dedicated to my parents for their love, support, and encouragement.

ACKNOWLEDGMENTS

This project would not have been brought to completion without the encouragement and advice of Dr. Judson Finley. Dr. Finley spent many hours discussing ideas, offering insight, and reviewing drafts of the manuscript. Many thanks to the members of my thesis committee. Dr. Tammy Rittenour provided training on optically stimulated luminescence dating and grain-size analysis. Dr. Jacob Freeman reviewed the manuscript and provided encouragement throughout my journey at Utah State University. Appreciation is expressed to Dr. David Byers, Dr. Molly Cannon, Dr. Anna Cohen, Dr. Stefani Crabtree, Megan Sills, Dr. Jason LaBelle (Colorado State University), and Laura Zeeman (Red Rocks Community College). I would also like to express my thanks to Dr. Finley, Dr. Erick Robinson, Mariah Walzer, Mike Bianchini, Paul Bionaz, Brooklynn Carnevale, and AJ Conti for their assistance with the fieldwork at Ivie Creek. Dr. Robinson also created the Bayesian Age Model for Ivie Creek and provided insight and advice on the results.

I would like to extend special thanks to my family, friends, and colleagues for their encouragement, support, and patience as I worked my way from the initial proposal writing to this final document. I could not have done it without all of you. I wish to thank my late stepdad, Dennis Wolf, for sparking my love for the outdoors. This research was funded by a National Science Foundation research award (BCS 2115151) to Dr. Finley, Dr. Robinson, and Dr. R. Justin DeRose.

Alexandra Wolberg

CONTENTS

LIST OF TABLES

LIST OF FIGURES

The archaeology of the North American northern Colorado Plateau represents an important case study where people incorporated agriculture into their lifeways, developed communities of varying sizes and complexity, and then returned to a more hunter-gatherer lifestyle over a 1000-year interval from AD 300–1300 (Simms 2016). The archaeological tradition of the region, known as Fremont, is well known for mixed strategies of foraging and farming, and this tradition ends coincident with a return to foraging after AD 1300. This pattern contrasts with the archaeology of the greater American Southwest and northern Mexico where, after adopting agriculture, many populations remained committed to producing surplus crops, even after widespread population contractions following AD 1300 (Madsen and Simms 1998). Thus, archaeologists have long been interested in the economics of how peoples on the northern Colorado Plateau incorporated maize agriculture into their societies and economies (e.g., Simms et al. 2020; Boomgarden et al. 2019; Barlow 2006; Barlow 2002; Madsen and Simms 1998); how maize agriculture impacted settlement systems (e.g., Talbot 2019; Coltrain and Leavitt 2002); and how the integration of maize agriculture into economies impacted the long-term regional population dynamics (e.g., Ingram and Patrick 2021; Freeman et al. 2021; Codding et al. 2022). At base, all these studies recognize that settlement decisions, longevity, and, ultimately, population growth and decline, are related to how farmers produce food and manage risk and uncertainty in dryland ecosystems.

Settlement location, size, and complexity in particular depend to some degree on how agricultural populations manage risk (e.g., Finley et al. 2020, 2023; Flannery 2002; Gilman1987; Strawhacker et al. 2020) because settlement choices are fundamental to accessing gardens, structuring information on surplus resources, and mobilizing support for agricultural labor and defense. In this thesis, I build on the idea that settlements are key focal point for farmers to create bundles of agricultural niches (Mabry 2005). An agricultural niche is created by the application of land tenure rules, technologies, and labor to specific geomorphic setting (Mabry 2005). For instance, in dryland agriculture, farmers often create irrigated fields in the floodplains of streams, terraced fields on the slopes of mountains, and small gardens at known seeps and springs. Given that both social aspects, such as tenure and labor and geomorphic aspects, such as slope, stream discharge, and sediments create agricultural niches, it stands to reason that both social-economic and geomorphic factors should impact settlements in dryland ecosystems. While social-economic factors clearly impact the diversity of niches used by farmers (Freeman 2012; Mabry 2005), it is critical to also understand how the geomorphology of dryland hydrological systems impacts and constraints the abundance and stability of potential niches on the landscape (Finley et al 2020, 2023).

For example, Finley et al. (2020) recently provided a basis for understanding Fremont socioecological variability using high-precision archaeological chronology and an annual precipitation reconstruction from tree rings. Observations from Cub Creek, a Fremont site in northeastern Utah, suggest that floodplains shifted rapidly, and that cut-and-fill cycles were timed with critical changes in regional precipitation variability that coincided with a shift from a sedentary village phase back to a more mobile foraging-farming strategy (Finley et al. 2023). They argue that the instability of the floodplains increased the uncertainty associated with creating productive agricultural niches in the floodplain and contributed to a shift in the local settlement system toward camps characteristic of communities who use mobility to minimize uncertainty in the production of food while meeting social obligations (Finley et al. 2023). Site-specific alluvial geoarchaeological reconstructions such as at Cub Creek provide insight into the socioecological constraints, specifically the stability of potential farming niches for early agricultural communities not widely available in western North America and comparable dryland ecosystems globally (Finley et al. 2023).

In this study, I continue to examine how the stability of floodplains may impact agricultural settlement strategies by studying the geoarchaeological context of Snake Rock Village (42SV5). This village is a Fremont site in east-central Utah on the margin of the San Rafael Desert (Aikens 1967). Snake Rock Village is ideal for building an alluvial reconstruction because it is adjacent to Ivie Creek, a source of perennial water, that today is deeply entrenched in its floodplain. This study provides a geoarchaeological context in the form of dated stratigraphic deposits, analysis of sediment types, and a Bayesian age model that develops a chronology for the timing of major cut-and-fill cycles at Ivie Creek. These cycles, as at Cub Creek, provide critical information on the stability of potential agricultural niches available to farmers in the area and constraints on their ability to minimize uncertainty in agricultural production through floodplain farming. I relate the mechanisms of floodplain construction to hydroclimate variability as the basis for evaluating the constraints on the availability of such agricultural niches and the growth potential of Snake Rock Village.

This paper addresses three primary objectives: first, I establish the site geoarchaeological context through field and laboratory descriptions using stratigraphic profiles, grain-size analysis, and radiocarbon dating; second, I use a Bayesian age model to constrain the key stratigraphic transitions; and third, I evaluate the impact of arroyo formation on the Fremont occupation of Snake Rock Village. Following Finley et al. (2023), this study investigates the stability of the local dryland alluvial system at Snake Rock Village and tests the prediction that the abandonment of Snake Rock Village corresponds with a phase of floodplain incision and arroyo formation. If the timing of site abandonment corresponds with arroyo formation, then this study provides additional support for the prediction that local hydroclimate and geomorphic thresholds control the persistence of dryland agricultural villages on the northern Colorado Plateau. Hydroclimate variability and arroyo formation may be environmental mechanisms that partially limit the shift of Fremont agriculturalists back to a more mobile lifestyle and, ultimately, the decline in importance of maize agriculture.

I begin with a review of the project location and provide information used in the interpretation of the stratigraphic record of Snake Rock Village. Next, I describe the methods used to build an alluvial chronology and Bayesian age model that constrains the timing of arroyo formation on Ivie Creek and then present the stratigraphic, sedimentological, and geochronological data used in my interpretation. Finally, I compare the results of the geoarchaeological analysis with a newly developed AMS radiocarbon chronology (Finley et al. 2023) of the Snake Rock Village occupation. I conclude with a discussion of the timing and possible controls of arroyo formation on Ivie Creek and its relation to the persistence of dryland agriculture in this marginal northern Colorado Plateau environment. The results of this investigation support the development of a framework to better understand the relationship between past alluvial cycles and the development of agriculture in the northern Colorado Plateau, an important gap in the Fremont archaeological record. While the geomorphic parameters of alluvial cycles are well-known in the Grand Staircase region of southern Utah (Townsend et al. 2019), this is less true to the north in areas like the San Rafael Desert and Uinta Basin (Finley et al. 2023). The results of this study also provide data on the impacts of dryland alluvial systems stability on the size, longevity, and social complexity of regional Fremont agricultural communities. Although the site area is superficially barren and inhospitable today, it was a favored spot for indigenous Fremont dryland farmers who made the environment work for them.

Project Setting

The study area (Figure 1) is located in central Utah on the Colorado Plateau physiographic province near the intersection of the San Rafael Desert and eastern Wasatch Mountains (Fenneman 1931; Aikens 1967). Ivie Creek is a short (30.1 km, 18.7 mi), east-trending perennial stream fed by run off from the Wasatch Mountains. The region is considered part of a transition zone between the eastern Great Basin and the northern Colorado Plateau, which have fundamental structural and geomorphic differences that create drainage basins with differing sensitivities to geomorphic change (Fenneman 1931; Finley et al. 2023).

The San Rafael Swell is an anticlinal dome of sandstone, shale, and limestone that was uplifted mostly between 60–40 million years ago during the Paleocene Laramide Orogeny (Jackson 1999). The Swell east of the project area is roughly 120-x-48 km (75-x-30 mi) that extends southwest from the Price River almost to the Fremont or Dirty Devil River and lies entirely within Emery County, Utah (Stokes 1988). Interstate 70 divides the Swell into northern and southern sections. The southern Swell is drained mainly by Muddy Creek, which Ivie Creek empties into approximately 16 km (10 mi) to the east of the Snake Rock Village. Based on the field investigation by WATEC, Inc. and studies by Kaman Tempo Corp. (1990) the water quality of Ivie Creek exhibits a very high salinity hazard, which could have been a hindering factor for Indigenous agriculture. The most prominent feature of the regional topography is a series of buttes, mesas, and castles which encircle an area locally known as “Sinbad Country” (Lupton

