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References

Ambrose 1986a

Stanley H. Ambrose & Michael J. DeNiro, *Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios*. nature **319** (1986), 321–324.

Behavioural modifications associated with the exploitation of new food resources have been linked to major steps in hominid evolution and in subsequent human cultural development1,2. Testing of specific hypotheses concerning the influence of dietary change on these processes would be facilitated by quantitative estimates of early hominid and human diets. Although most methods of obtaining such evidence provide only qualitative information2, the stable carbon and nitrogen isotope ratios of animal tissues, and in particular, bone collagen, can be used to quantify the consumption of foods having different isotopic compositions3-5. As reported here, analysis of the collagen of historic and prehistoric African human populations from Kenya, Tanzania and South Africa that have reasonably well-known diets shows that stable carbon and nitrogen isotope ratios in bone collagen can distinguish marine foragers from populations consuming terrestrial resources, pastoralists from farmers, farmers consuming grains from those consuming non-grain crops, and camel pastoralists from capri-bovine pastoralists.

Ambrose 1986b

Stanley H. Ambrose, *Stable Carbon and Nitrogen Isotope Analysis of Human and Animal Diet in Africa*. Journal of Human Evolution **15** (1986), 707–731.

The stable carbon and nitrogen isotope composition of bone collagen has been determined for 238 modern non-human mammals, comprising 43 species of herbivores and carnivores from grasslands and montane forests in Kenya and Tanzania, and 97 historic and prehistoric humans, representing 12 populations with different dietary adaptations from eastern and southern Africa. Among non-human species carbon isotope ratios separate grazers from browsers in open grasslands, forest floor from forest canopy, and forest floor from open grassland feeders. Nitrogen isotopes separate carnivores from herbivores and forest from savanna-living species. Water-dependent herbivores have lower nitrogen isotope ratios than drought-tolerant ones in the sarne habitat. Among human populations, carbon isotopes differentiate those who regularly consume grains and/or the protein of browsing animals from those who consume wild plants, non-grain crops and/or the protein of wild animals. Nitrogen isotopes differentiate those dependent on the milk, meat and blood of domestic animals or marine resources from those dependent mainly on plant foods. Combined use of carbon and nitrogen isotopes permits the differentiation of pastoralists from farmers, camel pastoralists from capri-bovine pastoralists, and grain farmers from non-grain farmers. The apparent presence of physiological and climatic influences on nitrogen isotope ratios within trophic levels complicates dietary interpretations of variations in nitrogen isotope ratios but may also offer a new tool of climatic reconstruction. It should nonetheless be possible to use the analysis of the isotopic composition of bone collagen as a quantitative technique for the reconstruction of diet, habitat selection, climate and water balance in prehistoric animal and human communities, and to test models that

suggest dietary adaptations were prime movers of hominid biological and cultural evolution.

Ambrose 1986c

Stanley H. Ambrose & Michael J. DeNiro, *The Isotopic Ecology of East African Mammals*. Oecologia **69** (1986), 395–406.

The stable carbon and nitrogen isotope ratios of bone collagen have been used to trace diet and habitat selection of the larger mammals of East Africa. 238 individuals of 43 species from montane forests and grasslands in Kenya and Tanzania have been analyzed. The results show that carbon isotopes discriminate between (1) grazers and browsers in savanna grasslands, (2) forest floor and savanna grassland herbivores and (3) forest floor and forest canopy species. Nitrogen isotopes discriminate between (4) carnivores and herbivores, (5) forest and savanna grassland herbivores, and (6) water-dependent and drought-tolerant herbivores. This technique provides a quantitative approach to assessing long-term habitat and diet selection and the role of resource partitioning in animal community structure.

Ambrose 1991

Stanley H. Ambrose, *Effects of Diet, Climate and Physiology on Nitrogen Isotope Abundances in Terrestrial Foodwebs*. Journal of Archaeological Science **18** (1991), 293–317.

Variations in nitrogen isotope ratios in terrestrial foodwebs are described, and alternative models for variation in the enrichment between trophic levels are evaluated. Nitrogen isotope ratios in bone collagen have been used to determine trophic levels and differentiate marine from terrestrial resource consumption among prehistoric humans. However, recent research in terrestrial ecosystems has revealed significant variation in nitrogen isotope ratios between habitats, and within trophic levels in the same environment. Foodwebs in hot, arid environments tend to have higher nitrogen isotope ratios than cool. wet ones. Within ecosystems, the stepwise enrichment between trophic levels is often greater in hot, arid environments. Within ecosystems, herbivore species with physiological adaptations to water conservation have higher nitrogen isotope ratios than water-dependent species. The nitrogen isotope ratios of human bones may be affected by climate and physiology and thus cannot be directly compared between different types of ecosystems without first determining the isotopic composition of the local foodweb and the stepwise enrichment between trophic levels.

Ambrose 1993

Stanley H. Ambrose, *Isotopic Analysis of Paleodiets: Methodological and Interpretative Considerations*. In: Mary K. Sandford (Hrsg.), *Investigations of Ancient Human Tissue*, *Chemical Analyses in Anthropology*. Food and Nutrition in History and Anthropology 10 (Langhorne / Berlin 1993), 59–130.

Ambrose 2006

Stanley H. Ambrose, *A Tool for All Seasons*. science **314** (2006), 930–931.

Laser ablation carbon isotope analysis of robust-australopithecine teeth provides insights into seasonal variations in ancestral diets, while minimizing damage to precious fossils.

An 2015

Cheng-Bang An, Weimiao Dong, Hu Li, Pingyu Zhang, Yongtao Zhao, Xueye Zhao & Shi-Yong Yu, *Variability of the stable carbon isotope ratio in modern and archaeological millets, Evidence from northern China*. Journal of Archaeological Science **53** (2015), 316–322.

JAS053-0316-Supplement.doc

Stable carbon isotopic analyses of human skeletal remains may provide fundamental evidence for human dietary reconstruction and subsistence strategies. Millet is closely associated with the emergence and development of agriculture-based societies in northern China. Although often overlooked, baseline values of millet seeds are essential for using stable isotope analysis to understand past human and animal diets. Here, we report spatial and temporal variations in the d13C values of millets by analyzing modern samples, including seeds and leaves, as well as archaeological samples. The d13C values of modern foxtail millet seeds range from -13.9 to -11.3 ‰, with a mean value of -12.3 ± 0.5 ‰(1s, n = 66), while d13C values for modern common millet seeds vary between -14.3 and -12.0 ‰, with a mean value of -12.8 ± 0.6 ‰ (1s, n = 19). There is an approximately 1 ‰ temporal change in d13C for millet grains. Leaves have lower d13C values than grains, implying that eaters living on different tissues of the same plant could show different isotopic values. These background d13C values must be considered when reconstructing the dietary history of a millet-based society.

Keywords: Stable carbon isotope | Millet | Diet | Archaeobotany | Northern China

Araus 2014

José L. Araus, Juan P. Ferrio, Jordi Voltas, Mònica Aguilera & Ramón Buxo, *Agronomic conditions and crop evolution in ancient Near East agriculture*. Nature Communications **5** (2014), 3953. DOI:10.1038/ncomms4953.

NatComm05-3953-Supplement1.pdf, NatComm05-3953-Supplement2.xls, NatComm05-3953-Supplement3.xls

The appearance of agriculture in the Fertile Crescent propelled the development of Western civilization. Here we investigate the evolution of agronomic conditions in this region by reconstructing cereal kernel weight and using stable carbon and nitrogen isotope signatures of kernels and charcoal from a set of 11 Upper Mesopotamia archaeological sites, with chronologies spanning from the onset of agriculture to the turn of the era.We show that water availability for crops, inferred from carbon isotope discrimination (d13C), was two- to fourfold higher in the past than at present, with a maximum between 10,000 and 8,000 cal BP. Nitrogen isotope composition (d15N) decreased over time, which suggests cultivation occurring under gradually less-fertile soil conditions. Domesticated cereals showed a progressive increase in kernel weight over several millennia following domestication. Our results provide a first comprehensive view of agricultural evolution in the Near East inferred directly from archaeobotanical remains.

Asam 2006

Tanja Asam, Gisela Grupe & Joris Peters, *Menschliche Subsistenzstrategien im Neolithikum, Eine Isotopenanalyse bayerischer Skelettfunde*. Anthropologischer Anzeiger **64** (2006), 1–23.

Originating from the Near East, the Neolithic lifestyle will reach Southeast Europe in its fully developed form in the course of the 7th millennium cal. BC. In the region of today's Bavaria this lifestyle can be evidenced from the middle of the

6th millennium cal. BC onwards. Stable isotope analyses of carbon and nitrogen in bone collagen, and of carbon and oxygen in the bone's structural carbonate of human skeletons from burial sites dated to the Linear Pottery Culture, the middle Neolithic, the Corded Ware and the Bell Beaker Culture revealed differences in the dietary behaviour between 5500 until 3000 BC, and between 3000 until 2000 BC, respectively. In late Neolithic times, meat procurement appears improved and the dietary spectrum as such broadened, evidencing a more secured and increasingly flexible subsistence strategy. Oxygen isotope ratios of the structural carbonate proved to be reliable climatic indicators and may be helpful in the dating of archaeological sites.

Keywords: Stable isotopes | neolithisation | Bavaria | subsistence strategy | food web.

Ausgehend vom Vorderen Orient wird die neolithische Lebensweise Südosteuropa in ihrer voll entwickelten Form im 7. vorchristlichen Jahrtausend erreichen und sich in (nord)westliche Richtung ausbreiten. Um die Mitte des 6. vorchristlichen Jahrtausends wird sie im heutigen bayerischen Raum nachweisbar. Eine Analyse menschlicher Skelettfunde aus bayerischen Fundplätzen der Linearbandkeramik, des mittleren Neolithikums, der Schnurkeramik und der Glockenbecherkultur in Bezug auf stabile Kohlenstoffund Stickstoffisotope des Knochenkollagens sowie stabiler Kohlenstoff- und Sauerstoffisotope des strukturellen Karbonates zeigte einen deutlichen Unterschied in der Ernährungsweise zwischen den Zeitspannen 5500 – 3000 v. Chr. und 3000 – 2000 v. Chr. Im jüngeren Zeitabschnitt deutet sich eine Verbesserung der Fleischversorgung bei insgesamt verbreitertem Nahrungsspektrum an, was gleichermaßen als Zeichen einer gesicherteren und flexibleren Subsistenz gedeutet werden kann. Die Sauerstoff-Isotopensignatur der Karbonatfraktion erwies sich als zuverlässiger Klimaindikator und kann bei der zeitlichen Einordnung von Fundplätzen hilfreich sein.

Keywords: Stabile Isotope | Neolithisierung | Bayern | Subsistenzstrategie | Nahrungsnetz.

Balasse 2002

Marie Balasse & Anne Tresset, *Early Weaning of Neolithic Domestic Cattle (Bercy, France) Revealed by Intra-tooth Variation in Nitrogen Isotope Ratios*. Journal of Archaeological Science **29** (2002), 853–859.

Evaluating the role of milk production in prehistoric subsistence economies requires a better estimation of the capacity of a milk-oriented husbandry under prehistoric conditions. Weaning pattern, which is linked to the length of lactation, is an important parameter in this estimation. In this study, weaning pattern is closely examined in Neolithic cattle from the site of Bercy (Paris, France, c. 4000 BC), by a study of intra-tooth (M1, M2) variation in the nitrogen isotope ratios (d15N) of dentine collagen. Collagen 15N is commonly used to trace the change of trophic level at weaning time. The pattern of change in collagen 15N in the first molar of two archaeological bovines is then compared with that observed in modern cattle weaned at known age. Results suggest that the Neolithic calves were weaned early. This could reflect either a shorter lactation for Neolithic cows, or early weaning imposed by the herder in order to reserve a bigger proportion of milk production for human consumption.

Keywords: Milk Production, Weaning, Neolithic, Nitrogen Isotope Ratios, Collagen, Dentine.

Balter 2012

Vincent Balter, José Braga, Philippe Télouk & J. Francis Thackeray, *Evidence for dietary change but not landscape use in South African*

early hominins. nature **489** (2012), 558–560.
n489-0558-Supplement.pdf
The dichotomy between early Homoand Paranthropusis justified partly on morphology1,2. In terms of diet, it has been suggested that early Homo was a generalist but that Paranthropus was a specialist3. However, this model is challenged and the issue of the resources used by Australopithecus, the presumed common ancestor, is still unclear. Laser ablation profiles of strontium/calcium, barium/calcium and strontium isotope ratios in tooth enamel are a means to decipher intra-individual diet and habitat changes. Here we show that the home range area was of similar size for species of the three hominin genera but that the dietary breadth was much higher in Australopithecus africanus than in Paranthropus robustus and early Homo. We also confirm that P. robustus relied more on plant-based foodstuffs than early Homo. A South African scenario is emerging in which the broad ecological niche of Australopithecus became split, and was then occupied by Paranthropus and early Homo, both consuming a lower diversity of foods than Australopithecus.

Balzer 1997

A Balzer, *In vitro decomposition of bone collagen by soil bacteria: the implications for stable isotope analysis in archaeometry*. Archaeometry **39** (1997), 415–429.

Begemann 1999

Friedrich Begemann, Konrad Kallas, Sigrid Schmitt-Strecker & Ernst Pernicka, *Tracing ancient tin via isotope analyses*. In: Andreas Hauptmann, Ernst Pernicka, Thilo Rehren & Unsal Yalgin (Hrsg.), *The Beginnings of Metallurgy*, *Proceedings of the International Conference „The Beginnings of Metallurgy“, Bochum 1995*. Veröffentlichungen aus dem Deutschen Bergbau-Museum 84 (Bochum 1999), 277–284.

Beherec 2016

Marc A. Beherec, Thomas E. Levy, O. r. Tirosh, Mohammad Najjar, Kyle A. Knabb & Yigal Erel, *Iron Age Nomads and their relation to copper smelting in Faynan (Jordan), Trace metal and Pb and Sr isotopic measurements from the Wadi Fidan 40 cemetery*. Journal of Archaeological Science **65** (2016), 70–83.
The Faynan region in southern Jordan is the largest copper ore resource zone in the southern Levant and was exploited for these ores beginning ca. 8000 years BP. We discuss the relationship between nomadic populations and major copper smelting sites during the Iron Age (ca. 1200-500 BCE) based on mortuary excavations and toxic metal analyses at the Wadi Fidan 40 cemetery, the largest Iron Age mortuary complex in southern Jordan. The Iron Age represents the first industrial revolution in this part of the Middle East. The study presented here is the first to employ chemical and isotopic measurements from a systematically excavated Iron Age mortuary population to determine exposure to Cu and Pb pollution and mobility patterns (based on Sr isotopes). We describe a methodology to control for post-depositional diagenetic uptake of chemical elements in human teeth recovered from the cemetery that has not previously been applied in Faynan in ancient pollution studies. The results suggest that most of the excess of Pb and Cu measured in tooth enamel samples were a product of post-depositional diagenetic addition. Our

findings suggest that the majority of people buried at theWadi Fidan 40 cemetery were not exposed to metal pollution during their lives. The few individuals who were exposed to metal pollution exhibited a spectrum of traits indicative of lifestyle and social status. The results bring into question how severe the ancient pollution impacted the lives of the Iron Age population living in Faynan.

Keywords: Mortuary archaeology | Trace metals | Nomads | Pollution | Copper metallurgy

Bell 2009

L. S. Bell, J. A. Lee Thorp & A. Elkerton, *The sinking of the Mary Rose warship: a medieval mystery solved?* Journal of Archaeological Science **36** (2009), 166–173.

The cause of the sinking of Henry VIII's Vice Flagship, the Mary Rose, as she sailed out to meet the French fleet on 19th July AD 1545, has remained an enduring mystery and contested encounter between the English and French Navies. The French claim was that the ship was holed by French cannon fire, whilst the English maintained that she sank due to a poorly executed navigational manoeuvre during the engagement. On the day of the sinking there was a total listed crew complement of 415 men onboard. Minimum number analysis of the commingled human assemblage identified only 179, from which we sampled 18 individuals from differing decks within the ship. We measured d13C and d15N in bone collagen, and d18O and d13C in enamel apatite of these individuals in order to obtain information about their diets and origins. While the collagen d13C and d15N data are similar to other medieval populations, the d18O data indicate that a significant proportion of the crew did not originate in Britain, but rather they emanated from warmer, more southerly, regions. These data suggest the presence of 33-60 % of non-natives, possibly mercenaries and/or 'prest' men, amongst the crew. Together with the contemporary remark shouted from the Mary Rose to a passing ship, that the Captain had the "type of knaves of whom, he could not rule", our results lend weight to the suggestion that poor communication may well have contributed the observed fatal navigational manoeuvre which led to her sinking.

Bell 2010

L. S. Bell, J. A. Lee-Thorp & A. Elkerton, *Sailing against the wind, Reply to Millard and Schroeder: 'True British sailors': A comment on the origin of the men of the Mary Rose.* Journal of Archaeological Science **37** (2010), 683–686.

We argue that a direct, empirical approach is still the most parsimonious and we reject the re-interpretation of the Mary Rose data presented by Millard and Schroeder (this issue). Whilst models have predictive power, large uncertainties are significant impediments where the research question revolves on quite subtle differences in d18O. Although some data for human d18OPO4 for the UK has just recently been made available, the data are all based on archaeological samples from multiple periods (Chenery et al., 2010) where the influence of past climate shifts (such as the Medieval Warm Epoch and Little Ice Age) are not considered, subsistence modes may be mixed, and patterns of residence or population movement are assumed. In order to resolve such issues we ultimately require studies of modern/ extant provenienced, or at least well-documented historical, human material, on a scale similar to those of Ehleringer et al. (2008) and Bowen et al. (2009).

Benson 2010

Larry V. Benson, *Who provided maize to Chaco Canyon after the mid-12th-century drought?* Journal of Archaeological Science **37** (2010), 621–629.

JArchSci37-0621-Supplement1.xls, JArchSci37-0621-Supplement2.xls

Between A.D. 1181 and 1200, in the early part of a climatically wet period, corn was imported to Chaco Canyon from a region outside the Chaco Halo (de.ned in this paper as the region between the base of the Chuska Mountains and Raton-Wells). Strontium-isotope (87Sr/86Sr) analyses of 12 corn cobs dating to this period match 87Sr/86Sr ratios from .ve potential source areas, including: the Zuni region, the Mesa Verde-McElmo Dome area, the Totah, the De.ance Plateau, and Lobo Mesa. The latter two areas were eliminated from consideration as possible sources of corn in that they appear to have been unpopulated during the time period of interest. Therefore, it appears that the corn cobs were imported from the Zuni region, the Mesa Verde-McElmo Dome area, or the Totah area during a time when the climate was relatively wet and when a surplus of corn was produced in regions outside Chaco Canyon. Based on proximity to and cultural af.liation with Chaco Canyon, it is hypothesized that the corn probably was imported from the Totah.

Bentley 2002

R. Alexander Bentley, T. Douglas Price, Jens Lüning, Detlef Gronenborn, Joachim Wahl & Paul D. Fullagar, *Prehistoric Migration in Europe: Strontium Isotope Analysis of Early Neolithic Skeletons.* Current Anthropology **43** (2002), 799–804.

Bentley 2003

R. Alexander Bentley, Lounes Chikhi & T. Douglas Price, *The Neolithic transition in Europe: comparing broad scale genetic and local scale isotopic evidence.* Antiquity **77** (2003), 63–66.

Genetic studies of modern populations are raising many interesting questions about how far the modern gene pool is owed to incoming populations during the agricultural revolution in Neolithic Europe. But, as the authors show, studies of isotopic data from cemeteries reveal a picture of increasing subtlety at local level. While early farmers may have been initially newcomers in the upper Rhine they may also have soon intermarried with contemporary hunter-gatherers in the uplands.

Keywords: European Neolithic agriculture, demography, stable isotope analysis

Bentley 2008

R. Alexander Bentley, Joachim Wahl, T. Douglas Price & Tim C. Atkinson, *Isotopic signatures and hereditary traits: snapshot of a Neolithic community in Germany.* Antiquity **82** (2008), 290–304.

A group of Linearbandkeramik people at Talheim, Germany were previously found to have died at the same time, probably in a massacre, and the authors were able to ask some searching questions of their skeletons. The isotope signatures of strontium, oxygen and carbon, which gave information on diet and childhood region, showed up three groups which correlated with hereditary traits (derived previously from the analysis of the teeth). In the local group, there were many local children but no adult women, suggesting they had been selectively taken alive at the time of the massacre. Another group, with isotope signatures derived from upland areas, includes two men who may have been closely related.

A third group has a composition suggestive of a nuclear family. The variations of one type of isotope signature with another suggested subtle interpretations, such as transhumance, and a probable labour division in the community between stockholders and cultivators. Here we see the ever-growing potential of these new methods for writing the 'biographies' of prehistoric skeletons.

Keywords: Neolithic, Germany, LBK, Talheim, isotope analysis, hereditary traits, transhumance

Bentley 2012

R. Alexander Bentley et al., *Community differentiation and kinship among Europe's first farmers*. PNAS **109** (2012), 9326–9330.

pnas109-09326-Supplement.docx

R. Alexander Bentley, Penny Bickle, Linda Fibiger, Geoff M. Nowell, Christopher W. Dale, Robert E. M. Hedges, Julie Hamilton, Joachim Wahl, Michael Francken, Gisela Grupe, Eva Lenneis, Maria Teschler-Nicola, Rose-Marie Arbogast, Daniela Hofmann and Alasdair Whittle

Community differentiation is a fundamental topic of the social sciences, and its prehistoric origins in Europe are typically assumed to lie among the complex, densely populated societies that developed millennia after their Neolithic predecessors. Here we present the earliest, statistically significant evidence for such differentiation among the first farmers of Neolithic Europe. By using strontium isotopic data from more than 300 early Neolithic human skeletons, we find significantly less variance in geographic signatures among males than we find among females, and less variance among burials with ground stone adzes than burials without such adzes. From this, in context with other available evidence, we infer differential land use in early Neolithic central Europe within a patrilocal kinship system.

Bocherens 1997

H. Bocherens, Gisela Grupe, A. Mariotti & Susanne Turban-Just, *Molecular preservation and isotopy of Mesolithic human finds from the Ofnet cave (Bavaria, Germany)*. Anthropologischer Anzeiger **55** (1997), 121–129.

Bocherens 2003

H. Bocherens & D. Drucker, *Trophic Level Isotopic Enrichment of Carbon and Nitrogen in Bone Collagen: Case Studies from Recent and Ancient Terrestrial Ecosystems*. Int. J. Osteoarchaeology **13** (2003), 46–53.

Prey-predator collagen enrichment values for carbon and nitrogen isotopic compositions are investigated. New enrichment values are given for the well-monitored ecosystem of Bialowieza primeval forest (Poland) for lynx and wolf. The impact of using different approximations in calculating such enrichment values is discussed. Several case studies of ancient vertebrate communities from Upper Palaeolithic sites in southwestern France are presented to check whether the enrichment values estimated for these past ecosystems are consistent with those measured in well-monitored modern ecosystems. The use of ranges of values rather than average ones is recommended, tentatively 0 to 2‰ for d13C and 3 to 5‰ for d15N.

Bocherens 2009

Hervé Bocherens, *Neanderthal Dietary Habits, Review of the Isotopic Evidence*. In: Jean-Jacques Hublin & Michael P.

Richards (Hrsg.), *The Evolution of Hominin Diets, Integrating Approaches to the Study of Palaeolithic Subsistence*. Vertebrate Paleobiology and Paleoanthropology (Dordrecht 2009), 241–250.

This example clearly illustrates that the collagen isotopic values of Neanderthal collagen provide data on the relative contribution of different protein resources, but it does not preclude a significant amount of plant food with low nitrogen content, as high as half the dry weight dietary intake.

Abstract: Carbon and nitrogen isotopic ratios of fossil bone collagen reflect those of the average diet, and can be preserved for tens of thousands of years under favorable conditions. Twelve European Neanderthal bones ranging in age from 100,000 to 32,000 years old have yielded reliable collagen. For this well-preserved collagen, isotopic signatures offer the possibility to reconstruct the dietary habits of Neanderthals. The degree of interpretation of the isotopic results depends on the paleoecological context, especially on the knowledge of the available food resources and their isotopic signatures. Animal bones associated with the studied human remains provide the most reliable source for such information. In addition, isotopic data from animal bones can be retrieved from nearby sites of similar age if they are not present in the hominid site. However, the precision of the interpretation decreases when difference in distance and age between hominids and fauna increases.

This paper illustrates how such isotopic investigations have impacted our understanding of Neanderthals' dietary habits. A critical review of the available data will be presented, with a discussion of some methodological points, such as preservation assessment and quantification of consumed protein resources. Comparisons of prey selection patterns based on isotopic results between Neanderthals and animal predators, such as hyenas, show that Neanderthals obtained much of their dietary proteins from very large herbivores in open environments by hunting. Discrepancies between prey consumption by the isotopic approach and by zooarcheology may point to individuals with special diets or transport decision that lead to the underrepresentation of very large mammal bones in archeological assemblages.

Keywords: Neanderthal | diet | carbon-13 | nitrogen-15 | collagen

Bocherens 2011

Hervé Bocherens, Dorothée G. Drucker & Heinrich Taubald, *Preservation of bone collagen sulphur isotopic compositions in an early Holocene river-bank archaeological site*. Palaeo **310** (2011), 32–38.

This study investigates the reliability of the sulphur isotopic compositions (d34S) of collagen in archaeological bones from an early Holocene river-bank site, Noyen-sur-Seine (France). The chemical composition (C, N, S) of whole bones compared to those of bones from cave sites suggests that contamination with sulphur is higher in the bones sampled from river bank deposits compared to those from caves, especially those that occur well above the water table. Sulphur content in fresh bone collagen suggests specific values for different mammal taxa, while sulphur content in reptile bones may not always be higher than those of mammals. In the early Holocene bones from Noyen-sur-Seine, the collagen has chemical characteristics within the overall range observed in modern bone collagen. However, co-variation between some diagenetic indicators, such as sulphur content and N/S in whole bone,

,% S in collagen, and S yield, and d34S values of collagen from the same species or ecological groups indicate that some diagenetic alteration may have influenced the collagen. Excluding samples possibly affected by this alteration, a difference in d34S is measured between freshwater and terrestrial fauna. We recommend further

work on the collagen sulphur contents in different species. Moreover, whole bone chemical compositions may help to screen samples for sulphur isotopic analyses of collagen that are to be used for palaeodietary reconstructions.

Keywords: Bone | Collagen | Diagenesis | Sulphur | Isotope

Bocherens 2014

Hervé Bocherens, Dorothée G. Drucker & Stéphane Madelaine, *Evidence for a ^{15}N positive excursion in terrestrial foodwebs at the Middle to Upper Palaeolithic transition in south-western France: Implications for early modern human palaeodiet and palaeoenvironment.* Journal of Human Evolution (2014), preprint, 1–13. DOI:10.1016/j.jhevol.2013.12.015.

JHumEvo2014-preprint-Supplement0322.pdf

The Middle to Upper Palaeolithic transition around 35,000 years ago coincides with the replacement of Neanderthals by anatomically modern humans in Europe. Several hypotheses have been suggested to explain this replacement, one of them being the ability of anatomically modern humans to broaden their dietary spectrum beyond the large ungulate prey that Neanderthals consumed exclusively. This scenario is notably based on higher nitrogen-15 amounts in early Upper Palaeolithic anatomically modern human bone collagen compared with late Neanderthals. In this paper, we document a clear increase of nitrogen15 in bone collagen of terrestrial herbivores during the early Aurignacian associated with anatomically modern humans compared with the stratigraphically older Châtelperronian and late Mousterian fauna associated with Neanderthals. Carnivores such as wolves also exhibit a significant increase in nitrogen15, which is similar to that documented for early anatomically modern humans compared with Neanderthals in Europe. A shift in nitrogen-15 at the base of the terrestrial foodweb is responsible for such a pattern, with a preserved foodweb structure before and after the Middle to Upper Palaeolithic transition in south-western France. Such an isotopic shift in the terrestrial ecosystem may be due to an increase in aridity during the time of deposition of the early Aurignacian layers. If it occurred across Europe, such a shift in nitrogen-15 in terrestrial foodwebs would be enough to explain the observed isotopic trend between late Neanderthals and early anatomically modern humans, without any significant change in the diet composition at the Middle to Upper Palaeolithic transition.

Keywords: Early Aurignacian | Collagen | Stable isotopes | Western Europe

Bogaard 2007

A. Bogaard, T. H. E. Heaton, P. Poulton & I. Merbach, *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** (2007), 335–343.

Recent archaeological studies of human diet have used stable nitrogen isotope ratios (d15N) from human bone collagen to infer the relative importance of terrestrial plant and animal foods. This approach is based on widely observed enrichment of d15N up the food chain, plants having distinctly lower values than the herbivores that consume them. Studies of early fanning diets in Britain, Denmark and Germany have tended to detect relatively high d15N values (e.g. c. +9 ‰), interpreted as evidence of a diet largely based on animal products, though archaeobotanical evidence for crop cultivation (e.g. carbonised cereal grain and chaff) is widespread. This paper investigates the impact of manuring on d15N values in modern cereals, and of charring on these cereal values. The results from two

long-term experiments demonstrate that manuring significantly raises d15N in cereal grain and chaff. Depending on manuring levels and frequency, it appears that human diets with a major component of such grain would conventionally be interpreted as indicating a largely animal-based diet or a mixed plant/animal diet. Moreover, preliminary analyses of experimentally charred grain and chaff from manured and unmanured conditions are promising for the extraction of reliable ancient d15N values from archaeobotanical cereal remains. The wider implications of these results, and the need for further work, are discussed.

Keywords: Nitrogen; Stable isotopes; Manuring; Cereals; Neolithic; Crop husbandry

Bogaard 2013

Amy Bogaard et al., *Crop manuring and intensive land management by Europe's first farmers*. PNAS **110** (2013), 12589–12594.

Amy Bogaard, Rebecca Fraser, Tim H. E. Heaton, Michael Wallace, Petra Vaiglova, Michael Charles, Glynis Jones, Richard P. Evershed, Amy K. Styring, Niels H. Andersen, Rose-Marie Arbogast, László Bartosiewicz, Armelle Gardeisen, Marie Kanstrup, Ursula Maier, Elena Marinova, Lazar Ninov, Marguerita Schäfer & Elisabeth Stephan

The spread of farming from western Asia to Europe had profound long-term social and ecological impacts, but identification of the specific nature of Neolithic land management practices and the dietary contribution of early crops has been problematic. Here, we present previously undescribed stable isotope determinations of charred cereals and pulses from 13 Neolithic sites across Europe (dating ca. 5900–2400 cal B.C.), which show that early farmers used livestock manure and water management to enhance crop yields. Intensive manuring inextricably linked plant cultivation and animal herding and contributed to the remarkable resilience of these combined practices across diverse climatic zones. Critically, our findings suggest that commonly applied paleodietary interpretations of human and herbivore d15N values have systematically underestimated the contribution of crop-derived protein to early farmer diets.

agriculture | prehistoric | husbandry | paleodiet

Bollongino 2013

Ruth Bollongino et al., *2000 Years of Parallel Societies in Stone Age Central Europe*. science **342** (2013), 479–481.

s342-0479-Supplement.pdf

Ruth Bollongino, Olaf Nehlich, Michael P. Richards, Jörg Orschiedt, Mark G. Thomas, Christian Sell, Zuzana FajkoŬová, Adam Powell & Joachim Burger

Debate on the ancestry of Europeans centers on the interplay between Mesolithic foragers and Neolithic farmers. Foragers are generally believed to have disappeared shortly after the arrival of agriculture. To investigate the relation between foragers and farmers, we examined Mesolithic and Neolithic samples from the Blätterhöhle site. Mesolithic mitochondrial DNA sequences were typical of European foragers, whereas the Neolithic sample included additional lineages that are associated with early farmers. However, isotope analyses separate the Neolithic sample into two groups: one with an agriculturalist diet and one with a forager and freshwater fish diet, the latter carrying mitochondrial DNA sequences typical of Mesolithic hunter-gatherers. This indicates that the descendants of Mesolithic people maintained a foraging lifestyle in Central Europe for more than 2000 years after the arrival of farming societies.

Bonsall 2015

Clive Bonsall et al., *Food for Thought, Re-assessing Mesolithic diets in the Iron Gates.* Radiocarbon (2015), preprint, 1–11. DOI:10.2458/azu_rc.57.18440.

Clive Bonsall, Gordon Cook, Catriona Pickard, Kathleen McSweeney, Kerry Sayle, László Bartosiewicz, Ivana Radovanović, Thomas Higham, Andrei Soicaru & Adina Boroneanţ

Stable isotope ratios of carbon, nitrogen, and sulfur in human bone collagen are used routinely to aid in the reconstruction of ancient diets. Isotopic analysis of human remains from sites in the Iron Gates section of the Lower Danube Valley has led to conlicting interpretations of Mesolithic diets in this key region of southeast Europe. One view (Bonsall et al. 1997, 2004) is that diets were based mainly on riverine resources throughout the Mesolithic. A competing hypothesis (Nehlich et al. 2010) argues that Mesolithic diets were more varied with at least one Early Mesolithic site showing an emphasis on terrestrial resources, and riverine resources only becoming dominant in the Later Mesolithic. The present article revisits this issue, discussing the stable isotope data in relation to archaeozoological and radiocarbon evidence.

Boríc 2004

Dušan Borić, Gisela Grupe & Joris Peters, *Is the Mesolithic-Neolithic subsistence dichotomy real? New stable isotope evidence from the Danube Gorges.* European journal of archaeology **7** (2004), 221–248.

Borić 2013

Dušan Borić & T. Douglas Price, *Strontium isotopes document greater human mobility at the start of the Balkan Neolithic.* PNAS **110** (2013), 3298–3303.

Questions about how farming and the Neolithic way of life spread across Europe have been hotly debated topics in archaeology for decades. For a very long time, two models have dominated the discussion: migrations of farming groups from southwestern Asia versus diffusion of domesticates and new ideas through the existing networks of local forager populations. New strontium isotope data from the Danube Gorges in the north-central Balkans, an area characterized by a rich burial record spanning the Mesolithic–Neolithic transition, show a significant increase in nonlocal individuals from ≈6200 calibrated B.C., with several waves of migrants into this region. These results are further enhanced by dietary evidence based on carbon and nitrogen isotopes and an increasingly high chronological resolution obtained on a large sample of directly dated individuals. This dataset provides robust evidence for a brief period of coexistence between indigenous groups and early farmers before farming communities absorbed the foragers completely in the first half of the sixth millennium B.C.

forager–farmer interaction | isotope analysis | the Balkans | Lepenski Vir | southeastern Europe

le Bras-Goude 2013

Gwenaëlle le Bras-Goude, Estelle Herrscher & Jean Vaquer, *Funeral practices and foodstuff behaviour: What does eat meat mean? Stable isotope analysis of Middle Neolithic populations in the Languedoc region (France).* Journal of Anthropological Archaeology **32** (2013), 280–287.

