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FEEDING HUMANS AND ANIMALS AT PRE-POTTERY NEOLITHIC NEVALI ÇORI (SE-ANATOLIA) AS EVIDENCED BY STABLE ISOTOPE ANALYSIS

Gisela GRUPE¹, Joris PETERS²

ABSTRACT

Analysis of light stable isotopes was applied to human and animal bones from Early to Middle Pre-Pottery Neolithic B contexts excavated at Nevalı Çori in southeast Anatolia. An attempt to reconstruct diets in humans and animals, the vertebrate food web, and local climatic conditions was based on the stable carbon and nitrogen isotopes in bone collagen and the carbon and oxygen isotopes in bone carbonate. Plant foods obviously played a major role in the nutrition of the site's inhabitants, as evidenced by the low $\delta^{15}\text{N}$ -values in their bone tissue. A conservative linear mixing model for the gross composition of the human diet at Nevalı Çori underscores the importance of cereals and pulses. Whereas the isotope signatures for various game species meet expectations in terms of their feeding and habitat preferences, the values obtained from bones considered to represent early stock-on-the-hoof reflect a dietary spectrum different from that of their wild, free-ranging relatives. We conclude that some pigs, sheep and goat were already intentionally nourished by their owners, whereby the overall low $\delta^{15}\text{N}$ -signatures in both humans and early livestock may have resulted from the consumption of protein-rich legumes.

Keywords: Neolithisation, Southeast Anatolia, stable isotopes, food web, early domesticates.

RÉSUMÉ

Une analyse des isotopes légers stables a été menée sur les ossements humains et animaux récoltés dans les contextes Néolithique acérémique B (PPNB) ancien et moyen fouillés à Nevalı Çori, dans le Sud-Est de l'Anatolie. Basée sur les isotopes stables du carbone et de l'azote du collagène des os et sur ceux du carbone et de l'oxygène des carbonates des os, une reconstitution de la diète des humains et des animaux, de la chaîne trophique des vertébrés et des conditions climatiques locales a été tentée. L'alimentation végétale a visiblement joué un rôle majeur dans la nutrition des occupants du site comme cela est mis en évidence par les valeurs $\delta^{15}\text{N}$ peu élevées dans leur tissu osseux. Un modèle de démelangeage linéaire de la composition brute de la diète humaine à Nevalı Çori souligne l'importance des céréales et des légumineuses. Alors que les signatures isotopiques des différentes espèces animales chassées correspondent

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aux résultats attendus en termes de préférences alimentaires et d'habitat, les valeurs obtenues sur des os considérés comme issus d'un cheptel primitif reflètent un spectre alimentaire différent de ceux de leurs congénaires libres et sauvages. Nous concluons que quelques cochons, moutons et chèvres étaient déjà nourris délibérément par leurs propriétaires. C'est la raison pour laquelle les signatures $\delta^{15}\text{N}$ globalement basses aussi bien chez les humains que chez les animaux des premiers troupeaux pourraient résulter de la consommation de légumineuses riches en protéines.

Mots-clés : Néolithisation, Anatolie du Sud-Est, isotopes stables, chaîne alimentaire, premières domestications.

INTRODUCTION

In large parts of the Fertile Crescent the expansion of grasslands at the end of the Pleistocene had a profound impact on human subsistence strategies, provoking a shift toward sedentism and an increased emphasis upon cereals and herbivore species as main sources of food. Prolonged sedentism, however, necessarily goes along with modifications in subsistence strategies (e.g. Bar-Yosef, Meadow 1995; Bar-Yosef 2000), as illustrated by the shift from hunting to herding over the course of the Neolithic. As such, the domestication of animals represents one stage in the transformation from incipient cultural control of a taxon by hunter-gatherers to livestock husbandry in fully agricultural societies because from a functional point of view, the succession from (1) hunting to (2) cultural control of wild species, for example by keeping single or few animals to serve as walking larders, to (3) domestication, where humans begin to take control of the reproduction of animals by isolating them from their wild relatives, and finally (4) livestock husbandry, can be considered an evolutionary continuum involving increasing input of human energy per animal (Peters *et al.* 2005).

Archaeofaunal research during the last decade suggests that the Upper Euphrates and Tigris drainages of the 9th millennium cal. BC represents core areas for the domestication of food animals in the Near East (e.g. Helmer *et al.* 1998; Peters *et al.* 1999, 2005). Whereas Anatolia and in particular the southern Anti-Taurus appears of interest in the illumination of the process of sheep, pig, and probably also goat domestication (e.g. Legge 1996; Buitenhuis 1997; Hongo, Meadow 1998; Peters *et al.* 1999, 2005; Russel *et al.* 2005), the North-Syrian Euphrates valley can be postulated as one of the core areas for the domestication of *Bos* (Helmer *et al.* 2005). These observations do not exclude domestication events in other parts of the Fertile Crescent, as DNA-studies of present-day livestock breeds suggest a polytopic origin of most livestock species (e.g. Loftus *et al.* 1994; Bradley *et al.* 1998; Hiendleder *et al.* 1998; Giuffra *et al.* 2000; Luikart *et al.* 2001; Troy *et al.* 2001; Larson *et al.* 2005). Unfortunately, ancient DNA does not preserve well in bone specimens from arid regions (Bollongino, Vigne 2008), nor is it possible for the moment to evaluate the domestication status of Neolithic specimens on the basis of ancient DNA alone and without considering the cultural contexts the specimens were collected from. The disparities between the molecular and archaeological clocks, moreover, remain considerable (Ho, Larson 2006).

Animal domestication and the emergence and spread of agro-pastoralism influenced the distribution and abundance of wild taxa, which now had to compete over food and space with their domestic descendants. Because adequate feeding of stock on the hoof appears crucial in order to ensure their continuous survival in captivity, one might ask how people dealt with this issue at the onset of husbandry practices, *i.e.* at a time when animals had to be kept within or at least close to the settlement to avoid their escaping. One promising approach to evaluate the nutritional status of vertebrate taxa is analysing the light stable isotopes preserved in the collagen and structural carbonate of their bones. Stable isotope analyses also permit (1) verification of dietary adaptations and position in the human trophic web, (2) reconstruction of palaeoenvironmental conditions at the time the settlement was inhabited, and (3) documentation of migration events (e.g. Ambrose 1993; Balasse *et al.* 2002; Grupe *et al.* 2003; Richards *et al.* 2003).

Bone collagen is a water-insoluble molecule protected by biological apatite. It can therefore survive intact for very long periods of burial underground. Stable carbon ($^{13}\text{C}/^{12}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$) isotopes

in bone collagen are related to the protein part of the diet. As a result, all essential amino acids contain carbon from dietary protein. Based on fractionation processes taking place during amino acid synthesis, the $\delta^{13}\text{C}$ -value in a consumer's bone collagen is approximately 5‰ more positive than the dietary source (for a comprehensive review see Ambrose 1993). In terrestrial environments, major fractionations occur during plant photosynthesis, for example in C_3 -plants (Calvin cycle) that discriminate significantly more against the heavy isotope ^{13}C than C_4 -plants (Hatch-Slack cycle). On average, the $\delta^{13}\text{C}$ value of C_3 -plants is -26‰ and exhibits a marked degree of variability due to differences in temperature and precipitation. The most negative values are found on the bottom of dense forests (canopy effect) and are caused by the recycling of CO_2 . C_4 -plants do not thrive in dense forests and prefer warm and more arid environments. Their $\delta^{13}\text{C}$ values are less variable and average about -12‰. Since the $\delta^{13}\text{C}$ values of C_3 - and C_4 -plants do not overlap, the $\delta^{13}\text{C}_{\text{coll}}$ of the consumer's bone collagen directly reflects the plant component of its diet (*e.g.* Richards *et al.* 2003).

Nitrogen in bone collagen is also exclusively related to dietary protein, which results in a pronounced trophic level effect and is expressed in the consumer's $\delta^{15}\text{N}$ values (Ambrose 1991, 1993). Consumers at higher trophic levels have more positive collagen $\delta^{15}\text{N}$ values. Although the enrichment in ^{15}N varies according to species specific metabolic pathways, it averages 3‰ (Minagawa, Wada 1984). It has also been established that water stress in terrestrial vertebrates results in higher $\delta^{15}\text{N}$ values in the bone collagen of water-conserving mammals (camels as well as sheep and goat to a certain degree) compared to water dependent animals (*e.g.* cattle, horse) due to the excretion of concentrated ^{15}N depleted urea (Ambrose 1991). $\delta^{15}\text{N}$ values are of primary importance for the establishment of vertebrate food webs, especially with regard to omnivorous taxa, the trophic position of which can best be established by comparison of their isotopic ratios with those from pure herbivores and carnivorous animals. The intestinal flora of ruminants may also contribute to enrichment with ^{15}N in the magnitude of a trophic level effect (Steinhour *et al.* 1982). As such, both $\delta^{13}\text{C}_{\text{collagen}}$ and $\delta^{15}\text{N}$ are climate sensitive.

Bone structural carbonate can be analyzed for its stable carbon ($^{13}\text{C}/^{12}\text{C}$) and oxygen ($^{18}\text{O}/^{16}\text{O}$) isotope signatures. In bone, CO_3 may substitute for both the PO_4 and OH groups in the crystal lattice of biological apatite and displays considerable diagenetic resistance. Adsorbed and thus labile carbonate is removed from the bone sample during sample preparation processing (H_3PO_4 treatment, for methods; Kohn, Cerling 2002). The $\delta^{13}\text{C}_{\text{carb}}$ of a consumer's bone is also related to its diet, but here the carbon is derived from blood bicarbonate, which stems from all dietary components including lipids and carbohydrates. Fractionation factors of $\delta^{13}\text{C}$ from food into bone carbonate are much higher than from diet to bone collagen: they can vary from 9.6‰ (DeNiro, Epstein 1978) to 10‰ (Ambrose 1993) and 12‰ (Krueger, Sullivan 1984; Lee-Thorp *et al.* 1989), and up to 14‰ in large ruminants (Iacumin *et al.* 1996). Fractionation factors for the pathway between dietary fat and its incorporation into the consumer's tissues are negative, hence fat is isotopically lighter than proteins and carbohydrates. Carnivores satisfy their nutritional requirements with proteins and their energy demands with lipids from their prey, while herbivores get amino acids from plant protein and the transamination of keto acids, and cover their energy needs with plant carbohydrates. Consequently, the spacing between $\delta^{13}\text{C}$ in carbonate and $\delta^{13}\text{C}$ in collagen are significantly smaller in carnivores compared to herbivores. The $\delta^{13}\text{C}_{\text{carb}} - \delta^{13}\text{C}_{\text{coll}}$ is a very useful figure to assess the trophic position of individuals in the food chain. Since $\delta^{13}\text{C}_{\text{carb}} - \delta^{13}\text{C}_{\text{coll}}$ is negatively related to $\delta^{15}\text{N}$, the $\delta^{13}\text{C}_{\text{carb}}$ -values of bones without preserved collagen can be readily compared with bones from individuals of the same species in which collagen could successfully be retrieved. For bone specimens in an advanced state of diagenesis where no intact collagen remnants are preserved, $\delta^{13}\text{C}_{\text{carb}}$ still provides valuable information about an individual's or species' trophic position. Also, it is possible to distinguish consumers of C_3 - or C_4 -plants as well as mixed feeders and forest dwelling animals.