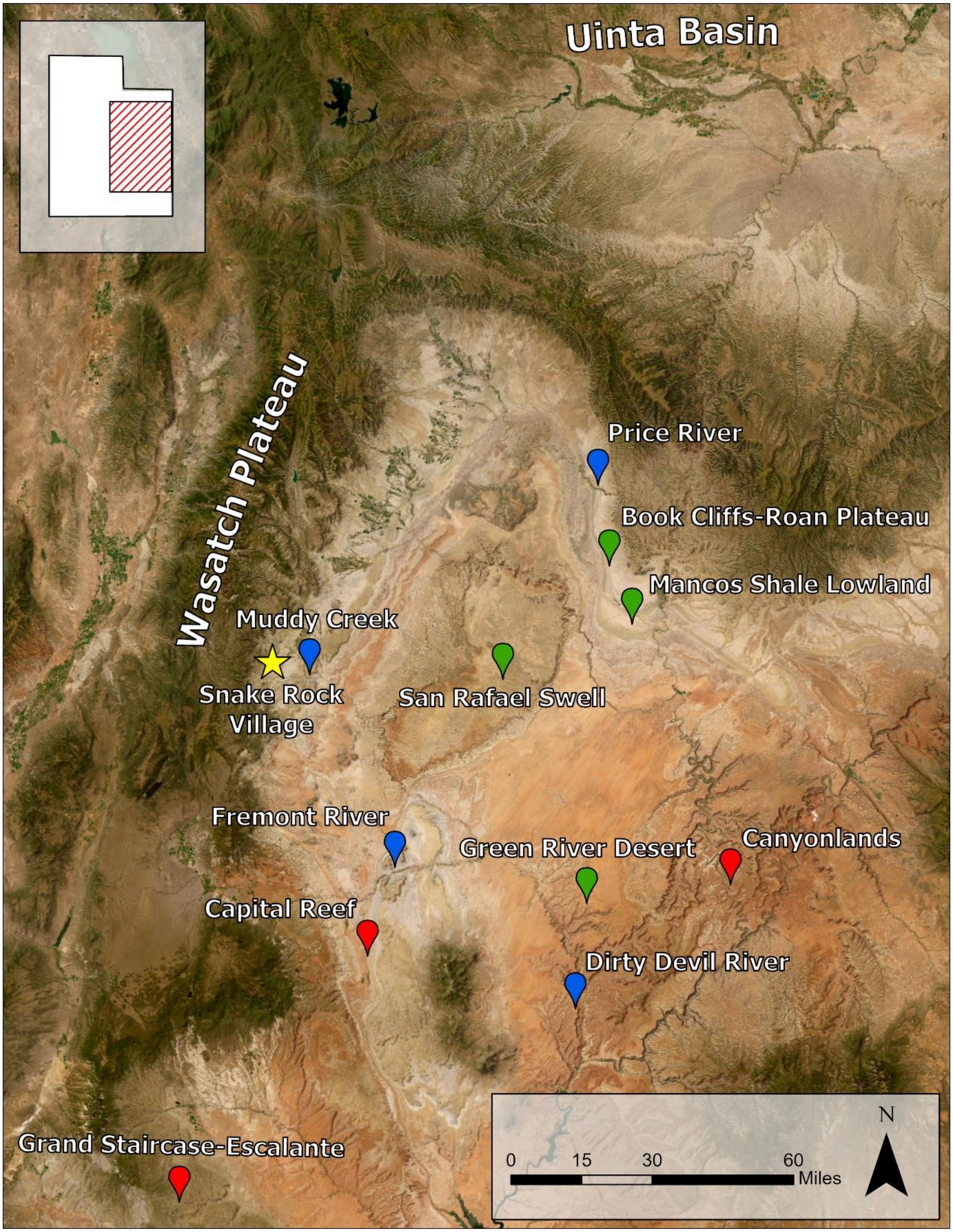

Figure 1. Geographic map of places mentioned in text. Snake Rock Village is located at the yellow star.

1912). Other major regional landscapes include the Uinta Basin and Book Cliffs-Roan Plateau to the north, the Mancos Shale Lowland Section to the east, the Green River Desert to the south, and Wasatch Plateau to the west (Stokes 1988). Capital Reef National Park, Grand Staircase-Escalante National Monument, and the Canyonlands area of the Colorado Plateau are all located south of the project area.

Within the Ivie Creek drainage, elevations range from 750 m (2461 ft) asl in the canyon bottoms to 3840 m (12,600 ft) asl at Mount Peale, the highest point in Utah outside the Uinta Mountains. The valley floor in the study area lies at an elevation of 1981 m (6500 ft) asl. The average annual minimum and maximum temperatures for the period of record (AD 1901–1978) in Emery, Utah, are -0.4 C (31.3 F) and 15.9 C (60.6 F), respectively (Western Regional Climate Center 2023). Extreme temperatures of -28.9 C (-20 F) in January and >37.8 C (100 F) in July are not uncommon. The local growing season averages 121 frost-free days. The average annual precipitation is 18.6 cm (7.3 in). Local vegetation is typical of the arid shale desert of the Colorado Plateaus ecoregion (Woods et al. 2001). The region is sparsely vegetated with mat salt brush (*Atriplex corrugata*), bud sagebrush (Picrothamnus desertorum), galleta grass (*Pleuraphis jamesii*), and desert trumpet (*Eriogonum inflatum*). Floodplains support greasewood (*Glossopetalon spinescens*), alkali sacaton (*Sporobolus airoides*), seepweed (*Suaeda maritima*), and shadescale (*Atriplex confertifolia*).

The drainage basin area for Ivie Creek is 129.5km^2 (50 mi^2) (Whitaker 1969). Ivie Creek is bedrock constrained in the vicinity of the study area and upstream in the Wasatch Mountains, but it has a broad alluvial floodplain from the mouth of Ivie Creek Canyon to its confluence with the Muddy River. The primary sediment sources for Ivie Creek alluvium are Mancos Shale, the Bluegate member of Mancos Shale, Emery Sandstone, and Quaternary pediments that form locally (Utah Geological Survey 2023). Ivie Creek is currently entrenched 3–4.6 m (10–15 ft) into the valley fill. Arroyo dynamics are partly driven by sediment supply, vegetation cover, and channel aggradation rates, and partly by external climate forcing (Harvey and Pederson 2011). Some alluvial valleys in the Colorado Plateau approach complete re-filling before they become sensitive to incision (Townsend et al. 2019). Alluvial cycles of aggradation and entrenchment are driven by gradient thresholds and complex response dynamics. Geomorphic thresholds can be triggered by both autogenic (i.e., sediment supply) and allogeneic (i.e., climate) controls and can operate in tandem to control arroyo cycles (Townsend et al. 2019). During the Fremont occupation, a change in land use activities, and an allogenic control on arroyo dynamics, may have increased sediment supply into the alluvial system. This increased sediment supply could have exceeded a threshold causing an arroyo incision which may have resulted in floodplain agriculture no longer being possible. An increase of sediments can lead to over steepened reaches due to non-continuous transport of sediment downstream. When floods occur, the stream will then cut new channels.

Snake Rock Village Archaeology

The Fremont culture occupied the northern Colorado Plateau and the eastern Great Basin for approximately 1,000 years from AD 300–1300 (Madsen and Simms 1998). The region is characterized by the terminal spread of maize agriculture in western North America as part of the Fremont archaeological complex (Madsen and Simms 1998). Fremont material culture is characterized by pithouse architecture, masonry granaries, plain and painted grayware pottery, one-rod-and-bundle basketry, “Utah”-style trough metates, highly stylized anthropomorphic rock art, and clay figurines that mimic rock art designs. A significant element of Fremont behavior was their ability to alter their lifeways, particularly subsistence and mobility, according to a highly variable social and natural environment (Madsen and Simms 1998). This flexibility allowed early farmers to make the most out of the spatially heterogeneous environment.

The Fremont used many different niches within the northern Colorado Plateau and eastern Great Basin that supported dryland farming, especially those focused on stream valleys. The Fremont inhabited the valleys because the flat floodplain bottoms offered more suitable environments for food production relative to other potential niches, such as rainfed fields (Mabry 2004). Finley et al. (2021) proposed that regional differences in community size and longevity were based on key differences in geomorphic systems. The northern Colorado Plateau floodplain niche concentrates discharge in narrow valleys with potentially high discharge, whereas the eastern Great Basin is dominated by alluvial fans that tend to disperse runoff. Snake Rock Village provides an opportunity to test the prediction that the abandonment of the village associates with a decrease in geomorphic stability.

Dryland farming has always been uncertain in western North America Indigenous agriculture due to erratic precipitation, inconsistent mountain snowpack, and a growing season often shortened by unpredictable late freezes in June and early freezes in August (Simms 2016). This unpredictable seasonality made crop production difficult in the high deserts of the northern Colorado Plateau and the eastern Great Basin. When investigating people who practice rain-fed dryland farming, both climate and geomorphology are important factors because they create critical opportunities and limitations for farmers. Most traditional agriculture practices take place within alluvial floodplains that are prone to deposition and erosion (Ingram 2015). Extreme erosion, or arroyo formation, has a temporal component dictated largely by climate variability and changes in discharge regime (Harvey and Pederson 2011). In contrast, the spatial component is strongly influenced by local geomorphology and vegetation (Townsend et al. 2019). Dryland farming at higher elevations was vulnerable to periods of drought and frost, whereas floodwater and canal irrigation farming at lower elevations was vulnerable to large floods and floodplain dynamics (Huckleberry 2015). Indigenous farmers undoubtedly adapted to climate variability and associated landscape dynamics through technological and social mechanisms, including diversification of subsistence strategies, agricultural intensification, food storage, trade, and changes in mobility (Madsen and Simms 1998).

Snake Rock Village is a classic Fremont site that was first tested by George Gunnerson in 1957 and fully excavated by Mel Aikens in 1964 (Aikens 1967). It is one of several major Fremont sites located across Utah north of the Colorado River. Snake Rock Village is located near the mouth of Ivie Creek Canyon at the base of the eastern Wasatch Mountains. The site is in an important transitional zone with relatively easy access to neighboring Fremont communities in the Sevier Valley to the west, as well as contemporary Ancestral Pueblo communities in the Four Corners region. This interaction and exchange is evident in the diverse pottery assemblage at Snake Rock Village, which comes from both areas (Aikens 1967). A total of 26 structures were excavated at the site, which include both round and square pithouses and rectangular above-ground structures (Jennings 1978). New AMS ages (n=26) on maize and wood from pithouses and storage structures across the site suggest that Snake Rock Village was occupied from around AD 970 to AD 1240 (Finley et al. 2023) (Table 1). The modeled occupational span at Snake Rock Village is between 160–260 years (95.4% probability) and most likely was

Table 1: Highest Posterior Probability Density (68% and 95%) of the Archaeological Model.

	Probability	
	68%	95%
Start Snake Rock Village	AD 995–1025	AD 970–1110
End Snake Rock Village	AD 1190–1230	AD 1060–1240
Span Snake Rock Village	170–230 years	30–260 years

occupied for 200 years. This new high-precision AMS radiocarbon chronology of the village occupation paired with geoarchaeological analysis of the Ivie Creek floodplain presented here enables a direct comparison of the occupational timing of Snake Rock Village and arroyo formation on Ivie Creek. This study tests the central prediction that the abandonment of Snake Rock Village corresponds with a phase of floodplain incision and arroyo formation.

