

**PALEOENVIRONMENTAL RECONSTRUCTION OF TWO PALEOINDIAN SITES
IN NORTH-CENTRAL NEW MEXICO**

by

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Abstract

This project examines bison teeth $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values at two Paleoindian sites (Boca Negra Wash site and Water Canyon site) in north-central New Mexico. The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values are compared across the sites to evaluate if there is a change in the habitat and climate the bison and humans were living in during the Younger Dryas into the Early Holocene. The results show that $\delta^{13}\text{C}$ values remained consistent while the $\delta^{18}\text{O}$ values are more negative in the Younger Dryas than in the Early Holocene. Additionally, the $\delta^{13}\text{C}$ results showed that the ratio of C_3 to C_4 grasses remained constant from the Younger Dryas into the Early Holocene. My preliminary conclusion is that the $\delta^{18}\text{O}$ shift reflects separate hunting strategies during the two periods. However, further research is needed to demonstrate if the $\delta^{18}\text{O}$ values are due to climate or the herding behavior of the bison.

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Introduction

Archaeologists use paleoenvironmental reconstructions to model the past and help understand the people who lived in a particular environment (Ballenger et al. 2011; Emery and Kennedy Thornton 2008; Mullen 2007; Stanford 2005). Pollen, packrat middens, tree rings, and speleothems are just a few proxy records that archaeologists have used to understand and reconstruct paleoenvironments (Ballenger et al. 2011). Stable isotopes found in faunal remains are another climate proxy and are particularly useful to archaeologists since they are a typical, durable material culture class.

This project will analyze the isotopic ratios of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ extracted from bison teeth to develop a proxy environmental record for the early Paleoindian and late Paleoindian periods in north-central New Mexico. Analyzing $\delta^{18}\text{O}$ can help determine the climate while analyzing $\delta^{13}\text{C}$ can help sample the plants in the environment. $\delta^{18}\text{O}$ is the ratio of ^{18}O to ^{16}O and provides a proxy for precipitation and determining an animal's water source. $\delta^{13}\text{C}$ is the ratio of ^{13}C to ^{12}C . Analyzing $\delta^{13}\text{C}$ provides a proxy for the composition of ancient vegetation communities (Sharp 2017). Plants have evolved different photosynthetic pathways for absorbing carbon, and these different carbon pathways impact carbon isotope ratios in the plants themselves. For example, C_3 plants include trees, shrubs, and grasses that inhabit cooler, wetter environments ($\delta^{13}\text{C}$ values of -22‰ to -32‰ with a mean of -27‰). C_4 plants exist in warmer, drier environments ($\delta^{13}\text{C}$ values of -9‰ to -17‰ with a mean of -13‰) (Holliday 2000; Sharp 2017). CAM (crassulacean acid metabolism) is another photosynthetic pathway some plants, such as cacti, evolved (Sharp 2017), but bison are obligate grazers and do not feed on CAM plants (Hoppe 2006; Hoppe et al. 2006; Roe 1951).

Stable isotopic studies are ideal for archaeologists since the proxy record is directly associated with the archaeological record. Stable isotopic studies, in particular, have been used to

examine Paleoindian sites in the U.S. Southwest (Connin et al. 1998; Friedman 1983; Holliday 2000; Hoppe 2004; Lovvorn et al. 2001; Mullen 2007). Those studies, for the most part, have focused on two climatically-defined temporal intervals: the Younger Dryas (12,900 – 11,600 cal B.P.) and the Early Holocene (ca. 11,600 cal B.P.) (Allen and Anderson 2000; Armour et al. 2002; Ballenger et al. 2011; Fall 1987; Markgraf and Scott 1981; Polyak et al. 2004; Reasoner and Jodry 2000; Thompson et al. 1994). The Younger Dryas was a millennium-long return to glacial maximum-like conditions across North America near the end of the last ice age (Allen and Anderson 2000; Armour et al. 2002; Ballenger et al. 2011; Connin et al. 1998; Feng et al. 2014; Holliday 2000; Holliday et al. 2006; Mullen 2007; Polyak et al. 2004; Reasoner and Jodry 2000; Thompson et al. 1994). The Terminal Pleistocene was the end of the last Ice Age, after which the climate shifted rapidly to warmer conditions similar to those we see today in the Southwest (Allen and Anderson 2000; Armour et al. 2002; Betancourt et al. 2001; Lovvorn et al. 2001; Markgraf and Scott 1981; Thompson et al. 1994; Vierling 1998). Thus, in the Southwest during the Younger Dryas, we should see colder conditions than in the Early Holocene. These colder conditions might favor C₃ species, including the grasses on which bison fed.

In this paper, I examine two primary research questions. First, can we see this expected environmental shift from the Younger Dryas to the Early Holocene in the remains of *Bison antiquus* at two archaeological sites in central New Mexico? Additionally, is there a shift in the water sources *B. antiquus* uses from the Younger Dryas to the Early Holocene? Based on those research questions, this study will investigate the following hypotheses:

H₀: The C₃ and C₄ grasses ratio remained stable between the Younger Dryas and the Early Holocene.

H₁: The ratio of C₄ to C₃ grasses was higher in the early Holocene than in the Younger Dryas.

H₀: $\delta^{18}\text{O}$ will remain stable between the Younger Dryas and the Early Holocene.

H₁: $\delta^{18}\text{O}$ will differ between the Younger Dryas and the Early Holocene.

To investigate these hypotheses, I will employ $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ analysis of bison tooth enamel from two sites in the Rio Grande Valley (Fig. 1). The first site is the Late Paleoindian bison kill site at Water Canyon (ca. 10,720-10,400 cal B.P.), which dates to the early Holocene (Holliday et al. 2019). I will then compare these results to an earlier study of stable isotopes in bison tooth enamel (Mullen 2007) at the Early Paleoindian (Folsom) site of Boca Negra Wash (ca. 12,845 – 12,255 cal B.P.) dating to the Younger Dryas (Holliday et al. 2006; Huckell et al. 2011).

