COMPASS

The Student Anthropology Journal of Alberta

Volume 1, Number 1, October 2017

Compass aims to navigate its readers through the four exciting fields of Anthropology. Our student journal highlights the exemplary level of academic research in Anthropology at the University of Alberta and elsewhere

Compass is published annually as collaboration between the Association of Graduate Anthropology Students (AGAS) and the Department of Anthropology at the University of Alberta. Formerly *Diversipede,* our student-run publication allows undergraduate and graduate students to share their work and ideas, creating a platform for discussion and knowledge. Submissions consist of original ongoing research, reviews of current anthropological issues, and anything related to an anthropological interest form any of the sub-fields. https://journals.library.ualberta.ca/compass

Editors in Chief: *Katherine Bishop* (PhD Candidate)
Victoria van der Haas (PhD Candidate)

Copy Editors: *J. Jeffrey Werner* (PhD Candidate)
Stephanie Brown (MA)

Reviewing Staff: *Anna Bettini* (PhD Student)
Jennifer Hallson (MA)
Karl Berendt (MA Student)
Kira McLachlin (MA Student)
Christina Poletto (MA Student)
Dafna Rachok (MA Student)

Logo Design: *Amy Reedman* (MA Student)

Faculty Liaison: *Marko Zivkovic* (PhD, Associate Professor)

Administrative Support: *Sonya Betz* (Digital Initiatives Projects Librarian)

Associate Partners: Association of Graduate Anthropology Students (AGAS)
Richard Frucht Memorial Lecture Series and Student Conference
Department of Anthropology, University of Alberta

Please send all editorial correspondence to compass@ualberta.ca
or to the following mailing address:

COMPASS Student Journal
c/o Association for Graduate
Anthropology Students (AGAS)
13-15 HM Tory Building
University of Alberta
Edmonton, Alberta
T6G2H4

Compass (ISSN: 2371-6096)

The Creative Commons-Attribution License 4.0 International applies to all works published by Compass. Authors will retain copyright of the work. This license lets other distribute, remix, tweak, and build upon work published in Compass, even commercially, as long as there is an acknowledgement of the work’s authorship and initial publication in this journal.

Powered by OJS | Open Journal Systems
PKP | Public Knowledge Project

Attribution CC BY

COMPASS: The Student Anthropology Journal of Alberta

A Note from the Editors in Chief,

Roughly one year ago Katherine came to Victoria with a proposition to create a student journal. We ended up discussing publishing opportunities and went through our previous experiences. While completing her degrees at Ontario Universities, Katherine was given the opportunity to work on two student journals. She had seen the benefits of students working with the publishing process in a low-stakes environment. Coming from a Dutch University, Victoria never had the opportunity to work with a student journal as it simply was not a practice there, but felt the need and desire to do so. Despite our different backgrounds we both enthusiastically agreed that a student journal would afford students chances to get involved and become better writers.

We set out to create a platform that fosters a less stressful and more hands-on publishing environment for everyone. Although our department already had an Anthropology Journal (Diversipede), it was not well known and all of the previous staff had since graduated. We wanted to give the journal a makeover to be inclusive to all members of our department, bring the journal into an open-access forum to reach a larger audience, and format the process to allow more students to get involved. After months of working with our (at that time) small team of volunteers and library liaison, we had a website, a logo, and a growing interest in publishing our first issue. More volunteers came on board and after months of reviews, copyedits, and formatting later, we are proud to introduce our first issue. We sincerely thank all those who helped bring this issue to fruition, and hope that this is the first of many.

Although this is the "Anthropology Journal of Alberta", we encourage any student to get involved and welcome any who are interested in submitting their work or becoming reviewers. We have paired with Library Services to provide hands-on training for reviewers to learn the ins and outs of the processes and expectations. If you are at a University that does not yet have a student journal, and are similarly interested in creating one, we are more than happy to discuss our experiences with you and provide some tips that worked for us.

We look forward to sharing our first issue and hope to provide possibilities and support for anthropology students. Please consider submitting your own research to COMPASS and reaching the audience it deserves.

Sincerely,

Katherine G. Bishop and Victoria M. van der Haas
(*PhD Candidates, University of Alberta*)

COMPASS: The Student Anthropology Journal of Alberta

IN THIS ISSUE

ARTICLES

Identification of macrofossils within stone tools

A possibility for tracing the source of artifacts?

by Timothy E. Allan and Matthew Bolton

This paper discusses the application of malacological identification of macrofossils in stone tools. A macroscopically distinct toolstone utilized by prehistoric peoples, reported widely in archaeological consulting literature across central and southern Alberta (Meyer *et al.* 2007; de Mille 2009; Bohach 2010; Porter 2014), features fossilized root traces and occasional large fossil shells. These fossils can be identified, and correlated with temporal and geologic formations indicative of the environments within which the taxa occurred. Artifacts with fossils morphologically coherent with *Hydrobia*, *Lioplacodes*, and *Viviparus* spp. are identified in stone artifacts analyzed in this paper. These taxa are consistent with depositional environments of Paleocene period Paskapoo Formation sedimentary rocks, particularly, as identified at the Blindman-Red Deer River confluence and Joffre roadcut paleontological localities (Hoffman and Stockey 2011). In this paper we explore how the identification of these fossils offer clues to the procurement areas which were sought out by prehistoric toolmakers. We do not suggest that all Red Deer Mudstone is from these localities, though the fossil molluscs presented so far do not refute this conclusion, but we do suggest that identifying large fossil shells can be a critical diagnostic tool for identifying the geologic origin of artifacts.

Recent decades have seen a surge in papers published on “archaeological sourcing,” or the linking of archaeological materials to their geologic origin to draw inferences on mobility and procurement. These studies are often valuable in identifying systems of long distance trade and mobility patterns by identifying sources of rock made to construct stone tools and debris. Shackley (2008) reports nearly 35 papers published in *Archaeometry* on archaeometric analysis of lithic materials between 2000 and 2007 alone. Systematic and conclusive analysis of stone tool materials and their suspected sources has great potential to reveal information about prehistoric mobility and resource selection. However, sourcing studies often rely upon intensive, expensive, and destructive methodology in order to provide conclusive results. Methods such as petrographic analysis (Fenton and Ives 1984; Kristensen *et al.* 2016a, 2016b), inductively coupled plasma mass spectrometry (ICP-MS) (ten Bruggencate *et al.* 2016; MacKay *et al.* 2013), and instrumental neutron activation analysis (INAA) (Kendall and Macdonald 2015) require the destruction or alteration of artifacts. In amorphous cryptocrystalline silicates, such as chert or flint, research has been conducted into microfossils within the matrix of the artifacts to distinguish chert varieties (Biittner and Jamieson 2008). However, this analysis also required the invasive alteration of material culture, such as destroying artifacts for geochemical analysis or thin sectioning. In most cases, archaeologists and curators look for non-destructive methods of

---

Timothy E. Allan is a Master’s student at the University of British Columbia (Department of Anthropology 6303 NW Marine Drive, Vancouver, BC V6T 1A1 [t.allan@alumni.ubc.ca]). **Matthew Bolton** is a researcher in Quaternary Environments at the Royal Alberta Museum, Alberta Canada.

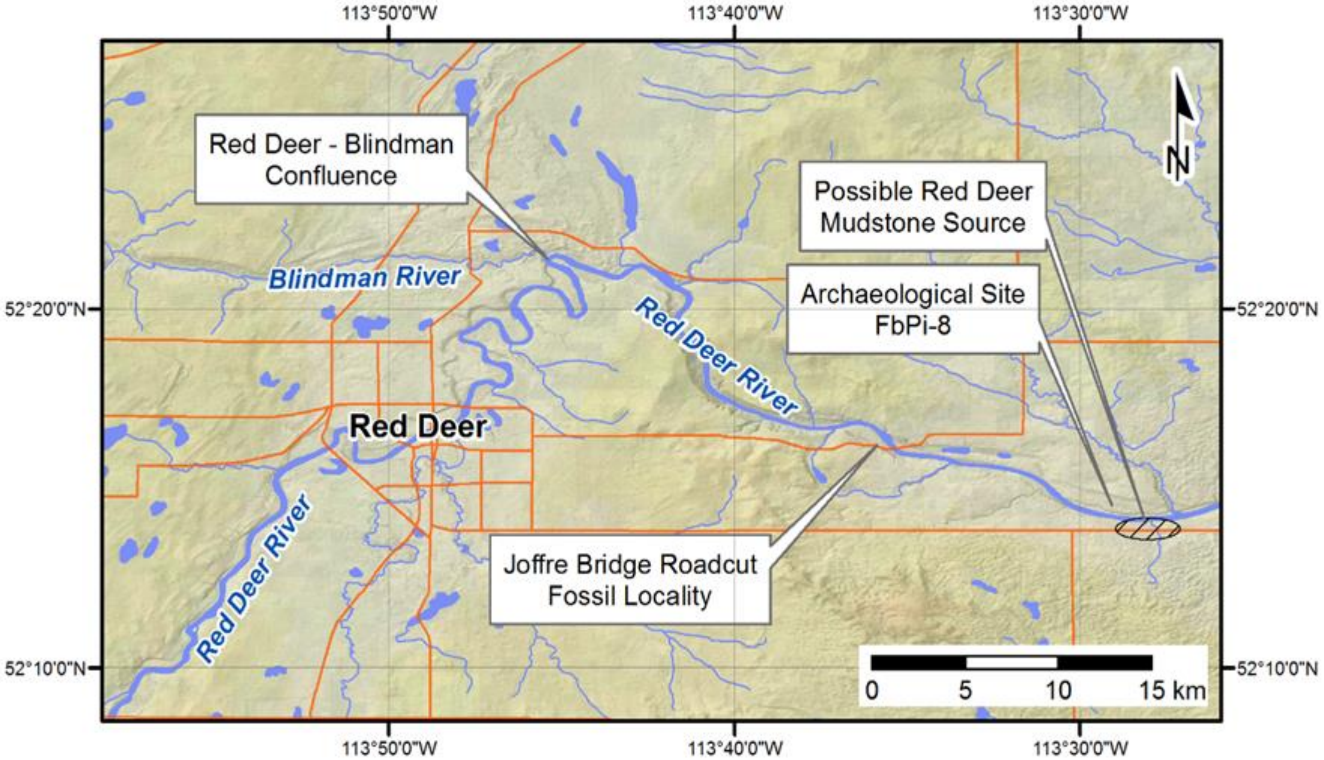


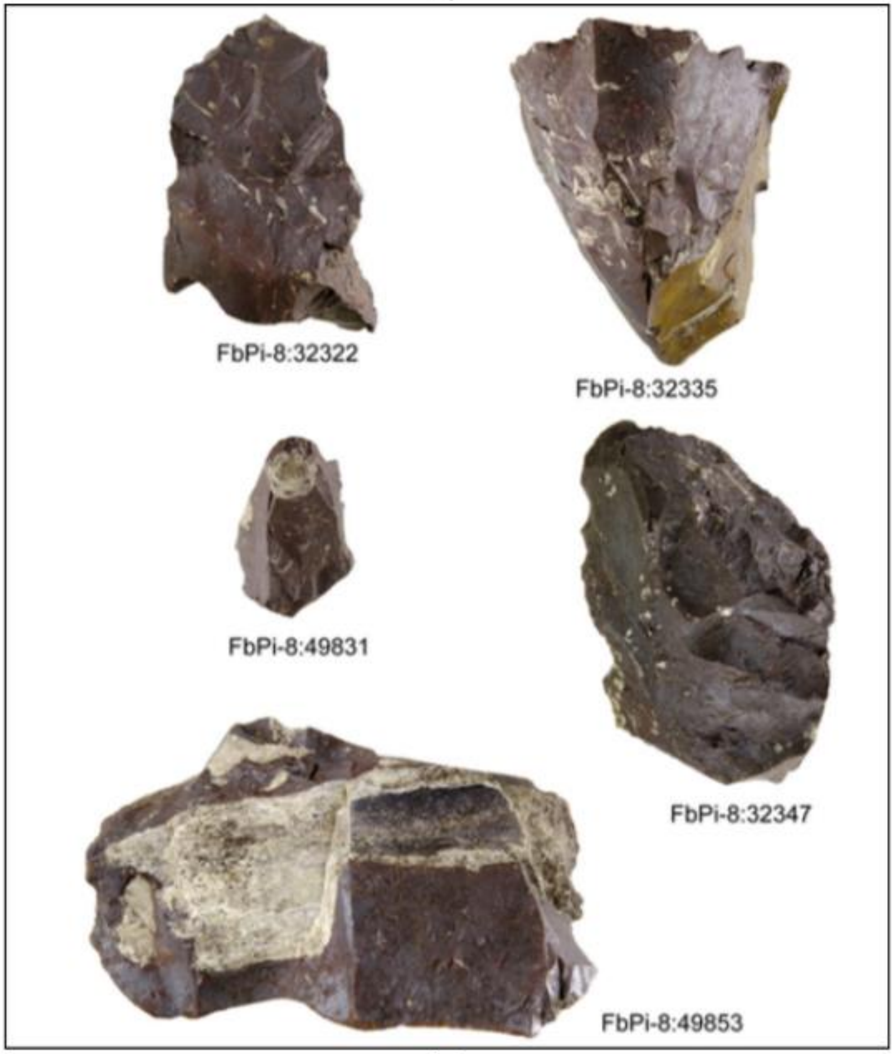
Figure 1. Map of Red Deer, Alberta and surrounding area; locales described in this paper are highlighted. Note: site locations have been generalized.

archaeological sourcing to preserve the integrity of artifacts for posterity or cultural significance, and maintain potential for museum display. Macrofossils, such as mollusc shells or plant remains, are not uncommon in archaeological hand samples. When macrofossils are visible, they can often be identified when viewed with a hand lens or low-powered microscope. This paper will present a case for the presence of macrofossils within stone tools from Central Alberta, and discuss the potential for their origin in that region's Paskapoo Formation sedimentary rocks. Although only a few examples are presented, this article is intended to show the potential of fossil identification in establishing the provenance of fossiliferous stone tools. At present, the authors know of no published works that have provenanced archaeological material using the identification of large fossils within artifacts.

Paskapoo 'Chert' or Red Deer Mudstone?

Consultants (Bohach 2010; de Mille 2009; Meyer *et al.* 2007; Porter 2014) have described a fine grained, dark red to tan mudstone, commonly with black patina and white macrofossil inclusions or 'bog material' as 'Paskapoo Chert' and 'Red Deer Mudstone' across central Alberta. We have reviewed these descriptions, both in the literature and of artifacts discussed in this paper. Based on our observations of museum specimens, this material is a fine to medium grained siltstone, rather than an amorphous cryptocrystalline silica such as chert. We suggest that the term "Red Deer Mudstone" is a better representation of the material described in this paper over "Paskapoo Chert", since the latter does not caption its true mineralogical properties so far observed.

a)



b)

Figure 2a. Discarded heat treated cobble from FbPi-8, arrows pointing to fossil vertebrates.
Figure 2b. Prepared cores from FbPi08. Adapted from Porter (2014).

Fossil Content, Geological Origins and Heat Treatment

This material has been commonly identified in reports by Meyer *et al.* (2007), de Mille (2009), Bohach (2010), and Porter (2014), as having fossil inclusions of plants and gastropods visible in hand samples. Porter (2014) and Bohach (2010) suspect this material was procured and heat treated at the archaeological site FbPi-8 (fig. 1), on a high fluvial terrace of the Red Deer River. Heat treatment probably improved the working characteristics of the material, turned it a dark red to tan colour, and turned the plant fossils white. Evidence of heat treatment is presented as discarded cobbles with red discoloration suggestive of intentional burning (fig. 2a). FbPi-8 yielded several cobbles that contained fossil plants, shells, and vertebrate fishes. These cobbles were possibly discarded following insufficient heat treatment or because the exceptionally high fossil density proved too difficult to work into useable tools. Several prepared cores were also present, having much more 'knappable' proportions of fossils (fig. 2b). The prepared cores also had a more lustrous quality than the discarded samples and appeared almost waxy, perhaps a product of heat treatment. FbPi-8 contained several buried hearth features and primary reduction debitage indicative of a lithic workshop (Porter 2014). Macroscopic qualities of the materials found at FbPi-8 match those of projectile points donated to the museum by private collectors. These donated specimens are the artifacts of interest in this paper. Our preliminary investigation into Red Deer Mudstone tools has uncovered projectile points with identifiable fossils at FfPh-15, FfPi-13, FfPi-15, FfPm-1, and FgPh-1, and sites designated from private collector's surface finds in the greater Red Deer, Central Alberta region. For the protection of these sites' integrity, and for the privacy of landowners, we chose not to reveal the precise location of these sites in this article, but more generalized locations are shown later.

FbPi-8 (Red Deer Mudstone Workshop) is situated near two paleontological research localities that have yielded a diverse array of plant and animal life from the Late Paleocene; these sites are located at a roadcut near the Joffre Bridge, and at the confluence of the Red Deer and the Blindman River (fig. 1) (Fox 1990; Hoffman and Stockey 2011; Taylor and Stockey 1984; Wighton and Wilson 1986). Both localities include lithology and fossil assemblages that are typical of the Paskapoo Formation (G. Hoffman, personal communication 2017). The Joffre roadcut locality features seven beds or units interpreted as fluvial, swamp, lacustrine and floodplain deposits (Hoffman and Stockey 2011). The rock types present include claystone, mudstone, calcareous mudstone, coaly mudstone, siltstone, medium-grained sandstone, and a thin coal bed. Most include scattered mollusc shells and/or plant remains; rarely, some include remains of vertebrate fish and reptiles, or insects (Hoffman and Stockey 2011). The main exposures at the Blindman River locality are a bed of grey calcareous mudstone that is interpreted as a lacustrine deposit, and a medium-grained sandstone that is interpreted as a fluvial channel deposit. Both contain plant and mollusc fossils and, rarely, insect and vertebrate remains (Fox 1990; Taylor and Stockey 1984).

Fossiliferous Projectile Points

The stone tools discussed in detail in this article (FfPh-15a; FfPi-13:16) are currently housed in the Royal Alberta Museum (RAM) Archaeological Collections, and were all surface finds donated by private collector, Stanley Reynolds. These artifacts lack any stratigraphic context; however, they offer a wealth of raw

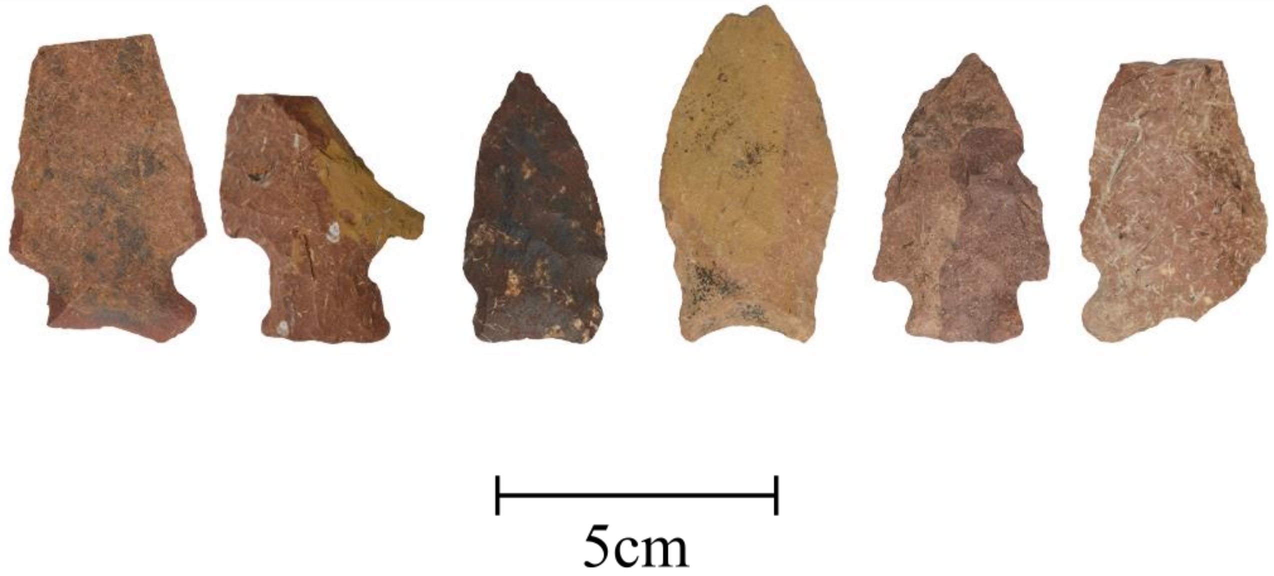


Figure 3. A selection of projectile points from the Reynolds Collection with fossils. Photo by Author.

material and geographic information, which in turn can reveal patterns in the distribution of artifacts from distinctive rock types. In aggregate, the material donated from Reynolds will be henceforth referred to as the Reynolds Collection. All artifacts were photographed with permission from the RAM Curator of Archaeology, Jack Brink. Artifacts conform to the macroscopic characteristics of Red Deer Mudstone, described earlier. Of the ten projectile points photographed from the Reynolds Collection that matched the descriptions (three of which are shown in Figure 3), eight contained root traces indicative of the Red Deer Mudstone, and two contained possibly identifiable fossil molluscs (fig. 4, 5).

FfPh-15:a is a projectile point from the RAM's Reynolds Collection (fig. 4). It is a large, stemmed, atlatl or spear point that is broken across the blade; the base of the point is flat, flares slightly, and is approximately 2.5 cm at its widest (fig. 4). Based on these morphological characteristics, this projectile point fits closely with the classification of Burmis Points, like those found at EgPn-700 near Calgary (Vivian *et al.* 2011). Points of this morphology have been found in association with archaeological material dated to between 7000-7800 years BP (Peck 2011).The point is reddish brown, with spots of tan patina matrix towards the center right of the blade. Two large (*ca.* 4-5 mm) conispiral molluscs are visible externally in this artifact. These shells were inspected and photographed using a dissecting (10 to 40 times magnification) microscope under plain light. Although identification of the fossil gastropods from the points is tentative at best considering the minor cross-sectional views, the fossils are apparently dextrally coiling turbinate shells. The shells could belong to several aquatic gastropod taxa, although they appear morphologically coherent with *Hydrobia*, *Lioplacodes*, and *Viviparus* spp. Other apparent fossil mollusc remains visible in FfPh-15:a are large and rather flatly convex, perhaps indicating clams (Pelecypoda) (e.g., *Unio* or *Sphaerium* spp., among the most common fossils in the Paskapoo Formation (Hamblin 2004) or other Gastropoda.

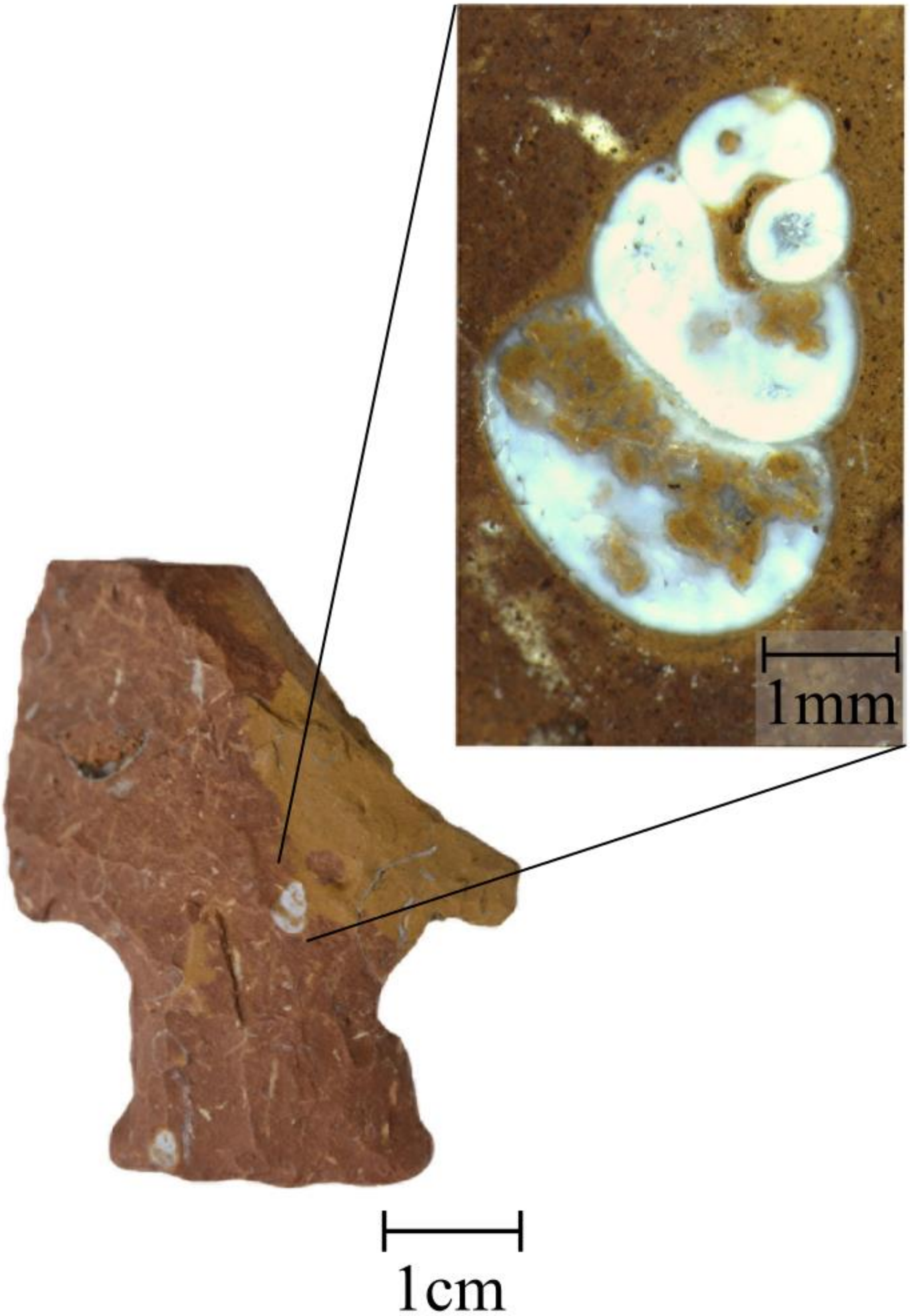


Figure 4. Stemmed projectile point (FfPh-15:a) with a mollusc fossil enlarged. Photos by Author.

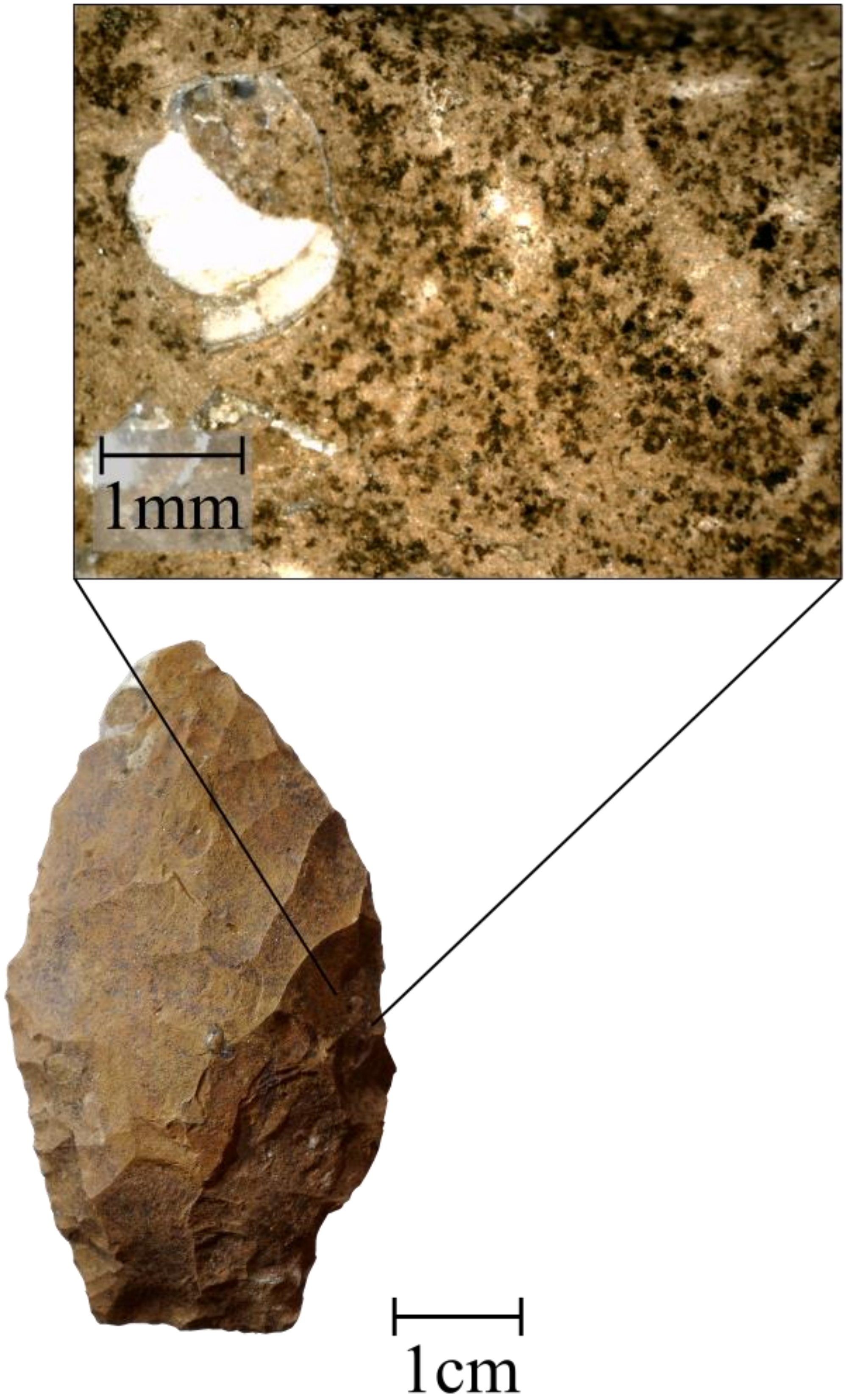


Figure 5. Leaf-shaped projectile point (FfPi-13:16) with a mollusc fossil. Photo courtesy of Todd Kristensen.

