Exploitation of domestic mammals in the Eastern Pyrenees during the Neolithic Human diet ary pattern s at the site of Mont ou (Corb ère s-les-Cabane s, France) using bone collagen stable isotopes (δ13C, δ15N)

G. Le Bras-Goude, F. Claustre

VIE ET MILIEU - LIFE AND ENVIRONMENT, 2009, 59 (2): 215-221

EXPLOITATION OF DOMESTIC MAMMALS IN THE EASTERN PYRENEES DURING THE NEOLITHIC HUMAN DIETARY PATTERNS AT THE SITE OF MONTOU (CORBÈRES-LES-CABANES, FRANCE) USING BONE COLLAGEN STABLE ISOTOPES ($\delta^{13}C$, $\delta^{15}N$)

G. LE BRAS-GOUDE[1], F. CLAUSTRE[2]*

[1] *Laboratoire d'Anthropologie des Populations du Passé, UMR 5199 PACEA, Université Bordeaux 1, Avenue des Facultés, 33405 Talence CEDEX, France*

[2] *UMR 5608 TRACES, Université de Toulouse- Le Mirail, Maison de la Recherche, 5 allées Antonio-Machado, 31058 Toulouse CEDEX 9, France*

**Corresponding author: hygee2@wanadoo.fr*

NEOLITHIC
PYRENEES
DIET
ISOTOPE
CARBON
NITROGEN

ABSTRACT. – The neolithisation process is at the origin of many socio-economic and cultural changes in the northwestern Mediterranean since the end of the 7th millennium BC. Within this chronological and cultural framework, we carried out stable isotope analyses on both animal and human bones at the archaeological site of Montou (Corbères-les-Cabanes, Eastern Pyrenees) in order to study the dietary patterns of a human group considered as mobile breeders in these highlands. The results show, among other things, that the main part of human diet proteins derived from terrestrial animal resources, probably from domestic livestock, but in various proportion according to the individuals. No marine and/or freshwater resources were consumed. Moreover, dogs show similar stable isotope values as human and they probably shared the same food resources. Lastly, dietary patterns at Montou seem to be similar to those of other Neolithic populations in Languedoc plain area whatever the type of site.

INTRODUCTION

The new processes of food production, as animal husbandry and agricultural techniques, involve modifications of the foodstuff of the first Neolithic populations and new relationships between humans and the environment. The growing influence of humans on the management of natural resources is not without consequences in this environment, and also for these new societies. Being vectors of both cultural cohesion and difference, economic and social, foodstuffs can tell us about human behaviors. In this chronological and cultural framework, the study of human diet at the archaeological site of Montou (Corbères-les-Cabanes, Eastern Pyrenees) will provide data concerning resources (vegetable, animal) exploited in the uplands. In this geographical context, and according to archaeozoological studies, cave sites are considered as stages along the transhumance route, and the dietary study allows us to track the possible variability in the exploitation of raw resources, especially animal ones, within a human group considered as mobile stock-breeders. The aim of this article is to present original and specific data about human diet using stable C and N isotopes in bone collagen. This method allows us to get direct information about protein consumption by humans at both individual and collective scales; data particularly scarce in the northwestern Mediterranean area and all the more in a collective burial context.

MATERIALS AND METHODS

The archaeological site: The site of Montou is a cave located in Eastern Pyrenees in Corbères-les-Cabanes (Fig. 1) at 290 m of altitude where it overlooks the plain of Roussillon, ca. 30 km apart from the Mediterranean coast. This karstic system is composed of many galleries and rooms and some of them have been excavated during the forties by P Ponsich and colleagues and then during the seventies and the eighties by F Claustre (Claus-