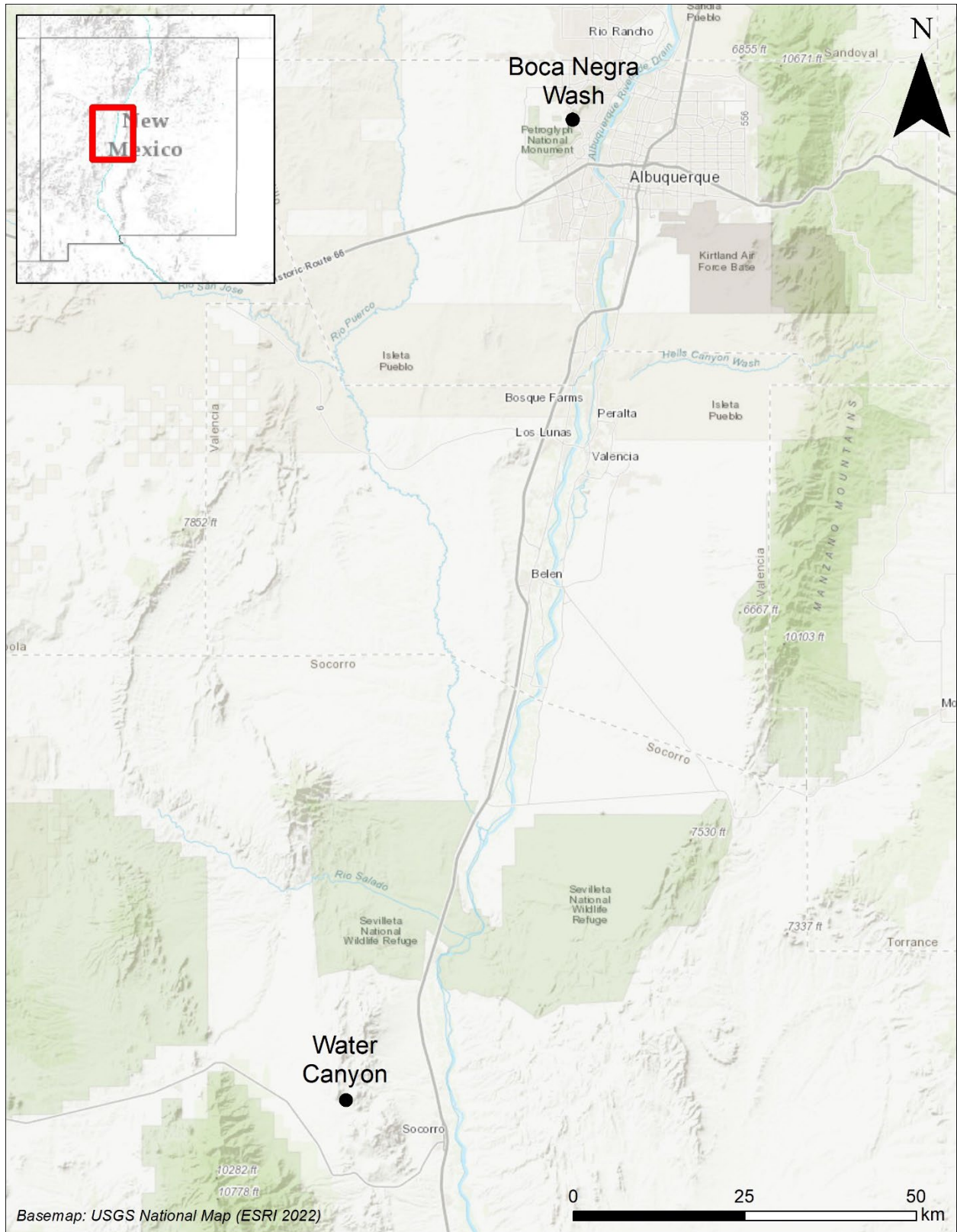


Figure 1: Map showing Boca Negra Wash and Water Canyon

Background and Literature Review

The Paleoindian Period

The Paleoindian period began ~13,000 years ago and lasted until ~10,000 years ago. Several cultural complexes are associated with the Southwest Paleoindian period, including Clovis and Folsom—which comprise the Early Paleoindian period—and the Cody Complex, part of the Late Paleoindian period. These cultural complexes are characterized by large game hunting and a lack of plant food processing tools (Cordell and McBrinn 2016; Huckell 2005; Kornfeld et al. 2010). Much of the Paleoindian period is associated with the terminal glacial period and the Younger Dryas interval – a return to glacial maximum-like conditions. It is unclear what caused the Younger Dryas. However, a widely accepted hypothesis is that freshwater drained from the Laurentide ice sheet into the North Atlantic Ocean, which shut down the Atlantic Meridional Overturning Circulation (AMOC), reducing the northward transfer of heat from the tropics (Tarasov and Peltier 2005).

Shortly after the Younger Dryas's termination, we also see the end of the Folsom technocomplex and the appearance of other complexes such as Agate Basin, Plainview, and (slightly later) the Cody Complex. The diagnostic lithic artifact for the Folsom period is the Folsom Point, a fluted dart point associated with several bison kill sites (Cordell and McBrinn 2016; Huckell 2005; Kornfeld et al. 2010; Stanford 2005). However, unlike the Folsom Complex, a single projectile point does not characterize the Cody Complex; instead, square-based, stemmed types such as Alberta, Eden, Scottsbluff, Firstview, Kersey, and others, along with the distinctive Cody Knife, identify the Cody Complex (Cordell and McBrinn 2016; Huckell and Judge 2007; Justice 2002; Kornfeld et al. 2010; Stanford 2005).

The Boca Negra Wash Site, A Folsom Bison Kill/Camp (ca. 12,170 - 10,600 cal B.P.)

First discovered in 1997, the Boca Negra Wash site is in the Middle Rio Grande Basin, just east of Petroglyph National Monument, along the eastern margins of the basalt flow emanating from

the Albuquerque Volcanoes. Today the area is a desert grassland with scattered junipers, developed primarily on eolian sand overlying basalt. The site was excavated during a University of New Mexico (UNM) field school from 2001 to 2004 (Holliday et al. 2006; Huckell et al. 2011). This site consists of two spatially discrete loci situated along a playa lake's southern and eastern margins. Excavations at these two loci (but primarily those at Locus B) produced over three hundred pieces of tooth enamel and forty-five occurrences of small splinters of large mammal bone, all representing *B. antiquus*. In addition, the two loci yielded over 2,300 flaked stone artifacts, consisting of broken Folsom points and Folsom point preforms, channel flakes, unifacially retouched flake tools, utilized flakes, and debitage. Unfortunately, no other remains of *B. antiquus* were recovered because the site was likely a campsite where the remains were processed, and the site was not buried deeply or rapidly, which would have helped in its preservation (Holliday et al. 2006).