Methods

Geoarchaeology Field Methods

One locality that is representative of the Ivie Creek alluvial system was selected for analysis in this study (Figure 2). Given that stratigraphic deposits in dryland alluvial systems can reveal past landscape responses to changes in climate, hydrology, and cultural activity, special

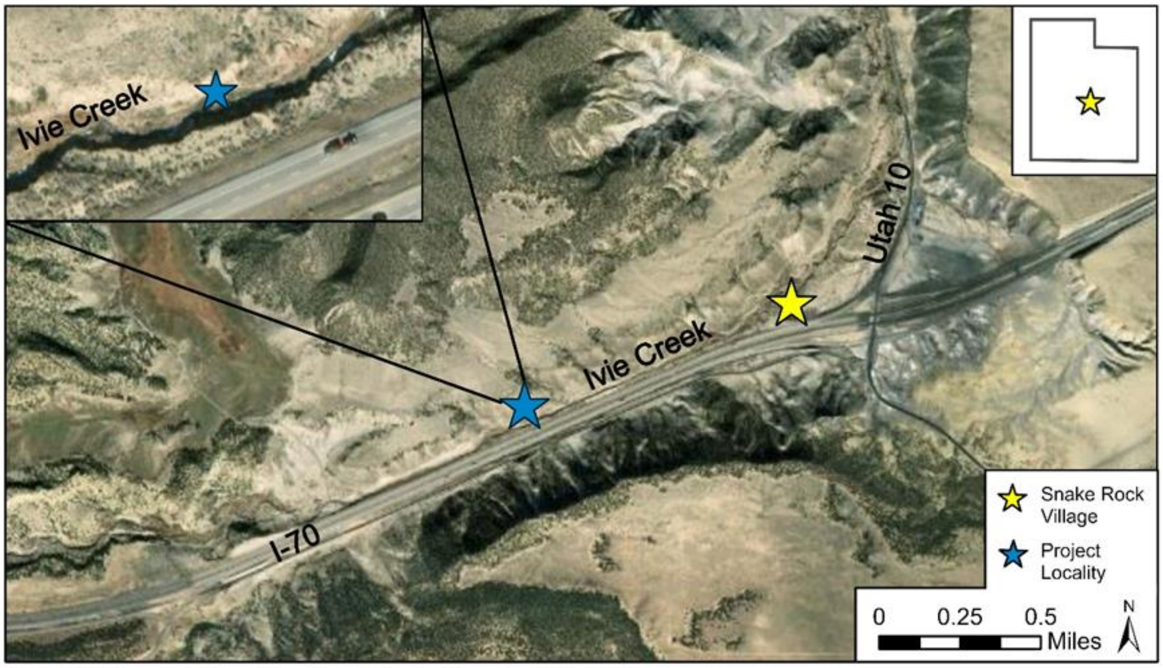

Figure 2. Location of Snake Rock Village and Project Locality.

attention and detailed notes were collected on Ivie Creek Alluvial Locality I (ICAL1). ICAL1 is located near the mouth of Ivie Creek Canyon and is 400m upstream from Snake Rock Village. Exposures at the locality were cleared into three profile walls. Profile walls were faced to create fresh stratigraphic exposures prior to measurement, description, and collection of samples for grain-size analysis, radiocarbon dating, and optically stimulated luminescence (OSL) dating. Notes on grain size, Munsell color, type of sedimentary structure, hardness, effervescence, boundary characteristics, bioturbation, charcoal content, and other observations were collected for each profile. The profiles were all measured in cm below the ground surface. Radiocarbon and OSL sample locations were mapped onto the hand-drawn profile illustrations.

Grain-size analysis

Representative sediment samples were collected from Profile 1 and Profile 2 for grain-size analysis. No representative sediment samples were collected from Profile 3. Sediment samples were collected from each of the main stratigraphic units in Profile 1. Clay layers, thin silt layers, and poorly sorted gravel layers from Profile 2 were not included. Samples from Profile 2 were taken from planar bedded sands and massive sands. Sediment samples were analyzed in the USU Geoarchaeology Lab and the USU Sedimentology Lab. Samples were gently homogenized with a mortar and pestle then split and weighed to create a base sample weight. Sediments were passed through two nested screens into a solid pan, the samples were manually sieved to separate cobbles and pebbles (> 2 mm), granules (1-2 mm), and coarse to fine sand (<1 mm). Each size classification was weighed to determine the percentage of cobbles, pebbles, and sand based on the Wentworth (1922) classification scheme.

Grain-size distributions were measured using a Malvern Mastersizer 2000-series laser particle-size analyzer using distilled (DI) water (Figure 3). Pump speed was set to 2800 revolutions per minute to maintain all sediment in suspension. Subsamples were added to a 1000ml DI water beaker until the laser obscuration reached 5–10%. The subsamples were then sonicated for 60s to ensure aggregates of sediment were broken apart. Each sample was subsampled three times, and grain-size distribution measurements were collected over three 30s integration times for each subsample producing nine measurements per sample. Once the analysis was complete the Malvern Mastersizer was flushed with clean DI water before starting the next subsample. Once grain-size distributions were measured, the grain-size results were entered into an Excel spreadsheet, the average of the subsamples were calculated, and the percentages of each grain-size classification was determined.

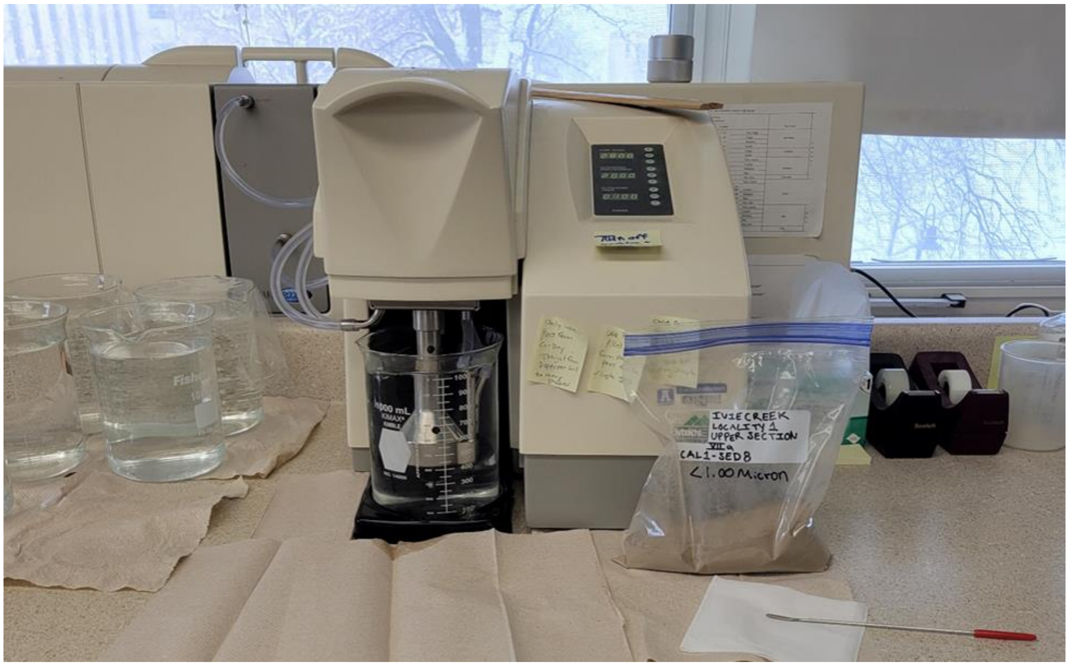

Figure 3: Utah State University Sedimentology Lab Malvern Mastersizer 2000.

Radiocarbon Dating

Charcoal and sediment samples for AMS dating were pretreated following standard acid–base–acid procedures. The samples were graphitized by hydrogen reduction at 525°C with an iron catalyst (Santos et al. 2007) and measured by AMS at the Keck AMS laboratory at the University of California Irvine (Southon et al. 2004). The ^{14}C data were normalized to results from six aliquots of the NIST OX-1 standard (SRM 4990B) run with each batch and corrected for isotopic fractionation using stable isotope measurements (del ^{13}C) performed online using the AMS spectrometer. Samples were measured multiple times over a 24-hr period. The reported errors on the ages consider the scatter in repeated runs and uncertainties in the normalizing standards and background subtractions and counting statistics. Standard radiocarbon ages are reported in years before 1950 (BP) with errors at one standard deviation. Radiocarbon ages were calibrated at two sigma error using the IntCal20 calibration curve (Reimer et al. 2020) and the median value of the calibrated age range. Calibrated ages are reported in calendar years AD/BC.

Bayesian Age Modeling

Bayesian chronological modeling revolutionized chronology building in archaeology by providing a robust mathematical framework for incorporating date estimates on the calendar scale, such as radiocarbon dating and luminescence dating, and archaeological information, such as stratigraphy, artifact typologies, and the written historical record (Bayliss 2015). This method for interpreting radiocarbon ages in archaeological studies produces a combined chronology that should be more reliable than its individual components (Bayliss 2015). The principal reason for Bayesian chronological modeling is to reduce the uncertainty of radiocarbon calibration effects on the age of dated events, in this case deposition of sediment units and arroyo formation. The construction of the Bayesian age model for the timing of arroyo formation in Ivie Creek was built by Dr. Erick Robinson using the software OxCal v4.4 for the age modeling and calibrated the ages using the Intcal20 calibration dataset (Bronk Ramsey 2021; Reimer et al. 2020). The model is a *Sequence* constrained by sample depth (cm below surface) that allows for stratigraphic ordering and radiocarbon ages to be incorporated into the OxCal Command Query Language 2 algorithms. The *Boundary* function was used to constrain the modeled start and end of each stratum that was sampled. The model posterior estimates are rounded to the closest five years and quoted in *italics* following methods established by Bayliss (2015). Each model produces 68% and 95% highest posterior density estimates for the defined parameters.

Results

Stratigraphic Observations

ICAL1 is located near the mouth of Ivie Creek Canyon and is a south-facing wall of the modern Ivie Creek arroyo (Figure 4). The locality was selected because there was one valley fill exposed in the modern arroyo and was thought to provide the best window to capture the valley fill chronology. Stratigraphic profiles were exposed in the upper, presumably younger, valley fill sequence (Profile 1) and the lower, presumably older, valley fill sequence (Profile 2). A third section (Profile 3) was exposed and sampled because there was a visible charcoal-enriched layer. The relative position of each profile is illustrated in Figure 4. The stratigraphy of each profile is presented in Figures 5–10 (Profile 1, 2, and 3 illustrations). Stratigraphic descriptions are presented in Tables 1–3.

Figure 4: Ivie Creek Alluvial Locality I (ICAL1) with Profiles 1, 2, and 3 noted. Note the meander scar and developed colluvial wedge next to Profile 1.

Figure 5: Stratigraphic profile of Ivie Creek Profile 1.