FfPi-13:16 is another projectile point from the RAM’s Reynolds Collection (fig. 5). The artifact is an unfinished, complete, leaf-shaped point with a flat, tapered base; the artifact is approximately 6 cm long, 3.5 cm wide, and has a 1.8 cm wide base. Leaf-shaped projectiles are an ambiguous morphology; as such we have not assigned this artifact with a temporal distinction. This point also contains several turbinate fossil shells. One of these shells is visible in cross-section, wherein the posterior of the body whorl is cut through, exposing its interior. Though it at first appears sinistrally coiled, the general morphology of the snail appears inconsistent with sinistral snails (e.g., Physids); it is visibly reversed from the normal apertural view, seen enlarged in Figure 5 inset. The visible section of the shell indicates an elongate (i.e., taller than wide) body whorl that is not greatly expanded, however, the cross-cutting view of the shell has likely obscured some diagnostic features. As such, this attribute may exclude some *Vivaparus* and *Liplacodes*, although dependable differentiation for these specimens is unrealistic. Other small molluscs are also apparent in the point; one (a larger dextral turbinate or fusiform shell) is located very near the point’s apex. This shell appears to have an intact external surface and a clear view of the body whorl or aperture; following further investigation it may be identifiable to the species level.

The identification of fossilized macroremains, as with the shells preserved in the artifacts described above, requires clear representation of multiple features, often from a variety of angles. As such, even where preservation is very good, the certainty of taxonomic identification is often inherently lacking (e.g., Hartman *et al.* 1989). Further close inspection of these fossiliferous artifacts is required to provide a clearer perception of the chronological origin of the materials, and will be useful for narrowing the geographic uncertainty of the stone sourcing.

Paleontological Discussion

Hydrobia is known from a variety of environments, such as brackish or highly saline waters, however deposition from a lacustrine environment is likely. This genus is consistent with the imbedded fossils described in artifacts FfPi-13:16 and FfPh-15:a. Paleoenvironmental work from the Paskapoo and neighboring Porcupine Hills Formations provide evidence for early Paleocene aridity (Hamblin 2004); this interpretation is echoed by Jerzykiewicz and Sweet’s (1988) findings from other rocks in the Albertan Foothills. However, the inclusion of coal, and increased plant fossils indicate a shift to moister conditions throughout the Paleocene. This is supported by McIver’s (1989) interpretation of climate from the Ravenscrag Formation of southwestern Saskatchewan.

Fossil *Viviparus* and *Lioplacodes* potentially present in FfPi-13:16 and FfPh-15:a, are both known globally from freshwater lacustrine environments or slow-moving streams (e.g., Chin, Hartman, and Roth 2009; Radley and Barker 2000; Szymanek, Kryzyaztof, and Niychoruk 2016). Likewise, extant *Sphaerium* clams (as may have been visible in FfPh-15:a) live in either lentic or lotic fresh water (Clarke 1981), and as such, probably indicate a similar local depositional environment. If the larger shell remains in FfPh-15:a represent *Unio*, they probably represent the fauna of a riverine environment, though this genus exists in some lakes as well (Dillon 2000; Ostrovsky, Gophen, and Kilikhamen 1993). Considering this, the general ecological signal derived from the malacological fauna of these artifacts (regardless of the precise taxon or taxa the molluscs belong to) represents a fluvial-lacustrine environment,

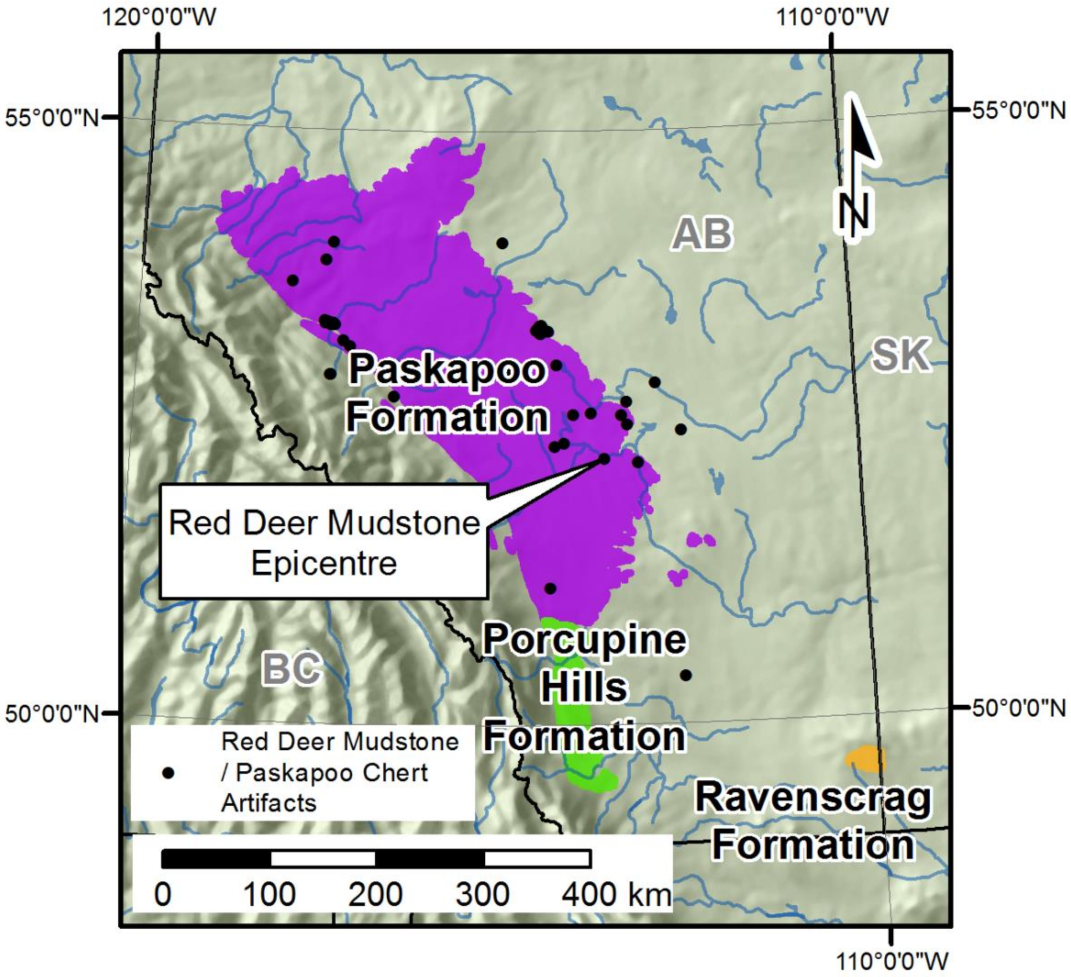


Figure 6. Map highlighting Albertan extent of select fossiliferous Paleogene-aged rocks, the epicenter of Red Deer Mudstone artifact finds, and the distribution of reported Red Deer Mudston / Paskapoo Chert artifacts found by consultants. Bedrock mapping from Prior *et al.* (2013).

much like that identified in the Blindman-Red Deer and Joffre roadcut localities.

The presence of three prospective genera (i.e., *Hydrobia*, *Lioplacodes*, and *Viviparus*) are known from the Paskapoo Formation and similar regionally proximate Paleocene rocks, associating these artifacts to a general region of procurement (Tozer 1956). Given the malacological evidence and the proximity to Paskapoo Formation exposures, it is likely that fossiliferous rocks from the Paskapoo Formation, deposited in the Paleocene, were procured and modified to construct the artifacts described in this paper. However, the taxa remarked upon in this paper are also known from other rock formations, so the Red Deer River region discussed here may not be the sole source of Red Deer Mudstone. We hypothesize that following further investigation it will be revealed that the toolstone material we call Red Deer Mudstone in this paper is actually a mosaic of materials of similar appearance from multiple sources. Red Deer Mudstone/Paskapoo Chert artifacts have been reported by consultants at 68 archaeological sites, covering a wide swath of the Paskapoo Formation across the province (Todd Kristensen, personal communication 2017) (fig. 6). Alternative potential sources include other Paskapoo Formation exposures in western central and southern Alberta (Tozer 1956), the nearby Porcupine Hills Formation (Henderson 1935), or perhaps as far away as the Ravenscrag Formation (Cypress Hills Alberta/Saskatchewan) or Montana (Yen 1948). The extent of these formations in Alberta are shown in Figure 6. Macrofossil identification may be a means of linking artifacts to specific source locations with future research. Clearly there is a need to further explore the nature of the Red Deer Mudstone tools, such as through petrographic or mineralogical analysis of artifacts and likely parent rocks.

Conclusion, Future Directions

This paper has revealed that mollusc macrofossils can be used to support claims of stone tool provenance. Here, some large fossils that have been described as a diagnostic feature of Red Deer Mudstone were investigated to support the material’s possible origin within Paskapoo Formation sedimentary rocks. Given this promising start, the utility of macrofossil identification for provenance purposes must be explored. Once a baseline of data has been established, such as petrographic study of both artifacts and parent rock from suspected sources, fossils could potentially become a convenient indicator of this material. Large fossil molluscs are clearly visible in some artifacts described as Red Deer Mudstone from private collections in central Alberta. They can be quickly and reasonably accurately identified (probably up to genus or species), all without the use of expensive or destructive analytical methods. This leaves us to consider why this material, with clearly visible and distinct fossils within, was selected for in prehistoric times. In future research, we would like to consider possible social factors surrounding this material’s procurement and modification (particularly heat treatment). In an area where quartzite (a harder and more knappable rock) is locally available, Red Deer Mudstone was sought out and intentionally modified to improve its tool making quality. Perhaps the bold white fossils visible in this material gave Red Deer Mudstone value beyond the utilitarian, and sources were actively sought because of this quality over arguable more pragmatic rock types.

The non-destructive malacological methods described in this paper can provide further clues as to the depositional environment of the parent rock, and may potentially be used to infer the geologic formation that the artifact was procured from. Paskapoo Formation rocks are distributed throughout central and southern Alberta (Prior *et al.* 2013; also see Figure 6). However, the distribution of specific (i.e., indicator) Paleocene fossils may narrow the prehistoric procurement areas of this material considerably. Although only a preliminary summary, the results of this paper indicate that some fossils within Red Deer Mudstone artifacts are identifiable, at least to morphotype, and possibly to genus or finer resolution, and represent distinct depositional contexts. I plan to expand on the potential of this research, and continue to develop a method related to fossil representation within artifacts and its application in archaeology.

Acknowledgements

The authors would like to recognize that these artifacts were constructed by the ancestors of modern indigenous peoples, now living in Treaty 6 and Treaty 7 territory. The authors would like to thank Todd Kristensen, Historic Resources Management Branch, and Georgia Hoffman, University of Alberta, for sharing information and supporting this project. We would also like to thank Jack Brink, RAM Curator of Archaeology, for providing access to the collections and for granting permission to publish the artifact photographs. We would also like to recognize the relationship the RAM and the Archaeological Survey of Alberta have with the private collectors

and land owners of Alberta. Without all these people and groups, this project would not have been possible.

References Cited

Bohach, Lisa. 2010. *Palaeontological Assessment Permit #Bohach-2010-002*. Paleontological Permit Report. Stantec Consulting Ltd.

Biittner, K.M, and S.M. Jamieson. 2008. Chert raw material utilization at the Bark site (BpGp-12), Peterborough County, Southern Ontario. *Ontario Archaeology* 81:13-29.

Clarke, Arthur Haddleton. 1981. *The freshwater molluscs of Canada*. Research Report. National Museum of Natural Sciences, National Museums of Canada, Ottawa.

Chin, Karen, Joseph H. Hartman, and Barry Roth. 2009. Opportunistic exploitation of dinosaur dung: fossil snails in coprolites from the Upper Cretaceous two Medicine Formation of Montana *Lethaia* 42(2):185-198.

de Mille, Christy. 2009. *Historical Resources Impact Assessment; Decker Phase 4 Property Area*. Archaeological Permit Report. Lifeways Canada Limited Report. 09-040.

Dillon, Robert T. 2000. *The ecology of freshwater molluscs*. Cambridge, UK: Cambridge University Press.

Fenton, M., and J. W. Ives. 1984. The stratigraphic position of Beaver River Sandstone. *Archaeological Society of Alberta Occasional Paper Series* 19: 128-136

Fossilworks. 2017. Hydrobia Hartmann 1821 (snail). http://fossilworks.org/bridge.pl?a=taxonInfo&taxon_no=85011%20# (accessed March 21, 2017).

Fox, R.C. 1990. The succession of Paleocene mammals in western Canada. In *Dawn of the age of mammals in the northern part of the Rocky Mountain interior, North America. Geological Society of America, Special Paper* 243: 51-70.

Hamblin, A. P. 2004. *Paskapoo-Porcupine Hills formations in western Alberta: synthesis of regional geology and resource potential*. Ottawa: Geological Survey of Canada.

Hartman, J. H., G. A. Buckley, D. W. Krause, and T. J. Kroeger. 1989. Paleontology, stratigraphy, and sedimentology of Simpson Quarry (early Paleocene), Crazy Mountains Basin, south-central Montana. In *1989 MGS Field Conference, Montana Centennial.* 173-185.

Henderson, Junius. 1935. Fossil non-marine Mollusca of North America. In *Geological Society of America Special Papers* 3. 1-290.

Hoffman, Georgia L., and Ruth A. Stockey. 2011. Geological setting and paleobotany of the Joffre Bridge Roadcut fossil locality (Late Paleocene), Red Deer Valley, Alberta. *Canadian Journal of Earth Science.* 36: 2073-2084.

Jerzykiewicz, T., & Sweet, A. R. (1988). Sedimentological and palynological evidence of regional climatic changes in the Campanian to Paleocene sediments of the Rocky Mountain Foothills, Canada. *Sedimentary geology* 59(1-2): 29-76.

Kendall and Macdonald. 2012. Chert artifact-material correlation at Keatly Creek using geochemical techniques. In *Toolstone Geography of the Pacific Northwest*. Simon Fraser University Press. 49-61.

Kristensen, Todd J., Morin, Jesse, Duke, M. John M., Locock, Andrew J., Lakevold, Courtney, Giering, Karen, and John W. Ives. 2016a. Precontact Jade in Alberta: The geochemistry, mineralogy and archaeological significance of Nephrite ground stone tools. *Archaeological Survey of Alberta Occasional Paper Series* 36: 113-135.

Kristensen, Todd J., Turney, Michael, Woywitka, Robin, Tsang, Brian, Gingras, Murray, Rennie, Patrick, Robertson, Elizabeth, Jones, Travis, Speakman, Jeff, and John W. Ives. 2016b. Beaver River sandstone: A silicified toolstone from northeast Alberta, Canada. *Archaeological Survey of Alberta Occasional Paper Series*. 36: 136-153.

MacKay, Glenn, Burke, Adrian L., Gauthier, Gilles, and Charles D. Arnold. 2013. Mackenzie Inuit lithic raw material procurement in the Lower Mackenzie Valley: the importance of social factors. *Arctic* 66 (4): 483-499.

McIver, E. E. 1989. Fossil flora of the Paleocene Ravenscrag Formation, southwestern Saskatchewan, Canada. PhD dissertation, University of Saskatchewan, Saskatoon.

Meyer, Daniel A., Saxberg, Nancy, Somer, Brad, Roe, Jason, and Carmen Olson. 2007. *Historical resources impact mitigation, Elk Valley Coal Corporation Cardinal River operations 2005-396*. Archaeological Permit Report. Lifeways of Canada Limited Report.

Ostrovsky, I., M. Gophen, and I. Kalikhman. 1993. Distribution, growth, production, and ecological significance of the clam Unio terminalis in Lake Kinneret, Israel. *Hydrobiologia* 271, (1). 49-63.

Peck, Trevor R. 2011. *Light From Ancient Campfires, Archaeological Evidence for Native Lifeways on the Northern Plains*. Edmonton: Athabasca University Press.

Porter, Meaghan. 2014. *Historical resources impact mitigation 12-182.* Archaeological Permit Report. Stantec Consulting Ltd Report.

Prior, G.J., Hathway, B., Glombick, P.M., Pană, D.I., Banks, C.J., Hay, D.C., Schneider, C.L., Grobe, M., Elgr, R. and Weiss, J.A. 2013. *Bedrock geology of Alberta; Alberta Energy Regulator, AER/AGS Map 600, scale 1:1 000 000.*

Radley, Jonathan D., and Michael J. Barker. 2000. Palaeoenvironmental significance of storm coquinas in a Lower Cretaceous coastal lagoonal succession (Vectis Formation, Isle of Wight, southern England). *Geological Magazine* 137(2):193-205.

Shackley, M. S.. 2008. Archaeological Petrology and the Archaeometry of Lithic Materials. *Archaeometry* 50(2):194-215.

Szymanek, Marcin, Krzysztof Bińka, and Jerzy Nitychoruk. 2016. stable 18O and 13C isotope records of Viviparus diluvianus (Kunth, 1865) shells from Holsteinian (MIS 11) lakes of eastern Poland as palaeoenvironmental and palaeoclimatic proxies." *Boreas* 45(1):109-121.

Taylor, T.N., and Stockey, R.A. 1984. Field Guide, *Second International Organization of Paleobotany conference, Edmonton, Alberta*, pp. 17–24.

ten Bruggencate, Rachel, E., S. Brooke Milne, Mostafa Fayek, Robert W. Park, Douglas R. Stenton, and Anne C. Hamilton. Forthcoming. Characterizing southern Baffin Island chert: A cautionary tale for provenance research. *Journal of Archaeological Science: Reports.*

Tozer, E. T. 1956. *Uppermost Cretaceous and Paleocene non-marine molluscan faunas of western Alberta*. Research Report. Department of Mines and Technical Surveys.

Vivian, Brian, Dow, Amanda, Blakey, Janet, and Jason Roe. 2011. The Everblue Springs Site and the early transitional Bison kill sites of the Alberta foothills, 7,200 Years Ago. *Occasional Papers of the Archaeological Society of Alberta* 11:1-281

Wighton, D. C. and M.V.H. Wilson. 1986. The Gomphaescinae (Odonta: Aeshnidae): new fossil genus: reconstructed phylogeny and geographical history. *Systematic Entomology* 11: 505-522.

Yen, Teng-Chien. 1948. Paleocene fresh-water mollusks from southern Montana. No. 214-C. 1948. *Shorter contributions to general geology*: 35-50.

Gluten-free Rome

Celiac disease in the bioarchaeological record

by Rachel Simpson

Celiac disease, an autoimmune disorder triggered by consumption of the gluten protein, is theorized to have originated alongside the domestication of wheat during the European Agricultural Revolution, ca. 8 000 BCE (Freeman 2013**)**. Human conditions that primarily affect soft tissue, like celiac disease, do not leave tangible evidence on the skeleton and therefore it is difficult to prove their presence. However, recent analyses have employed a suite of macroscopic, molecular, and chemical techniques to establish that a Roman Imperial (100–300 CE) individual from Cosa, Italy, likely suffered from celiac disease. This paper analyzes the works of these researchers and argues that this case study exemplifies modern bioarchaeology, which frequently requires an arsenal of methods beyond visual observation. Using similar syntheses of techniques bioarchaeologists can possibly identify celiac disease in individuals predating 100 CE, recreating the origins of celiac disease as well as tackling other previously 'impossible' research questions in this field.

Introduction

When did celiac disease originate? Scholars have long suggested that the Neolithic Agricultural Revolution in Europe (ca. 8 000 BCE) is responsible for a number of diseases and nutritional deficiencies due to agriculture's lack of dietary diversity, implications for social organization and sedentism, and human adaptation (Jönsson *et al.* 2005, Pinhasi and Stock 2011). A number of digestive diseases linked to the adoption of agriculture, such as celiac disease which afflicts at least 1% of most human populations, remain a modern issue (Mustalahti *et al.* 2010; Rubio-Tapia *et al.* 2012**)**. Researchers suggest that celiac disease originated with the onset of wheat cultivation (Freeman 2013); however, it is difficult to recognize the ailment in the palaeopathological record (Rühli and Ikram 2014: 55). Other research has traced the first diagnoses of the ailment to the second century CE based on the writings of the classical physician Aretaeus the Cappadocian (Losowsky 2008; Freeman 2013). Given that celiac disease is a soft tissue disorder and therefore osteologically absent, there is no way to substantiate these hypotheses.

Italian researchers argue that a skeleton from Roman Imperial (100–300 CE) Tuscany is the first recorded case of archaeological celiac disease. This is due to observable signs of malnutrition in the skeleton, the presence of genetic haplotypes associated with celiac disease, and stable isotope analysis of the remains (Gasbarrini *et al.* 2010, 2012; Scorrano *et al.* 2014). This paper will provide a background on both the Neolithic Agricultural Revolution and celiac disease, evaluate the "Case of Cosa," and argue that in encountering archaeologically ambiguous issues, the most valuable approach is a medley of research techniques.

Rachel Simpson is a BA (Honours) student in the Department of Anthropology, Economics, and Political Science at MacEwan University (Room 7-368, City Centre Campus, 10700 – 104 Ave., Edmonton, Alberta, T5J4S2 [simpsonr34@mymacewan.ca).

The Agricultural Revolution

One of the world's first Agricultural Revolutions took place in approximately 8 000–10 000 BCE in the Levant region of the Middle East, marking the initial shifts from foraging to agriculture with the domestication of cereals (Pinhasi and Stock 2011). Wheat was originally domesticated from a wild einkorn variety approximately 8 000 BCE in the Karacadag mountains of modern-day Turkey (Heun *et al.* 1997). From this epicentre, wheat cultivation spread across the globe. Wheat and *alphita* (barley with hulls removed) largely constituted the carbohydrate and protein components of the classical Mediterranean diet (Foxhall and Forbes 1982). Currently, it is a part of almost all human diets.

Extensive research exists concerning the impacts of the Neolithic Agricultural Revolution on human life, particularly in terms of changing lifeways (Kelly 1992), social (in)equality (Hayden 1995), and health (Larsen 2006). The adoption of agriculture likely originated through idyllic climatic and social conditions among foragers (Pinhasi and Stock 2011; Bowles and Choi 2015). Bowles and Choi (2015) argue that inferred forager values, such as community sharing practices and collective decision-making, were incompatible with increasing dependence on agriculture, which thrives on individual or nuclear family incentives. Consequently, Bowles and Choi (2015) suggest that the early agricultural transition may have involved increased productivity of land but not necessarily productivity of labour. A shift toward private ownership of land, overall sedentism, and private storage of food surpluses would have slowly developed and led to task specialization and social stratification (Pinhasi and Stock 2011). Additionally, these shifts led to widespread population growth as sedentism supports human fertility and reductions in interbirth intervals (Kelly 1992: 59).

Despite the overall success of sedentary human groups (Wells and Stock 2007), Pinhasi and Stock (2011) argue that there may be a "trade-off" between increased population size and health. Several immediate health implications arose as a result of this transition from foraging to agriculture. Sedentism and overcrowding led to diseases brought about by poor sanitation, as humans increasingly lived in close proximity to their waste and contaminated water (Armelagos *et al.* 1996; Pinhasi and Stock 2011). The zoonotic transmission of disease also became an issue due to humans living in close quarters with their domesticated animals (Armelagos *et al.* 1996). There were also several health implications caused by the consumption of domesticated plants themselves. Transitioning from a diverse foraging diet to one that relies on select carbohydrate-rich cereals led to large-scale nutritional deficiencies in specific nutrients (Larsen 2006). Issues with dental health, anemia, and malnutrition are evident in the skeletal record by pathological markers like dental caries (Eshed, Gopher, and Hershkovitz 2006; Larsen 2006), porotic hyperostosis and cribra orbitalia (Papathanasiou, Larsen, and Norr 2000; Stravopodi *et al.* 2009), and enamel hypoplasia (Krenz-Niedbala 2014) respectively. These studies refute earlier perspectives that agriculture resulted in an overall lifestyle improvement for humans, paving the way for urbanism (Childe 1950).

Many of these direct health implications correspond to recent human evolution as a result of the transition from foraging to agriculture (Pinhasi and Stock 2011). Humans developed lactase persistence and were able to metabolize increased starch quantities, which Jönsson *et al.* (2005) propose were evolutionary legacies of dietary lectins and leptin resistance. The leptin system is an arrangement of proteins that send signals that inhibit food consumption, facilitate the growth of blood vessels, and regulate metabolism and immunity. Lectins are classes of ingested proteins that differ among organisms based on diet. Jönsson *et al.* (2005) argue that the human leptin system is adapted for certain classes of dietary lectins. Given *Homo sapiens'* foraging origins, there is a clash between lectins of domesticated cereals and the lectins compatible with the human leptin system. This mismatch of lectins and leptins has led to a rise in certain diseases, including Type 2 Diabetes, obesity, cardiovascular disease, and celiac disease, all which are prevalent in agrarian societies and infrequent in horticultural and foraging societies (Jönsson *et al.* 2005).

Celiac Disease

Aetiology

Celiac disease is a disorder in which an autoimmune response is triggered by the ingestion of gluten, a dietary protein in domesticated wheat (*Triticum* spp.), barley (*Hordeum vulgare*), and rye (*Secale cereale*) (Fasano and Catassi 2001). The only modern treatment for this disease is continual avoidance of gluten in one's diet. By removing the pathogen from a celiac patient's diet, the autoimmune response ceases. Gluten causes the immune system to target the small intestine, leading to inflammation and damage to villi (Holmes, Catassi, and Fasano 2009).

Celiac disease results in malabsorption of nutrients from the small intestine, and it is commonly characterized by symptoms of indigestion, weight loss, diarrhea, and fatigue (Fasano and Catassi 2001; Ransford *et al.* 2002). In atypical cases, there is also development of steatorrhea; nutritional deficiencies, especially anemia; dermatitis herpetiformis, a gluten-sensitive skin rash (Reunala 1998); gluten ataxia, a neurological manifestation of gluten sensitivity (Jackson *et al.* 2012); and other autoimmune diseases, such as diabetes mellitus (Fasano and Catassi 2001).

The aforementioned symptoms of celiac disease occur in the soft tissues and consequently there are no osteological manifestations of celiac disease. However, some atypical presentations of the disease may have osteological implications. Iron-deficient anemia is a common symptom of celiac disease (Fasano and Catassi 2001; Ransford *et al.* 2002), which can sometimes be identified on skeletal remains. Additionally, celiac disease has been associated with osteopenia and osteoporosis in some individuals (Valdimarsson *et al.* 1996), and therefore there is a higher prevalence of bone fractures among patients with celiac disease than among the general population (Vazquez *et al.* 2000). Children and adolescents with untreated celiac disease may also exhibit a relatively shorter stature due to nutrient malabsorption (Groll *et al.* 1980). Lastly, 30% of individuals with long-term untreated celiac disease exhibit enamel hypoplasia (Smith and Miller 1979; Wierink *et al.* 2007). Therefore, the limited skeletal manifestations of celiac disease may sometimes include porotic hyperostosis, cribra orbitalia**,** reduced mineral content in bone, reduced bone density, short stature, and/or enamel hypoplasia (Roberts and Manchester 2007: 230; Bianchi and Bardelli 2008). However, it should be noted that these symptoms are not exclusively diagnostic of celiac disease.

Genetic Basis

Haplotypes are sections of linked genes on a chromosome that are typically inherited together. Celiac disease occurs in individuals with a predisposing human leukocyte antigen system (HLA) haplotype: HLA-DQ2 or HLA-DQ8 (Green and Cellier 2007; Holmes, Catassi, and Fasano 2009). Higher incidences of the HLA-B8 antigen are also correlated with higher incidences of celiac disease (Cronin and Shanahan 2001). Although 30–35% of humans exhibit these haplotypes, not all individuals with these haplotypic genetic predispositions will develop celiac disease in their lifetimes (Schuppan,Junker, and Barisani 2009). According to Holmes, Catassi, and Fasano (2009), latent celiac disease can be triggered in genetically-predisposed individuals by large amounts of gluten, infection, and other forms of physiological stress, including pregnancy, puberty, or surgery.

History

Like obesity, diabetes, and cardiovascular disease, celiac disease is sometimes considered a "disease of affluence" due to its frequency following the Industrial Revolution (Jönsson *et al.* 2005). However, its rise in frequency during modern times may have more to do with superior methods of diagnosis and greater awareness than its actual origins. Some scholars presume that celiac disease originated sometime after the domestication of wheat (Freeman 2013). According to Freeman (2013), the first diagnosis of celiac disease can be traced back to Aretaeus the Cappadocian, a Greek physician of the second century CE who wrote of an ailment he named "coeliac" that he derived from the Greek word for abdomen, "koiliakos". Aretaeus wrote that "coeliac" involves chronic diarrhea, food indigestion, and abdominal pain; however, these symptoms are not exclusive to celiac disease. Freeman (2013) indicates that "coeliac" may instead be mesothelioma, a cancer of the organ linings. As mesothelioma and celiac disease are diseases of the intestine, both present similar symptoms. Additionally, mesothelioma was 600–800 times more common in ancient Cappadocian villages than in the rest of the world (Freeman 2013) due to environmental carcinogens (Selçuk *et al.* 1992) and the prevalence of an autosomal dominant gene throughout the population (Roushdy-Hammady 2001). Overall, the origins of celiac disease remain uncertain. Celiac disease was officially recognized by physician Samuel Gee, who hypothesized that the "coeliac affection" could potentially be cured by diet (Gee 1888). Finally, in 1950, the dietary connection was revealed; celiac disease was linked to the ingestion of cereals (Dicke 1950).