In 2007 Patrick Mullen (2007) conducted an isotopic analysis on a sample of the enamel found at Boca Negra Wash and compared these data to populations of modern bison from two ranches in New Mexico. Mullen (2007) found that the $\delta^{13}\text{C}$ enamel values suggested that C_4 grasses dominated the *B. antiquus* diet. Mullen hypothesized that this pattern was due to "... 1) a strong unimodal summer precipitation regime; 2) a carbon dioxide-starved atmosphere; and 3) a north-south trending migration pattern for bison of the Boca Negra Wash site" (2007:42). He also found that the first molars (M1) of the modern bison produced more negative values than the other molars'; this is likely because M1s form while the bison calf is still *in utero*/nursing, thus capturing a fractionated $\delta^{13}\text{C}$ from the mother (Gadbury et al. 2000). Probable examples of M1s appear in the Boca Negra Wash samples, based on their more negative $\delta^{13}\text{C}$ values. Unfortunately, the degree of fragmentation made identifying individual teeth based on morphology impossible.

Judge (1973) determined that out of 15 Folsom sites and 14 Folsom localities he analyzed in the Central Rio Grande Valley, 73 percent occurred near a playa as their nearest water source, with streams taking up the remainder. In addition, 94 percent of Folsom sites were close to playas, even if a stream was closer to the site. Moreover, 80 percent of the sites are east or northeast of the playas, suggesting the Folsom people used these areas as traps for bison, camping downwind from the playas. If the Folsom people focused on hunting near lakes, that pattern might be observed in the $\delta^{18}\text{O}$ values.

The Water Canyon Site, a Cody Complex Bison Kill (ca. 10,720 – 10,400 cal B.P.)

The Water Canyon Site was first discovered in 2001 by a cultural resource management survey. The site lies in west-central New Mexico, to the southeast of La Jencia Basin, at the edge of a northeastern bajada of the Magdalena Mountains. The site is located on and named for Water Canyon (a tributary of the Rio Grande) (Holliday et al. 2019) and is dominated by desert scrubland (Dick-Peddie et al. 1993). The initial pollen studies for Water Canyon indicated that the site was vegetated with sagebrush, birch, and maple forest during the late Pleistocene/early Holocene (Dello-Russo et al. 2010). The Office of Contract Archaeology (OCA) at UNM conducted systematic test excavations at the site starting in 2008. The OCA uncovered faunal remains (primarily bison, likely *B. antiquus*), projectile points (thirteen diagnostic and fragmented points found on the surface and a diagnostic Eden point found *in situ*), hundreds of core flakes, biface thinning flakes, and other tools. Investigators also documented two bison bone bed loci; the lower bone bed was designated Locus 5 (containing the *in situ* Eden point), and the upper bone bed was designated Locus 1. Locus 1 is stratigraphically above Locus 5, which was discovered later to date to ~9,150 cal B.P., placing it in the Early Archaic period (Holliday et al. 2019). Locus 5 was carbon-dated to ~10,400 cal B.P., placing it in the Paleoindian period (Holliday et al. 2019). Therefore, to ensure results from the periods in question, all samples collected for this project came from Locus 5.

In contrast with Folsom, Judge (1973) found that streams made up the nearest water source out of five Cody sites in the Rio Grande Valley. Additionally, all five sites appeared near arroyo traps used for bison. So again, if the Cody people were focused on hunting bison near streams, that pattern may be observed in the $\delta^{18}\text{O}$ values.

Bison antiquus Ecology

B. antiquus are an ideal species for isotopic studies and paleoenvironmental reconstruction. *B. antiquus* ranged throughout New Mexico and North America during the Paleoindian period. It was the only megafaunal species to survive the mass extinction event at the end of the Ice Age in North America and is considered a direct ancestor to modern bison (*B. bison*). *B. antiquus* was ~ 15-25 percent larger than modern bison, with an average adult male weighing approximately 1,588 kg (Kues 2008). Modern observations of bison demonstrate that their diet consists of >90 percent grasses (Hoppe 2006; Hoppe et al. 2006). Like modern bison, *B. antiquus* was an obligate grazer, eating grasses throughout its range (Kues 2008). In addition, female bison can usually produce offspring at three years old, with one calf a year in the spring (Roe 1951). Thus, bison are an ideal candidate for stable isotope analysis since they are a direct proxy for the isotopic signal of the grasses at the time they lived, and their diets changed little throughout the time they lived in North America.

Study Area Environmental Setting

During the Paleoindian period (late Pleistocene to early Holocene), several significant climatic shifts happened across North America, particularly the U.S. Southwest. The Bølling-Allerød interstadial (~14,000 – 12,900 cal B.P.) brought warmer, drier weather to the Southwest and a shift in precipitation patterns characterized by wetter winters (Asmerom et al. 2010; Polyak et al. 2012, 2004). However, by the Younger Dryas, precipitation patterns shifted again, favoring rainier summers; (Ballenger et al. 2011; Cordell and McBrinn 2016; Feng et al. 2014; Polyak et al. 2012,

2004). By this time, *B. antiquus* was the only remaining megafaunal species left in North America (Kues 2008). By the early Holocene, the current monsoonal rainfall pattern for the southwest became established (Ballenger et al. 2011; Cordell and McBrinn 2016; Polyak et al. 2012, 2004); additionally, *B. bison* replaced *B. antiquus* (Kues 2008). Oxygen isotopic data shows that during the Younger Dryas, tropical or subtropical summer storms from the southeast were most likely the source of the precipitation in the Southwest, this being the beginning of the monsoonal weather patterns found in parts of the region today (Connin et al. 1998; Cotton et al. 2016; Paruelo and Lauenroth 1996). The isotopic data correlates with studies of speleothems in caves in New Mexico, indicating a shift to wetter conditions during the Younger Dryas (Asmerom et al. 2010; Polyak et al. 2012, 2004).