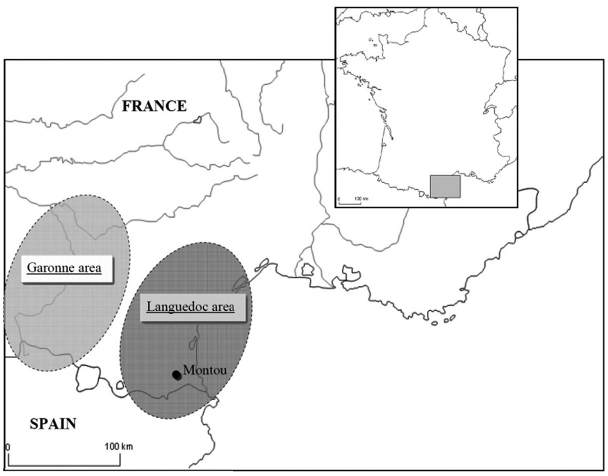

Fig. 1 – Location of the archaeological site of Montou (Corbères-les-Cabanes, Eastern Pyrenees, France).

tre & Ponsich 2000). In the cave of Montou, different periods are represented, from the Palaeolithic to the Middle Ages, but we focused our work on the Neolithic period and especially on the Montbolo culture (first half of the 4th millennium cal. BC) (Valentin *et al*. 2003). Concerning the Neolithic period, excavations have shown different areas, domestic and funeral. In the latter, a collective burial with multiple episodes of deposition containing at least ten individuals was discovered. This burial is composed of 3 sectors: two of them with mainly adult remains and another one with mainly immature remains (*ibid*.).The anthropological study was performed by Valentin *et al*. (2003). This study highlights that the individuals buried are 5 adults and 5 children. The cranium remains give some biological information about sex and age. The adult group is composed of an old woman, two old men and a young man. Among the children, there are a perinatal individual, scarce remains of an infant and 3 other well preserved individuals (*ibid*.). Bone samples were taken from 5 adults and 3 children from this burial. For the adult individuals, we have selected the radius, one of the anatomical parts used for the establishment of the MNI (Minimal Number of Individuals), in order to sample each of them. However, it was not possible to link these samples with biological data. For the immature individuals, with age estimations of 7, 4 and 1 year, we sampled different skeletal elements: tibia and humerus. The archaeozoological study performed by Loirat (2000) in the domestic area highlighted an important contribution of sheep and goat in livestock, exploited for both meat and milk, and the exploitation of domestic pig and cattle for meat. The wild species (rabbit, small carnivores, roe deer, red deer, turtle and birds) represent 12 % of the faunal remains in this part of the site. However, the main animal resource seems to come from cattle (*ibid*.). In the funeral area, these species as well as dogs were also present but the too small assemblage did not allow a study of faunal exploitation (Loirat 2000). Moreover, the comparison of archaeozoological results between Montou and an over Middle Neolithic cave in Eastern Pyrenees, Belesta, shows a possible complementarity between sites (difference of animal exploitation), and thus the possible role of the cave as a seasonal stage in a pastoral nomadism system (Loirat 2000). No marine or aquatic food remains was found in the cave and it is probable that the territory in which human and animal moved did not included the coast. Considering these results and in order to know the contribution of animal protein in the human diet, bone remains (n = 21) of all these above domestic species, as well as dog, were also sampled for stable isotope analysis.