The relationship of $\delta^{18}\text{O}$ in water to temperature is well known, and $\delta^{18}\text{O}$ has in the past frequently proved to be a valid palaeothermometer (Aitken 1991). The isotopic composition of biological apatite in mammals also depends on the temperature of the body fluids, and there is a constant offset between the $\delta^{18}\text{O}$ of the body water and the phosphate group, as well as between PO_4 and CO_3 (Iacumin *et al.* 1996; Stephan 1999; cf. also review by Kohn, Cerling 2002). Since $\delta^{18}\text{O}$ in meteoric water varies with temperature, latitude, altitude and distance from the coast, $\delta^{18}\text{O}$ in bone can function as a valuable tool in establishing the ecological origin of immigrants to the site. However, $\delta^{18}\text{O}$ in biological apatite may also be

influenced by humidity, and species specific metabolic peculiarities have to be taken into account (Luz *et al.* 1990; Koch *et al.* 1991). As far as is known at present, $\delta^{18}\text{O}$ /temperature relationships are straightforward for poikilothermic taxa, since in their tissues $\delta^{18}\text{O}$ depends largely on water composition and temperature. This relationship is much more complex in thermoregulating animals (mammals and birds), where a clear connection between humidity, diet, and metabolic constraints also exists (Kohn, Cerling 2002). Nevertheless, $\delta^{18}\text{O}$ in bone carbonate of mammals reflects the oxygen isotopy of drinking water, which in turn depends on climatic parameters, especially temperature (Longinelli 1984; Mays 2000). Consequently, the $\delta^{18}\text{O}$ -values in bone carbonate can serve as an indicator to trace the ecogeographical origin of hunted game (White *et al.* 1998; Dupras, Schwarz 2001).

MATERIAL AND METHODS

Material

The archaeofaunal remains submitted for stable isotope analysis essentially come from the Pre-Pottery Neolithic site of Nevalı Çori (37°35' N, 38°39' E). This settlement is situated in the hilly landscape of the Anti-Taurus at an altitude of *ca* 490 m ASL, some 3 km south of the Euphrates on one of its minor tributaries, the Kantara Çay. The valley of the Kantara Çay was called “Nevalı Çori” by the local inhabitants, which literally means “Valley of Pestilence”. The site was excavated in the framework of the “Archaeological Rescue Project of the Lower Euphrates”, initiated by the Turkish government prior to the flooding of the region. Archaeological work at Nevalı Çori began in 1983 and came to an end in 1992 when the Atatürk dam was put into operation (Hauptmann 1993, 1999).

Neolithic site habitation at Nevalı Çori probably started at the transition from the PPNA to the PPNB and lasted throughout the PPNB (Schmidt 1998a). Five Neolithic occupation levels (I-V) with more than 25 buildings have been excavated. The bulk of the archaeofauna analysed comes from Early and Middle PPNB contexts. Radiocarbon dates have been processed on different materials (Schmidt 1998a, pers. comm. 2004; Thissen 2002). The correspondence of the consecutive levels to the chronostratigraphy is outlined in table 1. Materials from occupation Level V are rare because of post-depositional erosion. From an architectural viewpoint clear parallels exist between the house types found at Nevalı Çori and those recorded from Çayönü Tepesi. At Nevalı Çori, however, a ritual area was also excavated. It is characterised by an elaborate architecture and the presence of megalithic art in form of a T-shaped stone pillar (Hauptmann 1999). This pillar is smaller than the ones uncovered at late PPNA Göbekli Tepe, but its overall shape as well as the motif depicted on it—a pair of human arms with hands in bas-relief—show close similarities with the decorated megaliths from Göbekli Tepe.

At Early PPNB Nevalı Çori the presence of livestock has been postulated using criteria such as diachronic changes in taxonomic frequencies, significant (osteo)morphological and -metrical changes, and a shift in the pattern of exploitation of a species, as reflected by its age profile (Peters *et al.* 2005). Recently the use of changes in ungulate body size to differentiate the wild ancestor from its domestic descendant has been challenged because size reduction may not necessarily occur at the beginning of the process (Vigne 2000; Zeder, Hesse 2000). Moreover, the size of wild as well as domestic populations can be affected by other phenomena such as climate (Davis 1987; Peters 1998), whilst conscious breeding can even produce animals of the same size or larger than the progenitors. Nevertheless, it could be shown that Early Holocene populations of ungulates tend to react with a reduction of body size to the changes imposed on them during the process of domestication, unconscious selection by humans favouring smaller and perhaps not fully mature animals for reproductive purposes likely being a key factor (Uerpmann 1996; Zohary *et al.* 1998).

A total of 90 human bones and 140 animal bone finds have been subjected to collagen isotope analysis from the Nevalı Çori assemblage. A sub-sample of 44 specimens was also subjected to structural carbonate analysis. The carbonate analyses of the remaining animal bone specimens are still in progress. While the animal bones represent consumption refuse, the human bones analysed in this study originate from burials in domestic structures and, as such, have been found commingled with the animal bones. Bone specimens

were sorted according to their stratigraphical position (K. Schmidt, pers. comm. 2004) and care was taken to avoid the investigation of more than one bone from the same individual by selecting few skeletal elements for each taxon and by taking samples from archaeological features located at a distance from each other.

Level	Culture	Material dated	Lab. No.	¹⁴ C-dates BP	cal. BC 68	cal. BC 95
I/II	Early PPNB	human bone	OxA-8303	9280 ± 55	8490 ± 110	8720-8270
		animal bone	KIA 14756	9263 ± 42	8470 ± 100	8670-8270
		cereal	Hd-16782-351	9243 ± 55	8450 ± 100	8650-8250
		cereal	Hd-16783-769	9212 ± 76	8440 ± 110	8660-8220
		animal bone	KIA 14762	9207 ± 43	8420 ± 90	8600-8240
		human bone	OxA-8235	9180 ± 60	8410 ± 90	8590-8230
		animal bone	KIA 14760	9100 ± 43	8340 ± 70	8480-8200
		human bone	OxA-8236	8960 ± 60	8120 ± 110	8340-7900
III	Late Early PPNB	human bone	OxA-8234	8930 ± 60	8090 ± 110	8310-7870
		animal bone	KIA 14757	9020 ± 41	8180 ± 90	8360-8000
	Early Middle PPNB	human bone	OxA-8382	8990 ± 90	8130 ± 140	8410-7850
		human bone	OxA-8381	8710 ± 100	7810 ± 160	8130-7490
IV	Middle PPNB	animal bone	KIA 14758	8864 ± 48	8020 ± 140	8300-7740
		animal bone	KIA 14761	8778 ± 46	7860 ± 110	8080-7640
		human bone	OxA-8247	8610 ± 90	7690 ± 110	7910-7470

Table 1—¹⁴C-dates available for Nevalı Çori. The stratigraphic position of the dated materials following K. Schmidt (1998a, pers. comm. 2006). BP dates with SD, calibrated dates at the 65% and 95 % level as available at <http://www.context-database.de>

Methods

The samples were first mechanically cleaned under running tap water, followed by an ultrasonic cleaning in distilled water and air drying. About 500 mg of each sample were pulverised in a ZrO₂-coated mill.

Gelatine was extracted by demineralisation of about 250 mg whole bone powder in 10 mL HCl for 20 minutes under constant motion. The sample was then centrifuged for 5 minutes at 3000 rpm and washed with distilled water. The pellet was then transferred to 10 mL 0.125M NaOH and remained in solution for 20 hours under constant motion, followed by centrifuging and washing. Last, the sample was incubated into 10 mL 0.001M HCl for a minimum of 10 (maximum 17) hours at 90°C, filtered (pore size 5 µm) and lyophilized. Carbon and nitrogen isotope ratios of the gelatine were measured by a Thermo Finnigan mass spectrometer, coupled with a CNH-analyser (NA 2500), and expressed by the conventional δ-notation against PBD- or AIR-standard, respectively. Calibration of the laboratory standard was matched against IAEA standards NBS 19 and NBS 20 (for CO₂), and against N 1 and N 2 (for N₂). Measurement error never exceeded 0.15‰.

To check for the integrity of the extracted gelatine, 2 mg of each of the lyophilised samples was hydrolysed with 1 mL 6N HCl for 11 to 15 hours at 115°C. After evaporation of the acid, the hydrolysate was solubilised in 1 mL 0.2M lithium-citrate-buffer (pH 2.2). Then, 40 µL from each solution was used in amino acid analysis (amino acid analyser LKP Alpha Plus II, Pharmacia).

About 100 mg whole bone powder was incubated into 5 mL 4% NaOCl for two to three days (until gas development was completed) for extraction of the structural carbonate. The solution had to be changed after the first day in several cases. The sample was then centrifuged for 5 min. at 5000 rpm and washed in distilled water. The pellet was transferred into 5 mL acetate/acetic acid-buffer (pH 4.75) and remained for 5 hours under constant motion. The samples are then centrifuged, washed and lyophilised again. Finally, they are placed in an oven at 50°C for several hours. Stable carbon and oxygen isotope ratios of the structural carbonate are determined using a coupled analysis system (Thermo Finnigan mass spectrometer, Gasbench II and Delta plus). Laboratory standards were calibrated against IAEA standards NBS 18 and NBS 19. Isotopic ratios are expressed in the δ -notation against a PDB-standard. Measurement error never exceeded 0.1‰.

RESULTS

Bone collagen

A total of 44 out of 90 human bone fragments could be analysed in terms of collagen isotopic ratios at Nevalı Çori, since only 56 specimens yielded any gelatine at all, while the gelatine of 12 of these did not meet the criteria—molar C/N ratio, %C, %N, amino acid profile—for a state of preservation that would permit a valid interpretation of the δ -values. Care was taken to check all four criteria, with amino acid analyses being carried out to verify the integrity of the collagen in specimens which had been considered “good” based on the other three criteria (see fig. 4 in Lösche *et al.* 2006). A sub-sample of 20 human and 24 animal bones were analysed for stable isotopes in the structural carbonate. Average apatite proportions were 72.71% for human and 67.57% for animal bones; hence the expectation of approximately 70% apatite in whole bone was met. We are, however, aware of the present and for the moment still unavoidable shortcoming of a lack of adequate integrity checks for the structural carbonate which would be equivalent to those available for collagen. Measurement data are summarised in table 2.