Prevalence and Distribution

On average, 1% of individuals in most modern populations have celiac disease (Mustalahti *et al.* 2010; Rubio-Tapia *et al.* 2012). Celiac disease is found across all human populations that regularly consume gluten, which Accomando and Cataldo (2004: 492**)** refer to as a "global village" of celiac disease. The haplotypes HLA-DQ2 and -DQ8 are not ancestry-specific and there is no patterned distribution of celiac disease. Despite this, there are pockets of higher incidences of celiac disease in Western Ireland, the "celiac belt" of India, Mexico, and Finland (Cronin and Shanahan 2001, Holmes, Catassi, and Fasano 2009, Mustalahti *et al.* 2010). This variation in the pervasiveness of celiac disease often corresponds to the quantity of wheat consumed in a region. Certain regions of East Asia consume little wheat, and consequently have low frequencies of population-wide celiac disease; in contrast 0.3–2.4% of European populations that regularly consume glutenous grains have celiac disease (Holmes, Catassi, and Fasano 2009; Mustalahti 2010).

There are some cases in which the incidence of celiac disease does not correspond to gluten consumption. Populations in Ireland exhibit a slightly higher incidence of population-wide celiac disease than near countries like Germany (Cronin and Shanahan 2001). According to Simoons (1981), this can be explained by the spread of wheat cultivation across the globe. Regions with a longer history of wheat cultivation have had a longer time to adapt to cereals and humans may micro-evolve to tolerate them. Areas such as Ireland have only recently adopted large-scale consumption of wheat, formerly preferring to cultivate oats and potatoes, and therefore do not possess adaptations for metabolizing gluten (Cronin and Shanahan 2001). Without knowing the origin of celiac disease, it is difficult to prove any of these evolutionary hypotheses. Additionally, any conclusions drawn from the distribution of celiac disease should be taken with some reservation, as lack of awareness and/or lack of availability of screening can lead to underdiagnoses of certain conditions (Coresh *et al.* 2005). Therefore, the currently-known incidence of celiac disease may not reflect the true incidence of celiac disease.

The Case of Cosa

Although the initial diagnosis of celiac disease is thought to be with Greek physician Aretaeus, celiac disease has never been established from an osteological context. The origins of celiac disease are largely hypothetical, as it does not leave a marked pathology on bone. Despite these limitations, Gasbarrini *et al.* (2010) hypothesized that a Roman Imperial (100–300 CE) skeleton discovered in Cosa, Italy was a long-term sufferer of celiac disease. In subsequent works (Gasbarrini *et al.* 2012, Scorrano *et al.* 2014), a suite of different bioarchaeological methods were employed in order to support this assessment, including morphological and pathological evidence, ancient DNA (aDNA) analysis, and stable isotope analysis.

Celiac Disease Inferred from Pathological Morphology

In their initial case report, Gasbarrini *et al.* (2010) suggest that the Roman Imperial individual recovered from the site of Cosa, Tuscany suffered from celiac disease until her death. Age estimates of the Cosa individual suggest that she was in her late teens or early twenties when she died in first century CE. She was buried in a terracotta “alla cappuccina” (gabled tiles) tomb of quality architecture along with grave goods of bronze and gold jewelry. Gasbarrini *et al.* (2010) infer that the grave goods and the tomb itself suggest that the individual was from a wealthy family of high socioeconomic standing.

Gasbarrini *et al.* (2010) listed a number of osteological characteristics consistent with undernourishment and anemia. Stature estimations put the individual’s height at approximately 140 cm, which is short compared to community data (Giannecchini *et al.* 2008). The dentition exhibited signs of enamel hypoplasia and reduced overall size of the teeth. Enamel hypoplasia is caused by a slowed secretion of enamel matrix (Roberts and Manchester 2007: 75). The skull exhibits cribra orbitalia, a marker of chronic childhood anemia in which the superior aspect of the eye orbits is porous (Roberts and Manchester 2007: 231). Long bones show a thinning of diaphyseal compact bone. These conditions are often attributed to chronic stress, including but not limited to, undernourishment and anemia. Given that the grave goods and tomb are suggestive of a high socioeconomic status, symptoms of malnourishment are unlikely to reflect a lack of access to food resources and poor socioeconomic conditions. Therefore, Gasbarrini *et al.* (2010) use the evidence of cribra orbitalia, short stature, and enamel hypoplasia as the sole evidence of undernutrition caused by celiac disease.

While celiac disease could result in these osteological features, cribra orbitalia, stature, and enamel hypoplasia are multifactorial in their aetiology. Iron deficient anemia can be inferred osteologically by porotic hyperostosis, cribra orbitalia, and analysis of iron in bone (Roberts and Manchester 2007: 230). Anemia is frequently a symptom of celiac disease as it can result from digestive damage, and by extension, malabsorption of nutrients. Gasbarrini *et al.* (2010) use this osteological evidence of anemia as primary evidence that the individual had celiac disease. However, anemia is not always caused by diet and is not specific to celiac disease. Genetic hemolytic anemias unrelated to diet (e.g., thalasemia and sickle-cell anemia), enzyme deficiencies, parasitic infections, and abnormal red blood cells can also cause cribra orbitalia and/or porotic hyperostosis (Roberts and Manchester 2007: 232–233; Rothschild 2012). Several other conditions produce symptoms associated with anemia, including but not limited to Crohn’s disease (Gasché *et al.* 1994), chronic kidney disease (McClellan *et al.* 2004), cancers (Dicato *et al.* 2010), and menstruation (Milman, Clausen, and Byg 1998).

Similarly, enamel hypoplasia and short stature are not exclusively linked to celiac disease nor do they appear in all cases of celiac disease. Enamel hypoplasia is linked to celiac disease in some patients (Smith and Miller 1979; Wierink *et al.* 2007) but as a non-specific stress indicator. It is also linked to environmental and societal stressors such as food shortage (Geber 2014), weaning (Ash *et al.* 2016) and birth weight (Nelson *et al.* 2013). Enamel hypoplasia can also be a hereditary condition (Robinson, Miller, and Worth1966). Stature is partly inherited from parents but also results from a variety of other intrinsic causes, including hormonal deficiencies in human Growth Hormone (hGH) or thyroid hormones, organ diseases such as Crohn’s Disease or cystic fibrosis, genetic syndromes including Turner Syndrome, Noonan Syndrome, and Prader Willi Syndrome (Rogol and Hayden 2014).

In their work, Gasbarrini *et al.* (2010) neglect to address the possibility of other conditions causing the same pathologies, and do not provide any explanation why celiac disease was their sole conclusion. Inferring celiac disease from non-specific morphological traits on a poorly preserved skeleton is poor execution of the scientific method regardless of the authors’ suggestion for further research on this individual (e.g. stable carbon isotope analysis to reconstruct diet).

Celiac Disease Inferred from Ancient DNA

Skeletal and dental pathologies alone are insufficient indicators of celiac disease, causing Gasbarrini *et al.* (2012) to turn to genetic methods for support. The importance of ancient DNA (aDNA) analysis has recently been amplified in bioarchaeological studies, providing answers to questions regarding migration, social organization, family relatedness, origin and evolution of genes, disease, and diet (Stone, 2008). Gasbarrini *et al.* (2012) postulate that if 99.5% of celiac disease patients have the same HLA haplotypes, the same predisposition in the Cosa individual would confirm the possibility of celiac disease. Celiac disease and the HLA-DQ2 and -DQ8 haplotypes are not mutually interchangeable, as only 2–5% of individuals with this haplotypic makeup develop celiac disease (Schuppan, Junker, and Barisani 2009). Gasbarrini *et al.* (2012) therefore caution that the individual having the genetic predisposition for risk of celiac disease does not definitively ‘prove’ celiac disease, but it would rule-in the possibility. If she exhibited a disposition other than HLA-DQ2 or DQ8, it would likely mean that the Cosa individual did not have celiac disease (Gasbarrini *et al.* 2012).

Based on their aDNA analysis, the Cosa individual was homozygous for the HLA-DQ2 haplotype most common among celiac disease sufferers. The researchers took several precautions to ensure this was an accurate result and not contaminated by bacterial, fungal, or researcher DNA. Their analysis (1) extracted aDNA from a number of different locations throughout the skeleton, (2) ran the nuclear DNA and mtDNA of researchers handling the material to cross-check against, and (3) ran multiple independent analyses of the aDNA. Therefore, researcher error is unlikely to have confounded these results. Paired with the morphological observations from Gasbarrini *et al.* (2010), Gasbarrini *et al.*'s (2012) aDNA analysis supports the hypothesis that the Cosa individual had celiac disease, and that celiac disease existed by at least the Roman Imperial period. However, the presence of HLA-DQ2 alone does not necessarily mean the individual has celiac disease, as 30–35% of humans exhibit these same genes. Gasbarrini *et al.*'s (2012) genetic results do not contradict Gasbarrini *et al.* (2010) but they also do not prove the hypothesis of celiac disease.

Celiac Disease Inferred from Stable Isotope Analysis

Scorrano *et al.* (2014) approached the Cosa case from a different angle, employing stable isotope analysis as a mode of palaeodiet reconstruction. Carbon isotopes analyzed from the organic portion of bone (e.g. collagen) can be used to identify a diet of plants that use a specific photosynthetic pathway, whereas nitrogen isotopes derived from collagen can be used to distinguish diets of different protein sources (Katzenberg 2008). Carbon has two stable isotopes, ^{13}C and ^{12}C, which become integrated into plants from atmospheric and oceanic sources via photosynthesis (Schoeninger and Moore 1992). The ratio of the heavier ^{13}C isotope relative to the lighter ^{12}C isotope is represented by the δ^{13}C value (Schoeninger and Moore 1992). Terrestrial C_3 plants employ three-carbon intermediate molecules in the Calvin-Benson cycle as part of photosynthesis (C_3 plants are typically crops), while C_4 plants employ four-carbon intermediates (C_4 plants are typically grasses).C_3 and C_4 plants also vary in the proportion of ^{13}C taken-up, resulting in distinct ranges of δ^{13}C values (Hoefs 2015: 285).Animals of different habitats each have different isotopic signatures based loosely on the available carbon states of local flora (Schoeninger and Moore 1992; Hoefs 2015: 285). Thus, a diet of C_3 plants (e.g. wheat and other cultivars) will yield a different carbon isotope ratio compared to a diet of C_4 plants (e.g. corn, millet, and wild grasses). Nitrogen isotope analysis is based on the foundation that diets of higher trophic levels have enriched nitrogen relative to lower levels (Katzenberg 2008; Hoefs 2015: 289). As an example, an herbivorous diet will produce a lower nitrogen isotope value than a carnivorous diet. Additionally, diets of freshwater and marine animals are differentiated based on nitrogen isotopes according to trophic level and carbon isotopes because of the presence of dissolved inorganic carbon in marine sources (Katzenberg 2008).

Studies have shown that the Mediterranean diet is mostly characterized by terrestrial, rather than marine and freshwater resources (Craig, Biazzo, and Tafuri 2006). Imperial Rome had a dichotomized diet, with upper and middle class Romans consuming more olives, wine, and wheat, and the poor and enslaved consuming more millet (Killgrove and Tykot 2013). Nevertheless, crossover of all foods existed between groups, and intra-regional variation across the vast Roman Empire existed to a large degree. Isotope studies from throughout Italy have demonstrated the dietary breadth of the Empire. For example, Romans at Velia consumed a higher proportion of cereals (Craig *et al.* 2009), whereas those at Isola Sacra likely consumed more marine foods than other areas (Prowse *et al.* 2004) and those at St. Callixtus consumed a higher proportion of freshwater resources (Rutgers *et al.* 2009).

Individual isotopic studies are important, but analyzing one's isotopic values may have little merit without a population baseline. Scorrano *et al.* (2014) encountered sampling issues in this endeavor as there are no contemporary skeletal populations near Cosa. Alternatively, Scorrano *et al.* (2014) compared the Cosa individual's results to the Roman isotope studies mentioned above in addition to Cosa (Forum period) samples that date to later periods (sixth century CE and eleventh to twelfth centuries CE). This was not ideal, as dietary variation occurs across time and space; however, stable isotope analyses of skeletons from these two later time periods revealed carbon and nitrogen values consistent with each other. Faunal remains were also sampled to establish the available local terrestrial and aquatic food web and associated faunal isotopic values (Scorrano *et al.* 2014).

Results from the stable isotope analysis showed that the Cosa individual had carbon levels similar to the terrestrial animals studied, but with significant differences in nitrogen isotope levels. When compared to data from other Imperial Age Roman sites throughout Italy, the Cosa individual's carbon and nitrogen isotope values also varied. As mentioned above, these contemporary populations from other sources show variation in their consumption of cereals, freshwater, and marine foods. The Cosa individual's isotopic values align closely with those of the St. Callixtus sample, thought to have largely consumed freshwater fish (Rutgers *et al.* 2009). Roman period Cosa carbon and nitrogen values also varied from later-era Forum skeletons. From these results, Scorrano *et al.* (2014) suggest that the Cosa individual likely consumed a large proportion of C_3 plants or terrestrial (C_3 plant-consuming animals) whereas later Forum inhabitants consumed more C_4 plants. However, these results must be taken with some reservation, due to difficulty in interpreting the meaning of these results without access to isotope levels of the Cosa population contemporary to the individual's time. Furthermore, analysis of stable isotopes from pathological bone can sometimes be distorted (Katzenberg and Lovell 1999). In their analysis, Katzenberg and Lovell (1999) examined pathological evidence of periostitis, fractures, bone atrophy, and osteomyelitis. Their analysis concluded that new bone growth alters the isotopic interpretation, as it records an accelerated period of bone remodelling and consequently, produces higher δ^{15}N levels. Celiac disease has never been researched from an osteological or isotopic perspective, and any resulting effects of the condition on bone could confound this type of research.

In support of a celiac disease diagnosis, Scorrano *et al.* (2014) propose two explanations for why the Cosa individual had isotope values that were 'outliers' when compared to her home population, why she was isotopically similar to those of the St. Callixtus sample and how these facts might relate to her inferred celiac disease. First, they suggest that the individual began to follow a different diet focused on terrestrial animals or freshwater fish, perhaps after realizing that cereals were an irritant. Avoiding cereals would not have alleviated her illness or cured the intestinal atrophy as gluten must be entirely eliminated from a celiac patient's diet and it is unlikely that she would have been able to remove it completely. Alternatively, Scorrano *et al.* (2014) propose that intestinal malabsorption of nutrients would have caused the individual to starve. Her body would be forced to metabolize her own muscle tissue for nutrients, leading to higher nitrogen isotope values that appear to show a diet of a higher trophic level similar to a diet of terrestrial animals or freshwater fish.

Taken on its own, one would not be able to interpret celiac disease from this stable isotope analysis. The Cosa individual's carbon and nitrogen values could have a plethora of implications other than a gastrointestinal disorder. However, in conjunction with the previously published works, this article is valuable in legitimizing the hypothesis of Gasbarrini *et al.* (2010, 2012). Because the same interpretation could be drawn from all three studies, it is feasible that this individual had celiac disease, making this case the first instance of possible celiac disease from the archaeological record. The collective contribution of macroscopic, molecular, and chemical evidence was essential in substantiating the initial hypothesis of Gasbarrini *et al.* (2010). Applying this assortment of techniques to future skeletal samples will help to establish earlier cases of celiac disease and pursue concrete evidence of the origins of celiac disease.

Discussion and Conclusions

The antiquity of celiac disease is an underexplored topic in science, including paleopathology. Due to a lack of historical documentation and diagnostic morphological characteristics on bone, celiac disease can be only officially traced back to its nineteenth century discovery.

This paper summarizes the archaeological evidence for celiac disease in ancient Rome. Taking the works of Gasbarrini *et al.* (2010, 2012), or Scorrano *et al.* (2014) on their own provides insufficient evidence of celiac disease. Taken together, however, these morphological, genetic, and isotopic studies present a possible instance of celiac disease in the archaeological record. However, this more holistic interpretation of celiac disease from the Cosa individual is by no means a differential diagnosis.

The morphological osteological evidence presented by Gasbarrini *et al.* (2010) is not exclusive to celiac disease and could result from numerous other biological and cultural circumstances. Their argument would have been strengthened by considering these other possible causes of the Cosa individual's pathological characteristics. While not detracting from Gasbarrini *et al.*'s (2010) initial hypothesis, the genetic and stable isotope evidence published by Gasbarrini *et al.* (2012) and Scorrano *et al.* (2014) respectively does not conclusively prove the celiac disease hypothesis either. As discussed above, the majority of individuals genetically predisposed to celiac disease do not develop it in their lifetimes. The stable isotope results showed that the Cosa individual under study likely consumed a larger proportion of terrestrial animals and/or freshwater fish; however, there were several limitations to this study, particularly a lack of contemporaneous human samples from Cosa and an absence of any prior research pertaining to the impact of celiac disease on stable isotope analysis.

The results presented in both Gasbarrini *et al.* (2012) and Scorrano *et al.* (2014) would have benefitted from comparison to the community data of Cosa. What was the prevalence of the HLA-DQ2 haplotype among the Roman Imperial Cosa population and does it make the genotype of the individual under study more or less significant? Were the individual's carbon and nitrogen isotopic values consistent with other Cosa inhabitants or were the values outliers, and consequently suggestive of an abnormal diet? Unfortunately, no contemporary individuals were excavated in Cosa, making these research questions impossible for the researchers to answer.

Their findings have implications for the scholarly community in terms of celiac disease research and paleopathology at the inception of the Agricultural Revolution, as their results demonstrate the possible antiquity of celiac disease, a disorder commonly associated with modern times. There has been a recent "gluten-free boom" (Gaesser and Angedi 2015: 1) resulting from a rise in diagnoses of celiac disease, gluten intolerance, and wheat allergies as well as an emerging popularity of the gluten-free diet among individuals unaffected by the above conditions (2). Given that this subject concerns a large proportion of the general public, research into the origins, past prevalence, and evolution of celiac disease are significant scientific endeavours. While the works of Gasbarrini *et al.* (2010, 2012) and Scorrano *et al.* (2014) are encumbered with limitations and cannot be taken as definitive proof of archaeological celiac disease, they present a possible picture of celiac disease and more importantly, they expose a need for future paleopathological research on the affliction.

In conclusion, future bioarchaeological studies in celiac disease should be undertaken. Using new osteological samples and similarly holistic methodologies, while addressing the discussed limitations present in Gasbarrini *et al.* (2010, 2012) and Scorrano *et al.* (2014), researchers may be able to attain more conclusive diagnoses of celiac disease. This case study's multifaceted research methodology, while limited in some ways, demonstrates the value in applying a suite of pathological and molecular techniques to bioarchaeological remains. Employing similar approaches may help tackle other 'unanswerable' questions in the future.

References Cited

Accomando S., and F. Cataldo. 2004. The global village of celiac disease. *Digestive and Liver Disease* 36(7): 492–498.

Armelagos, George J., Barnes, Kathleen C., and James Lin. 1996. Disease in human evolution: The re-emergence of infectious disease in the third epidemiological transition. *National Museum of Natural History Bulletin for Teachers* 18(3): 1–6.

Ash, Abigail, Michael Francken, Ildikó Pap, Zdeněk Tvrdý, Joachim Wahl, and Ron Pinhasi. 2016. Regional differences in health, diet, and weaning patterns amongst the first Neolithic farmers of central Europe. *Scientific Reports* 6: 29458.

Bianchi, Maria Luisa, and Maria Teresa Bardella. 2008. Bone in celiac disease. *Osteoporosis International* 19: 1705–1716.

Bowles, Samuel, and Jung-Kyoo Choi, eds. 2015. The Neolithic Agricultural Revolution. *Santa Fe Working Papers*: 1–51.

Childe, V. G. 1950. The Urban Revolution. *Town Planning Review* 21: 3–17.

Coresh, Josef, Danita Byrd-Holt, Brad C. Astor, Josephine P. Briggs, Paul W. Eggers, David A. Lacher, and Thomas H. Hostetter. 2005. Chronic kidney disease awareness, prevalence, and trends among U.S. adults 1999 to 2000. *Journal of the American Society of Nephrology* 16: 180–188.

Craig, Oliver E., Marco Biazzo, and M. A. Tafuri. 2006. Palaeodietary records of coastal Mediterranean populations. *Journal of Mediterranean Studies* 16: 63–78.

Craig, Oliver E., Marco Biazzo, Tasmin C. O'Connell, Peter Garnsey, Cristina Martinez-Labarga, Roberta Lelli, Loretana Salvadei, Gianna Tartaglia, Alessia Nava, Lorena Renò, Antonella Fiammenghi, Olga Rickards, and Luca Bondioli. 2009. Stable isotopic evidence for diet at the Imperial Roman coastal site of Velia (1st and 2nd centuries AD) in Southern Italy. *American Journal of Physical Anthropology* 139(4): 572–583.

Cronin, Cornelius C., and Fergus Shanahan. 2001. Why is celiac disease so common in Ireland? *Perspectives in Biology and Medicine* 44(3): 342–352.

Dicato, M., L. Plawny, and M. Diederich. 2010. Anemia in cancer. *Annals of Oncology* 21(S7): 167–172.

Dicke, Willem-Karel. 1950. Investigation of the harmful effects of certain types of cereal on patients with coeliac disease. Doctoral dissertation, University of Utretcht.

Eshed, Vered, Avi Gopher, and Israel Hershkovitz. 2006. Tooth wear and dental pathology at the advent of agriculture: New evidence from the Levant. *American Journal of Physical Anthropology* 130: 145–159.

Fasano, Alessio, and Carlo Catassi. 2001. Current approaches to diagnosis and treatment of celiac disease: An evolving spectrum. *Gastroenterology* 120(3): 636–651.

Foxhall, Lin, and Hamishk A. Forbes. 1982. Sitometreia: The role of grain as a staple food in classical antiquity. *Chiron* 12: 41–90.

Freeman, Hugh James. 2013. The Neolithic Revolution and subsequent emergence of the celiac affection. *International Journal of Celiac Disease* 1(1): 19–22.

Gaesser, Glenn A., and Siddhartha S. Angadi. 2015. Navigating the gluten-free boom. *Journal of the American Academy of Physician Assistants* 28(8): 1–18.

Gasbarrini, Giovanni, Luca Miele, Gino R. Corazza, and Antonio Gasbarrini. 2010. When was celiac disease born? The Italian case from the archaeological site of Cosa. *Journal of Clinical Gastroenterology* 44(7): 502–503.

Gasbarrini, Giovanni, Olga Rickards, Cristiana Martínez-Labarga, Elsa Pacciani, Filberto Chilleri, Lucrezia Laterza, Giuseppe Marangi, Franco Scaldaferri, and Antonio Gasbarrini. 2012. Origin of celiac disease: How old are predisposing haplotypes? *World Journal of Gastroenterology* 18: 5300–5304.

Gasché, Christoph, Walter Reinisch, Heather Lochs, Babak Parsaei, Sarolta Bakos, Julie Wyatt, G. F. Fueger, and Alfred Gangl. 1994. Anemia in Crohn's disease: Importance of inadequate erythropoietin production and iron deficiency. *Digestive Diseases and Sciences* 39: 1930–1934.

Geber, Jonny. 2014. Skeletal manifestations of stress in child victims of the Great Irish Famine (1845–1852): Prevalence of enamel hypoplasia, Harris lines, and growth retardation. *American Journal of Physical Anthropology* 155: 149–161.

Gee, Samuel J. 1888. On the coeliac affection. *St. Bartholomew's Hospital Report* 24: 17–20.

Giannecchini, Monica, and Jacopo Moggi-Cechi. 2008. Stature in archaeological samples from Central Italy: Methodological issues and diachronic changes. *American Journal of Physical Anthropology* 135: 284–292.

Green, Peter H.R., and Christophe Cellier. 2007. Medical progress: celiac disease. *The New England Journal of Medicine* 357: 1731–1743.

Groll, A., M. A. Preece, D. C. A. Candy, J. M. Tanner, J. T. Harries. 1980. Short stature as the primary manifestation of coeliac disease. *The Lancet* 316(8204): 1097–1099.

Hayden, Brian. 1995. Pathways to power: Principles for creating socioeconomic inequalities. In *Foundations of social inequality*. Douglas Price and Gary M. Fienman, eds. Pp. 15–88. New York: Plenum.

Heun, Manfred, Ralf Schäfer-Pregl, Dieter Klawan, Renato Castagna, Monica Ascerbi, Basilio Borghi, and Francesco Salamini. 1997. Site of einkorn wheat domestication identified by DNA fingerprinting. *Science* 278: 1312–1314.

Hoefs, Jochen. 2015. *Stable Isotope Geochemistry*. 7th edition. Switzerland: Springer.

Holmes, Geoffrey, Carlo Catassi, and Alessio Fasano . 2009. Definition and Epidemiology. In *Fast facts: Celiac disease.* 2nd edition. Abingdon, Oxford: Health Press.

Jackson, Jessica R., William W. Eaton, Nicola G. Cascella, Alessio Fasano, and Deanna L. Kelly. 2012. Neurologic and psychiatric manifestations of celiac disease and gluten sensitivity. *Psychiatric Quarterly* 83: 91–102.

Jönsson, Tommy, Stefan Olsson, Bo Ahrén, Thorklid C. Bøg-Hansen, Anita Dole, and Staffan Lindberg. 2005. Agrarian diet and diseases of affluence: Do evolutionary novel dietary lectins cause leptin resistance? *BMC Endocrine Disorders* 5(10): 1–7.

Katzenberg, M. Anne, and Nancy C. Lovell. 1999. Stable isotope variation in pathological bone. *International Journal of Osteoarchaeology* 9: 316–324.

Katzenberg, M. Anne. 2008. Stable isotope analysis: A tool for studying past diet, demography, and life history. In *Biological anthropology of the human skeleton.* Katzenberg, M. Anne, and Shelley R. Saunders, eds. 2nd edition. Pp. 413–441. Hoboken, NJ: John Wiley & Sons.

Kelly, Robert L. 1992. Mobility/sedentism: Concepts, archaeological measures, and effects. *Annual Review of Anthropology* 21: 43–66.

Killgrove, Kristina, and Robert H. Tykot. 2013. Food for Rome: A stable isotope investigation of diet in the Imperial period (1st–3rd centuries AD). *Journal of Anthropological Archaeology* 32: 28–38.

Krenz-Niedbala, Marta. 2014. A biocultural perspective on the transition to agriculture in Central Europe. *Anthropologie* 52(2): 115–132.

Larsen, Clark Spencer. 2006. The agricultural revolution as environmental catastrophe: Implications for health and lifestyle in the Holocene. *Quaternary International* 150: 12–20.

Losowsky, M.S. 2008. A history of coeliac disease. *Digestive Diseases* 26: 112–120.

McClellan, William, Stephen L. Aronoff, W. Kline Bolton, Sally Hood, Daniel L. Lorber, K. Linda Tang, Thomas F. Tse, Brian Wasserman, and Marc Leiserowitz. 2004. The prevalence of anemia in patients with chronic kidney disease. *Current Medical Research and Opinion* 20(9): 1501–1510.

Milman, N., J. Clausen, and K. Byg. 1998. Iron status in 268 Danish women aged 18–30 years: Influence of menstruation, contraceptive method, and iron supplementation. *Annals of Hematology* 77(1–2): 13–19.

Mustalahti, Kirsi, Carlo Catassi, Antti Reunanen, Elisabetta Fabiani, Margit Heier, Stan McMillan, Liam Murray, Marie-Helene Metzger, Maurizio Gasparin, Enzo Bravi, and Markku Mäki. 2010. The prevalence of celiac disease in Europe: Results of a centralized, international mass screening project. *Annals of Medicine* 42: 587–595.

Nelson, Suchitra, Jeffrey A. Albert, Cuiyu Geng, Shelley Curtan, K Lang, S Miadich, M Heima, Anchal Malik, G. Gerretti, Hafsteinn Eggertsson, R. L. Slayton, and Peter Milgrom. 2013. Increased enamel hypoplasia and very low birthweight infants. *Journal of Dental Research* 92: 788–794.

Papathanasiou, Anastasia, Clark Spencer Larsen, and Lynette Norr. 2000. Bioarchaeological inferences from a Neolithic ossuary from Alepotrypa Cave, Diros, Greece. *International Journal of Osteoarchaeology* 10(3): 210–228.

Pinhasi, Ron, and Jay L. Stock, eds. 2011. *Human bioarchaeology of the transition to agriculture.* Chichester, West Sussex: Wiley-Blackwell.

Prowse, Tracy, Henry P. Schwarcz, Shelley Saunders, Roberto Macchiarelli and Luca Bondioli. 2004. Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. *Journal of Archaeological Science* 31: 259–272.

Ransford, Rupert A. J., Mark Hayes, Martin Palmer, and Michael J. Hall. 2002. A controlled, prospective screening study of celiac disease presenting as iron deficiency anemia. *Journal of Clinical Gastroenterology* 35(3): 228–233.

Reunala, Timo. 1998. Dermatitis herpetiformis: Coeliac disease of the skin. *Annals of Medicine* 30(5): 416–418.