Stable isotope method: For the past three decades, stable isotope analysis of both carbon and nitrogen in bone collagen has often been used in archaeology for dietary reconstruction. The general principle of this method is "you are what you eat". In the case of the bones and teeth found in archaeological contexts, proteins ingested are used for the formation of collagen (Ambrose & Norr 1993), the main protein of these tissues. More information about the technique and method can be found in Ambrose (1993) and Katzenberg (2000). The isotopic values are denoted $\delta^{13}C$ for carbon and $\delta^{15}N$ for nitrogen and given in units ‰ (per mil). During the Neolithic in the south of France, C4 plants were not yet cultivated (Marinval 1988), thus in this context $\delta^{13}C$ can tell us about the consumption of marine food: a value close to -20 ‰ indicates a diet exclusively composed of terrestrial protein, in contrast to a value close to -12 ‰ which indicates a diet exclusively composed of marine resources (Chisholm *et al*. 1982, Richards & Hedges 1999). Moreover, $\delta^{15}N$ can tell us about the location of the individual in the trophic web; the value recorded in bone collagen of a predator is 3-5 ‰ higher than that of its prey (Minagawa & Wada 1984, Schoeninger & DeNiro 1984, Bocherens & Drucker 2003). As each environment has its specific range of isotopic values according to ecological parameters (Park & Epstein 1960, van Klinken *et al*. 1994), palaeodietary reconstruction must take into consideration isotopic values of animals from the same archaeological site as the humans. Moreover, the turnover of bone collagen is around 10 years (Ambrose 1993, O'Connell & Hedges 1999), so the carbon and nitrogen stable isotope recorded allows us to know the averaged diet of the last years of an individual's life. To sum up, stable isotope values of C and N are relevant to understanding the environment in which resources are exploited and the location of the individual in the trophic web. Furthermore, the interpretation of isotopic results and the reconstruction of paleodiet behaviors is possible thanks to present studies, controlled feeding experiments and ecological research (Ambrose & Norr 1993, Ben-David *et al*. 1997, Sponheimer *et al*. 2003). Bone collagen of samples was extracted according to Longin's method (1971), readapted by Bocherens (1992). Bone is mechanically cleaned and also with ultrasonic sound. Then, the sample is crushed and demineralized in a HCl (1M) solution. Next, the contaminants (lipids and humic contaminants) are removed from organic matter with a NaOH (0.125M) solution and the collagen is solubilized in a weak HCl solution (0.01M) and freeze-dried. Elemental composition of C and N and stable isotope analysis are measured on 0.5 mg of extracted collagen with an IRMS "Isoprime" (measuring error of 0.3 ‰) coupled with and elemental analyzer NC 2500 Carlo Erba in the EPOC laboratory (UMR CNRS 5805, Department of Geology and Oceanography, University Bordeaux 1, France).

RESULTS

Samples preservation conditions

The proportions of carbon and nitrogen, the C/N ratio and the extraction yield allow us to appreciate both the quality and quantity of collagen preserved in each sample (Ambrose 1990). In this study, we consider as correct the samples for which extraction yield are higher than 10 mg/g and for which the contents of C and N are higher or equal to 30 % and 10 % respectively. These limits are relatively broad knowing that in fresh bone collagen the contents of C and N are respectively on average 39 % and 14 % (Ambrose 1990). Furthermore, collagen with C/N ratios outside the range of 2.9-3.6 (DeNiro 1985), is excluded of the analysis of data due to contamination and/or disrepair risks (Fig. 2). In Montou, 6 humans and 15 faunal samples respect these preservation measures and are used for the presentation of results and the discussion. All results are given in the Table I; excluded samples are in italics.

The animals

Among animals, $\delta^{13}C$ values range from -18.0 ‰ to -20.5 ‰ for domestic herbivores (sheep/goat and cattle; 19.8 ‰ ± 1.0; n = 5), from -18.5 ‰ to -19.5 ‰ for omnivorous species (pigs; -19.0 ‰ ± 0.3; n = 5) and from -18.5 ‰ to -19.0 ‰ for carnivorous species (dogs; -18.8 ‰ ± 0.2; n = 4). Concerning the $\delta^{15}N$ values, the greatest range is recorded among the omnivores (3.2 ‰; 5.7 ‰ ± 1.4) because of a more mixed diet with varied amounts of animal proteins. For dogs, the $\delta^{15}N$ are on average higher than the whole faunal group (8.4 ‰ ± 0.5) but the range of values recorded is smaller (1.2 ‰). These results bring to light a homogeneous diet for this species with a sizeable contribution of animal protein. In the domestic herbivore group ($\delta^{15}N$ = 5.8 ‰ ± 0.9), the $\delta^{15}N$ range is sustantial (2.6 ‰) for animals with a diet composed of vegetation. However, if the specific result of the "caprin 6" (7.5 ‰) is excluded, isotopic values recorded comply with expected values (Bocherens 1997). The sample of the "caprin 6" is a fragment of the distal part of sheep's humerus and no archaeozoological data indicates that it could be a young animal.