The aim of this study is to reconstruct the dietary patterns and economic behaviours of Neolithic populations in the Northwestern Mediterranean using isotopic and archaeological data. Burials come from four sites located in Languedoc–Roussillon region in French Mediterranean area. These sites are dated from the Middle Neolithic period (ca. 4500–3500 BC). They represent the Chasséen culture, characterized by regional features, such as economy management, resulting from territorial control. For this investigation, a stable isotopes (d13C and d15N) method has been used on 50 human bone collagens and 28 associated animal bones. This method provides direct dietary information on the protein consumed including the relative amounts of marine vs. terrestrial and animal vs. plant proteins in diets. Isotopic results are mainly compared to archaeological data to understand economic distinctions and potential social status variations between different groups using specific funeral practices, i.e. lithic chamber graves vs. domestic/funeral pits. Results show that individuals buried in lithic chamber graves and those buried in pits did not have the same dietary pattern. This result suggests a possible differentiation between two socio-economic groups, i.e. consumers of resources from herding and from farming. No aquatic food appeared to be routinely consumed by these individuals despite a relative close proximity to sea and freshwater sources. Moreover, these outcomes lead us to hypothesize that: (1) funeral practices could be linked to specific economies and/or (2) to different social status and that (3) burial type and foodstuff could be an expression of religious worship. Further research could include data from other areas, such as Spanish Catalonia where there are funeral structures similar to Languedoc lithic chamber graves.

Keywords: Neolithic | Languedoc | Mediterranean | Funeral practices | Diet | Isotope | Nitrogen | Carbon

Brauns 2013

Michael Brauns, Roland Schwab, Guntram Gassmann, Günther Wieland & Ernst Pernicka, *Provenance of Iron Age iron in southern Germany: a new approach.* Journal of Archaeological Science **40** (2013), 841–849.

Ores, slag, and blooms from an Early Iron Age smelting site in the Black Forest, southern Germany, were analysed in view of their possible provenance in combination with products from a modern smelting experiment. Rather than employing lead isotope ratios, like in a previous study, osmium and strontium isotope ratios are used for the discussion of provenance. The results of the smelting experiment with iron ores from the archaeological site and their comparison with original finds show the high potential of osmium as a tracer to determine provenance. Strontium may be an additional indicator but possible contaminations need to be assessed. A Celtic iron ingot has also been analysed to check the potential of osmium for further provenance studies.

Keywords: Iron ingots | Iron Age | Provenance | Osmium isotope ratios | Strontium isotope ratios | Mass spectrometry

Budd 2003

Paul Budd, Carolyn Chenery, Janet Montgomery & Jane Evans, *You are what you ate: isotopic analysis in the reconstruction of prehistoric residency.* In: Mike Parker Pearson (Hrsg.), *Food, Culture and Identity in the Neolothic and Early Bronze Age.* BAR International Series 1117 (Oxford 2003), 69–78.

Budd 2013

Chelsea Budd, Malcolm Lillie, Songül Alpaslan-Roodenberg, Necmi Karul & Ron Pinhasi, *Stable isotope analysis of Neolithic and Chalcolithic populations from Aktopraklık, northern Anatolia*. Journal of Archaeological Science **40** (2013), 860–867.

JArchSci40-0860-Supplement1.xlsx

This paper presents the results of stable isotope (carbon and nitrogen) analysis of human and faunal remains from the site of Aktopraklık, one of the earliest farming sites in the Eastern Marmara region of Northwest Anatolia. Excavations at this site have shown that occupation occurs from the middle of the 7th millennium BC through to the middle of the 6th millennium BC. The earliest Neolithic activity at this location occurs at the settlement site of Aktopraklık C. Since 2004 a number of Neolithic and Early Chalcolithic burials have been recovered from the settlement areas and an Early Chalcolithic cemetery (Aktopraklık B and A respectively). To date a total of 60 individuals have been recovered from Aktopraklık, 23 of which (20 adults [10 males, 8 females and 2 indet adults] and 3 children below ca. 12 years of age) form the basis of the current isotope study. In addition, 14 faunal samples from cattle, pig, sheep/goat and fallow deer are included in the analysis in order to facilitate a consideration of trophic level shifts and to interpret the 13C data. The data represents the first isotopic study of a farming community from this region of Anatolia. This region is important to our understanding of the northwestwards transmission of farming into Europe from the Near East, and as such Aktopraklık represents a key site for studying the diet of farmers at the transition to agriculture. The close clustering of isotope values overall indicates homogeneity in subsistence practices for this farming population. Interestingly, the isotope values indicate a general focus on C3 terrestrial resources at Aktopraklık, despite the close proximity of both freshwater and marine environments where alternative resources could have been procured.

Keywords: Neolithic farming | Stable isotope analysis | d13C and d15N | Prehistoric cemeteries and sites | Human bone | Faunal remains | Collagen | Anatolia

Buizert 2014

Christo Buizert et al., *Greenland temperature response to climate forcing during the last deglaciation*. science **345** (2014), 1177–1180.

s345-1177-Supplement.pdf

Christo Buizert, Vasileios Gkinis, Jeffrey P. Severinghaus, Feng He, Benoit S. Lecavalier, Philippe Kindler, Markus Leuenberger, Anders E. Carlson, Bo Vinther, Valérie Masson-Delmotte, James W. C. White, Zhengyu Liu, Bette Otto-Bliesner & Edward J. Brook

Greenland ice core water isotopic composition (d18O) provides detailed evidence for abrupt climate changes but is by itself insufficient for quantitative reconstruction of past temperatures and their spatial patterns. We investigate Greenland temperature evolution during the last deglaciation using independent reconstructions from three ice cores and simulations with a coupled ocean-atmosphere climate model. Contrary to the traditional d18O interpretation, the Younger Dryas period was $4.5° \pm 2°$C warmer than the Oldest Dryas, due to increased carbon dioxide forcing and summer insolation. The magnitude of abrupt temperature changes is larger in central Greenland (9° to 14°C) than in the northwest (5° to 9°C), fingerprinting a North Atlantic origin. Simulated changes in temperature seasonality closely track changes in the Atlantic overturning strength and support the hypothesis that abrupt climate change is mostly a winter phenomenon.

Burt 2015

Nicole M. Burt, *Individual dietary patterns during childhood, An archaeological application of a stable isotope microsampling method for tooth dentin.* Journal of Archaeological Science **53** (2015), 277–290.

Diet from the late medieval Fishergate House cemetery site (York, UK) is reconstructed using nitrogen and carbon stable isotope ratio analysis from tooth dentin. Deciduous teeth from 42 subadult individuals (fetal to 5–6 years) were used to reconstruct weaning practices at a population and an individual level. This is the first archaeological use of this microsampling method (dentin ≥.3 mg). This method allows an individual's changing diet to be reconstructed from the fetal period through weaning. The fetal signals show a complicated relationship with adult female ratios, having higher d15N values than expected. At this site, there is an unusual decoupling between peak mortality (4–6 years) and weaning (2 years). The mean d15N ratios for weaned children were enriched when compared to the adult females (12.4 ‰ ± 1.29 and 11.4 ‰ ± 1.1; statistically significant to $p < .05$). Early childhood diet is surprisingly high in marine fish and/or pork given the low socioeconomic class of the sample. This is a departure in weaned diet from contemporary communities and may be responsible for the unusual disconnect between peak mortality and weaning. When the individual dietary reconstructions were combined with each individual's rib reconstruction the presence of a true child specific diet was clear starting at approximately 2 years of age. Some individuals diverge from the population norm and have an extended breastfeeding period linked to poor health. The increased resolution of microsampling allows bioarchaeologists to test detailed time depended questions about early childhood diet and health.

Keywords: Deciduous teeth | Carbon | Nitrogen | Britain | Medieval

Carlson 2014

Bryce A. Carlson & John D. Kingston, *Chimpanzee isotopic ecology, A closed canopy C3 template for hominin dietary reconstruction.* Journal of Human Evolution **76** (2014), 107–115.

JHumEvo076-0107-Supplement.csv, JHumEvo076-0107-Supplement.wk1

The most significant hominin adaptations, including features used to distinguish and/or classify taxa, are critically tied to the dietary environment. Stable isotopic analyses of tooth enamel from hominin fossils have provided intriguing evidence for significant C4/CAM (crassulacean acid metabolism) resource consumption in a number of Plio-Pleistocene hominin taxa. Relating isotopic tooth signatures to specific dietary items or proportions of C3 versus C4/CAM plants, however, remains difficult as there is an ongoing need to document and quantify isotopic variability in modern ecosystems. This study investigates the ecological variables responsible for carbon isotopic discrimination and variability within the C3-dominated dietary niche of a closed canopy East African hominoid, Pan troglodytes, from Ngogo, Kibale National Park, Uganda.

d13C values among C3 resources utilized by Ngogo chimpanzees were highly variable, ranging over 13 ‰. Infrequent foraging on papyrus (the only C4 plant consumed by chimpanzees at the site) further extended this isotopic range. Variation was ultimately most attributable to mode of photosynthesis (C3 versus C4), food type, and elevation, which together accounted for approximately 78 % of the total sample variation. Among C3 food types, bulk carbon values ranged from .24.2 ‰ to .31.1 ‰ with intra-plant variability up to 12.1 ‰. Pith and sapling leaves were statistically more 13C depleted than pulp, seeds, flowers, cambium, roots, leaf buds, and leaves from mature trees. The effect of elevation on carbon variation was highly significant and equivalent to an approximately 1 ‰ increase

in d13C for every 150 m of elevation gain, likely reflecting habitat variability associated with topography. These results indicate significant d13C variation attributable to food type and elevation among C3 resources and provide important data for hominin dietary interpretations based on carbon isotopic analyses.

Keywords: Stable isotope | Carbon | Pan troglodytes | Uganda | Paleodiet

Cerling 2009

Thure E. Cerling, George Wittemyer, James R. Ehleringer, Christopher H. Remien & Iain Douglas-Hamilton, *History of Animals using Isotope Records (HAIR): A 6-year dietary history of one family of African elephants*. PNAS **106** (2009), 8093–8100.

pnas106-08093-Supplement.pdf

The dietary and movement history of individual animals can be studied using stable isotope records in animal tissues, providing insight into long-term ecological dynamics and a species niche. We provide a 6-year history of elephant diet by examining tail hair collected from 4 elephants in the same social family unit in northern Kenya. Sequential measurements of carbon, nitrogen, and hydrogen isotope rations in hair provide a weekly record of diet and water resources. Carbon isotope ratios were well correlated with satellite-based measurements of the normalized difference vegetation index (NDVI) of the region occupied by the elephants as recorded by the global positioning system (GPS) movement record; the absolute amount of C4 grass consumption is well correlated with the maximum value of NDVI during individual wet seasons. Changes in hydrogen isotope ratios coincided very closely in time with seasonal fluctuations in rainfall and NDVI whereas diet shifts to relatively high proportions of grass lagged seasonal increases in NDVI by ≈2 weeks. The peak probability of conception in the population occurred ≈3 weeks after peak grazing. Spatial and temporal patterns of resource use show that the only period of pure browsing by the focal elephants was located in an over-grazed, communally managed region outside the protected area. The ability to extract time-specific longitudinal records on animal diets, and therefore the ecological history of an organism and its environment, provides an avenue for understanding the impact of climate dynamics and land-use change on animal foraging behavior and habitat relations.

Chakraborty 2014

Subrata Chakraborty, B. H. Muskatel, Teresa L. Jackson, Musahid Ahmed, R. D. Levine & Mark H. Thiemens, *Massive isotopic effect in vacuum UV photodissociation of N_2 and implications for meteorite data*. PNAS **111** (2014), 14704–14709.

Nitrogen isotopic distributions in the solar system extend across an enormous range, from -400 ‰, in the solar wind and Jovian atmosphere, to about 5,000 ‰ in organic matter in carbonaceous chondrites. Distributions such as these require complex processing of nitrogen reservoirs and extraordinary isotope effects. While theoretical models invoke ion-neutral exchange reactions outside the protoplanetary disk and photochemical self-shielding on the disk surface to explain the variations, there are no experiments to substantiate these models. Experimental results of N2 photolysis at vacuum UV wavelengths in the presence of hydrogen are presented here, which show a wide range of enriched d15N values from 648 ‰ to 13,412 ‰ in product NH3, depending upon photodissociation wavelength. The measured enrichment range in photodissociation of N2, plausibly explains the range of d15N in extraterrestrial materials. This study suggests the importance of photochemical processing of the nitrogen reservoirs within the solar nebula.

nitrogen isotopes | organic molecules | perturbation

Chenery 2007

Carol Chenery, *The Amesbury Archer: Oxygen isotope analysis.* (2007). <http://www.wessexarch.co.uk/projects/amesbury/tests/oxygen_isotope.html> (2008-05-10).

Chu 2006

Nan-Chin Chu, Gideon M. Henderson, Nick S. Belshaw & Robert E. M. Hedges, *Establishing the potential of Ca isotopes as proxy for consumption of dairy products.* Applied Geochemistry **21** (2006), 1656–1667.

AppGeochem21-1656-Supplement.pdf

A procedure has been developed which allows precise determination of Ca isotope ratios in natural and organic samples such as bones, milk and other biological materials. In this study the procedure is used to determine Ca isotope ratios in modern dietary systems and to establish the potential of Ca isotopes as a paleodiet tracer by analysis of bones. Multi-sampling across a 5 cm portion of a red deer jawbone shows invariant Ca isotope ratios and suggests negligible isotopic effect during bone remodelling. The difference between Ca isotopes in red deer diet and bones from one location was 0.65‰, in agreement with a previous study of diet/bone offsets. Similar values for modern deer-bone d44/42Ca from four geographically diverse populations demonstrate that geological/environmental conditions do not cause large variability and suggest that diet is the major cause for variations in bone d44/42Ca. d44/42Ca of herbivore milk is found to be ≈0.5 to 0.6 higher than the corresponding diet. Modern human milk has a d44/42Ca of -1.15 (n = 4) and is isotopically the lightest material reported in this study. This suggests that, for these samples, a significant portion of Ca intake was from dairy sources, and that human milk has Ca which is, again, ≈0.6‰ isotopically lighter than dietary Ca intake. Finally, Ca isotope ratios are presented from a variety of samples formed during fermentation processes (e.g., curds, whey, etc.) which indicate that these processes do not fractionate Ca isotopes significantly. Together, the data in this paper indicate that, because milk is an important dietary source of Ca with a distinctive signature, Ca isotope ratios should provide a tracer for past dairy consumption. A simplified model is outlined to demonstrate the ability to quantify dairy consumption by the analysis of Ca isotopes in bones.

O'Connell 1999

T. C. O'Connell & R. E. M. Hedges, *Investigations Into the Effect of Diet on Modern Human Hair Isotopic Values.* American Journal of Physical Anthropology **108** (1999), 409–425.

ABSTRACT Carbon and nitrogen isotopic analysis of body tissues is one of the few techniques that can furnish quantitative information about the diet of archaeological humans.

The study of the effects of various diets on modern human isotopic values can help to refine palaeodietary theories, and such work also enables the testing of palaeodietary theories independent of archaeological remains and interpretations.

This report discusses the use of modern human hair as a sample material for isotopic analysis. The biogenic carbon and nitrogen isotopic signal is well preserved in hair, and the isotopic values of the keratin can be related to diet. We show that atmospheric and cosmetic contamination of hair keratin does not appear to affect the measured isotopic values.

In a small study of Oxford residents, we demonstrate that the magnitude of the nitrogen isotopic values of hair keratin reflects the proportion of animal protein consumed in the diet: omnivores and ovo-

lacto-vegetarians have higher d15N than vegans. There was an observed relationship between the reported amount of animal protein eaten (either meat or secondary animal products) and the nitrogen isotopic values within the two groups of omnivores and ovo-lacto-vegetarians, indicating that an increasing amount of animal protein in the diet results in an increase in the d15N of hair keratin. This provides the first independent support for a long-held theory that, for individuals within a single population, a diet high in meat equates to elevated nitrogen isotopic values in the body relative to others eating less animal protein.

The implications of such results for the magnitude of the trophic level effect are discussed. Results presented here also permit a consideration of the effects of a change of diet in the short and long term on hair keratin isotopic values.

Copley 2003

M. S. Copley, R. Berstan, S. N. Dudd, G. Docherty, A. J. Mukherjee, V. Straker, S. Payne, & R. P. Evershed, *Direct chemical evidence for widespread dairying in prehistoric Britain*. PNAS **100** (2003), 1524–1529.

Domesticated animals formed an important element of farming practices in prehistoric Britain, a fact revealed through the quantity and variety of animal bone typically found at archaeological sites. However, it is not known whether the ruminant animals were raised purely for their tissues (e.g., meat) or alternatively were exploited principally for their milk. Absorbed organic residues from pottery from 14 British prehistoric sites were investigated for evidence of the processing of dairy products. Our ability to detect dairy fats rests on the observation that the d13C values of the C18:0 fatty acids in ruminant dairy fats are ≈2.3‰ lower than in ruminant adipose fats. This difference can be ascribed to (i) the inability of the mammary gland to biosynthesize C18:0; (ii) the biohydrogenation of dietary unsaturated fatty acids in the rumen; and (iii) differences (i.e., 8.1‰) in the d13C values of the plant dietary fatty acids and carbohydrates. The lipids from a total of 958 archaeological pottery vessels were extracted, and the compound-specific d13C values of preserved fatty acids (C16:0 and C18:0) were determined via gas chromatography-combustion-isotope ratio mass spectrometry. The results provide direct evidence for the exploitation of domesticated ruminant animals for dairy products at all Neolithic, Bronze Age, and Iron Age settlements in Britain. Most significantly, studies of pottery from a range of key early Neolithic sites confirmed that dairying was a widespread activity in this period and therefore probably well developed when farming was introduced into Britain in the fifth millennium B.C.

Cormie 1996

A. B. Cormie & H. P. Schwarcz, *Effects of climate on deer bone $\delta^{15}N$ and $\delta^{13}C$: Lack of precipitation effects on $\delta^{15}N$ for animals consuming low amounts of C_4 plants*. Geochimica et Cosmochimica Acta **60** (1996), 4161–4166.

Abstract-We have examined the relationship of bone collagen d15N and d13C to climatic variables, humidity, temperature, and amount of precipitation using fifty-nine specimens of North American white-tailed deer (Odocoileus virginianus) from forty-six different locations. In previous studies of African mammals there was a significant correlation between bone collagen d15N and local amount of precipitation. Results presented here similarly show an increase in d15N with

decreasing amount of precipitation but only for 25 % of the animals, namely those consuming more than 10 % C4 plants. These animals also exhibited a significant correlation between d13C and temperature which mirrors previous observations for grasses suggesting that these deer consume grasses during times of population and nutrient stress.

In contrast, even in dry areas containing high proportions of C4 grasses, the majority of the deer had consumed low amounts of C4 plants and these deer did not have d15N which correlate with amount of precipitation. Only when deer deviated from their normal feeding patterns by consuming C4 plants or grasses did their d15N correlate with amount of rainfall. For these animals, consumption of C4 plants or grasses may signal conditions of water and nutrient stress. An increase in d15N of bone collagen may result from combined effects from excretion of concentrated urine (to conserve water) and increased internal recycling of nitrogen (to conserve nitrogen).

Craig 2003

Oliver E. Craig, *Dairying, dairy products and milk residues: potential studies in European prehistory*. In: Mike Parker Pearson (Hrsg.), *Food, Culture and Identity in the Neolothic and Early Bronze Age*. BAR International Series 1117 (Oxford 2003), 89–96.

DeNiro 1978

Michael J. DeNiro & Samuel Epstein, *Influence of diet on the distribution of carbon isotopes in animals*. Geochimica et Cosmochimica Acta **42** (1978), 495–506.

The influence of diet on the distribution of carbon isotopes in animals was investigated by analyzing animals grown in the laboratory on diets of constant carbon isotopic composition. The isotopic composition of the whole body of an animal reflects the isotopic composition of its diet, but the animal is on average enriched in d13C by about 1‰ relative to the diet. In three of the four cases examined, the 13C enrichment of the whole body relative to the diet is balanced by a 13C depletion of the respired CO2. The isotopic relationships between the whole bodies of animals and their diets are similar for different species raised on the same diet and for the same species raised on different diets. However, the d13C values of whole bodies of individuals of a species raised on the same diet may differ by up to 2‰. The relationship between the 13C/12C ratio of a tissue and the 13/12C ratio of the diet depends both on the type of tissue and on the nature of the diet. Many of the isotopic relationships among the major biochemical fractions, namely the lipid, carbohydrate and protein fractions, are qualitatively preserved as diet carbon is incorporated into the animal. However, the difference between the d13C values of a biochemical fraction in an animal and in its diet may be as large as 3‰. The d13C values of the biochemical components collagen, chitin and the insoluble organic fraction of shells, all of which are often preserved in fossil material, are related to the isotopic composition of the diet.

These results indicate that it will be possible to perform dietary analysis based on the determination of the 13C/12C ratio of animal carbon. Analysis of the total animal carbon will in most cases provide a better measure of diet than the analysis of individual tissues, biochemical fractions, or biochemical components. The limits of accuracy of this method will generally restrict its application to situations in which the diet is derived from sources with relatively large differences in their d13C values, such as terrestrial vs aquatic organisms or C3 vs C4 plants. The method should be applicable to fossil as well as to living material.

DeNiro 1981

Michael J. DeNiro & Samuel Epstein, *Influence of diet on the distribution of nitrogen isotopes in animals*. Geochimica et Cosmochimica Acta **45** (1981), 341–351.

The influence of diet on the distribution of nitrogen isotopes in animals was investigated by analyzing animals grown in the laboratory on diets of constant nitrogen isotopic composition.

The isotopic composition of the nitrogen in an animal reflects the nitrogen isotopic composition of its diet. The d15N values of the whole bodies of animals are usually more positive than those of their diets. Different individuals of a species raised on the same diet can have significantly different d15N values. The variability of the relationship between the d15N values of animals and their diets is greater for different species raised on the same diet than for the same species raised on different diets. Different tissues of mice are also enriched in 15N relative to the diet. with the difference between the d15N values of a tissue and the diet depending on both the kind of tissue and the diet involved. The d15N values of collagen and chitin, biochemical components that are often preserved in fossil animal remains. are also related to the d15N value of the diet.

The dependence of the d15N values of whole animals and their tissues and biochemical components on the d15N value of diet indicates that the isotopic composition of animal nitrogen can be used to obtain information about an animal's diet if its potential food sources had different d15N values. The nitrogen isotopic method of dietary analysis probably can be used to estimate the relative use of legumes vs non-legumes or of aquatic vs terrestrial organisms as food sources for extant and fossil animals. However, the method probably will not be applicable in those modern ecosystems in which the use of chemical fertilizers has influenced the distribution of nitrogen isotopes in food sources.

The isotopic method of dietary analysis was used to reconstruct changes in the diet of the human population that occupied the Tehuacan Valley of Mexico over a 7000 yr span. Variations in the d13C and d15N values of bone collagen suggest that C4 and/or CAM plants (presumably mostly corn) and legumes (presumably mostly beans) were introduced into the diet much earlier than suggested by conventional archaeological analysis.

DeNiro 1985

Michael J. DeNiro, *Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction*. nature **317** (1985), 806–809.

Since its introduction in 1977, stable isotope analysis of bone collagen has been widely used to reconstruct aspects of prehistoric human and animal diets. This method of dietary analysis is based on two well-established observations, and on an assumption that has never been tested. The first observation is that bone collagen 13C/12C and 15N/14N ratios reflect the corresponding isotope ratio of an animal's diet. The second is that groups of foods have characteristically different 13C/12C and/or 15N/14N ratios. Taken together, the two observations indicate that the isotope ratios of collagen in the bones of a living animal reflect the amounts of these groups of foods that the animal ate. Thus, it has been possible to use fresh bone collagen 13C/12C ratios to determine the relative consumption of C3 and C4 plants, while 13C/12C and 15N/14N ratios have been used to distinguish between the use of marine and terrestrial foods. The 15N/14N ratios of fresh bone collagen probably also reflect the use of leguminous and non-leguminous plants as food, but this has not yet been demonstrated. Prehistoric consumption of these same groups of foods has been reconstructed from isotope ratios of collagen extracted

from fossil bone. Implicit in the application of the isotopic method to prehistoric material is the assumption that bone collagen isotope ratios have not been modified by postmortem processes. Here I present the first examination of the validity of this assumption. The results show that postmortem alteration of bone collagen isotope ratios does occur, but that it is possible to identify prehistoric bones whose collagen has not undergone such alteration.

DIEFENDORF 2010

Aaron F. Diefendorf, Kevin E. Mueller, Scott. L. Wing, Paul L. Koch, & Katherine H. Freeman, *Global patterns in leaf ^{13}C discrimination and implications for studies of past and future climate*. PNAS **107** (2010), 5738–5743.

pnas107-05738-Supplement1.pdf, pnas107-05738-Supplement2.xls

Fractionation of carbon isotopes by plants during CO2 uptake and fixation (Dleaf) varies with environmental conditions, but quantitative patterns of Dleaf across environmental gradients at the global scale are lacking. This impedes interpretation of variability in ancient terrestrial organic matter, which encodes climatic and ecological signals. To address this problem, we converted 3,310 published leaf d13C values into mean Dleaf values for 334 woody plant species at 105 locations (yielding 570 species-site combinations) representing a wide range of environmental conditions. Our analyses reveal a strong positive correlation between Dleaf and mean annual precipitation (MAP; R2 = 0.55), mirroring global trends in gross primary production and indicating stomatal constraints on leaf gas-exchange, mediated by water supply, are the dominant control of Dleaf at large spatial scales. Independent of MAP,we show a lesser, negative effect of altitude on Dleaf and minor effects of temperature and latitude. After accounting for these factors, mean Dleaf of evergreen gymnosperms is lower (by 1–2.7‰) than for other woody plant functional types (PFT), likely due to greater leaf-level water-use efficiency. Together, environmental and PFT effects contribute to differences in mean Dleaf of up to 6‰ between biomes. Coupling geologic indicators of ancient precipitation and PFT (or biome) with modern Dleaf patterns has potential to yield more robust reconstructions of atmospheric d13C values, leading to better constraints on past greenhouse-gas perturbations. Accordingly, we estimate a 4.6‰ decline in the d13C of atmospheric CO2 at the onset of the Paleocene-Eocene Thermal Maximum, an abrupt global warming event ≈55.8 Ma.

biogeochemistry | ecophysiology | fractionation | PETM

DRAKE 2012

Brandon L. Drake, David T. Hanson & James L. Boone, *The use of radiocarbon-derived $\Delta^{13}C$ as a paleoclimate indicator: applications in the Lower Alentejo of Portugal*. Journal of Archaeological Science **39** (2012), 2888–2896.

JArchSci39-2888-Supplement.zip

Values of d13C are frequently reported with radiocarbon dates from organic materials. In C3 plants d13C values have been linked to changes in water use efficiency as a response to arid conditions. By calculating 13C discrimination (D13C) from 13C isotopic composition (d13C), archaeologists can gain potentially valuable inference into past climate conditions. Values of D13C reflect the process of discrimination against heavier 13C isotopes of carbon by comparing the d13C of samples to that of the atmosphere, and can be calculated when records of atmospheric d13CO2 are available. The present study examines a 1300 year history of radiocarbon-derived D13C from the Lower Alentejo of Portugal using charcoal recovered from excavations of a series of medieval habitation sites in the study area.

To calculate D13C, the posterior means generated from Bayesian change-point analysis of d13CO2 records were used. Archaeological data were then compared to contemporary ecological studies of D13C of the same taxa against instrumental records of climate. Values of D13C fell within mean ranges for the taxa through a period of population growth between the 7th and 10th centuries AD. During the height of the Medieval Warm Period in the 11th century AD D13C values frequently fell to low levels associated with arid conditions. At this time environmental degradation and erosion were documented. Values of D13C increased for a brief period in the early 12th century AD before the rural Lower Alentejo was largely abandoned for nearly two centuries. Another period of aridity occurred in the 16th and 17th centuries AD. Radiocarbon-derived D13C is a potentially useful paleoclimate proxy for archaeologists provided that results can be paired with observed D13C variation in studies that pair these data with instrumental climate records.

Keywords: Stable carbon isotopes | Portugal | Medieval warm period | Abandonment | 13C discrimination | Carbon discrimination | Water use efficiency | Radiocarbon

Drucker 2003

Dorothée G. Drucker, Hervé Bocherens, Daniel Billiou, *Evidence for shifting environmental conditions in Southwestern France from 33 000 to 15 000 years ago derived from carbon-13 and nitrogen-15 natural abundances in collagen of large herbivores.* Earth and Planetary Science Letters **216** (2003), 163–173.

A paleoenvironmental reconstruction of terrestrial environments in Southwestern France between 33 and 15 cal kyr BP is provided using d13C and d15N variations in collagen of three herbivorous mammals. Altogether 161 analyses have been carried out on collagen extracted from skeletal fragments of reindeer, horse and Bos/Bison from four successive chronological phases covering the end of MOIS 3 and MOIS 2. The d13C values of ungulate collagen are clearly separated between the studied species. They are interpreted as reflecting a stable dietary adaptation in a changing environment. The variations of d15N values of ungulate collagen are significant, especially between specimens from MOIS 3 and specimens from MOIS 2, with a minimum during the Last Glacial Maximum. This phenomenon seems to reflect changes in the activity of nitrogen cycling processes associated with permafrost development. Carbon and nitrogen isotopic composition of fossil herbivore collagen are worth investigating as paleoecological and paleoenvironmental tracers in Upper Pleistocene periglacial continental contexts.

Keywords: carbon-13; collagen; Europe; Last Glacial Maximum; nitrogen-15; paleoenvironment

Drucker 2004

D. Drucker And H. Bocherens, *Carbon and Nitrogen Stable Isotopes as Tracers of Change in Diet Breadth during Middle and Upper Palaeolithic in Europe.* Int. J. Osteoarchaeology **14** (2004), 162–177.

Carbon and nitrogen stable isotope ratios in fossil bone collagen have been used as evidence for an increase of diet breadth between Middle Palaeolithic Neanderthals and Early Upper Palaeolithic anatomically modern humans. In this paper, we revisit the rules of palaeodietary reconstruction using collagen stable isotopes and reassess the possible isotopic signatures of potential protein resources available to prehistoric humans. It appears that the Interpretation of the human's isotopic signature does not necessarily imply a significant proportion of aquatic-derived protein in the diet neither for Neandertal nor for first anatomically modern humans

in Europe. Exploitation of aquatic ecosystems by humans needs to be supported by further zooarchaeological evidence. Nevertheless, isotopic biogeochemistry of fossil human collagen can be very useful in palaeodietary reconstructions provided that basic rules are followed while selecting samples of coeval fauna, in Order to establish the end members of different food resources. Significant progress investigating the evolution of subsistence strategies in fossil hominids is expected from a combination of zooarchaeological and isotopic data.

Key words: anatomically modern human; collagen; diet; Middle Palaeolithic; Neanderthal; stable light isotopes; Upper Palaeolithic

Dupras 2001

Tosha L. Dupras & Henry P. Schwarcz, *Strangers in a Strange Land: Stable Isotope Evidence for Human Migration in the Dakhleh Oasis, Egypt*. Journal of Archaeological Science **28** (2001), 1199–1208.

This study utilizes a combination of both stable oxygen and nitrogen isotope ratios to determine migration patterns for a large sample of human remains from the Kellis 2 cemetery (c. AD 250) in the Dakhleh Oasis, Egypt. Stable oxygen isotopic analysis has been used to identify potential migrants in several di.erent populations. In this study, the data resultant from the combination of oxygen isotope ratios from bone apatite and nitrogen isotope ratios from bone collagen indicate that at least two individuals are not native to the Oasis, as shown by their lower nitrogen values and more positive oxygen isotopes, approaching values documented for residents of the Nile Valley and Nubia. The most isotopically distinctive individual is lepromatous, suggesting that he may have been exiled to the oasis from the Nile Valley. Interestingly, all individuals who have di.erent isotope values are male, supporting the idea that males may have been involved in caravan trade between the Oasis and the Nile Valley.

Dürrwächter 2003a

Claudia Dürrwächter, Oliver E. Craig, Gillian Taylor, Matthew J. Collins, Joachim Burger & Kurt W. Alt, *Ernährungsrekonstruktion in neolithischen Populationen anhand der Analyse stabiler Isotope: Trebur (HST/GG) und Herxheim (späte LBK)*. Berichte der Kommission für Archäologische Landesforschung in Hessen **7** (2003), 43–53.

Dürrwächter 2003b

Dürrwächter, C., Craig, O.E., Taylor, G., Collins, M.J., Burger, J. & Alt, K.W., *Rekonstruktion der Ernährungsweise in der mittel- und frühneolithischen Bevölkerungen von Trebur/Hessen und Herxheim/Pfalz*. Bull. Soc. Suisse d'Anthropologie **9** (2003), 1–16.

Dürrwächter 2006

Dürrwächter C, Craig O E, Collins M J, Burger J & Alt KW, *Beyond the grave: variability in Neolithic diets in Southern Germany*. Journal of Archaeological Science **33** (2006), 39–48.

Eerkens 2011

Jelmer W. Eerkens, Ada G. Berget & Eric J. Bartelink, *Estimating weaning and early childhood diet from serial micro-samples of dentin collagen*. Journal of Archaeological Science **38** (2011), 3101–3111.

Age of weaning is an important measure of parental investment, and in various human and non-human primate studies, has been correlated with a range of developmental factors such as stature, cognitive functions, obesity, ability to cope with stress, and rates of disease. Archaeological estimation of the weaning process is generally at the level of an entire burial population, creating some challenges in using such data to test anthropological theory. We describe a method that tracks the weaning process at the individual level, based on the measurement of stable nitrogen and carbon isotope ratios in serial sections of first molar dentin collagen. We apply this micro-sampling technique to a sample of individuals from CA-CCO-548, a well-studied and ancient site on the banks of Marsh Creek in Central California. Results show great variation between individuals in both the length of the weaning process, the age at which breastfeeding stopped, and the source of early complementary childhood foods.

Keywords: Weaning; Breastfeeding; Diet; Stable nitrogen and carbon isotopes; Micro-sampling

Eerkens 2014

Jelmer W. Eerkens, Alex de Voogt, Tosha L. Dupras, Samuel C. Rose, Eric J. Bartelink & Vincent Francigny, *Intra- and inter-individual variation in $\delta^{13}C$ and $\delta^{15}N$ in human dental calculus and comparison to bone collagen and apatite isotopes*. Journal of Archaeological Science **52** (2014), 64–71.