The $\delta^{13}\text{C}$ - and $\delta^{15}\text{N}$ -values for the collagen extracts of human bones are plotted in figure 1. With the exception of a single adult human individual which on stratigraphical grounds turned out to be of

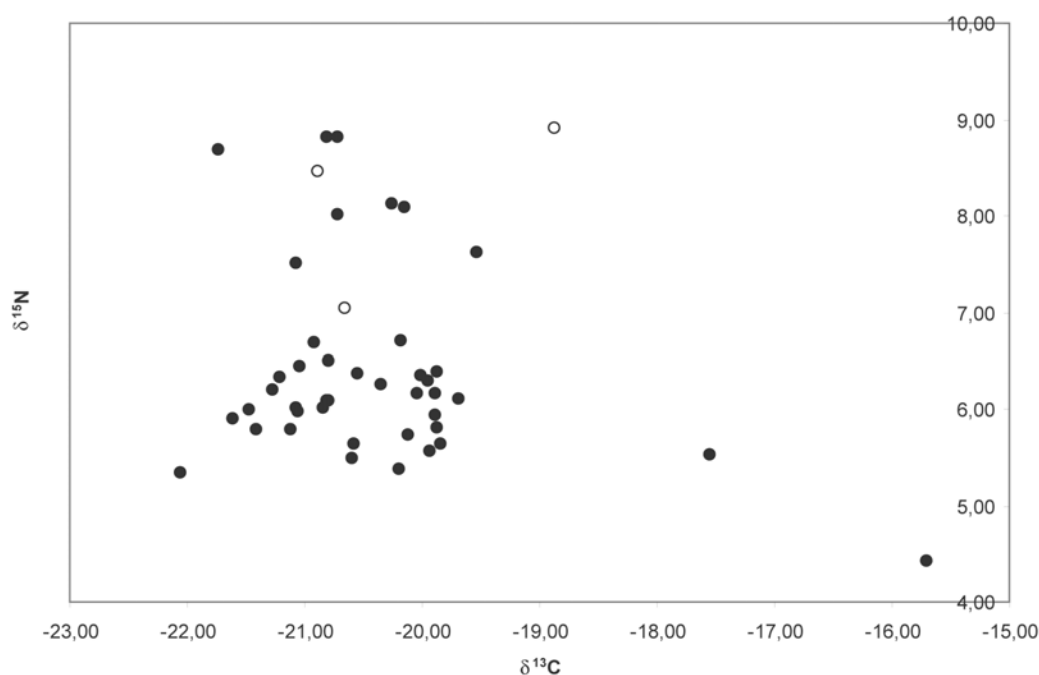


Fig. 1—Bivariate plot of $\delta^{13}\text{C}_{\text{collagen}}$ and $\delta^{15}\text{N}$ for human bones, all strata. Note the exceptional position of a single post-Neolithic individual (bottom right). Open circles: children younger than three years of age.

post-Neolithic origin, all $\delta^{13}\text{C}$ -values measured range between -23‰ and -18‰. These values clearly indicate a C_3 -plant biome. The aforementioned human sample had a significantly more positive $\delta^{13}\text{C}$ -value which is best interpreted by mixed consumption of C_3 - and C_4 -plants. The same individual is also conspicuous in terms of its carbonate isotopic signatures (see below). The human $\delta^{15}\text{N}$ -values show a considerable variability, ranging from a minimum of 4.43‰ to a maximum of 8.83‰. However, the majority of the adult humans cluster nicely between 5‰ and 7‰, while only few individuals display $\delta^{15}\text{N}$ -values between 7‰ and 9‰. Elevated $\delta^{15}\text{N}$ -values are also visible in the isotopic signature from the three bones from children younger than three years of age. These children were likely not yet completely weaned and therefore reveal a more “carnivorous” dietary signature. Unfortunately, due to the high degree of fragmentation of the human bones, no relationship between $\delta^{15}\text{N}$ and biological markers (sex, stature) could be assessed. A look at the median carbon and nitrogen isotopic ratios of human bone collagen reveals no diachronic trend (table 3). For all levels, average $\delta^{15}\text{N}$ is not much higher than 6‰. Obviously plant foods were very important in the diet of the Nevalı Çori inhabitants.

Species	n coll/ n carb	$\delta^{15}\text{N}_{\text{coll}}$	sd	$\delta^{13}\text{C}_{\text{coll}}$	sd	$\delta^{13}\text{C}_{\text{carb}}$	sd	$\delta^{18}\text{O}_{\text{carb}}$	sd	$\delta^{13}\text{C}_{\text{carb}}$ - $\delta^{13}\text{C}_{\text{coll}}$
Man, adult <i>Homo sapiens</i>	42/17	6,14 (4,43/8,83)	1	-20,6 (-22,06/-15,71)	1,1	-12,53 (-13,52/-7,93)	1,3	-7,35 (-8,55/-5,55)	0,7	8,26
Man, infans <i>Homo sapiens</i>	3/3	8,46 (7,04/8,91)	1	-20,66 (-20,9/-18,87)	1,1	-13,63 (-13,88/-12,32)	0,8	-7,44 (-7,66/-6,69)	0,5	6,87
Aurochs <i>Bos primigenius</i>	4/2	8,2 (7,85/9,01)	0,5	-19,99 (-22,22/-19,10)	1,3	-12,23 (-12,30/-12,16)	0,1	-11,1 (-12,48/-9,72)	2	8,77
Red deer <i>Cervus elaphus</i>	5/2	6,9 (5,55/7,85)	0,8	-20,88 (-22,66/-20,56)	0,9	-11,87 (-12,21/-11,52)	0,5	-9,74 (-13,05/-6,42)	4,7	10,35
Goitered gazelle <i>Gazella subgutturosa</i>	7/2	6,62 (5,85/7,28)	0,6	-20,02 (-20,48/-19,48)	0,4	-11,5 (-11,98/-11,02)	0,7	-8,6 (-13,83/-3,36)	7,4	8,25
Asiatic wild ass <i>Equus hemionus</i>	1/0	7,2		-20,42						
(Domestic) sheep <i>Ovis orientalis</i> (f. <i>aries</i>)	5/2	6,1 (5,22/7,30)	0,9	-20,3 (20,76/-19,92)	0,3	-11,57 (-12,07/-11,07)	0,7	-10,31 (-13,61/-7,01)	4,7	8,55
Hare <i>Lepus capensis</i>	7/4	4,82 (2,37/9,03)	2,7	-21,42 (-21,73/-19,24)	1	-11,93 (-12,42/-11,17)	0,5	-10,87 (-13,07/-7,33)	2,4	8,9
(Domestic) goat <i>Capra aegagrus</i> (f. <i>hircus</i>)	5/2	6,33 (3,92/6,80)	1,2	-20,41 (-21,25/-19,29)	0,7	-11,2 (-11,43/-10,96)	0,3	-13,07 (-14,08/-12,06)	1,4	8,79
(Domestic) pig <i>Sus scrofa</i> (f. <i>domesticus</i>)	8/2	5,54 (3,86/8,18)	1,2	-20,33 (-20,69/-19,92)	0,3	-11,59 (-12,15/-11,02)	0,8	-11,3 (-14,16/-8,43)	4,1	8,75
Badger <i>Meles meles</i>	3/2	9,46 (9,02/9,47)	0,3	-18,61 (-19,04/-18,29)	0,4	-12,72 (-13,30/-12,13)	0,8	-6,67 (-6,89/-6,44)	0,3	5,95
Red fox <i>Vulpes vulpes</i>	3/2	9,58 (7,79/10,27)	1,3	-21,12 (-21,51/-19,76)	0,9	-12,06 (-12,38/-11,74)	0,5	-10,13 (-13,80/-6,45)	5,2	8,38
Dog <i>Canis lupus</i> f. <i>familiaris</i>	2/1	8,94 (8,90/8,98)	0,1	-19,18 (-19,30/-19,06)	0,2	-12,47		-9,98		6,59
Wolf <i>Canis lupus</i>	0/1					-12,29		-6,38		
Wild cat <i>Felis silvestris</i>	1/1	8,41		-18,20		-12,62		-7,16		5,58
Sand cat <i>Felis margarita</i>	1/0	7,37		-18,93						

Table 2—Collagen and carbonate isotopic ratios for human and animal bone finds from Nevalı Çori.

n coll/n carb = number of specimens for collagen and carbonate analyses, respectively.

sd = standard deviation. For all δ -values, median value and variability (in brackets) are listed.

For individual values see Lösch et al. 2006, table 3.

Species	n	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
Early domestic sheep	2	5,22; 6,10	-20,30; -19,92
Wild sheep	2	5,28; 7,30	-20,76; -19,94
Early domestic goat	1	5,99	-21,25
Wild goat	2	6,52; 6,33	-20,67; -20,41
Early domestic pig	4	3,86; 4,82; 5,40; 8,18	-20,57; -20,46; -20,33; -20,18
Wild boar	4	5,18; 5,67; 5,81; 6,10	-20,69; -20,33; -20,06; -19,92

Table 3—Comparison of collagen stable isotope ratios of wild sheep, goats and pigs compared to values obtained from their relatives likely being culturally controlled by humans.

The bivariate plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of animal bone collagen (fig. 2) reveals a clear separation of the carnivores and herbivores, with omnivores overlapping. As might be expected, wild cat, red fox and dog are located at the top of the food chain. Their bones show $\delta^{15}\text{N}$ -values between 7.5‰ and 10‰, which on average is 3–4‰ above the values recorded for herbivores.

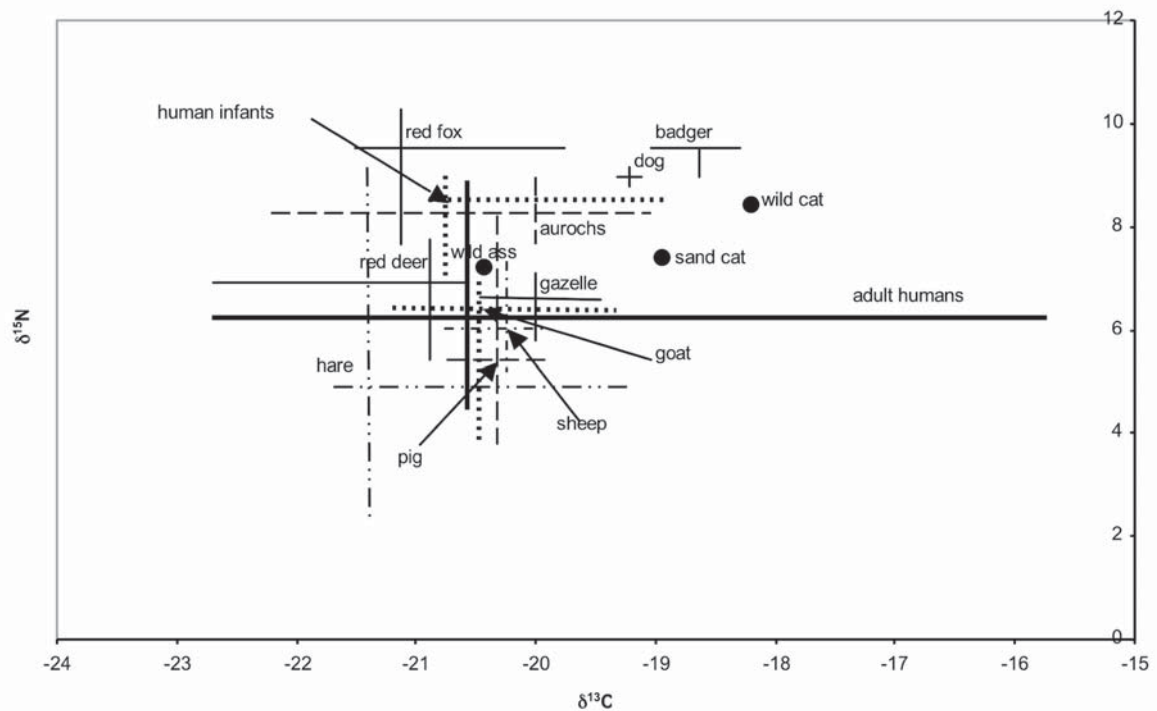


Fig. 2—Vertebrate food web including humans at Nevalı Çori, based on collagen stable isotope analyses. Median values and total variability are plotted for each species.