The impact of the Younger Dryas across the Southwest is a debated topic within archaeology (Ballenger et al. 2011). Being a millennium-long return to Ice Age-like temperature at the end of the Pleistocene, the Younger Dryas should favor C_3 plants across North America, including the U.S. Southwest. However, local environmental factors in specific areas may confound this pattern. Therefore, localized climate proxy records are essential for shaping our climate models in various locations at different periods. Previous research suggests that during the Late Glacial and the Younger Dryas, C_4 grass species were distributed across the Southwest (Cotton et al. 2016). The abundance of C_4 grasses during the Younger Dryas appears to be due to high summer precipitation (Connin et al. 1998; Cotton et al. 2016; Paruelo and Lauenroth 1996; Polyak et al. 2012, 2004).

Less studied than the Younger Dryas is the early Holocene. Multiple speleothems collected from New Mexican caves attest to local drying trends beginning in the early Holocene (Asmerom et al. 2010; Polyak et al. 2012, 2004). Palaeobotanical data from packrat middens also support this observation, demonstrating that Chihuahuan and the Sonoran Desert plant communities expanded

northward during the early Holocene, while alpine species became less frequent in the north, replaced with piñon-juniper woodlands (Betancourt 1990; Van Devender 1990). The drier conditions that began during this period characterize the Southwest's climate today (Dick-Peddie et al. 1993). Nevertheless, the Southwest is not a monolithic environment, particularly New Mexico. On the contrary, the state's boundaries cross several different environments, from alpine ecosystems in the northern parts of the state to xeric ecosystems in the south (Dick-Peddie et al. 1993). To control for these vast geographic variations in climate, I will focus on sites near the Rio Grande Valley, which encompasses characteristics of the Colorado Plateau and the Chihuahuan Desert (the Boca Negra Wash Site), and the Chihuahuan Desert (the Water Canyon Site).

The Boca Negra Wash Site is located within the Rio Grande Valley in a transitional area between the Chihuahuan Desert and the Colorado Plateau. The specific area around Boca Negra Wash is poorly studied regarding paleoenvironmental reconstructions, but nearby packrat middens suggest that during the Younger Dryas, the area was vegetated with forbs, grasses, juniper, and sagebrush (Betancourt 1990). Today, the site's landscape is characterized as a Plains-Mesa Sand Scrub environment dominated by sand sagebrush, alkali sacaton, and several species of grama grass (Dick-Peddie et al. 1993). On the Colorado Plateau, there is limited evidence of C₄ species in packrat middens or from isotopic studies of grazing animal diets, suggesting that during the Younger Dryas, this area was not receiving the summer rains (Connin et al. 1998). However, specifically at the Boca Negra Wash Site, stable carbon isotope data demonstrate that C₄ grasses dominated the diet of the bison associated with the site (Mullen 2007).

The Water Canyon Site is in the Chihuahuan Desert ecoregion. Yucca, scrub mesquite, juniper, and various grasses and forbs dominate the flats of this desert grassland (a vegetation community referred to as Chihuahuan Desert Scrub) (Dick-Peddie et al. 1993; Van Devender 1990).

According to packrat midden records, during the early Holocene, summer temperatures would have been approaching what we see today, and precipitation during the winter would have been greater than today (a 60 – 70 percent increase), the extra moisture supporting oak-juniper woodland in the area (Van Devender 1990). The early Holocene reflects a transition between the environment of the Younger Dryas and what we see today.

Isotopes and Isotopic Analyses in Archaeology

An isotope is a variant of an element that contains the same number of protons but a different number of neutrons (Sharp 2017). Archaeologists have been utilizing isotopes since carbon dating was introduced in the 1950s (Conroy 2005; Cordell and McBrinn 2016). Radiocarbon dating involves the decay of an unstable, radioactive ^{14}C back into a stable ^{14}N . However, not all isotopes are radioactive. Some isotopes are stable and are absorbed in the body at different rates based on what an animal eats/drinks (Asevedo et al. 2021; Cerling et al. 1997, 2015; Emery and Kennedy Thornton 2008; Hoppe 2006, 2006, 2004; Hoppe et al. 2006; Kristiansen et al. 2017; Millard et al. 2013; Mullen 2007; Sharp 2017). Reconstructions of past environments typically utilize isotopes of carbon, oxygen, and nitrogen found in plant and faunal remains (Asevedo et al. 2021; Cerling et al. 1997, 2015; Emery and Kennedy Thornton 2008; Hoppe 2006, 2004; Hoppe et al. 2005, 2006; Millard et al. 2013; Mullen 2007; Sharp 2017). This paper focuses on carbon and oxygen isotope analyses (nitrogen will not be analyzed due to cost and the nature of this study).

Carbon

Carbon exists in two stable forms in nature (^{12}C and ^{13}C). Carbon isotope ratios can provide paleoenvironmental proxies because plants absorb carbon isotopes (via CO_2) at different rates based on a plant's photosynthetic pathway (Asevedo et al. 2021; Emery and Kennedy Thornton 2008; Sharp 2017). C_3 and C_4 plants evolved different photosynthetic pathways, leaving different signatures when measuring their carbon (Asevedo et al. 2021; Sharp 2017). CAM (crassulacean acid

metabolism) is another photosynthetic pathway plants evolved (Sharp 2017), but bison do not feed on CAM plants (Hoppe 2006; Hoppe et al. 2006; Roe 1951).