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There are mixed opinions on the suitability of dental calculus for paleodietary reconstruction using stable isotope analysis. We examine d13C and d15N values of calculus samples from two regions, central California in the USA and Sai Island in the Sudan. When atomic C/N ratios are less than 12 in calculus, results show positive correlations at both the regional and individual level between stable isotopes of bone collagen and calculus, suggesting these materials track similar dietary behaviors. Correlations are still positive but lower between d13C values of calculus and bone apatite. Stable isotope ratios of calculus show between 30 % and 50 % greater variation than bone, are typically enriched in 15N (mean = 2.1 ‰ higher), and are depleted in 13C relative to bone collagen (mean = 0.8 ‰ lower) and apatite (mean = 6.4 ‰ lower). Calculus from multiple teeth was analyzed separately for seven individuals to examine intra-individual variation. Results show that within an individual d13C varies up to 1.8 ‰, and d15N up to 2.1 ‰, which may explain some of the weak bone-calculus correlations previously reported in the literature. When atomic C/N ratios are greater than 12, calculus correlates more poorly with bone collagen, suggesting these samples should be treated with caution.

Keywords: Stable isotope analysis | Nubia | Central California | Paleodiet | Dental calculus

Fahy 2013

Geraldine E. Fahy, Michael Richards, Julia Riedel, Jean-Jacques Hublin & Christophe Boesch, *Stable isotope evidence of meat eating and hunting specialization in adult male chimpanzees*. PNAS **110** (2013), 5829–5833.

Observations of hunting and meat eating in our closest living relatives, chimpanzees (Pan troglodytes), suggest that among primates, regular inclusion of meat in the diet is not a characteristic unique to Homo. Wild chimpanzees are known to consume vertebrate meat, but its actual dietary contribution is, depending on

the study population, often either unknown or minimal. Constraints on continual direct observation throughout the entire hunting season mean that behavioral observations are limited in their ability to accurately quantify meat consumption. Here we present direct stable isotope evidence supporting behavioral observations of frequent meat eating among wild adult male chimpanzees (Pan troglodytes verus) in Taï National Park, Côte d'Ivoire. Meat eating among some of the male chimpanzees is significant enough to result in a marked isotope signal detectable on a short-term basis in their hair keratin and long-term in their bone collagen. Although both adult males and females and juveniles derive their dietary protein largely from daily fruit and seasonal nut consumption, our data indicate that some adult males also derive a large amount of dietary protein from hunted meat. Our results reinforce behavioral observations of male-dominated hunting and meat eating in adult Taï chimpanzees, suggesting that sex differences in food acquisition and consumption may have persisted throughout hominin evolution, rather than being a recent development in the human lineage.

dietary ecology | stable isotope analysis | human evolution

Fenner 2014

Jack N. Fenner & Lori E. Wright, *Revisiting the strontium contribution of sea salt in the human diet*. Journal of Archaeological Science **44** (2014), 99–103.

Sea salt is getting increasing attention as a potential source of strontium incorporated into human tissues. One particularly interesting instance was published by one of us in 2005 in which sea salt was proposed as a possible reason why the stable strontium isotope ratios of ancient Maya human tooth enamel from Tikal, Guatemala, did not match the expected local strontium isotope signature. We revisit that analysis and identify a calculation error that led to an underestimate of the amount of salt required. Our revised mixing model increases the amount of salt required by 51 percent. We consider the implications of this for the case of the ancient Maya at Tikal and also discuss application of the mixing model in other circumstances.

Keywords: Sea salt | Strontium isotope ratio | Tikal | Maya | Maize | Yucatan

Fernandes 2012

Ricardo Fernandes, Marie-Josée Nadeau & Pieter M. Grootes, *Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite*. Archaeological and Anthropological Sciences (2012), preprint, 1–11. DOI:10.1007/s12520-012-0102-7.

Carbon stable isotope ratios (d13C), measured in human bone collagen (d13Ccollagen) and bioapatite (d13Cbioapatite), are commonly used indicators in ancient human diet reconstruction. The underlying assumption is that human tissues broadly reflect the d13C signal of dietary food sources (d13Cdiet) plus an isotopic offset. However, interpretation of results may be confounded by the differentiated routing of macronutrients (energy, that is carbohydrates and lipids, and protein) having associated different isotopic signals (d13Cenergy, d13Cprotein). Multiple regression analyses were conducted on data from controlled animal feeding experiments compiled by Froehle et al. (J Archaeol Sci 37:2662-2670, 2010). We derived a simple algebraic macronutrient-based model with d13Cbioapatite=10.1+d13Cdiet (‰) and d13Ccollagen=4.8+0.74 d13Cprotein+0.26 d13Cenergy (‰). While the established relationship for d13Cbioapatite is similar to previously known results, the model also suggests

that d13Ccollagen signal contributions originate from surprisingly consistent proportions of protein and energy macronutrients. Given that feeding experiments explore extreme variations in the proportion of diet macronutrients, the applicability of the proposed model and its predictions were tested in a variety of well-known, wild animal and human, natural contexts. Possible biochemical mechanisms explaining these empirical results are discussed.

Keywords: Carbon stable isotopes | Dietary routing | Animal feeding experiments | Macronutrients | Bone collagen | Bioapatite

Forrester 1994

Terrence Forrester, Asha V Badaloo, Chandrasekar Persaud & Alan A Jackson, *Urea production and salvage during pregnancy in normal Jamaican women*. American Journal of Clinical Nutrition **60** (1994), 341–346.

The pattern of aggregate nitrogen demand during pregnancy and the fetal and maternal components are unclear. Excess demand enhances efficiency of nitrogen utilization. Urea salvage contributes to enhanced efficiency. Dietary protein intake, urea production, and salvage of urea nitrogen were measured in eight nonpregnant control subjects, and trimesterly in nine pregnant women. Production was measured after prime-intermittent intravenous doses of [15N 15N]-urea by dilution of label in urinary urea. Dietary protein intake was greater in trimester 1 than in nonpregnant women (167 ± 36 vs 224 ± 60 mg $N \cdot kg^{-1} \cdot d^{-1}$), and increased further in trimester 2 (266 ± 59 mg $N \cdot kg^{-1} \cdot d^{-1}$). Urea production was not higher during pregnancy. Despite higher protein intake, urea salvage was higher in pregnancy (40 ± 24 nonpregnant vs 77 ± 23, 61 ± 31, and 51 ± 12 mg $N \cdot kg^{-1} \cdot d^{-1}$). Therefore, the demand-supply gap for nitrogen was greatest early in pregnancy when fetoplacental growth is slowest, and implies heightened maternal demand.

KEY WORDS Pregnancy, protein, urea salvage

France 2011

Christine A. M. France, Jennifer A. Giaccai & Nadia Cano, *The effects of PVAc treatment and organic solvent removal on $\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$ values of collagen and hydroxyapatite in a modern bone*. Journal of Archaeological Science **38** (2011), 3387–3393.

The stable isotopic analysis of archaeological and paleontological bones has become a common method to examine questions of ecology, climate, and physiology. As researchers addressing such questions incorporate museum collections in their studies, it is necessary to understand the isotopic effects of common preservation techniques utilized in such collections to ensure the preservation of original isotopic values. This study examines the effects of PVAc glue (polyvinyl acetate) applied in acetone solution and the subsequent removal of PVAc using various organic solvents on the d13C and d15N values of extracted bone collagen, the d13C and d18O values of carbonate in bone hydroxyapatite, and the d18O values of phosphate in hydroxyapatite. The data demonstrate that isotopic values in the collagen and phosphate are unaffected by any combination of PVAc treatment and solvent application. The carbonates show little variation in d13C values, but exhibit variable d18O values upon exposure to the PVAc solution. It is here suggested that d18O values from carbonates in PVAc-treated bones do not retain an original isotopic value and should not be included in future studies.

Keywords: Stable isotopes | Bone | Collagen | Hydroxyapatite | Polyvinyl acetate | PVAc

Fraser 2011

Rebecca A. Fraser et al., *Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices.* Journal of Archaeological Science **38** (2011), 2790–2804.

Rebecca A. Fraser, Amy Bogaard, Tim Heaton, Michael Charles, Glynis Jones, Bent T. Christensen, Paul Halstead, Ines Merbach, Paul R. Poulton, Debbie Sparkes & Amy K. Styring

This paper explores the impact of animal manure application on the d15N values of a broad range of crops (cereals and pulses), under a range of manuring levels/regimes and at a series of locations extending from northwest Europe to the eastern Mediterranean. We included both agricultural field experiments and areas where 'traditional' farming is practised. Our aim is to ground-truth interpretation of d15N values in archaeobotanical crop remains as evidence of past growing conditions and husbandry practices. The results confirm the potentially radical impact of manuring on d15N values in cereals, depending on manuring level, but indicate only a slight effect on pulses, which can fix atmospheric nitrogen. The expected geographical trend towards greater d15N with increasing climatic aridity is not apparent, probably because the growing conditions for crops are 'buffered' through crop management. Each of these observations has fundamental implications for archaeobotanical interpretation of d15N values as evidence of land use practices and (together with analysis of bone collagen/tooth enamel in potential consumers) palaeodiet.

Keywords: Nitrogen; Stable isotopes; Manuring; Neolithic; Crop husbandry; Palaeodiet

Fraser 2013

R. A. Fraser, A. Bogaard, M. Charles, A. K. Styring, M. Wallace, G. Jones, P. Ditchfield & T. H. E. Heaton, *Assessing natural variation and the effects of charring, burial and pre-treatment on the stable carbon and nitrogen isotope values of archaeobotanical cereals and pulses.* Journal of Archaeological Science **40** (2013), 4754–4766.

JArchSci40-4754-Supplement1.doc, JArchSci40-4754-Supplement2.doc, JArchSci40-4754-Supplement3.doc, JArchSci40-4754-Supplement4.doc, JArchSci40-4754-Supplement5.doc, JArchSci40-4754-Supplement6.doc

The aim of this study is to assess the potential of charred archaeobotanical cereal grain and pulse seed d13C and d15N values to provide evidence of crop growing conditions and as a potential component of palaeodietary studies. In order to reliably interpret archaeobotanical d13C and d15N values it is necessary to take into account the impact of charring, burial and laboratory pre-treatment procedures. We examine the effects of charring and burial on bulk d13C, d15N, %C, %N and C:N ratios in modern cereal and pulse material, and of cleaning by acid-base-acid (ABA) pre-treatment on modern and archaeobotanical charred material. Our study utilised bulk grain and seed samples to help account for within-ear/pod and between-plant variability in d13C and d15N values. Heating at relatively low temperatures and for prolonged times (230 °C for up to 24 h) is conducive to the formation of well preserved, undistorted charred cereal grain and pulse seed. Heating for 24 h has a systematic and predictable effect on d15N values, with increases of around 1 ‰ on average in cereal grains and pulse seeds, and no consistent impact on d13C values. Increases in d15N are likely due to the loss of lighter 14N via N-containing volatiles. Burial (for up to 2 years) and ABA pre-treatment have no significant effects on d13C or d15N values. After pre-treatment, however, the %C

and %N contents of the archaeobotanical material more closely resembles that of the modern charred grains and seeds, suggesting that archaeobotanical remains accumulate non-structural material during burial but retain their original carbon and nitrogen content. Therefore %C, %N contents and C:N ratios can provide useful criteria for assessing archaeobotanical preservation.

Keywords: Archaeobotany | Carbon isotopes | Nitrogen isotopes | Preservation | Pre-treatment

Frei 2015

Karin Margarita Frei et al., *Tracing the dynamic life story of a Bronze Age Female*. Scientific Reports **5** (2015), 10431. DOI:10.1038/srep10431.

SciRep05-10431-Supplement.pdf

Karin Margarita Frei, Ulla Mannering, Kristian Kristiansen, Morten E. Allentoft, Andrew S. Wilson, Irene Skals, Silvana Tridico, Marie Louise Nosch, Eske Willerslev, Leon Clarke & Robert Frei

Ancient human mobility at the individual level is conventionally studied by the diverse application of suitable techniques (e.g. aDNA, radiogenic strontium isotopes, as well as oxygen and lead isotopes) to either hard and/or soft tissues. However, the limited preservation of coexisting hard and soft human tissues hampers the possibilities of investigating high-resolution diachronic mobility periods in the life of a single individual. Here, we present the results of a multidisciplinary study of an exceptionally well preserved circa 3.400-year old Danish Bronze Age female find, known as the Egtved Girl. We applied biomolecular, biochemical and geochemical analyses to reconstruct her mobility and diet. We demonstrate that she originated from a place outside present day Denmark (the island of Bornholm excluded), and that she travelled back and forth over large distances during the final months of her life, while consuming a terrestrial diet with intervals of reduced protein intake. We also provide evidence that all her garments were made of non-locally produced wool. Our study advocates the huge potential of combining biomolecular and biogeochemical provenance tracer analyses to hard and soft tissues of a single ancient individual for the reconstruction of highresolution human mobility.

Froehle 2010

A. W. Froehle, C. M. Kellner & M. J. Schoeninger, *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** (2010), 2662–2670.

We analyzed carbon stable isotope data from bone collagen of animals consuming varied experimental diets, including recently published data from Warinner and Tuross [Warinner, C., Tuross, N., 2009. Alkaline cooking and stable isotope tissueediet spacing in swine: archaeological implications. Journal of Archaeological Science 36, 1690e1697; this journal]. Comparing regression lines for the relationship between collagen and diet d13C, we show that protein source, and not physiology, explains the apparent taxonomic difference between swine and rodents reported in that paper. Our results reveal a complex relationship between whole diet and dietary protein in determining collagen d13C values, such that in many cases, collagen alone may not provide reliable reconstructions of paleodiet. We advocate the simultaneous use of both collagen and apatite d13C, whenever possible, to assess the diets of prehistoric peoples.

Keywords: Collagen; Stable isotopes; Carbon; Paleodiet; Diet reconstruction; Swine; Rodents

Fuller 2004

Benjamin T. Fuller, James L. Fuller, Nancy E. Sage, David A. Harris, Tamsin C. O'Connell & Robert E. M. Hedges, *Nitrogen balance and $\delta^{15}N$: why you're not what you eat during pregnancy*. Rapid Communications in Mass Spectrometry **18** (2004), 2889–2896.

Carbon (13C/12C) and nitrogen (15N/14N) stable isotope ratios were longitudinally measured in human hair that reflected the period from pre-conception to delivery in 10 pregnant women. There was no significant change in the d13C results, but all subjects showed a decrease in d15N values (-0.3 to -1.1‰) during gestation. The mechanisms causing this decrease in hair d15N have not been fully elucidated. However, since the d15N values of dietary nitrogen and urea nitrogen are significantly lower compared to maternal tissues, it is hypothesized that the increased utilization of dietary and urea nitrogen for tissue synthesis during pregnancy resulted in a reduction of the steady state diet to a body trophic level effect by approximately 0.5-1‰. An inverse correlation (R2=0.67) between hair d15N and weight gain was also found, suggesting that positive nitrogen balance results in a reduction of d15N values independent of diet. These results indicate that d15N measurements have the ability to monitor not only dietary inputs, but also the nitrogen balance of an organism. A potential application of this technique is the detection of fertility patterns in modern and ancient species that have tissues that linearly record stable isotope ratios through time.

Fuller 2005

Benjamin T. Fuller, James L. Fuller, Nancy E. Sage, David A. Harris, Tamsin C. O'Connell & Robert E. M. Hedges, *Nitrogen balance and $\delta^{15}N$: why you're not what you eat during nutritional stress*. Rapid Communications in Mass Spectrometry **19** (2005), 2497–2506.

While past experiments on animals, birds, fish, and insects have shown changes in stable isotope ratios due to nutritional stress, there has been little research on this topic in humans. To address this issue, a small pilot study was conducted. Hair samples from eight pregnant women who experienced nutritional stress associated with the nausea and vomiting of morning sickness (hyperemesis gravidarum) were measured for carbon (d13C) and nitrogen (d15N) stable isotope ratios. The d13C results showed no change during morning sickness or pregnancy when compared with pre-pregnancy values. In contrast, the d15N values generally increased during periods of weight loss and/or restricted weight gain associated with morning sickness. With weight gain and recovery from nutritional stress, the hair d15N values displayed a decreasing trend over the course of gestation towards birth. This study illustrates how d15N values are not only affected by diet, but also by the nitrogen balance of an individual. Potential applications of this research include the development of diagnostic techniques for tracking eating disorders, disease states, and nitrogen balance in archaeological, medical, and forensic cases.

Fuller 2006a

B. T. Fuller, T. I. Molleson, D. A. Harris, L. T. Gilmour & R. E. M. Hedges, *Isotopic Evidence for Breastfeeding and Possible Adult Dietary Differences From Late/Sub-Roman Britain*. American Journal of Physical Anthropology **129** (2006), 45–54.

Historical documents indicate that breastfeeding and weaning practices have fluctuated in England through history. In order to obtain evidence for general breastfeeding patterns in Late/Sub-Roman Britain, stable carbon and nitrogen

isotope values were measured in juvenile and adult skeletons (n = 87) from the cemetery of Queenford Farm, Dorchester-on-Thames, Oxfordshire. As the site contained few individuals between 0-1.5 years of age, it was not possible to determine the initial timing for the introduction of weaning foods. Between ages 2-4 years, the mean ± SD d13C results (-20.2 ± 0.3‰) are significantly more negative (t = -4.03, P < 0.001) compared to adult females (-19.7 ± 0.3‰). This is interpreted as evidence of a different diet being fed to children during weaning. After age 2, the d15N values gradually decline, indicating complete cessation of breastfeeding by 3-4 years. Among adults, stature (males = 1.68 ± 0.06 m; females = 1.58 ± 0.07 m) and sexual dimorphism (106) were low, suggesting that the population was possibly under environmental stress. The d13C results for adults are similar, but females show a small but statistically significantly (t = -2.86, P < 0.01) lower mean d15N value (9.9 ± 0.9‰) compared to males (10.6 ± 0.5‰). These lower female d15N values possibly reflect the different physiology of the sexes (pregnancy and/or lactation) or the reduced consumption of animal/fish protein by women, and this may have been influenced by individual preference, family needs, or societal values of the era.

KEY WORDS stable isotopes; weaning; paleodiet; Romans; Queenford Farm

Fuller 2006b

B. T. Fuller, J. L. Fuller, D. A. Harris & R. E. M. Hedges, *Detection of Breastfeeding and Weaning in Modern Human Infants With Carbon and Nitrogen Stable Isotope Ratios*. American Journal of Physical Anthropology **129** (2006), 279–293.

Carbon (13C/12C) and nitrogen (15N/14N) stable isotope ratios were longitudinally measured in fingernail and hair samples from mother-infant pairs where infants were exclusively breastfed (n = 5), breast- and formula-fed (n = 2), or exclusively formulafed (n = 1) from birth. All exclusively breastfed infants had a dual enrichment in carbon (≈1‰) and nitrogen (≈2-3‰) when compared to maternal values. In contrast, breast- and formula-fed subjects had reduced enrichments compared to exclusively breastfed subjects, and the exclusively formula-fed infant showed no increase in d13C or d15N values. This finding of a carbon trophic level effect in breastfeeding infants suggests that 13C-enrichments of approximately 1 % in archaeological populations are not necessarily the result of the consumption of C4-based weaning foods such as maize or millet. During the weaning process, the d13C results for breastfed infants declined to maternal levels more rapidly than the d15N results. This suggests that d13C values have the potential to track the introduction of solid foods into the diet, whereas d15N values monitor the length of time of breast milk consumption. These findings can be used to refine the isotopic analysis of breastfeeding and weaning patterns in past and modern populations.

KEY WORDS stable isotopes; paleodiet, fingernails; d13C; d15N

García 2009

N. García García, R. S. Feranec, J.L Arsuaga, J. M. Bermúdez de Castro & E. Carbonell, *Isotopic analysis of the ecology of herbivores and carnivores from the Middle Pleistocene deposits of the Sierra De Atapuerca, northern Spain*. Journal of Archaeological Science **36** (2009), 1142–1151.

Carbon and oxygen isotope values reveal resource partitioning among the large mammal fauna from three contemporaneous Middle Pleistocene hominid-bearing

localities within the Sierra de Atapuerca (northern Spain). Carbon isotope values sampled from the tooth enamel of fauna present during Atapuerca Faunal Unit 6 show that a C3-dominated ecosystem surrounded the area where fossils were preserved during this time. For the herbivores, Fallow deer isotope values are significantly different from Red deer and horses and show that this species did not forage in open environments at this locality. Red deer and horses show similar feeding strategies with less negative carbon values implying use of more open environments for these taxa. For the carnivores, carbon isotope values for Ursus deningeri are significantly different from either lions (Panthera leo) or foxes (Vulpes vulpes) and support the contention that this species is herbivorous. Special metabolic mechanisms involved in hibernation in U. deningeri might also have influenced its isotope values. The carbon isotope values of remaining carnivores were similar and suggest that each was typically a generalist carnivore, eating a wide variety of prey items. While the isotopic results generally correspond to ecology indicated by previous techniques, this study shows that isotope analyses can provide further insights that alternate techniques do not provide. Isotope analyses can help elucidate the ancient ecology of taxa present in the Sierra de Atapuerca during the Middle Pleistocene allowing for an accurate portrayal of the setting in which humans lived.

Gąsiorowski 2014

Michał Gąsiorowski, Helena Hercman & Paweł Socha, *Isotopic analysis (C, N) and species composition of rodent assemblage as a tool for reconstruction of climate and environment evolution during Late Quaternary: A case study from Biśnik Cave (Częstochowa Upland, Poland)*. Quaternary International **339** (2014), 139–147.

Rodent remains are potentially a powerful tool in paleoecological reconstructions. Rodents are a worldwide group of mammals inhabiting all climatic zones, from arctic tundra to tropical forests. Some of their representatives have narrow ranges of environmental tolerance, while others have cosmopolitan distributions. Additionally, rodent remains are well preserved and numerous in cave sediments, and are easily identified to the species level. The species composition of rodent assemblage from the specific cave gives valuable data on ecosystem status around the site. Moreover, isotopic composition (C, N) of rodent remains provides information on some environmental factors, e.g. type of vegetation, soil activity, precipitation, and temperature. The material for this study was collected from the sediments of the Bisnik Cave (Poland). The cave is known from its sediment sequence deposited during the middle and late Pleistocene and Holocene, containing a rich collection of the Pleistocene fauna remains and archeological artifacts. The stratigraphy of the sediment sequence previously was based on archeological findings and several radiometric dates. In this study, we applied UeTh dating method to bone collagen, rodent tooth enamel, and cave bear tooth enamel. Finally, we revised the chronology of sediment sequence from the Bisnik Cave based on these new data. We found significantly higher variability of nitrogen and carbon isotopic composition in the lemming than in the common vole. However, both species show the same trends in isotopic composition of nitrogen in time. At the beginning of the record, d15N values were relatively high, suggesting intensive soil activity and, indirectly, mild climate. After that, from a stratigraphic layer dated to the early Würm glaciation, lower d15N values point to lower soil activity. Deterioration of ecosystem productivity and climate conditions were also confirmed by higher d13C. This indicates lower canopy effect and suggests conversion of vegetation around the cave. The isotopic record suggests high instability of the environmental conditions

during the Würm glaciations, with significantly warmer periods before and after the Last Glacial Maximum.

Gibbons 2008

Ann Gibbons, *Australopithecus Not Much of a Nutcracker*. science **320** (2008), 608–609.

Various plants absorb atmospheric carbon dioxide differently, and so by measuring the ratio of carbon isotopes in teeth, researchers can detect whether ancient hominins ate tropical grasses and sedges rich in carbon-13, or woody fruits, shrubs, and herbs with less carbon-13.

The isotopic data from the gracile australopithecines matches that of the robusts and suggests that both groups ate more diverse diets than expected, said paleoanthropologist Matt Sponheimer of the University of Colorado, Boulder, in his talk.

Giblin 2009

Julia Irene Giblin, *Strontium isotope analysis of Neolithic and Copper Age populations on the Great Hungarian Plain*. Journal of Archaeological Science **36** (2009), 491–497.

The strontium isotope ratio (87Sr/86Sr) is used in archaeological studies to identify major events of population movement in prehistory such as migration, conquest, and inter-marriage. This study shows that the strontium isotope method can be expanded to identify more subtle shifts in prehistoric human mobility. 87Sr/86Sr isotope ratios were analyzed in dental enamel from human and faunal specimens from the Late Neolithic and Copper Age on the Great Hungarian Plain. The archaeological record indicates that several aspects of life changed during the transition from the Late Neolithic to the Copper Age (ca. 4500 BC) in Hungary; evidence for increased interaction over a wide geographical area, less resource pooling and the use of secondary products has been used to support the idea that local populations became more mobile, perhaps due to the adoption of an agro-pastoral economy. Results from this study identify a change in the range of strontium isotope values from the Late Neolithic to the Copper Age from a very narrow range of values to a much broader range of values, which suggests that changes in how land and resources were utilized on the Great Hungarian Plain affected incorporation of strontium into the skeletal system. This study indicates that the strontium isotope ratio is a valuable tool for identifying more subtle changes in prehistoric behavior such as a shift to a more pastoral economy.

Keywords: Neolithic | Copper Age | Hungary | Isotopes | 87SR/86SR | Human mobility | Diet

Giblin 2013

Julia I. Giblin, Kelly J. Knudson, Zsolt Bereczki, György Pálfi & Ildikó Pap, *Strontium isotope analysis and human mobility during the Neolithic and Copper Age, A case study from the Great Hungarian Plain*. Journal of Archaeological Science **40** (2013), 227–239.

From the Late Neolithic to the Early Copper Age on the Great Hungarian Plain (4500 BC, calibrated) a transformation in many aspects of life has been inferred from the archaeological record. This transition is characterized by changes in settlements, subsistence, cultural assemblages, mortuary customs, and trade networks. Some researchers suggest that changes in material culture, particularly the replacement of long-occupied tells with smaller, more dispersed hamlets, indicates a shift from sedentary farming villages to a more mobile, agropastoral society that

emphasized animal husbandry and perhaps secondary products of domestication. In a previous study (Giblin, 2009), preliminary radiogenic strontium (87Sr/86Sr) isotope data from human dental enamel showed that Copper Age individuals expressed more variable isotope values than their Neolithic predecessors. These data provided support for the idea that Copper Age inhabitants of the Plain were acquiring resources from a greater geographic area, findings that seemed consistent with a more mobile lifestyle. In this article a larger sample from human and animal skeletal material is used to re-evaluate earlier work and shed new light on the transition from the Neolithic to the Copper Age in eastern Hungary. The expanded sample of strontium isotopes from human dental enamel shows that 87Sr/86Sr values are more variable during the Copper Age, but the change is more pronounced in the Middle Copper Age than in the Early Copper Age. These results, along with recently published complementary research, indicate that the transition from the Late Neolithic tell cultures of the Plain to the more dispersed Copper Age hamlets was more gradual than previously thought, and that the emergence of an agropastoral economy does not explain changes in settlement and material culture.

Keywords: Neolithic | Copper Age | Hungary | Isotope | Strontium | Mobility

Giblin 2016

Julia I. Giblin & Richard W. Yerkes, *Diet, dispersal and social differentiation during the Copper Age in eastern Hungary*. Antiquity **90** (2016), 81–94.

Why did the early farming societies of southeast Europe 'collapse' and become apparently less complex at the end of the Neolithic? Stable isotope analysis of human bone collagen from Late Neolithic and Copper Age cemeteries in eastern Hungary provides new insights into this question by exploring dietary changes during this key transitional period. Results show that diet did not change significantly over time, and there was no evidence that individuals of different sex or social status were consuming privileged diets. The changes of this period appear to indicate a reorganisation of society, perhaps based around extended families, with greater dispersal across the landscape, but without reliance on dairying or the emergence of powerful leaders.

Keywords: Hungary | Neolithic | Copper Age | diet | stable isotope analysis | carbon | nitrogen

Gil 2014

Adolfo F. Gil et al., *Isotopic evidence on human bone for declining maize consumption*. Journal of Archaeological Science **49** (2014), 213–227.

Adolfo F. Gil, Ricardo Villalba, Andrew Ugan, Valeria Cortegoso, Gustavo Neme, Catalina Teresa Michieli, Paula Novellino & Víctor Durán

This paper explores variation in maize consumption among human societies in arid environments of central-western Argentina over the last 2500 years. Increasingly positive human d13C signatures suggest a high intake of C4 resources (maize) until ca. A.D. 1400. After this time, the importance of maize in the diet drops and never reaches pre-Hispanic consumption rates, despite the known importance of maize to Inka and other late-prehistoric societies in the region. This decline appears to be related to colder temperatures during the Little Ice Age from the beginning of the 15th to the mid19th centuries.

Keywords: Maize | Subtropical Andes | Central western Argentina | Diet | Climate | Farming | Foraging | Stable isotopes | Carbon isotopes | Late Holocene | Little ice age

Grauel 2013

Anna-Lena Grauel et al., *What do SST proxies really tell us? A high-resolution multiproxy study in the Gulf of Taranto, central Mediterranean Sea, ($U^{K'}_{37}$, TEX^{H}_{86} and foraminifera $\delta^{18}O$).* Quaternary Science Reviews **73** (2013), 115–131.

qsr73-0115-Supplement1.pdf, qsr73-0115-Supplement2.xls

Anna-Lena Grauel, Arne Leider, Marie-Louise S. Goudeau, Inigo A. Müller, Stefano M. Bernasconi, Kai-Uwe Hinrichs, Gert J. de Lange, Karin A. F. Zonneveld & Gerard J. M. Versteegh

We present a multiproxy reconstruction of sea surface temperatures (SST) and coastal environmental changes covering the last 600 years on sediments from the Gulf of Taranto, central Mediterranean Sea. The reconstruction is based on UK'37 (alkenones from haptophytes), TEXH86 (membrane lipids of marine crenarchaeota), and d18O and d13C of Globigerinoides ruber (white and pink) and of Uvigerina mediterranea. The amplitudes of the temperature signals reconstructed from d18O of G. ruber (white), TEXH86 and UK'37 exceed the amplitudes observed in other reconstructions of local and Northern Hemisphere temperature. UK'37-based SSTs reflect mainly winter/spring conditions with an additional influence of changing nutrient supplies related to water column mixing and runoff. TEXH86-based temperatures reflect SSTs of the oligotrophic summer season, while influences from near-coastal areas may complicate its interpretation. Co-variation between both lipid-based SST records suggests a common environmental mechanism during the last 600 years. d18O of G. ruber (white) also reflects summer conditions and is amplified by changes in salinity and nutrient availability, which are caused by variations in the relative influence of the Western Adriatic Current (WAC) and of the Ionian Surface Waters (ISW). The combination of SST TEXH86 and d18O of G. ruber (white) shows that the circulation in the Gulf of Taranto underwent significant changes during the last 600 years.

Gregg 2009

M. W. Gregg, E. B. Banning, K. Gibbs & G. F. Slater, *Subsistence practices and pottery use in Neolithic Jordan: molecular and isotopic evidence.* Journal of Archaeological Science **36** (2009), 937–946.

This paper presents direct evidence of subsistence practices and pottery use at a Late Neolithic site at al-Basatîn, northern Jordan. Measurable concentrations of C16:0 and C18:0 were recovered from 8 of 10 archaeological pottery fragments through use of a microwave-assisted silica gel and aminopropyl solvent protocol developed for the isolation and concentration of free fatty acids in marine sediments. Subsequent isotopic analysis of the surviving C16:0 and C18:0 saturated fatty acids revealed d13C ratios consistent with those of adipose fats of ruminant and non-ruminant animals pastured on lands adjacent to the Jordan Valley. The high recovery of diagnostic compounds from the al-Basatîn material is discussed in context of a wider examination of the initial development and use of pottery in the Fertile Crescent, and the emerging debate concerning the efficacy of stable carbon isotope values in characterizing organic residues embedded in pottery fragments recovered from the earliest ceramic horizons in the Middle East and Europe.

Keywords: al-Basatîn | Jordan | Wadi Ziqlab | Neolithic | Archaeological pottery | Organic residues | GC-MS, GCdC-IRMS | d13C values | Microwave-assisted extraction

Gregoricka 2012

Lesley A. Gregoricka & Susan Guise Sheridan, *Ascetic or affluent? Byzantine diet at the monastic community of St. Stephen's, Jerusalem*

from stable carbon and nitrogen isot. Journal of Anthropological Archaeology **32** (2012), 63–73. DOI:10.1016/j.jaa.2012.10.002.

Stable carbon and nitrogen isotope ratios from bone collagen in skeletons from the Byzantine (5th–7th century AD) monastery of St. Stephen's in Jerusalem were examined in conjunction with a review of historical sources detailing dietary practices during this period in the Levant. Relatively low d13C ratios (-19.0 ± 0.5‰, 1σ) indicate a diet consisting primarily of C3 sources and display continuity with textual records describing monastic daily life. Conversely, human d15N values (9.6 ± 1.2‰, 1σ) are enriched in 15N relative to local fauna (7.3 ± 1.1‰, 1σ) and point to the contribution of animal protein to the diet, an unexpected result based on both the rarity and expense of these luxury food items as well as dietary prohibitions associated with an ascetic monastic lifestyle. No sex-based differences in diet were detected for either d13C or d15N values, suggesting that men and women consumed isotopically similar foods. As the vast majority of monastic communities in the ancient Near East were located in the desert, the urban setting of St. Stephen's monastery allows for a unique glimpse into a rarely-explored facet of Byzantine life.

Keywords: Stable isotope analysis | Diet | Bone collagen | Carbon | Nitrogen | Byzantine | Near East

Gron 2016

Kurt J. Gron, Janet Montgomery, Poul Otto Nielsen, Geoff Nowell, Joanne Peterkin, Lasse Sørensen & Peter Rowley-Conwy, *Strontium isotope evidence of early Funnel Beaker Culture movement of cattle.* Journal of Archaeological Science: Reports **6** (2016), 248–251.

Themovement of livestock across and within landscapes is increasingly being recognized as common in northern European prehistoric contexts, and was performed for various purposes. However, almost nothing is known about the movement of livestock in the earliest phase of the southern Scandinavian Neolithic Funnel Beaker Culture (ENI, TRB, 4000–3500 cal BC), or even if such movement is indicated. In this study, domestic cattle (Bos taurus) teeth from the early Neolithic sites Almhov, Sweden (N = 6) and Havnelev, Denmark (N = 7) were analyzed in order to determine the presence and character of potential livestock movement in this period. Tooth enamel strontium isotope analyses indicated a range of variation in local origin of the animals: some probably local and some non-local. Importantly, both sites yielded an individual exhibiting strontium isotope ratios indicatingmovement fromelsewhere and over a body ofwater via boat. Although based on a small number of cattle, the movement of livestock is indicated in the earliest Neolithic in the region and provides evidence of social, economic, or other connections over substantial distances.

Keywords: Strontium isotopes | Funnel Beaker Culture | Neolithic | Cattle | Scandinavia

Grupe 2009

Gisela Grupe, Dirk Heinrich & Joris Peters, *A brackish water aquatic foodweb: trophic levels and salinity gradients in the Schlei fjord, Northern Germany, in Viking and medieval times.* Journal of Archaeological Science **36** (2009), 2125–2144.