The high position in the food web of the omnivorous badger may be somewhat puzzling, but here it serves as a reminder that the diet of a badger may consist of up to 50% earthworms, *i.e.* animals rich in proteins and fat.

Also conspicuous is the high median $\delta^{15}\text{N}$ value (8.20‰) for the herbivorous aurochs. Richards *et al.* (2003) made a similar observation for the aurochs at Neolithic Çatalhöyük. Given the large size of aurochs, plant foods with high protein contents would be selected when available. Fizet *et al.* (1995) state that

the urea excretion of bovids (and equids) is proportionate to the protein content of their food, that is, the lower the protein content, the lower the urea excretion will be. Since urea is depleted from the heavy nitrogen isotope (Ambrose 1991), the animal's body tissues become enriched with ^{15}N . As such, even the consumption of large amounts of food with low protein contents would lead to a considerable enrichment of the consumer's collagen with ^{15}N . Another possible explanation would be the recycling of nitrogen by ruminant bacteria, the amount of which is dependent on the kind of plants consumed (Hristov 2002), but which would also cause elevated $\delta^{15}\text{N}$ -values in the consumer's tissues. The latter hypothesis, however, can no longer be tested anymore since the Anatolian aurochs population is extinct.

A high variability in $\delta^{15}\text{N}$ values may be observed in hares. It probably relates to the remarkable capability in lagomorphs for extracting maximum value from their food. Their faecal material consists of two types: moist pellets, which are expelled and later eaten, and dry pellets, which are not eaten. The moist pellets are swallowed with little or no chewing, so most of the food travels through the digestive tract twice. Since hares prefer open habitats, the *Lepus* bones analysed in this study have the most negative $\delta^{13}\text{C}_{\text{collagen}}$ -values, even lower than the forest-dwelling red deer. This observation corroborates the assumption based on the ecological requirements of the taxa evidenced at Nevalı Çori that the site environs were characterised by open grasslands with stands of trees and shrubs rather than by densely forested areas.

All in all, the collagen isotopic ratios measured meet expectations in view of the feeding preferences of the different mammalian taxa identified at Nevalı Çori, while the human bones exhibit conspicuously low $\delta^{15}\text{N}$ -values with regard to an early Neolithic community which, on archaeozoological evidence, employed a broad spectrum meat procurement strategy based on large and small game hunting and livestock keeping. However, at the transition from the Early to the Middle PPNB the contribution to the human diet of meat from stock-on-the-hoof may perhaps not have exceeded 10% to 15% of the total meat intake (Peters *et al.* 2005).

Of particular interest, however, is the fact that within a single taxon, the isotope signature found in large-sized wild individuals differs from that obtained in individuals assumed to be kept spatially and genetically isolated from their wild relatives because of their relatively small size. When compared to values found in their free-ranging wild relatives, the latter specimens, though few in numbers, exhibit lower $\delta^{15}\text{N}$ values (*table 3*). We interpret the differences between the $\delta^{15}\text{N}$ -values of the large, wild animals and the small, presumably culturally-controlled individuals to the fact that the latter were being intentionally nourished by their owners.

Bone carbonate

The $\delta^{13}\text{C}_{\text{carbonate}}$ -values in human and animal bones vary from -13.70‰ to -11.20‰, which again fits a C_3 -plant biome according to the fractionation model developed by Lee-Thorp *et al.* (1989). A bivariate plot of $\delta^{15}\text{N}_{\text{collagen}}$ versus the $\delta^{13}\text{C}_{\text{carbonate}}/\delta^{13}\text{C}_{\text{collagen}}$ spacing (*fig. 3*) is in accordance with the trophic web based on collagen isotopic ratios, in that carnivores as well as human infants have higher $\delta^{15}\text{N}$ -values and lower $\delta^{13}\text{C}_{\text{carbonate}}/\delta^{13}\text{C}_{\text{collagen}}$ spacing. With regard to the adult humans, their largely herbivorous diet is confirmed.

The median $\delta^{18}\text{O}$ -value in humans (adults as well as infants) is -7.36‰, with a standard deviation of 0.70‰ only and no detectable diachronic trend. This suggests that all the PPN individuals hitherto analysed shared the same source(s) of drinking water, likely the Kantara Çay water course. The homogeneity of the $\delta^{18}\text{O}$ -values may also imply that the site inhabitants' movements were restricted in space, an observation supporting the assumption that their mode of subsistence already included the cultivation of plants, *e.g.* domestic einkorn (Pasternak 1998; Tanno, Willcox 2006), and the keeping and breeding of animals (Peters *et al.* 2005). Conceivably in Pre-Pottery Neolithic times, the mean annual temperatures may have been fairly constant in the Anti-Taurus region and along the Upper Euphrates, an idea confirmed by pollen analysis (Van Zeist, Bottema 1982; Hillman 1996) and supported by the osteometrical data of carnivore and ungulate taxa (Helmer *et al.* 1998; Peters *et al.* 1999, 2005).

An exception to the homogeneity in $\delta^{18}\text{O}$ -values observed is the aforementioned post-Neolithic adult individual, the only person displaying a C_4 -plant contribution to its nearly exclusive herbivorous diet

($\delta^{15}\text{N}$ 4.43‰, $\delta^{13}\text{C}_{\text{collagen}}$ -15.71‰). With a $\delta^{13}\text{C}_{\text{carbonate}}$ of -7.93‰ and a $\delta^{18}\text{O}$ of -5.55‰ (fig. 4), this individual obviously originated from a warmer, more arid region where C_4 -plants thrive, and must have come to Nevalı Çori not too long before his death.

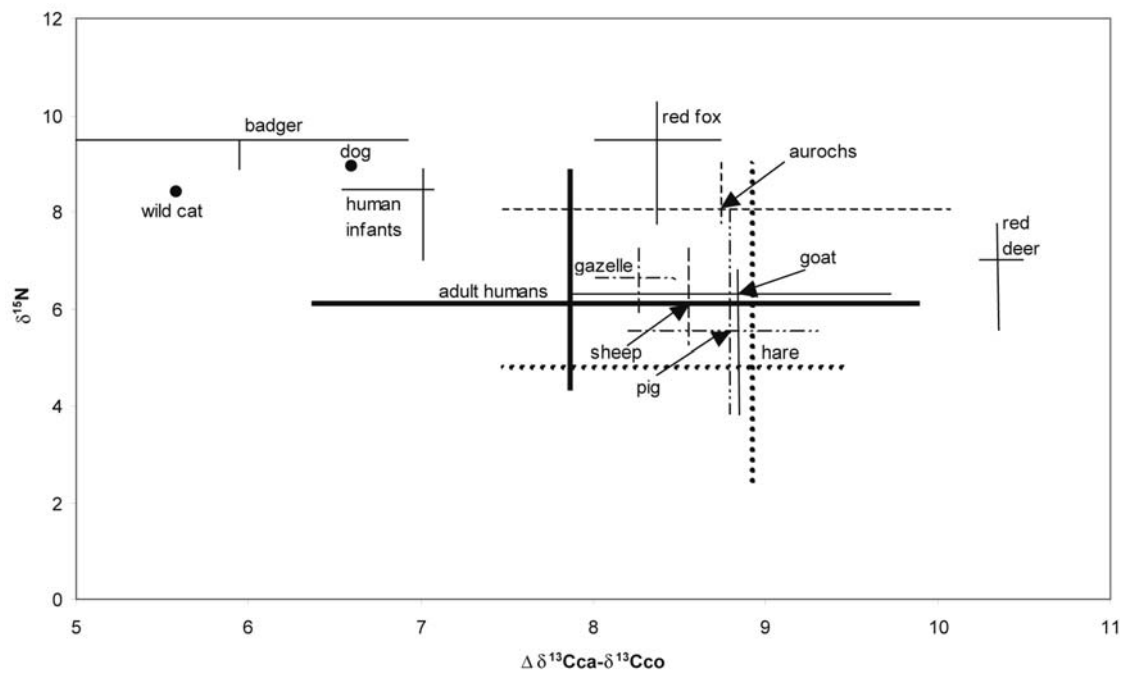


Fig. 3— $\delta^{15}\text{N}_{\text{collagen}}$ versus $\delta^{13}\text{C}_{\text{carbonate}}/\delta^{13}\text{C}_{\text{collagen}}$ spacings in humans and animals. Median values and total variability are plotted for each species.

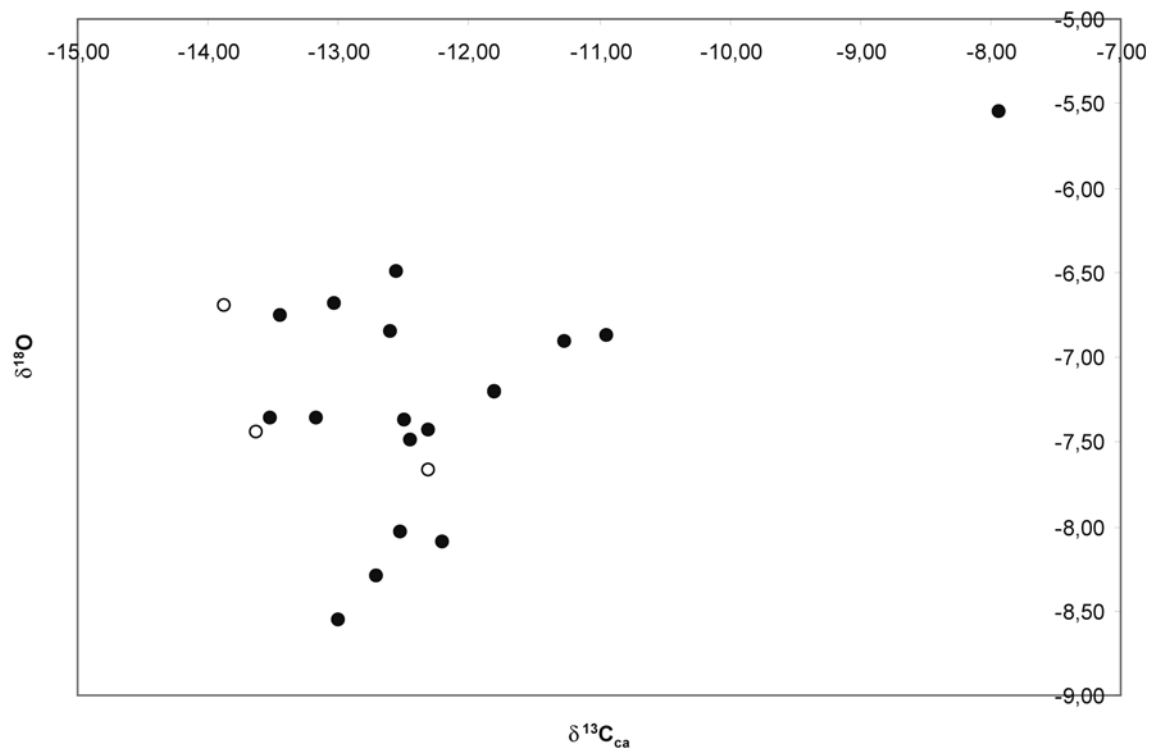


Fig. 4—Bivariate plot of carbonate $\delta^{13}\text{C}$ - and $\delta^{18}\text{O}$ -values for human bones. The conspicuous individual already indicated in fig. 1 also differs in terms of the carbonate isotopic ratios it displayed.