Roberts, Charlotte, and Keith Manchester. 2007. Metabolic and Endocrine Disease. In *The archaeology of disease.* 3rd edition. Ithaca, NY: Cornell University Press.

Robinson, Geoffrey C., James R. Miller, and H. M. Worth. 1966. Hereditary enamel hypoplasia: Its association with characteristic hair structure. *Pediatrics* 37(3): 498–502.

Rogol, Alan D., and Gregory F. Hayden. 2014. Etiologies and early diagnosis of short stature and growth failure in children and adolescents. *The Journal of Pediatrics* 164(5): S1–14.

Rothschild, Bruce. 2012. Extirpolation of the mythology that porotic hyperostosis is caused by iron deficiency secondary to dietary shift to maize. *Advances in Anthropology* 2(3): 157–160.

Roushdy-Hammady, I., J. Siegel, S. Emri, J. R. Testa, and M. Carbone. 2001. Genetic-susceptibility factor and malignant mesothelioma in the Cappadocian region of Turkey. *The Lancet* 357(9254): 444-445.

Rubio-Tapia, Alberto, Jonas F. Ludvigsson, Tricia L. Brantner, Joseph A. Murray, and James E. Everhart. 2012. The prevalence of celiac disease in the United States. *The American Journal of Gastroenterology* 107: 1538–1544.

Rühli, Frank J., and Salima Ikram. 2014. Purported medical diagnoses of Pharoah Tutankhamun, c. 1325 BC-. *HOMO* 65(1): 51–63.

Rutgers, L.V., M. van Strydonck, M. Boudin, and C. van der Linde. 2009. Stable isotope data from the early Christian catacombs of ancient Rome: New insights into the dietary habits of Rome’s early Christians. *Journal of Archaeological Science* 36: 1127–1134.

Schoeninger, Margaret J., and Katherine Moore. 1992. Bone stable isotope studies in archaeology. *Journal of World Prehistory* 6(2): 247–296.

Scorrano Gabriele, Mauro Brilli, Cristina Martinix-Labarga, Francesca Guistini, Elsa Pacciani, Filberto Chilleri, Franco Scaldaferri, Antonio Gasbarrini, Giovanni Gasbarrini, and Olga Rickards. 2014. Palaeodiet reconstruction in a woman with probable celiac disease: A stable isotope analysis of bone remains from the archaeological site of Cosa (Italy). *American Journal of Physical Anthropology* 154: 349–356.

Schuppan, Detlef, Yvonne Junker, and Donatella Barisani. 2009. Celiac disease: From pathogenesis to novel therapies. *Gastroenterology* 137*:* 1912–1933.

Selçuk, Ziya Toros, Lütfi Çöplü, Salih Emri, Ali Fuat Kalyoncu, Ahmet Altay Şahin, Yusuf Izzettin Bariş. 1992. Malignant pleural mesothelioma due to environmental mineral fiber exposure in Turkey: Analysis of 135 cases. *Chest* 102: 790–796.

Simoons, Frederick J. 1981. Celiac disease as a geographic problem. *Food, Nutrition and Evolution.* Dwain Newton Walcher and Norman Kretchmer, eds. New York: Mason.

Smith, D. M., and J. Miller. 1979. Gastro-enteritis, coeliac disease and enamel hypoplasia. *British Dental Journal* 147(4): 91–95.

Stone, Anne C. 2008. DNA analysis of archaeological remains. In *Biological anthropology of the human skeleton.* M. Anne Katzenberg and Shelley R. Saunders, eds. 2nd edition. Pp. 461–483. Hoboken, NJ: John Wiley & Sons.

Stravopodi, Eleni, Sotiris K. Manolis, Stravros Kousoulakos, Vassiliki Aleporou, and Michael P. Schultz. 2009. Porotic hyperostosis in Neolithic Greece: New evidence and further implications. *Hesperia Supplements* 43: 257–270.

Valdimarsson, T., O. Löfman, G. Toss, and M. Ström. 1996. Reversal of osteopenia with diet in adult coeliac disease. *Gut* 38: 322–327.

Vazquez, Horacio, Roberto Mazure, Diana Gonzalez, Daniel Flores, Silvia, Pedreira, Sonia Niveloni, Edgardo Smecuol, Eduardo Mauriño, and Julio C. Bai. 2000. Risk of fractures in celiac disease patients: A cross-sectional, case-control study. *American Journal of Gastroenterology* 95(1): 183–189.

Wells, Jonathon C.K., and Jay L. Stock. 2007. The biology of the colonizing ape. *Yearbook of Physical Anthropology* 50: 191–222.

Wierink, Claar D., Denise E. van Dierman, Irene H. A. Aartman, and Hugo S. A. Heymans. 2007. Dental enamel defects in children with coeliac disease. *International Journal of Paediatric Dentistry* 17(3): 163–168.

Using debitage analysis to investigate an Alberta archaeological site

by Jennifer Hallson

Ahai Mneh (FiPp-33) is a significant pre-contact archaeological site in Alberta. Located west of Edmonton on Lake Wabamun, this site contains material from the Early Prehistoric right up until Late Prehistoric pre-contact times. Ninety-five percent of the lithic artifacts collected are pieces of debitage. Aggregate analysis is a method of examining the whole of the debitage collection, rather than analysing singular pieces. This method is more time efficient, less subject to bias, replicable, and is used often, and successfully, at archaeological sites with immense quantities of debitage. Here I use aggregate analysis to examine the debitage assemblage from two field schools at Ahai Mneh. I investigate various characteristics such as size, raw material type, cortex amount, and number of dorsal scars. I argue that this method is successful, as it provided new information on where people were acquiring raw materials, as well as what types of flintknapping occurred at this site. These analyses resulted in the determination of a focus on local raw material, yet this material was being brought to the site as prepared cores or blanks, rather than complete unaltered cores. Tool production was the focus at this site, and this trend continued throughout time.

Introduction

Ahai Mneh (FiPp-33) is a significant archaeological site in Alberta that has produced material from the Early Prehistoric Period through to the Late Prehistoric Period. It is located south of Lake Wabamun and west of the city of Edmonton (fig. 1). Cultural Resource Management (CRM) work at this site has determined that it is a multicomponent pre-contact campsite (Soucey *et al.* 2009). Two field schools run by the Institute of Prairie Archaeology (IPA) at the University of Alberta in 2010 and 2012 support this determination. The majority of the artifacts found were pieces of lithic debitage: the detached pieces of stone created during the manufacture of stone tools (also known as flakes, debris, chips, or refuse). I performed aggregate analysis on the debitage collected during these field schools to identify and classify the debitage to further inform the overall site interpretation. Aggregate analysis is a method that groups debitage within an assemblage based on non-technological criteria (Larson 2004:6); i.e., not identifying the tool (technology) that was being produced. I argue that this method is successful at indicating activities and behaviour that occurred at the site with respect to lithic technology and argue that this method should be used at other sites where there are large amounts of debitage.

Previous Research at Ahai Mneh

Previous excavations and analysis at Ahai Mneh identify this site as a multi-component campsite where various activities (hunting, hide-working, etc.) occurred over a ca. 10 000 year span (Rawluk *et al.* 2011; Schenk and Yanicki 2011; Soucey *et al.* 2009). Ahai Mneh covers an area around 10 000 m^2 and contains projectile points from throughout the precontact period (Table 1). Occupation appears to have begun during the

---

Jennifer Hallson completed her MA in the Department of Anthropology at the University of Alberta (previous affiliation [hallson@ualberta.ca]).

Figure 1. Location of Ahai Mneh (FiPp-33) compared to Edmonton and Lake Wabamun.

Table 1. Identified projectile point styles excavated from Ahai Mneh (FiPp-33) and their associate ages, in radiocarbon years before present (RCYBP). Dates from Bubel, McMurchy, and Lloyd (2012).

Period (age in RCYBP)	Projectile Point Style/Complex	Age (RCYBP)
Early Prehistoric (11 200 – 7500)	Agate Basin	10 200 – 9600
	Scottsbluff	9000 – 8600
	Lusk	8300 – 7500
Middle Prehistoric (7500 – 1350)	Oxbow	4500 – 4100
	McKean	4200 – 3500
	Hanna	3900 – 3500
	Besant	2100 - 1500
Late Prehistoric (1350 – 250)	Avonlea	1350 – 1100
	Plains Triangular and Side-notched arrowheads	1100 – 250

Agate Basin Complex and continued periodically through to the Late Prehistoric, just prior to the contact period. Because of the amount of reoccupation and the depth of history, Ahai Mneh is an important part of Alberta's story.

Ahai Mneh was first identified in 1979 during a historical resources impact assessment (HRIA) that consisted only of surface survey (Fedirchuk 1979). In 2005, another HRIA was completed at Ahai Mneh that consisted of surface collections and 46 shovel tests. A total of 120 lithic and bone artifacts were recovered (Soucey *et al.* 2009:40). Further excavation of Ahai Mneh took place in 2008 as part of a historical resource impact mitigation (HRIM) project at four sites around Lake Wabamun (Soucey *et al.* 2009:1). Forty-four square metres and an additional 231 shovel tests were excavated, still accounting for a relatively small portion of the overall site. A total of 5798 artifacts were collected including stone tools, lithic debitage, and bone fragments (Soucey *et al.* 2009:45). Soucey *et al.*'s (2009:7) analyses of the stone tools suggested that this site had a larger variety of activities occurring at it compared to other precontact sites in the area.

A common problem encountered when interpreting Albertan archaeological sites is compressed stratigraphy. At Ahai Mneh, roughly 10 000 years of material culture are compressed into 30-40 cm thick deposits, which makes it difficult to identify components[1] and attribute artifacts to a specific time period or occupation. Rawluk *et al.* (2011) and Schenk and Yanicki (2011) performed analyses on the 2010 field school material from Ahai Mneh in an attempt to account for these issues. Rawluk *et al.* (2011) performed three-dimensional modeling of the excavated units to see if they could identify separate components. Their modeling of the three-point proveniences of the lithic artifacts, along with an examination of raw material frequencies, allowed them to tentatively identify two components in one excavation area (Area B) and three components in another (Area A). Schenk and Yanicki (2011) performed an in-depth study of the Early Prehistoric projectile points recovered from Ahai Mneh and suggested that there were multiple occupations represented during this time period.

Thorough aggregate analysis has not been completed on any of the Ahai Mneh material to date. The fact that debitage is the most common artifact found at this site calls for a study of this refuse assemblage. I expand on what has previously been learned about Ahai Mneh by analysing the debitage from the two field schools and using the results to learn more about the people using this site.

Review of Debitage Analysis Methods

Hundreds or thousands of years of taphonomic processes often result in an archaeological assemblage composed of only lithic material (Fig. 2). Of these lithics, debitage by far outnumbers stone tools, sometimes comprising over 99% of an assemblage (Shott 2004:211). Stone tools were frequently reused or repurposed, and often taken with the owner when they left a site, leaving few for archaeologists to find.

In contrast, flaking debris is often left at or near the location it was made (Binford 1983:153). Stone tools are the "sexy" part of lithic analysis, whereas debitage is often looked at as the necessary evil that must be excavated. Nonetheless, studying flaked debitage informs archaeologists on the acquirement, manufacture, use, and discard of stone tools and debris in the past, which can then inform us of past behaviour (Shott 2004:211-212).

---

[1] A component is a culturally homogeneous stratigraphic unit within a site and corresponds to the number of uses of a site (i.e., a site used once will have a single component, and a site used multiple times will have multiple components) (Darvill 2008).

Figure 2. A sample of debitage collected from Ahai Mneh (FiPp-33).

Various approaches to debitage analysis have been developed. Some methods concentrate on individual artifacts while others examine the assemblage as a whole (Andrefsky 2005:113; Odell 2003:120). Individual artifact analysis attempts to identify past behaviour based on a single artifact; for example, the presence of a biface reduction flake suggests that bifaces were manufactured and, likely, used (Andrefsky 2004, 2005). This type of analysis is very time consuming, and can fail to look at the population as a whole. Analysis of the entire assemblage examines the variability within the population to study past behaviour (Andrefsky 2004; 2005). Aggregate analysis studies the assemblage by stratifying the entire assemblage based on characteristics such as size and raw material type and then compares the frequencies in each stratum (Andrefsky 2005:131). Aggregate analysis introduces less bias than other methods, as it makes no assumptions about the type of technology occurring, and is less subject to human differences in identification (Larson 2004). For example, different archaeologists can use different terms for the same artifact, or use different definitions for the various flake types (Bradbury and Carr 2004:86). Using flake attributes that are more difficult to identify also introduces more bias due to the varying lithic expertise and experience of researchers (Bradbury and Carr 2004:86).

Mass analysis is a specific type of aggregate analysis that stratifies the assemblage according to size (Ahler 1989; Carr and Bradbury 2004:21). Mass analysis is a popular method for examining debitage assemblages due to its effectiveness, replicability, and time efficiency (Ahler 1989; Carr and Bradbury 2004:21). The theory behind mass analysis is that flintknapping is a reductive process: no flake can be larger than the core or tool it was produced from (Ahler 1989:89). During the reduction sequence from core to tool “the maximum possible size as well as average size of the flake byproducts should decrease significantly” (Ahler 1989:89). Mass analysis also eliminates intra-observer bias, as it does not assume that any specific technology is occurring (Larson 2004:6). This technique can also be performed without extensive training, as the size of a piece of debitage is simple to identify compared to other characteristics. It can even be completed mechanically with nested screens of decreasing size. Researchers can analyse thousands of flakes quite quickly, an obvious advantage that mass analysis has over more individual artifact based analysis (Ahler 1989:86-87). This method may be biased by field recovery methods, however; standard practice is to use quarter inch mesh to screen excavated fill, which does not always allow for the collection of small artifacts such as pressure flakes (Carr and Bradbury 2004:42). Another issue with mass analysis is that it can be influenced by taphonomic factors. Trampling and other post-depositional factors can break flakes and increase the number of smaller (broken) flakes, skewing the results. The largest problem, however, is mixed assemblages (Ahler 1989:89; Carr and Bradbury 2004:43; Shott 2004:219), which are discussed further below. Despite these limitations mass analysis continues to be a commonly used method and has "great potential for aiding our understanding of prehistoric lithic assemblages" (Carr and Bradbury 2004:41).

Bradbury and Carr (2004) performed flintknapping experiments to test whether debitage analysis could identify the type of lithic reduction (the process of reducing raw material, such as a core, into something else, such as a tool) occurring. The authors manufactured different cores and tools using various reduction types, including hard and soft hammer percussion, and examined the debitage created from each session (Bradbury and Carr 2004:70). They concluded that assemblages with a large proportion of blocky debris (also known as angular shatter: pieces of debitage with no identifiable flake attributes) are indicative of core reduction, whereas blocky debris was nearly non-existent, or even completely non-existent, during tool production (Bradbury and Carr 2004:73, 76). They found that core reduction assemblages generally contained 10-20% angular shatter (Bradbury and Carr 2004:73). This allowed the authors to perform the analyses quickly, making this form of analysis ideal for archaeological studies that are pressured to do more with less time – a common issue in modern archaeology. In particular, the speed with which aggregate and mass analysis can be completed is attractive for CRM companies that may not have the time for complex analyses.

Mixed assemblages still pose a problem for aggregate and mass analyses. These assemblages occur at sites where many activities are occurring (e.g., campsites), including core reduction and different types of tool production. Andrefsky (2005:141) advocates for using aggregate analysis only on assemblages that were deposited from a single distinct event. However, identification of distinct occupation events is not possible at many sites, including Ahai Mneh. Mass analysis cannot determine what types of tools were being produced (Andrefsky 2004:205); however, Bradbury and Carr's (2004:78-81) experiments demonstrated that aggregate analysis could distinguish between core reduction and tool production, even in mixed assemblages.

Andrefsky (2004) is quick to criticize the use of mass analysis for mixed assemblages but he does not suggest an alternative method, other than attempting to delineate individual components. I agree with Andrefsky (2004) that mass analysis cannot be the only form of analysis done on an assemblage, but I disagree that mass analysis cannot be done on mixed assemblages. The sheer volume of debitage from sites like Ahai Mneh requires the use of relatively efficient methods unless researchers want to devote hundreds of hours of time to individual analyses. The compressed nature of sites like Ahai Mneh does not allow for identification of single components, especially when the debitage counts are in the thousands or even millions. Many researchers

Figure 3. 1 m x 1 m units in Area A from the 2012 Institute of Prairie Archaeology field school. Looking west.

who continue to use and study debitage analysis see it as a useful way to quickly and simply learn about the assemblage and the site (e.g., Ahler 1989; Bradbury and Carr 2004; Larson 2004; Magne 1989). Bradbury and Carr's (2004) experiments prove that debitage analysis can be successful in mixed assemblages. While aggregate analysis of multi-component sites may introduce error due to the long period of use, I believe it is still a valuable tool to study what was recovered from a site.

Methods

Excavation and Cataloguing

During the two field schools a total of 24 1x1 metre units were excavated in three different areas (A, B, and C) within Ahai Mneh (fig. 3). Arbitrary 5 cm levels were used to control for provenience of screen finds. Three-point proveniences were taken for all artifacts found in situ and the fill was screened through ¼ inch mesh. Field school students and undergraduate volunteers catalogued the artifacts recovered based on a key provided by the IPA. Each individual artifact was given a unique catalogue number. Cataloguing and storage procedures conform to the Royal Alberta Museum's standards for submission of artifacts.

Debitage Analysis

Aggregate and mass analyses were chosen because of the large volume of debitage collected from this site. The following categories were analysed: size, raw material, debitage type, amount of cortex, and number of dorsal scars.

Magne (1989:17) lists dorsal scar count and amount of cortex as two of the most useful variables for reconstructing manufacturing stages of stone tools. The analysis was completed on the assemblage as a whole, but also by 5 cm level in an attempt to address the issue of mixed assemblages discussed above, and to see if patterns changed through time. Though lithic analysis novices completed the cataloguing and identification, this should minimally affect my analyses because the categories chosen for examination are easily identifiable by beginners.

A total of 8104 lithic artifacts were collected from Ahai Mneh during the two field schools, including 233 stone tools. Surface finds and artifacts recovered from shovel tests were omitted from the analysis because they do not have a secured provenience. As a result, 7709 pieces of debitage with known proveniences are available for this analysis. Angular shatter was not included in the analysis of cortex amount or dorsal scars because, by definition, a dorsal side cannot be identified, leaving 6991 pieces for analysis in these two categories.

Size:

The debitage was grouped into several size classes (<3.35 mm, 3.35-6.3 mm, 6.3-12.5 mm, 12.5-50.0 mm, and >50.0 mm[2]) based on total length from proximal to distal end. This method does ignore the variability of sizes due to other dimensions such as width and thickness (Andrefsky 2005:102). Because mass analysis can be completed using screens with different sized mesh to quickly divide debitage into these size classes, this can allow long, thin flakes to go through the mesh as long as the width is smaller than the mesh size. Length for this assemblage was measured using a ruler, and length was the size variable chosen because it is the dimension commonly measured by researchers, and is the standard measurement with which to complete mass analysis (Andrefsky 2005:132). Length is typically the largest dimension. Logically, larger flakes come from larger pieces of raw material, so are indicative of the earlier stages of reduction, whereas smaller flakes can be indicative of the later stages.

Raw Material:

The raw material of each artifact was identified during the cataloguing process. Raw material type is a frequent focus of archaeological study as it can inform archaeologists about where people were getting material for making tools. This could also indicate where people travelled to or whom they may have traded with to obtain raw material. Past levels of mobility and raw material preferences can then be examined. I used the frequencies of local versus exotic raw materials to determine the degree of movement the populations using Ahai Mneh exhibited.

Type:

Each piece of debitage at Ahai Mneh was identified as either a flake or a piece of angular shatter. Bradbury and Carr’s (2004) experiments indicated that assemblages with a high proportion of angular shatter are indicative of a focus on core reduction rather than tool production. I use this finding to determine whether core reduction or tool production was a focus at Ahai Mneh.

Amount of Cortex:

Cortex is the outer surface of a piece of raw material, and can be caused by chemical or mechanical weathering (Andrefsky 2005:103). Cortex is typically highly present in the initial stages of reduction, and is less so in later stages (Magne 1989:17). This follows the logical assumption that the exterior of the raw material

---

[2] These size classes roughly convert to 1/8”, 1/4”, 1/2”, and 2”, respectively.

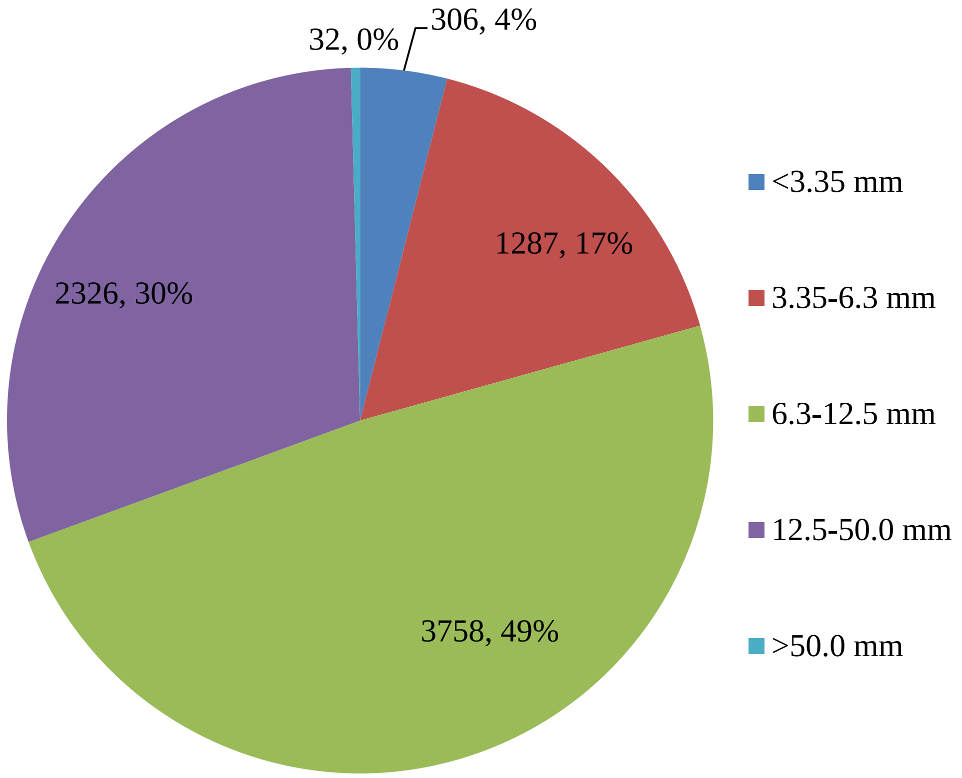


Figure 4. Results for the mass analysis of the Ahai Mneh (FiPp-33) debitage assemblage.

will be removed first, though the cortex amount will vary due to factors such as the amount of cortex on the original piece, reduction technique, and the type of artifact being produced (Andrefsky 2005:104). I use the amount of cortex present to determine the stages of reduction that were occurring more frequently at Ahai Mneh.

Dorsal Scars:

Andrefsky (2005:109) demonstrated intra-observer error when counting dorsal scars on flakes and created categories (0, 1, 2, and 3 or more) for analysis that account for this error. The number of dorsal scars increases as reduction continues (Magne 1989:17). I use the frequencies in each of these categories to examine which stages of reduction were occurring.

Results

Size Classes

The breakdown of the entire debitage assemblage by size class is shown in Figure 4. The majority of the pieces are less than 12.5 mm long, and there are few very large (>50.0 mm) and very small (<3.35 mm) pieces. The most frequent size class is 6.3-12.5 mm.

Raw Material

Figure 5 demonstrates the frequency of each raw material from the Ahai Mneh debitage assemblage. Materials with 20 pieces or less are grouped together under the category of “Other” for simplicity and to provide a better visual depiction (see Appendix A for list of raw

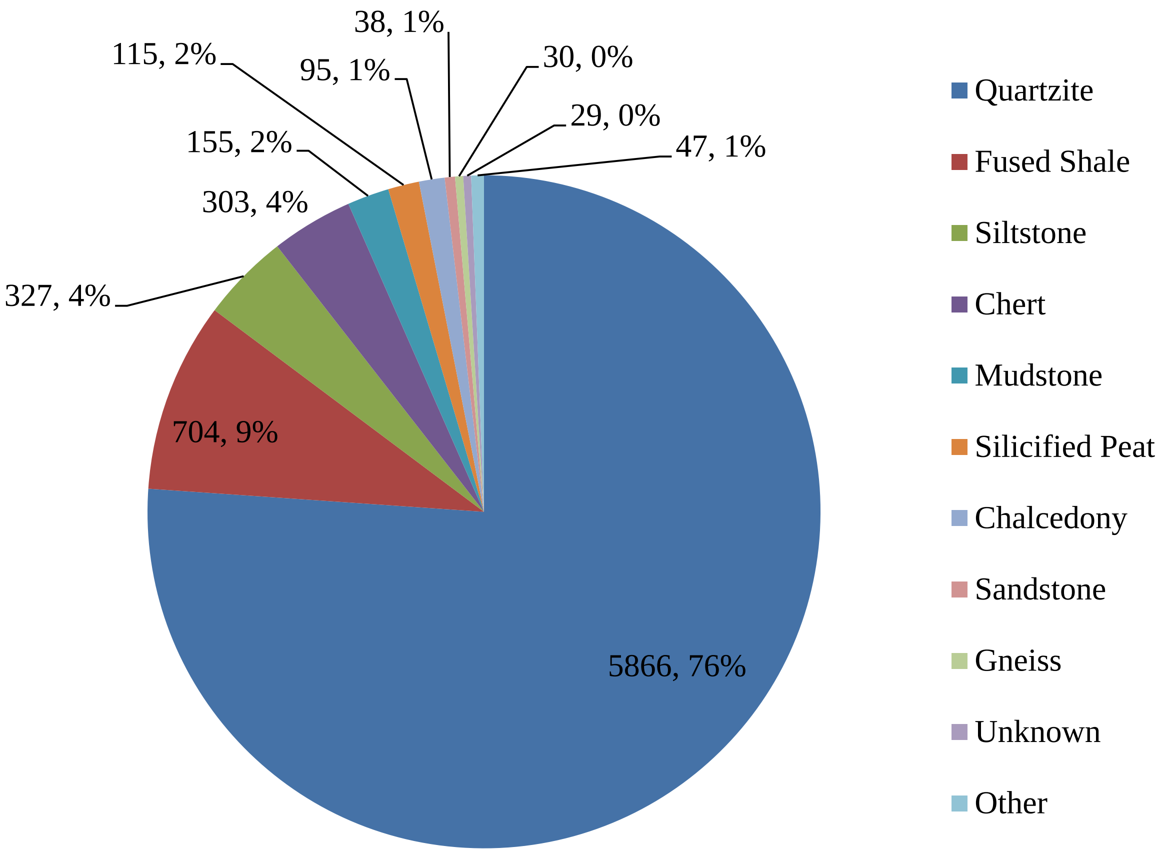


Figure 5. Raw material of the Ahai Mneh (FiPp-33) debitage assemblage.

materials included in "Other"). The assemblage is dominated by quartzite. This material is the most common found at Alberta archaeological sites, and would have been readily accessible as cobbles in the area, such as in creek and riverbeds (Bubel, McMurchy, and Lloyd 2012). The next most frequent raw material, fused shale, is also a local material found in coal seams in the surrounding area[3]. Other common materials, such as types of siltstone, chert, and mudstone, would also be fairly easy to obtain in various places in Alberta (Bubel, McMurchy, and Lloyd 2012). Exotic materials such as obsidian (N = 9) are present, but in low numbers. Another exotic material, Knife River Flint (KRF), has a single source in North Dakota and was common in Alberta during the Cody Complex (9600 – 8600 RCYBP) and Besant Phase (2100 – 1500 RCYBP) (Bubel, McMurchy, and Lloyd 2012:31). Despite Ahai Mneh having projectile points dating to these temporal periods, a limited amount of KRF was recovered (N = 6).

Types of Debitage

Figure 6 shows the proportion of flakes and angular shatter at Ahai Mneh. Angular shatter comprises only 9.3% of the Ahai Mneh assemblage. Some of the debitage from Ahai Mneh was identified to different flake types, such as biface reduction flakes and core reduction flakes, but the majority were not because students new to lithic analysis catalogued this assemblage.

---

[3] The Highvale Coal Mine surrounds Ahai Mneh to the north and east.

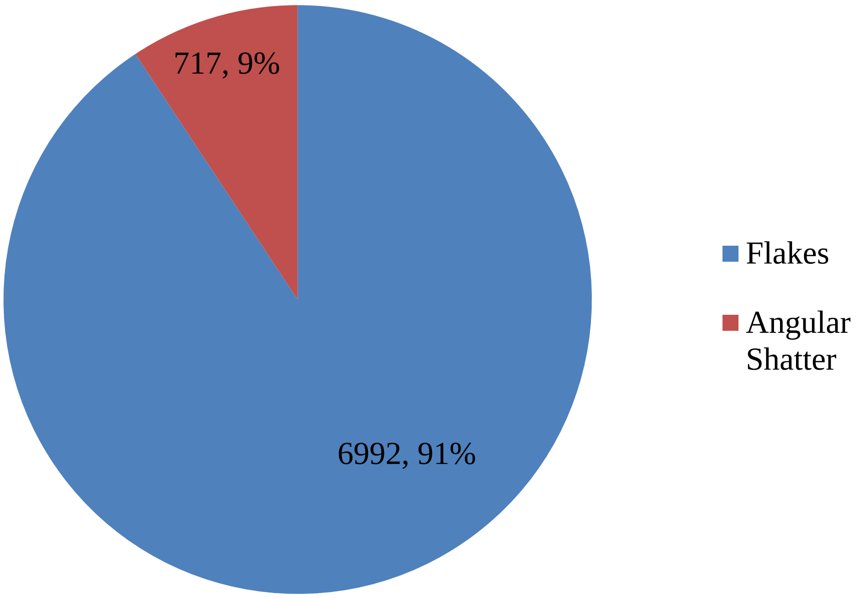


Figure 6: Proportion of flakes versus angular shatter in the Ahai Mneh (FiPp-33) debitage assemblage.