This study serves for the definition of baseline isotopic signatures of vertebrates living in the Schlei fjord, a brackish water inlet in the north German plain, where the salinity decreases from its mouth at the Baltic Sea towards the inland locations. The Viking trade centre Haithabu and its immediate successor, the town of

Schleswig, are located at opposite banks of the Schlei and constitute a settlement continuum from the 9th until the 13th century. This development not only includes a relocation of the settlement site, but also a change in economy and social structure, and witnesses the metamorphosis from an international trading locality to the rise and decline of a prototypical medieval town with town charter. In this paper, stable isotope ratios of bone collagen and bone structural carbonate of 141 vertebrate bone finds mainly of fish, birds, and sea mammals from both sites are reported to provide the baseline food web in this brackish water environment, which is the prerequisite for our ongoing studies aiming at the reconstruction of human subsistence strategies as well as the geographic origin of humans, animals, food stuffs, and raw materials in order to complete the historical picture of emerging medieval towns in a complex palaeoecosystem. In particular, we are able to show how a combination of stable isotopes from bone collagen and carbonate is capable of defining the salinity gradients in the aquatic environment.

Guiry 2012

Eric J. Guiry, *Dogs as Analogs in Stable Isotope-Based Human Paleodietary Reconstructions, A Review and Considerations for Future Use.* Journal of Archaeological Method and Theory **19** (2012), 351–376.

In contexts where human remains are scarce, poorly preserved, or otherwise unavailable for stable isotope-based paleodietary reconstruction, dog bone collagen as well as other tissues may provide a suitable proxy material for addressing questions relating to human dietary practices. Inferences drawn from applications of this "canine surrogacy approach" (CSA) must be made with caution to ensure the accuracy and transparency of conclusions. This paper shows that CSA applications are essentially analogical inferences which can be divided into two groups that provide specific types of information and may require different levels of substantiation. A framework of three categories of factors is outlined to aid in establishing positive, negative, and neutral elements of comparison of dog and human diets. CSA applications may benefit from explicitly detailing the type and nature of the analogical reasoning employed and from providing a systematic assessment of the degree to which stable isotope values of dogs and humans under comparison are thought to be like, unlike, or of unknown likeness.

Keywords: Dogs | Paleodiet | Human proxy | Stable isotopes

Halley 2014

D. J. Halley & Jørgen Rosvold, *Stable isotope analysis and variation in medieval domestic pig husbandry practices in northwest Europe, Absence of evidence for a purely herbivorous diet.* Journal of Archaeological Science **49** (2014), 1–5.

Stable isotope ratios have been widely used to infer past diets, domestication and husbandry practices of pigs, but few studies have addressed the proper baselines for such inferences. We analysed the diet of pig Sus scrofa from stable isotope analysis of carbon (d13C) and nitrogen (d15N) values of collagen from, urban Bergen, Norway (1300–1400 AD). These were compared with values from Skipshelleren (5500 BC – 200 AD); and from other medieval sites in NW Europe. Results indicated that the pigs from Bergen ate a very high proportion of marine protein compared to pigs and wild boar from Skipshelleren who ate a diet primarily of plant material. Results from other medieval sites in NW Europe show considerable variation in d13C and d15N values, indicating large variations in diet. However, none of the values are consistent with a diet wholly dominated by plant material; and therefore pig husbandry through outspan herding (pannage) without

supplementary feeding. We question interpretations to the contrary, which neglect the role of known differences in dietary fractionation between species in producing d13C and d15N values of tissue. Data from domestic pigs of ancient breeds undoubtedly raised by outspan herding/pannage are so far unavailable and would be instructive.

Keywords: Sus scrofa | Pig husbandry | Stable isotope | Diet | Iron Age | Medieval

Hanson 2016

Susan K. Hanson et al., *Measurements of extinct fission products in nuclear bomb debris, Determination of the yield of the Trinity nuclear test 70 y later*. PNAS **113** (2016), 8104–8108.

Susan K. Hanson, Anthony D. Pollington, Christopher R. Waidmann, William S. Kinman, Allison M. Wende, Jeffrey L. Miller, Jennifer A. Berger, Warren J. Oldham & Hugh D. Selby

This paper describes an approach to measuring extinct fission products that would allow for the characterization of a nuclear test at any time. The isotopic composition of molybdenum in five samples of glassy debris from the 1945 Trinity nuclear test has been measured. Nonnatural molybdenum isotopic compositions were observed, reflecting an input from the decay of the short-lived fission products 95Zr and 97Zr. By measuring both the perturbation of the 95Mo/96Mo and 97Mo/96Mo isotopic ratios and the total amount of molybdenum in the Trinity nuclear debris samples, it is possible to calculate the original concentrations of the 95Zr and 97Zr isotopes formed in the nuclear detonation. Together with a determination of the amount of plutonium in the debris, these measurements of extinct fission products allow for new estimates of the efficiency and yield of the historic Trinity test.

Keywords: nuclear forensics | nuclear testing | treaty monitoring | stable isotope perturbation measurements

Significance: This work describes an approach to postdetonation nuclear forensics involving isotopic measurements that allows for characterization of a nuclear detonation at any time. By performing high-precision measurements of stable isotope perturbations in nuclear bomb debris, it is possible to quantify short-lived fission products long after they have decayed below radiometric detection limits and become extinct. The extinct fission product concentrations can be used to reconstruct details of the nuclear device months to years after the detonation occurred. The approach is demonstrated by analysis of debris from the Trinity nuclear test and new estimates of the efficiency and yield of the historic test are presented.

Harbeck 2006

Michaela Harbeck, Reimer Dobberstein, Stefanie Ritz-Timme, Inge Schröder & Gisela Grupe, *Degradation von Biomolekülen in Knochen, Auswirkung auf die biologische Spurenkunde am Beispiel stabiler Isotopenverhältnisse im Kollagen*. Anthropologischer Anzeiger **64** (2006), 273–282.

Modern bone samples were experimentally degraded by incubation into water at increased temperature and examined in terms of their collagen content, the stable C and N isotopie ratios, and the molar C/N ratio. The same analyses were carried out with archaeological human bone of varying age (300 up to 8000 years). The experimentally degraded samples exhibited changes of the collagen' s integrity, which influence the stable isotope ratios. In the case of the archaeological material,

a correlation between stable d13C- and d15N-values and collagen content could be demonstrated. The molar C:N ratio was no suitable criterion for the assessment of the state of preservation of extractable collagen.

Keywords: Collagen | d13C | d15 N | molar C:N ratio | degradation.

Knochenproben wurden durch Inkubation in destilliertem Wasser bei erhöhter Temperatur experimentell degradiert und auf ihren prozentualen Kollagengehalt, die stabilen Isotopenverhältnisse von Kohlenstoff und Stickstoff sowie das molare Verhältnis von Kohlenstoff zu Stickstoff im verbliebenen Kollagen untersucht. Entsprechende Analysen wurden an archäologischem Knochenmaterial unterschiedlicher Zeitstellung (300 bis 8000 Jahre Liegezeit) durchgeführt. Es konnten durch experimentelle physiko-chemische Degradation hervorgerufene Veränderungen des Kollagens nachgewiesen werden, welche Einfluss auf die stabilen Isotopenverhältnisse von Kohlenstoff und Stickstoff haben. In dem archäologischen Material weisen Korrelationen zwischen stabilen Isotopenverhältniswerten und Kollagengehalt auf diagenetisch veränderte Verhältnisse hin. Das molare C:N-Verhältnis erwies sich als kein zuverlässiges Kriterium für die Abschätzung des Erhaltungsgrades von Kollagen.

Keywords: Kollagen | d13C | d15N | molares C:N-Verhältnis | Degradation.

Hart 2009

John P. Hart, Gerald R. Urquhart, Robert S. Feranec & William A. Lovis, *Non-linear relationship between bulk $\delta^{13}C$ and percent maize in carbonized cooking residues and the potential of false-negatives in detecting maize.* Journal of Archaeological Science **36** (2009), 2206–2212.

JArchSci36-2206-Supplement.doc

Bulk d13C values on charred cooking residues adhering to pottery sherd interior surfaces have been used as a source of information on the histories of maize in various locations in the western hemisphere. This approach is based on an assumption of a linear relationship between the percent maize in the resource mix cooked in a pot and d13C. Previous experiments suggest that this relationship is non-

linear, and maize may not be identified from bulk d13C values even when it contributed substantially to the resource mix. A second round of experiments, presented here, indicates that the mobilization of carbon from maize and C3 resources over time is the critical variable in residue formation and the resulting bulk d13C value. This is influenced by the form of maize being cooked.

Hart 2012

John P. Hart, William A. Lovis, Robert J. Jeske, & John D. Richards, *The potential of bulk $\delta^{13}C$ on encrusted cooking residues as independent evidence for regional maize histories.* American Antiquity **77** (2012), 315–325.

The histories of maize utilization in eastern North America have been substantially revised recently, primarily because of the analysis of charred cooking residues encrusted on pottery. A multifaceted research strategy of bulk d13C assays coupled with accelerator mass spectrometry radiocarbon data and microbotanical evidence can yield coherent regional maize use histories. Bulk d13C assay interpretation complications include (1) variations among vessels by site, (2) a potential for false negatives, and (3) a wide range of variation potentially present for any given time period. Regional histories using this approach can be quite variable without appropriate use of multiple lines of evidence.

Heaton 1986

Tim H. E. Heaton, John C. Vogel, Gertrud von la Chevallerie & Gill Collett, *Climatic influence on the isotopic composition of bone nitrogen.* nature **322** (1986), 822–823.

The 13C/12C isotope ratios in animal and human bone can be used as indicators of diet, more recently it was shown that the 15N/14N ratios of animals and humans are similarly determined by the food they eat. Specifically, the stable carbon isotope composition reflects the proportion of C3 and C4 plants at the base of the food chain, while both 15N and 13C reveal the difference between a marine and terrestrial diet in modern as well as archaeological contexts. Here we present data for human and animal bones from southern Africa which only partly conform to previously recognized patterns for 15N/14N ratios. Prehistoric human bones from a particular coastal region of South Africa show 15N/14N ratios consistent with the marine and terrestrial diets indicated by the 13C/12C ratios, but bones of both prehistoric humans and modern wild animals from a larger part of the subcontinent show variations in 15N/14N ratios which cannot be ascribed to known variations in diet. It appears that, in some environments, nitrogen isotope studies must also take into account the possible influence of the climate.

Heaton 1987

T. H. E. Heaton, *The $^{15}N/^{14}N$ Ratios of Plants in South Africa and Namibia: Relationship to Climate and Coastal/Saline Environments.* Oecologia **74** (1987), 236–246.

Data are presented for the 15N/14N ratios of 140 indigenous terrestrial plants from a wide variety of natural habitats in South Africa and Namibia. Over much of the area, from high-rainfall mountains to arid deserts, the (d15N values of plants lie typically in the range -1 to + 6‰; with no evident differences between C3 plants and C4 grasses. There is a slight correlation between d15N and aridity, but this is less marked than the correlation between the d15N values of animal bones and aridity. At coastal or saline sites, however, the mean d15N values for plants are higher than those at nearby inland or non-saline sites – e.g.: arid Namib coast (10‰ higher than inland Namib); wet Natal beach (5‰, higher than inland Natal); saline soils 500 km from coast (4‰, higher than non-saline soils). High values were also found at one site where there were no marked coastal or saline influences. These environmental effects on the isotopie composition of plants will extend upwards to the animals and humans they support. They therefore have important consequences for the use of nitrogen isotope data in the study of the dietary habits and trophic structures of modern and prehistoric communities.

Heaton 1999

Tim H. E. Heaton, *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** (1999), 637–649.

The d13C value of a C3 plant is influenced by the species' response to its environment, which is subject to natural changes with space and time. This paper reviews the magnitude of the resulting variations in plant d13C values—the differences between species, and the variations at different spatial and temporal scales—with particular emphasis on studies of tree wood. Because of these variations, any attempt to estimate the absolute d13C values of a plant food resource at a particular place and time in the past, even when based on analysis of archaeological plant remains, will be subject to uncertainties. Uncertainties due to a single factor

are commonly 1‰, and in many cases a combination of factors will lead to uncertainties of at least 2‰. Many of these factors are also relevant to archaeological studies based on differences between the d13C values of different individuals or populations of animal/humans. Where such differences are only a few per mil it may be difficult to unambiguously ascribe them to palaeodietary, rather than to palaeoenvironmental, causes.

Heaton 2009

Tim H. E. Heaton, Glynis Jones, Paul Halstead & Taxiarchis Tsipropoulos, *Variations in the $^{13}C/^{12}C$ ratios of modern wheat grain, and implications for interpreting data from Bronze Age Assiros Toumba, Greece*. Journal of Archaeological Science **36** (2009), 2224–2233.

Variations in the 13C/12C ratios of wheat grain at different spatial and temporal scales are examined by analysis of modern samples, including harvests of einkorn and durum wheat from Greece, and serve as a guide to interpreting data for Bronze Age grains from Assiros Toumba. The normal distribution and low variability of d13C values of einkorn from 24 containers in the Assiros storerooms are consistent with pooling of local harvests, but less likely to represent the harvest of several years or include grain imported from further afield. Correlation between emmer and spelt d13C values provides strong support for other evidence that these were grown together as a maslin crop. 13C discrimination (D) for the Bronze Age samples is estimated to be 2.5 ‰ larger than at present, and would be consistent with an intensive, horticultural regime of cereal cultivation, possibly involving some watering.

Hedges 2004

R. E. M. Hedges, *Isotopes and red herrings: comments on Milner et al. and Liden et al.* Antiquity **78** (2004), 34–37.

Change of diet in Northern Europe's Mesolithic – Neolithic transition: a new critique

The study of the proportions of stable isotopes of carbon and nitrogen which survive in ancient human and animal bones offers highly suggestive indications of ancient diets. Among the most remarkable results from such investigations is the dramatic change in diet which is thought to have occurred between the Mesolithic and the Neolithic when people turned from maritime to terrestrial food, from fish to meat and vegetables. The three contributions which follow challenge, modify, enhance or reflect on this model. In a pivotal critique of the evidence from Britain and Denmark, Milner et al. present a range of explanations for the signals of a maritime or terrestrial emphasis in diet and conclude that the change need not have been either rapid or total. Liden et al. show that, in southern Sweden, the preferences for fish over meat were related less to period or culture, but (reasonably enough) to location: fish-eaters live by the sea. Finally Robert Hedges takes up the question of partial marine diets and how to detect them, developing the idea that marine diets might give a fainter signal in people who were only getting small amounts of protein. Perhaps there were many such people in the new order of the Neolithic ...

Keywords: Northern Europe, Mesolithic, Neolithic, stable isotopes, diet

Hedges 2007

Robert E. M. Hedges & Linda M. Reynard, *Nitrogen isotopes and the trophic level of humans in archaeology*. Journal of Archaeological Science **34** (2007), 1240–1251.

Human and domesticate animal bone collagen d15N values in prehistory differ generally by 3‰ or more from Neolithic to post-Roman times in Northwest Europe, leading to an assumed dietary animal protein fraction of 60-80 % using a standard interpretation of d15N values. We examine the Assumptions on which this model rests, and the limitations of our knowledge in the analysis of d15N values in archaeology. We have developed a set of models which, with small changes made in assumptions (on the order of 1‰), can produce substantially lower estimates of the dietary animal protein fraction for given d15N values. We consider the implications of various dietary animal protein fractions on agricultural carrying capacities and human population densities in prehistory.

Keywords: Palaeodiet; Stable isotopes; Nitrogen; Protein; Trophic level

Howcroft 2014

Rachel Howcroft, Gunilla Eriksson & Kerstin Lidén, *Infant feeding practices at the Pitted Ware Culture site of Ajvide, Gotland*. Journal of Anthropological Archaeology **34** (2014), 42–53.

JAnthArch34-042-Supplement.docx

The infant feeding practices used at the Middle Neolithic Pitted Ware Culture (PWC) site of Ajvide on the Baltic island of Gotland were investigated using carbon and nitrogen stable isotope ratio analysis. The PWC were marine hunters with a seal-based economy, but were contemporary with the farming Funnel Beaker and Boat Axe Cultures. The carbon and nitrogen stable isotope ratios of bone collagen from adult females (14 individuals) and bone and dentine collagen from subadult individuals (23 individuals, 55 samples) from Ajvide were analysed. The results (mean ± 1s.d.) were d13C = .15.2 ± 0.4 ‰, d15N = 15.6 ± 0.5 ‰ for the adult females, and d13C = .15.3 ± 0.6 ‰, d15N = 16.5 ± 1.1 ‰ for the subadults. The majority of infants continued breastfeeding into the third or fourth year of life. There was some variation in the types of supplementary foods used and the timing of their introduction, perhaps due to seasonal variation in the availability of different resources. The isotope ratios from one infant, a neonate, were indicative of a much more terrestrial diet than usually consumed by the PWC, suggesting contact with the contemporary farming populations. Comparison of the results from Ajvide to those from other PWC sites in the Baltic region reveals that both adult and subadult dietary practices differed slightly between sites.

Keywords: Breastfeeding | Weaning | Seasonality | Neolithic | Sweden | Baltic | Stable isotope | Carbon | Nitrogen | Paleodiet

Hu 2009

Yaowu Hu, Hong Shang, Haowen Tong, Olaf Nehlich, Wu Liu, Chaohong Zhao, Jincheng Yu, Changsui Wang, Erik Trinkaus & Michael P, *Stable isotope dietary analysis of the Tianyuan 1 early modern human*. PNAS **106** (2009), 10971–10974.

We report here on the isotopic analysis of the diet of one of the oldest modern humans found in Eurasia, the Tianyuan 1 early modern human dating to ≈40,000 calendar years ago from Tianyuan Cave (Tianyuandong) in the Zhoukoudian region of China. Carbon and nitrogen isotope analysis of the human and associated faunal remains indicate a diet high in animal protein, and the high nitrogen isotope values suggest the consumption of freshwater fish. To confirm this inference, we measured the sulfur isotope values of terrestrial and freshwater animals around the Zhoukoudian area and of the Tianyuan 1 human, which also support the interpretation of a substantial portion of the diet from freshwater fish. This analysis

provides the direct evidence for the consumption of aquatic resources by early modern humans in China and has implications for early modern human subsistence and demography.

Humphrey 2008

Louise T. Humphrey, M. Christopher Dean, Teresa E. Jeffries & Malcolm Penn, *Unlocking evidence of early diet from tooth enamel*. PNAS **105** (2008), 6834–6839.

Recent developments in microspatial analysis of enamel chemistry provide the resolution needed to reconstruct detailed chronological records of an individual's early life history. Evidence of nutritional history, residential mobility, and exposure to heavy metals can potentially be retrieved from archaeological and even fossil teeth. Understanding the pattern and timing of incorporation of each trace element or stable isotope into enamel is crucial to the interpretation of the primary data. Here, we use laser ablation inductively coupled plasma mass spectrometry and ArcGIS software to map variation in calcium-normalized strontium intensities across thin sections of enamel from exfoliated deciduous teeth. Differences in calcium-normalized strontium intensities across each tooth reflect variation in tooth mineralization, implying that sampling location must be taken into account in interpreting results. Chronologically consistent shifts in calcium-normalized strontium intensities in teeth from children with known nursing histories reflect the onset and duration of breastfeeding and the introduction of nonmaternal sources of food. This tool is likely to be valuable for studying weaning and nursing behavior in the past. The distribution of normalized strontium intensities presented here is consistent with a model for the differential incorporation of strontium and calcium into enamel during the secretory and maturational phases of formation.

Jahren 2010

A. Hope Jahren & Brian A. Schubert, *Corn content of French fry oil from national chain vs. small business restaurants*. PNAS **107** (2010), 2099–2101.

pnas107-02099-Supplement.pdf

Several issues, ranging from sustainability to health, may interest the consumers in the corn content of their food. However, because restaurants are excluded from the Nutrition Labeling and Education Act of 1990, national chain restaurants provide nonspeci.c ingredient information and small businesses supply none. We measured the carbon isotope composition of fry oil in French fries purchased from 68 (67 %) of the 101 national chain fast food restaurants on Oahu (i.e., McDonald's, Burger King, Wendy's, Arby's, and Jack in the Box), and paired this with a similar number of small businesses (n = 66) to calculate minimum percent contribution of corn to total fry oil. We found that the majority (69 %) of the national chain restaurants served fries containing corn oil, whereas this was true for only a minority (20 %) of the small businesses. Corn oil is more expensive than soybean oil (for example) when purchased from a small business supplier, suggesting that large-scale corporate agreements are necessary to make corn oil frying cost-effective. When considering French fry oil along with corn-fed beef and chicken, as well as high-

fructose corn syrupsweetened soda, we see the pervasive in.uence of corn as an ingredient in national chain fast food.

Jaouen 2012

Klervia Jaouen, Vincent Balter, Estelle Herrscher, Aline Lamboux, Philippe Telouk & Francis Albarède, *Fe and Cu Stable Isotopes in*

Archeological Human Bones and Their Relationship to Sex. American Journal of Physical Anthropology **148** (2012), 334–340.

Accurate sex assignment of ancient human remains usually relies on the availability of coxal bones or well-preserved DNA. Iron (Fe) and copper (Cu) stable isotope compositions (56Fe/54Fe and 65Cu/63Cu, respectively) were recently measured in modern human blood, and an unexpected result was the discovery of a 56Fe-depletion and a 65Cu-enrichment in men's blood compared to women's blood. Bones, being pervasively irrigated by blood, are expected to retain the 56Fe/54Fe and 65Cu/63Cu signature of blood, which in turn is useful for determining the sex of ancient bones. Here, we report the 56Fe/54Fe, 65Cu/63Cu, and 66Zn/64Zn ratios from a suite of well-preserved phalanxes (n = 43) belonging to individuals buried in the 17th and 18th centuries at the necropolis of Saint-Laurent de Grenoble, France, and for which the sex was independently estimated from pelvic bone morphology. The metals were purified from the bone matrix by liquid chromatography on ion exchange resin and the isotope compositions were measured by multiple-collector inductively coupled plasma mass spectrometry. The results show that, as expected from literature data on blood, male bone iron is depleted in 56Fe and enriched in 65Cu relative to female. No sex difference is found in the 66Zn/64Zn ratios of bone. The concentration and isotopic data show no evidence of soil contamination. Four samples of five (77 %) can be assigned their correct sex, a result comparable to sex assignment using Fe and Cu isotopes in blood (81 %). Isotopic analysis of metals may therefore represent a valid method of sex assignment applicable to incomplete human remains.

KEY WORDS: metal stable isotopes; iron; copper; zinc; sex determination

Jaouen 2016

Klervia Jaouen, Melanie Beasley, Margaret Schoeninger, Jean-Jacques Hublin & Michael P. Richards, *Zinc isotope ratios of bones and teeth as new dietary indicators, Results from a modern food web (Koobi Fora, Kenya)*. Scientific Reports **6** (2016), 26281. DOI:10.1038/srep26281.

In order to explore the possibilities of using zinc (Zn) stable isotope ratios as dietary indicators, we report here on the measurements of the ratio of stable isotopes of zinc (66Zn/64Zn, expressed here as d66Zn) in bioapatite (bone and dental enamel) of animals from a modern food web in the Koobi Fora region of the Turkana Basin in Kenya. We demonstrate that d66Zn values in both bone and enamel allow a clear distinction between carnivores and herbivores from this food web. Differences were also observed between browsers and grazers as well as between carnivores that consumed bone (i.e. hyenas) compared to those that largely consume flesh (i.e. lions). We conclude that Zn isotope ratio measurements of bone and teeth are a new and promising dietary indicator.

Kalhan 2000

Satish C Kalhan, *Protein metabolism in pregnancy*. American Journal of Clinical Nutrition **71** (2000), 1249–1255.

Adaptation to pregnancy involves major changes in maternal metabolism to provide for the growing demands of the conceptus. Although changes in glucose metabolism, and possibly in fatty acid metabolism, occur in parallel with the increasing energy demands of the mother and the fetus, adaptation of protein metabolism appears to be in anticipation of maternal and fetal needs. During pregnancy, there is an excess of maternal nitrogen in the form of lean body mass over that deposited in the fetus and the products of conception; there is also a pregnancy-induced hypoaminoacidemia and a diminished amino acid response to

protein intake, suggesting an increased uptake of amino acids in the splanchnic compartment. With the use of stable-isotope-labeled tracers, it was shown that there is a decreased rate of urea synthesis during pregnancy that is evident early in gestation. Kinetic studies of leucine metabolism showed no significant change in leucine carbon turnover but a significantly lower rate of leucine nitrogen turnover, suggesting a lower rate of leucine transamination. These data suggest an integral regulation of whole-body protein and nitrogen metabolism starting early in gestation and aimed at conservation and accretion of nitrogen by the mother and the fetus.

KEY WORDS Pregnancy, protein, urea, stable isotopes, leucine

Kanstrup 2014

Marie Kanstrup, Mads K. Holst, Peter M. Jensen, Ingrid K. Thomsen & Bent T. Christensen, *Searching for long-term trends in prehistoric manuring practice, $\delta^{15}N$ analyses of charred cereal grains from the 4th to the 1st millennium BC*. Journal of Archaeological Science **51** (2014), 115–125.

JAS051-0115-Supplement.zip

Current concepts of prehistoric manuring are founded on limited and mainly circumstantial evidence, giving rise to much ambiguity with respect to the onset of systematic use of manure to enhance cereal production. This paper reports carbon (C) and nitrogen (N) contents and isotopic compositions (d13C, d15N) of charred grains of naked barley, emmer and spelt dating to the first four millennia of early agriculture in Denmark. The d15N values ranged from c. 0.5 ‰–5.5 ‰, 0.5 ‰–6.0 ‰ and 1.5 ‰–8 ‰ for spelt, emmer and naked barley, respectively. This study represents the until now most comprehensive investigation of long term trends in d15N values of charred cereal grains, which previous research have proposed as an indicator for prehistoric manuring practice. Our study suggests a longterm (3900–500 BC) decrease of manuring intensity in emmer cropping. Conversely the long-term (2300 BC – AD 1) trend for naked barley cropping displays a more distinct and significant increase (±2 ‰) in grain d15N values, reflecting an increased manuring intensity with an average d15N value of as high as 6 ‰. We interpret this trend as indicating the initiation of a more intensive and systematic manuring practice associated with cultivation of barley in the Early Iron Age (500 BC- 0). Although the isotopic signal ascribed to manuring was (somewhat) variable, the relative manuring effect was detected throughout the chronological continuum being investigated. Further, we observed that the conventional sample pre-treatment (acid-base-acid) induced an average d15N offset of 0.7 ‰ (pretreated sample > non pre-treated sample). This has not previously been reported. Methodological advancements are needed to remedy this issue and provide consensus about appropriate pretreatment of grain samples from archaeological sites. We conclude that N-isotope analysis of charred cereal grains constitutes a new and direct source of information about prehistoric manuring practice.

Keywords: Nitrogen isotopes | Archaeobotanical remains | Animal manure | Radiocarbon dates | Agricultural regimes

Katzenberg 1993

M. Anne Katzenberg, *Applications of Elemental and Isotopic Analysis to Problems in Ontario Prehistory*. In: Mary K. Sandford (Hrsg.), *Investigations of Ancient Human Tissue, Chemical Analyses*

in Anthropology. Food and Nutrition in History and Anthropology 10 (Langhorne / Berlin 1993), 335–360.

Trace element and stable isotope data allow the researcher to go beyond interpretations made possible from analyses of tools, botanical and faunal remains, but are also dependant on this information. Fluctuations in the relative importance of foods and the timing of the incorporation of cultigens into the diet are detectable. In southern Ontario, the use of stable isotopes of carbon confirm the timing and importance of maize as evidenced through other methods of investigation. The use of stable isotopes of nitrogen and the trace element Sr refute the hypothesis that animal protein decreased in importance with the increase of cultigens in the diet. These analyses further suggest details of human subsistence behavior, such as a shift in women's subsistence tasks. Comparisons of factors such as diet, settlement pattern and disease are refined with more detailed information on minor fluctuations in diet over time.

KELLNER 2007

Corina M. Kellner & Margaret J. Schoeninger, *A Simple Carbon Isotope Model for Reconstructing Prehistoric Human Diet*. American Journal of Physical Anthropology **133** (2007), 1112–1127.

A compilation of experimental animal data shows that neither d13C collagen nor d13C apatite nor D13C CO-AP indicate diagnostic reconstructions of diet, diet energy and diet protein. In contrast, plots of d13C collagen against d13C apatite provide a model of three regression lines (C3, C4, and marine diet protein) where position on each line indicates the energy source (C3, C4, or mixed). Neither body size nor trophic position appears to affect these relationships. Modern free-ranging, terrestrial fauna do not fit the model perhaps because they, unlike the experimental fauna, mainly use fermentation rather than digestion during energy metabolism. Archaeological humans fall as expected based on associated floral and faunal evidence. Foraging people plot at positions expected from associated C3 fauna and plants. Those from Cahokia plot, as expected, from associated deer, nuts, and maize whereas people from nearby smaller sites plot in positions consistent with eating more fish. Agriculturists from Ontario and Grasshopper Pueblo plot consistent with dependence on fish by the former and on turkeys by the latter. In Tierra del Fuego, people from interior regions ate more terrestrial fauna, as suggested by ethnohistoric reports, than did people from the coast. In the Southwestern Cape in South Africa individuals late in the sequence have pure C3 diets whereas ones early in the sequence ate marine protein as suggested by independent archaeological evidence. People on San Nicolas Island depended on C4 plants in contrast to other islands off California's coast. This simple model provides more detailed and precise dietary information than do individual isotopic measures.

KEY WORDS stable carbon isotopes; diet reconstruction; prehistoric human diet

KINASTON 2009

R. L. Kinaston, H. R. Buckley, S. E. Halcrow, M. J. T. Spriggs, S. Bedford & K. Neal d, A. Gray, *Investigating foetal and perinatal mortality in prehistoric skeletal samples: a case study from a 3000-year-old Paci.c Island cemetery site*. Journal of Archaeological Science **36** (2009), 2780–2787.

The Teouma skeletal sample from Vanuatu represents one of the few truly colonising populations in the Paci.c Islands. Therefore, investigating the factors that

may have affected foetal/infant mortality in this population is potentially important for understanding the success of settlement in this region of the world. We investigate whether stable isotope analyses of carbon and nitrogen in conjunction with skeletal ageing techniques, can aid in identifying whether the subadults from Teouma died before or after birth in an attempt to understand the potential threats to foetal and infant survival. Multiple skeletal ageing methods using diaphyseal lengths were used to age the young subadults (n = 7). Using regression-based skeletal ageing methods, four of the individuals were aged at around full-term gestation (37-42 weeks gestation), while the remaining three individuals died preterm. The isotope analyses did not assist in identifying the individuals that survived post-birth because none of the subadults displayed the 2-3 ‰ trophic increase in d15N values expected for a breastfed infant, probably as a result of their young age. However, all of the foetal/perinatal individuals exhibited higher d15N values in their bone collagen compared with the adult females of the sample, with two of the individuals demonstrating unusually high d15N values. The d13C values of the foetuses/perinates did not exhibit the same variation. We explore a number of possible explanations for this elevation of perinatal/foetal d15N values and tentatively suggest that this is a result of in utero stress as a consequence of chronic maternal ill-health. The osteological and palaeodemographic evidence supports the assertion that females, foetuses and perinates were susceptible to environmental stress within this colonising population, resulting in early death of the perinatal individuals in addition to early terminations of pregnancy or premature birth possibly caused by infectious and/or metabolic diseases.

Kinaston 2014

Rebecca Kinaston, Hallie Buckley, Frederique Valentin, Stuart Bedford, Matthew Spriggs, Stuart Hawkins & Estelle Herrscher, *Lapita Diet in Remote Oceania, New Stable Isotope Evidence from the 3000-Year-Old Teouma Site, Efate Island, Vanuatu*. PLoS ONE **9** (2014), e90376. DOI:10.1371/journal.pone.0090376.

Remote Oceania was colonized ca. 3000 BP by populations associated with the Lapita Cultural Complex, marking a major event in the prehistoric settlement of the Pacific Islands. Although over 250 Lapita sites have been found throughout the Western Pacific, human remains associated with Lapita period sites are rare. The site of Teouma, on Efate Island, Vanuatu has yielded the largest burial assemblage (n = 68 inhumations) of Lapita period humans ever discovered, providing a unique opportunity for assessing human adaptation to the environment in a colonizing population. Stable isotope ratios (d13C, d15N, d34S) of human bone collagen from forty-nine Teouma adults were analyzed against a comprehensive dietary baseline to assess the paleodiet of some of Vanuatu's earliest inhabitants. The isotopic dietary baseline included both modern plants and animals (n = 98) and prehistoric fauna from the site (n = 71). The human stable isotope data showed that dietary protein at Teouma included a mixture of reef fish and inshore organisms and a variety of higher trophic marine (e.g. marine turtle) and terrestrial animals (e.g. domestic animals and fruit bats). The domestic pigs and chickens at Teouma primarily ate food from a C3 terrestrial environment but their d15N values indicated that they were eating foods from higher trophic levels than those of plants, such as insects or human fecal matter, suggesting that animal husbandry at the site may have included free range methods. The dietary interpretations for the humans suggest that broad-spectrum foraging and the consumption of domestic animals were the most important methods for procuring dietary protein at the site. Males displayed significantly higher d15N values compared with females, possibly

suggesting dietary differences associated with labor specialization or socio-cultural practices relating to food distribution.

Kluge 2012

Tobias Kluge & Hagit P. Affek, *Quantifying kinetic fractionation in Bunker Cave speleothems using Δ_{47}*. Quaternary Science Reviews **49** (2012), 82–94.

qsr49-0082-Supplement.doc

Isotopic signals in speleothems are used for investigating paleoclimate variability on land and are useful to constrain the dating of prominent climate events. A quantitative use, however, is limited by an incomplete understanding of parameters contributing to the carbon and oxygen isotope signals. These include external and environmental parameters such as d18O of cave drip waters as well as internal parameters associated with speleothem formation, such as the presence of non-equilibrium effects and especially the magnitude of their isotopic shifts.

We explore the use of clumped isotopes as a new tool for investigating the kinetic isotope effect in speleothems. Holocene and modern speleothems from Bunker Cave (Germany) as well as modern material from the adjacent Dechen Cave are all offset from the equilibrium relationship due to kinetic fractionation. This kinetic offset in clumped isotopes is observed in a stalagmite despite mostly negative Hendy tests, providing a sensitive indicator for kinetic fractionation in cave carbonates. The temperature dependence of the clumped isotope values (0.005‰ per °C) is low compared to the observed magnitude of kinetic offsets (between -0.021 and -0.075‰), so that the mean offsets in apparent temperatures due to kinetic isotope effects are on the order of 10 °C. As a result clumped isotopes are useful in identifying temporal variations in the kinetic fractionation in a stalagmite, when the temperatures during the speleothem growth period are either relatively constant (variations <2 °C) or can be independently constrained.

The variations in the kinetic isotope fractionation in Bunker Cave are associated with changing drip water super saturation with periods of stronger prior calcite precipitation associated with lower kinetic offsets in the speleothem calcite. In contrast, stalagmite growth rates show no direct correlation with the degree of kinetic fractionation in the investigated range (13–1500 mm/a).