Typically, the $\delta^{13}\text{C}$ range for C_3 plants is -33‰ to -23‰, while C_4 plants range from -16‰ to -9‰ (Asevedo et al. 2021; Hoppe 2004; Sharp 2017). C_3 plants (e.g., sunflower, tobacco, potatoes) are most common and do not account for evaporation when photosynthesizing, so they do not filter the heavier ^{13}C from the environment leading to C_3 plants having lower $\delta^{13}\text{C}$ values when compared to C_4 plants (Asevedo et al. 2021; Sharp 2017). In addition, C_3 grasses are usually found at high elevations and high latitudes, associated with cool-growing seasons (Asevedo et al. 2021). On the other hand, C_4 plants (e.g., corn, switchgrass, sugarcane) are adapted for arid, high-luminosity environments, meaning that they must deal with evaporation during photosynthesis (Asevedo et al. 2021). To reduce the amount of water lost during photosynthesis, C_4 plants minimize how long their stomata are open, limiting water lost during photorespiration. In turn, this process filters the heavier ^{13}C leading to C_4 plants having higher $\delta^{13}\text{C}$ values when compared to C_3 plants (Asevedo et al. 2021; Sharp 2017). $\delta^{13}\text{C}$ values can also be affected by habitat. For example, C_3 plants from forested environments most often have a $\delta^{13}\text{C}$ value below -30‰, but C_3 plants in more open grassland/savanna settings have $\delta^{13}\text{C}$ values of -23‰ to -22‰ (Asevedo et al. 2021). However, because of their photosynthetic pathway, C_4 plants have values of $\delta^{13}\text{C}$ that range from -17‰ to -9‰ with a mean value of -13‰. (Asevedo et al. 2021).

Herbivorous animals eat plants and incorporate carbon into their bodies. As that carbon is incorporated, $\delta^{13}\text{C}$ fractionates. This process means that the $\delta^{13}\text{C}$ ratio will be lower in the animal than in the plant itself. For example, domesticated and wild bovid tooth enamel has a fractionated $\delta^{13}\text{C}$ value of $+14.6 \pm 0.3\text{‰}$ relative to the carbon in the plants eaten (Hoppe et al. 2005, 2006). Modern animals with a pure C_3 diet have an average $\delta^{13}\text{C}$ value of approximately -13‰ (-24.6‰ to -

9.3‰), while pure C₄ plant-eaters have an average δ¹³C of approximately +1‰ (-2.5‰ to 5.5‰) in their enamel (Cerling et al. 2015; Hoppe 2004; Hoppe et al. 2006). The δ¹³C can be further differentiated based on the habitat/lifestyle of an animal. For example, C₃ grazers and animals that feed in open woodland habitats have δ¹³C values that overlap (-7‰ to -8‰ and -11‰ to -10‰). In comparison, mixed feeder species (animals that feed on C₃ and C₄ plants) have either δ¹³C values intermediate to C₃ and C₄ exclusive feeders (-12‰ to -15‰) or comparable to C₄ grazers (2‰ to -1‰) (Cerling et al. 2015; Hoppe 2004; Hoppe et al. 2006).

Oxygen

Oxygen exists in three naturally occurring stable isotopes (¹⁸O, ¹⁷O, and ¹⁶O). ¹⁷O is the rarest, whereas ¹⁶O is the most common oxygen isotope (Sharp 2017). ¹⁷O is not used in paleoenvironmental analyses (Sharp 2017); however, ¹⁸O to ¹⁶O ratios can provide proxy evidence for an animal's environment. δ¹⁸O can accumulate in animals based on the water they drink and the water present in their food (Hoppe et al. 2005). However, bison are obligate drinkers; thus, their δ¹⁸O reflects their consumption of meteoric water (Hoppe et al. 2005, 2006). Therefore, δ¹⁸O values in bison can reflect several different climatic variables.

Unlike stable carbon isotopes, there is no specific fractionation factor to determine an environment based on the oxygen isotope ratios. Instead, a range of factors can affect the value of ¹⁸O, including precipitation, temperature, altitude, latitude, and other factors (Asevedo et al. 2021; Sharp 2017). For example, the more positive the δ¹⁸O value, the warmer/drier the habitats or seasons tend to be (Asevedo et al. 2021). In addition, since ¹⁸O has a greater mass than ¹⁶O, it will precipitate out first. Therefore, areas with heavy rainfall will have less ¹⁸O in the water supply. Conversely, ¹⁸O ratios will be high in an arid environment since ¹⁸O is heavier than ¹⁶O, hence, harder to evaporate than ¹⁶O (the evapotranspiration effect)(Asevedo et al. 2021; Sharp 2017).

$\delta^{18}\text{O}$ values can also be affected by water sources and evapotranspiration. For instance, $\delta^{18}\text{O}$ in a lake can capture the average in a habitat because lakes retain water longer and are buffered against large fluctuations in $\delta^{18}\text{O}$. Conversely, a river will capture seasonal trends in $\delta^{18}\text{O}$ because the water flows through an area and is replaced often. Similarly, open grasslands, commonly dominated by C_4 grasses, have a high evapotranspiration effect, leading to grazing animals having the most enriched $\delta^{18}\text{O}$, whereas forested environments tend to have less of an evapotranspiration effect (Asevedo et al. 2021). Finally, $\delta^{18}\text{O}$ values are also affected by the extent of polar/continental ice sheets, with colder periods having less ^{18}O in the water cycle because more of it is locked away in ice due to its weight (Sharp 2017). Thus, the $\delta^{18}\text{O}$ value can help determine an environment but cannot directly infer an environment. Overall, carbon and oxygen isotopes from animal remains provide valuable paleoenvironmental proxy data.

Methods

The Office of Contract Archaeology (OCA) on the campus of UNM currently houses the Water Canyon site teeth used in this study. I obtained permission to use the teeth from Dr. Robert Dello-Russo, former OCA Director. When initially discovered, most of the teeth were *in situ* in the jaw, but the bones were poorly preserved, leading to their disarticulation. I identified 99 teeth from the bison remains; 17 were whole, including incisors, premolars, and molars, and 82 were fragmentary, with 27 of the fragments identifiable as incisors, premolars, or molars. I identified 17 molar samples large enough for bulk enamel isotopic analysis (five whole teeth and 12 fragments) from the collection, which exceeds the minimum number of samples needed to reconstruct an average paleoenvironment (Hoppe 2006; Hoppe et al. 2005).

I then prepared the 17 samples using the protocol described in Ventresca Miller et al. (2018). I first cleaned the teeth using a toothbrush. Next, I removed ~ 0.1 mm of enamel from each tooth across the lingual or buccal surface laterally with a small drill (Figure 2). Finally, the tooth was drilled

above a weighing paper to catch the powdered sample. The drill bit was cleaned after each use to prevent contamination. Each sample was then poured into a micro-centrifuge tube for storage until needed.



