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The use of stable isotope ratio analysis to distinguish multiple prey kill events from mass kill events

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Abstract

Archaeologists working with prey animal bonebeds are interested in determining whether the animals were obtained through a single, mass kill event or instead accumulated over time from multiple hunting events. This is often difficult to determine. The author investigated the use of stable isotope ratio analysis to distinguish accumulations of individuals derived from multiple populations from mass kills of individuals from a single population. Carbon, oxygen and strontium stable isotope ratios were measured in tooth enamel from modern pronghorn (*Antilocapra americana*) with known mortality circumstances. These ratios were then analyzed using basic statistical methods as well as a scaled distance technique that permits integrated analysis of multiple isotopes and multiple samples, and a bootstrap subsampling approach was used to quantify differences among populations. It appears that, in some circumstances, stable isotope analysis can contribute to distinguishing bonebeds originating as accumulations of individuals derived from multiple populations from mass kills of individuals from a single population. Three-element isotope ratio distance measures provide the best isotopic indicator of pronghorn bonebed population origins, especially when bootstrap subsampling is used to compare to sites of known pronghorn population composition.
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1. Introduction

There is abundant archaeological evidence for prehistoric hunting of bison, pronghorn and other game in western North America (see Frison, 1986, 1991, 2004 for reviews of this evidence within the Northwestern Plains area). Unfortunately, it is difficult to use this evidence to investigate questions of optimal subsistence strategy and social aggregation because it is often uncertain whether particular archaeological assemblages resulted from mass kill events or accumulations of many kill episodes. Archaeologists confronted with substantial prehistoric bonebeds currently use a number of criteria for assessing whether a particular archaeological faunal assemblage is the result of a single mass kill or the accumulation of multiple kill events (e.g., Davis et al., 2000; Frison, 2000; Hill, 2002; Todd et al., 1992, 2001; Widga, 2004). Lubinski (1997: 124–206, 2000) provides a detailed discussion of many of these criteria as they relate to identification of a pronghorn mass kill. He separates the criteria into three categories: evidence for human-caused mortality (e.g., association with projectile points or presence of cut marks), evidence for a single depositional episode (e.g., stratigraphic association), and evidence for a single mortality event. This study evaluates and further develops a new technique using stable isotope analysis to address the last criterion.

The technique is based upon a simple idea: accumulations of individuals from multiple populations are likely to have more isotopic variability than an equal number of individuals from a single population. Specifically, if isotopic variation of specimens from a particular species in an archaeological assemblage exceeds the range of variation expected within a single population, then multiple kill events are likely to have occurred. If the range of variation is approximately the same as in a single

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population then there is no evidence for multiple population accumulation and a single mass kill is more probable (although multiple kills of animals from the same herd over a short time period is also possible). Inter-population differences in isotope ratios may be due to geographically- or temporally-based climatic differences (such as temperature and humidity change), geological differences (such as differences in the age of underlying geologic formations), or behavioral differences (such as differences in migration frequency or ranges). In some circumstances, there may be little isotopic difference among populations, which would lead to mis-identifying a multi-population accumulation as a single mass kill. Therefore it is important to assess the isotopic differences among samples of known population composition prior to assessing unknown samples. This approach, which was independently developed by Hoppe (2004) and Widga (2004), will be investigated using tooth enamel from modern pronghorn (*Antilocapra americana*).

Hoppe (2004) assessed the carbon, oxygen and strontium isotope ratio variation of two paleontological mammoth bonebeds thought to represent catastrophic herd mortality, and decided that only carbon isotopes showed sufficient inter-herd variation to confidently distinguish between herds. Hoppe suggests that oxygen and strontium isotope ratios in local water and geology, respectively, may have been so variable that this variability overwhelmed mammoth herd behavior-related variability. She then compared the carbon isotope variation in the paleontological mass mortality bonebeds to the variation within the Blackwater Draw, Miami and Dent mammoth archaeological assemblages. Her isotope ratio analysis suggests that all three assemblages are composed of mixtures of individuals from multiple herds (Hoppe, 2004: 139) and therefore likely represent multiple kill events within each site. She also noted that strontium isotope ratios of the Blackwater Draw mammoths indicate that there were two differing mammoth migration patterns: east to the Miami, Texas, area and west to the Rocky Mountain area (Hoppe, 2004: 142).