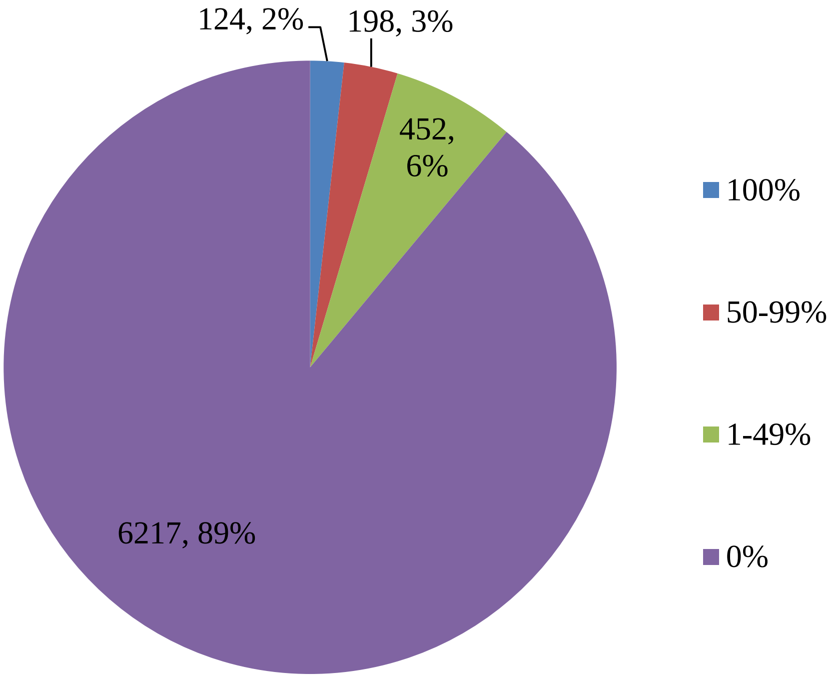


Figure 7: Amount of cortex on flakes from Ahai Mneh (FiPp-33).

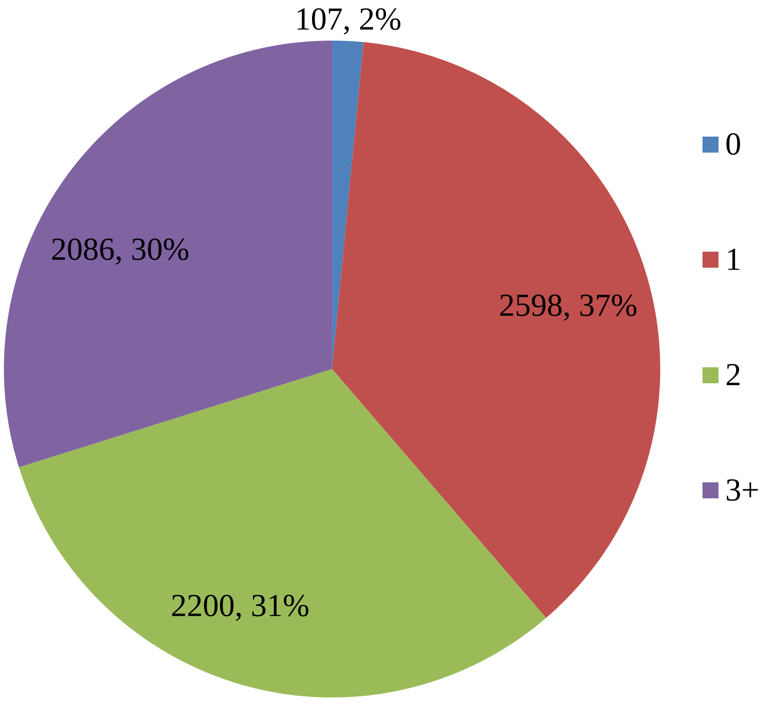


Figure 8. Number of dorsal scars on flakes from the Ahai Mneh (FiPp-33).

These identifications are not included here due to the high probability of incorrect and missed identifications.

Amount of Cortex

The majority of flakes (89%) analyzed at Ahai Mneh did not have any cortex present (fig. 7). The fused shale found at Ahai Mneh is found in outcrops near coal seams and does not have cortex. Removing these pieces from the analysis resulted in a similar 88% in the zero cortex category.

Dorsal Scars

Figure 8 depicts the number of dorsal scars on the flakes from Ahai Mneh according to Andrefsky's (2005) categories of 0, 1 , 2, and 3 or more dorsal scars. Except in the "0" category, there is a fairly even spread of flakes with one, two, and three or more dorsal scars (fig. 8).

Analysis by Level

To mediate the criticisms of using aggregate analysis for mixed assemblages and assemblages that span long time periods, I also examined the categories by level (see Appendix B). Though not a perfect fix, this does decrease the temporal time frame represented, increasing the likelihood that debitage found at the same level were produced at the same time. I examined the debitage collected from each 5 cm level, and my analysis produced the same results as above, which strengthens their validity. The compressed nature of this site does not allow for extremely precise single-component based analyses, but the level based analyses are still useful in analysing temporal trends.

Discussion

The size of the Ahai Mneh debitage was the first characteristic examined. Size can be an indicator of the reduction stage, as pieces tend to get smaller as reduction progresses (Ahler 1989:89). Debitage size is also an indicator of the size of raw material available at the site. The small number of large flakes suggests that the raw materials being brought to the site were not large to begin with. Given that the majority of the assemblage is quartzite, this is consistent with people collecting river cobbles for use. Also, if people were focusing on tool production, they may have prepared cores elsewhere and transported them to Ahai Mneh as smaller pieces. Another reason that large pieces of debitage are not found could be that raw material was utilized to its full extent; large flakes could be turned into tools, creating smaller flakes and leaving no unused larger flakes. However, provided that the majority of the raw material was locally obtained, utilizing all available raw material pieces would be unnecessary. The few cores (N = 15) that were excavated at this site are not large (majority are less than 500 grams), suggesting that few cores were brought to the site, cores were being highly utilized, cores were being transported away from the site, or a combination of these scenarios.

The results of the raw material analysis demonstrate a heavy reliance on local raw materials at Ahai Mneh, and supports the argument that trade for raw materials was not a focus while groups were occupying the site. Less than 1% of the lithic artifacts recovered from Ahai Mneh would be considered exotic. Since exotic materials such as obsidian and KRF do appear in higher frequencies at other Albertan sites throughout various time periods, I suggest that Ahai Mneh residents were not travelling or trading for these materials to the extent that other groups in the province were. Another possibility is that Ahai Mneh was occupied during periods of the year when trade or travel was not available. Instead, raw material seems to have been collected very near to the site, and may have been the reason for continuous reoccupation of Ahai Mneh.

Bradbury and Carr (2004:73) found that experimental assemblages had between 10-20% angular shatter. Angular shatter comprises less than 10% of the Ahai Mneh assemblage (9.3%), indicating that tool production was the focus, but that a minimal amount of core reduction did occur. Soucey *et al.* (2009) corroborate these findings as their debitage assemblage included only 11.4% angular shatter.

Most of the flakes from Ahai Mneh did not have cortex on them, suggesting that the later stages of reduction were occurring on site. As mentioned earlier, fused shale does not have cortex. The other raw materials found at the site, most notably quartzite, but also siltstone and chert, do typically have cortex. Magne (1989:17-18) states that after the initial reduction stages the amount of cortex should decrease sharply. The large quantity of flakes without cortex at Ahai Mneh (89%) indicates that the primary reduction stages, where cortex would be removed, occurred elsewhere. People were likely bringing in prepared cores, perhaps in the form of bifaces, and then completing final tool production at Ahai Mneh. Another explanation is that individuals were revitalizing used tools. For example, re-tipping broken projectile points for further use would produce flakes with no cortex.

The results from the analysis of dorsal scars are consistent with a focus on tool production, with core reduction occurring off site. If core reduction were more frequent, we would expect more flakes with zero or one dorsal scar. The number of dorsal scars increases as reduction progresses (Magne 1989:17). The dorsal side of flakes with zero dorsal scars are completely covered in cortex, and would be from the primary reduction stage. Only 2% of the flakes have zero dorsal scars (similarly, only 2% of the flakes have 100% cortex). Cortex may or may not be present on flakes with one dorsal scar, but these are more likely to be produced during the initial stages of reduction.

Overall, the results of the debitage analyses at Ahai Mneh support the interpretation that this was a campsite where people frequently made and rejuvenated tools. The results demonstrate a focus through time on tool production using raw materials that had been prepared off site. Local materials were obtained nearby and provided the bulk of resources. The later stages of the reduction sequence occurred more often, although all stages occurred in varying frequencies. The infrequency of cores, angular shatter, large flakes, and cortical flakes at Ahai Mneh suggest that people were bringing prepared cores or raw material to the site from another location. There were various ways for people to transport raw material more efficiently than carrying whole cores, including prepared cores, flake and biface blanks, and preforms (Pecora 2001). My analyses indicate that the majority of raw material transported to Ahai Mneh was done so in one of these forms. It would have been much more efficient to complete the initial reduction at the source rather than have to carry full cores to Ahai Mneh or other sites. In conjunction my analyses indicate that prepared cores or more formed tools (preforms) were brought to the site and that the later stages of production occurred at Ahai Mneh.

Ahai Mneh was utilized for thousands of years in what appears to be a similar way. Throughout time, people were bringing in previously processed raw materials rather than full cores. This site was evidently a good place for a campsite. The highest part of the site provides excellent visibility of the landscape for hunting or scouting. It is also near a large water source, Lake Wabamun, which has been present continually from the time the site was first occupied until the present (Hickman, Schweger, and Habgood 1984). Lake Wabamun did not dry up during the Hypsithermal (a warm, dry period during the middle Holocene), and therefore may have provided an oasis of sorts during this time. The North Saskatchewan River, a source of raw material and an avenue for transport, is less than 15 km southeast. If people were occupying Ahai Mneh for long periods of time they would need to replenish their raw material sources. Retooling would have been easily accomplished by acquiring local materials from rivers (quartzite) or nearby coal seams (fused shale) and bringing resources back as prepared materials. The landscape around Ahai Mneh was more suitable for setting up a large camp rather than areas right by the river or near the coal seams. Resource collection implies knowledge of the area and the available raw materials. I would argue that the consistent re-use of this site indicates knowledge of the local raw materials, and this access may have been one reason for continued use. Beck *et al.* (2002) indicated that the farther people had to travel, the more reduction occurred at a quarry. This suggests that the people occupying Ahai Mneh were mobile and potentially used this site as a base to retool with quartzite and fused shale before moving on.

Archaeological sites in Alberta so often yield only lithic material. Except for small, unidentifiable pieces of decomposed bone, most of the assemblage recovered at Ahai Mneh is lithic, and of that roughly ninety-five percent is debitage. Stone tool analysis is useful in identifying what tools are present at a site, and the tools can be used to indicate what activities took place (i.e., an endscraper suggests hide working took place). However, where a tool is discarded is not necessarily where it was used. Broken and reusable artifacts can be kept to be recycled or repaired instead of discarded (e.g., Binford 1976). A site where hide working occurred may show no evidence of it if all the tools were reused or recycled. Multiple cultural processes play into whether a stone tool will be discarded, including curation rates, breakage rates, size, manufacturing cost, transportation costs, and more (Adams 2003; Schiffer 1987; Shott 1989; Surovell 2009). Conversely, debitage is unique in that it is typically discarded at or very near its origin and then left in situ, with minimal cultural processes applied to it (Ahler 1989:86; Binford 1983:153; Schiffer 1987:267; Stevenson 1991). In this sense, debitage analysis can provide a way to study past activities without as much human intervention in discard and post-discard processes. Since such a large portion of the artifact assemblage at Ahai Mneh is debitage, debitage analysis is one of the few ways with which we can learn more about the past use of this site and the activities that occurred there. Examining the Ahai Mneh debitage collection as a whole and by level resulted in the identification of tool production as a main activity at this site, which could not be confirmed prior to this analysis.

I argue that debitage analysis should be a method applied to the many sites in Alberta and the rest of North America where lithic debitage is the main artifact collected. In particular, my analysis did not require large amounts of time, which is ideally suited for CRM or recovery-based archaeology. The most time consuming part of my analysis was the cataloguing and identifying of each artifact. However, many of these methods can be applied without individual cataloguing. For example, size can be examined with nested screens. As discussed previously, this method of size division does not keep a consistent dimension. My method of using length was more time consuming, since each flake was placed into a size category individually, but I argue this method is more consistent, and can still be done quite quickly if needed. Debitage can also be quickly sorted based on other characteristics, like amount of cortex, without individual cataloguing.

Aggregate debitage analysis is a technique that has the potential to be very useful for CRM archaeologists who do not have the time to do complex analyses, but do have time for simple debitage analyses to provide some initial conclusions. It will also be relatively easy to apply these methods to any collections that have already been catalogued, provided that the characteristics used were noted. The analysis does not require much training, as the characteristics noted are quantitative and can be easily replicated. This methodology is ideal for field school collections and CRM collections where the researchers may not be lithic or stone tool experts.

Conclusion

The analysis of the Ahai Mneh debitage assemblage concluded that tool production and rejuvenation were the main lithic activities occurring throughout time. Prior to the above analyses, it was evident that abundant flintknapping had occurred, but not for what exact purpose. From my analysis we now know that local material was relied on and that people were bringing prepared raw material to the site rather than complete cores. The initial stages of reduction were occurring elsewhere, with only the final reduction stages occurring at Ahai Mneh. The availability of raw material, along with the proximity of Lake Wabamun and the North Saskatchewan River, was likely a reason for the continued use of Ahai Mneh. The completed debitage analysis adds to the knowledge of the site’s history and indicates past land use and activity. Much more can and should be done not only with the above results, but also by applying more and other methods to the collection. Using multiple methods of analysis will provide a more holistic interpretation of site activities (Carr and Bradbury 2004; Larson 2004; Shott 2004). The stone tools from Ahai Mneh should be analysed and compared to this analysis, and the flakes should be individually analysed and identified to different types. It would also be fruitful to examine the debitage by excavation area, and include the previous CRM excavations in the analysis. This may reveal differences in activity among the areas. Learning everything possible about a site furthers our knowledge of Alberta's rich history, and also helps to protect significant sites from further destruction by identifying these key sites.

Acknowledgements

This paper is a reworked version of a term paper submitted to Todd Kristensen for his Stone Tools course in Winter 2015, and I thank him for earlier comments. Thank you to Dr. John (Jack) Ives, instructor of both 2010 and 2012 field schools, for his guidance. I also thank my fellow field school students and IPA volunteers for their work excavating and cataloguing this assemblage. Three anonymous reviewers provided valuable feedback and suggestions that greatly improved this paper.

References Cited

Adams, William Hampton. 2003. Dating Historical Sites: The Importance of Understanding Time Lag in the Acquisition, Curation, Use, and Disposal of Artifacts. *Historical Archaeology* 37(2):38-64.

Ahler, Stanley A. 1989. Mass Analysis of Flaking Debris: Studying the Forest Rather Than the Tree. In *Alternative Approaches to Lithic Analysis*. D. O. Henry and G. H. Odell, eds. Pp. 85-118. Archaeological Papers of the American Anthropological Association No. 1. Washington, D.C.

Andrefsky, William Jr. 2004. Partitioning the Aggregate: Mass Analysis and Debitage Assemblages. In *Aggregate Analysis in Chipped Stone*. Christopher T. Hall and Mary Lou Larson, eds. Pp. 201-210. Salt Lake City: The University of Utah Press.

——— 2005. *Lithics: Macroscopic Approaches to Analysis*, 2nd edition. New York: Cambridge University Press.

Beck, Charlotte, Amanda K. Taylor, George T. Jones, Cynthia M. Fadem, Caitlyn R. Cook, and Sarah A. Millward. 2002. Rocks are heavy: transport costs and Paleoarchaic quarry behaviour in the Great Basin. *Journal of Anthropological Archaeology* 21(4):481-507.

Binford, Lewis R. 1976. Forty-Seven Trips: A Case Study in the Character of Some Formation Processes of the Archaeological Record. In *Contributions to Anthropology: The Interior Peoples of Northern Alaska.* Edwin S. Hall Jr., ed. Pp. 299-351. Archaeological Survey of Canada, Paper No. 49.

——— 1983. *In Pursuit of the Past: Decoding the Archaeological Record*. New York: Thames and Hudson.

Bradbury, Andrew P. and Philip J. Carr. 2004. Combining Aggregate and Individual Methods of Flake Debris Analysis: Aggregate Trend Analysis. *North American Archaeologist* 25(1):65-90.

Bubel, Shawn, James McMurchy, and Duncan Lloyd. 2012. *Record in Stone: Familiar Projectile Points from Alberta.* Lethbridge, Alberta: Archaeological Society of Alberta: Lethbridge Centre.

Carr, Philip J., and Andrew P. Bradbury. 2004. Exploring Mass Analysis, Screen, and Attributes. In *Aggregate Analysis in Chipped Stone*. Christopher T. Hall and Mary Lou Larson, eds. Pp. 21-44. Salt Lake City: The University of Utah Press.

Darvill, Timothy. 2008. *The Concise Oxford Dictionary of Archaeology*. Oxford: Oxford University Press.

Fedirchuk, Gloria. 1979. FiPp-33 Archaeology Site Inventory Form. On file with the Archaeology Survey of Alberta, Edmonton.

Hickman, M., C. E. Schweger and T. Habgood. 1984. Lake Wabamun, Alta.: a paleoenvironmental study. *Canadian Journal of Botany* 62(7): 1438-1465

Larson, Mary Lou. 2004. Chipped Stone Aggregate Analysis in Archaeology. In *Aggregate Analysis in Chipped Stone*. Christopher T. Hall and Mary Lou Larson, eds. Pp. 3-17. Salt Lake City: The University of Utah Press.

Magne, Martin P.R. 1989. Lithic Reduction Stages and Assemblage Formation Processes. In *Experiments in Lithic Technology*. Daniel S. Amick and Raymond P. Mauldin, eds. Pp. 15-31. Oxford: BAR International Series 528.

Odell, George H. 2003. *Lithic Analysis*. Manuals in Archaeological Method, Theory, and Technique. New York: Springer Science + Business Media.

Pecora, Albert M. 2001. Chipped Stone Tool Production Strategies and Lithic Debris Patterns. In *Lithic Analysis: Context, Form, Meaning*. William Andrefsky Jr., eds. Pp. 173-190. Salt Lake City: The University of Utah Press.

Rawluk, Matt, Aileen Reilly, Jo-Anne Schenk, Peter Stewart, and Gabriel Yanicki. 2011. Identification of a Paleoindian Occupation in Compressed Stratigraphy: A Case Study from Ahai Mneh (FiPp-33). *Diversipede* 1(1):1-15.

Schenk, Jo-Anne and Gabriel Yanicki. 2011. Early Prehistoric Sites in Alberta and How They Relate to Ahai Mneh (FiPp-33). *Diversipede* 1(1):35-41.

Schiffer, Michael B. 1987. *Formation Processes of the Archaeological Record*. Albuquerque: University of New Mexico Press.

Shott, Michael J. 1989. On Tool-Class Use Lives and the Formation of Archaeological Assemblages. *American Antiquity* 54(1):9-30.

——— 2004. Aggregate Methods and the Future of Debris Analysis. *Aggregate Analysis in Chipped Stone*. Christopher T. Hall and Mary Lou Larson, eds. Pp. 3-17. Salt Lake City: The University of Utah Press.

Soucey, Kristen, Bruce F. Ball, and Loic Bosher. 2009. "Historical Resource Impact Mitigation. FiPp-33, FjPp-50, FjPq-36, and FjPq-37. TransAlta Generation Partnership. Highvale Mine Pits 3, 4, and 5 Expansion," 2 volumes. ASA Permit 2008-320. Report on file, Archaeological Survey of Alberta, Edmonton.

Stevenson, Marc G. 1991. Beyond the Formation of Hearth-Associated Artifact Assemblages. In *The Interpretation of Archaeological Spatial Patterning*. Ellen M Kroll and T. Douglas Price, eds. Pp. 269-299. New York: Plenum Press.

Surovell, Todd. 2009. *Toward a Behavioral Ecology of Lithic Technology: Cases From Paleoindian Archaeology*. Tucson: University of Arizona Press.

Appendix A: Raw material analysis.

Table A.1. Raw material counts and percentages included in the "Other" category from Ahai Mneh.

Raw Material	**Count**	**Percentage**
Quartz	13	0.17
Granite	11	0.14
Obsidian	9	0.12
Knife River Flint	6	0.08
Petrified Wood	5	0.06
Argillite	1	0.01
Basalt	1	0.01
Dacite	1	0.01

Appendix B: Debitage analysis by level at Ahai Mneh.

Table B.1. Debitage types distributed by level.

Level	**Type**									**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
1	171	65	9	3	45	11	1	0	13	**318**
2	1072	500	41	97	328	91	1	0	128	**2258**
3	1286	510	83	58	354	95	2	3	273	**2664**
4	721	296	49	40	77	47	1	3	188	**1422**
5	395	105	24	18	36	32	1	0	82	**693**
6	126	46	8	4	7	13	0	0	24	**228**
7	43	16	1	1	1		1	0	3	**66**
8	3	3	0	0	0	0	0	0	2	**8**
Other[4]	33	10	2	0	0	3	0	0	4	**52**
Total	**3850**	**1551**	**217**	**221**	**848**	**292**	**7**	**6**	**717**	**7709**

---

[4] "Other" indicates debitage that was not assigned to a specific level, including artifacts that fell from walls or were not properly provenienced.

Table B.2. Debitage size classes distributed by level.

Level	Size Class					Total
	1	2	3	4	5	
1	73	56	115	73	1	**318**
2	122	491	1068	569	8	**2258**
3	48	463	1350	791	12	**2664**
4	22	173	718	502	7	**1422**
5	36	70	327	256	4	**693**
6	4	21	99	104	0	**228**
7	1	8	41	16	0	**66**
8	0	0	7	1	0	**8**
Other	0	5	33	14	0	**52**
Total	**306**	**1287**	**3758**	**2326**	**32**	**7709**

Table B.3. Debitage cortex amount classes distributed by level.

Level	Amount of Cortex				Total
	0	1	2	3	
1	4	10	21	270	**305**
2	31	45	147	1907	**2130**
3	53	69	165	2104	**2391**
4	18	45	63	1107	**1233**
5	10	21	40	540	**611**
6	7	5	13	179	**204**
7	1	0	2	59	**62**
8	0	0	0	7	**7**
Other	0	3	1	44	**48**
Total	**124**	**198**	**452**	**6217**	**6991**

Table B.4. Debitage dorsal scar classes distributed by level.

Level	Dorsal Scars				Total
	0	1	2	3+	
1	3	160	74	68	**305**
2	24	817	705	584	**2130**
3	46	900	738	707	**2391**
4	16	421	394	402	**1233**
5	10	196	193	212	**611**
6	7	62	56	79	**204**
7	1	23	21	17	**62**
8	0	3	2	2	**7**
Other	0	16	17	15	**48**
Total	**107**	**2598**	**2200**	**2086**	**6991**

COMPASS (2017) Volume 1, Issue 1, Pages 42-65

Re-approaching palaeodiet in the Andes

Use and application of sulphur isotope analysis in reconstructing Peruvian palaeodiet

by Katherine G. Bishop

This research critically examines palaeodietary analyses in ancient Peru. Research is often approached using ceramics, flora, and faunal remains to examine human diet and behaviour prior to written records however these remains may not be indicative of items used exclusively for subsistence. More directed approaches employ stable isotope analyses of human remains as these data can provide direct indication of foods consumed during life. Peruvian isotope studies focus on ^{13}C-enrichment patterns, and follow the premise that *maize* (corn) was the main source of ^{13}C-enrichment recorded in bone collagen. Recent studies in Peru have identified other dietary sources that cause similar enrichment patterns, including *kiwicha* (pseudocereal), marine protein (e.g. shellfish, fish, and seals), and *mococho* (seaweed). As a result, additional methodologies must be employed to more sufficiently identify sources of subsistence in ancient Peru. I propose that stable sulphur isotope methodology may be used to overcome the issues presented. By critically reviewing previous palaeodietary analyses of Peru I examine current limitations and overview the application potential of carbon and nitrogen isotope studies complemented with sulphur isotope analysis of human and faunal remains within a Peruvian context. Ultimately I advocate for a more comprehensive approach to Peruvian palaeodiet.

This research investigates stable sulphur isotope analyses of human and animal remains to better examine human diet and subsistence in ancient Peru. Subsistence practices are an important characteristic of human diet and behaviour, and multiple research avenues have been employed to understand Peruvian palaeodiet. Ethnohistoric data from the Inkan period (~ 1500 CE) serve as comparative means for extrapolating dietary information from the material record however these data cannot definitively describe palaeodiet prior to written history (Bray 2003; Turner, Kingston, and Armelagos 2010). Evidence of ceramics, flora, and fauna from prehistoric assemblages identifies possible foodstuffs, but may not be indicative of items used exclusively for subsistence. Approaches using stable isotope analysis of human remains provide direct indication of foods consumed during life. Early isotopic studies focused on stable carbon and nitrogen analysis of bone collagen to identify diets with ^{13}C enrichment (DeNiro and Epstein 1981; DeNiro and Schoeninger 1983; Schoeninger, DeNiro, and Tauber 1983). This methodology has been utilized in Peruvian studies for the past 25 years under the premise that *maize* (corn) was the main source of ^{13}C enrichment in bone collagen (Burger and van der Merwe 1990).

Recent studies in Peru have identified other available food sources that cause ^{13}C enrichment in diet, including *kiwicha* (pseudo-cereal) (Cadwallader *et al.* 2012), marine protein (e.g. shellfish, fish, and seals) (Miller, Capriles, and Hastorf 2010), and *mococho* (seaweed) (Finucane, Agurto, and Isbell 2006). Current methodology is no longer sufficient for identifying sources of subsistence, limiting palaeodietary analyses for this region. To

---

Katherine G. Bishop is a doctoral candidate in the Department of Anthropology at the University of Alberta (13-15 Tory Building, Edmonton, Alberta, T6G 2H4 [kbishop@ualberta.ca]).

overcome this issue I will (i) review the biochemical applications of stable sulphur isotope analyses from other studies, (ii) review previous palaeodietary analyses of Peru and examine current limitations, and, (iii) critically examine the application potential of carbon and nitrogen isotope studies complemented with sulphur isotope analysis of human and faunal remains within a Peruvian context.

Quinoa, *Cuy*, and *Yuccas* – Examining Peruvian Palaeodiets

The Peruvian landscape contains different ecosystems which correspond to variation in elevation, soil aridity, and access to different water sources (Fernández, Panarello, and Schobinger 1999). The central portion of the country includes the Andes Mountains, which run from north to south, and contain many active volcanoes and shifting tectonic plates (Stewart 2015). The Pacific Ocean forms the western coast of the country, creating many branching marine river valleys and estuaries. The southern lowland region includes Lake Titicaca and the northern lowland region has the southern portion of the Amazon River; both are home to lush ecological environments (Miller, Capriles, and Hastorf 2010).

These varying ecologies support different flora and fauna and would have caused different subsistence niches for humans in the past (Tomczak 2003). Small-scale agriculture began with crops of manioc (*yucca* ssp.), vegetables, and fruits, which thrive in the arid environments to the west and more tropical environments to the northeast (Beresford-Jones *et al.* 2009). More efficient agricultural practices were required to sustain crops in arid environments and continue to support large modern populations (Downey 2015). Archaeological studies of settlement architecture have illustrated large-scale irrigation canals in many growing communities, highlighting the importance of subsistence agriculture for establishing statecraft (Downey 2015; Millaire and Eastaugh 2014). According to Moseley (1975), Peruvian ecosystems are particularly susceptible to the effects of El Niño. Based on ethnohistoric data, El Niño effects include large-scale temperature changes for aquatic environments, drought conditions, and destructive rainstorms resulting in mudslides (Moseley 1975). Subsistence availability will vary in each environmental niche according to its ecology (Miller, Capriles, and Hastorf 2010), ongoing climate changes (Beresford-Jones *et al.* 2009), and seasonal growing conditions (Williams and Katzenberg 2012).

Floral Analysis

There are many arid environments in Peru that enable the preservation of organic materials like seeds, pits, shells, and fruits. Using measures of speciation, quantity, and quality of the remains, Masur (2012) examined floral remains and identified available food items in specific niches. In her work at the Virú Valley, Masur (2012) recovered fragments of peanut, bean, chili pepper, squash, seaweed (*mococho* spp.), gourd, *yucca*, and corn (*maize* spp.). According to the context and prevalence of peanut remains, Masur (2012) argued that they were an elite food source within hierarchical societies. Other floral analyses (e.g. Beresford-Jones *et al.* 2009) have similarly examined available food and aspects of dietary importance in ancient Peru. Vegetation can be consumed directly or processed in a number of ways. For example *maize* can be processed into a fermented corn beer (*chicha*). According to Inkan ethnohistoric accounts, *chicha* was a focal aspect of subsistence that has been examined in other archaeological contexts (Bray 2003; Goldstein 2003). Botanical remains provide an indication of available crops within a region, however their form or function within diet is more difficult to examine entirely from floral remains.