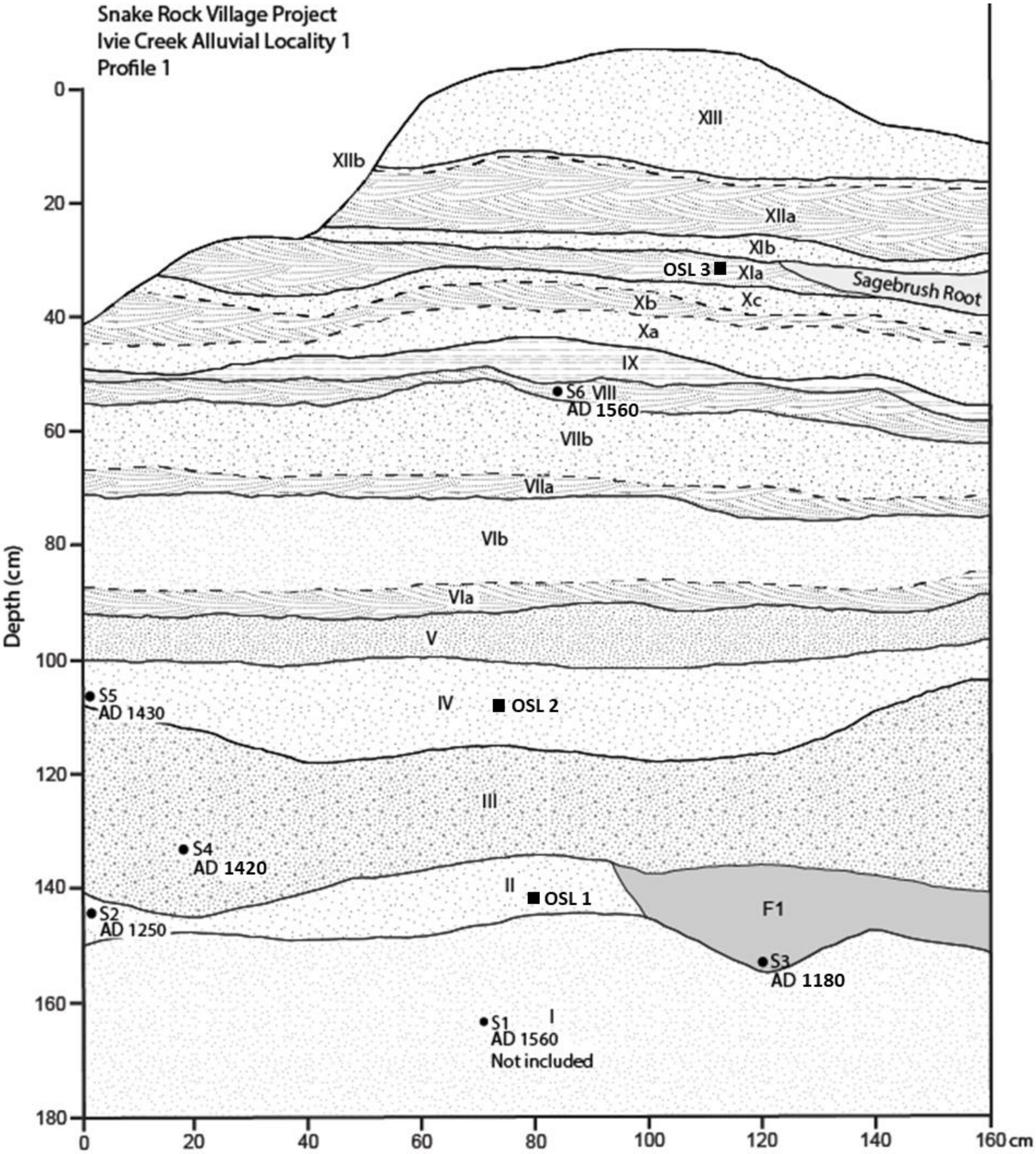

Figure 6: Stratigraphic profile illustration of Ivie Creek Profile 1. Corresponding median two-sigma calibrated radiocarbon ages noted next to radiocarbon sample locations.

Figure 7: Stratigraphic profile of Ivie Creek Profile 2.

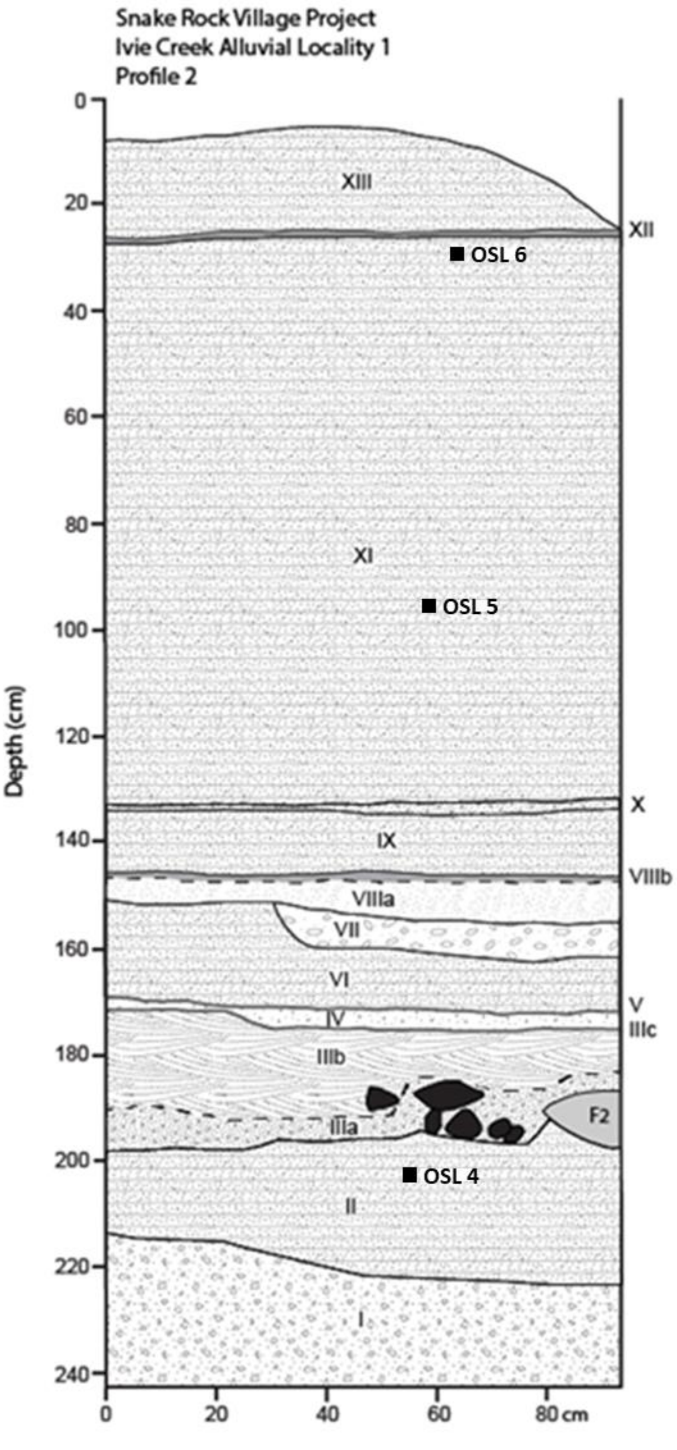

Figure 8: Stratigraphic profile illustration of Ivie Creek Profile 2.

Figure 9: Stratigraphic profile of Ivie Creek Profile 3.

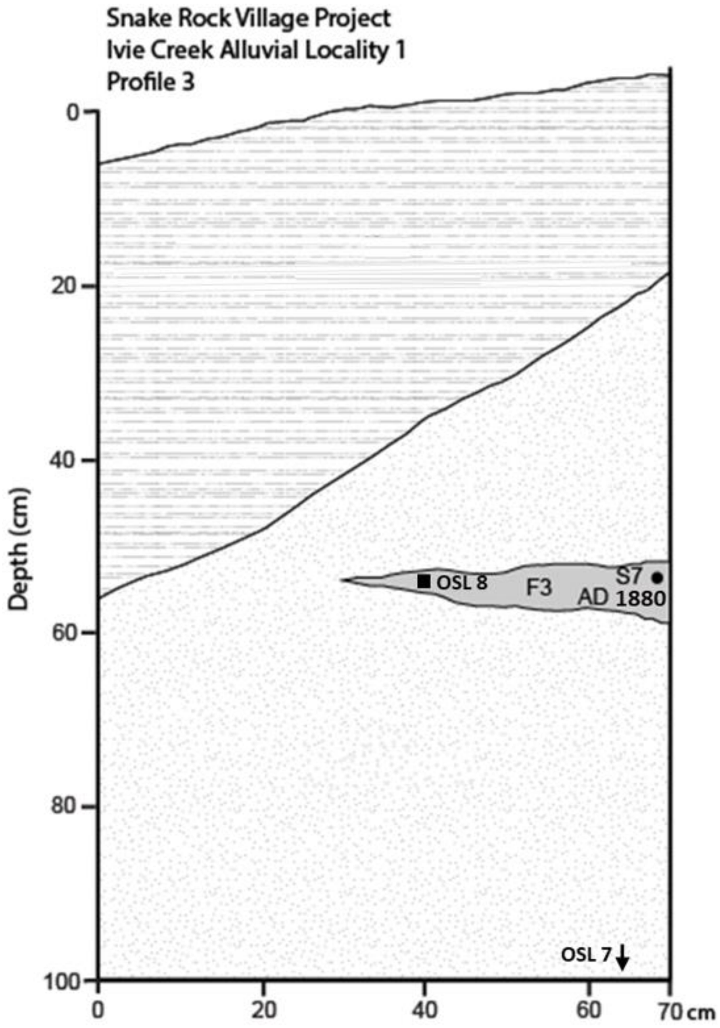

Figure 10: Stratigraphic profile of Ivie Creek Profile 3. Corresponding median two-sigma calibrated radiocarbon age noted next to sample location.

Table 2: Stratigraphy Descriptions of Profile 1.

I	Slightly silty clay; 10YR6/2 (light brownish gray); massive; very hard; effervescent; $CaCO_3$ filaments throughout; no lower boundary
II	Silty sand; 10YR6/4 (light yellowish brown); massive; very well sorted; soft; effervescent; abrupt lower boundary; Feature 1 is a possible cultural burn zone but not likely a fire hearth
III	Slightly silty clay; 10YR6/2 (light brownish gray); massive; very well sorted; very hard; violently effervescent; abrupt lower boundary; charcoal flecks throughout 1% by area
IV	Slightly silty fine to very fine sand; 10YR6/3 (pale brown); massive; well sorted; soft; violently effervescent; abrupt lower boundary
V	Silty clay; 10YR5/2 (grayish brown); massive; hard; effervescent; abrupt lower boundary
VIa	Silty sand; 10YR6/3 (pale brown); cross-bedded; soft; violently effervescent; abrupt lower boundary
VIb	Slightly silty clay; 10YR5/2 (grayish brown); massive; slightly hard; violently effervescent; abrupt lower boundary
VIIa	Slightly silty sand; 10YR5/2 (grayish brown); cross-bedded; soft; effervescent; abrupt lower boundary
VIIb	Silty clay; 10YR4/2 (dark grayish brown); massive; very hard; effervescent; abrupt lower boundary
VIII	Slightly silty sand; 10YR6/3 (pale brown); cross-bedded; soft; effervescent; abrupt lower boundary
IX	Clayey silt; 10YR4/2 (dark grayish brown); massive; soft; effervescent; abrupt lower boundary
Xa	Silty sand; 10YR5/2 (grayish brown); massive; soft; violently effervescent; abrupt lower boundary
Xb	Slightly silty sand; 10YR5/3 (brown); cross-bedded; very soft; violently effervescent; abrupt lower boundary
Xc	Silty clay; 10YR5/2 (grayish brown); massive; very hard; effervescent; abrupt lower boundary
XIa	Silty sand; 10YR5/3 (brown); cross-bedded; very soft; effervescent; abrupt lower boundary
XIb	Silty clay; 10YR6/3 (pale brown); massive; hard; violently effervescent; abrupt lower boundary
XIIa	Silty sand; 10YR5/4 (yellowish brown); cross-bedded; soft; violently effervescent; abrupt lower boundary
XIIb	Silty clay; 10YR8/1 (white); massive; hard; effervescent; abrupt lower boundary
XIII	Silty sand; 10YR5/3 (brown); massive; soft; effervescent; abrupt lower boundary

Table 3: Stratigraphy Descriptions of Profile 2.