Figure 2: The surface of a bison tooth before and after its surface was drilled

I pretreated each sample with acetic acid by adding the acid to the samples and placing each one on an electric agitator. I then allowed the samples to sit for 10 minutes. I then placed the samples in a microcentrifuge for 2 minutes. Next, I removed the acid on top with a pipette and added 2 mL of ultrapure water. The sample was then placed in the microcentrifuge for 2 minutes (and I repeated this step three times). The samples were then permitted to dry. Next, the samples were washed with 3% hydrogen peroxide for 15 minutes and rinsed, followed by a wash of 0.1 M acetic acid for 15 minutes and rinsed. Finally, I weighed the samples in the Stable Isotope

Laboratory, Department of Earth and Planetary Sciences (EPS), UNM, using the method described by Spötl and Vennemann (2003).

Dr. Atudorei of the EPS department loaded the samples in 12 mL borosilicate exetainers, then flushed them with helium. Samples were reacted for 24 hours with H_3PO_4 at 50°C . The evolved CO_2 was measured by continuous flow Isotope Ratio Mass Spectrometry using a Gasbench device coupled to a Finnigan Mat Delta Plus Isotope Ratio Mass Spectrometer. Reproducibility was better than 0.15‰ for both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ based on repeats of a laboratory standard (Carrara Marble). The standards were calibrated versus NBS 19, for which the $\delta^{13}\text{C}$ is 1.95‰ and $\delta^{18}\text{O}$ is 2.2‰ . I present the isotopic ratios in the per mil (‰) notation $\delta^{13}\text{C}$ (or $\delta^{18}\text{O}$) = $([\text{R}_{\text{sample}}/\text{R}_{\text{PDB}}]-1) \times 1000$, where R_{sample} and R_{PDB} are the ratios $^{13}\text{C}/^{12}\text{C}$ (or $^{18}\text{O}/^{16}\text{O}$) in the sample and standard respectively, and the isotope reference standard is PDB. I removed one sample (sample 15) from the analysis due to contamination (Viorel Atudorei, personal communication 2021).

Results

Table 1 presents the values for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ at Water Canyon and an interpretation of diet (C_4 -grazers or mixed C_3/C_4 -grazers) based on the $\delta^{13}\text{C}$ value. This classification is based on Cerling et al.'s (2015) isotopic results from over 1,900 extant herbivorous mammals, mainly from 30 different national parks and reserves in eastern and central Africa, and supplemented with published material from several institutions housing remains with known provenance. Their results consist of 47% Bovidae, 8% Equidae, and 45% other African herbivores collected from tooth enamel supplemented with keratin or collagen-corrected values. Most samples from Bovidae were taken from M3 teeth (Thure Cerling, personal communication 2022).

Table 1: The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values for Water Canyon and interpreted diet based on the $\delta^{13}\text{C}$ value

| Sample # | Tooth Type | $\delta^{13}\text{C}\text{‰}$ | $\delta^{18}\text{O}\text{‰}$ | C_4 vs. C_3/C_4 Diet |
|----------|------------|-------------------------------|-------------------------------|---|
| 1 | M3 | -0.44 | -7.18 | C_4 |
| 2 | M3 | -2.63 | -7.91 | C_3/C_4 |
| 3 | Frag | -0.70 | -5.47 | C_4 |
| 4 | Frag | -1.07 | -6.64 | C_3/C_4 |
| 5 | Frag | -5.83 | -8.22 | C_3/C_4 |
| 6 | M3 | -2.78 | -8.40 | C_3/C_4 |
| 7 | Frag | -0.38 | -8.24 | C_4 |
| 8 | Frag | -1.40 | -7.09 | C_3/C_4 |
| 9 | Frag | 0.71 | -7.29 | C_4 |
| 10 | Frag | 0.01 | -6.25 | C_4 |
| 11 | Frag | 0.11 | -4.64 | C_4 |
| 12 | M3 | -1.69 | -8.07 | C_3/C_4 |
| 13 | Frag | -1.33 | -7.00 | C_3/C_4 |
| 14 | Frag | 0.07 | -4.49 | C_4 |
| 16 | Frag | -2.13 | -7.17 | C_3/C_4 |
| 17 | M3 | 0.24 | -6.67 | C_4 |

Herbivores with $\delta^{13}\text{C}$ values of -8‰ or lower are classified as C_3 -browsers, and herbivores with $\delta^{13}\text{C}$ values of -1‰ or higher are classified as C_4 -grazers. The herbivores that fall between those values are classified as C_3/C_4 mixed diets (Cerling et al. 2015). Herbivores with the C_3/C_4 mixed diet classification can be grazers, browsers, or both. Since bison are obligate grazers (Hoppe 2006; Hoppe et al. 2006; Roe 1951), I interpret the results below -1‰ as suggesting that bison are C_3/C_4 -grazers.

The bison at Water Canyon have a range of $-5.89\text{‰} - 0.71\text{‰}$ with an average of -1.20‰ for $\delta^{13}\text{C}$ and a range of $-8.40\text{‰} - -4.49\text{‰}$ with an average of -6.92‰ for $\delta^{18}\text{O}$. Therefore, based on the $\delta^{13}\text{C}$ values, the bison at Water Canyon are 50% C_4 -grazers and 50% mixed C_3/C_4 -grazers (Cerling et al. 2015). However, this interpretation includes Sample 5, which will be discussed further below.

Table 2 presents the range and average for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ at Water Canyon and the Boca Negra Wash site. Mullen (2007) reports a range of $-8.38\text{‰} - 1.12\text{‰}$ with an average of -1.89‰ for

$\delta^{13}\text{C}$ and a range of -10.47‰ - -0.60‰ with an average of -4.41‰ for $\delta^{18}\text{O}$ for the bison at Boca Negra Wash. The bison at Boca Negra Wash are 43% C_4 -grazers and 57% C_3/C_4 -grazers (Cerling et al. 2015). However, this interpretation includes five samples that will be discussed further below.