Keywords: Stalagmite | Clumped isotopes | Equilibrium fractionation | Holocene | Hendy test | Growth rate

Knipper 2015

Corina Knipper et al., *Superior in Life—Superior in Death, Dietary Distinction of Central European Prehistoric and Medieval Elites*. Current Anthropology **56** (2015), 579–589.

CurrAnth56-579-Supplement.xls

Corina Knipper, Petra Held, Marc Fecher, Nicole Nicklisch, Christian Meyer, Hildrun Schreiber, Bernd Zich, Carola Metzner-Nebelsick, Vera Hubensack, Leif Hansen, Elke Nieveler, and Kurt W. Alt

Food production provoked social inequality in agricultural societies. Starting in the European late Neolithic, conspicuously equipped inhumations with elaborate grave architecture indicated representatives of local and possibly regional elites. However, burials are always shaped by a complex combination of the desires of the deceased and of the bereaved, along with ritual customs and norms. Therefore, a superior burial may not always be preceded by long-term superior life conditions. One widely accepted characteristic of social distinction is access to different, supposedly higher-quality food, which is deducible from light stable isotope analysis of carbon and nitrogen in bone collagen (d13C and d15N). Four remarkable cases

of high-elite individuals from the modern territory of Germany spanning from the Early Bronze Age to Medieval times exhibited d15N values that exceeded those of contemporaneous "commoner" populations significantly. This demonstrates outstanding dietary compositions, including larger shares of meat and dairy products but also possibly fish, poultry, and the meat of young animals. The results support enduringly different lifestyles and privileges for the representatives of the respective highest social class, despite very different prehistoric and historic contexts.

Significance: The pronounced social distinctness of the individuals investigated here is especially important because in previous studies, archaeologically implied social differences within cemeteries were sometimes only weakly represented in the stable isotope data (Privat, O'Connell, and Richards 2002) or revealed gradual differentiations rather than single outliers (Jay 2006; Le Huray and Schutkowski 2005; Oelze et al. 2012; Yoder 2012). In contrast, this study investigated single individuals that formed the very summit of accumulated wealth within their time periods. Their outstanding stable isotope ratios emphasize their outstanding social positions and show that exclusive lifestyles of single individuals were a regular phenomenon in Central European (pre)history. Despite dissimilar historical contexts, the general patterns are strikingly alike over more than 3 millennia and attest to sustainably different lifestyles and long-term privileges for individuals marked as the highest elite by their own societies.

Knudson 2010

Kelly J. Knudson, Hope M. Williams, Jane E. Buikstra, Paula D. Tomczak, Gwyneth W. Gordon & Ariel D. Anbar, *Introducing $\delta^{88/86}Sr$ analysis in archaeology: a demonstration of the utility of strontium isotope fractionation in paleodietary studies.* Journal of Archaeological Science **37** (2010), 2352–2364.

Isotopic methods are widely used in archaeology to investigate paleodiet. Here, we present a new method to identify trophic level in archaeological human populations and to investigate paleodiet. We demonstrate that strontium isotope compositions (reported as d88/86Sr) vary in a mass-dependent manner with increasing trophic level and can elucidate paleodiet in archaeological human populations. We present new mass-dependent strontium isotope data from tooth enamel and bone from individuals buried during the Late Intermediate Period (c. AD 1000e1300) in the large cemeteries of Chiribaya Alta, Chiribaya Baja, San Gerónimo, and El Yaral in the Ilo and Moquegua Valleys of southern Peru. We compare these data to radiogenic strontium isotope data (87Sr/86Sr) and light stable isotope data (d15Ncol and d13Ccol) from the same individuals to investigate geologic variability in strontium sources as well as marine food consumption among the Chiribaya. Our results demonstrate the utility of measurements of strontium isotope fractionation as a new tool for archaeological investigation of paleodiet. Importantly, this new technique can be used to generate paleodietary (d88/86Sr) and paleomobility (87Sr/86Sr) data from the same specimen, minimizing destructive analyses of invaluable archaeological material, and provides a new way to examine paleodiet through hydroxyapatite, which is particularly important when collagen is poorly preserved.

Keywords: Chiribaya, Andes, South America, Bone chemistry, Biogeochemistry, Trophic level, Radiogenic strontium, Stable strontium

Kohn 1999

Matthew J. Kohn, *Enhanced: You Are What You Eat.* science **283** (1999), 335–336.

s283-0335-Fig1.gif

Kohn 2010

Matthew J. Kohn, *Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo)ecology and (paleo)climate.* PNAS **107** (2010), 19691–19695.

pnas107-19691-Supplement1.pdf, pnas107-19691-Supplement2.xls

A broad compilation of modern carbon isotope compositions in all C3 plant types shows a monotonic increase in d13C with decreasing mean annual precipitation (MAP) that differs from previous models. Corrections for temperature, altitude, or latitude are smaller than previously estimated. As corrected for altitude, latitude, and the d13C of atmospheric CO2, these data permit refined interpretation of MAP, paleodiet, and paleoecology of ecosystems dominated by C3 plants, either prior to 7-8 million years ago (Ma), or more recently at mid- to high latitudes. Twenty-nine published paleontological studies suggest preservational or scientific bias toward dry ecosystems, although wet ecosystems are also represented. Unambiguous isotopic evidence for C4 plants is lacking prior to 7-8 Ma, and hominid ecosystems at 4.4 Ma show no isotopic evidence for dense forests. Consideration of global plant biomass indicates that average d13C of C3 plants is commonly overestimated by approximately 2‰.

aridity | carbon cycle | closed canopy | paleoprecipitation

Krajcarz 2014

Maciej T. Krajcarz & Magdalena Krajcarz, *The 200,000 year long record of stable isotopes ($\delta^{18}O$, $\delta^{13}C$) of cave bear (Ursus spelaeus) teeth from Biśnik Cave, Poland.* Quaternary International **339** (2014), 119–130.

The excavations in Biśnik Cave created an opportunity to investigate changes in d13C and d18O values of Ursus spelaeus teeth from one site along a 200,000 year period of sedimentation, for the first time in Eastern Europe. Bisnik Cave (Kraków-Częstochowa Upland, southern Poland) is a multilayered archaeological and paleontological site with late Middle Pleistocene and Late Pleistocene sediments, where several important changes of Quaternary climate have been recorded. The project considered if and how detailed the isotopic data from one multilayered site record these great climatic changes. The method used was an isotopic analysis of carbonate in bioapatite from tooth enamel. Teeth of cave bear (U. spelaeus) were chosen as research material. The results showed that the d18O values of cave bear teeth from Biśnik Cave range from -14.9 to -4.4 ‰ VPDB with some variation between particular layers. Values of d13C vary between -20.5 and -14.5 ‰ VPDB. The analysis revealed that isotopic record is diverse between different types of teeth, probably due to differences in time of growth and different impact of nursing and hibernation. The results verify the responsiveness of this species to great climatic changes during Middle and Late Pleistocene in Eastern Europe. Cave bear was an ecologically inflexible species, associated with the same type of food during 200,000 years and not able to cope with the coldest phases of the Pleistocene.

Krigbaum 2007

John Krigbaum, *Prehistoric Dietary Transitions, Stable Isotope and Dental Caries Evidence from Two Sites in Malaysia.* In: Mark Nathan Cohen & Gillian M. M. Crane-Kramer (Hrsg.), *Ancient Health, Skeletal Indicators of Agricutural and Economic Intensification.* (Gainesville 2007), 273–285.

Kuitems 2015

Margot Kuitems et al., *Carbon and nitrogen stable isotopes of well-preserved Middle Pleistocene bone collagen from Schöningen (Germany) and their paleoecological implications*. Journal of Human Evolution **89** (2015), 105–113.

Margot Kuitems, Johannes van der Plicht, Dorothée G. Drucker, Thijs Van Kolfschoten, Sanne W. L. Palstra & Hervé Bocherens

Carbon and nitrogen stable isotopes in bone collagen can provide valuable information about the diet and habitat of mammal species. However, bone collagen degrades in normal circumstances very rapidly, and isotope analyses are therefore usually restricted to fossil material with a Late Pleistocene or Holocene age. The Middle Pleistocene site of Schöningen, dated to around 300,000 years ago, yielded bones and teeth with an exceptionally good state of collagen preservation. This allowed us to measure reliable biogenic carbon and nitrogen stable isotope ratios for different herbivorous taxa from the families Elephantidae, Rhinocerotidae, Equidae, Cervidae, and Bovidae. The results provide insights regarding the paleoenvironmental setting in which Middle Pleistocene hominins operated. The vegetation consumed by the herbivores from the famous spear horizon originates from open environments. During the climatic Reinsdorf Interglacial optimum, the landscape seems to have been relatively open as well, but certainly included parts that were forested. The results also indicate some niche partitioning; different herbivore species used different plant resources. For instance, the horses seem to have been predominantly browsers, while the straight-tusked elephants were feeding chiefly on grass.

Keywords: Paleoecology | 13C | 15N | Collagen preservation | Large herbivorous mammals

Lamb 2014

Angela L. Lamb, Jane E. Evans, Richard Buckley & Jo Appleby, *Multi-isotope analysis demonstrates significant lifestyle changes in King Richard III*. Journal of Archaeological Science **50** (2014), 559–565.

JAS050-0559-Supplement.docx

The discovery of the mortal remains of King Richard III provide an opportunity to learn more about his lifestyle, including his origins and movements and his dietary history; particularly focussing on the changes that Kingship brought. We analysed bioapatite and collagen from sections of two teeth which formed during Richard's childhood and early adolescence, and from two bones: the femur (which averages long-term conditions), and the rib (which remodels faster and represents the last few years of life). We applied multi element isotope techniques to reconstruct a full life history. The isotopes initially concur with Richard's known origins in Northamptonshire but suggest that he had moved out of eastern England by age seven, and resided further west, possibly theWelsh Marches. In terms of his diet, there is a significant shift in the nitrogen, but not carbon isotope values, towards the end of his life, which we suggest could be explained by an increase in consumption of luxury items such as game birds and freshwater fish. His oxygen isotope values also rise towards the end of his life and as we know he did not relocate during this time, we suggest the changes could be brought about by increased wine consumption. This is the first suggestion of wine affecting the oxygen isotope composition of an individual and thus has wider implications for isotope-based palaeodietary and migration reconstructions.

Keywords: Richard III | Isotopes | Diet | Bioapatite | Collagen | Wine

Lee-Thorp 2006

Julia Lee-Thorp & Matt Sponheimer, *Contributions of Biogeochemistry to Understanding Hominin Dietary Ecology*. Yearbook of Physical Anthropology **49** (2006), 131–148.

Dietary ecology is one key to understanding the biology, lifeways, and evolutionary pathways of many animals. Determining the diets of long-extinct hominins, however, is a considerable challenge. Although archaeological evidence forms a pillar of our understanding of diet and subsistence in the more recent past, for early hominins, the most direct evidence is to be found in the fossils themselves. Here we review the suite of emerging biochemical paleodietary tools based on stable isotope and trace element archives within fossil calcified tissues. We critically assess their contribution to advancing our understanding of australopith, early Homo, and Neanderthal diets within the broader context of non-biogeochemical techniques for dietary reconstruction, such as morphology and dental microwear analysis. The most significant outcomes to date are the demonstration of high trophic-level diets among Neanderthals and Late Pleistocene modern humans in Glacial Europe, and the persistent inclusion of C4 grass-related foods in the diets of Plio-Pleistocene hominins in South Africa. Such studies clearly show the promise of biogeochemical techniques for testing hypotheses about the diets of early hominins. Nevertheless, we argue that more contextual data from modern ecosystem and experimental studies are needed if we are to fully realize their potential.

KEY WORDS fossil teeth; stable isotopes of carbon; nitrogen and oxygen; trace elements; microwear; dental morphology; australopiths; Homo; Neanderthals

Lidén 1995

Kerstin Lidén, *Megaliths, Agriculture, and Social Complexity, A Diet Study of Two Swedish Megalith Populations*. Journal of Anthropological Archaeology **14** (1995), 404–417.

This paper tests the relationship between the erection of megaliths and agriculture in Neolithic Scandinavia. A dietary change in two Swedish megalith populations was tested by analyses of stable carbon and nitrogen isotopes extracted from human bone collagen. Carbon isotopes show that marine resources still were utilized in the coastal area and nitrogen isotope indicates that the major part of the protein came from a high trophic level, i.e., animals. It is concluded that a change in diet, and hence subsistence, took place from a hunter-gatherer-based subsistence toward one based on pastoralism, not horticulturalism. The prerequisite for social complexity is discussed and the author favors sedentism as the major determinant.

Liden 2004

Kerstin Liden, Gunilla Eriksson, Bengt Nordqvist, Anders Gotherstrom & Erik Bendixen, *"The wet and the wild followed by the dry and the tame" – or did they occur at the same time? Diet in Mesolithic - Neolithic southern Sweden*. Antiquity **78** (2004), 23–37.

Change of diet in Northern Europe's Mesolithic – Neolithic transition: a new critique

The study of the proportions of stable isotopes of carbon and nitrogen which survive in ancient human and animal bones offers highly suggestive indications of ancient diets. Among the most remarkable results from such investigations is the dramatic change in diet which is thought to have occurred between the Mesolithic and the Neolithic when people turned from maritime to terrestrial food, from fish to meat and vegetables. The three contributions which follow challenge, modify, enhance or reflect on this model. In a pivotal critique of the evidence from Britain

and Denmark, Milner et al. present a range of explanations for the signals of a maritime or terrestrial emphasis in diet and conclude that the change need not have been either rapid or total. Liden et al. show that, in southern Sweden, the preferences for fish over meat were related less to period or culture, but (reasonably enough) to location: fish-eaters live by the sea. Finally Robert Hedges takes up the question of partial marine diets and how to detect them, developing the idea that marine diets might give a fainter signal in people who were only getting small amounts of protein. Perhaps there were many such people in the new order of the Neolithic ...

Keywords: Northern Europe, Mesolithic, Neolithic, stable isotopes, diet

Lightfoot 2012

Emma Lightfoot & Rhiannon E. Stevens, *Stable isotope investigations of charred barley (Hordeum vulgare) and wheat (Triticum spelta) grains from Danebury Hillfort: implications for palaeodietary reconstructions*. Journal of Archaeological Science **39** (2012), 656–662.

Palaeodietary studies typically focus on the analysis of bone collagen due to the limited availability of plant remains. Isotopic analysis of plant remains, however, allow for a more extensive consideration of the contribution of plants to the human diet and can potentially provide information about the environment in which the crops were grown. This paper reports the results of carbon and nitrogen isotope analyses performed on charred barley and wheat grains recovered from pits within Danebury Iron Age hillfort. To the best of our knowledge, this is the first Iron Age site in Britain from which charred grains have been isotopically analysed. Our results suggest that cereals found at the hillfort were grown in several different environmental contexts. The isotope data demonstrate that the herbivores were not consuming a diet primarily based on grains as the d15N values of the grains are very similar to those of the herbivores. Palaeodietary investigations typically assume that humans eating plant protein only would have the same d15N value as the local herbivores. This assumption is clearly invalid at Danebury, where the humans and animals appear to have consumed either different parts of the same plants or different plants. Researchers typically interpret high differences between human and animal d15N values as indicative of diets high in animal protein, however where major plant resources have d15N values similar to those of the herbivores our ability to distinguish between plant and animal sources of protein in the diet is limited. Our research has demonstrated that whenever possible it is desirable to measure the isotopic signatures of potential major plant resources in order to understand past subsistence strategies.

Keywords: Cereal | Palaeodiet | Carbon | Nitrogen | Iron Age | Collagen | Danebury

Liu 2008

Alexander G. S. C. Liu, Erik R. Seiffert & Elwyn L. Simons, *Stable isotope evidence for an amphibious phase in early proboscidean evolution*. PNAS **105** (2008), 5786–5791.

pnas105-05786-Supplement.pdf

The order Proboscidea includes extant elephants and their extinct relatives and is closely related to the aquatic sirenians (manatees and dugongs) and terrestrial hyracoids (hyraxes). Some analyses of embryological, morphological, and paleontological data suggest that proboscideans and sirenians shared an aquatic or semiaquatic common ancestor, but independent tests of this hypothesis have proven elusive. Here we test the hypothesis of an aquatic ancestry for advanced proboscideans by measuring d18O in tooth enamel of two late Eocene proboscidean genera,

Barytherium and Moeritherium, which are sister taxa of Oligocene-to-Recent proboscideans. The combination of low d18O values and low d18O standard deviations in Barytherium and Moeritherium matches the isotopic pattern seen in aquatic and semiaquatic mammals, and differs from that of terrestrial mammals. d13C values of these early proboscideans suggest that both genera are likely to have consumed freshwater plants, although a component of C3 terrestrial vegetation cannot be ruled out. The simplest explanation for the combined evidence from isotopes, dental functional morphology, and depositional environments is that Barytherium and Moeritherium were at least semiaquatic and lived in freshwater swamp or riverine environments, where they grazed on freshwater vegetation. These results lend new support to the hypothesis that Oligocene-to-Recent proboscideans are derived from amphibious ancestors.

Lovis 2011

William A. Lovis, Gerald R. Urquhart, Maria E. Raviele & John P. Hart, *Hardwood ash nixtamalization may lead to false negatives for the presence of maize by depleting bulk $\delta^{13}C$ in carbonized residues.* Journal of Archaeological Science **38** (2011), 2726–2730.

Among the multiple proxies for detecting maize in precontact economies is the use of d13C analysis of carbonized residues from ceramic cooking vessels. Although maize horticulture was widely established in Eastern North America (ENA) by A.D. 1000, there are carbonized residues from ceramic assemblages after this date that lack the elevated d13C values indicative of the presence of maize. This may be due to the true absence of maize, or other factors including the masking of maize. Prior experimental research by Hart et al. demonstrated that the addition of C3 plants or consumers to two part mixes with maize can mask maize presence even when maize is the dominant ingredient. Here we investigate the effect of alkali processing of maize (nixtamalization) on d13C using the widespread ENA process of boiling maize kernels with wood ash, a C3 product, to create hominy. Our experiments test whether or not the process of hardwood ash nixtamalization can mask the presence of maize in adhering carbonized residues by depleting d13C values, and whether there is a reciprocal d13C enrichment effect on the hardwood ash employed in nixtamalization. Overall, there is substantial d13C depletion of residues when maize is cooked with hardwood ash, and hardwood ash cooked with maize shows the reciprocal enrichment. Therefore, the depleted values after the adoption of maize may be false negatives due to the nixtamalization process.

Keywords: Alkali processing; Hominy; Pottery residue; Bulk d13C; Maize histories; Prehistoric cooking techniques

McClelland 1997

Irene S. M. McClelland, Chandarika Persaud & Alan A. Jackson, *Urea kinetics in healthy women during normal pregnancy.* British Journal of Nutrition **77** (1997), 165–181.

Urea kinetics were measured in normal women aged 22-34 years at weeks 16,24 and 32 on either their habitual protein intake (HABW.) or a controlled intake of 60 g protein/d (CONTROL), using primed-intermittent oral doses of [15N 15N]urea and measurement of plateau enrichment in urinary urea over 18 h (ID) or a single oral dose of [15N 15N]urea and measurement of enrichment of urea in urine over the following 48 h (SD). The intake of protein during HABIT-ID (80 g/d) was greater than that on HABIT-SD (71 g/d); urea production as a percentage of intake was significantly greater at week 16 for HABIT-ID than HABIT-SD, whereas urea hydrolysis at week 16 was greater for HABIT-SD than HABIT-ID

and urea excretion at week 32 was greater for HABIT-ID than HABIT-SD. The combined results for HABIT-ID and HABIT-SD showed a significant reduction in urea production at week 32 compared with week 24. Urea excretion decreased significantly from week 16 to week 24 with no further decrease to week 32 and urea hydrolysis was significantly greater at week 24 than either week 16 or week 32. Compared with HABIT, on CONTROL there was a decrease in urea production at week 16, and urea excretion was significantly reduced at week 16. For all time periods urea production was closely related to the sum of intake plus hydrolysis. Hydrolysis was greatest at week 24 and closely related to urea production. There was a significant inverse linear relationship overall for hydrolysis as a proportion of production and excretion as a proportion of intake. The results show that on HABIT N is more effectively conserved in mid-pregnancy through an increase in urea hydrolysis and salvage, and during late pregnancy through a reduction in urea formation. Lowering protein intake at any stage of pregnancy increased the hydrolysis and salvage of urea. The staging of these changes was later than that in pregnancy in Jamaica.

[15N]urea : Urea kinetics : Protein requirements : Pregnancy

Macko 1999

Stephen A. Macko, Michael H. Engel, Vladimir Andrusevich, Gert Lubec, Tamsin C. O'Connell & Robert E. M. Hedges, *Documenting the diet in ancient human populations through stable isotope analysis of hair*. Phil. Trans. Royal Society B **354** (1999), 65–76.

Fundamental to the understanding of human history is the ability to make interpretations based on artefacts and other remains which are used to gather information about an ancient population. Sequestered in the organic matrices of these remains can be information, for example, concerning incidence of disease, genetic defects and diet. Stable isotopic compositions, especially those made on isolates of collagen from bones, have been used to help suggest principal dietary components. A signi¢cant problem in the use of collagen is its long-

term stability, and the possibility of isotopic alteration during early diagenesis, or through contaminating condensation reactions. In this study, we suggest that a commonly overlooked material, human hair, may represent an ideal material to be used in addressing human diets of ancient civilizations. Through the analysis of the amino-acid composition of modern hair, as well as samples that were subjected to radiation (thus simulating ageing of the hair) and hair from humans that is up to 5200 years old, we have observed little in the way of chemical change. The principal amino acids observed in all of these samples are essentially identical in relative abundances and content. Dominating the compositions are serine, glutamic acid, threonine, glycine and leucine, respectively accounting for approximately 1517components (for example, alanine, valine, isoleucine) show similar constancy between the samples of different ages. This constancy clearly indicates minimal alteration of the amino-acid composition of the hair. Further, it would indicate that hair is well preserved and is amenable to isotopic analysis as a tool for distinguishing sources of nutrition. Based on this observation, we have isotopically characterized modern individuals for whom the diet has been documented. Both stable nitrogen and carbon isotope compositions were assessed, and together provide an indication of trophic status, and principal type (C3 or C4) of vegetation consumed.True vegans have nitrogen isotope compositions of about 7‰ whereas humans consuming larger amounts of meat, eggs, or milk are more enriched in the heavy nitrogen isotope. We have also analysed large cross-sections of modern humans from North America and Europe to provide an indication of the variability seen in a population (the supermarket diet). There is a wide di-

versity in both carbon and nitrogen isotope values based at least partially on the levels of seafood, corn-fed beef and grains in the diets. Following analysis of the ancient hair, we have observed similar trends in certain ancient populations. For example, the Coptics of Egypt (1000 BP) and Chinchorro of Chile (5000-800 BP) have diets of similar diversity to those observed in the modern group but were isotopically in£uenced by local nutritional sources. In other ancient hair (Egyptian Late Middle Kingdom mummies, ca. 4000 BP), we have observed a much more uniform isotopic signature, indicating a more constant diet.We have also recognized a primary vegetarian component in the diet of the Neolithic Ice Man of the Oetztaler Alps (5200 BP). In certain cases, it appears that sulphur isotopes may help to further constrain dietary interpretations, owing to the good preservation and sulphur content of hair. It appears that analysis of the often-overlooked hair in archaeological sites may represent a signi¢cant new approach for understanding ancient human communities.

MAKAREWICZ 2015

Cheryl A. Makarewicz & Judith Sealy, *Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues*, *Expanding the prospects of stable isotope research in archaeology*. Journal of Archaeological Science **56** (2015), 146–158.

The use of stable isotope ratio analysis in archaeology has exploded over the past few decades to the point where it is now an established tool that is routinely used to investigate questions relating to diet and mobility. Early applications focused mostly on the analysis of human skeletal tissues as a way to reconstruct major shifts in human diet, but current stable isotopic approaches have expanded to include high resolution analyses of human, animal, and plant remains, which are helping to better define the resource exploitation and management strategies that underscore changes in the human diet. In addition, stable isotopic data sets are now regularly filtered through interpretive archaeological theoretical frameworks to explore socially mediated food acquisition and consumption choices, mortuary practices, and social identity. Much work remains to be done in documenting the biological and ecological variation in the distribution of stable isotopes in ancient food webs and the mechanisms responsible for the isotopic signals observed in archaeological plant and animal tissues. Here, we identify several areas in stable isotope analysis where additional 'first principles' driven research would help to improve existing isotopic methods, or develop new ones, and consequently improve our ability to answer questions of archaeological significance. We consider the strengths and limitations of the application of stable isotope analysis to ancient skeletal material obtained from archaeological contexts. We also pay particular attention to nitrogen isotopic variation in ancient ecosystems, organic oxygen and hydrogen isotopes; to mixing models as a means of estimating source contributions in human diet, mobility, and isoscapes; and to how compound specific analyses may help detangle dietary routing. We conclude with a plea for greater scientific rigour and more informed use of stable isotope analyses and call for a closer integration of stable isotope analysis with other aspects of archaeological research programmes, in order to optimise the information that isotopes can provide.

Keywords: Dietary reconstruction | Nitrogen | Oxygen | Hydrogen | Isoscapes | Mixing-model | Dietary routing | Amino-acid

MARTIN 2015

Jeremy E. Martin, Derek Vance & Vincent Balter, *Magnesium stable isotope ecology using mammal tooth enamel*. PNAS **112** (2015), 430–435.

Geochemical inferences on ancient diet using bone and enamel apatite rely mainly on carbon isotope ratios (d13C) and to a lesser extent on strontium/calcium (Sr/Ca) and barium/calcium (Ba/Ca) elemental ratios. Recent developments in nontraditional stable isotopes provide an unprecedented opportunity to use additional paleodietary proxies to disentangle complex diets such as omnivory. Of particular relevance for paleodietary reconstruction are metals present in large quantity in bone and enamel apatite, providing that biologically mediated fractionation processes are constrained. Calcium isotope ratios (d44Ca) meet these criteria but exhibit complex ecological patterning. Stable magnesium isotope ratios (d26Mg) also meet these criteria but a comprehensive understanding of its variability awaits new isotopic data. Here, 11 extant mammal species of known ecology from a single locality in equatorial Africa were sampled for tooth enamel and, together with vegetation and feces, analyzed for d26Mg, d13C, Sr/Ca, and Ba/Ca ratios. The results demonstrate that d26Mg incorporated in tooth enamel becomes heavier from strict herbivores to omnivores/ faunivores. Using data from experimentally raised sheep, we suggest that this 26Mg enrichment up the trophic chain is due to a 26Mg enrichment in muscle relative to bone. Notably, it is possible to distinguish omnivores from herbivores, using d26Mg coupled to Ba/Ca ratios. The potential effects of metabolic and dietary changes on the enamel d26Mg composition remain to be explored but, in the future, multiproxy approaches would permit a substantial refinement of dietary behaviors or enable accurate trophic reconstruction despite specimen-limited sampling, as is often the case for fossil assemblages.

stable isotopes | magnesium | carbon | equatorial mammals | paleoecology Reconstructing

van der Merwe 1978

Nikolaas J. van der Merwe & J. C. Vogel, *^{13}C Content of human collagen as a measure of prehistoric diet in woodland North America*. nature **276** (1978), 815–816.

Millard 2000

Andrew R. Millard, *An Evaluation of the Possible Use of Nitrogen Isotopes to Detect Milking in Cattle*. In: Geoff Bailey, Ruth Charles & Nick Winter (Hrsg.), *Human Ecodynamics, Proceedings of the Association for Environmental Archaeology conference 1998 held at the University of Newcastle upon Tyne*. (Oxford 2000), 134–140.

Millard 2010

Andrew R. Millard & Hannes Schroeder, *'True British sailors': a comment on the origin of the men of the Mary Rose*. Journal of Archaeological Science **37** (2010), 680–682.

Bell et al. (2009) have recently published an isotopic investigation of the origins of 18 men whose remains were found in the wreck of the Mary Rose, Henry VIII's warship, which sank in 1545. They conclude that a high proportion of the ship's crew were foreigners and that this may have contributed to confusion on board ship and the sinking of the vessel. We have re-evaluated the data of Bell et al. and conclude that only one of the 18 sailors demonstrably spent his childhood outside the British Isles.

Milner 2004

N. Milner, O. E. Craig, G. N. Bailey, K. Pedersen & S. H. Andersen, *Something fishy in the Neolithic? A re-evaluation of stable isotope analysis of Mesolithic and Neolithic coastal populations.* Antiquity **78** (2004), 9–22.

Change of diet in Northern Europe's Mesolithic – Neolithic transition: a new critique

The study of the proportions of stable isotopes of carbon and nitrogen which survive in ancient human and animal bones offers highly suggestive indications of ancient diets. Among the most remarkable results from such investigations is the dramatic change in diet which is thought to have occurred between the Mesolithic and the Neolithic when people turned from maritime to terrestrial food, from fish to meat and vegetables. The three contributions which follow challenge, modify, enhance or reflect on this model. In a pivotal critique of the evidence from Britain and Denmark, Milner et al. present a range of explanations for the signals of a maritime or terrestrial emphasis in diet and conclude that the change need not have been either rapid or total. Liden et al. show that, in southern Sweden, the preferences for fish over meat were related less to period or culture, but (reasonably enough) to location: fish-eaters live by the sea. Finally Robert Hedges takes up the question of partial marine diets and how to detect them, developing the idea that marine diets might give a fainter signal in people who were only getting small amounts of protein. Perhaps there were many such people in the new order of the Neolithic ...

Keywords: Northern Europe, Mesolithic, Neolithic, stable isotopes, diet

Minagawa 1984

Masao Minagawa & Eitaro Wada, *Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between $\delta^{15}N$ and animal age.* Geochimica et Cosmochimica Acta **48** (1984), 1135–1140.

The isotopic composition of nitrogen was measured in marine and fresh-water animals from the East China Sea, The Bering Sea, Lake Ashinoko and Usujiri intertidal zone. Primary producers showed average d15N versus atmospheric nitrogen of +5.0‰ (+3.4 to +7.5) in the Bering Sea and Lake Ashinoko, and +6.8‰ (+6.0 to +7.6) in Usujirintertidal zone. Blue green algae from the East China Sea show an average -0.55‰ (-0.8 to +1.2). All consumers, zooplankton, fish and bird exhibited stepwise enrichment of 15N with increasing trophic level. The 15N enrichment at a single feeding process ranged from +1.3 to +5.3 averaging +3.4 ± 1.1‰. This isotopic fractionation seems to be independent of habitat.

The effect of age in animals was obtained by analyzing two marine mussels. The soft tissue nitrogen showed +2.0‰ enrichment relative to that of primary producers, and the magnitude was almost constant with shell ages ranging from 0 to 8 years.

A similar 15N enrichment occurs in all Molluscs, Crustaceans, Insecta, Amphibia, Fish, Ave and Mammal species regardless of the difference in the form of excreted nitrogen and in laboratory cultured fish, brine shrimp and mice (+2.9 to +4.9 ‰). The excreted ammonia from guppy was sufficiently light to balance the concentration bf 15N to animal body.

Moore 2004

Peter D. Moore, *Isotopic biogeography.* Progress in Physical Geography **28** (2004), 145–151.

The development of biogeography as a science has involved the assimilation of both new concepts and new techniques. Such conceptual advances as evolution by natural selection and the movements of continents revolutionized the way in which biogeographers interpreted the spatial patterns of organisms. Similarly, new techniques for assembling data, from pollen analysis to molecular phylogeny, have opened up new routes of investigation, helping to answer some old questions and, in the process, generating many more. Biogeography, being very much an interdisciplinary science bravely carving out its own niche, has been very willing to draw upon the resources of its parent sciences, biology, geography and geology, and it is increasingly looking towards the discipline of chemistry for further research tools. One aspect of chemistry that is proving particularly helpful is the study of stable isotopes in the environment (Lajtha and Michener, 1994).

Several elements, including those that are most abundant in living organisms (such as carbon, oxygen and nitrogen) occur in different isotopic forms. Some isotopes are unstable and radioactive, and their decay has long been used as a means of dating rocks. They have also been exploited in the study of element movements through the biosphere, as in the case of the Chernobyl accident on 26 April 1986. Within two to three months the radioisotopes 134Cs and 137Cs were found to be enhanced in the bodies of the human residents of Glasgow, UK. It was traced to the supply of milk from cows that were in turn consuming contaminated herbage (Watson, 1986). The subsequent process of decay and dilution of these radionuclides has been studied in the fish of Swedish lakes (Sundbom et al., 2003), and this work displays that current levels of 137Cs are still ten times that of pre-Chernobyl times.

Other naturally occurring isotopes are more stable and it is these that are being used increasingly by biogeographers to trace the movements of certain elements, or the movements and activities of those organisms that contain these elements. Their value results from the fact that various biological processes, including photosynthesis and nitrogen fixation, involve enzymes that fractionate the isotopes found in nature and therefore leave a distinct isotopic signature in their products. Stable isotopes have been used in the study of climatic history, the evolution of the biosphere, the biogeochemical cycling of elements, the development and spread of different photosynthetic pathways and diets of animals in palaeoecosystems.

Müller 2003

Wolfgang Müller, Henry Fricke, Alex N. Halliday, Malcolm T. McCulloch & Jo-Anne Wartho, *Origin and Migration of the Alpine Iceman.* science **302** (2003), 862–866.

s302-0862-Supplement.pdf

The Alpine Iceman provides a unique window into the Neolithic-Copper Age of Europe. We compared the radiogenic (strontium and lead) and stable (oxygen and carbon) isotope composition of the Iceman's teeth and bones, as well as 40Ar/39Ar mica ages from his intestine, to local geology and hydrology, and we inferred his habitat and range from childhood to adult life. The Iceman's origin can be restricted to a few valleys within ≈60 kilometers south(east) of the discovery site. His migration during adulthood is indicated by contrasting isotopic compositions of enamel, bones, and intestinal content. This demonstrates that the Alpine valleys of central Europe were permanently inhabited during the terminal Neolithic.

Naito 2013

Yuichi I. Naito, Yoshito Chikaraishi, Naohiko Ohkouchi & Minoru Yoneda, *Evaluation of carnivory in inland Jomon hunter-gatherers*

based on nitrogen isotopic compositions of individual amino acids in bone collagen. Journal of Archaeological Science **40** (2013), 2913–2923.

Archaeological studies including stable carbon and nitrogen isotope analyses of bone collagen from human remains have suggested their heavy dependence on terrestrial foods during the Jomon period in the inland central region in Japan. However, it is not easy to quantitatively evaluate the extent of carnivory for archaeological human remains based on the bulk collagen chemistry, because of variable 15N-enrichment factor along the trophic step and background isotopic variations in ecosystems. In order to overcome these problems and more precisely evaluate diets of prehistoric humans who strongly adapted to terrestrial environment, in this study we applied nitrogen isotope analysis of individual amino acids in bone collagen to two inland human populations in the Jomon period. Our results suggest that the two populations were predominantly dependent on the C3-plant-based terrestrial ecosystem and consumed little aquatic resources. Furthermore, their mean trophic positions (2.7 for both cases) are closer to that of the fox (2.8–3.0) rather than those of pure herbivores (2.0–2.2), and show little change over time. These results are the first evidence that inland Jomon populations may have had more carnivorous diets than is traditionally considered.