Ceramic Analysis

Ceramic fragments also indicate aspects of subsistence through analyses of vessel form and function (Goldstein 2003), artwork (Somerville *et al.* 2015), and residues on ceramic fabric (Duncan, Pearsall, and Benfer 2009). Ancient *chicha* production is illustrated on ceramic vessels from sites at Lake Titicaca (Goldstein 2003). Somerville *et al.* (2015:412) have identified specific "*chicha* drinking goblets" in grave good assemblages associated with the Tiwanaku people. Bray (2003:3) examined ceramic assemblages to analyze "food, feasting, and gender" within the Inka empire. In this study the form and functionality of each vessel was studied to determine the role of women in the domestic sphere of large-scale state populations. Food storage vessels and preparation methodology have also been indicated using macroscopic ceramic analyses and ethnohistoric data in conjunction (Duncan, Pearsall, and Benfer 2009). According to Bray (2003:7), "potatoes could be eaten green, roasted, cooked, or in stews," or "preserved through a process of alternative exposure to sun and frost" as a means of dehydrating them for storage. When used in conjunction, ceramic, ethnohistoric, and botanical evidence indicate a more holistic picture of crops and preparation methods for available foods.

Foods that are cooked in ceramic vessels may leave a residue of food remains on the vessel fabric (Salque *et al.* 2012). Unlike basic floral analysis, residue analysis indicates direct processing or cooking of floral remains. Zarrillo *et al.* (2008) analyzed cooking vessels and food-processing tools (e.g. grinding stones) from a site in Ecuador and identified the presence of charred *maize* starch residues. Despite a lack of macrobotanical remains in their assemblage, Zarrillo *et al.* (2008) were able to identify accessible crops and potential food items that had been directly processed. In preceramic sites, like Buena Vista, Peru, Duncan, Pearsall, and Benfer (2009) similarly analyzed bottle gourd and squash vessels to identify the presence of food residues. Due to the excellent preservation conditions in Peru, these utilitarian vessels contained ancient residues of *yuccas*, potato, chili pepper, arrowroot, and tree root (*algarrobo* spp.). Unlike the charred residues from Ecuador, Duncan, Pearsall, and Benfer (2009) interpreted the floral residues from drinking vessels as support for the concept of fermented *yuccas* and *algarrobo* into alcoholic beverages. Botanical and ceramic analyses from archaeological contexts can be used to identify foods prepared and stored in antiquity. Alternatively, floral remains can be processed for medicinal and decorative (e.g. dye for fabrics) means, which makes it difficult to interpret 'food remains' that were definitively used for dietary purposes.

Faunal Remains

Meat is an important part of Peruvian diet, and processing patterns on faunal bone indicate which animals were likely butchered and/or cooked for consumption in the past. Venet-Rogers (2013) examined evidence of tool cut marks and charring or burning on faunal remains from Gallinazo Group in Peru; both signs indicate that fauna were prepared for subsistence. This near-coastal site included deposits of fish (anchovy, mackerel, and sharks), molluscs (clams, limpets, and urchins), reptiles (iguana and tegus), birds (gulls, pelicans, and ducks), and mammals (camelids, guinea pigs, and deer), all of which exhibited some form of processing or butchery (Venet-Rogers 2013).

Miller and Burger (1995) examined faunal assemblages at Chavín de Huántar and documented a change in the quantity and quality of specific cuts of meat. Their analysis indicated that earlier populations preferred deer meat, whereas more recent populations depended on camelid meat for subsistence. Miller and Burger (1995) utilized previous studies of animal carcass weight and known meat utility values to examine how different animals were utilized at this site. Their study supported the hypothesis that dried camelid meat was used by travelling herders in the society. Dried meat and fish products (*ch'arki*) are reported to have been efficient year-round food products for direct consumption or as trade goods (Miller and Burger 1995; Venet-Rogers (2013). Meat utility, taxonomic analyses, and butchery patterns indicate which fauna were available for consumption and which elements were 'preferred cuts'. Lipid residue analysis on ceramics has also been used to identify evidence of animal by-product (e.g. milk) processing in other contexts (Salque *et al.* 2012). Lipid residue analysis has not been conducted on Peruvian ceramic assemblages, but studies of this nature could identify camelid by-products or the direct processing of animal flesh, which would add to the subsistence data in this region.

Limitations and a More Direct Approach

Floral and faunal artifacts illustrate available food items however they do not indicate remains that were definitively intended for human consumption. Ceramic residue analysis of cooked materials provides evidence of material preparation, but still may not identify remains that were directly prepared for human diet. According to Cadwallader *et al.* (2012), fruits found in Peru, like the prickly pear, were used for human food and animal fodder, whereas tobacco was grown for recreational and medicinal smoking use. In order to identify foods that were directly consumed by humans, many studies focus on examining human osteological remains.

Similar to ceramic residue analysis, starch grains preserved in human dental calculus illustrate foods that were processed by the human mouth. Piperno and Dillehay (2008) identified seed, nut, and other fruit starches on human dental remains from early and middle Holocene sites in northern Peru. Their analysis showed that domesticated plant species were consumed much earlier than previous botanical studies suggested. When dental plaque mineralizes it forms dental calculus, and any starch molecules that were stuck in the plaque will preserve as an 'oral fingerprint' (Piperno and Dillehay 2008). Modern studies have shown that certain particles, like more adhesive starches, will preferentially preserve in dental plaque (Leonard *et al.* 2015). Alternatively, animal protein sources and liquids like *chicha* would not be captured by dental calculus analysis. These factors bias research and create an overrepresentation of certain food types (Leonard *et al.* 2015). This method provides more direct evidence of floral items that pass through the oral cavity, but does not definitively illustrate foods that were consumed. In the modern horticultural population studied by Leonard *et al.* (2015), palm leaf remains were found in dental plaque because of palm-leaf basket-making practices. Without ethnographic information detailing basketry practices, dental plaque analysis might have led to the interpretation that palm leaves were a food item (Leonard *et al.* 2015). There are many positive applications of dental calculus analysis, but it still does not identify direct evidence of ancient subsistence.

Alternatively, stable isotope analysis permits an examination of the chemical composition of human bones, highlighting the foods ingested during life (Schwarcz and Schoeninger 2011). The carbon and nitrogen stable isotopes of bone collagen are utilized to examine predator-prey relationships of the regional food chain (Ambrose and Norr 1993; Richards *et al.* 2003). These fundamental principles of stable isotope methodology have been applied to many different research contexts in Peru (e.g., Goldstein 2003, Horn *et al.* 2009, and Tomczak 2003). Chemical analyses of human bone can be used to directly analyze palaeodiet.

Stable Isotope Methodology

Bodies incorporate elements from the surrounding environment through diet, which are reflected in the isotopic composition of proteins used for structural elements such as hair, bone, and keratin (Schwarcz 2000). Structurally, bone is composed of ~70% mineral (bioapatite) and ~30% protein (collagen) (Schwarcz and Schoeninger 2011). Carbon atoms from proteins are preferentially routed to collagen, so the stable isotope values from collagen mostly reflect the protein component of diet (Krueger and Sullivan 1984). Total diet is analyzed using carbon isotope differences recorded in the carbonate fraction of tooth enamel (Ambrose and Norr 1993; Lee-Thorp and van der Merwe 1987).

Carbon

Many elements exist on earth in numerous radioactive and non-radioactive (stable) forms. Carbon isotopes occur naturally in two different stable forms that vary in weight. Carbon atoms maintain the same number of protons (six) and electrons (six) with varying numbers of neutrons between stable isotopes. A carbon isotope with six neutrons (^{12}C) weighs less than a carbon isotope with seven neutrons (^{13}C), causing them to react differently (Hoefs 2009). Both forms of carbon are naturally occurring in flora, fauna, and mineral, but in varying quantities. Stable isotopes are expressed as a ratio between the heavier and lighter isotope. The ratio of $^{13}C/^{12}C$ is measured in parts per mille (‰) within the sample, and is recorded as a delta value ($\delta^{13}C$) in relation to an international standard (Hoefs 2009:28). Carbon's standard (Vienna Pee Dee Belemnit, or VPDB) is naturally ^{13}C-enriched and causes most sample $\delta^{13}C$ values to be expressed as negative values (Hoefs 2009).

Bioavailable carbon can come from atmospheric CO_2 and dissolved inorganic carbon, and the analysis of $\delta^{13}C$ in bone collagen is used to differentiate dietary aspects of plant and animal-protein as they relate to available carbon sources (Schwarcz 2000). Carbon isotope ratios of plant tissues are impacted by the photosynthetic pathway each plant uses to fix carbon. Most cultivars (e.g. *yuccas*, fruits, and vegetables) use the C_3 photosynthetic pathway and are referred to as C_3 plants. The C_3 photosynthetic pathway discriminates against ^{13}C, giving C_3 plants a ^{13}C-depleted carbon isotope ratio ($\delta^{13}C$ between -30‰ and -25‰) (DeNiro and Schoeninger 1983) (fig. 1). Wild grasses and a few cultivars (e.g. *maize*) use the C_4 photosynthetic pathway and are referred to as C_4 plants. The C_4 photosynthetic pathway does not heavily discriminate against ^{13}C compared to C_3 plants, giving C_4 plants a comparably ^{13}C-enriched carbon isotope ratio ($\delta^{13}C$ between -20‰ and -15‰) (Schwarcz 2000) (fig. 1). Table 1 also summarizes other influences on the carbon isotope composition of diet that are visually illustrated by Figure 1.

Nitrogen

Nitrogen is available in atmospheric N_2, nitrogen-containing compounds (e.g., nitrite and ammonia) and in nitrogen-fixing organisms (e.g., algae and bacteria) (Schoeninger, DeNiro, and Tauber 1983). The two most commonly occurring nitrogen isotopes are ^{15}N and ^{14}N, and the ratio ($^{15}N/^{14}N$) is most frequently used to illustrate differences in predator-prey relations as they relate to available nitrogen resources (DeNiro and Epstein 1981). Predators are ^{15}N-enriched when they consume prey ($\delta^{15}N$ values are +3‰ with each subsequent step up the food chain), a process known as the 'trophic level effect' (Schwarcz and Schoeninger 2011) (fig. 1). Aquatic environments contain more levels in their

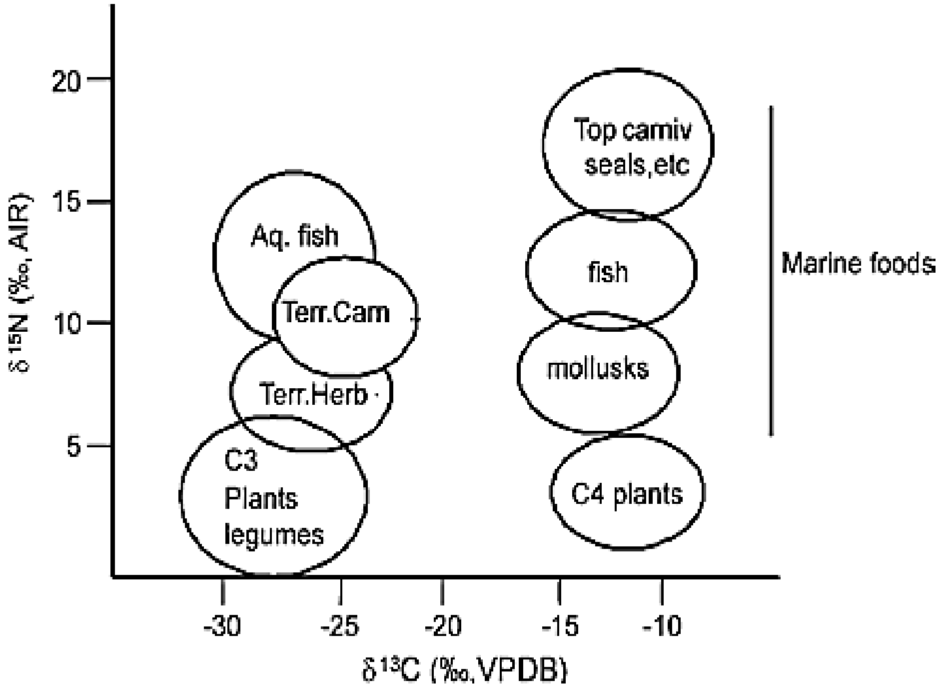


Figure 1. Trophic level representation illustrating relative $\delta^{13}C$ and $\delta^{15}N$ for different plants and animals (from Schwarcz and Schoeninger 2011:732)

food chain, so consumers of aquatic resources will illustrate subsequently higher $\delta^{15}N$ values (Schoeninger, DeNiro, and Tauber 1983). Table 1 outlines other sources of nitrogen that influence stable isotope signatures.

Isotopes in Conjunction

Studies that integrate multiple isotopes can lead to a more accurate understanding of local subsistence practices. For example, marine fauna exhibit $\delta^{13}C$ and $\delta^{15}N$ values that are different from terrestrial fauna (fig. 1). Large mackerels are more ^{13}C-enriched than llamas that feed on C_3 plants because of the carbon-content of dissolved inorganic carbon in water (DeNiro and Epstein 1981). Mackerel will also have a more positive $\delta^{15}N$ ratio than llamas because carnivores occupy apex positions in aquatic food chains, and aquatic systems have more food chains (DeNiro and Epstein 1981). If the llama has consumed a *maize*-heavy diet, it will be more ^{13}C-enriched than the mackerel because of the C_4 plant photosynthetic pathway (Krueger and Sullivan 1984). If the diet has a mix of C_3 and C_4 plants, the $\delta^{13}C$ values will be much more variable (Schwarcz and Schoeninger 2011).

Stable isotope analyses have also been used to indicate animals that have been specifically fed for consumption (Finucane, Agurto, and Isbell 2006). In particular, *cuy* (guinea pig) is a common dish in modern highland Peruvian diet. *Cuy* that are intended for consumption are fed an omnivorous diet of mixed vegetation and protein sources, which would be reflected by mid-range $\delta^{13}C$ and $\delta^{15}N$ values consistent with other omnivores (e.g. pigs, dogs). Wild *Cuy* likely reflect a ^{15}N-depleted diet compared to their domesticated counterparts because they are not feeding on ^{15}N-enriched sources in the wild. Finucane, Agurto, and Isbell (2006) documented archaeological *cuy* remains that had ^{15}N-elevated bone collagen and indicated guinea pigs that were specifically fed for human subsistence.

TABLE 1. The relative influence of specific factors on isotope signatures (recorded in bone collagen), when compared to the norm[1,5]

Category	**Influence on Isotope Signature**			**References**
	δ^{13}C	**δ^{15}N**	**δ^{34}S**	
Marine Protein	Increase[2]	Increase	Variable[3]	Craig *et al.* 2006; Nehlich *et al.* 2011; Privat, O'Connell, and Hedges 2007; Richards, Fuller, and Hedges 2001, 2003
***Mococho* (Seaweed)**	Increase	Increase	Variable	Finucane, Agurto, and Isbell 2006; Froehle, Kellner, and Schoeninger 2010; Horn *et al.* (2009); Richards, Fuller, and Molleson 2006
Fungi	Increase	Decrease	N/T	Millard *et al.* 2011
Maize, Kiwicha	Increase	-	N/T	Cadwallader *et al.* 2012; Krueger and Sullivan 1984; Schwarcz and Schoeninger 2011
Shallow Water Organisms	Decrease	Increase	Decrease	Craig *et al.* 2006; Miller, Capriles, and Hastorf 2010; Nehlich *et al.* 2011
Salt Marsh Grazing	-	Increase	Increase	Britton *et al.* 2008; Madgwick *et al.* 2013; Weinstein *et al.* 2000
Freshwater Protein	-	Increase	Variable	Craig *et al.* 2006; Katzenberg 1989; Linderholm and Kjellström 2011; Nehlich *et al.* 2011
Terrestrial Protein	-	Increase	-	Katzenberg 1989; Nehlich *et al.* 2011; Richards *et al.* 2003; Schwarcz 2000
Manured Cultigens	-	Increase	Variable	Bogaard *et al.* 2007; Mizota and Sasaki (1996)
Legumes[4]	-	Decrease	N/T	DeNiro and Epstein 1981
Sea-Sprayed Cultigens	-	-	Increase	Horn *et al.* 2009; Richards, Fuller, and Hedges 2001; Richards *et al.* 2003
Geographic Change	-	-	Variable	Craig *et al.* 2006; Nehlich *et al.* 2011; Richards, Fuller, and Hedges 2001, 2003; Wilson *et al.* 2007

1 Isotopically 'normal' here refers to a small-bodied herbivore that consumes C_3 plants, no meat, and has no other influences acting on ingested dietary protein.
2 Increase is contested (see: Reitsema *et al.* 2013)
3 Average range of +17‰ to +20‰ contested (see: Craig *et al.* 2006; Nehlich *et al.* 2011)
4 Legumes grown with or without manure
5 Adapted from Bishop (2013)
(-) No change; (N/T) Information has not yet been tested

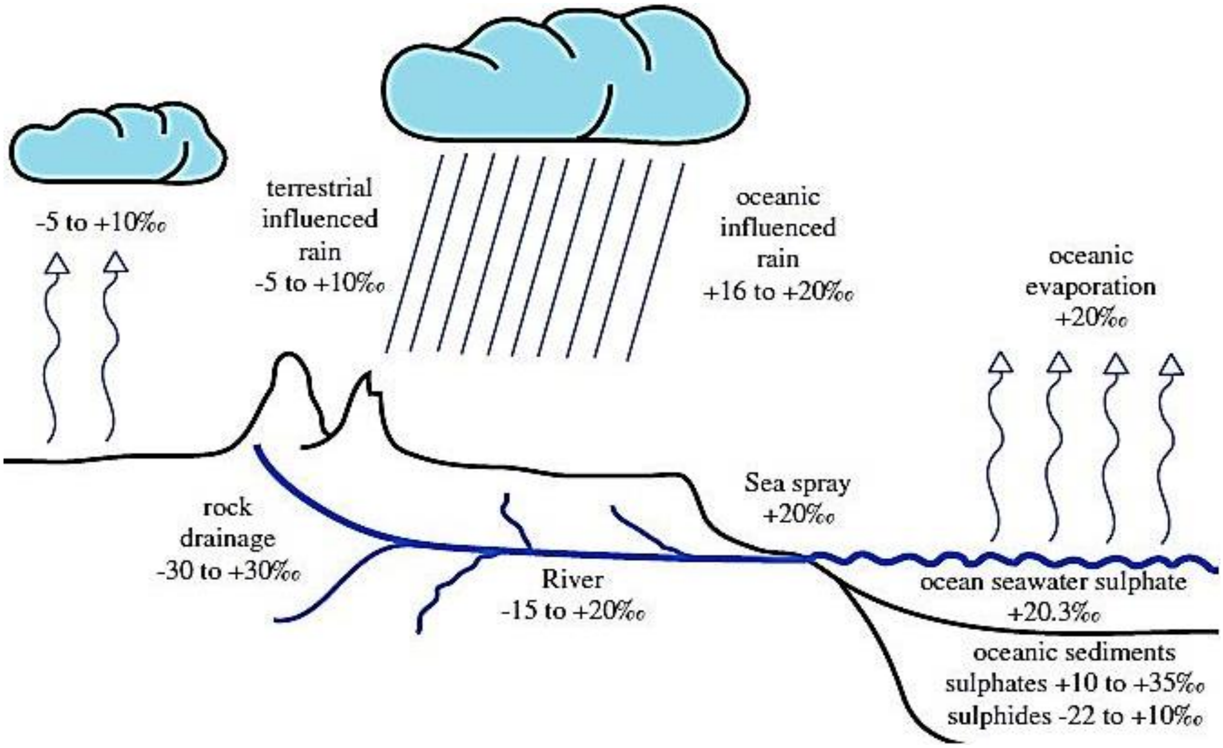


Figure 2. Visual overview of sulphur cycling, including expected sulphur isotope values within the environment (from Nehlich 2015:3).

Many Peruvian palaeodietary studies examine stable carbon and nitrogen isotope values from human bone collagen. Studies illustrate different subsistence practices according to significant variation in individual age (Turner, Kingston, and Armelagos 2010), sex (Somerville *et al.* 2015), political regimes (Lambert *et al.* 2012), and in areas where there were different animal husbandry practices (Finucane, Agurto, and Isbell 2006). Alternatively, some studies have been unable to identify specific parameters of subsistence practices (Burger and van der Merwe 1990; Kellner and Schoeninger 2008). All of these analyses worked under the premise that *maize* was the main source of ^{13}C enrichment in Peru. According to Cadwallader *et al.* (2013), multiple plant sources can elevate δ^{13}C values, including *kiwicha* and the prickly pear (*Opuntia* spp.). Finucane, Agurto, and Isbell (2006) identified ^{13}C- and ^{15}N-enriched bone collagen in rodent samples, which was attributed to the consumption of *mococho* in a non-coastal area. Carbon isotope analysis can no longer be used to examine the direct consumption of *maize* in Peruvian diets. This illustrates a major limitation of carbon and nitrogen stable isotope analyses, and to some extent, all analyses that examine isotopic composition of bone: the specific isotope analyzed limits the aspects of palaeodiet that can be analyzed through isotope studies.

Same Materials, New Method

Sulphur isotopes are a recent addition to palaeodietary studies (Craig *et al.* 2006; Sayle *et al.* 2013; Vika 2009). The main sources of sulphur originate from the earth’s core, atmospheric SO_2, oceanic sulphur and bacterial environments in the sediment of freshwater (Trust and Fry 1992; Richards *et al.* 2003). Figure 2 visually illustrates sulphur variation across a typical landscape. The two most commonly

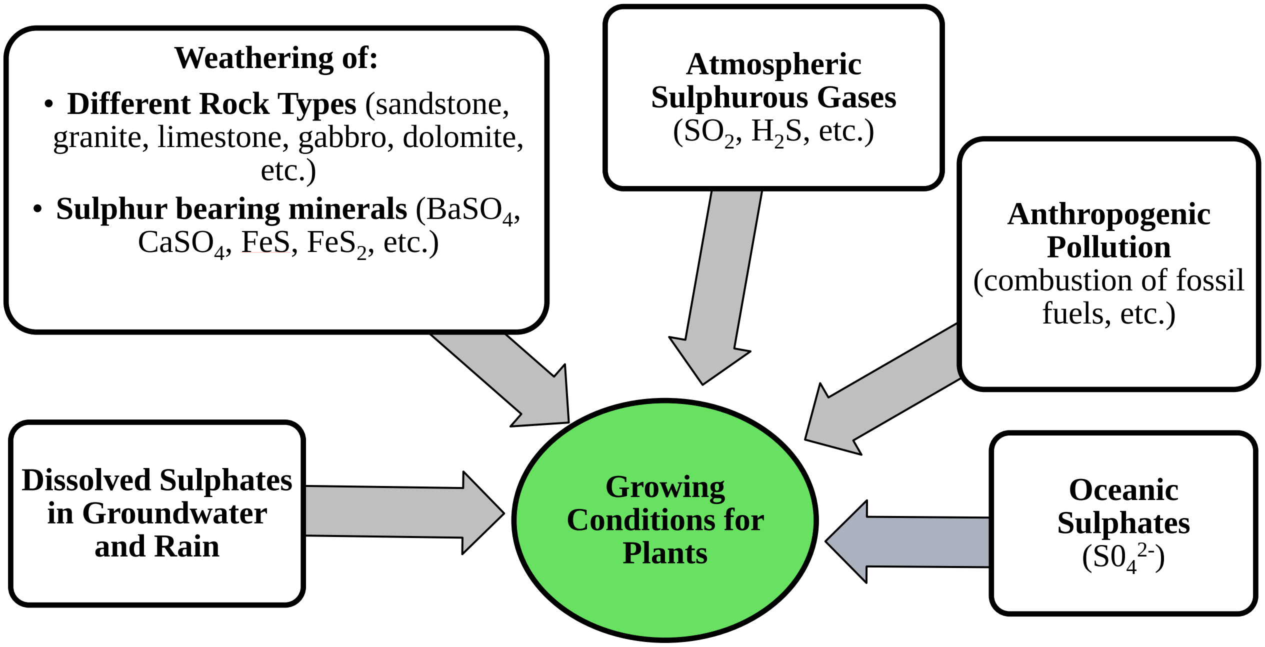


Figure 3. Environmental reservoirs influencing the amount of sulphur taken up by growing plants (created according to the information presented in Nehlich 2015).

occurring sulphur isotopes are ^{34}S and ^{32}S, and the ratio (^{34}S$^{/32}$S) is used to illustrate differences in nutrient source (Krouse and Coplen 1997). All of the sources of sulphur impact the δ^{34}S composition of each environmental niche (fig. 3), which is then reflected in the stable isotope signatures of the organisms consuming food from these regions (fig. 4) (Nehlich 2015). Insignificant fractionation occurs between landscape, flora, and fauna, enabling a direct indication of dietary niche source (Nehlich and Richards 2009).

Most studies have focused on the use of sulphur isotopes as a tool for differentiating fauna found in various aquatic environments (e.g., Craig *et al.* 2006; Leach *et al.* 2001; Nehlich *et al.* 2011). According to Privat, O'Connell, and Hedges (2007), sulphur isotope data coupled with nitrogen isotope values from their Russian study samples reflected a terrestrial-based diet in one group, but a freshwater source in another. Richards, Fuller, and Hedges (2001) additionally examined the influence of regional bedrock signatures on two terrestrial assemblages in order to examine the potential use of sulphur isotopes in terrestrial migration analyses. An inland Medieval England site at Bordesley Abbey (ca. 1300 CE), and an inland Mesolithic Ukraine site at Oleneostrovski (ca. 6500 BCE) contained human and faunal remains with δ^{34}S values (~12‰ and ~6‰, respectively) that were consistent within each population, and were distinct from other populations within their study (Richards, Fuller, and Hedges 2001). Their analysis also demonstrated that oceanic sulphur has a δ^{34}S of ~21‰, whereas freshwater sulphur ranges from δ^{34}S -22‰ to +22‰, and is reflected in the tissues of fauna that live within each niche (fig. 3, 4) (Richards, Fuller, and Hedges 2001; Richards *et al.* 2001; 2003). This δ^{34}S value for marine environments (+20‰ to +21‰) has also been documented in other studies (Nehlich, Barrett, and Richards 2013; Thode, Monster, and Dunford1961).

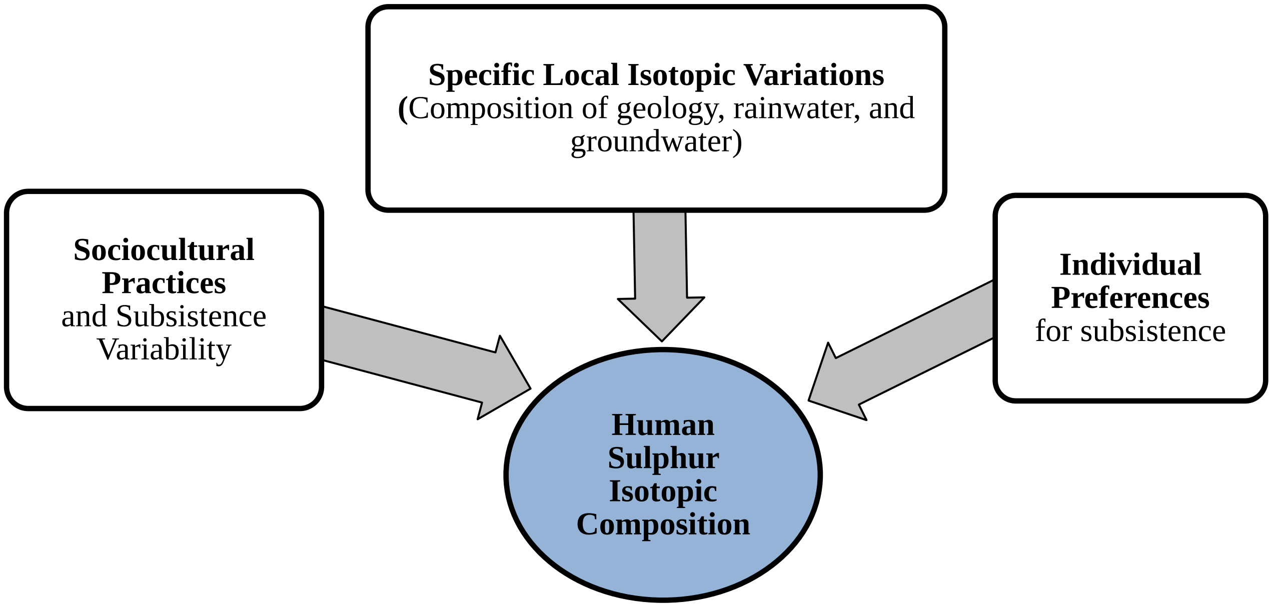


Figure 4. Environmental and cultural influences of human sulphuric isotope composition. (created according to the information presented in Nehlich 2015).