Table 2: The range and average for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values for bison at Water Canyon and Boca Negra Wash

| | Average | | Range | |
|------------------------|-----------------------|-----------------------|--------------------------------|----------------------------------|
| | $\delta^{13}\text{C}$ | $\delta^{18}\text{O}$ | $\delta^{13}\text{C}$ | $\delta^{18}\text{O}$ |
| Water Canyon | -1.20‰ | -6.92‰ | $-5.83\text{‰} - 0.71\text{‰}$ | $-8.40\text{‰} - -4.49\text{‰}$ |
| Boca Negra Wash | -1.89‰ | -4.41‰ | $-8.38\text{‰} - 1.12\text{‰}$ | $-10.47\text{‰} - -0.60\text{‰}$ |

A Mann-Whitney U indicates that the $\delta^{13}\text{C}$ values at both sites are comparable (Mann-Whitney $U = 202$, $z = 0.52$, $p = .5999$). However, the Mann-Whitney U for the $\delta^{18}\text{O}$ at both sites reveals a statistical difference (Mann-Whitney $U = 55.5$, $z = 4.0991$, $p = <.01$). Thus, the bison at both sites had a similar diet, but the water they obtained is different.

Figure 3 is a scatter plot showing the isotopic values for Water Canyon and Boca Negra Wash. A few things stand out from Figure 3. First, the $\delta^{13}\text{C}$ values for both sites are similar, while Water Canyon has more negative $\delta^{18}\text{O}$ values when compared to Boca Negra Wash on average. Second, Sample 5 from Water Canyon clusters with five samples from Boca Negra Wash with slightly more negative $\delta^{13}\text{C}$ values.

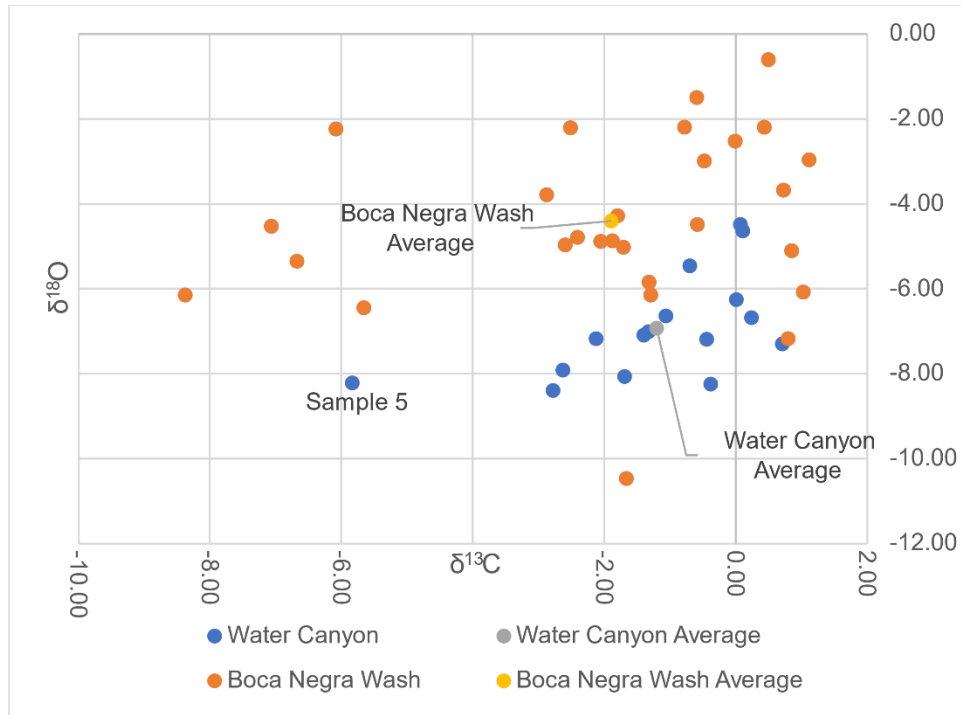


Figure 3: Isotopic analysis results comparing the bison at Water Canyon (blue) and Boca Negra Wash (orange) in ‰

The Boca Negra Wash analyses were conducted on fragmentary enamel samples, so individual teeth could not be identified precisely (Mullen 2007). This same problem occurred at Water Canyon, with several samples too fragmentary to identify a specific tooth type. Mullen (2007) proposed that the more negative values could be due to isotopically “lighter” M1 teeth being sampled. Mullen found that when he compared the Boca Negra Wash results against modern bison where the tooth’s identity was known, the isotopically “lighter” teeth were M1s.

Based on that observation, I further separated Boca Negra Wash into population A (those clustering near Sample 5 from Water Canyon; five teeth) and population B (the remaining 23 teeth) because population A has isotopically “light” $\delta^{13}\text{C}$ values matching a C_3/C_4 mixed diet (Cerling et al. 2015) or *in utero* M1 enamel formation (Gadbury et al. 2000; Mullen 2007). Furthermore, a Mann-Whitney U indicates that the $\delta^{13}\text{C}$ values for the two populations are statistically different (Mann-Whitney $U = 0$; $z = 3.419$, $p = <.01$).

Several factors can contribute to these results. These include (i) population A/Sample 5 calved at a different time than the rest of the herd, (ii) population A/Sample 5 grew up in a different area, or (iii) M1 teeth have a different $\delta^{13}\text{C}$ value due to the formation of the M1 *in utero* and when nursing as a calf. The first hypothesis is not likely since bison have a calving season once a year in the spring, where all the calves are born around the same time (Gadbury et al. 2000; Roe 1951). The second hypothesis is possible but unlikely since bison herds are family units (Roe 1951). However, Gadbury et al. (2000) have demonstrated that the M1 formation process can lead to negative $\delta^{13}\text{C}$ values compared to the rest of the molars, as calves obtain $\delta^{13}\text{C}$ from the mother's bloodstream (*in utero*) or milk (as a calf). Their results show a shift of 2-3‰ between the M1 and M3, which aligns with the low end of the $\delta^{13}\text{C}$ values from Water Canyon and Boca Negra Wash (see Table 1 and Figure 3) and agrees with Mullen's (2007) results with modern bison teeth. Therefore, I favor the third hypothesis over the two other hypotheses as being more parsimonious. In addition, there are possibly more bison remains at Water Canyon (Dello-Russo et al. 2010; Holliday et al. 2019); thus, finding identifiable M1 teeth and comparing their $\delta^{13}\text{C}$ values to these results may resolve this issue.