The humans

Among humans, isotopic values range from -18.2 ‰ to -19.1 ‰ (-18.7 ‰ ± 0.3; n = 6) for $\delta^{13}C$, and from 7.3 ‰ to 11.2 ‰ (8.7 ‰ ± 1.3) for $\delta^{15}N$ (Fig. 3). Within the adult group (n = 3) the range of carbon isotopic values is 0.4 ‰ and that of nitrogen isotopic values is 1.7 ‰. In the immature group (n = 3) the range of isotopic values is 0.4 ‰ for carbon and for nitrogen the range is higher than the adult group: 3.0 ‰. This result is the consequence of an "outlier" among the children; if we exclude the sample "Child 3", the $\delta^{15}N$ range in the immature group is much less variable: 0.3 ‰. In the whole human group the $\delta^{15}N$ range is 3.9 ‰. When the very high $\delta^{15}N$ value of the "child 3" (11.2 ‰) is excluded, the range is 1.8 ‰, which is similar to that observed by O'Connell and Hedges (1999) for human group with an omnivorous diet.

DISCUSSION

Domestic animals at the site of Montou have $\delta^{13}C$ and $\delta^{15}N$ inside the range expected for terrestrial plant eaters. The animal diet did not include marine resources (e.g. seaweed) as we can see sometimes in archaeological sites

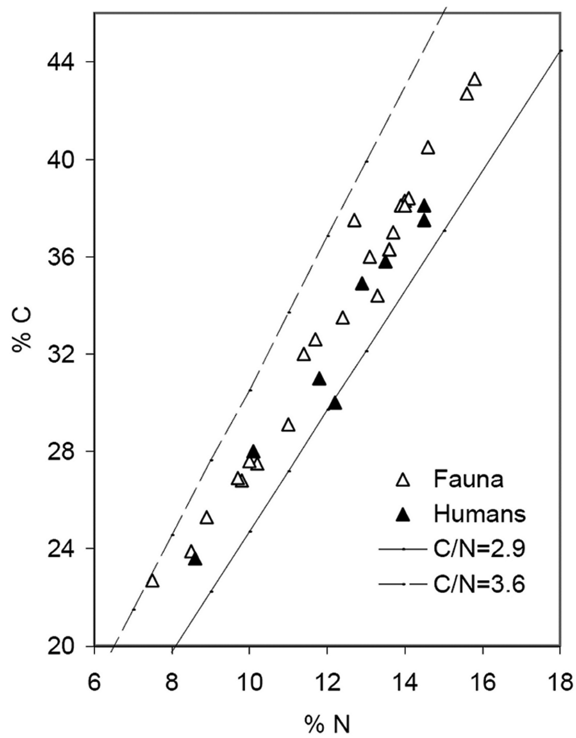

Fig. 2 – Elemental concentration (C and N) of extracted collagen from human and faunal remains.

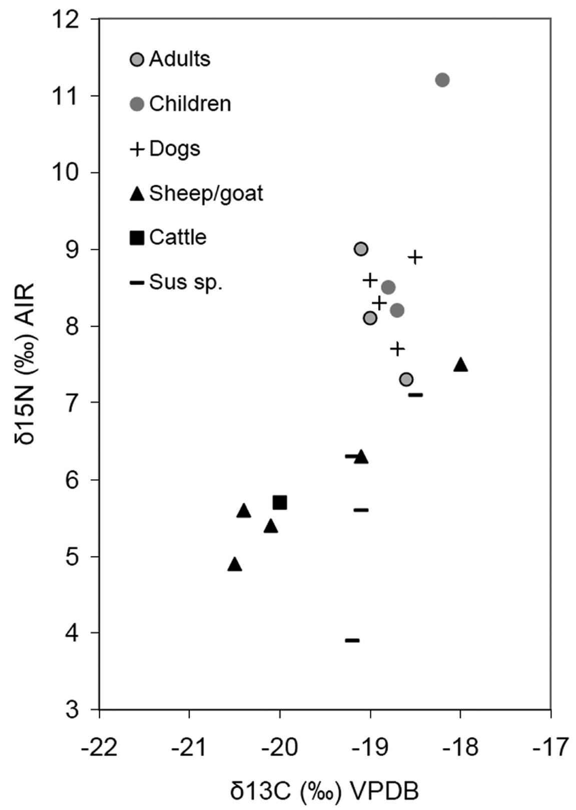

Fig. 3 – $\delta^{13}C$ and $\delta^{15}N$ values from humans and animals sampled at the site of Montou.