New Isotopes in Conjunction with Old Isotopes

Sulphur isotopes are recorded from the protein portion of bone (collagen) and hair (keratin), making them ideal to study in conjunction with carbon and nitrogen (Nehlich and Richards 2009). When plants grow, they incorporate nutrients into their roots based on those available in the soil, and according to growing conditions (Bogaard *et al.* 2007; van Klinken, Richards, and Hedges 2000). Ground nutrients influence δ^{15}N and δ^{34}S, whereas growing conditions and plant type will influence δ^{13}C, δ^{15}N, and δ^{34}S values in organisms (table 1). Regional temperature, humidity, and environment can all influence which plants will grow in each niche, and whether they will be available for human consumption (Heaton 1999). Similarly, aquatic reservoirs will also influence the δ^{13}C and δ^{34}S recorded in aquatic food chains (fig. 5). Accordingly, carbon, nitrogen, and sulphur isotopes recorded in human and faunal bone will change in different feeding niches (Lee-Thorp and Beaumont 1995; Schwarcz 2000). Table 1 illustrates the relative influence of different environments and food types on carbon, nitrogen, and sulphur isotope values recorded in bone collagen.

Mococho

Consuming *mococho* would enrich ^{13}C, reflect marine sulphur values (elevated to no more than 20‰), and can marginally enrich the ^{15}N in collagen. The study conducted by Richards, Fuller, and Molleson (2006) on the Newark Bay Viking site (600-1450 CE) in Scotland included the remains of animals that may have consumed seaweed, or cultigens that were fertilized with seaweed. Pig remains with recorded carbon and nitrogen isotope values of -20.6±1.3‰ and +8.4±1.6‰, respectively, indicated direct seaweed consumption (Richards, Fuller, and Molleson 2006). Alternatively, sheep/goats with

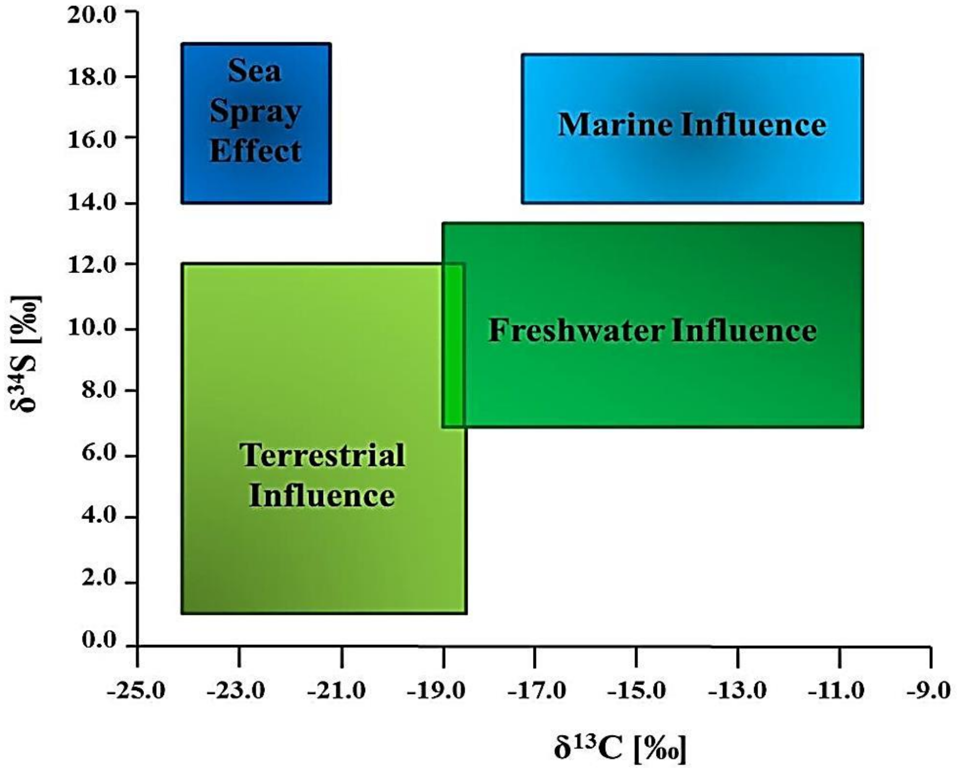


Figure 5. Relative impacts of various reservoirs on $\delta^{13}C$ and $\delta^{34}S$ values of archaeological bone collagen (adapted from Nehlich 2015).

measured isotope values consistent with increased average nitrogen values (+7.0±0.9‰), which did not demonstrate significantly increased carbon values (-21.8±0.8‰) indicated animals that consumed manured cultigens (refer to Table 1 on manuring effects) (Richards, Fuller, and Molleson 2006). In Peru, Finucane, Agurto, and Isbell (2006) suggested that elevated $\delta^{13}C$ in mice was due to consumption of seaweed from coastal sources. Madgwick *et al.* (2013) identified fauna that fed on halophytes (saline-loving plants) grown in salt marshes due to their isotope values which reflected a trophic level shift in $\delta^{15}N$ values, ^{13}C enrichment, and $\delta^{34}S$ values consistent with marine source consumption. Salt marsh grazers would have isotopic values that are different from those due to manuring because of increased $\delta^{34}S$ values attributed to aquatic sediments (Madgwick *et al.* 2013). Isotopic analysis of carbon, nitrogen, and sulphur can be used to effectively identify halophytic foods in palaeodiet.

Shallow Water Sources

Studies also investigated how isotopic values vary in aquatic environments according to water depth. Craig *et al.* (2006) analyzed faunal remains in northern Europe along the Baltic Sea (ca. 3900 BCE) and demonstrated that their sample had ^{34}S- and ^{13}C-depleted collagen compared to fauna in other aquatic environments. Shallow water niches have depleted heavy sulphur sources because of microbial sulphur cycling into sediments (Bottrell and Raiswell 2000). Heavy carbon depletion was due to reduced concentration of dissolved inorganic carbonate (Craig *et al.* 2006), which has also been documented in other studies involving shallow aquatic niches (Richards 2001). Shallow water environments were also investigated by Nehlich *et al.* (2011) using isotopes recorded in fauna from four sites in Oxfordshire, United Kingdom: Barrow Hills (100-300 CE), Tubney Wood Quarry (200-600 CE), Queenford Farm (400-600 CE), and Queens' College (1400-1500 CE). In both studies, δ^{34}S values were roughly -20‰ to -17‰ and δ^{13}C was approximately -30‰ (Craig *et al.* 2006; Nehlich *et al.* 2011). Isotope signatures of δ^{34}S and δ^{13}C that are similar to those recorded by Nehlich *et al.* (2011) are unique, and would likely illustrate a shallow water source. Shallow water sources can be natural, as both studies documented, and form specific niches in the Peruvian lowlands near Lake Titicaca.

Sulphur Variation in Peru

Every ecological niche has a unique isotopic baseline value (Nehlich 2015). Currently there are no baseline sulphur isotope values (modern or ancient) that have been established in Peru. According to ecological studies of sulphur isotope pathways (Böttcher 2001; Hollingsworth 2006; Mossmann *et al.* 1991; Mizota and Sasaki 1996; Sakai and Matsubaya 1977; Shearer *et al.* 1996; Trust and Fry 1992), known geochemical properties of sulphur (Bottrell and Raiswell 2000; Krouse and Coplen 1997; Sakai 1957; Thode, Monster, and Dunford 1961), and previous archaeological applications of sulphur in other contexts (Craig *et al.* 2006; Nehlich *et al.* 2010; Nehlich *et al.* 2014; Privat, O'Connell, and Hedges 2007; Richards, Fuller, and Hedges 2001; Richards *et al.* 2001; 2003), Figure 6 was created to illustrate proposed isotopic trends in Peru. There are three isotopically distinct features about the Peruvian landscape which all impact regional sulphur variation.

Coastal Influences (Pacific Ocean)

According to all sources, oceanic sulphur is very uniform "due to the constant cycling of water through all oceans" (Nehlich 2015:4). Estuaries, which stem from coastal systems and have joint impact from freshwater sources, will demonstrate more variable sulphur isotope values due to soil and rock leaching, erosion, groundwater, and geological formations (Hollingsworth 2006). The entire western coast of Peru is impacted by the sulphur content of the Pacific Ocean, and any marine protein sources would similarly reflect ^{34}S enrichment to roughly 20‰. According to Bottrell and Raiswell (2000:102) the Peru Margin, located along the Pacific coast of Peru, "is unusual in possessing an extensive thickness of dissolved, sulphide-bearing pore-waters, which combined with sedimentation rate, give several millions years of sediment exposure to dissolved sulphide." Not only would coastal resources be expected to reflect the ^{34}S-enriched niche, but there would be a marked sea-spray effect inland from the coast. Average sea-spray effects have been measured roughly 30 km inland (Nehlich 2015:10), but this value is expected to be larger along the Pacific coast of Peru due to the Peru Margin documented by Bottrell and Raiswell (2000). Accordingly, Figure 6 has a projected sea-spray niche impact of up to 100 km from the Pacific coast (marked in yellow). In this niche, vegetation will reflect ^{34}S enrichment up to +20‰ because of evaporated oceanic sulphates absorbing into the local landscape (Horn *et al.* 2009).

Volcanic Rock and the rest of the Andes Mountains

Information related to the sulphur isotopic content of the Andes Mountains is limited however the available geochemical and soil-based information for this region is sufficient for an extrapolation of probable baseline sulphur values. For example, the Andes Mountains are composed of volcanic rock and many active volcanic systems (Stewart 2015). If the sulfur of the Andes Mountains was derived from marine sulfur during

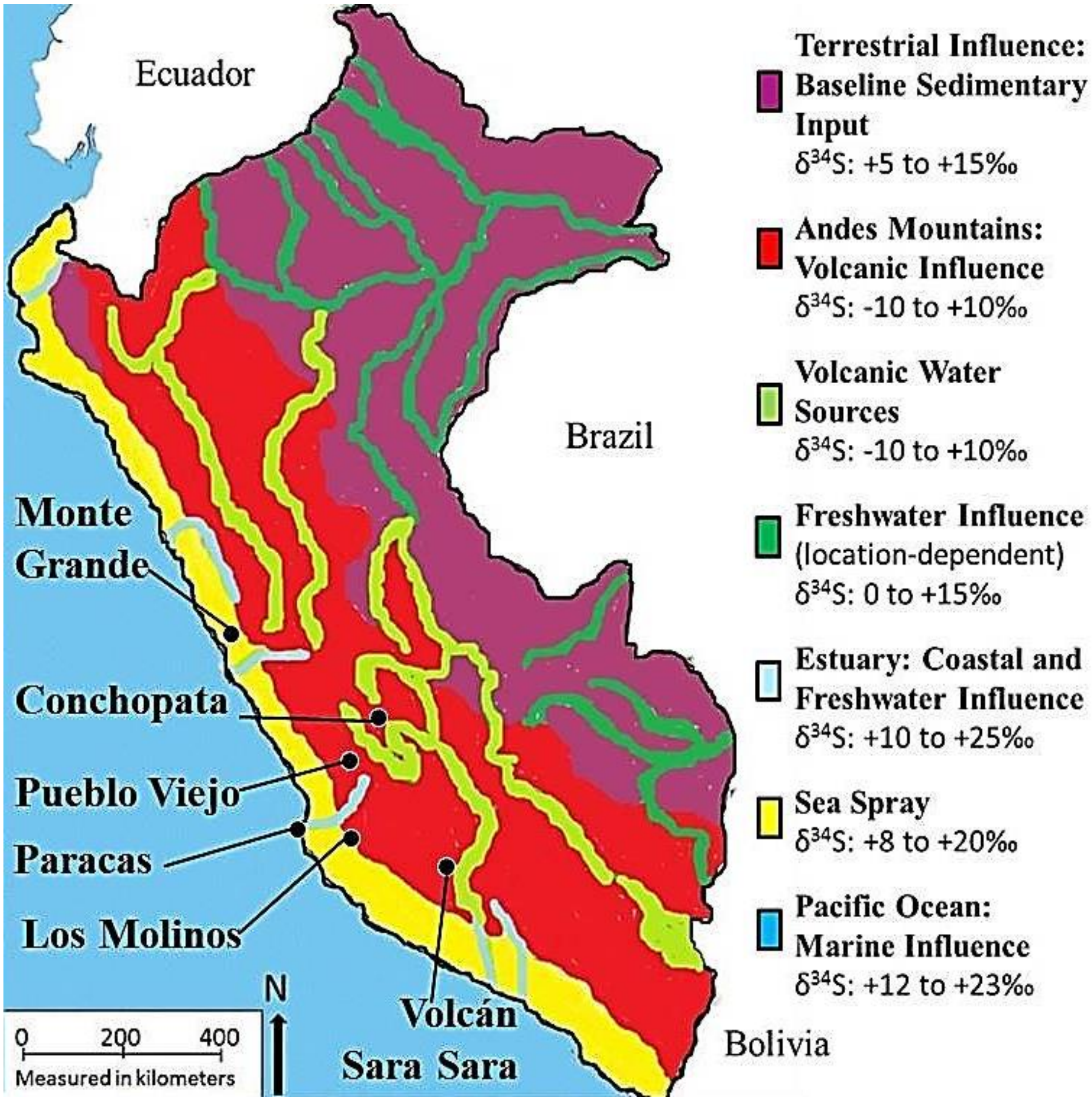


Figure 6. The proposed contour lines representing the overall variability and ranges of sulphur isotopic composition in Peru based on the values and discussion provided in text (e.g., Craig *et al.* 2006; Fornander, Eriksson, and Lidén 2008; Nehlich 2015). Site names refer to the case studies discussed below.

eruption, Lalonde and Beaudoin (2015) argue that the isotopic values would measure between 0‰ and +10‰. Alternatively, other studies of volcanic lakes have indicated that "sulphide minerals of igneous origin… are depleted in the heavy sulphur", due to "the isotopic exchange reaction between native sulphur and hydrogen sulfide" (Sakai 1957:153, 160). Christenson and Tassi (2015:129) have identified that "the δ^{34}S signature of bulk mantle [sulphur] is similar to that of the internationally accepted standard value derived from the Canyon Diablo Troilite meteorite" (CDT), suggesting that the bulk mantle of the Andes Mountain will average around 0‰. Varying quantities of gypsum and pyrite within volcanic terrains will also cause ^{34}S depletion, as these rock types also have stereotypically lower δ^{34}S values (fluctuating between -10‰ and +10‰) (Sakai and Matsubaya 1977). According to Bottrell and Raiswell (2000:99), volcanic pyrite undergoes "limited diagenetic alteration", but will become depleted in ^{34}S when oxidized (δ^{34}S ~ -16‰). Overall, this suggests that the Andes Mountains will be mostly depleted in heavy sulphur at higher altitudes where there is less impact from marine sulphur and more impact from oxidized pyrite (ranging from -10‰ to +10‰) (illustrated in red, fig. 6).

Volcanic lakes or other bodies of water within the Andes Mountains will likely be ^{34}S-enriched due to freshwater influences (e.g., weathering of rock, atmospheric sulphurous gases) (Konhauser, Fyfe, and Kronberg 1994). Aquatic sources that are found at lower elevations are expected to illustrate a gradient of sulphur values, likely from -10‰ at higher elevations to +10‰ at lower elevations (illustrated in lime green, fig. 6) (Christenson and Tassi 2015). Volcanic lakes also impact the sulphur content of nearby terrestrial sediments, but not to the same extent that has been recorded for sea-sprayed niches adjacent to coastal sources (Hollingsworth 2006).

Lowland Freshwater Sources (Lake Titicaca and the Amazon River)

Unlike marine environments, niches impacted by freshwater sources will have more variable sulphur content across the landscape (Sayle *et al.* 2013). The Amazon River system in the northeast and Lake Titicaca's freshwater system in the southeast regions of Peru will likely vary in heavy sulphur and cause δ^{34}S values of 0‰ to +15‰ (Nehlich 2015; Privat, O'Connell, and Hedges 2007). In particular, the Amazon River system is known for being highly fertile and would be expected to have ^{34}S-enriched isotopic niches because of its biotic activity (Bottrell and Raiswell 2000; Konhauser, Fyfe, and Kronberg 1994). According to Nehlich (2015:4) freshwater sulphur values will "vary according to site geochemistry and sulphate reduction or sulphide oxidation." Some of these riverine systems may have also had connections with the Pacific Ocean, which will also vary as a result of the recycled sulphur composition within the water sources (Bottrell and Raiswell 2000). Because of this, and due to the close proximity of the active Andes Mountains, freshwater influences may range in δ^{34}S from 0‰ to 15‰ (illustrated in green, fig. 6) (Nehlich 2015).

Despite isotopic variability anticipated across freshwater sources, no sulphurous influence is expected to raise values higher than 20‰, as they are not currently connected to marine resources. Similar to the sea-spray effect along marine coasts, available sulphur along the lowland 'terrestrial' eastern half of Peru will be impacted by the riverine systems (Bocherens, Drucker, and TaPubald 2011). The leeward side of the Andes Mountains are projected to have ^{34}S depletion due to the minimal erosion of sulphur-bearing rocks and minerals, but will increase in δ^{34}S with increasing distance from the mountains (anticipated +5‰ to +15‰, illustrated as purple in fig. 6) (Rafter, Kaplan, and Hulston 1960 *in* Thode, Monster, and Dunford 1961). Additional studies will be required to sample ancient baseline sulphur isotope values at different niches throughout Peru.

Application: Case Studies

Three case studies were chosen to critically examine the applicability of sulphur isotope methodology in Peru (table 2). One example highlights the limitations of analyzing palaeodiet in Peru by only focusing on δ^{13}C and δ^{15}N values in human and animal remains (Finucane, Agurto, and Isbell 2006). The second (Wilson *et al.* 2007) and third (Horn *et al.* 2009) examples examine carbon, nitrogen, and sulphur isotope values recorded in mummy scalp hair from Peru. The benefits and limitations of these two case studies highlight strategies that should be employed moving forward with palaeodietary analysis in this region.

TABLE 2. Case study contextual information, including major conclusions, limitations within each study, and the proposed sulphur isotope analysis findings.

Study	Context	Methods and Materials	Study Conclusions	Issues within Study	Proposed Solution
Finucane, Agurto, and Isbell (2006)	Conchopata (550-1000 CE)	40 Human and camelid, other fauna: collagen ($\delta^{13}C$, $\delta^{15}N$) and carbonate ($\delta^{13}C$)	(1) Maize as staple crop; (2) two distinct camelid management strategies	Elevated mice $\delta^{13}C$ likely due to seaweed; raises questions about human $\delta^{13}C$ values	Analyze contribution of marine sources: $\delta^{34}S$ elevated from baseline values (+20‰)
Wilson *et al.* (2007)	Volcán Sara Sara (1430-1530 CE)	1 Human: hair keratin ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$)	(1) No evidence of marine diet; (2) distinct movement of individual.	Small sample size. No baseline data. Suspected non-local.	Larger sample size. Analyze hair and bone $\delta^{34}S$.
Horn *et al.* (2009)	Monte Grande, Pueblo Viejo, Paracas and Los Molinos (500 BCE-1000 CE)	Multiple mummies and camelid wool: hair keratin ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$)	(1) Sites had different access to marine resources; (2) evidence of *mococho* being fed to camelids	Overall trends analyzed; no account for seasonality or migration.	Analyze (monthly) segments of hair $\delta^{34}S$.

Case Study #1: Mice, Mococho, and Management Strategies

Finucane, Agurto, and Isbell (2006) examined archaeological remains from Conchopato recorded to the Middle Horizon (AD 550-1000) (fig. 6, table 2). Researchers compared isotopes recorded from human bone collagen to those recorded in tooth enamel bicarbonate to establish the role of *maize* in palaeodiet. This was accomplished by examining the mean difference of $\delta^{13}C$ between paired samples of carbonate (full diet) in enamel and collagen (protein portion of diet) in bone. Based on their findings they assert that maize was a staple part of diet, and was not merely a ceremonial cultigen, which had been argued elsewhere (e.g. Hastorf and Johannessen 1993). The second aim of this study was to examine the carbon and nitrogen isotopes in faunal bone collagen to determine if specialized animal management strategies were practiced. Supported by current ethnographic data, *Puna* camelid pastoralism during the Wari polity involved two major husbandry regimes that: (1) utilized maize fodder grazing locally in the *yunga* region (2200-2600m in elevation); and, (2) involved transhumance in the highland *puna* region (>4100m in elevation), well above maize growing altitude.

One major limitation of this study is that the authors failed to account for the marine influence on human isotopic values. The spacing between carbonate and collagen did illustrate that ^{13}C enrichment was most likely due to C_4 plants; however, Finucane, Agurto, and Isbell (2006:1771) conclude that:

> although the observed nitrogen isotope signatures could result from the consumption of marine protein, this is extremely unlikely considering the site's distance from the ocean and the high transportation costs associated with transporting fish or shellfish to the sierra from the Pacific [Ocean].

The authors deny the possibility of marine resource consumption by humans, but then later use marine sources to explain the elevated carbon and nitrogen values observed in a mouse bone collagen sample: "a diet composed primarily of marine plants would produce the observed isotopic value, yet leave little if any physical residue in the archaeological record" (Finucane, Agurto, and Isbell 2006:1773). This contradiction was one of the major limitations of their study, and illustrates issues with carbon and nitrogen isotope analyses in Peru.

If sulphur isotope values were recorded from the bone collagen fragments sampled in Finucane, Agurto, and Isbell (2006), it would aid in the discussion of access to marine resources. Conchopata is located in the high-lands of the Andes Mountains and would be expected to have a baseline sulphur isotope value of -10 to +10‰, depending on the erosion of volcanic sulphur and impact from rain patterns (Bottrell and Raiswell 2000) (fig. 6). Small-bodied herbivores would normally be tested to establish local baseline isotope values, however the anomalous mouse in Finucane, Agurto, and Isbell (2006) shows that this practice may generate misleading data. Fortunately, marine sulphur isotope signatures are so unique (~20‰), that any faunal or human isotope values that reflect ^{34}S enrichment would be indicative of the consumption of food from a marine subsistence niche, or an individual who has migrated from that environment.

More local trends could be established using sulphur isotope analysis depending on how contained the sulphur isotope niche is around Conchopata. If this region has a unique sulphur isotope value that is distinct from nearby water sources or camelid migration routes, sulphur isotope values may be used to strengthen the examination of distinct camelid husbandry regimes in Finucane, Agurto, and Isbell (2006). Likely, the *yunga* region will reflect higher δ^{34}S values (0‰ to +10‰) due to organic matter in the soils from the irrigation systems used for *maize* agriculture (Mizota and Sasaki 1996). Alternatively, the *puna* grassland will likely reflect lower δ^{34}S values (-10‰ to 0‰) due to the erosion of volcanic pyrite in the volcanic highlands that already reflects ^{34}S depletion (Hollingsworth 2006). Ultimately, a marine dietary contribution, such as *mococho,* would be indicated by a much more elevated δ^{34}S value depending on the amount of halophytes consumed.

Case Study #2: Sarita, Sacrifice, and Capacocha Children

Wilson *et al.* (2007) examined five mummified children located at the sites of Volcán Sara Sara in Peru (n=1: Sarita), and Volcán Llullaillaco in northwest Argentina (n=4). Dated to the pre-conquest period (1430–1520 CE), Wilson *et al.* (2007) wanted to understand the final months of life for ritually killed *capacocha* children. Good preservation enabled scalp hair to be sampled for the analysis of carbon, nitrogen, oxygen, hydrogen, and sulphur isotopes (fig. 7), as well as mitochondrial DNA analysis (mtDNA). For the purposes of this analysis, I will only focus on the carbon, nitrogen, and sulphur isotope values recorded by Wilson *et al.* (2007). Based on their

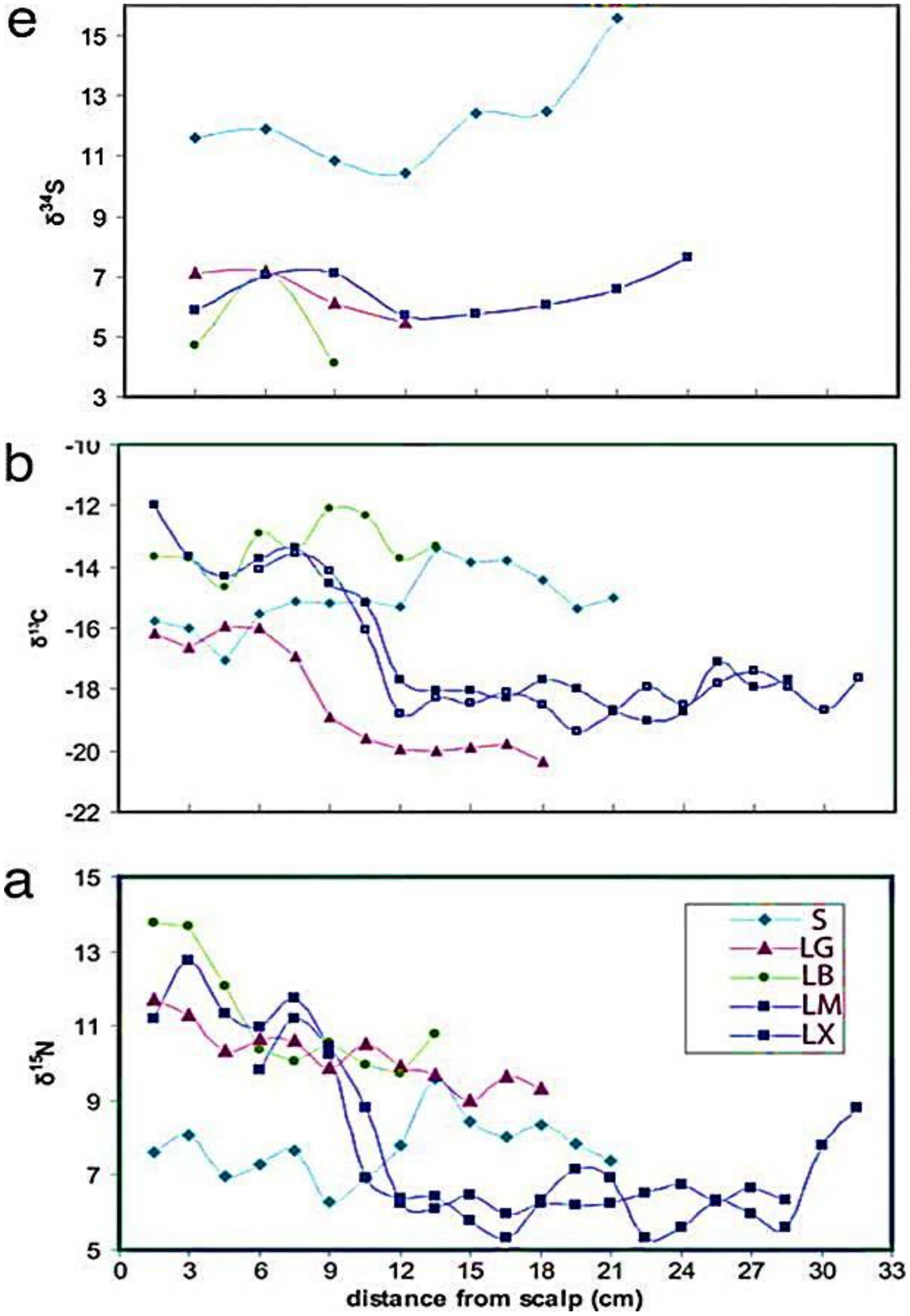


Figure 7. Stable isotope values of $\delta^{15}N$ (a), $\delta^{13}C$ (b), and $\delta^{34}S$ (e) recorded from scalp hair (from Wilson *et al.* 2007:16457). Particular attention in-text is given to Sarita (-♦- S).

results, individuals travelled from villages at lower altitudes to the highlands (likely Cusco) where they were fed special foods and prepared for their roles as tribute to the gods.

All samples recorded diets with increased protein sources and ^{13}C enrichment (attributed to *maize*) roughly 12 months prior to death (fig. 7a, 7b, respectively). The four Argentinian mummies (LG, LB, LM, and LX) demonstrated little variation in $\delta^{34}S$ however the Peruvian mummy illustrated a 5.2‰ decrease in $\delta^{34}S$ roughly 12 months prior to death (fig. 7e). This ^{34}S depletion has been attributed to a change in subsistence niche for Sarita while travelling to Cusco (Wilson *et al.* 2007). Marked decreases in $\delta^{34}S$ for all five individuals provided conclusive evidence that the children were not fed special marine-protein diets, disproving the original hypothesis. Ultimately this study provided a new approach to analyzing ritual sacrifice, examined the diets of *capacocha* children, and identified evidence of changes in subsistence niches.

Scalp hair is a more effective medium for isotopic analysis as it measures dietary protein on a monthly basis rather than a multi-year basis (Macko *et al.* 1999). According to Williams and Katzenberg (2012), hair grows roughly 0.35 mm / day, equating to roughly one centimetre of hair per month. Wilson *et al.* (2007) analyzed hair increments that represented 1.5 month periods. This incremental measurement was selected to ensure that a sufficient sulphur mass was recorded from each keratin sample. According to Nehlich (2015:7) keratin has a mass that is roughly 5% sulphur, compared to the ~1% sulphur content-by-mass value recorded in bone collagen. Fernández, Panarello, and Schobinger (1999) also analyzed isotope values recorded in scalp hair in other mummies in South America however their methods were based on an older approach (Macko *et al.* 1999). In this approach the entire hair sample was analyzed as a bulk sample to ensure sufficient sulphur content. In their study, sulphur values indicated individuals from more coastal regions (likely impacted by the sea-spray effect) compared to those that came from more highland or low-inland regions (Macko *et al.* 1999). Alternatively, newer and more refined methods of hair analysis have identified diet during a more specific period of life (Williams and Katzenberg 2012). Migration, seasonality, and more specific dietary trends can all be examined using isotopes analysed from hair samples.