Furthermore, removing Sample 5 and population A from Water Canyon and Boca Negra Wash leads to a different, and I feel more accurate, assessment of the dietary habits at both sites. Without Sample 5, the bison at Water Canyon are 53% C_4 -grazers and 47% mixed C_3/C_4 -grazers (Cerling et al. 2015). Moreover, removing population A, the bison at Boca Negra Wash are 52% C_4 -grazers and 48% C_3/C_4 -grazers (Cerling et al. 2015). Thus, the two populations are remarkably similar based on their $\delta^{13}\text{C}$ values but differ in their $\delta^{18}\text{O}$ values. These results also suggest that the bison, although slightly favoring C_4 grasses, were not obligate C_4 -grazers and would supplement their diet with C_3 grasses if the opportunity arose.

Conclusion

The $\delta^{13}\text{C}$ results showed that the bison from both sites had a remarkably similar diet, with the Water Canyon bison being 53% C_4 -grazers and 47% mixed C_3/C_4 -grazers and the Boca Negra Wash bison being 52% C_4 -grazers and 48% C_3/C_4 -grazers; this leads to acceptance of the null hypothesis for C_3 and C_4 grasses. In addition, the $\delta^{18}\text{O}$ results show that the bison from both sites obtained their water from a different source, with the bison at Water Canyon having a more negative value of $\delta^{18}\text{O}$, leading to a rejection of the $\delta^{18}\text{O}$ null hypothesis. Thus, I do not see a change in the consumption of grasses from the Younger Dryas to the Early Holocene.

Although there is no significant difference between the $\delta^{13}\text{C}$ results, there is a difference in $\delta^{18}\text{O}$. A few scenarios can explain the change in $\delta^{18}\text{O}$ without a change in $\delta^{13}\text{C}$. First, the bison may have migrated through the Rio Grande Valley during the early Paleoindian Period to avoid the winter in what is now north-central New Mexico. If they spent the winter in a warmer, southern location and moved up the Rio Grande Valley during the summer, this could explain the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ results for Boca Negra Wash. However, the more negative $\delta^{18}\text{O}$ values in the Water Canyon bison suggest that the population did not migrate south, staying in a cooler, northern climate during the Early Holocene (Asevedo et al. 2021).

Alternatively, the observations from Judge (1973) could also explain the different $\delta^{18}\text{O}$ signals. Judge (1973:193–195, 245) found that Folsom hunted near lakes, whereas Cody hunted near streams and rivers. Consequently, bison populations drinking mainly from lakes instead of rivers would have more positive $\delta^{18}\text{O}$ values (Asevedo et al. 2021). Therefore, the Water Canyon and Boca Negra Wash bison's $\delta^{18}\text{O}$ could signal the primary water source the bison were using. Another factor that might explain the difference in $\delta^{18}\text{O}$ at the two sites is that during the Younger Dryas, there was higher precipitation during the summer (Connin et al. 1998; Cotton et al. 2016; Paruelo and

Lauenroth 1996; Polyak et al. 2012, 2004). Higher precipitation leads to more positive $\delta^{18}\text{O}$ values in the water (Sharp 2017), which may have impacted the $\delta^{18}\text{O}$ values in the bison at Boca Negra Wash.

Overall, the $\delta^{13}\text{C}$ results in this study demonstrate a mix of C_3 and C_4 grasses during the Younger Dryas and Early Holocene in north-central New Mexico along the Rio Grande Valley, with the bison population slightly preferring C_4 grasses. These results indicate a similar habitat for north-central New Mexico along the Rio Grande Valley from 12,170 – 10,400 cal B.P. Unfortunately, the scope of this research cannot resolve which of the above factors explains the difference in $\delta^{18}\text{O}$ at either site. Further research into this subject is needed. Specifically, this issue could be resolved by sampling sites from the same periods (Folsom and Cody). Continuing to find a difference in hunting patterns between Folsom and Cody (Judge 1973) and continued evidence of more positive $\delta^{18}\text{O}$ at Folsom sites compared to Cody sites would suggest concordance between the isotopic and archaeological data. Future isotopic analysis of Paleoindian material should keep this observation in mind.

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Appendix

The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values from Water Canyon

| Sample # | FS Number | Project | LA Number | weight (mg) | $\delta^{13}\text{C}\text{‰}$ | $\delta^{18}\text{O}\text{‰}$ | Tooth Type | Comments |
|----------|-----------|------------------------|-----------|-------------|-------------------------------|-------------------------------|------------|----------------------------------|
| 1 | 5029 | 41.901 | 134764 | 6.468 | -0.44 | -7.18 | M3 | |
| 2 | 5121 | WC field school | 134764 | 6.212 | -2.63 | -7.91 | M3 | |
| 3 | 5171 | UNM field school | 134764 | 6.561 | -0.70 | -5.47 | Frag | |
| 4 | 5140 | WC field school | 134764 | 6.114 | -1.07 | -6.64 | Frag | |
| 5 | 5080 | 41.901 | 134764 | 6.336 | -5.83 | -8.22 | Frag | |
| 6 | 5140 | WC field school | 134764 | 6.242 | -2.78 | -8.40 | M3 | |
| 7 | 5102 | 41.901 | 134764 | 6.428 | -0.38 | -8.24 | Frag | |
| 8 | 5118 | 41.901 | 134764 | 6.994 | -1.40 | -7.09 | Frag | |
| 9 | 5125 | WC field school/41.901 | 134764 | 6.178 | 0.71 | -7.29 | Frag | |
| 10 | 5037 | 41.901 | 134764 | 6.45 | 0.01 | -6.25 | Frag | |
| 11 | 5055 | WC field school | 134764 | 6.499 | 0.11 | -4.64 | Frag | |
| 12 | 5013 | 41.901 | 134764 | 6.896 | -1.69 | -8.07 | M3 | |
| 13 | 5145 | WC field school | 134764 | 6.075 | -1.33 | -7.00 | Frag | |
| 14 | 5148 | WC field school | 134764 | 6.261 | 0.07 | -4.49 | Frag | |
| 15 | 5151 | WC field school | 134764 | 6.575 | -1.46 | -5.47 | Frag | Removed because of contamination |
| 16 | 1198 | WC 2012 | 134764 | 5.184 | -2.13 | -7.17 | Frag | |
| 17 | 1276 | WC 2012 | 134764 | 6.89 | 0.24 | -6.67 | M3 | |