Keywords: Amino acid | Nitrogen isotope | Ancient diet | Jomon | Trophic position

Naito 2016

Yuichi I. Naito et al., *Ecological niche of Neanderthals from Spy Cave revealed by nitrogen isotopes of individual amino acids in collagen*. Journal of Human Evolution **93** (2016), 82–90.

Yuichi I. Naito, Yoshito Chikaraishi, Dorothée G. Drucker, Naohiko Ohkouchi, Patrick Semal, Christoph Wißing & Hervé Bocherens

This study provides a refined view on the diet and ecological niche of Neanderthals. The traditional view is that Neanderthals obtained most of their dietary protein from terrestrial animals, especially from large herbivores that roamed the open landscapes. Evidence based on the conventional carbon and nitrogen isotopic composition of bulk collagen has supported this view, although recent findings based on plant remains in the tooth calculus, microwear analyses, and small game and marine animal remains from archaeological sites have raised some questions regarding this assumption. However, the lack of a protein source other than meat in the Neanderthal diet may be due to methodological difficulties in defining the isotopic composition of plants. Based on the nitrogen isotopic composition of glutamic acid and phenylalanine in collagen for Neanderthals from Spy Cave (Belgium), we show that i) there was an interindividual dietary heterogeneity even within one archaeological site that has not been evident in bulk collagen isotopic compositions, ii) they occupied an ecological niche different from those of hyenas, and iii) they could rely on plants for up to ≈20 % of their protein source. These results are consistent with the evidence found of plant consumption by the Spy Neanderthals, suggesting a broader subsistence strategy than previously considered.

Keywords: Neanderthal | Nitrogen isotope | Amino acid | Ecological niche | Subsistence strategy | Plant diet

Nehlich 2010

Olaf Nehlich, Dušan Borić, Sofija Stefanović & Michael P. Richards, *Sulphur isotope evidence for freshwater fish consumption: a case study from the Danube Gorges, SE Europe*. Journal of Archaeological Science **37** (2010), 1131–1139.

To explore the use of sulphur isotopes as an indicator of the consumption of freshwater fish, we undertook sulphur isotope analysis on bone collagen extracted from humans and animals from five archaeological sites from the Danube Gorges region dating from the Mesolithic to the middle Neolithic periods. The results show a difference in the sulphur isotope values between freshwater and terrestrial ecosystems of 8.7 ‰. To reconstruct human diets, bone collagen from 24 individuals was analysed for carbon, nitrogen and sulphur isotopic values. The nitrogen isotope ratios ranged from 10.3 to 16.5 ‰ and the carbon isotope ratios ranged from ≈20.8 to ≈18.3 ‰. Low nitrogen isotope values were found for individuals with low sulphur isotope ratios reflecting the low sulphur isotopic values of the terrestrial animals. The highest human nitrogen isotope values coincided with higher sulphur isotope ratios, which are related to the higher sulphur isotope values of the freshwater fish. Intermediate human sulphur isotopic ratios between these two extremes showed mixed diets of both terrestrial and freshwater resources.

Nitsch 2010

E. K. Nitsch, L. T. Humphrey & R. E. M. Hedges, *The effect of parity status on $\delta^{15}N$: looking for the "pregnancy effect" in 18th and 19th century London*. Journal of Archaeological Science **37** (2010), 3191–3199.

This study examined the effect of parity status on d15N using the well-characterised 18th and 19th century skeletal collection from the crypt of Christ Church, Spitalfields, London. We tested whether the cumulative effect of multiple pregnancies and breastfeeding could significantly reduce female d15N values compared to males. The results from stable isotope analysis of 92 adult ribs show that the population of Spitalfields had relatively little variation in diet, compared to contemporary urban populations, and had abundant animal and marine protein. We were able to rule out any effect attributable to socioeconomic status, date or age at death on the stable isotope ratios. There were no significant differences in d15N due to parity status, nor were there any differences between males and females. Models of collagen turnover rates in ribs suggest that the effect of d15N depletion due to pregnancy would be undetectable except in ideal circumstances, where bone of the optimal turnover period was sampled, and in cases where multiparous individuals died shortly after parturition.

Keywords: Stable isotopes; Carbon; Nitrogen; Palaeodiet; Pregnancy; Spitalfields; London; Parity

Nuklidkarte 1998

G. Pfennig, H. Klewe-Nebenius & W. Seelmann-Eggebert, *Karlsruher Nuklidkarte*. (Karlsruhe ^{6}1998).

Oelze 2011a

Vicky M. Oelze et al., *Exploring the contribution and significance of animal protein in the diet of bonobos by stable isotope ratio analysis of hair*. PNAS **108** (2011), 9792–9797.

pnas108-09792-Supplement.pdf

Vicky M. Oelze, Benjamin T. Fuller, Michael P. Richards, Barbara Fruth, Martin Surbeck, Jean-Jacques Hublin and Gottfried Hohmann

In primates, age, sex, and social status can strongly influence access to food resources. In Pan, these criteria are assumed to influence access to vertebrate meat. However, the significance of meat in terms of its role in the nutrition of Pan is still debated. Here we present a study using stable carbon and nitrogen isotope

ratios in hair samples from habituated, wild bonobos (Pan paniscus) to explore these issues. Over a period of 5 mo hair samples were collected from fresh bonobo nests at LuiKotale, Democratic Republic of Congo. Hair samples were assigned to known individuals and were of sufficient length to allow the evaluation of isotopic variation over several months. Samples of plant foods and sympatric fauna were also analyzed. The d13C and d15N results of the bonobo hair were remarkably homogeneous over time and for the group as a whole. There are no differences in diet between the sexes. Within the group of males, however, there was a positive correlation between dominance status and d15N. The isotopic data indicate that the contribution of fauna to bonobo diet is marginal and that plant food is the dietary protein source. In only some cases did elevated d15N hair values correlate with observed faunivory and not correspond to the d15N measured in the dominant plant foods. Given the large variation in hunting and meat eating of Pan across the African continent, the detection of seasonal changes in faunivory by elevated d15N values in sectioned ape hair is a promising approach.

feeding ecology | great apes

Oelze 2011b

Vicky M. Oelze, Angelina Siebert, Nicole Nicklisch, Harald Meller, Veit Dresely & Kurt W. Alt, *Early Neolithic diet and animal husbandry: stable isotope evidence from three Linearbandkeramik (LBK) sites in Central Germany.* Journal of Archaeological Science **38** (2011), 270–279.

The first appearance of the Neolithic Linearbandkeramik (LBK) in Central Germany occurred during the 6th millennium BC. However, though LBK sites are abundant in the German loess areas, there are only a few studies that reconstruct the diet of these first farmers using biochemical methods. Here we present the largest study undertaken to date on LBK material using stable isotope analysis of carbon and nitrogen to reconstruct human diet and animal husbandry strategies. We analyzed the bone collagen of 97 human individuals and 45 associated animals from the sites of Derenburg, Halberstadt and Karsdorf in the Middle Elbe-Saale region of Central Germany. Mean adult human values are -19.9 ± 0.4 ‰ for d13C and 8.7 ± 0.8 ‰ for d15N. The d13C values are typical for terrestrial, temperate European regions, whereas the d15N values fall within an expected range for farming societies with a mixed diet consisting of products from domestic animals and plants. The consumption of unfermented dairy products is unlikely as there is direct palaeogenetic evidence of lactose intolerance available for one of the sites. There are no clear indications for dietary differences in sex. Young children under three years of age are enriched in d15N due to breastfeeding indicating that weaning likely occurred around the age of three years. The fauna exhibit mean d13C values of -20.9 ± 0.8 ‰ and mean d15N values of 7.0 ± 0.9 ‰ respectively. Variation in the d13C and d15N in the domestic animals is probably caused by different livestock managements.

Keywords: Neolithic; Linearbandkeramik; Diet; Isotopes; Carbon; Nitrogen

Passey 2015

Benjamin H. Passey, *Biogeochemical tales told by isotope clumps.* science **348** (2015), 394–395.

Molecules with two or more heavy isotopes provide insights into diverse biological and geological phenomena.

The clumped isotope anomalies will help place much-needed constraints on biogeochemical sources, sinks, and budgets of O2 and CH4, perhaps even over

glacial-interglacial cycles from gases trapped in ice cores. Similar effects are possible in other biogenic gases like nitrous oxide and ethane.

Pearson 2015

Jessica A. Pearson, Amy Bogaard, Mike Charles, Simon W. Hillson, Clark Spencer Larsen, Nerissa Russell & Katheryn Twiss, *Stable carbon and nitrogen isotope analysis at Neolithic Çatalhöyük, Evidence for human and animal diet and their relationship to households*. Journal of Archaeological Science **57** (2015), 69–79.

The long-term excavations at Çatalhöyük, a Neolithic site in central Turkey, have uncovered over 100 houses, which have been associated with at least 400 human skeletons and one million recorded animal bones. This large assemblage has enabled an extensive programme of stable carbon and nitrogen isotope analysis, which was designed to explore animal hunting and herding practices and how human diet varied according to age, sex, burial practice, location and over time. The isotope values for sheep and cattle show how both were herded in a range of locations which consisted of pure C3 and also mixed C3/ C4 plant locations. We sampled animals from middens adjacent to the buildings where people were buried to provide house-by-house diet reconstruction. However, very few of the people buried in the houses demonstrate a clear dietary relationship to these associated middens. Similarly, people buried in the same house seem to have had different diets to one another. We argue that these data suggest diet at Neolithic Çatalhöyük was a carefully structured, long-lived and repetitious process and that houses may not have functioned as the simple domestic units that they are often assumed to be.

Keywords: Carbon isotopes | Nitrogen isotopes | Collagen | Diet | Çatalhöyük | Neolithic

Periodensystem 2002

Ekkehard Fluck & Klaus G. Heumann, *Periodensystem der Elemente*. (Weinheim ^{3}2002).

Petroutsa 2010

Eirini I. Petroutsa & Sotiris K. Manolis, *Reconstructing Late Bronze Age diet in mainland Greece using stable isotope analysis*. Journal of Archaeological Science **37** (2010), 614–620.

The Late Bronze Age is a period of great importance in prehistoric Greece, due to the rise of the Mycenaean and Minoan civilizations. Settlements, palatial complexes and cemeteries have been excavated whilst a plethora of .ndings among which wall paintings and artifacts provided a large amount of information regarding the period. In this paper we examine the sources of dietary protein of four populations, from mainland Greece, in light of documentary and archaeological evidence in an effort to identify dietary trends within and between groups that re.ect everyday behavior. These are being studied with the aid of biomolecular archaeology using stable isotope analysis in human and faunal remains. Isotopic data to date suggests a rather homogeneous diet mainly based on C3 plant and animal protein. There are no individuals with d13C and d15N values that could represent important marine protein intake, despite proximity to the Aegean Sea.

Phillips 2012

Donald L. Phillips, *Converting isotope values to diet composition, The use of mixing models*. Journal of Mammalogy **93** (2012), 342–352.

A common use of stable isotope analysis in mammalogy is to make inferences about diet from isotope values (typically d13C and d15N) measured in tissues and food sources of a consumer. Mathematical mixing models are used to estimate the proportional contributions of food sources to the isotopie composition of the tissues of a consumer, which reflect the assimilated diet. This paper reviews basic mixing models and how they work; additional refinements also are described that include addressing uncertainty, larger numbers of sources, combining sources, concentration effects, and Bayesian statistical frameworks. Information is provided on where to access software for the various models. Numerous examples are cited to show application of these models in the mammal research literature.

Keywords: diet | mixing model | stable isotopes

Poulsen 2010

Christopher J. Poulsen, Todd A. Ehlers & Nadja Insel, *Onset of Convective Rainfall During Gradual Late Miocene Rise of the Central Andes*. science **328** (2010), 490–493.

s328-0490-Supplement.pdf

A decrease in the ratio of 18O to 16O (d18O) of sedimentary carbonate from the Bolivian Altiplano has been interpreted to indicate rapid surface uplift of the late Miocene Andean plateau (AP). Here we report on paleoclimate simulations of Andean surface uplift with an atmospheric general circulation model (GCM) that tracks oxygen isotopes in vapor. The GCM predicts changes in atmospheric circulation and rainfall that influence AP isotopic source and amount effects. On eastern AP slopes, summer convective precipitation increases by up to 6 millimeters per day (>500 %) for plateau elevations that are greater than about 2000 meters. High precipitation rates enhance the isotope amount effect, leading to a decrease in precipitation d18O at high elevations and an increase in d18O lapse rate. Our results indicate that late Miocene d18O depletion reflects initiation and intensification of convective rainfall.

Price 1998

T. Douglas Price, Gisela Grupe & Peter Schröter, *Migration in the Bell Beaker period of central Europe*. Antiquity **72** (1998), 405–412.

Recent strontium isotope analysis of Beaker burials from Bavaria raises important new questions about prehistoric migrations in Europe.

Privat 2002

Karen L. Privat, Tamsin C. O'Connell & Michael P. Richards, *Stable Isotope Analysis of Human and Faunal Remains from the Anglo-Saxon Cemetery at Berinsfield, Oxfordshire: Dietary and Social Implications*. Journal of Archaeological Science **29** (2002), 779–790.

Stable carbon and nitrogen isotope values were obtained from human and faunal bones from the Early Anglo-Saxon cemetery site at Wally Corner, Berinsfield, Oxfordshire, U.K. These values were used to characterize the diet of the burial community as a whole and to analyse dietary patterns within sub-groups determined by sex, age, grave goods, and possible household arrangement. While dietary variability is observed in all sub-groups tested, we identify an apparent distinction between the average diets of individuals classified as "wealthy" and "intermediately wealthy" and those classified as "poor". A similar dietary di.erence indicates a status-based age di.erential between males under and over 30 years old, also reflected in the archaeological record. A notable absence of dietary di.erentiation was noted between males and females at Berinsfield, indicating that sex-

based societal classification did not significantly influence an individual's access to the various food sources available to the Berinsfield community. Conclusions drawn from these isotopic data are of use in adding to the picture of daily life and social structure in early Anglo-Saxon Britain.

Privat 2007

Karen L. Privat, Tamsin C. O'Connell & Robert E. M. Hedges, *The distinction between freshwater- and terrestrial-based diets: methodological concerns and archaeological applications of sulphur stable isotope analysis*. Journal of Archaeological Science **34** (2007), 1197–1204.

Sulphur isotopes in archaeological bone collagen are not routinely analysed in palaeodietary studies. Here we investigate the potential contribution that sulphur isotope analysis can provide toward the study of ancient human diet and economy, with particular emphasis on the distinction between freshwater and terrestrial consumers. For material from the Late Bronze Age site of Chicha in the south-western Eurasian forest-steppe, sulphur isotopes effectively separate freshwater and terrestrial animal food resources. The sulphur isotope data coupled with nitrogen isotope values from Chicha reflect a dietary reliance upon freshwater animal protein (fish) for the Late Bronze Age inhabitants. In contrast, sulphur isotope values for freshwater and terrestrial potential food species from the Eneolithic site of Bil'shivtsi in western Ukraine were indistinguishable, demonstrating that d34S values cannot always be relied upon to identify freshwater and terrestrial consumers. The data from this study support the adoption of d34S analysis as a standard component of palaeodietary studies; apart from its potential to distin-guish freshwater from terrestrial consumers, it can provide supplementary dietary information not evident from the carbon and nitrogen isotope data. In addition, certain indices are considered that may be used to assess the validity of sulphur isotope data, as currently exist for carbon and nitrogen. According to the analysis of modern collagen samples, N:S appears to be a broad indicator of collagen sulphur isotope quality. How-ever, more work needs to be done to establish an effective means by which highly-altered sulphur isotope values can be identified and thereby removed from consideration.

Keywords: Sulphur; Stable isotopes; Palaeodiet; Eurasia

Radosevich 1993

Stefan C. Radosevich, *The Six Deadly Sins of Trace Element Analysis: A Case of Wishful Thinking in Science*. In: Mary K. Sandford (Hrsg.), *Investigations of Ancient Human Tissue*, *Chemical Analyses in Anthropology*. Food and Nutrition in History and Anthropology 10 (Langhorne / Berlin 1993), 269–332.

Rawlings 2010

Tiffany A. Rawlings & Jonathan C. Driver, *Paleodiet of domestic turkey, Shields Pueblo (5MT3807), Colorado: isotopic analysis and its implications for care of a household domesticate*. Journal of Archaeological Science **37** (2010), 2433–2441.

Isotopic analysis of domestic turkey (Meleagris gallopavo) bones from Shields Pueblo, southwest Colorado, USA, suggests that these birds consumed a diet high in C4 plants. This contrasts with the diet of local herbivores, where much lower percentages of C4 plants were recorded. In view of the prevalence of maize (Zea mays) in the human diet of Ancestral Puebloan people, we suggest that turkeys

were fed food scraps and surplus maize, rather than being allowed to forage for themselves. This suggests that turkeys were carefully tended in the household. Analysis of specimens from other sites in the northern South-west shows that this pattern of turkey feeding characterizes all of the sampled horticultural communities.

Keywords: Carbon isotopes; Diet reconstruction; Fauna; Nitrogen isotopes; Southwest region; U.S.A

Reitsema 2013

L. J. Reitsema, T. Koz1owski & D. Makowiecki, *Human–environment interactions in medieval Poland, A perspective from the analysis of faunal stable isotope ratios.* Journal of Archaeological Science **40** (2013), 3636–3646.

Stable isotope analyses of faunal remains provide valuable information about human-environment interactions in the past, including insights into past animal husbandry and land management strategies. Here, we report stable carbon (d13C) and nitrogen (d15N) isotope values of collagen and carbonate from archaeological fauna from Kałdus, a medieval settlement in North-Central Poland, to better understand human-environment interactions during a period of increasing urbanism and marketization. Wild and domestic animals can be separated on the basis of their isotopic values. The mean d15N value for 12 domesticated animals is 7.6 ± 1.2‰ and for 5 wild animals is 4.3 ± 0.5‰ ($p = 0.002$). The mean collagen d13C value for domesticated animals is -20.6 ± 1.1‰ and for wild animals is -22.0 ± 0.5‰ ($p = 0.004$). The mean carbonate d13C value for domesticated animals is -13.14 ± 1.3‰ and for wild animals is -14.14 ± 0.9‰ ($p = 0.034$). The "canopy effect" and anthropogenic effects that alter stable isotope ratios of plants (manuring, swidden agriculture and ploughing) are discussed in relation to these differences. Fish are isotopically variable, which suggests broad-spectrum fishing strategies and/or trade, and increases our awareness of the difficulties in interpreting human paleodiet when freshwater fish were on the menu.

Keywords: Land management | Carbon | Nitrogen | Animal husbandry | Collagen | Carbonate | Fish | Zooarchaeology

Reynard 2008

L. M. Reynard & R. E. M. Hedges, *Stable hydrogen isotopes of bone collagen in palaeodietary and palaeoenvironmental reconstruction.* Journal of Archaeological Science **35** (2008), 1934–1942.

JArchSci35-1934-Supplement.pdf

The stable hydrogen isotope ratios (dD) of bone collagen in archaeological human and animal samples demonstrate a trophic level effect, with increasing dD from herbivores to omnivores to humans, in steps of 10-30‰. In addition the archaeological sites studied (Yarnton, Eton Rowing Lake, Danebury Environs – Suddern Farm, and Windmill Hill in the UK, Balatonszárszó in Hungary, and Huari in Peru) demonstrate geographical variation in dD. The detection of manuring in prehistory by comparison of d15N to dD values in humans and a local herbivore (cattle) is also considered. This work is the first to measure dD in a large number and range of archaeological samples, with several animal species and humans. It demonstrates unequivocally that dD is different between species in ancient material, increasing from herbivores to omnivores to carnivores.

Keywords: Hydrogen; Stable isotopes; Trophic level; Palaeoclimate; Palaeodiet; Bone; Collagen

Reynard 2010

L. M. Reynard, G. M. Henderson & R. E. M. Hedges, *Calcium isotope ratios in animal and human bone*. Geochimica et Cosmochimica Acta **74** (2010), 3735–3750.

GeoCosmo74-3735-Supplement.pdf

Calcium isotopes in tissues are thought to be influenced by an individual's diet, reflecting parameters such as trophic level and dairy consumption, but this has not been carefully assessed. We report the calcium isotope ratios (d44/42Ca) of modern and archaeological animal and human bone (n = 216). Modern sheep raised at the same location show 0.14 ± 0.08‰ higher d44/42Ca in females than in males, which we attribute to lactation by the ewes. In the archaeological bone samples the calcium isotope ratios of the herbivorous fauna vary by location. At a single site, the archaeological fauna do not show a trophic level effect. Humans have lower d44/42Ca than the mean site fauna by 0.22 ± 0.22‰, and the humans have a greater d44/42Ca range than the animals. No effect of sex or age on the calcium isotope ratios was found, and intra-individual skeletal d44/42Ca variability is negligible. We rule out dairy consumption as the main cause of the lower human d44/42Ca, based on results from sites pre-dating animal domestication and dairy availability, and suggest instead that individual physiology and calcium intake may be important in determining bone calcium isotope ratios.

Reynard 2011

L. M. Reynard, G. M. Henderson & R. E. M. Hedges, *Calcium isotopes in archaeological bones and their relationship to dairy consumption*. Journal of Archaeological Science **38** (2011), 657–664.

The calcium isotope ratios (d44/42Ca) of bones from humans and fauna from three archaeological sites, Taforalt, Abu Hureyra, and Danebury, are evaluated in order to assess whether calcium isotope ratios of bones can be used to detect dairy consumption by adult humans. At each site the fauna d44/42Ca is the same regardless of species, while the humans have lower d44/42Ca than the local animals by 0.24±0.41‰ (site means). However we cannot ascribe this difference to dairy consumption, given this humanefaunal difference also occurs in Epipalaeolithic and Mesolithic adult humans, where dairy consumption is unlikely. Rather, this difference appears to be a result of differences in metabolic processes or other aspects of diet between humans and fauna. Minimal isotopic change in sequential acid leaches of bone powders and consideration of the high calcium concentration in bone suggest that bone calcium isotope ratios are not substantially affected by diagenetic change.

Keywords: Calcium; Ca; Isotope; Bone; Dairy; Milk; Diet; Taforalt; Abu Hureyra; Danebury

Reynard 2015

Linda M. Reynard & Noreen Tuross, *The known, the unknown and the unknowable, Weaning times from archaeological bones using nitrogen isotope ratios*. Journal of Archaeological Science **53** (2015), 618–625.

JAS053-0618-Supplement.pdf

Empirical observations of d15N of bone collagen by age at death from 56 archaeological sites (n = 1560) document an increase over the adult mean at ages ≈0–2 years. These observations are generally consistent with a hypothesis that posits a difference in trophic level between the nursing infant and the mother; however, using these data to reconstruct weaning ages is problematic. The assumptions used to determine age of weaning are reviewed; uncertainty in the isotopic trophic

offsets, high scatter due to low sample numbers, errors in the age determination of infants, and how representative the samples are for the whole population are possible contributors to uncertainty in determining weaning times from archaeological bones. Other possible explanations for these age-related isotopic differences have generally not been considered in the archaeological literature. Factors bearing further investigation are the possibility of developmental (nondietary) differences in tissue isotopic composition, incorporation of non-protein nitrogen in milk and the effects of the gut microbiome.

Richards 1998

M. P. Richards, R. E. M. Hedges, T. I. Molleson & J. C. Vogel, *Stable Isotope Analysis Reveals Variations in Human Diet at the Poundbury Camp Cemetery Site*. Journal of Archaeological Science **25** (1998), 1247–1252.

Stable isotope analysis was undertaken on 48 individuals from Iron Age, Roman and Post-Roman periods of the Poundbury Camp Cemetery, Dorchester, England. Variations in diet, reflected by the stable isotope values, were observed between individuals from the different time periods. Differences in diet within the Late Roman period were particularly interesting, as we found that the isotope values could be related to burial type. We also found evidence of possible immigrants at Poundbury; individuals that may have come to the site from a warmer climate.

Richards 2000

Michael P. Richards, Paul B. Pettitt, Erik Trinkaus, Fred H. Smith, Maja Paunović, & Ivor Karavanić, *Neanderthal diet at Vindija and Neanderthal predation: The evidence from stable isotopes*. PNAS **97** (2000), 7663–7666.

Archeological analysis of faunal remains and of lithic and bone tools has suggested that hunting of medium to large mammals was a major element of Neanderthal subsistence. Plant foods are almost invisible in the archeological record, and it is impossible to estimate accurately their dietary importance. However, stable isotope (d13C and d15N) analysis of mammal bone collagen provides a direct measure of diet and has been applied to two Neanderthals and various faunal species from Vindija Cave, Croatia. The isotope evidence overwhelmingly points to the Neanderthals behaving as top-level carnivores, obtaining almost all of their dietary protein from animal sources. Earlier Neanderthals in France and Belgium have yielded similar results, and a pattern of European Neanderthal adaptation as carnivores is emerging. These data reinforce current taphonomic assessments of associated faunal elements and make it unlikely that the Neanderthals were acquiring animal protein principally through scavenging. Instead, these findings portray them as effective predators.

Richards 2001

Michael P. Richards, Paul B. Pettitt, Mary C. Stiner & Erik Trinkaus, *Stable isotope evidence for increasing dietary breadth in the European mid-Upper Paleolithic*. PNAS **98** (2001), 6528.

New carbon and nitrogen stable isotope values for human remains dating to the mid-Upper Paleolithic in Europe indicate significant amounts of aquatic (fish, mollusks, andyor birds) foods in some of their diets. Most of this evidence points to exploitation of inland freshwater aquatic resources in particular. By contrast, European Neandertal collagen carbon and nitrogen stable isotope values do not indicate significant use of inland aquatic foods but instead show that they obtained

the majority of their protein from terrestrial herbivores. In agreement with recent zooarcheological analyses, the isotope results indicate shifts toward a more broad-spectrum subsistence economy in inland Europe by the mid-Upper Paleolithic period, probably associated with significant population increases.

Richards 2002

M. P. Richards, S. Mays & B. T. Fuller, *Stable Carbon and Nitrogen Isotope Values of Bone and Teeth Reflect Weaning Age at the Medieval Wharram Percy Site, Yorkshire, UK*. American Journal of Physical Anthropology **119** (2002), 205–210.

We report on the measurements of carbon and nitrogen stable isotopes of both bone and teeth from a single site and population (Medieval Wharram Percy), undertaken to explore variations due to weaning in a past population. There have been a number of recent studies of weaning using d15N values of ribs, and we indicate a number of assumptions that must be met before the results of such studies can be correctly interpreted. We found that rib collagen d15N values decrease to adult levels after age 2 years, indicating that weaning occurred at or before this age. Rib collagen d13C values are also more enriched than adult d13C values before age 2 years, and we argue that this is due to the so-called k-arnivoreëffect in d13C. We measured teeth and rib d15N values from the same individuals and found that for individuals up to age 11 years, tooth dentine d15N is higher than adult rib d15N values, indicating that the dentine was formed during breast-feeding and that there was almost no turnover of dentine since. We observed some decrease in d13C and d15N rib values, compared to adult rib and teeth values, for the few years after weaning that may relate to a theoretically predicted physiological nitrogen imbalance during this period of rapid growth, but this is more likely due to a childhood diet (up to age 9) which was isotopically different from later diet, possibly consisting of a greater proportion of plant foods.

Richards 2003a

Michael P. Richards, Rick J. Schulting & Robert E. M. Hedges, *Sharp shift in diet at onset of Neolithic*. nature **425** (2003), 366.

Richards 2003b

Mike P. Richards, *Explaining the dietary isotope evidence for the rapid adoption of the Neolithic in Britain*. In: Mike Parker Pearson (Hrsg.), *Food, Culture and Identity in the Neolothic and Early Bronze Age*. BAR International Series 1117 (Oxford 2003), 31–36.

Richards 2009

Michael P. Richards & Erik Trinkaus, *Isotopic evidence for the diets of European Neanderthals and early modern humans*. PNAS **106** (2009), 16034–16039.

pnas106-16034-Supplement.pdf

We report here on the direct isotopic evidence for Neanderthal and early modern human diets in Europe. Isotopic methods indicate the sources of dietary protein over many years of life, and show that Neanderthals had a similar diet through time (≈120,000 to≈37,000 cal BP) and in different regions of Europe. The isotopic evidence indicates that in all cases Neanderthals were top-level carnivores and obtained all, or most, of their dietary protein from large herbivores. In contrast, early modern humans (≈40,000 to ≈27,000 cal BP) exhibited a wider range of

isotopic values, and a number of individuals had evidence for the consumption of aquatic (marine and freshwater) resources. This pattern includes Oase 1, the oldest directly dated modern human in Europe (≈40,000 cal BP) with the highest nitrogen isotope value of all of the humans studied, likely because of freshwater fish consumption. As Oase 1 was close in time to the last Neanderthals, these data may indicate a significant dietary shift associated with the changing population dynamics of modern human emergence in Europe.

Richards 2015

M. P. Richards, I. Karavanić, P. Pettitt & P. Miracle, *Isotope and faunal evidence for high levels of freshwater fish consumption by Late Glacial humans at the Late Upper Palaeolithic site of Šandalja II, Istria, Croatia*. Journal of Archaeological Science **61** (2015), 204–212.

Here we report on isotope and faunal evidence for intensive use of freshwater resources by Late Upper Palaeolithic humans from the .Sandalja II site in Croatia. Carbon and nitrogen bone collagen isotopic analysis of humans and fauna from the site indicate that the main protein source in human diets at this time was freshwater fish, which is in contrast to the vertebrate remains that show a high abundance of large terrestrial herbivores from the Late Upper Palaeolithic levels at the site. These data add to the growing body of research that shows an increasing intensification in the use of aquatic resources in Europe towards the end of the Pleistocene.

Keywords: Late Upper Palaeolithic | Palaeodiet | Isotopes | Freshwater fish

Rutgers 2009

L. V. Rutgers, M. van Strydonck, M. Boudin & C. van der Linde, *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** (2009), 1127–1134.

This study reports on the first attempt that determines the diet of a small but conceivably representative section of Rome's early Christian community by means of d13C and d15N measurements on collagen extracted from twenty-two samples of human bone. Samples derive from the Liberian Region in the catacombs of St. Callixtus on the Appian Way - an area that has been radiocarbon dated to the period from the mid-3rd through early 5th century AD. Comparing our results to those produced for several other sites, we argue that this population's typical diet included freshwater fish. We also briefly discuss breastfeeding and the freshwater reservoir effect, to then explore the dietary, art historical, and possible sociological ramifications of our results.

Salazar-García 2014

D. C. Salazar-García, M. P. Richards, O. Nehlich & A. G. Henry, *Dental calculus is not equivalent to bone collagen for isotope analysis, A comparison between carbon and nitrogen stable isotope analysis from same individuals*. Journal of Archaeological Science **47** (2014), 70–77.

JAS047-0070-Supplement.pdf

A comparison between carbon and nitrogen stable isotope analysis of bulk dental calculus, bone and dentine collagen from same individuals from the Medieval site of El Raval (Alicante, Spain)

Palaeodietary reconstruction using the carbon and nitrogen isotope values of bone and dentine collagen is a well-established method and the biochemical processes involved are well known. Researchers have recently explored using bulk

samples of dental calculus as a substitute for bone and dentine collagen in dietary analyses, because calculus can be sampled without causing damage to the teeth, and may be useful in situations where more destructive analyses are not possible, or where collagen is poorly preserved. Several questions remain about the use of bulk calculus as a source of carbon and nitrogen isotope data, however. It is not yet clear how much of an individual's life span dental calculus represents, what portions of the diet it records, and how diagenesis effects the carbon and nitrogen isotope values of this material. Most importantly, there have been no comparative studies of collagen and calculus isotope values, which are necessary to establish the value of bulk calculus as a source of accurate isotope values. Here we report the comparison of carbon and nitrogen stable isotope analyses of bulk calculus to those from bone and dentine collagen. These analyses have been performed on individuals from the El Raval Mudéjar Medieval Cemetery (Eastern Iberia, 15th century A.D.). Although calculus isotope values may be broadly similar to expected values at the population level, we report here no correlation between collagen and bulk dental calculus values at the individual level. As a result, we recommend that carbon and nitrogen analysis on bulk dental calculus should only be used as a last resource archaeological dietary marker, if at all.

Keywords: Stable isotopes | Collagen | Dental calculus | Diet | Medieval period

Sandias 2015

Michela Sandias & Gundula Müldner, *Diet and herding strategies in a changing environment, Stable isotope analysis of Bronze Age and Late Antique skeletal remains from Ya'amūn, Jordan.* Journal of Archaeological Science **63** (2015), 24–32.

JAS063-0024-Supplement.docx

Carbon and nitrogen stable isotope ratios of 45 human and 23 faunal bone collagen samples were measured to study human diet and the management of domestic herbivores in past Jordan, contrasting skeletal remains from the Middle and Late Bronze Age and the Late Roman and Byzantine periods from the site of Ya'amun near Irbid. The isotope data demonstrate that the management of the sheep and goats changed over time, with the earlier animals consuming more plants from semi-arid habitats, possibly because of transhumant herding strategies. The isotope data for fish presented here are the first from archaeological contexts from the Southern Levant. Although fish of diverse provenance was available at the site, human diet was predominately based on terrestrial resources and there was little dietary variability within each time-period. Isotopic variation between humans from different time-periods can mostly be explained by 'baseline shifts' in the available food sources; however, it is suggested that legumes may have played a more significant role in Middle and Late Bronze Age diet than later on.

Keywords: Carbon and nitrogen isotopes | Bone collagen | Bronze Age | Roman period | Byzantine period | Fish

Schoeller 1999

Dale A. Schoeller, *Isotope Fractionation: Why Aren't We What We Eat?* Journal of Archaeological Science **26** (1999), 667–673.

The isotopic composition of an element records information about its history. Given a fossil, it is possible to analyse the isotopic composition of the elements in the fossil and to use this to reconstruct the diet that the animal consumed. The process of dietary reconstruction, however, is far from simple. Biological systems are quite complex and can themselves introduce isotopic fractionations that may distort the dietary information. The aim of this paper is to review the concepts of isotope fractionation under steady-state conditions to provide a framework for

discussion of dietary reconstruction. Among the elements of interest for dietary reconstruction, nitrogen bears a distinct role. This is because nitrogen is almost unique to protein. A secondary aim of this paper is then to review nitrogen metabolism. The final aim is to combine these in postulating a simple isotopic model of nitrogen metabolism.

SCHOENINGER 1983

Margaret J. Schoeninger, Michael J. DeNiro & Henrik Tauber, *Stable Nitrogen Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet*. science **220** (1983), 1381–1383.