According to Sarita's isotope values, her diet was enriched in ^{15}N and some ^{13}C, and depleted in ^{34}S within the same 9 month period (12-21 cm distance from scalp, fig. 7). The carbon and nitrogen data for this timeframe would normally be identified as representing a marine-based diet, which should be accompanied by ^{34}S-enriched keratin. Based on Sarita's $\delta^{34}S$ value (~10‰), she was more likely consuming larger portions of C_4 cultigens (e.g. *maize* or *kiwicha*) and protein from a freshwater or terrestrial source, and was changing subsistence niches. Depending on nearby freshwater sources, a diet with increased freshwater protein from a shallow-water niche may also cause ^{34}S-depletion (Craig *et al.* 2006). Sarita's recorded $\delta^{15}N$ values nine months prior to death may also be interpreted as a diet based on seasonal protein sources, as illustrated by the sine-curved pattern (fig. 7a). This fluctuation is also observed among the four mummies from Argentina. Sarita and the other *capacocha* children had drastically different diets in the four to nine months prior to death, which would not have been visible in the osteological material, or according to full-strand isotopic analysis of hair.

Case Study #3: Large-Scale Mummy Study

Horn *et al.* (2009) conducted a large-scale isotopic study of mummy teeth, scalp hair, and camelid textiles from remains located at Los Molinos, Monte Grande, Paracas, and Pueblo Viejo from the Middle Paracas (500 BCE) to the end of the Wari culture (1000 CE) (fig. 6, table 2). Full strands of hair were sampled to indicate the average diet for each mummy, which was then illustrated as the average subsistence trend for each population (fig. 8). Based on the combined data recorded in $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ values in hair and wool, Horn *et al.* (2009) concluded that individuals from Paracas had a marine-heavy diet, whereas Monte Grande may

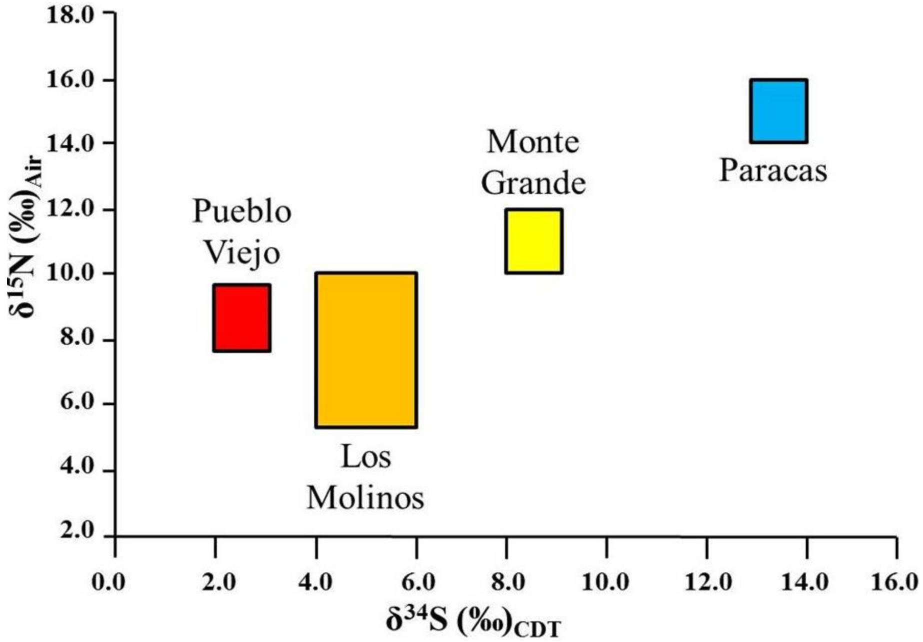


Figure 8. Mean values for $\delta^{15}N$ vs. $\delta^{34}S$ analyzed on recent and archaeological hair and wool from various sites discussed in text. Based on values interpreted from Horn *et al.* (2009:184).

have had food items grown in a sea spray-affected niche.

Comparing the geographic locations of these four sites, the recorded sulphur values (fig. 6, 8) match the anticipated ranges outlined in Figure 6. Pueblo Viejo, which is the most elevated site sample, is located approximately 500 km from the Pacific Ocean, and would have volcanic sulphur sources. Accordingly, Pueblo Viejo human hair has a $\delta^{34}S$ range of +2‰ to +3‰ (anticipated -10‰ to +10 ‰). Los Molinos A and C are located roughly 90 km from the Pacific Ocean at at the base of the Andes Mountains, and would be expected to have either a terrestrial sulphur source or a low-level volcanic influence (anticipated 0‰ to +16‰). The average range for both assemblages is +4‰ to +6‰ in human hair, supporting the values estimated in Figure 6. The Los Molinos averages were also too ^{34}S-depleted to indicate a sea-spray influence supporting the estimation of Nehlich (2015) that sea-spray only affects areas less than 30 km from a coastal niche. Accordingly, Monte Grande, which *is* located less than 30 km from the coast, is identified as having some se- spray influence (+8‰ to +9‰ in human hair) (Horn *et al.* 2009). Paracas, the only study sample located on the Pacific coast, had an average $\delta^{34}S$ of +13‰ to +14‰ in human hair, indicating that there was some marine influence on subsistence. The larger spread of sulphur values in wool was not discussed by Horn *et al.* (2009) (fig. 8), but may be indicative of expansive grazing niches throughout a larger space, similar to the management 'zones' recorded by Finucane, Agurto, and Isbell (2006).

This study confirmed many of the $\delta^{34}S$ trends anticipated across different subsistence niches in Peru (fig. 6) but also highlighted some of the limitations of broad-scale sulphur isotope studies. Unlike Wilson *et al.* (2007), who examined monthly segments of scalp hair, Horn *et al.* (2009) recorded isotopes from full strands of hair. This method is similar to analyzing bone samples. Full strands of hair indicate the relative diet for one to two years depending on the length of each strand, which may confound dietary differences indicative of seasonality (Williams and Katzenberg 2012), transhumance (White *et al.* 2009), and migration (Wilson *et al.* 2007). Alternatively, this study highlights discernible differences in baseline sulphur values for a small region in Peru, suggesting that other areas can also have unique sulphurous niches.

Cautionary Analysis Moving Forward

Sulphur isotope analyses require establishing baselines for each niche. Once established, deviations from the baseline can be interpreted as the inclusion of a dietary item from a different source. Figure 6 illustrates relative sulphur variability according to a number of sources for the Peruvian landscape. The geology of this landscape must first be considered. The Pacific Ocean is a large marine source that has been extensively studied and fauna that grow within this environment would be expected to reflect a sulphur isotope value of roughly +21‰ (Mossman *et al.* 1991). Small river valleys that stem from the Pacific Ocean, but turn into shallow-bedded estuaries, would have specific sulphur content based on the marine source and influence from local sedimentary sources (Böttcher 2001). Fauna that grow in estuary conditions will have site-specific values that should range between +10‰ and +25‰. Alternatively, freshwater sources east of the Andes Mountains would be expected to have more depleted sulphur values as they approach the Amazon riverbed (Bottrell and Raiswell 2000). According to Konhauser, Fyfe, and Kronberg (1994), the Amazon riverbed does not have recorded sediments of sulphur, and fauna that grow in these conditions would only get sulphurous content from other surrounding sediments and runoff from the Andes Mountains. The isotopic values for these areas would be closer to 0‰ due to a lack of stored sulphur within the sediments. The Andes Mountains, according to Konhauser Fyfe, and Kronberg (1994:172) are geologically active areas "mixed with newly extruded mantle elements", including sulphur. Due to the presence of pure sulphur, and the attrition of these elements throughout the Andes, the sulphuric content of vegetation and fauna living within these areas would be ^{34}S-depleted, reflecting a lower recorded value of -20‰ to 0‰. Each area within Peru will have a unique sulphuric value based on the available sources of geological sediments and rainwater-deposited aerosols (Nehlich 2015).

Due to modern anthropogenic contamination, the sulphur isotope content of each site location is unobtainable through modern sampling (Richards *et al.* 2003). Baseline isotope values must be established for each site using small-bodied (non-mobile) fauna recorded within each archaeological assemblage. In Peru this could involve recording sulphur isotope values in the collagen of rodents (except for guinea pigs[1]), lagomorphs, and lizards from archaeological assemblages. Domesticated animals may provide local baseline values, but could also represent diets attributed to non-locally grown fodder, which will skew baseline isotope values (Millard *et al.* 2011). Once a representative sulphur niche baseline is established, values will provide a comparative measure for the proportion of locally grown flora and locally-raised fauna in the diet.

Conclusions

Stable isotope analysis enables a direct investigation of the foods consumed in the past, which is not possible using other methods of botanical and faunal analysis. The exact

---

[1] Recall Finucane, Augurto, and Isbell (2006): *cuy* can be raised domestically for consumption and may reflect non-local omnivore isotope signatures. They are not ideal for providing a baseline.

parameters of palaeodiet are unobtainable from one method alone. Sulphur isotope analysis permits an examination of palaeodietary sources but it can easily be confounded by local isotopic variability. Instead of analyzing sulphur isotopes in bone collagen, it would be most beneficial to examine δ^{34}S values measured in segments of hair from human and faunal archaeological remains. Numerous archaeological sites in Peru yield sufficient preservation for the recovery and sampling of hair remains, including hair samples already recorded by Horn *et al.* (2009); Knudson, Aufderheide, and Buikstra (2007); Szpak *et al.* (2015), Webb, White, and Longstaffe (2013), White *et al.* (2009), Williams and Katzenberg (2012), and Wilson *et al.* (2007). The previously established limitations in sulphur isotope analysis should not discredit the approach, but instead promote caution in its application. The type of isotope analyzed may limit palaeodietary analysis, but it can provide supplementary dietary information not evident from floral, ceramic, and faunal analyses alone.

Acknowledgements

This project stems from my MA Research (Bishop 2013) and was refined during my Doctoral coursework. Considerable thanks go to both of my supervisors, Tracy Prowse and Sandra Garvie-Lok, respectively. Many colleagues at Western University are referenced here with earnest thanks. Gratitude is also given to four anonymous reviewers, and colleagues Victoria and Christina, who were always available to provide insight on previous drafts.

References Cited

Ambrose, S.H., and L. Norr. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In, *Prehistoric Human Bone*. Springer: Berlin, Germany, pp.1-37.

Beresford-Jones, D.G., S.T. Arce, O. Q. Whaley, and A.J. Chepstow-Lusty. 2009. The role of *Prosopis* in ecological and landscape change in the Samaca Basin, lower Ica Valley, south coast Peru from the early horizon to the late intermediate period. *Latin American Antiquity* 20(2):303-332.

Bishop, K.G. 2013. *Meat, bones, and isotopes: Faunal remains in Roman subsistence analysis.* (Unpublished MA Thesis). McMaster University, Hamilton, Ontario.

Bocherens, H., D.G. Drucker, and H. TaPubald. 2011. Preservation of bone collagen sulphur isotopic compositions in an early Holocene river-bank archaeological site. *Palaeogeography, Palaeo-climatology, and Palaeoecology* 310:32-38.

Bogaard, A., H.E. Heaton, P. Poulton, and I. Merbach. 2007. The impact of manuring on nitrogen isotope ratios in cereals: Archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34:335-343.

Böttcher, M.E. 2001. Sulfur isotope fractionation in the biogeochemical sulfur cycle of marine sediments. *Isotopic Environmental Health Studies* 37:97-99.

Bottrell, S.H., and R. Raiswell. 2000. Sulphur isotopes and microbial sulphur cycling in sediments. In, *Microbial Sediments.* Riding, R.E., and S.M. Awramik, Eds. Springer-Verlag Berlin Heidleberg Publishing, Berlin, Germany, pp. 96-104.

Bray, T.L. 2003. Inka pottery as culinary equipment: Food, feasting, and gender in Imperial state design. *Latin American Antiquity* 14(1):3-28.

Burger, R.L., and N.J. van der Merwe . 1990.Maize and the origin of highland Chavín Civilization: an isotopic perspective. *American Anthropologist* 92(1):85-95.

Cadwallader, L., D.G. Beresford-Jones, O.Q. Whaley, and T.C. O'Connel. 2012. The signs of maize? A reconsideration of what ^{13}C values say about paleodiet in the Andean region. *Human Ecology* 40:487-509.

Christenson, B., and F. Tassi. 2015. Gases in volcanic lake environments. In, *Volcanic Lakes*, Rouwet, D., B. Christenson, F. Tassi, and J, Vandemeulebrouck, Eds. Springer Heidelberg, New York, New York, pp. 125-154.

Craig, O.E., B. Ross, S.H. Andersen, N. Milner, and G.N. Bailey. 2006. Focus: Sulphur isotope variation in archaeological marine fauna from northern Europe. *Journal of Archaeological Science* 33:1642-1646.

DeNiro, M.J., and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochemica et Cosmochimica Acta,* 45:341-351.

DeNiro, M.J., and M.J. Schoeninger. 1983. Stable carbon and nitrogen isotope ratios of bone collagen: Variations within individuals, between sexes, and within populations raised on monotonous diets. *Journal of Archaeological Science* 10:199-203.

Downey, J. (2015). *Statecraft in the Virú Valley, Peru in the First Millenium A.D.* (Unpublished PhD Dissertation). Western University, London, Ontario.

Duncan, N.A., D.M. Pearsall, and R.A. Benfer, Jr. 2009. Gourd and squash artifacts yield starch grains of feasting foods from preceramic Peru. *Proceedings of the National Academy of Science* 106(32):13202-13206.

Fernández, J., H.O. Panarello, and J. Schobinger. 1999. The Inka mummy from Mount Aconcagua: Decoding the geographic origin of the "messenger to the deities" by means of stable carbon, nitrogen, and sulfur isotope analysis. *Geoarchaeology* 14:27-46.

Finucane, B., P.M. Agurto, and W.H. Isbell. 2006. Human and animal diet at Conchopata, Peru: Stable isotope evidence for maize agriculture and animal management practices during the middle horizon. *Journal of Archaeological Science* 33:1766-1776.

Fornander, E., G. Eriksson, and K. Lidén. 2008. Wild at heart: Approaching pitted ware identity, economy and cosmology through stable isotopes in skeletal material from the Neolithic site Korsnäs in Eastern Central Sweden. *Journal of Anthropology and Archaeology* 27:281-297.

Froehle, A.W., C.M. Kellner, and M.J. Schoeninger. 2010. FOCUS: Effect of diet and protein source on carbon stable isotope ratios in collagen: Follow up to Warinner and Tuross (2009). *Journal of Archaeological Science* 37:2662-2670.

Goldstein, P.S. 2003. From stew-eaters to maize-drinkers: The chicha economy and the Tiwanaku expansion. In, *The Archaeology and Politics of Food and Feasting in Early States and Empires*, Bray, T. L. Ed. Kluwer Academic/Plenum Publishers, New York, pp. 143–172.

Hastorf, C.A., and S. Johannessen. 1993. Pre-Hispanic political change and the role of *maize* in the central Andes of Peru. *American Anthropologist* 95(1):115-138.

Heaton, T.H.E. 1999. Spatial, species, and temporal variations in the $^{13}C/^{12}C$ ratios of C_3 plants: Implications for palaeodiet studies. *Journal of Archaeological Science* 26:637-649.

Hoefs, J. 2009. *Stable Isotope Geochemistry*, 6th ed. Springer: Berlin, Germany.

Hollingsworth, E.R. 2006. *Elemental and isotopic chemistry of the Uzon Caldera: The evolution of thermal waters, gas, and mineral precipitation.* (Unpublished MA Thesis). The University of the South, Athens, Georgia.

Horn, P., S. Hölzl, S. Rummel, G. Åberg, S. Schiegl, D. Biermann, U. Struck, and A. Rossmann. 2009. Humans and camelids in river oases of the Ica-Palpa-Nazca region in pre-Hispanic times: Insights from H-C-N-O-S-Sr isotope signatures. In, *New Technologies for Archaeology: Multidisciplinary Investigations in Palpa and Nasca, Peru*. Reindel, M., and Wagner, G. A. Eds. Natural Science in Archaeology. Springer, Berlin, pp. 173–192.

Izeta, A.D., A.G. Laguens, M.B. Marconetto, and M.C. Scattolin. 2009. Camelid handling in the meridional Andes during the first millennium AD: A preliminary approach using stable isotopes. *International Journal of Osteoarchaeology* 19:204-214.

Kellner, C.M., and M.J. Schoeninger. 2008. Wari's Imperial influence on local Nasca diet: The stable isotope evidence. *Journal of Anthropological Archaeology* 27:226-243.

Knudson, K.J., A.E. Aufderheide, and J.E. Buikstra. 2007. Seasonality and paleodiet in the Chiribaya polity of southern Peru. *Journal of Archaeological Science* 34:451-462.

Konhauser, K.O., W.S. Fyfe, and B.I. Kronberg. 1994. Multi-element chemistry of some Amazonian waters and soils. *Chemical Geology* 111:155-175.

Krouse, H.R., and T.B. Coplen. 1997. Reporting of relative sulfur isotope-ratio data. *Pure and Applied Chemistry* 69(2):293-295.

Krueger, H.W., and C.H. Sullivan 1984. Models for carbon isotope fractionation between diet and bone. *Stable Isotopes in Nutrition* 258:205-220.

Lambert, P.M., C.M. Gagnon, B.R. Billman, M.A. Katzenberg, J. Carcelén, and R.H. Tykot. 2012. Bone chemistry at Cerro Oreja: A stable isotope perspective on the development of a regional economy in the Moche Valley, Peru during the early intermediate period. *Latin American Antiquity* 23(2):144-166.

Leach, F, C. Quinn,J. Morrison, and G. Lyon. 2001. The use of multiple isotope signatures in reconstructing prehistoric human diet form archaeological bone from the Pacific and New Zealand. *New Zealand Journal of Archaeology* 23:31-98.

Lee-Thorp, J.L., and P.B. Beaumont. (1995). Vegetation and seasonality shifts during the late quaternary deduced from $^{13}C/^{12}C$ ratios of grazers at Equus Cave, South Africa. *Quaternary Research* 43(3):426-432.

Lee-Thorp, J.L., and N.J. van der Merwe. 1987. Carbon isotope analysis of fossil bone apatite. *South African Journal of Science* 83(11):712-715.

Leonard, C., Vashro, L., J.F. O'Connell, and A.G. Henry. 2015. Plant microremains in dental calculus as a record of plant consumption: A test with Twe forager-horticulturalists. *Journal of Archaeological Science: Reports* 2:449-457.

Macko, S.A., M.H. Engel, V. Andrusevich, G. Lubec, T.C. O'Connell, and R.E.M. Hedges. 1999. Documenting the diet in ancient human populations through stable isotope analysis of hair. *Philosophical Transactions of the Royal Society B: Biological Sciences* 354(1379):65-76.

Madgwick, R., N. Sykes, H. Miller, R. Symmons, J. Morris, and A. Lamb. 2013. Fallow deer (*Dama dama dama*) management in Roman South-East Britain. *Archaeological and Anthropological Sciences* 5(2):111-122.

Masur, L.J. 2012. *Peanuts and prestige on the Peruvian north coast: The archaeology of peanuts at Huaca Gallinazo (V-59) and Huaca Santa Clara (V-67).* (Unpublished MA Thesis). The University of British Columbia, Vancouver, British Columbia.

Millaire, J-F., and E. Eastaugh. 2014. Geophysical survey on the coast of Peru: The early prehispanic city of Gallinazo Group in the Virú Valley. *Latin American Antiquity* 25(3):239-255.

Miller, G.R., and R.L. Burger. 1995. Our father the Cayman, our dinner the Llama: Animal utilization at Chavín de Huántar, Peru. *American Antiquity* 60(3):421-458.

Miller, M.J., J.M. Capriles, and C.A. Hastorf. 2010. The fish of Lake Titicaca: Implications for archaeology and changing ecology through stable isotope analysis. *Journal of Archaeological Science* 37:317-327.

Mizota, C., and A. Sasaki. 1996. Sulfur isotope composition of soils and fertilizers: Differences between Northern and Southern hemispheres. *Geoderma* 71:77-93.

Moseley, M.E. 1975. *The Maritime Foundations of Andean Civilizations*. Cummings Publishing Company, Inc., Menlo Park.

Mossmann, J-R., A.C. Aplin, C.D. Curtis, and M.L. Coleman. 1991. Geochemistry or inorganic and organic sulphur in organic-rich sediments from the Peru Margin. *Geochimica et Cosmochimica Acta* 55(12):3581-3595.

Nehlich, O. 2015. The application of sulphur isotope analyses in archaeological research: A review. *Earth-Science Reviews* 142:1-17.

Nehlich, O., and M.P. Richards. 2009. Establishing collagen quality criteria for sulfur isotope analysis of archaeological bone collagen. *Archaeological and Anthropological Science* 1:59-75.

Nehlich, O., D. Boric, S. Stefanovic, and M.P. Richards. 2010. Sulfur isotope evidence for freshwater fish consumption: A case study from the Danube Gorges, SE Europe. *Journal of Archaeological Science* 37:1131-1139.

Nehlich, O., B.T. Fuller, M. Jay, A. Mora, R.A. Nicholson, C.I. Smith, and M.P. Richards. 2011. Application of sulphur isotope ratios to examine weaning patterns and freshwater fish consumption in Roman Oxfordshire, UK. *Geochemica et Cosmochimica Acta* 75:4963-4977.

Nehlich, O., J.H. Barrett, and M.P. Richards. 2013. Spatial variability in sulfur isotope values of archaeological and modern cod (*Gadus morhua*). *Rapid Communication in Mass Spectrometry* 27:2255-2262.

Nehlich, O., V. Oelze, M. Jay, M. Conrad, H. Stäuble, W. Teegan, and M.P. Richards. 2014. Sulphur isotope ratios of multi-period archaeological skeletal remains from central Germany: A dietary and mobility study. *Anthropologie (BRNO)*, LII:15-33.

Piperno, D.R., and T.D. Dillehay. 2008. Starch grains on human teeth reveal early broad crop diet in northern Peru. *Proceedings of the National Academy of Science* 105(50):19622-19627

Privat, K.L., T.C. O'Connell, and R.E.M. Hedges. 2007. The distinction between freshwater- and terrestrial-based diets: Methodological concerns and archaeological applications of sulphur stable isotope analysis. *Journal of Archaeological Science* 34:1197-1204.

Rafter, T.A., I.R. Kaplan, and J.R. Hulston. 1960. Sulphur isotopic measurements on sulphur and sulphates in New Zealand geothermal and volcanic areas. *New Zealand Journal of Science* 1: 103-126.

Richards, M.P., B.T. Fuller, and R.E.M. Hedges. 2001. Sulphur isotopic variation in ancient bone collagen from Europe: implications for human palaeodiet, residence mobility, and modern pollutant studies. *Earth and Planetary Science Letters* 191:185-190.

Richards, M.P., B.T. Fuller, M. Sponheimer, T. Robinson, and L. Ayliffe. 2003. Sulphur isotopes in palaeodietary studies: A review and results from a controlled feeding experiment. *International Journal of Osteoarchaeology* 13:37-45.

Richards, M.P., B.T. Fuller, and T.I. Molleson. 2006. Stable isotope palaeodietary study of humans and fauna from the multi-period (Iron Age, Viking and Late Medieval site of Newark Bay, Orkney). *Journal of Archaeological Science* 33:122-131.

Richards, M.P., P.B. Pettitt, M.C. Stiner, and E. Trinkaus. 2001. Stable isotope evidence for increasing dietary breadth in the European mid-Upper Paleolithic. *Proceedings of the National Academy of Science* 98:6528-6532.

Sakai, H. 1957. Fractionation of sulphur isotopes in nature. *Geochimica et Cosmochimica Acta*, 12:150-169.

Sakai, H., and O. Matsubaya. 1977. Stable isotopic studies of Japanese geothermal systems. *Geothermics* 5:97-124.

Salque, M., G. Radi, A. Tagliacozzo, B. Pino Uria, S. Wolfram, I. Hohle, H. Stauble, A. Whittle, D. Hofmann, J. Pechtl, S. Schade-Lindig, U. Eisenauer, and R.P. Evershed. 2012. New insights into the Early Neolithic economy and management of animals in Southern and Central Europe revealed using lipid residue analyses of pottery vessels. *Anthropozoologica*, 47(2):45-62.

Sayle, K.L., G.T. Cook, P.L. Ascough, H.R. Hastie, A. Einarsson, T.H. McGovern, M.T. Hicks, A. Edwald, and A. Fridriksson. 2013. Application of ^{34}S analysis for elucidating terrestrial, marine and freshwater ecosystems: Evidence of animal movement/husbandry practices in an early Viking community around Lake Myvatn, Iceland. *Geochemica et Cosmochimica Acta* 120: 531–544.

Schoeninger M.J., M.J. DeNiro, and H. Tauber. 1983. Stable nitrogen ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220(4604):1381-1383.

Schwarcz, H.P. 2000. Some biochemical aspects of carbon isotopic paleodiet studies. In, *Biogeochemical Approaches to Paleodietary Analysis*, Ambrose, A., and Katzenberg, A. Eds. Kluwer Academic/Plenum Publishers: New York, pp. 189-210.

Schwarcz, H.P., and M.J. Schoeninger. 2011. Stable isotopes of carbon and nitrogen as tracers for paleodiet reconstruction. Handbook of Environmental Isotope Geochemistry. Advances in Isotope Geochemistry, Part 5, pp. 725-742, DOI: 10.1007/978-3-642-10637-8_34.

Shearer, C.K., G.D. Layne, JJ. Papike, and M.N. Spilde. 1996. Sulfur isotopic systematics in alteration assemblages in martian meteorite Allan Hills 84001. *Geochimica et Cosmochimica Acta* 60(15):2921-2926.

Somerville, A.D., P.S. Goldstein, S.I. Baitzel, K.L. Bruwelheide, A.C. Dahlstedt, L. Yzurdiaga, S. Raubenheimer, K.J. Knudson, and M.J. Schoeninger. 2015. Diet and gender in the Tiwanaku Colonies: Stable isotope analysis of human bone collagen and apatite from Moquegua, Peru. *American Journal of Physical Anthropology* 158(3):408-422.

Szpak, P., J-F. Millaire, C.D. White, G.F. Lau, F. Surette, and F.J. Longstaffe. 2015. Origins of Prehispanic camelid wool textiles from the north and central coasts of Peru traced by carbon and nitrogen isotopic signatures. *Current Anthropology* 56(3):449-459.

Stewart, N. 2015. Andes Mountains. In, *Encyclopaedia Britannica*. Retrieved from http://www.britannica.com/place/Andes-Mountains.

Thode, H.G., J. Monster, and H.B. Dunford. 1961. Sulphur isotope geochemistry. *Geochimica et Cosmochimica Acta* 25:159-174.

Tomczak, P.D. 2003. Prehistoric diet and socioeconomic relationships within the Osmore Valley of Southern Peru. *Journal of Anthropological Archaeology* 22(3):262–278.

Trust, B.A., and B. Fry. 1992. Stable sulphur isotopes in plants: A review. *Plant, Cell and Environment* 15:1105-1110.

Turner, B.L., J.D. Kingston, and G.J. Armelagos. 2010. Variation in dietary histories among the immigrants of Machu Picchu: Carbon and nitrogen isotope evidence. *Chumgara, Revista de Antropología* 42(2):515-534.

Ugan. A., and J. Coltrain. 2011. Variation in collagen stable nitrogen values in black-tailed jackrabbits (*Lepus californicus*) in relation to small-scale difference sin climate, soil, and topography. *Journal of Archaeological Science* 38:1417-1429.

van Klinken, G.J., Richards, M.P., and R.E.M. Hedges. 2000. An overview of causes for stable isotopic variations in past European human populations: Environmental, ecophysiological, and cultural effects. In, *Biogeochemical Approaches to Paleodietary Analysis*, Ambrose, A., and Katzenberg, A. Eds. Kluwer Academic/Plenum Publishers: New York, pp. 39-63.

Venet-Rogers, C. 2013. *A study of faunal consumption at the Gallinazo Group Site, northern coast of Peru.* (Unpublished MA Thesis). Western University, Ontario, London, Ontario.

Vika, E. 2009. Strangers in the grave? Investigating local provenance in a Greek Bronze Age mass burial using δ^{34}S analysis. *Journal of Archaeological Science* 36:2024-2028.

Webb, E., C. White, and F. Longstaffe. 2013. Dietary shifting in the Nasca Region as inferred from carbon- and nitrogen-isotope compositions of archaeological hair and bone. *Journal of Archaeological Science* 40(1):129-139.

White, C.D., A.J. Nelson, F.J. Longstaffe, G. Grupe, and A. Jung. 2009. Landscape bioarchaeology at Pacatnamu, Peru: Inferring mobility from δ^{13}C and δ^{15}N values of hair. *Journal of Archaeological Science* 36(7):1527-1537.

Williams, J.S., and M.A. Katzenberg. 2012. Seasonal fluctuations in diet and death during the late horizon: A stable isotopic analysis of hair and nail from the central coast of Peru. *Journal of Archaeological Science* 39:41-57.

Wilson, A.S., T. Taylor, M.C. Ceruti, J.A. Chavez, J. Reinhard, V. Grimes, W. Meier-Augenstein, L. Cartmell, B. Stern, M.P. Richards, M. Worobey, I. Barnes, and M.T.P. Gilbert. 2007. Stable isotope and DNA evidence for ritual sequences in Inca child sacrifice. *Proceedings of the National Academy of Science* 104:16456-16461.

Zarrillo, S., D.M. Pearsall, J.S. Raymond, M.A. Tisdale, and D.J. Quon. 2008. Directly dated starch residues document early formative maize (*Zea mays* L.) in tropical Ecuador. *Proceedings of the National Academy of Science* 105(13):5006-5011.