I	Gravel: pebble to cobble size; clast supported; moderately sorted with some pebbles suspended in silt matrix
II	Slightly silty sand; 10YR6/3 (pale brown); planar bedding; well sorted; effervescent; soft; abrupt lower boundary; roots throughout 1% by area
F2	Feature 2 is a possible cultural burn zone; approximately 20 cm thick pinching out to the west; extending 20 cm from east wall
IIIa	Slightly gravelly (70%); 10YR5/3 (brown); massive; poorly sorted; soft; effervescent; abrupt lower boundary; includes silt clasts and basalt cobble
IIIb	Slightly silty fine sand; 10YR6/3 (pale brown); cross-bedded; well sorted; soft; effervescent; gradual lower boundary; coal throughout 1% by area
IIIc	Silt; no color
IV	Slightly gravelly; 10YR6/2 (light brownish gray); massive; poorly sorted; soft; effervescent; abrupt lower boundary
V	Silt; no color
VI	Slightly silty fine sand; 10YR6/3 (pale brown) with 7.5YR5/8 (strong brown); planar bedding; well sorted; slightly hard; mildly effervescent; abrupt lower boundary; includes an iron oxidized feature – 10% area
VII	Sandy gravel; clast supported; 10YR5/3 (brown) with 7.5YR5/8 (strong brown); massive; poorly sorted; soft; violently effervescent; gradual lower boundary; includes an iron oxidized feature – 10% area
VIIIa	Slightly silty very fine sand; 10YR7/4 (very pale brown) with 7.5YR5/8 (strong brown); massive; well sorted; slightly hard; effervescent; abrupt lower boundary; includes an iron oxidized feature – 30% area
VIIIb	Clay; 10YR7/1 (light gray); columnar; well sorted; very hard; effervescent; abrupt lower boundary
IX	Slightly silty sand; 10YR6/3 (pale brown); planar bedding; well sorted; soft; effervescent; abrupt lower boundary; includes an iron oxide feature – 50% area
X	Slightly sandy silt; 10YR7/1 (light gray) with 7.5YR5/8 (strong brown); massive; well sorted; slightly hard; effervescent; gradual lower boundary; includes an iron oxide feature – 50% area
XI	Slightly silty sand; 10YR6/2 (light brownish gray); planar bedding; well sorted; slightly hard; slightly effervescent; abrupt lower boundary; roots throughout 1% by area
XII	Clay; 10YR7/1 (light gray); columnar; well sorted; very hard; effervescent; abrupt lower boundary; roots throughout 1% by area
XIII	Slightly silty sand; 10YR6/3 (pale brown); planar bedding; well sorted; soft; slightly effervescent; abrupt lower boundary; roots throughout 1% by area

Table 4: Stratigraphy Descriptions of Profile 3.

I	Fine sand; massive; charcoal flecking throughout
II	Very fine sand; planar beds; Feature 3 is a possible cultural burn zone of charcoal-enriched sediments; approximately 10 cm thick; extending 40 cm from east wall; pinching out to the west but not likely a fire hearth

The measured section of Profile 1 is 1.5m wide and 2m deep. Profile 1 is composed of stacked beds that fine upwards. Basal contacts between beds are abrupt, and facies are predominantly composed of massive and well-sorted sands with occasional finer beds and cross-bedded sands. Feature 1, a possible cultural burn zone but not likely a fire hearth, is located in Stratum II of Profile 1. It is a possible cultural feature because it is a concentration of charcoal-enriched sediments measuring >1m long that pinches out in both directions, but it does not have a rock layer or oxidation rind typical of fire hearths. Stratigraphic descriptions for Profile 1 are provided in Table 2. The measured section of Profile 2 is 1m wide and 2.5m deep. Profile 2 is composed of stacked tabular fluvial beds that are capped by silt layers. Basal contacts between beds are abrupt, and facies are predominantly composed of planar bedded sands and well-sorted sands with occasional finer beds. Feature 2, a possible cultural burn zone, is located between Stratum II and IIIa of Profile 2 and is next to silt clasts and basalt cobbles. Stratigraphic descriptions for Profile 2 are provided in Table 3. The measured section of Profile 3 is 75cm wide and 1m deep. Profile 3 is composed of planar beds of very fine and fine sand. Basal contact between beds is abrupt, and charcoal flecking is throughout Stratum I. Feature 3, a possible cultural burn zone of charcoal-enriched sediments, is in Stratum I of Profile 3. Stratigraphic descriptions for Profile 3 are provided in Table 4.

Grain-Size Analysis

Twenty-nine samples for grain-size analysis were collected from Profile 1 and Profile 2. No samples were collected from Profile 3. Nineteen samples were taken from Profile 1 and ten samples from Profile 2. The sedimentology of Profile 1 is different than Profile 2. In Profile 1, sediments alternate dominantly from sand to silt as the depth increased and sediments are finer than Profile 2 (Figure 11). Profile 2 is dominantly sand with two strata where grains are >1 mm (gravels and pebbles) and sediments are much coarser than Profile 1 (Figure 12). Profile one has repeated or cyclical graded beds which are characteristic of overbank deposition, while Profile 2 is significantly sandier, which reflects primary channel deposits.

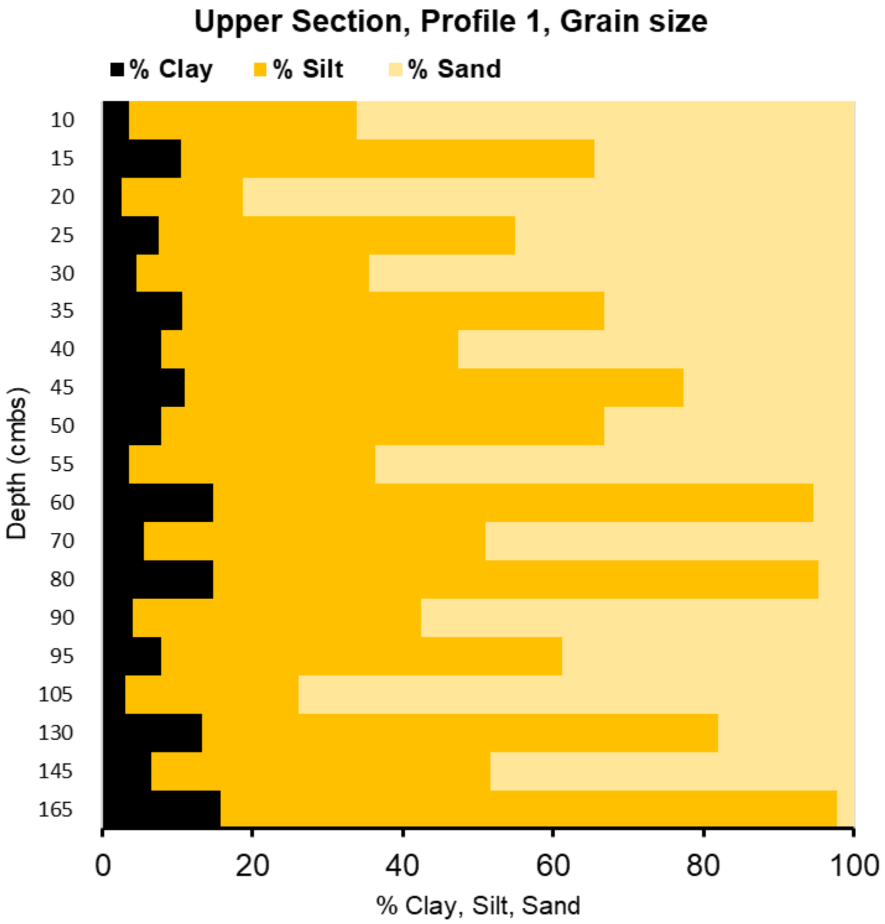

Figure 11: Profile 1 Grain Size Results.

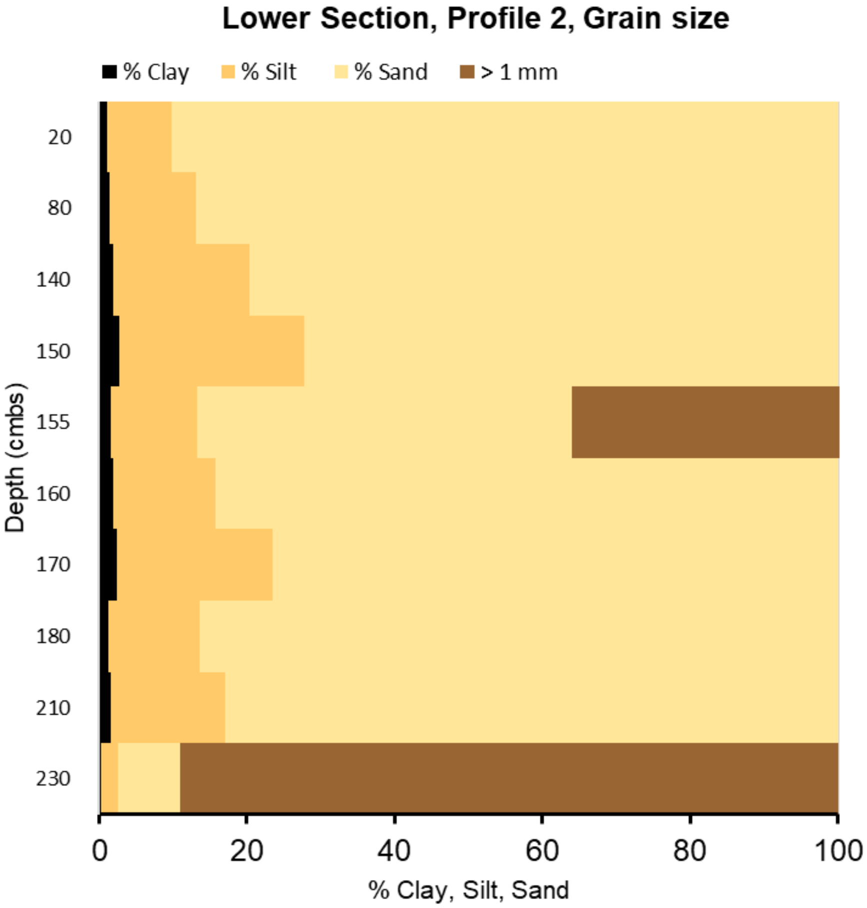

Figure 12: Profile 2 Grain Size Results.

Radiocarbon Chronology

Seven charcoal samples were selected for AMS radiocarbon dating with six samples from Profile 1 and one sample from Profile 3. One sample was collected from Profile 2 but was determined under low-power magnification to be detrital coal likely from the Mancos Shale. AMS radiocarbon results from charcoal and bulk sediment are presented in Table 5.

Table 5: Radiocarbon Results of Ivie Creek Alluvial Locality 1.

Sample Number	Lab Number (UCIAMS)	Context	Depth (cmbs)	Sample Type	Conventional Radiocarbon Age (yrs BP)	2-Sigma Median Age (cal yr BC/AD)
ICAL1-S1	268102	Profile 1, Stratum I	164	Charcoal	355+/-15	AD 1560
ICAL1-S2	268103	Profile 1, Stratum II	143	Charcoal	780+/-15	AD 1250
ICAL1-S3	268104	Profile 1, Feature 1	153	Charcoal	885+/-15	AD 1180
ICAL1-S4	268105	Profile 1, Stratum III	133	Charcoal	520+/-15	AD 1420
ICAL1-S5	268106	Profile 1, Stratum IV	106	Charcoal	495+/-15	AD 1430
ICAL1-S6	268107	Profile 1, Stratum VIII	54	Bulk Sediment	325+/-15	AD 1560
ICAL1-S7	268108	Profile 3, Feature 2	54	Charcoal	210+/-15	AD 1880

Conventional radiocarbon ages from these samples range from 855±15 ^{14}C yr BP to 210±15 ^{14}C yr BP. While most radiocarbon ages were stratigraphically consistent, one radiocarbon age indicates evidence of a colluvial wedge (deposits that typically occur on hillslopes) or meander scar (a meander causing transportation of younger sediment injected into older/lower deposits) (ICAL1-S1 dated to 355+/-15 ^{14}C yr BP). For this reason, ICAL1-S1 is not included in the Ivie Creek Age Model. Radiocarbon dating was used to develop a chronostratigraphic record of Profile 1 and Profile 3. Sample 2 in stratum II Profile 1 dated to 780+/-15 ^{14}C yr BP (AD 1250) and sample 3 in Feature 1 located next to stratum II dated to 855+/-15 ^{14}C yr BP (AD 1180). Sample 4 of stratum III Profile 1 dated to 520+/-15 ^{14}C yr BP (AD 1420). Sample 5 of stratum IV of Profile 1 dated to 495+/-15 ^{14}C yr BP (AD 1430). Sample 6 from Stratum VIII dated to 325+/-15 ^{14}C yr BP (AD 1560). Sample 7 in Feature 3 of Profile 2 dated to 210+/-15 ^{14}C yr BP (AD 1880).