Open circles: Children younger than three years of age.

The interpretation of $\delta^{18}\text{O}$ -values in animal bones is less straightforward, since not only drinking behaviour (obligatory *versus* irregular or non-drinkers) has to be taken into account, but also other metabolic specificities like thermoregulation. Browsing animals, for instance, will consume plant leaves enriched with ^{18}O , since evaporation of H_2^{16}O is facilitated. Animals which pant or sweat preferably will exhale or excrete the light oxygen isotope, hence their body tissues become enriched with ^{18}O (Sponheimer, Lee-Thorp 2001). Nocturnal animals consume plants which are comparatively depleted in ^{18}O , since evaporation rates are highest at noon (Förstel 1982; Sponheimer, Lee-Thorp 1999). Some interesting issues can already be addressed, however, even using this limited set of data. Based on the body part distribution of ungulate remains at Nevalı Çori, Schmidt (1998b) suggested many hunting activities may have taken place at higher altitudes, particularly in the mountain ranges close to the settlement. Since at that time, animal husbandry appears still to have been in its infancy, many *Capra* bones found at the site could have derived from such hunting trips to the steeper, higher slopes of the Anti-Taurus where bezoar goat occurs naturally. The arid-environment adapted goitred gazelle *Gazella subgutturosa*, on the other hand, likely preferred the warmer, drier foothills of the Anti-Taurus and the adjacent Syrian steppe. The difference in mean annual temperature between the mountainous and steppic habitats is reflected by the $\delta^{18}\text{O}$ signature, with significantly lower values in *Capra* compared to *Gazella* (fig. 5). Neither would the inhabitants of this settlement necessarily have had to make long-distance hunting trips to obtain gazelles or wild goats. These herbivores are known to undertake migrations related to temperature, precipitation and (seasonal) availability of preferred food plants. Conceivably the site's locality near the ecotone of the Anti-Taurus and the Syrian steppe enabled the inhabitants to hunt wild goats during winter when the snow covered mountains forced *Capra* to descend in order to feed at lower altitudes, and to pursue gazelles in spring/early summer, when there would have been ample vegetation cover after the rains.

Since aurochs, red deer and sheep on average exhibit $\delta^{18}\text{O}$ -values between those obtained for *Capra* and *Gazella*, their signatures likely reflect the conditions of more temperate open woodland and river valley habitats suitable not only for them but also the human population inhabiting the settlement. Presumably, the isotope signatures of *Bos*, *Cervus* and (domestic) *Ovis* reflect the mean annual temperature which once characterised the Nevalı Çori settlement area and the nearby Euphrates valley.

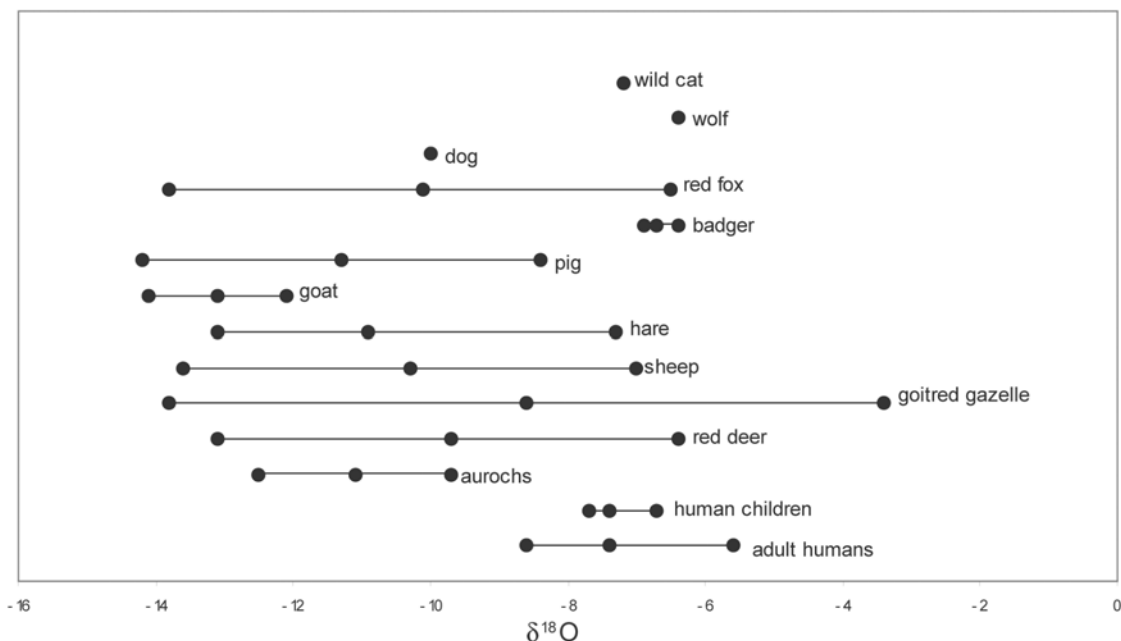


Fig. 5—Variability and median $\delta^{18}\text{O}$ per species, also reflecting fine-scaled climatic conditions at the site (cf. text).

DISCUSSION

While the distribution and variability of stable isotopes in bone collagen and carbonate of the various animal species from Nevalı Çori meet expectations relative to their feeding habits, habitat preferences and metabolism specifics, the largely plant-oriented human dietary spectrum was totally unexpected (fig. 2). One possible interpretation of the stable isotope signatures measured in the Early and Middle PPNB humans of Nevalı Çori is that they contradict a stable animal protein supply, suggesting that this aceramic Neolithic community may have faced difficulties securing meat. However, while traditional hypotheses explaining the success of the Neolithisation process underline the enhanced security and predictability of the meat supply, related to the domestication of the herbivorous sheep and goat, and which accordingly became one of the main criteria to separate the Neolithic from the preceding Protoneolithic (Uerpmann 1979), in hindsight this perspective may be flawed. Based on what is known from the archaeological and ethnographic record throughout the world we know that the transition from hunting and gathering to farming eventually resulted not only in more work but also in poorer quality nutritional conditions and heavier disease burdens (Cohen, Armelagos 1984; Diamond 1992). Palaeopathological findings of human teeth, in particular the high frequency of Linear Enamel Hypoplasia (25 out of 45 individuals), corroborates the view that the population living at PPN Nevalı Çori suffered from health problems. However, a trend toward lower LEH-frequencies in individuals associated with the later Early Neolithic levels can be observed, and this has been tentatively interpreted as evidence for an improved mastery of agricultural techniques during the course of the Pre-Pottery Neolithic (Teegen, Schultz 1997). Conceivably the primary concern during the search for a new home territory by the Nevalı Çori founder generation may have been locating soils suitable for plant cultivation, primarily domestic einkorn *Triticum monococcum* and pulses (Pasternak 1995, 1998). Thus, game availability and density may have been a less decisive criterion in selecting the Kantara Çay valley as a place to settle.

However, there may be another phenomenon which at least partly—if not completely—accounts for the unexpectedly low $\delta^{15}\text{N}$ -values in the human bones from Nevalı Çori, namely the regular consumption of legumes by the site inhabitants. The pulses exploited by the early PPN peoples of South-eastern Anatolia include lentils *Lens* spp., field peas *Pisum* spp., grass-peas *Lathyrus* spp., and bitter vetch *Vicia ervilia* (e.g. Pasternak 1995, 1998; Miller 2002). Pulses generally have very low $\delta^{15}\text{N}$ -values due to the way they fix molecular nitrogen using symbiotic bacteria. In turn this process may be reflected in the consumer's collagen. Presumably the regular consumption of larger quantities of legumes considerably lowered the $\delta^{15}\text{N}$ -values in human bone. In addition, pulses are rich in protein (up to 25%), though the bio-availability of dietary protein is dependent on its content of essential amino acids. Wheat for instance is low in lysin, while beans are low in methionine. Hence, a combination of wheat and beans or cereals and pulses in general, can lead to a protein supply for the human consumer resulting potentially in a bio-availability of up to 90%. In this respect, it is of interest that in Neolithic South-eastern Anatolia, where people consumed pulses most, their contribution to the human diet obviously declines over the course of the Neolithic, a parallel phenomenon with the growing importance of animal husbandry. This pattern makes sense on nutritional grounds since regardless of peoples' conscious knowledge, a steady supply of meat or milk would satisfy the same human protein needs as the consumption of pulses together with cereals (Miller 2002).

Since the common reconstruction of vertebrate food webs based on bone collagen isotope ratios such as the one presented in this paper for Nevalı Çori, relies exclusively on the analysis of mineralised hard tissues (the material mostly preserved in archaeological contexts and therefore available for study, as opposed to parts of edible plants), one shortcoming of any such approach is the lack of exact isotopic baseline data for the proportion of vegetation entering the food chain. A quantification of the gross nutritional entities (e.g. plants, meat) in the population's daily diet would be highly desirable. At present, such an assessment of the relative contribution of dietary items reflected in the consumer's collagen isotopic ratio is still very difficult. For modern ecosystems, a software for isotopic sourcing is available from the US Environment Protection Agency (cf. Phillips, Gregg 2003), but whether this type of modelling is suitable for assessment of past ecosystems is still a matter of debate (e.g. Bocherens, Drucker 2006; Richards *et al.* 2006).

As early as 1991, Schwarcz (1991) introduced a linear mixing model to approximate the proportion of dietary items which accumulate in the collagen isotopic signature of the consumer's bone. Basically,

the measurement of two isotopic ratios (here: $\delta^{13}\text{C}$, $\delta^{15}\text{N}$) permits the reconstruction of the contribution of three end-members of the consumer's diet. It has recently been questioned whether such conservative models are applicable at all, since they are based on the assumption that all dietary end-members equally contribute both elements to the diet or their isotopic ratios respectively. In other words, the gross C/N ratios of the dietary components should be the same (Phillips 2001). While this certainly does not hold for whole plants compared to edible animal tissues (meat, fat), it should be recalled that stable C and N isotopic ratios in the consumer's bone collagen are only related to dietary protein. Given this prerequisite, we have tried to establish a linear mixing model for the average human diet at Nevalı Çori.