Table I – Results of analysis of human and animal bone collagen from Montou. Data in italics do not meet preservation criteria and are excluded from the discussion.

Montou	Species	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	% C	% N	C/N	Yield (mg/g)
Adult A	*Human*	*-18.3*	*9.1*	*28.0*	*10.1*	*3.2*	*34.2*
Adult B	Human	-19.0	8.1	34.9	12.9	3.1	42.7
Adult C	*Human*	*-18.9*	*8.7*	*23.6*	*8.6*	*3.2*	*30.0*
Adult D	Human	-19.1	9.0	31.0	11.8	3.0	25.2
Adult E	Human	-18.6	7.3	30.0	10.2	2.9	46.7
Child 1	Human	-18.8	8.5	35.8	13.5	3.1	75.2
Child 2	Human	-18.7	8.2	38.1	14.5	3.0	46.6
Child 3	Human	-18.2	11.2	37.5	14.5	3.0	145.7
Dog 1	*Canis f.*	-19.0	8.6	37.0	13.7	3.1	80.2
Dog 3	*Canis f.*	-18.5	8.9	33.5	12.4	3.1	51.3
Dog 4	*Canis f.*	-18.9	8.3	32.0	11.4	3.3	41.5
Dog 5	*Canis f.*	-18.7	7.7	36.3	13.6	3.1	70.8
Cattle 1	*Bos taurus*	*-18.0*	*4.5*	*26.8*	*9.8*	*3.2*	*11.1*
Cattle 2	*Bos taurus*	*-19.4*	*4.7*	*22.7*	*7.5*	*3.5*	*12.9*
Cattle 3	*Bos taurus*	*-18.9*	*5.7*	*27.5*	*10.2*	*3.1*	*105.7*
Cattle 4	*Bos taurus*	-20.0	5.7	32.6	11.7	3.2	80.7
Cattle 5	*Bos taurus*	*-21.1*	*6.0*	*27.6*	*10.0*	*3.2*	*86.7*
Caprin 1	*Ovis aries/Capra hircus*	-20.4	5.6	43.3	15.8	3.2	115.2
Caprin 2	*Ovis aries/Capra hircus*	-20.1	5.4	42.7	15.6	3.2	98.3
Caprin 3	*Ovis aries/Capra hircus*	*-19.0*	*5.9*	*23.9*	*8.5*	*3.3*	*12.4*
Caprin 4	*Ovis aries*	*-19.9*	*6.1*	*25.3*	*8.9*	*3.3*	*7.9*
Caprin 5	*Ovis aries/Capra hircus*	*-19.1*	*6.3*	*29.1*	*11.0*	*3.1*	*21.7*
Caprin 6	*Ovis aries*	-18.0	7.5	38.3	14.0	3.2	114.2
Caprin 7	*Ovis aries/Capra hircus*	-20.5	4.9	36.3	13.6	3.1	13.3
Pig 1	*Sus* sp.	-18.5	7.1	36.0	13.1	3.2	15.5
Pig 2	*Sus* sp.	-19.1	5.6	38.1	13.9	3.2	54.6
Pig 3	*Sus* sp.	-19.2	6.3	34.4	13.3	3.0	48.9
Pig 4	*Sus* sp.	-19.2	3.9	38.4	14.1	3.2	82.6
Pig 5	*Sus* sp.	-19.5	5.2	38.1	14.0	3.2	32.4

(Balasse *et al.* 2005). Moreover, their $\delta^{13}C$ values are not low enough to suspect the consumption of ^{13}C depleted plants of shaded environment as forest floor (Balasse *et al.* 2000, Noe-Nygaard *et al.* 2005). Thus, it appears that animals, and thereby humans, lived in terrestrial and relatively open environments (probably plain or mountain according to the period of the year).