The dl5N values of bone collagen from Eskimos and from Northwest Coast Indians dependent on salmon fishing are about 10 per mil more positive than those from agriculturalists in historic times. Among prehistoric humans, two groups dependent on marinefood sources show bone collagen d15N values that are 4 to 6 per mil more positive than those from two agricultural groups. The nitrogen isotope ratios of bone collagen from prehistoric inhabitants of the Bahamas are anomalously low for reasons that relate to the biogeochemical cycle of nitrogen in coral reefs.

SCHOENINGER 1984

Margaret J. Schoeninger & Michael J. Deniro, *Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals*. Geochimica et Cosmochimica Acta **48** (1984), 625–639.

The stable nitrogen and carbon isotope ratios of bone collagen prepared from more than 100 animals representing 66 species of birds, fish, and mammals are presented. The d15N values of bone collagen from animals that fed exclusively in the marine environment are, on average, 9‰ more positive than those from animals that fed exclusively in the terrestrial environment; ranges for the two groups overlap by less than 1‰. Bone collagen d15N values also serve to separate marine fish from the small number of freshwater fish we analyzed. The bone collagen d15N values of birds and fish that spent part of their life cycles feeding in the marine environment and part in the freshwater environment are intermediate between those of animals that fed exclusively in one or the other system. Further, animals that fed at successive trophic levels in the marine and terrestrial environment are separated, on average, by a 3‰ difference in the d15N values of their bone collagen. Specifically, carnivorous and herbivorous terrestrial animals have mean d15N values for bone collagen of +8.0 and +5.3 ‰ respectively. Among marine animals, those that fed on fish have a mean d15N value for bone collagen of + 16.5 ‰ whereas those that fed on invertebrates have a mean d15N value of +13.3 ‰. These results support previous suggestions of a 3 ‰ enrichment in d15N values at each successively higher trophic level. In contrast to the results for d15N values, the ranges of bone collagen d13C values from marine and terrestrial feeders overlap to a great extent. Additionally, bone collagen d13C values do not reflect the trophic levels at which the animals fed. These results indicate that bone collagen d15N values will be useful in determining relative dependence on marine and terrestrial food sources and in investigating trophic level relationships among different animal species within an ecosystem. This approach should be applicable to animals represented by prehistoric or fossilized bone in which collagen is preserved.

SCHURR 1998

Mark R. Schurr, *Using Stable Nitrogen-Isotopes to Study Weaning Behavior in past Populations*. World Archaeology **30** (1998), 327–342.

Several different methods have been used to explore weaning behavior in past populations, including demographic profiles, non-specific osteological indicators of stress, and bone chemistry studies. Stable nitrogen-isotope ratios of prehistoric bone proteins provide an especially useful method for reconstructing the weaning patterns of archaeological populations. A demographic measure of fertility (the D30+/D5+ ratio) is compared with age-related changes in stable nitrogen-isotope ratios for human burials from one historic cemetery and two prehistoric ones. The stable nitrogen-isotope ratios show that each population had a characteristic and distinctive combination of weaning time and rate, and that neither the timing nor tempo of weaning was clearly correlated with the demographic measure of fertility. These results demonstrate the feasibility of using stable nitrogenisotope ratios to compare weaning patterns and fertility in past populations. This example also shows that the relationship between fertility and weaning behavior is complex.

Schwarcz 1991

Henry P. Schwarcz, *Some Theoretical Aspects of Isotope Paleodiet Studies*. Journal of Archaeological Science **18** (1991), 261–275.

The introduction of stable isotope analysis (carbon, nitrogen, hydrogen, sulphur) of bones and food residues allows anthropologists to define more precisely the actual consumption patterns ofextinct populations. However, this requires that: (a) we know the ranges of compositions of possible foods; (b) that there be isotopic variability in these foods (although some information about trophic-levels can be obtained for consumers of isotopically monotonous foods; (c) that isotopic offsets (fractionations) between diet and sample (e.g. collagen) are known; and (d) that samples are well-preserved. We can determine the dietary proportions of N+1 foods if isotope ratios are measured for N elements and if no three foods are co-linear in δ-

space. Studies of ancient human populations from North and Central America are used to show that: (a) variation in diet within a single time plane for a given cultureïs very limited except possibly where status differences occur; (b) variation in diet through space and time can be easily recognized and may in some cases be related to independently inferrable historical or environmental factors.

Schwarcz 1999

Henry P. Schwarcz, Tosha L. Dupras & Scott I. Fairgrieve, *^{15}N Enrichment in the Sahara: In Search of a Global Relationship*. Journal of Archaeological Science **26** (1999), 629–636.

We have analysed human and animal collagen samples from three geographically and temporally distinct cemeteries at the Dakhleh Oasis, Egypt. All sites display strikingly high average values of d15N: Kellis 1 (Late Ptolemaic-Early Roman period) 18.0‰; Kellis 2 (Romano-Christian period) 18.0‰, and ‘ein Tirghi (Roman period) 17.0‰. Rainfall at Dakhleh is essentially zero. The d15N values for humans and animals lie on the respective quasi-linear relationship between rainfall and d15N found by Heaton et al. (1986). Data from Dakhleh and other sites suggest that a single linear trend describes the rainfall-d15N relationship in a wide range of sites. This correlation is believed to be due to a combination of two effects: excretion of excess 15N-depleted urea in order to increase osmolality of urine (Ambrose & DeNiro, 1986a, b) and 15N-enrichment in arid-region plants, as a result of 15N-enrichment in soils. Higher d15N values in human consumers were acquired through consumption of animal-derived protein. High d15N in desert soils may be caused by volatilization of isotopically light ammonia formed during bacterial activity, an effect which increases near to the soil surface.

Sealy 1985

Judith C. Sealy & Nikolaas J. van der Merwe, *Isotope assessment of Holocene human diets in the southwestern Cape, South Africa*. nature **315** (1985), 138–140.

Models of seasonal mobility to exploit seasonally abundant food sources have been proposed for prehistoric hunter-gatherers in many parts of the world1-3. Some such hypotheses involve fundamental and insufficiently tested assumptions about the nature of both hunter-gatherer societies and the archaeological evidence that they leave. The present study is an independent test of such a hypothesis proposed for the southwestern Cape of South Africa. In this strongly ecologically differentiated area there are four distinct ecological zones that would have offered four different sets of resources to prehistoric people. Obvious modern seasonal fluctuations in these resources, plus a considerable amount of archaeological evidence, led to the suggestion that prehistoric hunter-gatherers moved in a regular seasonal cycle across the zones4,5; this would have allowed them to make maximum use of temporarily plentiful plant and animal foods in some areas, while avoiding lean periods in others. However, as reported here, direct measurements of food intake, as reflected in the stable carbon isotope ratios of archaeological human skeletons, reveal that this was not the case. The implications of this study extend beyond the relevance to local archaeology to more general questioning of the ways in which archaeological data should be used to generate hypotheses.

Sealy 2014

Judith Sealy, Malia Johnson, Michael Richards & Olaf Nehlich, *Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis, Comparing whole bone demineralization with gelatinization and ultrafiltration*. Journal of Archaeological Science **47** (2014), 64–69.

We compare two methods of isolating bone collagen for stable carbon and nitrogen isotope analysis. The older method (as practised at the University of Cape Town) demineralizes bone 'chunks', while the newer method (as practised at the Max Planck Institute for Evolutionary Anthropology in Leipzig) involves demineralization, gelatinization and ultra-filtration to select only higher molecular weight protein fragments for isotopic analysis. The latter method was developed for problematic (i.e. poorly-preserved) samples and while it is more rigorous, it is also significantly more expensive and more labor-intensive. Our aim is to find out whether there is any difference between the d13C and d15N of bone collagen isolated from relatively well-preserved bones using the two methods. Our sample set consists of 5 modern and 47 archaeological animal and human bones from the southern and western parts of South Africa. Archaeological specimens range in age from a few hundred to approximately six thousand years old. Collagenwas extracted, its quality assessed using %C, %N and C:N, and d13C and d15N values measured independently in both laboratories. There are no statistically significant differences between the sets of d13C and d15N values from the two laboratories. For relatively well-preserved bones, the 'chunk' method of collagen preparation continues to be an acceptable alternative to more sophisticated collagen extraction protocols for C and N isotope analysis.

Keywords: Palaeodiet | Stable isotope | Carbon | Nitrogen | Collagen extraction method

Shackleton 1974

N. J. Shackleton, *Attainment of isotopic equilibrium between ocean wa-*

ter and the benthonic foraminifera genus Uvigerina, Isotopic changes in the ocean during the last glacial. Colloques Internationaux du C.N.R.S. **219** (1974), 203–209.

It is shown that even when the oxygen isotopic composition of foraminiferal tests is examined using non-standard analytical methods, the measurements may be expressed in terms of the PDB standard. In order to investigate departure from isotopic equilibrium, comparison must be made not with an empirical relationship determined for molluscs in a limited temperature range, but with a relationship based on inorganic calcite precipitation in the temperature range of interest. By such a comparison it is found that Uvigerina deposits its test at or near isotopic equilibrium in the temperature range 0.8 °C to 7 °C. Values for the isotopic composition of tests of this genus which lived during the last glacial can only be explained in terms of a change in the mean oxygen isotopic composition of the oceans which probably exceeded 1 ‰ for about 20 000 years, and exceeded 0.5 ‰ for about 70 000 years.

Sherwood 2011

Owen A. Sherwood, Moritz F. Lehmann, Carsten J. Schubert, David B. Scott & Matthew D. McCarthy, *Nutrient regime shift in the western North Atlantic indicated by compound-specific $\delta^{15}N$ of deep-sea gorgonian corals.* PNAS **108** (2011), 1011–1015.

pnas108-01011-Supplement.pdf

Despite the importance of the nitrogen (N) cycle on marine productivity, little is known about variability in N sources and cycling in the ocean in relation to natural and anthropogenic climate change. Beyond the last few decades of scientific observation, knowledge depends largely on proxy records derived from nitrogen stable isotopes (d15N) preserved in sediments and other bioarchives. Traditional bulk d15N measurements, however, represent the combined influence of N source and subsequent trophic transfers, often confounding environmental interpretation. Recently, compound-specific analysis of individual amino acids (d15N-AA) has been shown as a means to deconvolve trophic level versus N source effects on the d15N variability of bulk organic matter. Here, we demonstrate the first use of d15N-AA in a paleoceanographic study, through analysis of annually secreted growth rings preserved in the organic endoskeletons of deep-sea gorgonian corals. In the Northwest Atlantic off Nova Scotia, coral d15N is correlated with increasing presence of subtropical versus subpolar slope waters over the twentieth century. By using the new d15N-AA approach to control for variable trophic processing, we are able to interpret coral bulk d15N values as a proxy for nitrate source and, hence, slope water source partitioning. We conclude that the persistence of the warm, nutrient-rich regime since the early 1970s is largely unique in the context of the last approximately 1,800 yr. This evidence suggests that nutrient variability in this region is coordinated with recent changes in global climate and underscores the broad potential of d15N-AA for paleoceanographic studies of the marine N cycle.

compound-specific isotope analysis | deep-sea corals | nitrogen cycle | North Atlantic Oscillation | stable N isotopes

Sjögren 2013

K.-G. Sjögren & T. Douglas Price, *A complex Neolithic economy, Isotope evidence for the circulation of cattle and sheep in the TRB of western Sweden.* Journal of Archaeological Science **40** (2013), 690–704.

We report here the results of strontium, oxygen and carbon isotope analysis of teeth from domestic animals at two Neolithic settlement sites in Falbygden,

Sweden. The main result is the high mobility of domestic animals, particularly of cattle but also of sheep. More than half of the analysed cattle teeth show strontium isotope signals indicating that they were raised in an area of Precambrian rock, outside the sedimentary Cambro-Silurian rocks found in Falbygden. This is in marked contrast to pigs, which were mostly local to Falbygden. The mobility of cattle is much higher than that of humans, for which the frequency of immigrants is about 25 %.

We suggest that West Sweden in the Neolithic was not a local but a regional economy, where not only prestige items and humans were circulating but also basic components of subsistence. Such a regional economy would have drawn together the megalithic-building population in Falbygden with its nonmegalithic neighbours. In addition, it seems that cattle had a particular place in the Neolithic symbolic system, beyond their economic and practical value.

Keywords: Neolithic | Sweden | Falbygden | Economy | Mobility | Cattle | Strontium isotopes | Oxygen isotopes | Carbon isotopes

Sjögren 2016

Karl-Göran Sjögren, T. Douglas Price & Kristian Kristiansen, *Diet and Mobility in the Corded Ware of Central Europe*. PLoS ONE **11** (2016), e155083. DOI:10.1371/journal.pone.0155083.

pone11-e0155083-Supplement1.docx, pone11-e0155083-Supplement2.pdf

Isotopic investigations of two cemetery populations from the Corded Ware Culture in southern Germany reveal new information on the dating of these graves, human diet during this period, and individual mobility. Corded Ware Culture was present across much of temperate Europe ca. 2800–2200 cal. BC and is represented by distinctive artifacts and burial practices. Corded Ware was strongly influenced by the Yamnaya Culture that arose in the steppes of eastern Europe and western Eurasia after 3000 BC, as indicated by recent aDNA research. However, the development of CW on different chronological and spatial scales has to be evaluated. Examination of the CW burials from southern Germany supports an argument for substantial human mobility in this period. Several burials from gravefields and larger samples from two large cemeteries at Lauda-Königshofen "Wöllerspfad" and at Bergheinfeld "Hühnerberg" contributed the human remains for our study of bone and tooth enamel from the Corded Ware Culture. Our results suggest that Corded Ware groups in this region at least were subsisting on a mix of plant and animal foods and were highly mobile, especially the women. We interpret this as indicating a pattern of female exogamy, involving different groups with differing economic strategies.

Somerville 2013

Andrew D. Somerville, Mikael Fauvelle & Andrew W. Froehle, *Applying new approaches to modeling diet and status: Isotopic evidence for commoner resiliency and elite variability in the Classic Maya lowlands*. Journal of Archaeological Science **40** (2013), 1539–1553.

Classic Maya states were characterized by a high degree of socioeconomic stratification. This paper investigates the degree to which status, as defined by grave goods and tomb construction, influenced dietary patterns of elites and commoners throughout the Classic Period (200–900/1000 AD) of the southern lowlands. We compile a database (N = 102) of previously-published stable isotope ratios (d13C collagen, d13C apatite, and d15N collagen) from Maya bone mineral and collagen, and interrogate these data through two new isotopic modeling techniques: a simple carbon isotope model (Kellner and Schoeninger, 2007; Froehle et al., 2010) and

a multivariate isotope model (Froehle et al., 2012). We find that Maya elite diet varied significantly through time in terms of maize consumption and trophic level, while commoner diet remained remarkably stable. These findings provide new information relevant to studies of ancient Maya class structure and to studies of subsistence strategies of the pre-Columbian Americas.

Keywords: Apatite | Collagen | Maya | Bioarchaeology | Simple carbon isotope model | Multivariate isotope model | Paleodiet

Sponheimer 1999

Matt Sponheimer & Julia A. Lee-Thorp, *Isotopic Evidence for the Diet of an Early Hominid, Australopithecus africanus*. science **283** (1999), 368–370.

Current consensus holds that the 3-million-year-old hominid Australopithecus africanus subsisted on fruits and leaves, much as the modern chimpanzee does. Stable carbon isotope analysis of A. africanus from Makapansgat Limeworks, South Africa, demonstrates that this early hominid ate not only fruits and leaves but also large quantities of carbon-13 enriched foods such as grasses and sedges or animals that ate these plants, or both. The results suggest that early hominids regularly exploited relatively open environments such as woodlands or grasslands for food. They may also suggest that hominids consumed highquality animal foods before the development of stone tools and the origin of the genus Homo.

Sponheimer 2003

M. Sponheimer et al., *An experimental study of nitrogen flux in llamas: is ^{14}N preferentially excreted?* Journal of Archaeological Science **30** (2003), 1649–1655.

M. Sponheimer, T.F. Robinson, B.L. Roeder, B.H. Passey, L.K. Ayliffe, T.E. Cerling, M.D. Dearing & J.R. Ehleringer

Nitrogen isotope analysis is now commonly used to investigate the diets, and to a lesser extent, the environments of ancient populations. These studies assume that mammals are predictably enriched in 15N over their food, and concomitantly, that 15N becomes increasingly concentrated as one moves up the food chain. The literature commonly states that this 15N-enrichment of mammalian tissues is due to preferential excretion of light nitrogen (14N), but there are few data to support this assertion. To address the gap, we conducted two nitrogen flux trials in which four llamas (Lama glama) were fed high- and low-protein diets. The ratios of fecal nitrogen loss to urinary nitrogen loss were 0.30 and 0.88 on the high- and low-protein diets respectively. Feces were enriched in 15N by approximately +3‰ on both diets, whereas urinary nitrogen was depleted in 15N (-2.1‰) on the low-protein diet, but not significantly different from intake d15N on the high-protein diet. Most importantly, there was no statistically significant difference between dietary and total excreta d15N on either diet. Given these data and theoretical considerations, we argue that the nitrogen influx and eflux of adult mammals at steady state should be isotopically commensurate. However, during growth, diet change, thermal or nutritional stress, animals may not be at steady state and fractionation between intake and excreta d15N may occur.

Keywords: Nitrogen isotopes; Nitrogen balance; Fractionation; Excreta; Paleodiet; Paleoenvironment; Llama

Sponheimer 2003a

M. Sponheimer, T. Robinson, L. Ayliffe, B. Roeder, J. Hammer, B. Passey, A. West, T. Cerling, D. Dearing & J. Ehleringer, *Nitrogen Iso-*

topes in Mammalian Herbivores: Hair $\delta^{15}N$ Values from a Controlled Feeding Study. Int. J. Osteoarchaeology **13** (2003), 80–87.

Nitrogen isotope analysis is a common technique for investigating dietary behaviour in modern and archaeological populations. One of its primary uses is to provide trophic level information. This application is possible because of a 3‰ enrichment in 15N along each step in the food chain, resulting in carnivores having higher d15N values than herbivores, which in turn have higher d15N values than plants. Much variation has also been observed within a trophic level, although the reasons for this are poorly understood. Here we present the results of a controlled feeding study designed to test the effects of gut anatomy and dietary protein levels on hair d15N values within a trophic level. The data reveal that mammalian herbivores eating identical diets can have hair d15N values that differ by as much as 3.6‰. This is particularly striking as it suggests that interspecific physiological differences can lead to larger shifts in d15N values than a shift in trophic level. We also found that diet-hair fractionation was 2.3‰ greater when herbivores were fed high-protein (19they were fed low-protein (9mammalian herbivores are 15N-depleted urine and 15N-enriched faeces. We reason that an increase in the ratio of urinary to faecal nitrogen efflux leads to greater diet-hair fractionation on the high-protein diet.

Sponheimer 2003b

Matt Sponheimer, Todd Robinson, Linda Ayliffe, Ben Passey, Beverly Roeder, Lisa Shipley, Elvia Lopez, Thure Cerling, Denise De, *An experimental study of carbon-isotope fractionation between diet, hair, and feces of mammalian herbivores*. Canadian Journal of Zoology **81** (2003), 871–876.

Abstract: The carbon-isotope composition of hair and feces offers a glimpse into the diets of mammalian herbivores. It is particularly useful for determining the relative consumption of browse and graze in tropical environments, as these foods have strongly divergent carbon-

isotope compositions. Fecal d13C values reflect the last few days consumption, whereas hair provides longer term dietary information. Previous studies have shown, however, that some fractionation occurs between dietary d13C values and those of hair and faces. Accurate dietary reconstruction requires an understanding of these fractionations, but few conlrolled-feeding studies have been undertaken to investigate these fractionations in any mammalian taxa, fewer still in large mammalian herbivores. Here, we present data from the first study of carbon-isotope fractionation between diet, hair, and feces in multiple herbivore taxa. All taxa were fed pure alfalfa (Medictigo saliva) diets for a minimum period of 6 months, at which point recently grown hair was shaved and analyzed for carbon isotopes. The mean observed diet-hair fractionation was +3.2‰, with a range of +2.7 to +3.5‰. We also examined diet-feces fractionation for herbivores on alfalfa and bermudagrass (Cyiwdon dacryton) feeds. The mean diet-feces fractionation for both diets was -0.8‰, with less fractionation for alfalfa (-0.6‰) than bennudagrass (- l.0‰). Fecal carbon turnover also varies greatly between taxa. When diets were switched, horse (Eqtius caballus) feces reflected the new diet within 60 h, but alpaca (Lama pacos) Feces did not equilibrate with the new diet for nearly 200 h. Thus, fecal carbon isotopes provide far greater dietary resolution for hindgut-fermenting horses than foregut-

fermenting alpacas.

Sponheimer 2006

Matt Sponheimer, Benjamin H. Passey, Darryl J. de Ruiter, Debbie

Guatelli-Steinberg, Thure E. Cerling & Julia A. Lee-Thorp, *Isotopic Evidence for Dietary Variability in the Early Hominin Paranthropus robustus*. science **314** (2006), 980–982.

s314-0980-Supplement.pdf

Traditional methods of dietary reconstruction do not allow the investigation of dietary variability within the lifetimes of individual hominins. However, laser ablation stable isotope analysis reveals that the d13C values of Paranthropus robustus individuals often changed seasonally and interannually. These data suggest that Paranthropus was not a dietary specialist and that by about 1.8 million years ago, savanna-based foods such as grasses or sedges or animals eating these foods made up an important but highly variable part of its diet.

Stevens 2006

Rhiannon E. Stevens, Adrian M. Lister & Robert E. M. Hedges, *Predicting diet, trophic level and palaeoecology from bone stable isotope analysis, A comparative study of five red deer populations*. Oecologia **149** (2006), 12–21.

C and N stable isotope ratios of red deer (Cervus elaphus) bone collagen (154 individuals) from five modern populations occupying geographically different habitats are reported. No significant difference was observed between deer occupying forested and non forested environments subject to similar climatic condi tions suggesting a simple "canopy effect" is not observed. Mean population 613C is negatively correlated with tem perature whereas mean population 615N is positively cor related with temperature. A weak but significant positive correlation was observed between deer age and collagen 813C values from the Isle of Rum population (Scotland). The amount of intra-population isotope variability is not consistent among populations; thus significant numbers of individuals from each species are required for modern food web studies, for palaeodietary baseline data, and for palaeoecological studies.

Keywords: Carbon | Canopy effect | Collagen | Nitrogen | Temperature

Stevens 2010

Rhiannon E. Stevens, Roger M. Jacobi & Thomas F. G. Higham, *Reassessing the diet of Upper Palaeolithic humans from Gough's Cave and Sun Hole, Cheddar Gorge, Somerset, UK*. Journal of Archaeological Science **37** (2010), 52–61.

Richards et al. (2000) reconstructed the diet of the human remains found in Gough's and Sun Hole Cave through isotope analysis. They concluded that these people consumed an entirely terrestrial-based diet. Their reconstruction was based upon comparison of the results from human bones with those from a very small number of associated animals. The diets of the Gough's and Sun Hole Cave human were different from the other six Upper Palaeolithic humans from the British Isles for which dietary information has been obtained through isotope analysis. The work of Richards et al. (2000) suggests that they were the only ones for whom marine or freshwater resources did not play a signi.cant role in their diets. We test this through further analyses of faunal remains from Gough's Cave, Sun Hole and other contemporary sites (Kent's Cavern, Aveline's Hole, Kendrick's Cave). Despite the limited faunal sample, the original palaeodietary reconstruction is broadly consistent with our findings. The isotope values of the main protein sources consumed by the humans from both sites are consistent with those of red deer and bovines, and, for a single individual, with that of horse and red deer. Reindeer was postulated in

the original reconstruction as a potential food source, but this seems very unlikely based on our isotope reconstruction and the archaeological remains.

Stokes 2011

Helen R. Stokes, Gundula Müldner & Emma Jenkins, *An investigation into the archaeological application of carbon stable isotope analysis used to establish crop water availability: solutions and ways forward.* In: Steven Mithen & Emily Black (Hrsg.), *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley.* (Cambridge 2011), 373–380.

Carbon stable isotope analysis of charred cereal remains is a relatively new method employed by archaeological scientists to investigate ancient climate and irrigation regimes. The aim of this study was to assess the effect of environmental variables on carbon isotope discrimination (Δ) in multiple environments to develop the technique and its archaeological application, using crops grown at three experimental stations in Jordan. There are two key results: (1) as expected, there was a strong positive relationship between water availability and Δ; (2) site, not water input, was the most important factor in determining Δ. Future work should concentrate on establishing ways of correcting Δ for the influence of site specific environmental variables and on assessing how well carbon isotope discrimination values are preserved within the archaeological record.

Stone 2004

Richard Stone, *Putting the Stone in Stonehenge.* nature **304** (2004), 1889–1891.

Styring 2013

A. K. Styring et al., *The effect of charring and burial on the biochemical composition of cereal grains, Investigating the integrity of archaeological plant material.* Journal of Archaeological Science **40** (2013), 4767–4779.

JArchSci40-4767-Supplement.pdf

A. K. Styring, H. Manning, R. A. Fraser, M. Wallace, G. Jones, M. Charles, T. H. E. Heaton, A. Bogaard & R. P. Evershed

Stable isotope analysis of charred archaeobotanical cereal grains has the potential to provide direct evidence of crop growing conditions in the past and to refine palaeodietary predictions. If isotope values of archaeobotanical material are to be considered robust, it is necessary to characterise the compositional changes associated with their charring and burial. This study used a suite of analytical techniques, including FT-IR and solid state 13C NMR, to characterise changes in the biochemical composition of modern einkorn grains with heating at 230 °C for 2 h, 4 h, 8 h and 24 h, encompassing conditions that replicate their undistorted ancient counterparts. The biochemical composition of archaeobotanical charred einkorn grains was also investigated by FT-IR and solid state 13C NMR in order to assess the changes in composition which occur during burial. Results of FT-IR and solid-state 13C NMR show that heating of modern einkorn grains resulted in Maillard reactions between cereal proteins and starch, forming high molecular weight melanoidins, which contain both alkyl and aromatic carbon. Loss of low molecular weight carbon and nitrogen-containing volatiles resulted in a slight but non-systematic increase in the d13C values and a systematic increase of 0.8 ‰ in the d15N values of the charred einkorn grains. Solid-state 13C NMR shows

that the ancient charred einkorn grains consisted entirely of aromatic carbon and retained a similar proportion of nitrogen to their modern 24 h charred counterparts, despite a significantly lower concentration of amino acids. This indicates that the amino acid nitrogen in the ancient charred grains was retained in the stable melanoidins whose polymeric structure makes them resistant to subsequent degradation.

Keywords: Cereal grains | Heat treatment | Chars | Ancient | FTIR | NMR | Maillard

Styring 2014

Amy K. Styring, Rebecca A. Fraser, Amy Bogaard & Richard P. Evershed, *The effect of manuring on cereal and pulse amino acid $\delta^{15}N$ values*. Phytochemistry **102** (2014), 40–45.

Phytochemistry102-0040-Supplement.pdf

Amino acid d15N values of barley (Hordeum vulgare) and bread wheat (Triticum aestivum) grains and rachis and broad bean (Vicia faba) and pea (Pisum sativum) seeds, grown in manured and unmanured soil at the experimental farm stations of Rothamsted, UK and Bad Lauchstädt, Germany, were determined by GC-C-IRMS. Manuring was found to result in a consistent 15N-enrichment of cereal grain amino acid d15N values, indicating that manuring did not affect the metabolic routing of nitrogen (N) into cereal grain amino acids. The increase in cereal grain d15N values with manuring is therefore due to a 15N-enrichment in the d15N value of assimilated inorganic-N. Greater variation was observed in the 15N-enrichment of rachis amino acids with manuring, possibly due to enhanced sensitivity to changes in growing conditions and higher turnover of N in rachis cells compared to cereal grains. Total amino acid d15N values of manured and unmanured broad beans and peas were very similar, indicating that the legumes assimilated N2 from the atmosphere rather than N from the soil, since there was no evidence for routing of 15N-enriched manure N into any of the pulse amino acids. Crop amino acid d15N values thus provide insights into the sources of N assimilated by non N2-fixing and N2-fixing crops grown on manured and unmanured soils, and reveal an effect of manure on N metabolism in different crop species and plant parts.

Keywords: Hordeum vulgare | Triticum aestivum | Vicia faba | Pisum sativum | Amino acids | Nitrogen | d15N values | Manure

Styring 2015

Amy K. Styring et al., *Refining human palaeodietary reconstruction using amino acid $\delta^{15}N$ values of plants, animals and humans*. Journal of Archaeological Science **53** (2015), 504–515.

JAS053-0504-Supplement.docx

Amy K. Styring, Rebecca A. Fraser, Rose-Marie Arbogast, Paul Halstead, Valasia Isaakidou, Jessica A. Pearson, Marguerita SchEafer, Sevasti Triantaphyllou, Soultana Maria Valamoti, Michael Wallace, Amy Bogaard & Richard P. Evershed

The large discrepancies between the estimates of animal protein consumption made with and without taking into account the d15N values of charred cereal grains and pulses illustrate the importance of plant d15N values in palaeodietary interpretations.

An established method of estimating the trophic level of an organism is through stable isotope analysis of its tissues and those of its diet. This method has been used in archaeology to reconstruct past human diet from the stable nitrogen isotope (d15N) values of human and herbivore bone collagen. However, this approach, using the 15N-enrichment of human bone collagen d15N values over associated herbivore bone collagen d15N values to predict the relative importance of animal

protein, relies on the assumptions that: (i) the d15N values of plants consumed by humans and herbivores are identical, and (ii) the 15Nenrichment between diet and consumer is consistent. Bone collagen amino acid d15N values have the potential to tackle these uncertainties, as they constrain the factors influencing bone collagen d15N values. In this study, the d15N values of glutamic acid and phenylalanine in human and herbivore bone collagen isolates from Neolithic sites in Germany, Greece and Turkey were determined by gas chromatography-combustion-isotope ratio mass spectrometry. The fraction of animal protein in total dietary protein consumed by the humans was estimated by: (i) comparing bulk human and herbivore collagen d15N values, (ii) comparing bulk human and herbivore collagen and ancient charred cereal grain d15N values, (iii) comparing human bone collagen d15NGlutamic acid and d15NPhenylalanine values, and (iv) comparing d15NGlutamic acid values of human and herbivore bone collagen and estimated d15NGlutamic acid values of ancient charred cereal grains. Where determined cereal grain d15N values are higher than estimated herbivore forage values, estimates of animal protein consumption are significantly lower, emphasising the importance of the plant nitrogen contribution to human bone collagen. This study also highlights the need for further investigation into: (i) the D15NConsumer-Diet values of glutamic acid and phenylalanine in terrestrial ecosystems, and (ii) D15NGlutamic acid-Phenylalanine values of common plant foods in order to improve the accuracy and more widespread applicability of amino acid-based methods for palaeodietary reconstruction.

Keywords: Bone collagen | Cereal grains | Amino acids | Nitrogen | d15N values | Palaeodiet

Styring 2016

Amy Styring, Ursula Maier, Elisabeth Stephan, Helmut Schlichtherle & Amy Bogaard, *Cultivation of choice: new insights into farming practices at Neolithic lakeshore sites*. Antiquity **90** (2016), 95–110.

The high-quality organic preservation at Alpine lakeshore settlement sites allows us to go beyond simplistic reconstructions of farming in the Neolithic. The rich archaeological datasets from these sites may be further complemented by methods such as nitrogen isotope (d15N) analysis of charred crop remains. At Hornstaad-H¡§ornle IA and Sipplingen, on the shore of Lake Constance in south-west Germany, this method has been used to provide a unique insight into strategies of cultivation such as manuring on both a spatial and temporal scale.

Keywords: south-west Germany | Neolithic | Alpine foreland | agriculture | nitrogen isotopes | archaeobotany

Szpak 2012

Paul Szpak, Jean-François Millaire, Christine D. White & Fred J. Longstaffe, *Influence of seabird guano and camelid dung fertilization on the nitrogen*. Journal of Archaeological Science **39** (2012), 3721–3740.

JArchSci39-3721-Supplement.xls

Organic fertilizers have the capacity to alter the nitrogen isotopic composition of plants. Camelid dung and seabird guano are two potentially important fertilizers in the agricultural systems of western South America, particularly Peru and Chile. This paper presents isotopic data (d13C and d15N) from field grown plants (maize, Zea mays) fertilized with the following four treatments: CO (control, no fertilizer applied), AS (ammonium sulfate, a chemical fertilizer), DU (camelid dung), and SG (seabird guano). Plants were grown in experimental plots in the Virú Valley,

northern Peru. Plants fertilized with the chemical fertilizer presented very similar isotopic compositions compared to the control. Conversely, the camelid dung fertilized plants were characterized by higher d15N values compared to the control plants (by 1.8 to 4.2‰ depending on the plant part). The seabird guano fertilized plants were greatly enriched in 15N in comparison to the control plants (by 11.3 to 20.0‰). The results of this study have important implications for the reconstruction of human diet using isotopic data derived from bone collagen and related tissues, particularly in the prehispanic Andes, but also in Europe and North America during the 19th century, when Peruvian seabird guano was used extensively. Specifically, the interpretation of the relative contributions of plant and animal protein to the diet on the basis of bulk isotopic compositions of bone collagen (or similar tissues) may be confounded by camelid dung fertilization if the carbon isotopic compositions of the two sources are similar. Likewise, the interpretation of the relative contributions of maize and marine protein may be confounded by seabird guano fertilization.

Keywords: Nitrogen stable isotopes | Fertilizer | Guano | Camelid dung | Andes | Paleodiet | Agriculture

Szpak 2014

Paul Szpak, Fred J. Longstaffe, Jean-François Millaire & Christine D. White, *Large variation in nitrogen isotopic composition of a fertilized legume*. Journal of Archaeological Science **45** (2014), 72–79.

JAS045-0072-Supplement.pdf

Plant nitrogen isotopic compositions are highly variable and are influenced by a diversity of environmental and anthropogenic factors, including the application of animal-derived fertilizers. Legumes that acquire most of their nitrogen from atmospheric N2 (rather than mineralized soil nitrogen) tend to have relatively low d15N values (consistently around 0 ‰), and it has been presumed that their d15N values are largely or wholly unaffected by fertilization. This study presents nitrogen isotopic data from leguminous (garden bean, Phaseolus vulgaris) and non-leguminous (summer squash, Cucurbita pepo) plants subjected to seabird guano fertilization while growing under controlled conditions. Both bean and squash tissue d15N values were substantially increased by seabird guano fertilization: +16.3 to +19.2 ‰ for bean and +19.6 to +24.5 ‰ for squash. The results of this study demonstrate that the enrichment in plant 15N resulting from seabird guano fertilization occurs consistently in non-maize species. Moreover, it demonstrates that under conditions of high soil nitrogen availability, leguminous plants may obtain a substantial portion of their nitrogen through the uptake of inorganic soil nitrogen (ammonium and nitrate), rather than atmospheric N2. In general, where the d15N values of fertilizers differ substantially from that of endogenous soil nitrogen and mineralized nitrogen derived from the fertilizer is readily available, a significant manuring effect can be expected in leguminous plants.