Ivie Creek Age Model

The Bayesian model successfully provides 68% and 95% ranges for the start and end of deposition on the Ivie Creek floodplain (Figure 13; Table 6). Figure 14 shows how the model structure incorporates the sequence language. The start of the Ivie Creek floodplain sequence is estimated to have occurred from *cal AD 1155 to AD 1310* (68.2% probability) but most probably from cal *AD 1080–1380* (95.4% probability). The end of the Ivie Creek floodplain sequence is estimated to have occurred either from *cal AD 1480 to AD 1645* (68.2% probability) but most probably from *cal AD 1440–1700* (95.4% probability) or from *cal AD 1600 to AD 1810* (68.2%

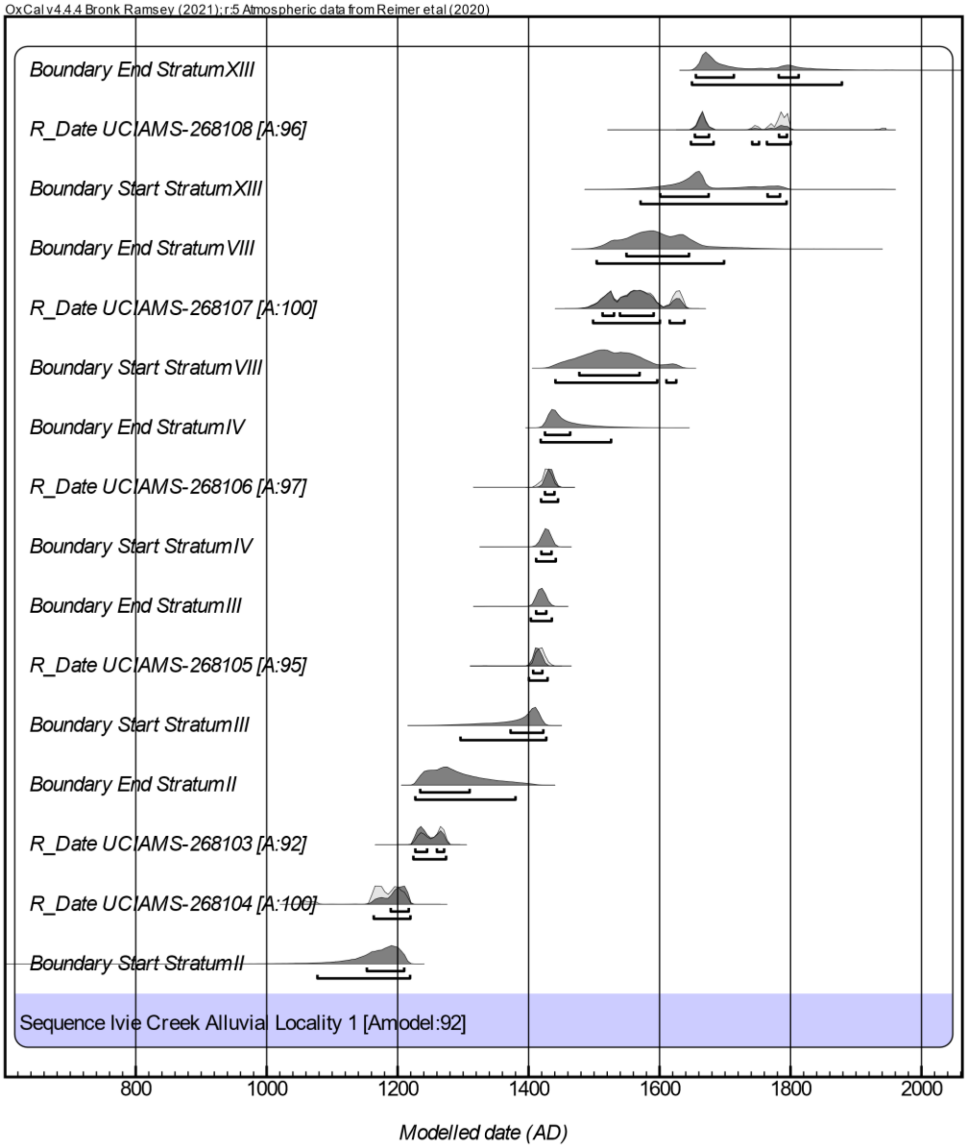

Figure 13: Radiocarbon Multiplot of the Ivie Creek Alluvial Locality 1 Floodplain Sequence.

probability) but most probably from *cal AD 1570–1880* (95.4% probability). The start of Stratum II sequence is estimated to have occurred from *cal AD 1155 to AD 1210* (68.2% probability) but most probably from *cal AD 1080–1220* (95.4% probability) (Figure 14). The end of Stratum II sequence is estimated to have occurred from *cal AD 1235 to AD 1310* (68.2% probability) but most probably from *cal AD 1230–1380* (95.4% probability) (Figure 15).

Table 6: Highest Posterior Probability Density (95%) of the Stratigraphic Model.

	Range	**Median**	**^{14}C Sample**	**Profile**
Start Ivie Creek Alluvial Locality 1	AD 1080–1380	AD 1230	S2 & S3	1
End Ivie Creek Alluvial Locality 1	AD 1440–1700	AD 1570	S6	1
End Ivie Creek Alluvial Locality 1	AD 1570–1880	AD 1725	S7	3

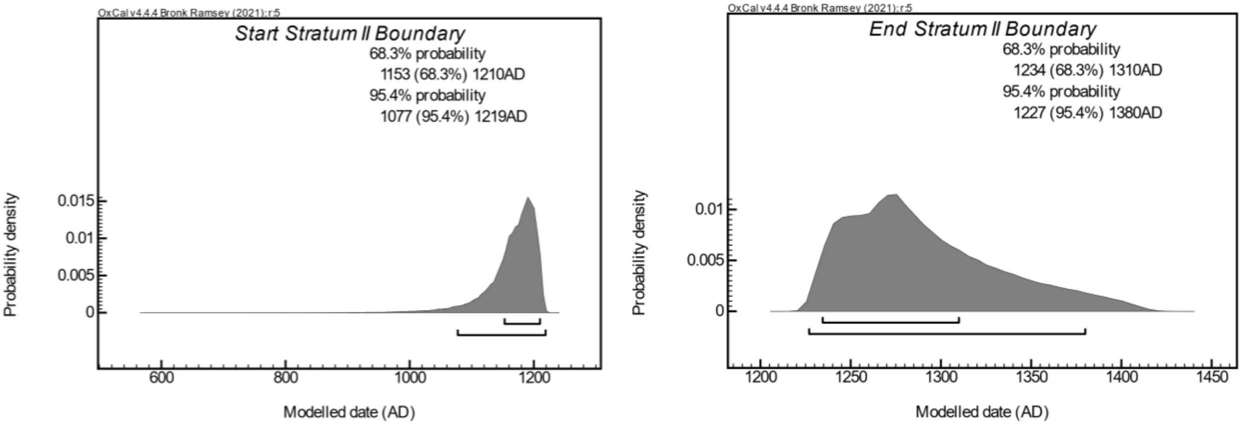

Figure 14: Modeled 95.4% posterior probability density functions for start and end of Stratum II of Profile 1.

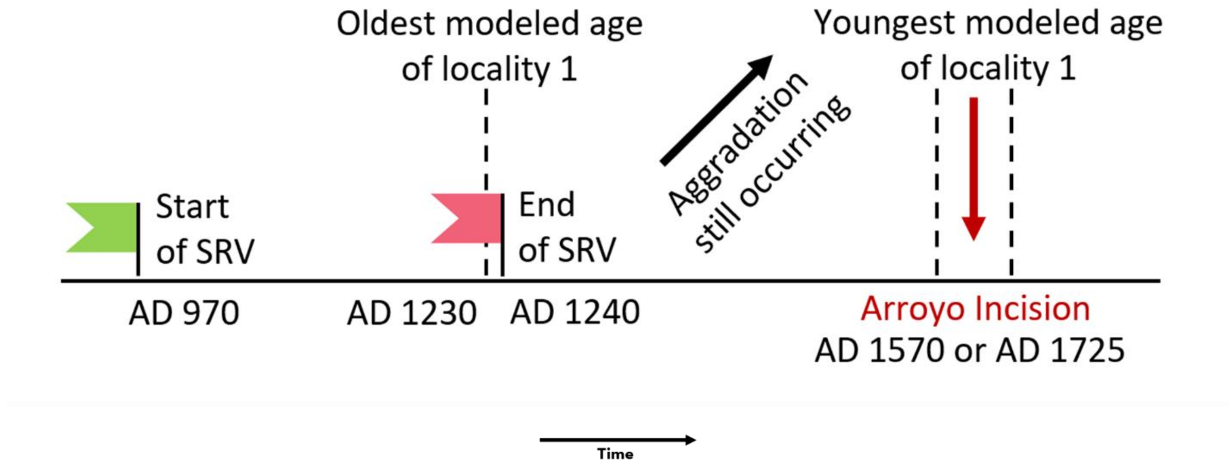

Figure 15: Chronology of Snake Rock Village and Ivie Creek.

Discussion

In this paper, I have investigated the potential impact of alluvial cut-and-fill cycles on the occupation of the Snake Rock Village settlement. The study builds on the long-held idea that the structure, size, and longevity of settlements relates to how farmers cope with risk and uncertainty in dryland ecosystems (e.g., Finley et al 2020; Flannery 2002; Gilman 1987; Strawhacker et al. 2020). Importantly, farmers create bundles of agricultural niches, and these bundles have both a social-economic dimension and a geomorphic dimension. Building on the earlier work of Finley et al. (2020) and Finley et al. (2023) that geomorphic instability correlates with the abandonment of farming villages in one region of the northern Colorado Plateau, I tested whether the longevity and abandonment of Snake Rock Village also associates with changes in geomorphic stability, specifically the down cutting of Ivie Creek. The basic idea is that more geomorphic stability should lead to more cultural stability, holding the social-economic dimension equal, in the productivity and reliability of floodplain agricultural niches.