The difference of stable isotope values between humans and herbivores (caprinae and cattle; n = 5) for carbon is on average 1.0 ‰ and for nitrogen 2.4 ‰. The difference of stable isotope values between humans and combined herbivorous and omnivorous species (Caprinae, cattle and pigs; n = 10) for carbon is on average 0.8 ‰ for and for nitrogen 3.0 ‰. These results show that humans have a higher location in the trophic web than most of the species sampled and indicate that the human diet is mixed (vegetal and animal proteins) with a varied contribution from animal proteins according to the individual (Fig. 3). This isotopic study can not reveal the specific sources of animal protein because the different species are not statistically distinct. If we add to our results the archaeological study performed by Loirat (2000) in the domestic area of the cave, we could expect that animal protein mainly came from the meat and/or milk of adult animals. Actually, the consumption of young animals (unweaned) would mark the bone collagen of humans with higher isotopic values than we recorded. Moreover, these results suggest that the coastal environment was not exploited by humans for food resources. The freshwater resources were also not included in the diet despite the exploitation of riverside vegetation during the Middle Neolithic period in this area (Heinz *et al.* 2004). The dogs analyzed in Montou have isotopic values similar to the human group possibly indicating identical protein consumption. Thus, they have probably shared the same meals as humans and/or consumed the rests of human meals. Relationships and dietary pattern between domestic dogs and humans can be different according to the archaeological site (e.g. Noe-Nygaard 1988, Clutton-Brock & Noe-Nygaard 1990, Cannon *et al.* 1999, Eriksson & Zagorska 2003). On one hand, the similarity between stable isotope values of dogs and humans has been observed on some Mesolithic and Neolithic sites in northern Europe (Noe-Nygaard 1988, Clutton-Brock & Noe-Nygaard 1990). On the other hand, some studies on prehistoric and historic periods show that dogs have low-

Table II – Mean and standard deviation of stable isotope values recorded in Neolithic human and faunal remains in Languedoc and Garonne areas (data from Herrscher & Le Bras-Goude 2008) and Montou.

Region	Samples	N	Mean ± SD $\delta^{13}C$ (‰)	Mean ± SD $\delta^{15}N$ (‰)
Languedoc	Humans	32	-19.5 ± 0.5	8.1 ± 0.8
	Herbivores/omnivores	11	-19.9 ± 0.6	6.3 ± 0.4
	Dogs	4	-19.4 ± 0.3	7.8 ± 0.3
Garonne	Humans	17	-20.6 ± 0.3	9.8 ± 0.9
	Herbivores/omnivores	15	-20.9 ± 0.9	6.6 ± 1.2
	Dogs	5	-20.3 ± 0.3	9.4 ± 0.5
Montou	Humans	6	-18.7 ± 0.3	8.7 ± 1.3
	Humans without “child 3“	5	-18.8 ± 0.2	8.2 ± 0.6
	Herbivores/omnivores	10	-19.5 ± 0.8	5.7 ± 1.0
	Dogs	4	-18.8 ± 0.2	8.4 ± 0.4

est $\delta^{15}N$ values compared to the average human values from the same site (Murray & Schoeninger 1988, Boric *et al.* 2004, Valentin *et al.* 2006). This last trend is also observable, to an extent, in other Middle Neolithic sites in south of France (Table II) but no statistical difference is recorded between dogs and humans (Herrscher & Le Bras-Goude 2008).