Widga (2004: 38–41), as part of a larger analysis of Early Archaic bison procurement, compared the carbon isotope variation within bison from several components of the Spring Creek and Logan Creek sites in Nebraska to that of bison from Paleoindian mass kill components at the Agate Basin site and the multiple-kill Plains Village sites of Helb and Talking Crow. He found that Spring Creek and at least one Logan Creek component appear to represent single-episode procurement events. Widga (2004: 39, 41) acknowledges that the comparative samples from differing time periods are of uncertain comparative value, and that a number of untested assumptions are included in his isotopic analysis. Nevertheless, a qualitative assessment of the range of variation suggests that bison mass kill sites may have substantially less carbon isotope variation than do multiple kill sites (Widga, 2004: 41).

These are both quite interesting studies which introduce a technique that promises to improve our understanding of prehistoric hunting practices. The study reported here further analyzes and develops isotopic characterization of bonebeds along several lines. Both Hoppe and Widga used ancient animal remains thought to result from known mortality events to characterize unknown mortality events. This was necessary because the animals used in those studies (mammoth and bison) no longer roam wild, so no modern sample set is available. Although partially circumscribed by fences and other artificial structures, pronghorn remain wild within Wyoming and therefore serve as a good test case for the Hoppe-Widga isotopic variation technique. My study also expands upon previous work by introducing a scaling and distance approach that simultaneously incorporates isotopic information from multiple elements, and a bootstrap technique that provides quantitative comparisons of isotopic variability between locations.

2. Relevant isotope chemistry

A very brief introduction to characteristics of carbon, oxygen and strontium isotope ratios in animal tissues is presented below. More detailed information may be found in a number of general references (e.g., Ehleringer and Rundel, 1989; Faure and Mensing, 2005; Katzenberg, 2000) and in the specific references cited below.

Carbon isotope ratios are particularly important in the analysis of diet. There are two different photosynthetic pathways commonly utilized by plants (termed the C3 and C4 pathways), each of which has unique fractionation mechanisms that produce distinguishable carbon isotope ratios. The carbon isotope ratios in C3 plants range from about −20 to −35 per mil (‰) while in C4 plants the ratio ranges from −9 to −14‰ (Ehleringer and Rundel, 1989). A third pathway, termed CAM, produces a wide range of carbon isotopes (−11 to −31‰) but is primarily used by cacti, which are unlikely to constitute a significant pronghorn food. The pathways are well understood; most plants use the C3 pathway, although C4 and CAM plants are abundant in warm, arid, and semiarid environments (Blankenship, 2002: 171–203; Boutton, 1991; Farquhar et al., 1989). The carbon isotope ratio in pronghorn enamel is determined by the proportions of C3, C4 and CAM plants consumed during the period of enamel formation.

Oxygen isotope ratios in mammal tissues are derived from body water, which includes drinking water, water obtained directly from food, and metabolic water produced by oxidation of food (Koch, 1998). Heavier isotopes require more energy to evaporate, and less energy to condensate, than do light isotopes, so water vapor is depleted in heavy isotopes as compared to its source, and becomes even more depleted with subsequent rainouts. Each rainout event is caused by temperature reduction, and the number of previous rainout events is determined by geographical location as well as climatic factors. In arid environments, water may be less depleted than otherwise expected due to evaporative enrichment (Higgins and MacFadden, 2004; Levin et al., 2006). Oxygen isotope ratios in meteoric water are therefore governed by climate and geography (Clark and Fritz, 1997). Mammals maintain a nearly constant body temperature, so there is a consistent, predictable relationship between source water oxygen ratios and those in body water, with body water showing a more positive ratio than its source (Koch et al., 1994). As discussed below, pronghorn can

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