At Snake Rock Village the results do not fit with the prediction that hydroclimate variability and arroyo formation are environmental mechanisms that limited the persistence of this Fremont village. The data suggest that the Ivie Creek floodplain would have been stable for Fremont agriculturalists for over 330 or 485 years after abandonment, demonstrating that local hydroclimate, and geomorphic thresholds did not control the abandonment of Snake Rock Village. Further, the long period of floodplain stability did not limit earlier occupations of the settlement. This finding helps build our understanding of the regional variability in the geomorphic constraints on farming on the northern Colorado Plateau.

Key Findings

Geochronological results indicate that at least one episode of Late Holocene aggradation and entrenchment occurred in Ivie Creek. The start of aggradation began with the bedload of Profile 2 and ended at stratum XIII of Profile 1 or ended at stratum II of Profile 3. Entrenchment occurred after stratum XIII of Profile 1 or after stratum II of Profile 3 and is now where Ivie Creek flows today. Based on stratigraphic observations, both Profile 1 and Profile 3 have similar floodplain silt packages suggesting that they are composed of the same deposits. Considering both stratigraphic and AMS results it was interpreted that Profile 2 contains the oldest deposits,

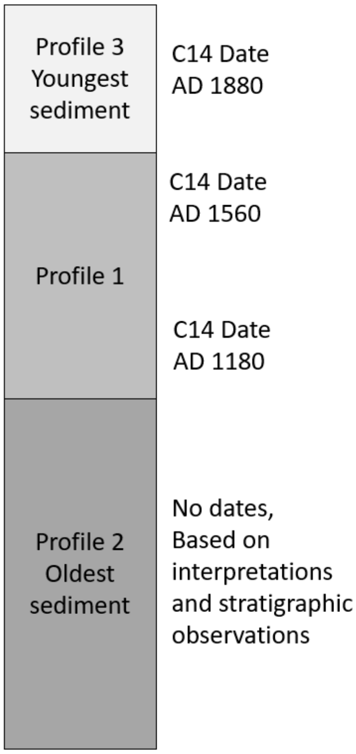

Figure 16. Stratigraphic observations and interpretations of all three profiles and related AMS dates.

Profile 1 deposits are above and younger than Profile 2 deposits, and Profile 3 deposits are above and younger than Profile 1 deposits (Figure 16).

The focus of this study was to investigate the stability of the local dryland alluvial system of Ivie Creek and test the expectation that the abandonment of Snake Rock Village corresponds to floodplain incision and arroyo formation. Radiocarbon ages from Profile 1 and Profile 3 indicate that the Ivie Creek alluvial fills are late-Holocene to modern in age, ranging from before AD 1180 to AD 1880. Six ages were incorporated into the Ivie Creek age model (^{14}C samples 2, 3, 4, 5, 6, and 7). The modeled start date of Ivie Creek deposition is most probably from *cal AD 1080–1380* and the modeled end date is most probably from *cal AD 1440–1700* or *AD 1570–1880*. The start of the Ivie Creek age model overlaps with the end of the Snake Rock Village occupation at AD 1240 (Table 1, Figure 14, Table 6, and Figure 15). The two ^{14}C ages associated with the end of Snake Rock Village occupation are Sample 2 in Stratum II of Profile 1 (780$\underline{+}$15 ^{14}C yr BP (AD 1250)) and Sample 3 in Feature 1 of Profile 1 located next to Sample 2 (855$\underline{+}$15 ^{14}C yr BP (AD 1180)) (Table 1 and Figure 6). The results of the Ivie Creek geoarchaeological model indicate that Ivie Creek located in the vicinity of Snake Rock Village was in a phase of floodplain construction during the village occupation and remained stable for 330 or 485 years after its abandonment (Figure 15).

There are noticeable differences between the sediment composition of Profile 1 and Profile 2. Profile 1 alternated from being a lower energy depositional environment (silt and clay) to a higher energy deposition environment (sand), whereas Profile 2 was a higher energy deposition environment (Figure 11 and 12). Profile 1 was alternating from low to high energy depositional conditions for 330 to 485 years but then there was shift to a high-energy depositional environment after AD 1570. If the entrenchment occurred around AD 1880 (based off the ^{14}C age of Sample 7 in Feature 3), the entrenchment would be consistent with the initiation of modern arroyo formation throughout the Colorado Plateau (Bryan 1925; Graf 1983; Webb 1991; Hereford 2002).

The Ivie Creek data adds to recent analysis of alluvial cycles in the northern Colorado Plateau. Range Creek, located approximately 120 miles from Ivie Creek in the Grand Staircase region of southern Utah, had three episodes of entrenchments at AD 1130, prior to AD 1670, and in the late AD 1800s (Rittenour et al. 2015). Kanab Creek, located approximately 175 miles from Ivie Creek in south-central Utah, had five episodes of entrenchments at 1500–1200 BC, 400 BC–AD 0, AD 700–800, AD 1000–1200, and in AD 1883 (Townsend et al. 2019). Cub Creek, located approximately 200 miles from Ivie Creek in Dinosaur National Monument, had three

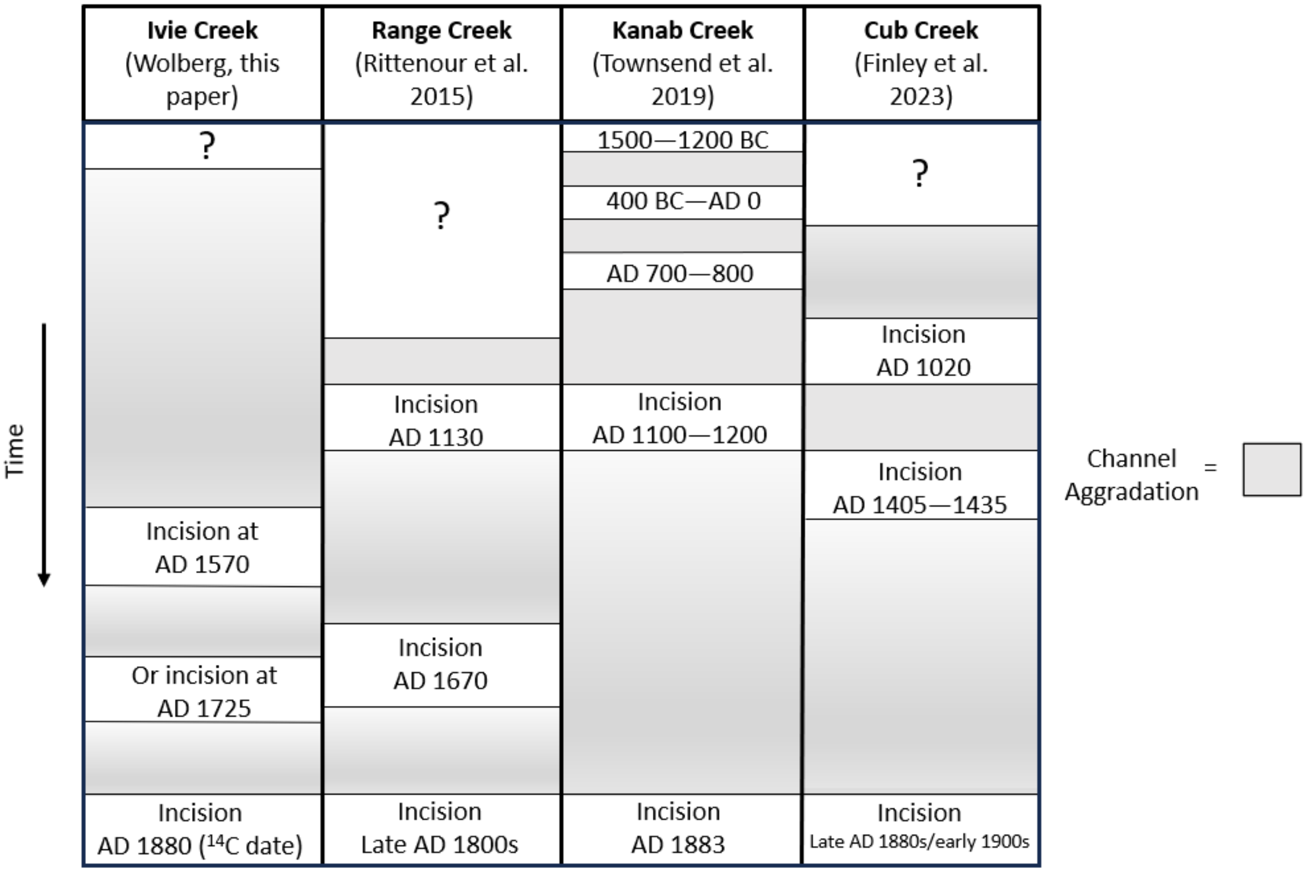

Figure 17: Regional comparisons of arroyo entrenchment timing between Ivie Creek, Range Creek, Kanab Creek, and Cub Creek.

episodes of entrenchments at AD 1020, AD 1405–1435, and in the late AD 1800s/early 1900s (Finley et al. 2023). A regional comparison shows episodes of entrenchments in the mid to late AD 1800s at Ivie Creek, Range Creek, Kanab Creek, and Cub Creek (Figure 17). Otherwise, episodes of entrenchment at these locations do not correlate with Ivie Creek. This may indicate that the mechanisms for arroyo formation across these areas are partially driven by local sediment supply, the rate of channel aggradation, hydroclimate variability, and that these systems must approach complete re-filling before they become sensitive to incision (Townsend et al.

2019). Once arroyo dynamics approach complete re-filling, entrenchment is triggered by local slope-thresholds.

Limitations

A limitation of the research is that organic material, charcoal, or bulk sediment were not present for radiocarbon dating of Profile 2, and there are currently no ages constraining the chronology of Profile 2. Although OSL samples were collected at the locality, OSL dating results are ongoing for Ivie Creek. The results from OSL dating will add important data about the chronology of Profile 2 and clarify the age of stratum II of Profile 1. The lack of OSL ages limited the interpretation of the findings of this study. However, having no associated ages with Profile 2 does not impact the ability for this research to address the prediction of this study. In Profile 1 alone the research shows that arroyo formation does not correspond with the abandonment of Snake Rock Village.

Implication for Future Fremont Work

Our understanding of the processes enabling the sustained occupation and growth of agricultural villages is currently being investigated in Fremont research (Finley et al. 2022). Talbot (2019) concluded that “only when researchers develop local and regional Fremont chronologies will archaeologists be able to begin exploring in greater depth social behavior.” The substantial question Finley et al. (2022) are investigating is can hydroclimatic-geomorphic factors determine the formation, longevity, population size, and relative social complexity of

Fremont villages? The research presented in this thesis developed a localized chronology which contributes to building a regional chronology of central Utah's San Rafael Desert and aids in the study of Fremont variability. Once eastern Great Basin and northern Colorado Plateau local and regional chronologies are further developed and correlated to this study, Fremont researchers can begin to better understand the social behavior of agricultural communities. While the findings in this research do not support the working hypothesis, the results will incentivize researchers to investigate other explanations for the abandonment of Snake Rock Village.

Recommendations

The results of this study indicate that further explorations as to why Fremont agriculturalists abandoned Snake Rock Village are necessary. Analysis of the completed OSL dating is a first step towards understanding more about the Ivie Creek alluvial chronology. Avenues for further study include extending Profile 1 to a deeper depth to see if geological deposits that capture the start and span of the Snake Rock Village occupation can be exposed. This study provides benchmark preliminary data for the Ivie Creek location. It is recommended that further investigations be completed at Ivie Creek based on this benchmark data. Further investigations of alluvial chronologies at other Fremont village sites in Ivie Creek Canyon and near Snake Rock Village (such as Five Finger Ridge, Poplar Knob, Old Woman, or Round Spring) could be used to determine if arroyo formation in other valleys corresponded with village abandonment. The water quality of Ivie Creek could also be investigated further to determine if the high salinity reported by WATEC, Inc. and studies by Kaman Tempo Corp. (1990) was a factor that may have impacted the soil quality and contributed to the abandonment of Snake Rock Village.