Within the human group, a difference in isotopic values exists, but only between adults. “Adult E” could have consumed less animal protein than “adult D”. Without data about sex and age estimations for each individual, it is difficult to suggest that the divergence observed between these individuals mirrors a biological difference. However, this hypothesis is not excluded knowing that both sexes and different ages are present in this human group. On one hand, dietary variance between male and female has already been brought to light in few archaeological sites (e.g. Polet *et al.* 1994, Ambrose *et al.* 2003, Prowse *et al.* 2005). Moreover, the study of Subirà and Malgosa (1996) concerning the Neolithic in Pyrenean region highlights a difference of meat consumption between the sexes using trace element analysis in bone mineral. But on the other hand, this hypothesis can not be supported by the stable isotope results recorded in other Neolithic populations from the south of France (Herrscher & Le Bras-Goude 2008). A social distinction could also be suggested, but it can not be checked assessed in the collective burial context because artefacts can not be linked to individuals.

The children 1 and 2 have similar stable isotope values and the same location in the trophic web as most of adults. The age difference between these two children and also between immatures and adults seem not a discriminating factor regarding to the diet. Concerning the one year-old child, as we explained above, its $\delta^{13}C$ and specifically $\delta^{15}N$ are higher than these of the other individuals found in the cave. The difference in $\delta^{15}N$ recorded between this child compared to the other individuals is +2.8 ‰, corresponding to almost a full trophic level. Considering the child’s age and the geographical location of the site (ca. 30 km apart from the coast), the consumption of mother’s milk seems to be a relevant hypothesis to explain the high $\delta^{15}N$ value. During the breastfeeding period, children consume the milk of their mother leading to an enrichment of about 3 ‰ (Fogel *et al.* 1989, Schurr 1997). Thereby, bone collagen $\delta^{15}N$ of the infant is higher than that of the mother, corresponding to a higher location in the trophic web. This result only indicates that at Montou, the weaning age seems to be beyond 1 year-old. We don’t aim to discuss this point, since our sampling methodology is not adapted for that (Balasse 1999, Herrscher 2003). However, it brings an over data for prehistoric periods, as the breastfeeding and weaning patterns are different according to both period and location (Jay *et al.* 2008).

The location of the humans from Montou in the trophic web and their diet are in agreement with other results recorded on populations from the “Chasséen” period in the Languedoc plain region (Fig. 1; Table II) (Le Bras-Goude *et al.* 2006). However, if we compare these observations to a wider geographical context including the Garonne area (Fig. 1; Table II), the diet of Pyrenean as well as Languedoc Neolithic populations is different and probably less rich in animal proteins overall, or in animal proteins from a high trophic level (e.g. freshwater fish) than the Garonne populations (Herrscher & Le Bras-Goude 2008). These observations would indicate that during Middle Neolithic period in Languedoc plain and Pyrenees areas, even if the type of site could be linked to a specific economy (e.g. pastoralism for cave and agriculture for open air site), the proportion of animal protein consumed by humans seems not influenced by the management of food resources.

To conclude, this study of stable isotopes in bone collagen of both human and domestic animals from the archaeological site of Montou shows that the diet of this population is probably based on mixed proteins (animal and vegetal) with a varied proportion of animal resources according to the individual. In comparison with the archaeozoological data (Loirat 2000) we know that the animal proteins consumed by humans come from meat resources, probably mainly from adult domestic sheep, goat and cattle. No marine and/or freshwater resources seem to be included in the diet and if these humans were mobile stock-breeders, our study is not able to differentiate the possible various terrestrial environments exploited by them. Lastly, the human dietary patterns at the site of Montou seem to be similar to these currently observed in other Middle Neolithic populations in Languedoc plain region whatever the type of site.

ACKNOWLEDGEMENTS - This article was performed in *memoriam* of F Claustre, Archaeologist, and responsible for the collection of Montou. This work was possible thanks to a French scientific program "Space and funeral expressions during the middle Neolithic in the Pyrenean world and its outskirts" directed by Dr J Vaquer (CNRS UMR 5608 TRACES, Toulouse), and his team, specifically E Herrscher. It was supported by CNRS funding for analytical cost and Aquitaine and CNRS for a PhD grant. K Charlier, I Billy and EPOC laboratory (UMR 5805, DGO, University Bordeaux 1, France) are thanked for their technical help and the "Maison du Patrimoine Françoise Claustre" (Céret) and its staff for their help in providing access to the materiel and D Loirat for access to the archaeozoological studies. M Balasse and M Richards for their scientific advice, C Couture-Veschambre and JJ Hublin, PhD supervisors, are also thanked. We also express our gratitude to the 3 reviewers for their very helpful comments and corrections. At least, our recognition is for R Fons, coordinator of the 30th symposium of mammalogy, in which this study was presented.