To achieve this goal, the isotopic ratios of the dietary end-members have to be estimated from the measured collagen isotopic ratios under consideration from the known fractionation factors (e.g. Newsome *et al.* 2004): first, the isotopic signature of edible plants is estimated from the bone collagen isotopic data from pure, preferably non-ruminant herbivores: $\delta^{13}\text{C}_{\text{plant}} = \delta^{13}\text{C}_{\text{herbivore collagen}} - 5\text{‰}$; and $\delta^{15}\text{N}_{\text{plant}} = \delta^{15}\text{N}_{\text{herbivore collagen}} - 3\text{‰}$. Second, the isotopic signature of animal meat is estimated on the basis of bone collagen isotopic data from the consumer: $\delta^{13}\text{C}_{\text{meat}} = \delta^{13}\text{C}_{\text{consumer collagen}} - 4\text{‰}$, and $\delta^{15}\text{N}_{\text{meat}} = \delta^{15}\text{N}_{\text{consumer collagen}}$ (the variation of $\delta^{15}\text{N}$ in the various proteins in an individual body is negligible; Ambrose, Norr 1993). Last, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of the *total* diet of a human being are assumed to be 5‰ and 3‰ lower than the respective isotopic signatures measured in the human bone collagen. For the approximation of the human diet at Nevalı Çori, end-members chosen were the edible plants (calculated from the bone collagen isotopic ratios of hare and Asiatic wild ass), gazelle meat (more than 50% of the animal bones recovered were identified as *Gazella* bones), and sheep and goat as representatives of the other consumed taxa. The linear mixing model is based on the assumption that

$$\delta^{15}\text{N}_{\text{consumer collagen}} = f_1\delta^{15}\text{N}_{\text{vegetation}} + f_2\delta^{15}\text{N}_{\text{gazelle meat}} + f_3\delta^{15}\text{N}_{\text{sheep/goat meat}} \quad (1)$$

$$\delta^{13}\text{C}_{\text{consumer collagen}} = f_1\delta^{13}\text{C}_{\text{vegetation}} + f_2\delta^{13}\text{C}_{\text{gazelle meat}} + f_3\delta^{13}\text{C}_{\text{sheep/goat meat}} \quad (2)$$

$$\text{and } f_1 + f_2 + f_3 = 1. \quad (3)$$

End-members are abbreviated as follows: vegetation = A, gazelle meat = B, sheep/goat meat = C, and the consumer collagen = D; so that f_{1-3} appears as f_{A-C} . The resolution of the three unknown factors f_{A-C} is calculated based on these equations

$$f_A = (\delta^{15}\text{N}_C - \delta^{15}\text{N}_B) * (\delta^{13}\text{C}_D - \delta^{13}\text{C}_B) - (\delta^{13}\text{C}_C - \delta^{13}\text{C}_B) * (\delta^{15}\text{N}_D - \delta^{15}\text{N}_B) / \\ (\delta^{15}\text{N}_C - \delta^{15}\text{N}_B) * (\delta^{13}\text{C}_A - \delta^{13}\text{C}_B) - (\delta^{13}\text{C}_C - \delta^{13}\text{C}_B) * (\delta^{15}\text{N}_A - \delta^{15}\text{N}_B) \quad (4)$$

$$f_B = (\delta^{13}\text{C}_D - \delta^{13}\text{C}_C) - (\delta^{13}\text{C}_A - \delta^{13}\text{C}_C) * f_A / (\delta^{13}\text{C}_B - \delta^{13}\text{C}_C) \quad (5)$$

$$\text{and } f_C = 1 - f_A - f_B \quad (6)$$

The resulting model approximates a proportion of 82% plant protein and 18% protein from the meat of goats, sheep and gazelles in the human diet as a whole (fig. 6), whereby 8% of this animal protein would have been derived from gazelles alone. This approximation confirms a) the interpretation of the human stable isotopic data in terms of a largely plant-oriented diet since roughly 80% of the dietary protein would be derived from plants, and verifies b) the preponderance of gazelles among the hunted animals. Note that the estimation of the isotopic signatures of the edible plants results in a very low $\delta^{15}\text{N}$ (fig. 6), supporting our hypothesis that the majority of bio-available protein could have been supplied by pulses.

Such an approximation would also be useful for the reconstruction of animal diets, e.g. in case of predator/prey relationships, or for the estimation of the percentages of C_3 - and C_4 -plants in an herbivore's diet, an important issue relative to the later phases of the Neolithic transition. It is important to stress at this point that these models are very conservative approximations. In addition they have been established using

pooled isotopic data obtained per species. No doubt, the resulting percentages will therefore not hold for every individual, but are helpful in defining the gross composition of the daily diet, which in turn should help characterise the mode of subsistence. For the single, post-Neolithic human individual analysed in the course of this study (see above), its $\delta^{13}\text{C}_{\text{collagen}}$ (-15.7‰) would result from a plant food mixture composed of 72% C_3 - and 28% C_4 -plant protein, or roughly 3/4 C_3 - and 1/4 C_4 -plants.

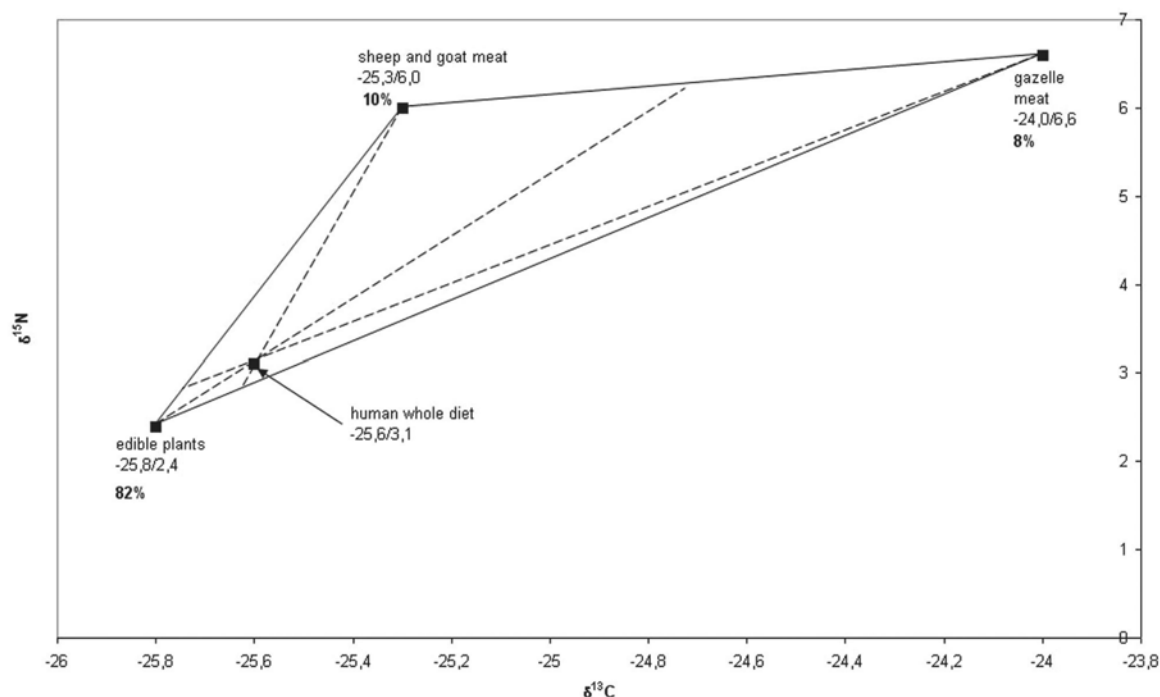


Fig. 6—Conservative linear mixing model for the gross composition of the human diet at Nevalı Çori.
For the estimation of the stable isotopic signatures of the dietary end-members see text.

Also of interest are the lower $\delta^{15}\text{N}$ -values in the collagen of bones considered to represent animals under cultural control based on their relative small size (see above). The difference is most pronounced in pigs, for which the assumed early domestic form subsumes more trophic levels than does wild boar, and has $\delta^{15}\text{N}$ -values ranging from those characteristic of a pure herbivore to those exhibited by omnivores. Based on present-day observations, it has been noted that grazing pressure exerted on the vegetation cover by herds of ungulates quickly causes a decline in legumes relative to other wild plants, since legumes are selected for by the grazing animals because of their high energy yield. Because of their reduced mobility compared to wild animals, the continuous keeping of early domestic stock near the settlement would likely have resulted in a reduction of legumes in the vegetation cover, if not overgrazing. In this respect, the lowered $\delta^{15}\text{N}$ -values in the small *Ovis*, *Sus* and *Capra* specimens strongly suggest the opposite trend, with an ample intake of pulses. Obviously, these animals received the leftovers of the legumes collected and/or cultivated for human consumption, or at least they were allowed to graze the fields after the crops had been harvested. If this idea proves correct, it would be the earliest evidence for deliberate feeding of stock on-the-hoof, underscoring the hypothesized domestic status of these individuals. Given the preference of ungulates for legumes, one can even imagine that they competed over food with their keepers!

For Neolithic Çatalhöyük, Richards and co-workers (2003) could show that people lived on a mixed diet using stable isotope analyses, with animal protein largely coming from goats and sheep (or their milk). A conspicuous result of their analyses was the considerable variability in $\delta^{13}\text{C}_{\text{carbonate}}$ -values from the sheep bones, which were indicative of the occurrence of edible C_4 -plants. A single adult individual from the

human sample at Nevalı Çori, revealed a C_4 -plant deriving part of its diet in the bone's collagen values, combined with an elevated $\delta^{18}O$ -ratio in its carbonate fraction. Both isotope signals permit the identification of this post-Neolithic individual as a late immigrant from a warmer region, where C_4 -plants would have been more abundant.

A preliminary analysis of collagen stable isotopes in human and animal bone finds from two other PPN sites located near Nevalı Çori, namely late/final PPNA Göbekli Tepe (*ca* 9200-8600 cal. BC) and late/final PPNB Gürcütepe II (*ca* 7500-7000 cal. BC), revealed that all animals (wild and domestic) had been feeding in a C_3 -plant biome. A single human bone fragment was available only for each site, with $\delta^{13}C_{\text{collagen}}$ -values of -19.68‰ (Göbekli Tepe) and -18.75‰ (Gürcütepe), respectively. These values are in agreement with a C_3 -plant biome. The $\delta^{15}N$ -values for these two Neolithic human individuals were 9.98‰ (Göbekli Tepe) and 8.68‰ (Gürcütepe), respectively and therefore considerably higher than those of the humans from Nevalı Çori. Human bone fragments collected from Byzantine graves near Gürcütepe II, however, produced $\delta^{13}C_{\text{collagen}}$ -values between -10‰ and -15‰, implying a considerable contribution of C_4 -plants to their diet (Dummler 2004). A mean $\delta^{15}N$ -value of 13.16‰, moreover, clearly locates these individuals at the top of the food chain.