Conclusions

The goal of this research was to test the relationship between the occupational timing of Snake Rock Village AD 970–1240 and the formation of a 4.5m deep arroyo. This was accomplished by pairing a high-precision AMS radiocarbon chronology of the village occupation with a new AMS radiocarbon reconstruction of the Ivie Creek floodplain 400m upstream from the site. This research relates the mechanisms of floodplain construction to hydroclimate variability as the basis for considering constraints on the growth potential of Snake Rock Village. This study provides a geoarchaeological context in the form of dated stratigraphic deposits, analysis of sediment types, and a Bayesian chronology that constrains the timing of major cut-and-fill cycles at Ivie Creek. Six AMS ages constrain the age of the Ivie Creek valley fill. While some evidence from other locations implicates arroyo formation as one factor contributing to the abandonment of early agricultural villages in other parts of the northern Colorado Plateau (Finley et al. 2023), arroyo formation does not constrain the persistence of floodplain farming on Ivie Creek. The abandonment of Snake Rock Village does not correspond with an incision of the adjacent floodplain, instead the Ivie Creek floodplain was still aggrading when Snake Rock Village was abandoned. The Ivie Creek geoarchaeological model revealed the incision did not occur until 330 to 485 years after abandonment. This study showed that arroyo formation cannot be implicated for the abandonment of Snake Rock Village and arroyo formation was not a primary risk to the persistence and longevity of a settled village in Snake Rock Village.

References

Aikens, Melvin

1967 Excavations at Snake Rock Village and Bear River No. 2 Site. *Anthropological Papers* 87:1-65.

Barlow, K. R.

2002 Predicting maize agriculture among the Fremont: An economic comparison of farming and foraging in the American Southwest. *American Antiquity* 67:65-88.

Bayliss, Alix

2015 Quality in Bayesian chronological models in archaeology. *World Archaeology* 47:677-700.

Boomgarden, S. A., D. Metcalfe, and E.T. Simons

2019 An optimal irrigation model: theory, experimental results, and implications for future research. *American Antiquity* 84:252-273.

Bryan, Kirk

1925 Date of channel trenching (arroyo cutting) in the arid Southwest. *Science* 62:338–334.

Bronk Ramsey, Christopher

2021 OxCal v4. 4.4. Electronic document, https://c14.arch.ox.ac.uk/oxcal.html, accessed March 16, 2023.

Codding, B.F., J. Brenner Coltrain, L. Louderback, K.B. Vernon, K.E. Magargal, P.M. Yaworsky, E. Robinson, S.C. Brewer, and J.D. Spangler

2022 Socioecological dynamics structuring the spread of farming in the North American Basin-Plateau Region. *Environmental Archaeology* 27:434-446.

Coltrain, Joan Brenner, and Steven W. Leavitt

2002 Climate and Diet in Fremont Prehistory: Economic Variability and Abandonment of Maize Agriculture in the Great Salt Lake Basin. *American Antiquity* 67(3):453-485.

Fenneman, Nevin Melancthon

1931 *Physiography of Western United States*. University of Michigan Press, Ann Arbor.

Finley, Judson Byrd, Erick Robinson, R. Justin DeRose, and Elizabeth Hora

2020 Multidecadal Climate Variability and the Florescence of Fremont Societies in Eastern Utah. *American Antiquity*, 85(1):93-112.

Finley, Judson Byrd, Erick Robinson, and R. Justin De Rose

2022 Hydroclimatic Variability and the Evolution of Socioecological Complexity in Dryland Farming Communities. Manuscript on file, Anthropology Program, Utah State University, Logan, Utah.

2023 Arroyo formation impacts on an early dryland agricultural community in Northeastern Utah, USA. *Geoarcheology* 38:109–126.

Finley, Judson Byrd, Erick Robinson, R. Justin DeRose, James Allison, and Matthew Bekker

2023 High-Precision AMS Radiocarbon Chronologies Demonstrate Short-Lived Agricultural Village Occupations on the Northern Colorado Plateau. Poster presented at the 88th Annual Meeting of the Society for American Archaeology, Portland, Oregon.

Flannery, K.V.

2002 The origins of the village revisited: from nuclear to extended households. *American Antiquity* 67:417-433.

Freeman, Jacob

2012 Alternative adaptive regimes for integrating foraging and farming activities. *Journal of Archaeological Science* 39:3008-3017.

Freeman, J., Robinson, E., Beckman, N., Bird, D., Baggio, J.A., and Anderies, J.M.

2020 The global ecology of human population density and interpreting changes in paleo-population density. *Journal of Archaeological Science* 120:1-9.

Freeman, J., J.M. Anderies, N.G. Beckman, E. Robinson, J.A. Baggio, D. Bird, C. Nicholson, J.B. Finley, J.M. Capriles, A.F. Gil, and D. Byers

2021 Landscape engineering impacts the long-term stability of agricultural populations. *Human Ecology* 49:369-382.

Gilman, P.A.

1987 Architecture as artifact: Pit structures and pueblos in the American Southwest. *American Antiquity* 52:538-564.

Graf, William L.

1983 The arroyo problem: Paleohydrology and paleohydraulics in the short term. In *Background to Paleohydrology*, edited by K. J. Gregory, pp. 279-302. New York: John Wiley and Sons.

Harvey, Jonathan E., and Joel L. Pederson

2011 Reconciling arroyo cycle and paleoflood approaches to late Holocene alluvial records in dryland streams. *Quaternary Science Reviews* 30:855-866.

Hereford, Richard

2002 Valley-fill alluviation during the Little Ice Age (ca. A.D. 1400–1880), Paria River basin and southern Colorado Plateau, United States. *Geological Society of America* 114:1550-1563.

Huckleberry, Gary

2015 Defining the Environmental Context of Indigenous Agriculture in the Southwest: What We Don't Know about Middle to Late Holocene Climate Change and Floodplain Dynamics. In *Traditional Arid Lands Agriculture*, edited by Scott E. Ingram and Robert C. Hunt, pp. 89–130. The University of Arizona Press, Tucson, Arizona.

Ingram, Scott E.

2015 Human Vulnerability to Dry Periods. In *Traditional Arid Lands Agriculture*, edited by Scott E. Ingram and Robert C. Hunt, pp. 131–160. The University of Arizona Press, Tucson, Arizona.

Ingram, S.E., and S.M. Patrick

2021 Human securities, sustainability, and migration in the ancient US Southwest and Mexican Northwest. *Ecology & Society*, 26:9.

Jackson, A. Lynn

1999 Geology of the San Rafael Swell. In *Hiking and Exploring Utah's San Rafael Swell*, edited by Michael R. Kelsey, pp. 197–207. Kelsey Publishing, Provo.

Jennings, Jesse D.

1978 *Prehistory of Utah and the Eastern Great Basin*. University of Utah Press, Salt Lake.

Lupton, Charles T.

1912 Notes on the geology of the San Rafael Swell, Utah. *Journal of the Washington Academy of Sciences* 2:185-188.

Mabry, Jonathan

2005 Diversity in Early Southwestern Farming and Optimization Models of Transition to Agriculture. In *Subsistence and Resource Use Strategies of Early Agricultural Communities* *in Southern Arizona*, edited by Michael W. Diehl, pp. 113-152. Center for Desert Archaeology, Tucson, Arizona.

Madsen, David B., and Steven R. Simms

1998 The Fremont Complex: A Behavioral Perspective. *Journal of World Prehistory* 12:255-336.

Reimer, Paula J., et al.

2020 The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* 62:725-757.

Rittenour, Tammy M., Larry L. Coats, and Duncan Metcalfe

2015 Investigation of late and post-Fremont alluvial stratigraphy of Range Creek, east-central Utah: Use of OSL when radiocarbon fails. *Quaternary International* 362:63-76.

Santos, G. M., Moore, R. B., Southon, J. R., Griffin, S., Hinger, E., & Zhang, D.

2007 AMS^{14}C Sample Preparation at the KCCAMS/UCI Facility: Status Report and Performance of Small Samples. *Radiocarbon* 49:255–269.

Simms, Steven R.

2016 *Ancient Peoples of the Great Basin & Colorado Plateau*. 2nd ed. Routledge, New York.

Simms, S. R., T.M. Rittenour, C. Kuehn, and M.B. Cannon.

2020 Prehistoric irrigation in Central Utah: chronology, agricultural economics, and implications. *American Antiquity* 85:452-469.

Southon, John, et al.

2004 The Keck Carbon Cycle AMS Laboratory, University of California, Irvine: Initial Operation and a Background Surprise. *Radiocarbon* 46:41-49.

Strawhacker, C., Snitker, G., Peeples, M.A., Kinzig, A.P., Kintigh, K.W., Bocinsky, K., Butterfield, B., Freeman, J., Oas, S., Nelson, M.C. and Sandor, J.A.

2020 A landscape perspective on climate-driven risks to food security: Exploring the relationship between climate and social transformation in the preHispanic US Southwest. *American Antiquity* 85:427-451.

Stokes, William Lee

1988 *Geology of Utah*. 2nd ed. Utah Museum of Natural History and Utah Geological and Mineral Survey, Salt Lake City.

Townsend, Krik F., Michelle S. Nelson, Tammy M. Rittenour, and Joel L. Pederson

2019 Anatomy and evolution of a dynamic arroyo system, Kanab Creek, southern Utah, USA. *The Geological Society of America Bulletin* 131:2094-2109.

Talbot, Richard K.

2019 The City Creek Fremont and Late Great Salt Lake Fremont Adaptations. In *The City Creek Site: Fremont Archaeology in Salt Lake City*, edited by Richard K. Talbot and Lane D. Richens, pp. 225–241. Occasional Paper No. 15. Museum of Peoples and Cultures, Brigham Young University, Provo, Utah.

Utah Geological Survey

2023 Sediment Information for Ivie Cree. Electronic document, https://geology.utah.gov/apps/intgeomap/, accessed March 9, 2023.

Webb, Robert H., Smith, Spence S., and McCord, V. Alexander S.

1991 *Historic Channel Change of Kanab Creek, Southern Utah and Northern Arizona*. Grand Canyon Natural History Association, Grand Canyon Village, Arizona.

Wentworth, Chester K.

1922 A Scale of Grade and Class Terms for Clastic Sediments. *The Journal of Geology* 30:377-392.

Weitzel, Elic M., and Brian F. Codding

2022 The Ideal Distribution Model and Archaeological Settlement Patterning, *Environmental Archaeology* 27:349-356.

Whitaker, G. L.

1969 *Summary of Maximum Discharges in Utah Streams*. United States Geological Survey in cooperation with the Utah Department of Natural Resources Division of Water Rights. Submitted to United States Geological Survey, Technical Publication No. 21. Copies available from United States Geological Survey.

Woods, A. J., et al.

2001 *Ecoregions of Utah*. US Geological Survey.