Keywords: Stable isotopes | Nitrogen | Fertilizer | Seabird guano | Legumes | Pulses | Paleodiet

Tacail 2017

Théo Tacail, Béatrice Thivichon-Prince, Jeremy E. Martin, Cyril Charles, Laurent Viriot & Vincent Balter, *Assessing human weaning practices with calcium isotopes in tooth enamel*. PNAS **114** (2017), 6268–6273.

pnas114-06268-Supplement.xlsx

Weaning practices differ among great apes and likely diverged during the course of human evolution, but behavioral inference from the fossil record is hampered by

a lack of unambiguous biomarkers. Here, we show that early-life dietary transitions are recorded in human deciduous tooth enamel as marked variations in Ca isotope ratios (d44/42Ca). Using a sequential microsampling method along the enamel growth axis, we collected more than 150 enamel microsamples from 51 deciduous teeth of 12 different modern human individuals of known dietary histories, as well as nine enamel samples from permanent third molars. We measured and reconstructed the evolution of 44Ca/42Ca ratios in enamel from in utero development to first months of postnatal development. We show that the observed variations of d44/42Ca record a transition from placental nutrition to an adult-like diet and that Ca isotopes reflect the duration of the breastfeeding period experienced by each infant. Typically, the d44/42Ca values of individuals briefly or not breastfed show a systematic increase during the first 5–10 mo, whereas individuals with long breastfeeding histories display no measurable variation in d44/42Ca of enamel formed during this time. The use of Ca isotope analysis in tooth enamel allows microsampling and offers an independent approach to tackle challenging questions related to past population dynamics and evolution of weaning practices in hominins.

Keywords: calcium isotopes | tooth enamel | dietary transitions | weaning | breast milk

Significance: The practice of weaning, the dietary transition from exclusive breastfeeding to exclusive nonmilk food, is a key aspect of development and evolution of hominins, but its study in the fossil record is hampered by a lack of unambiguous biomarkers. Ca stable isotope ratios of skeletal remains are expected to bear information about milk consumption. Here we demonstrate that modern human tooth enamel records a temporal variation of Ca isotope compositions, which is related to breastfeeding duration. Ca isotopes could be used as a biomarker for reconstruction of weaning practices in past human and fossil hominin species.

Tankersley 2016

Kenneth Barnett Tankersley, Denis G. Conover & David L. Lentz, *Stable carbon isotope values ($\delta^{13}C$) of purslane (Portulaca oleracea) and their archaeological significance.* Journal of Archaeological Science: Reports **7** (2016), 189–194.

Elemental Analyzer Isotope RatioMass Spectrometrywas used to determine the d13C values of common purslane (Portulaca oleracea), a highly edible and nutritious annual succulent and member of the Portulacaceae family, which uses both C4 fixation and Crassulacean acid metabolism (CAM) photosynthesis. The d13C values for the plant range between .11.2 ‰ and .20.5 ‰ (C4 .11.2 ‰ to .13.9 ‰, CAM.17.6 ‰ to .20.5 ‰), which overlaps with d13C values for maize (Zeamays).9.1 ‰ to.17.3 ‰. Both plants occur on late Holocene archaeological sites in eastern North America and likely contributed to the d13C ratios reported for ancient human collagen and hydroxyapatite. Taphonomically, P. oleracea has a lower archaeological visibility because it is completely edible and the seeds are tiny (0.02 to 0.76 mm) in comparison to maize kernels and cobs. Therefore, we can no longer assume that maize was the only significant plant food in the late Holocene diet of eastern North America, which elevated d13C ratios in ancient human tissues.

Keywords: Stable carbon isotope value | Photosynthesis | Archaeobotany | Paleobotany | Paleodiet | Common purslane (Portulaca oleracea) | Maize (Zea mays) | Eastern North America | Late Holocene | Bioarchaeology

Tauber 1981

Henrik Tauber, *^{13}C evidence for dietary habits of prehistoric man in Denmark*. nature **292** (1981), 332–333.

Carbon isotopes are fractionated by natural processes such as photosynthetic assimilation of CO, and its absorption in water. Carbon fractionation is affected by the type of melabolism used by the plant to fix CO2 and differs in marine and terrestrial plants. This natural fractionation pattern is passed down the food chain and may therefore be used to elucidate questions on the origin of carbon compounds in nature. Here, the 13C fractionation pattern has been used to investigate the dietary habits of prehistoric man in northwestern Europe. The results show that whereas Danish Mesolithic man lived on a diet dominated by sea food, in the Neolithic the human diet consisted predominantly of terrestrial food.

Thompson 1992

G. N. Thompson & D. Halliday, *Protein turnover in pregnancy*. European Journal of Clinical Nutrition **46** (1992), 411–417.

Whole-body protein metabolism was studied at 13,24 and 35 weeks gestation in six healthy women using a continuous infusion [13C]leucine technique. Values were expressed in terms of fat-free body weight (FFM) calculated using literature standards for changes in total body potassium during pregnancy. Mean protein synthesis increased from 5.3 (±0.6SD) g/kg FFM/24h at 13 weeks to 5.9±0.5 (P<0.1) at 24 weeks and 6.1±0.6 at 35 weeks (P<0.05 vs 3 weeks). Similar increases were noted in catabolism so that net loss changed little. Protein synthesis at 24 and 35 weeks gestations was significantly greater than that in 17 healthy, non-pregnant women (4.9±0.6, P<0.001). These data indicate that there are substantial increases in protein turnover during pregnancy.

Towers 2011

Jacqueline Towers, Mandy Jay, Ingrid Mainland, Olaf Nehlich & Janet Montgomery, *A calf for all seasons? The potential of stable isotope analysis to investigate prehistoric husbandry practices*. Journal of Archaeological Science **38** (2011), 1858–1868.

The Early Bronze Age barrows at Irthlingborough and Gayhurst in central England are notable for the large number of cattle (Bos taurus) remains associated with their human Beaker burials. Previous work using strontium isotope analysis has indicated that most of the cattle analysed, and one aurochs (Bos primigenius), were of local origin. In this study, stable isotope analysis of enamel and bone was carried out to investigate whether the mature cattle had experienced similar husbandry practices, climate and environment. Bulk carbon, nitrogen and sulphur isotope analysis of collagen suggested most were consuming similar sources of plant protein from environments probably local to the sites and this was supported by high resolution intra-enamel carbon isotope profiles. Oxygen isotope profiles indicated the aurochs and most of the cattle experienced similar climatic regimes: the only exception being an animal with a non-local strontium isotope ratio. However, a comparison of seasonality profiles of the local animals using estimated tooth formation times showed that there was no consistency in season of birth: the animals appeared to have been born throughout the year. Cattle can breed throughout the year but it requires considerable human effort and intervention to successfully overwinter young stock; it is therefore unlikely to have been carried out without good reason and benefit if winters were harsh. One reason is to ensure a continuous supply of milk. Measuring oxygen isotope profiles to identify year-round calving may thus be a potential indicator of dairying economies.

Keywords: Stable isotope analysis | Tooth enamel | Bone collagen | Intra-tooth sampling | Cattle husbandry | Dairying

Travis 2008

John Travis, *Trail of Mare's Milk Leads to First Tamed Horses*. science **322** (2008), 368.

Stear reported at the meeting that she found the isotopic signature of mare's milk on 5500-year-old pottery fragments from Kazakhstan. "It is the smoking gun for horse domestication, since no one would attempt to milk a wild mare." Stear used carbon isotopes to confirm the presence of equine fats on about 50 Botai shards, but the method couldn't distinguish between lipids from milk or meat. So she tested local horse meat and koumiss and confirmed a hypothesis posed by Evershed and Alan Outram of the University of Exeter, U.K.: that horse meat and milk contain different amounts of the hydrogen isotope deuterium. For reasons related to the isotope's heavier weight, summer rains in the region contain much more deuterium than winter precipitation. Because mares are only milked after they foal in the spring, researchers theorized that the isotope would be concentrated in milk, whereas horse meat's deuterium signal would be averaged over the course of each year. Testing the ancient potsherds, Stear found that five had the horsemilk deuterium signature. "The way she did it was quite elegant," says Oliver Craig, a biomolecular archaeologist at the University of York.

Tsutaya 2016

Takumi Tsutaya, Akina Shimomi, Shiori Fujisawa, Kazumichi Katayama & Minoru Yoneda, *Isotopic evidence of breastfeeding and weaning practices in a hunter-gatherer population during the Late/Final Jomon period in eastern Japan*. Journal of Archaeological Science **76** (2016), 70–78.

JAS076-0070-Supplement1.docx, JAS076-0070-Supplement2.kml

Jomon hunteregatherers in Japan commonly show Neolithic characteristics, such as intensive utilization of potteries, grinding stones, and many plant food sources. In this study, breastfeeding and weaning practices in a Jomon hunteregatherer population are investigated to evaluate two hypotheses concerning the relations between utilization of potteries/plant foods and early weaning and children's diet around and after the weaning process. Stable carbon and nitrogen isotope ratios were investigated for 46 subadult and 47 adult human skeletons excavated from the Yoshigo site of the Late/Final Jomon period (approximately 4000–2300 years BP) in eastern Japan. A new analytical procedure was developed and residuals of nitrogen isotope ratios were calculated to cancel out the effect of positive correlation in the carbon and nitrogen isotope ratios. Age changes in the residuals showed that the age at the end of weaning in the Yoshigo population was 3.5 years (2.3–5.5 years in 95 % credible interval), which is not younger than that in typical non-industrialized populations and the other skeletal hunteregatherer populations. Furthermore, most infants were probably weaned using a combination of the same food sources as those eaten by adults. These results suggest that the utilization of pottery and plant food per se is not a sole determinant of the age at the end of weaning in past human populations, and a special diet was not always applied during and just after the weaning process.

Keywords: Breastfeeding | Carbon and nitrogen stable isotope analysis | Diet | Hunteregatherer | Subadult | Weaning | Yoshigo site

Ugan 2011

Andrew Ugan & Joan Coltrain, *Variation in collagen stable nitrogen values in black-tailed jackrabbits (Lepus californicus) in relation to small-scale differences in climate, soil, and topography.* Journal of Archaeological Science **38** (2011), 1417–1429.

Longstanding observations about the relationship between increasing aridity and 15N enrichment in mammalian collagen values have led to an interest in their use as a paleoclimatic marker. Here we report on variability in collagen nitrogen values from five modern and two archaeological samples of blacktailed jackrabbits (Lepus californicus) from the eastern Great Basin of the United States (N = 178 individuals). Nitrogen d15N values were highly variable within all samples. Modern samples showed significant differences despite similarities in average annual precipitation and temperature. Archaeological samples were indistinguishable from each other or from modern samples taken from the same area despite independent evidence for differences in precipitation for the two prehistoric periods considered. Differences between modern samples were most strongly associated with soil characteristics. We discuss these results in light of their relationship with topography and vegetation and highlight their implications for archaeological applications of stable nitrogen analyses in several contexts.

Keywords: Zooarchaeology; Paleoclimate; Stable isotopes; Stable nitrogen; Great basin; Small mammal; Lagomorph

Ugan 2012

Andrew Ugan & Joan Coltrain, *Stable isotopes, diet, and taphonomy: a look at using isotope-based dietary reconstructions to infer differential survivorship in zooarchaeological assemblages.* Journal of Archaeological Science **39** (2012), 1401–1411.

JArchSci39-1401-Supplement.zip

Archaeology has always faced the problem of making informed inferences based on an incomplete record. Zooarchaeological studies of prehistoric hunting and diet offer a clear case in point, where a range of behavioral and taphonomic factors can produce a substantial disconnect between what people actually captured and ate and what archaeologists recover and interpret. We explore this disconnect by presenting stable C and N data for wild faunas, archaeological maize, and three human burials from Fremont-period sites in southeastern Utah, the United States. We use these data to estimate faunal contributions to prehistoric diets and compare the results with previous zooarchaeological analyses of faunas from the same sites. Results for the two approaches differ sharply, with isotopic estimates showing much higher contributions of small and lowland game.We discuss these results in terms of both local prehistory and wider issues of taphonomy and dietary analysis.

Keywords: Stable isotopes | Great Basin | Taphonomy | Dietary reconstruction | SISUS

Vaiglova 2014

Petra Vaiglova et al., *An integrated stable isotope study of plants and animals from Kouphovouno, southern Greece, A new look at Neolithic farming.* Journal of Archaeological Science **42** (2014), 201–215.

JArchSci42-0201-Supplement.pdf

Petra Vaiglova, Amy Bogaard, Matthew Collins, William Cavanagh, Christopher Mee, Josette Renard, Angela Lamb, Armelle Gardeisen & Rebecca Fraser

This paper presents the first study that combines the use of ancient crop and animal stable isotopes (carbon and nitrogen) and Zooarchaeology Mass Spectro-

metry species identification (ZooMS) for reconstructing early farming practices at Kouphovouno, a Middle-Late Neolithic village in southern Greece (c. 5950–4500 cal. BC). Debate surrounding the nature of early farming predominantly revolves around the intensity of crop cultivation: did early farmers move around the landscape while practicing temporary farming methods such as slash and burn agriculture or did they create more permanent fields by investing high labor inputs into smaller pieces of land that produced higher crop yields? The need to address these questions using a direct assessment of the intensity and scale of cultivation is apparent, and an integrated stable isotope approach provides such an opportunity. The results of this study support the model of small-scale mixed farming, where crop cultivation and animal husbandry are closely integrated. The farmers directed their intensive management towards crops grown for human consumption (free-threshing wheat), while growing fodder crop (hulled barley) more extensively. Pulses were cultivated under a high-manuring/high-watering regime, likely in garden plots in rotation with free-threshing wheat. The diets of the livestock enable us to investigate which parts of the landscape were used for browsing and grazing and indicate that animal management changed in the Late Neolithic. The sheep and goats were now kept in smaller numbers and grazed together and new pasture grasses may have been sought for the grazing of cattle. This study demonstrates that beyond its applicability for palaeodietary reconstruction, analysis of stable isotopes of archaeological crop and animal remains has important implications for understanding the relationship between humans, plants and animals in an archaeological context.

Keywords: Stable isotopes | Carbon | Nitrogen | ZooMS | Archaeobotany | Archaeozoology | Aegean | Neolithic

Verano 1993

John W. Verano & Michael J. DeNiro, *Locals or Foreigners? Morphological, Biometric and Isotopic Approaches to the Question of Group Affinity in Human Skeletal Remains Recovered from Unusual Archaeological Contexts*. In: Mary K. Sandford (Hrsg.), *Investigations of Ancient Human Tissue*, *Chemical Analyses in Anthropology*. Food and Nutrition in History and Anthropology 10 (Langhorne / Berlin 1993), 361–386.

Results of the isotopic analyses of bone collagen indicate that the four individuals in Group I of the mass burial fall well within the range of carbon and nitrogen values for the Pacatnamu sample, suggesting that they consumed a similar mixed diet of marine and terrestrial resources. In contrast, nitrogen isotopic ratios for six individuals in Groups II and III of the mass burial suggest consumption of a primarily terrestrial diet, different from that of the Pacatnamu population. Although as a pooled sample, individuals in Groups II and III cannot be shown to be drawn from a population with a significantly different mean d15N value from that of the Pacatnamu Late Period sample (using a t-test), d15N values for six individuals fall more than two standard deviations from the Late Period mean.

Results of biometric comparisons between the mass burial individuals and possible source populations do not suggest a northern highlands origin for any individuals, if it can be assumed that the Cajamarca samples are representative of contemporaneous northern highland populations. The discriminant function generated between the Pacatnamu and the Chicama Valley samples, in contrast, classifies about half of the mass burial individuals into each group. It is difficult to interpret the meaning of these results given the lack of other comparative samples from the Jequetepeque and Chicama valleys. Unfortunately, the discriminant function can only classify a test case into one of the defined reference samples. “Neither” or

"none of the above" are not possible classification options. Additional comparative samples from the Jequetepeque and Chicama valleys might help resolve the issue, but at present none are available.

Further studies of carbon and nitrogen isotopic ratios in prehistoric north coast Peruvian populations are needed to document the degree of between-and within-population variability in bone collagen isotopic composition and the relative distinctiveness of coastal and inland populations. Until such research is done, the results of the present study must be considered only preliminary and suggestive. Nevertheless, these preliminary results demonstrate the potential application of carbon and nitrogen isotopic analysis of bone collagen not only to traditional issues of paleodietary reconstruction, but also to the question of population affinity in unknown skeletal remains.

Vika 2012

Efrossini Vika & Tatiana Theodoropoulou, *Re-investigating fish consumption in Greek antiquity: results from $\delta^{13}C$ and $\delta^{15}N$ analysis from fish bone collagen*. Journal of Archaeological Science **39** (2012), 1618–1627.

One of the frequently encountered issues in ancient Greek dietary reconstructions through isotope analyses has been the apparent unimportance of fish protein in human diets. The significance of this observation is amplified by the abundant ichthyofaunal remains, iconographic evidence and literary information on fish and fishing, pertaining to almost all sites and time periods of Greek antiquity. In this project, we measured for the first time isotopes from a large number of fish bones from Greek sites dating from the Mesolithic to the Classical times, aiming to investigate whether this absence is an artefact of the methodology or whether it reflects a reality of restricted fish consumption. Results show that regional trends are stronger that temporal ones in fish isotope values. The range of values overlaps with terrestrial resources, making it difficult or impossible to reject fish consumption based on isotope data alone. This variability proposes a reconsideration of the amount of fish in ancient Greek diets specifically for each site and amplifies the importance of interdisciplinary studies, especially for regions with variable ecological resources.

Keywords: Stable isotopes | Collagen | Fish | Diet | Ancient Greece | Aegean

Viner 2010

Sarah Viner, Jane Evans, Umberto Albarella & Mike Parker Pearson, *Cattle mobility in prehistoric Britain, Strontium isotope analysis of cattle teeth from Durrington Walls (Wiltshire, Britain)*. Journal of Archaeological Science **37** (2010), 2812–2820.

An important role has been envisaged for cattle during the Neolithic period in Britain based on their prominence within the faunal assemblages of the period as a whole. The relative ease with which cattle can be moved over long distances and the requirement to provide ample pastureland leads almost inescapably to the consideration of prehistoric cattle movement. This paper presents the results of an investigation into the mobility of Late Neolithic cattle at the well-known site of Durrington Walls, Wiltshire. 87Sr/86Sr values from cattle (Bos taurus) teeth were compared to local vegetation samples, well established values from archaeological material and to known geological conditions in order to determine whether individual animals were raised in areas with similar geological conditions as those found at the site (i.e. chalkland), and therefore whether the animals were of allochthonous or autochthonous origin. In total, 13 mandibular molars

from DurringtonWalls were analysed. Two of the animals included in the study were certainly raised under conditions similar to those found in the vicinity of Durrington Walls, but the other 11 provided signatures so distinct from that found locally that they could not have been raised on chalkland. From the results it is suggested that cattle were brought to the site from a variety of grazing areas in different parts of Britain. The implication of these findings is that the movement of cattle was undertaken during the Late Neolithic, and that in a number of cases substantial distances must have been traversed in order for animals to reach the site. In addition, the study provided valuable information for the interpretation of the site, which attracted people from a variety of regions, probably for ceremonial reasons.

Keywords: Britain | Neolithic | Durrington Walls | Cattle | Strontium | Mobility

Vogel 1977

J. C. Vogel & Nikolaas J. van der Merwe, *Isotopic Evidence for Early Maize Cultivation in New York State*. American Antiquity **42** (1977), 238–242.

Plants metabolize carbon dioxide photosynthetically either through a 3-carbon (Calvin) or 4-carbon pathway. Most plants are of the C-3 type; C4 plants are primarily grasses adapted to hot, arid environments. Since C4 plants have a higher 13C/1 2 C ratio than C-3 plants, animals and humans with a significant C-4 plant food-intake will have higher 13C/1 2C ratios as well. Maize is a C4 plant, hence maize cultivators living in predominantly C-3 plant environments should show significant isotopic differences from local hunter-gatherers in their skeletal remains; the importance of maize in their diet should also be measurable. The practicability of this method is demonstrated for New York State archaeological materials and wider implications are mentioned.

Voigt 2004

Christian C. Voigt & Felix Matt, *Nitrogen stress causes unpredictable enrichments of ^{15}N in two nectar-feeding bat species*. Journal of Experimental Biology **207** (2004), 1741–1748.

We estimated the effect of nitrogen stress on the nitrogen isotope enrichments in wing membrane and blood of two nectar-feeding bats (Glossophaga soricina and Leptonycteris curasoae) by offering a nitrogen-poor diet with a high d15N and d13C. Before the experiment, bats were sustained on a normal diet with a low d15N and d13C. Under this first food regime, the fractionation of nitrogen isotopes averaged 3.1‰ d15N for blood and 4.4‰ d15N for wing membrane, which was almost twice as high as the corresponding fractionation of carbon isotopes. After switching to the nitrogen-poor diet, the enrichment of heavy isotopes increased for both elements in all tissues under study. The recently published estimates of half-life of carbon isotopes indicated a low turnover rate of carbon in wing membrane and blood and an almost constant halflife over varying losses of body mass. The estimates of half-life of nitrogen were two to six times higher than those of carbon. We argue that this discrepancy was caused by the mixing of nitrogen isotopes from internal and external sources. The mixing effect was probably negligible for carbon as the amount of ingested carbon outweighed the amount of mobilized carbon from internal sources. A correlation between the estimated turnover rates of nitrogen and losses of body masses was probably obscured by the additional fractionation of nitrogen isotopes in catabolic animals. We conclude that the interpretation of nitrogen isotope data of free-ranging animals is difficult when the animal's diet is changing to a critical nitrogen content.

Key words: nitrogen isotope, nitrogen stress, fractionation, mixing, Glossophaga soricina, Leptonycteris curasoae.

Wallace 2013

M. Wallace, G. Jones, M. Charles, R. Fraser, P. Halstead, T. H. E. Heaton & A. Bogaard, *Stable carbon isotope analysis as a direct means of inferring crop water status and water management practices*. World Archaeology **45** (2013), 388–409.

WorldArchaeology45-388-Supplement.pdf

Stable carbon isotope analysis of plant remains is a promising tool for researchers studying palaeoclimate and past agricultural systems. The potential of the technique is clear: it offers a direct measure of the water conditions in which plants grew. In this paper, we assess how reliably stable carbon isotope discrimination can be used to infer water conditions, through the analysis of present-day crop plants grown at multiple locations across the Mediterranean and south-west Asia. The key findings are that: (1) D13C, as expected, provides an indication of water conditions, (2) even for plants grown in similar conditions there is variation in D13C and (3) D13C may reflect crop water status for a period beginning well before the grain filling period. A new framework is presented which increases the robustness with which D13C values of plant remains can be interpreted in terms of the water conditions in which ancient crops grew.

Keywords: Carbon isotopes | Archaeobotany | Experimental archaeology | Cereals | Pulses | Water | Rainfall | Irrigation.

Wang 2015

David T. Wang et al., *Nonequilibrium clumped isotope signals in microbial methane*. science **348** (2015), 428–431.

s348-0428-Supplement.pdf

David T. Wang, Danielle S. Gruen, Barbara Sherwood Lollar, Kai-Uwe Hinrichs, Lucy C. Stewart, James F. Holden, Alexander N. Hristov, John W. Pohlman, Penny L. Morrill, Martin Könneke, Kyle B. Delwiche, Eoghan P. Reeves, Chelsea N. Sutcliffe, Daniel J. Ritter, Jeffrey S. Seewald, Jennifer C. McIntosh, Harold F. Hemond, Michael D. Kubo, Dawn Cardace, Tori M. Hoehler & Shuhei Ono

Methane is a key component in the global carbon cycle, with a wide range of anthropogenic and natural sources. Although isotopic compositions of methane have traditionally aided source identification, the abundance of its multiply substituted "clumped" isotopologues (for example, 13CH3D) has recently emerged as a proxy for determining methane-formation temperatures. However, the effect of biological processes on methane's clumped isotopologue signature is poorly constrained. We show that methanogenesis proceeding at relatively high rates in cattle, surface environments, and laboratory cultures exerts kinetic control on 13CH3D abundances and results in anomalously elevated formation-temperature estimates. We demonstrate quantitatively that H2 availability accounts for this effect. Clumped methane thermometry can therefore provide constraints on the generation of methane in diverse settings, including continental serpentinization sites and ancient, deep groundwaters.

Warinner 2009

Christina Warinner & Noreen Tuross, *Alkaline cooking and stable isotope tissue-diet spacing in swine: archaeological implications*. Journal of Archaeological Science **36** (2009), 1690–1697.

In this study we examine the effects of alkaline cooking on carbon and oxygen stable isotopic ratios of mineralized tissues from nine pigs raised on monotonous mixed C3/C4 vegetarian diets. Two sources of collagen (humerus and mandible) and two sources of apatite (humerus and enamel) were analyzed. Within each diet group, humerus and mandible collagens were found to record equivalent d13C and d18O ratios; however, enamel apatite was found to be enriched over bone apatite by 2.3 ‰ in carbon and 1.7 ‰ in oxygen. Alkaline cooking was found to slightly, but signi.cantly increase the D13Ccollagen-diet and D18Ocollagen-diet of bone collagen. A similar trend towards enrichment was observed in bone and enamel D13Capatite-diet and D18O apatite-

diet, but the differences were not signi.cant. Observed isotopic shifts were consistent with increased nutrient utilization of the alkaline-cooked maize as compared to raw maize. In addition, a reexamination of the relationship between diet and tissue carbon isotopic values suggests that species and alimentary type should be considered when interpreting ancient diets.

Webb 2015

Emily C. Webb, Noah V. Honch, Philip J. H. Dunn, Gunilla Eriksson, Kerstin Lidén & Richard P. Evershed, *Compound-specific amino acid isotopic proxies for detecting freshwater resource consumption*. Journal of Archaeological Science **63** (2015), 104–114.

Of central importance to palaeodietary reconstruction is a clear understanding of relative contributions of different terrestrial (i.e., C3 vs. C4 plants) and aquatic (i.e., freshwater vs. marine) resources to human diet. There are, however, significant limitations associated with the ability to reconstruct palaeodiet using bulk collagen stable isotope compositions in regions where diverse dietary resources are available. Recent research has determined that carbon-isotope analysis of individual amino acids has considerable potential to elucidate dietary protein source where bulk isotopic compositions cannot. Using d13CAA values for human and faunal remains from Zvejnieki, Latvia (8th – 3rd millennia BCE), we test several isotopic proxies focused on distinguishing freshwater protein consumption from both plant-derived and marine protein consumption. We determined that the D13CGly-Phe and D13CVal-Phe proxies can effectively discriminate between terrestrial and aquatic resource consumption, and the relationship between essential d13CAA values and the D13CGly-Phe and D13CVal-Phe proxies can differentiate among the four protein consumption groups tested here. Compound-specific amino acid carbon-isotope dietary proxies thus enable an enhanced understanding of diet and resource exploitation in the past, and can elucidate complex dietary behaviour.

Keywords: Amino acids | Carbon isotopes | Nitrogen isotopes | Palaeodiet | Zvejnieki | Latvia

Williams 1993

John A. Williams, *Benefits and Obstacles of Routine Elemental and Isotopic Analysis in Bioarchaeological Research Contracts*. In: Mary K. Sandford (Hrsg.), *Investigations of Ancient Human Tissue, Chemical Analyses in Anthropology*. Food and Nutrition in History and Anthropology 10 (Langhorne / Berlin 1993), 387–412.

The routine inclusion of stable isotope and trace element analysis in bioarchaeological research contracts should be generally beneficial. The results obtained by various researchers have demonstrated the validity of these techniques in discerning dietary components and their potential role in organic pathology. However,

contract bioarchaeology follows a pattern different from that of other forms of sponsored research. Analysis usually takes place long after the disinterment of skeletal remains. The archaeologist and physical anthropologist often work as two separate entities with a general lack of coordinated effort. This creates numerous obstacles to a more integrated analytical methodology. Given the nature of competitive bidding and lack of control over samples and sample sizes, the results obtained lack the depth of more controlled studies of large skeletal population samples.

The results discussed here illustrate both the benefits and obstacles of the routine inclusion of stable isotope and trace element analysis in bioarchaeology contracts. Using d13C and d15N values, seven of nine samples indicated a diet consisting primarily of C4 plants (maize) and terrestrial herbivores (bison). All but one of these sites had a post-

horticultural culture-historic association. The remaining two samples, both from site 39LM256, with radiocarbon dates within the middle to late Woodland, had stable isotope ratios indicating a diet of terrestrial herbivores with little or no maize consumption.

The analysis of seven trace elements, on the other hand, was less clear cut. Fe concentrations varied widely, possibly due to differential diagenesis, the type of bone analyzed and/or Fe deficiency. Zn concentrations also varied, with several samples displaying levels consistent with clinical and subclini-cal forms of Zn deficiency. Both Fe and Zn deficiencies could result from diets high in maize and low in animal protein (see Prasad 1978). All nine samples displayed markedly depressed Cu concentrations. The reasons for these observations regarding this element are unknown however. The lack of control of sample sizes, inconsistent sample composition, and the nature of these burials (i.e., shoreline erosion) suggest that diagenetic factors are the most probable cause.

These results do not provide a clear mandate for continued inclusion of stable isotope and trace element analysis in routine contract bioarchaeology. While the database is increased by this avenue of research, the lack of interpretability remains a serious detriment. For this reason, the guidelines offered recently by the Skeletal Database Committee of the Paleopathology Association are particularly encouraging. Hopefully, these recommendations will help to bridge gaps between archaeologists, governmental agencies and the contract bioarchaeologists/physical anthropologists.

Wilson 2007

Andrew S. Wilson et al., *Stable isotope and DNA evidence for ritual sequences in Inca child sacrifice.* PNAS **104** (2007), 16456–16461.

pnas104-16456-Supplement.htm

pnas104-16456-Fig2.pdf, pnas104-16456-Fig3.pdf, pnas104-16456-Fig4.pdf

Andrew S. Wilson, Timothy Taylor, Maria Constanza Ceruti, Jose Antonio Chavez, Johan Reinhard, Vaughan Grimes, Wolfram Meier-Augenstein, Larry Cartmell, Ben Stern, Michael P. Richards, Michael Worobey, Ian Barnes and M. Thomas P. Gilbert

Four recently discovered frozen child mummies from two of the highest peaks in the south central Andes now yield tantalizing evidence of the preparatory stages leading to Inca ritual killing as represented by the unique capacocha rite. Our interdisciplinary study examined hair from the mummies to obtain detailed genetic and diachronic isotopic information. This approach has allowed us to reconstruct aspects of individual identity and diet, make inferences concerning social background, and gain insight on the hitherto unknown processes by which victims were selected, elevated in social status, prepared for a high-altitude pilgrimage, and

killed. Such direct information amplifies, yet also partly contrasts with, Spanish historical accounts.

Yamazaki 2014

E. Yamazaki, S. Nakai, Y. Sahoo, T. Yokoyama, H. Mifune, T. Saito, J. Chen, N. Takagi, N. Hokanishi & A. Yasuda, *Feasibility studies of Sn isotope composition for provenancing ancient bronzes*. Journal of Archaeological Science **52** (2014), 458–467.

This study examined isotope fractionation during bronze casting and assessed variation in Sn isotope composition of Chinese bronze products to ascertain whether a Sn isotope tracer is applicable to provenance studies of bronze products or not. A casting experiment revealed that the Sn isotope composition of a bronze block surface becomes slightly heavier, 0.22 ‰ in d124Sn/120Sn scale, (d124Sn/120Sn = [(124Sn/120Sn sample)/ (124Sn/120Sn standard)-1]*1000), than original Sn beads because of selective evaporation of light isotopes.The Sn isotope compositions of six bronze product samples excavated in China were analyzed. The variation of d124Sn/120Sn in the six samples was as great as 0.4 ‰. Six bronze samples showed small but detectable isotope variation that surpassed isotope shift during casting. Results suggested that the application of Sn isotope ratio to provenance studies of bronze products was of limited use because of the small variation. However, it was also shown that the Sn isotope ratio can be applied for provenancing a bronze sample with a distinct isotope composition.

Yeakel 2009

Justin D. Yeakel et al., *Cooperation and individuality among man-eating lions*. PNAS **106** (2009), 19040–19043.

pnas106-19040-Supplement1.pdf, pnas106-19040-Supplement2.xls

Justin D. Yeakel, Bruce D. Patterson, Kena Fox-Dobbs, Mercedes M. Okumura, Thure E. Cerlinge, Jonathan W. Moore, Paul L. Koch and Nathaniel J. Dominy

Cooperation is the cornerstone of lion social behavior. In a notorious case, a coalition of two adult male lions from Tsavo, southern Kenya, cooperatively killed dozens of railway workers in 1898. The "man-

eaters of Tsavo" have since become the subject of numerous popular accounts, including three Hollywood films. Yet the full extent of the lions' man-eating behavior is unknown; estimates range widely from 28 to 135 victims. Here we use stable isotope ratios to quantify increasing dietary specialization on novel prey during a time of food limitation. For one lion, the ≈13C and ≈15N values of bone collagen and hair keratin (which reflect dietary inputs over years and months, respectively) reveal isotopic changes that are consistent with a progressive dietary specialization on humans. These findings not only support the hypothesis that prey scarcity drives individual dietary specialization, but also demonstrate that sustained dietary individuality can exist within a cooperative framework. The intensity of human predation (up to 30 % reliance during the final months of 1898) is also associated with severe craniodental infirmities, which may have further promoted the inclusion of unconventional prey under perturbed environmental conditions.

Yeung 2015

Laurence Y. Yeun,2 Jeanine L. As,1 Edward D. Young, *Biological signatures in clumped isotopes of O_2*. science **348** (2015), 431–434.

s348-0431-Supplement.pdf

The abundances of molecules containing more than one rare isotope have been applied broadly to determine formation temperatures of natural materials. These

applications of “clumped” isotopes rely on the assumption that isotope-exchange equilibrium is reached, or at least approached, during the formation of those materials. In a closed-system terrarium experiment, we demonstrate that biological oxygen (O2) cycling drives the clumped-isotope composition of O2 away from isotopic equilibrium. Our model of the system suggests that unique biological signatures are present in clumped isotopes of O2—and not formation temperatures. Photosynthetic O2 is depleted in 18O18O and 17O18O relative to a stochastic distribution of isotopes, unlike at equilibrium, where heavy-isotope pairs are enriched. Similar signatures may be widespread in nature, offering new tracers of biological and geochemical cycling.

Yi 1999

Wen Yi et al., *Tin isotope studies of experimental and prehistoric bronzes*. In: Andreas Hauptmann, Ernst Pernicka, Thilo Rehren & Unsal Yalgin (Hrsg.), *The Beginnings of Metallurgy*, *Proceedings of the International Conference „The Beginnings of Metallurgy“, Bochum 1995*. Veröffentlichungen aus dem Deutschen Bergbau-Museum 84 (Bochum 1999), 285–290.

Wen Yi, Paul Budd, Rona A. R. McGill, Suzanne M. M. Young, Alex N. Halliday, Randolph Haggerty, Brett Scaife & A. Mark Pollard