CONCLUSIONS

The “Neolithic Revolution” gave way to a subsistence strategy based on agro-pastoralism, but food production could not possibly have arisen through a conscious process because the world's first farmers had no model of farming to observe around them (Diamond 2002). Instead, the origins of domestication involved unforeseen consequences of two sets of changes—changes in plants and animals and changes in human behaviour. The complexity of the sociocultural and biological phenomena that went hand in hand with the development of food production helps explain why many aspects of the process are still poorly understood, despite considerable progress in archaeo(bio)logical research over the last decade (*e.g.* Harris 1996; Cauvin 1997; Guilaine 2000; Cappers, Bottema 2002; Peters, Schmidt 2004). While traditional hypotheses explaining the success of the Neolithisation process underline the enhanced security and predictability relative to food procurement brought about by the nutritional complementarity and productivity of the crop-livestock combination, this perspective is flawed in hindsight and may well overlook the fact that the initial stages of animal husbandry must have been characterised by “learning by doing” (Roberts 2002). Early domesticates, therefore, might well have constituted precious goods which were not readily or regularly consumed. Based on the combined faunal evidence from Pre-Pottery Neolithic B sites in the northern Fertile Crescent as one of the core regions for the domestication of plants and animals and for the integration of domestic ungulates into the production of grain crops—conceivably the most revolutionary step in the development of Southwest Asian agro-pastoralism (Harris 2002)—this transitional stage of “learning by doing” may have lasted at least 500 years, if not longer (Peters *et al.* 2005).

The stable isotope data presented in this study provide information on the dietary adaptations of a PPNB community, characterised by the cultivation of einkorn and perhaps pulses and by the possible breeding in captivity of sheep, pigs and goats. Contrary to our expectations and in total disagreement with observations made elsewhere, humans do not figure at the top of the food chain, their essentially plant-oriented diet reflected in the $\delta^{15}N$ -values found in their bone tissue. One possible explanation is that meat procurement could not be secured all year round since the availability of important game species may have fluctuated seasonally. Gazelle and wild goat, for example, display $\delta^{18}O$ -values characteristic for warmer and cooler climates respectively compared to the more “temperate” ungulates aurochs and wild boar, which likely were confined year-round to the Euphrates valley and its tributaries. If the site's inhabitants indeed suffered from a deficit in animal protein supply, however, this may have been counterbalanced by an increased intake of legumes, for which there is ample archaeobotanical evidence at the site. Since pulses generally have very low $\delta^{15}N$ values due to their mode of fixation of molecular nitrogen by symbiotic bacteria, their consumption might have caused a lowering of $\delta^{15}N$ in the bone tissue of the consumer. In the

case of the Nevalı Çori inhabitants, this might explain their unique position in the trophic web. Whether or not this is a coincidence, the few bone specimens of sexually mature animals considered to represent early domestic forms on the basis of their smaller size clearly display lower $\delta^{15}\text{N}$ -values compared to the isotope signatures measured in their wild counterparts. This strongly suggests a dietary supply containing legumes, which even today is considered a valuable and necessary component of animal fodder.

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BIBLIOGRAPHY

- AITKEN M.J. 1991, *Science-based dating in archaeology*, Longman, London.
- AMBROSE S.H. 1991, "Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs", *Journal of Archaeological Science* 18, p. 293-317.
- AMBROSE S.H. 1993, "Isotopic analysis of paleodiets: Methodological and interpretative considerations", in M.K. Sandford (ed.), *Investigations of Ancient Human Tissues. Chemical Analysis in Anthropology*, Langhorne, Pennsylvania, p. 59-130.
- AMBROSE S.H., NORR L. 1993, "Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate", in J.B. Lambert, G. Grupe (eds), *Prehistoric Human Bone. Archaeology at the Molecular Level*, Springer-Verlag, Berlin, p. 1-37.
- BALASSE M., AMBROSE S.H., SMITH A.B., PRICE T.D. 2002, "The seasonal mobility model for prehistoric herders in the south-western Cape of South Africa assessed by isotopic analysis of sheep tooth enamel", *Journal of Archaeological Science* 30, p. 205-215.
- BAR-YOSEF O. 2000, "The context of animal domestication in Southwestern Asia", in M. Mashkour, A.M. Choyke, H. Buitenhuis, F. Poplin (eds), *Archaeozoology of the Near East* 4, ARC-Publicatie 32, Groningen, p. 185-195.
- BAR-YOSEF O., MEADOW R.H. 1995, "The origins of agriculture in the Near East", in T.D. Price, A.B. Gebauer (eds), *Last Hunters-First Farmers. New Perspectives on the Prehistoric Transition to Agriculture*, School of American Research, Santa Fe, p. 39-94.
- BOCHERENS H., DRUCKER G.D. 2006, "Isotope evidence for paleodiet of late Upper Paleolithic humans in Great Britain: A response to Richards *et al.* (2005)", *Journal of Human Evolution* 51, p. 440-442.
- BOLLONGINO R., VIGNE J.-D. 2008, "Temperature monitoring in archaeological animal bone samples in the Near East arid area, before, during and after excavation", *Journal of Archaeological Science* 35, p. 873-881.
- BRADLEY D.G., LOFTUS R.T., CUNNINGHAM P., MACHUGH D.E. 1998, "Genetics and domestic cattle origins", *Evolutionary Anthropology* 6, p. 79-86.
- BUITENHUIS H. 1997, "Aşıklı Höyük: a 'proto-domestication' site", *Anthropozoologica* 25-26, p. 655-662.
- CAPPERS R.T.J., BOTTEMA S. (eds) 2002, *The Dawn of Farming in the Near East*, Studies in Early Near Eastern Production, Subsistence, and Environment 6, Berlin.
- CAUVIN J. 1997, *Naissance des divinités. Naissance de l'agriculture*, CNRS Éditions, Collection empreintes (2^e édition), Paris.
- COHEN M.N., ARMELAGOS G.J. 1984, *Paleopathology at the Origins of Agriculture*, Batsford Press, Orlando.
- DAVIS S.J.M. 1987, *The Archaeology of Animals*, Batsford Press, London.
- DENIRO M.J., EPSTEIN S. 1978, "Influence of diet on the distribution of carbon isotopes in animals", *Geochimica et Cosmochimica Acta* 42, p. 495-506.
- DIAMOND J. 1992, *The Third Chimpanzee: The Evolution and Future of the Human Animal*, Harper Perennial, New York.
- DIAMOND J. 2002, "Evolution, consequences and future of plant and animal domestication", *Nature* 418, p. 700-707.
- DUMMLER S. 2004, *Wirbeltiernahrungsnetze zur Zeit der Neolithischen Transition in Anatolien*, Diploma-Thesis, Univ. of München.
- DUPRAS T.L., SCHWARZ H.P. 2001, "Strangers in a strange land: stable isotope evidence for human migration in Dakhleh Oasis, Egypt", *Journal of Archaeological Science* 28, p. 1199-1208.

- FIZET M., MARIOTTI A., BOCHERENS H., LANGE-BADRE B., VANDERMEERSCH B., BOREL J.-P., BELLON G. 1995, "Effect of diet, physiology and climate on carbon and nitrogen stable isotopes of collagen in a Late Pleistocene anthropic palaeoecosystem: Marillac, Charente, France", *Journal of Archaeological Science* 22, p. 67-79.
- FÖRSTEL H. 1982, " $^{18}\text{O}/^{16}\text{O}$ -ratios of water in plants and in their environment (results from Fed. Rep. Germany)", in H.-L. Schmidt, H. Förstel, K. Heinzinger (eds), *Stable isotopes*, Proceedings of the 4th Int. Conference, Jülich, March 23-26, 1981, Elsevier, Amsterdam, p. 173-178.
- GIUFFRÀ E., KUJAS J.M.H., AMARGER V., CARLBORG Ö., JEON J.-T., ANDERSSON L. 2000, "The origin of the domestic pig: independent domestication and subsequent introgression", *Genetics* 154, p. 1785-1791.
- GRUPE G., MIKIC Z., PETERS J., MANHART H. 2003, "Vertebrate food webs and subsistence strategies of Meso- and Neolithic populations of central Europe", in G. Grupe, J. Peters (eds), *Deciphering Ancient Bones. The Research Potential of Bioarchaeological Collections*, Documenta Archaeobiologiae 1, Rahden/Westf., p. 193-213.
- GUILAINE J. (ed.) 2000, *Premiers paysans du monde. Naissances des agricultures*, Errance, Paris.
- HARRIS D.R. (ed.) 1996, *The Origins and Spread of Agriculture and Pastoralism in Eurasia*, UCL Press, London.
- HARRIS D.R. 2002, "Development of the agro-pastoral economy in the Fertile Crescent during the Pre-Pottery Neolithic period", in R.T.J. Cappers, S. Bottema (eds), *The Dawn of Farming in the Near East. Studies in Early Near Eastern Production, Subsistence, and Environment* 6, Ex Oriente, Berlin, p. 67-83.
- HAUPTMANN H. 1993, "Ein Kultgebäude in Nevalı Çori", in M. Frangipane, H. Hauptmann, M. Liverani, P. Matthiae, M. Mellink (eds), *Between the Rivers and over the Mountains. Archaeologica Anatolica et Mesopotamica Alba Palmieri Dedicata*, Gruppo Editoriale Internazionale, Roma, p. 37-69.
- HAUPTMANN H. 1999, "The Urfa region", in M. Özdoğan, N. Başgelen (eds), *Neolithic in Turkey*, Arkeolojive sanat Yayınları, Istanbul, vol. 1, p. 65-86, vol. 2, p. 39-55.
- HELMER D., ROITEL V., SAÑA SEGUÍ M., WILLCOX G. 1998, "Interprétations environnementales des données archéozoologiques et archéobotaniques en Syrie du nord de 16 000 BP à 7000 BP, et les débuts de la domestication des plantes et des animaux", in M. Fortin, O. Aurenche (eds), *Espace naturel, espace habité en Syrie du Nord (X^e-II^e millénaires av. J.-C.)*, TMO 28, Lyon, p. 9-33.
- HELMER D., GOURICHON L., MONCHOT H., PETERS J., SAÑA SEGUÍ M. 2005, "Identifying early domestic cattle from Pre-Pottery Neolithic sites on the Middle Euphrates using sexual dimorphism", in J.-D. Vigne, J. Peters, D. Helmer (eds), *The First Steps of Animal Domestication*, Oxford Books, Oxford, p. 86-95.
- HIENDLEDER S., MAINZ K., PLANTE Y., LEWALSKI H. 1998, "Analysis of mitochondrial DNA indicates that domestic sheep are derived from two different ancestral maternal sources: no evidence for contributions from Urial and Argali sheep", *Journal of Heredity* 89, p. 113-120.
- HILLMAN G. 1996, "Late Pleistocene changes in wild plant-foods available to hunter-gatherers of the northern Fertile Crescent: possible preludes to cereal cultivation", in D.R. Harris (ed.), *The Origins and Spread of Agriculture and Pastoralism in Eurasia*, UCP Press, London, p. 159-203.
- HO S.Y.W., LARSON G. 2006, "Molecular clocks: when times are a-changing", *Trends in Genetics* 22 (3), p. 79-83.
- HONGO H., MEADOW R.H. 1998, "Pig exploitation at Neolithic Çayönü Tepesi (Southeastern Anatolia)", in S.M. Nelson (ed.), *Ancestors for the Pigs: Pigs in Prehistory*, MASCA Research Papers in Science and Archaeology 15, Philadelphia, p. 77-98.
- HRISTOV A.N. 2002, "Fractionation of ammonia nitrogen isotopes by ruminal bacteria in vitro", *Animal Feed Science and Technology* 100, p. 71-77.
- IACUMIN P., BOCHERENS H., MARIOTTI A., LONGINELLI A. 1996, "An isotopic palaeoenvironmental study

- of human skeletal remains from the Nile Valley”, *Palaeogeography, Palaeoclimatology, Palaeoecology* 126, p. 13-30.
- KOCH P.L., BEHRENSMEYER A.K., TUROSS N., FOGEL M.L. 1991, “Isotopic fidelity during bone weathering and burial”, *Carnegie Institute Washington Yearbook*, p. 105-110.
- KOHN M.J., CERLING T.E. 2002, “Stable isotope compositions of biological apatite”, in M.J. Kohn, J. Rakovan, J.M. Hughes (eds), *Phosphates. Geochemical, Geobiological, and Materials Importance*, Reviews in Mineralogy and Geochemistry 48, p. 455-488.
- KRUEGER H.W., SULLIVAN C.H. 1984, “Models for carbon isotope fractionation between diet and bone”, in J.F. Turland, P.E. Johnson (eds), *Stable Isotopes in Nutrition*, ACS Symposium Series 258, p. 205-220.
- LARSON G., DOBNEY K., ALBARELLA U., FANG M., MATISOO-SMITH E., ROBINS J., LOWDEN S., FINLAYSON H., BRAND T., WILLERSLEV E., ROWLEY-CONWY P., ANDERSSON L., COOPER A. 2005, “Worldwide phylogeography of wild boar reveals multiple centers of pig domestication”, *Science* 307, p. 1618-1621.
- LEE-THORP J.A., SEALY J.C., MERWE N.J. VAN DER 1989, “Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet”, *Journal of Archaeological Science* 16, p. 585-599.
- LEGGE A.J. 1996, “The beginning of caprine domestication in South-west Asia, and in the Near East”, in D.R. Harris (ed.), *The Origins and Spread of Agriculture and Pastoralism in Eurasia*, UCL Press, London, p. 238-262.
- LÖSCH S., GRUPE G., PETERS J. 2006, “Stable isotopes and dietary adaptations in human and animals at Pre-Pottery Neolithic Nevalı Çori, SE-Anatolia”, *American Journal of Physical Anthropology* 131, p. 181-193.
- LOFTUS R.T., MACHUGH D.E., BRADLEY D.G., SHARP P.M., CUNNINGHAM P. 1994, “Evidence for two independent domestications of cattle”, *Proceedings of the National Academy of Sciences* 91, p. 2757-2761.
- LONGINELLI A. 1984, “Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research?”, *Geochimica et Cosmochimica Acta* 48, p. 385-390.
- LUIKART G., GIELLY L., EXCOFFIER L., VIGNE J.-D., BOUVET J., TABERLET P. 2001, “Multiple maternal origins and weak phylogeographic structure in domestic goats”, *Proceedings of the National Academy of Sciences* 98, p. 5927-5932.
- LUZ B., CORMIE A.B., SCHWARCZ H.P. 1990, “Oxygen isotope variations in phosphate of deer bones”, *Geochimica et Cosmochimica Acta* 54, p. 1723-1728.
- MAYS S. 2000, “New directions in the analysis of stable isotopes in excavated bones and teeth”, in M. Cox, S. Mays (eds), *Human osteology, archaeology and forensic science*, Medical Media Ltd., Greenwich, p. 425-438.
- MILLER N.F. 2002, “Tracing the development of the agropastoral economy in Southeastern Anatolia and Northern Syria”, in R.T.J. Cappers, S. Bottema (eds), *The Dawn of Farming in the Near East. Studies in Early Near Eastern Production, Subsistence, and Environment* 6, Ex Oriente, Berlin, p. 85-94.
- MINAGAWA M., WADA E. 1984, “Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between $\delta^{15}\text{N}$ and animal age”, *Geochimica et Cosmochimica Acta* 48, p. 1135-1140.
- NEWSOME S.D., PHILLIPS D.L., CULLETON B.J., GUILDERSON T.P., KOCH P.L. 2004, “Dietary reconstruction of an early to middle Holocene human population from the central California coast: Insights from advanced stable isotope mixing models”, *Journal of Archaeological Science* 31, p. 1101-1115.
- PASTERNAK R. 1995, “Die botanischen Funde aus Nevalı Çori, Türkei (akeramisches Neolithikum). Ein Vorbericht”, in H. Kroll, R. Pasternak (eds), *Res archaeobotanicae*, Proceedings of the 9th Symposium, Oetker-Voges Verlag, Kiel, p. 345-358.
- PASTERNAK R. 1998, “Investigations of botanical remains from Nevalı Çori, PPNB, Turkey: a short interim report”, in A.B. Damania, J. Valkoun, G. Willcox, C.O. Qualset (eds), *The Origins of Agriculture and Crop Domestication*, ICARDA, Aleppo, p. 170-177.

- PETERS J. 1998, *Römische Tierhaltung und Tierzucht. Eine Synthese aus archäozoologischer Untersuchung und schriftlich-bildlicher Überlieferung*, Passauer Universitätsschriften zur Archäologie 5, Rahden/Westf.
- PETERS J., HELMER D., DRIESCH A. VON DEN, SAÑA SEGÚI M. 1999, "Early animal husbandry in the Northern Levant", *Paléorient* 25 (2), p. 27-48.
- PETERS J., SCHMIDT K. 2004, "Animals in the symbolic world of Pre-Pottery Neolithic Göbekli Tepe, South-eastern Turkey: a preliminary assessment", *Anthropozoologica* 39 (1), p. 179-218.
- PETERS J., DRIESCH A. VON DEN, HELMER D. 2005, "The upper Euphrates-Tigris Basin: cradle of agropastoralism?", in J.-D. Vigne, J. Peters, D. Helmer (eds), *The First Steps of Animal Domestication*, Oxbow Books, Oxford, p. 96-124.
- PHILLIPS D.K. 2001, "Mixing models in analyses of diet using multiple stable isotopes: a critique", *Oecologia* 127, p. 166-170.
- PHILLIPS D.K., GREGG J.W. 2003, "Source partitioning using stable isotopes: Coping with too many sources", *Oecologia* 136, p. 261-269.
- RICHARDS M.P., JACOBI R., STRINGER C., PETTIT P.B., COOK J. 2006, "Marine diets in the European late Upper Paleolithic: a reply to Bocherens and Drucker (2006)", *Journal of Human Evolution* 51, p. 443-444.
- RICHARDS M.P., PEARSON J.A., MOLLESON T.I., RUSSELL N., MARTIN L. 2003, "Stable isotope evidence of diet at Neolithic Çatalhöyük, Turkey", *Journal of Archaeological Science* 30, p. 67-76.
- ROBERTS N. 2002, *The Holocene. An Environmental History*, Blackwell, Malden (2nd edition), Oxford.
- RUSSELL N., MARTIN L., BUITENHUIS H. 2005, "Cattle domestication at Çatalhöyük revisited", *Current Anthropology* 46, p. 101-108.
- SCHMIDT K. 1998a, *Das Nevalıçorien. Materielle Kultur und rituelle Welt einer obermesopotamischen Fazies des akeramischen Neolithikums*, Unpubl. Habilitationsthesis, University of Heidelberg.
- SCHMIDT K. 1998b, "Frühneolithische Tempel. Ein Forschungsbericht zum präkeramischen Neolithikum Obermesopotamiens", *Mitteilungen der Deutschen Orientgesellschaft* 130, p. 17-49.
- SCHWARZ H.P. 1991, "Some theoretical aspects of isotope paleodiet studies", *Journal of Archaeological Science* 18, p. 261-275.
- SPONHEIMER M., LEE-THORP J.A. 1999, "Oxygen isotopes in enamel carbonate and their ecological significance", *Journal of Archaeological Science* 26, p. 723-728.
- SPONHEIMER M., LEE-THORP J.A. 2001, "The oxygen isotope composition of mammalian enamel carbonate from Morea Estate, South Africa", *Oecologia* 126, p. 153-157.
- STEINHOUS W.D., STOKES M.R., CLARK J.H., ROGERS J.A., DAVIS C.L., NELSON D.R. 1982, "Estimation of the proportion of non-ammonia-nitrogen reaching the lower gut of the ruminant derived from bacterial and protozoal nitrogen", *British Journal of Nutrition* 48, p. 417-431.
- STEPHAN E. 1999, *Sauerstoffisotopenverhältnisse im Knochengewebe großer terrestrischer Säugetiere — Klimaproxies für das Quartär in Mittel- und Westeuropa*, Tübinger Geowissenschaftliche Arbeiten, Reihe E (Mineralogie, Petrologie und Geochemie) Bd. 6/99, Aachen.
- TANNO K., WILLCOX G. 2006, "How fast was wild wheat domesticated?", *Science* 311, p. 1886.
- TEEGEN W.R., SCHULTZ M. 1997, "Transverse linear enamel hypoplasia in the PPNB population of Nevalı Cori (Turkey)", *American Journal of Physical Anthropology* 24, p. 226-227.
- THISSEN L. 2002, "Appendix I. CANew ¹⁴C databases and ¹⁴C charts, Anatolia, 10,000-5000 cal. BC", in F. Gérard, L. Thissen (eds), *The Neolithic of Central Anatolia. Internal developments and external relations during the 9th-6th Millennia cal. BC*, Ege Yayınları, Istanbul, p. 299-337.
- TROY C.S., MACHUGH D.E., BAILEY J.F., MAGEE D.A., LOFTUS R.T., CUNNINGHAM P., CHAMBERLAIN A.T., SYKES B.C., BRADLEY D.G. 2001, "Genetic evidence for Near Eastern origins of European cattle", *Nature* 410, p. 1088-1091.
- UERPMMANN H.-P. 1979, *Probleme der Neolithisierung des Mittelmeerraumes*, Beihefte TAVO B 28, Wiesbaden.

- UERPMMANN H.-P. 1996, "Animal domestication—accident or intention?", in D.R Harris (ed.), *The Origins and Spread of Agriculture and Pastoralism in Eurasia*, UCL Press, London, p. 227-237.
- VAN ZEIST W., BOTTEMA S. 1982, "Vegetational history of the Eastern Mediterranean and the Near East during the last 20,000 years", in J.L. Bintliff, W. van Zeist (eds), *Palaeo-climates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory*, BAR International Series 133, Oxford, p. 277-321.
- VIGNE J.-D. 2000, "Les débuts néolithiques de l'élevage des ongulés au Proche-Orient et en Méditerranée : acquis récents et questions", in J. Guilaine (éd.), *Premiers paysans du monde. Naissances des agricultures*, Errance, Paris, p. 143-168.
- WHITE C.D., SPENCE M.W., STUART-WILLIAMS H. LE Q., SCHWARCZ H.P. 1998, "Oxygen isotopes and the identification of geographical origins: the Valley of Oaxaca versus the Valley of Mexico", *Journal of Archaeological Science* 25, p. 643-655.
- ZEDER M.A., HESSE B. 2000, "The initial domestication of goats in the Zagros Mountains 10,000 years ago", *Science* 287, p. 2254-2257.
- ZOHARY D., TCHERNOV E., HORWITZ L.K. 1998, "The role of unconscious selection in the domestication of sheep and goats", *Journal of Zoology, London* 245, p. 129-135.