REFERENCES

Ambrose SH 1990. Preparation and characterisation of bone and tooth collagen for isotopic analysis. *J Archaeol Sci* 17: 431-451.

Ambrose SH 1993. Isotopic analysis of paleodiets: methodological and interpretative considerations. *In* Sandford MK ed, Isotopic analysis of paleodiets: methodological and interpretative considerations. Gordon and Breach Science Publishers, Langhorne, USA: 59-130.

Ambrose SH, 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* Lambert JB, Grupe G eds, Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. Springer-Verlag, Berlin, Germany: 1-37.

Ambrose SH, Buikstra J, Krueger HW 2003. Status and gender differences in diet at Mound 72 Cahokia revealed by isotopic analysis of bone. *J Anthropol Archaeol* 22: 217-226.

Balasse M 1999. De l'exploitation du lait au Néolithique moyen en Europe tempérée. Examen des modalités de sevrage des bovins par l'analyse isotopique des ossements archéologiques. PhD Thesis, Univ Paris VI: 244 p.

Balasse M, Tresset A, Bocherens H, Mariotti A, Vigne JD 2000. Un abattage "post-lactation" sur des bovins domestiques néolithiques. Etude isotopique des restes osseux du site de Bercy (Paris, France). *Ibex. J Mountain Ecol Anthropozool* 5: 39-48.

Balasse M, Tresset A, Dobney K, Ambrose S H 2005. The use of isotope ratios to test for seaweed eating in sheep. *J Zool* 266: 283-291.

Ben-David M, Flynn RW, Schell DM 1997. Annual and seasonal changes in diets of martens: evidence from stable isotope analysis. *Oecologia* 111: 280-291.

Bocherens H 1997. Signature isotopique dans le collagène des os. *C R Soc Biol* 4: 493-510.

Bocherens H, Drucker D 2003. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. *Int J Osteoarchaeol* 13: 46-53.

Boric D, Grupe G, Peters J, Mikic Z 2004. Is the Mesolithic-Neolithic subsistence dichotomy real? New stable isotope evidence from the Danube Gorges. *Eur J Archaeol* 7: 221-248.

Cannon A, Schwarcz HP, Knyf M 1999. Marine-based subsistence trends and the stable isotope analysis of dog bones from Namu, British Columbia. *J Archaeol Sci* 26: 399-407.

Chisholm BS, Nelson D E, Schwarcz HP 1982. Stable isotope ratios as a measure of marine versus terrestrial protein in ancient diet. *Science* 216: 1131-1132.

Claustre F, Ponsich P 2000. Complément à l'étude de la céramique néolithique de la galerie close de Montou. *Etud Roussillon* 13: 79-96.

Clutton-Brock J, Noe-Nygaard N 1990. New osteological and C-isotope evidence on Mesolithic dogs: companions to hunters and fishers at Star Carr, Seamer Carr and Kongemose. *J Archaeol Sci* 17: 643-653.

DeNiro MJ 1985. Post-mortem preservation and alteration of in vivo bone collagen isotope ratios on relation to palaeodietary reconstruction. *Nature* 317: 806-809.

Eriksson G, Zagorska I 2003. Do dogs eat like humans? Marine stable isotope signals in dog teeth from inland Zvejnieki. *In* Krindgen H, Knutson K, Larsson L, Loeffler D, Akerlund A eds, Do dogs eat like humans? Marine stable isotope signals in dog teeth from inland Zvejnieki. Oxbow Monographs, Oxford, England: 160-168.

Fogel M L, Tuross N, Owsley DW 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. *Annu Rep Geophys Lab Carnegie Inst Wash:* 111-117.

Goude G 2007. Etude des modes de subsistance de populations néolithiques (VIe-IVe millénaires av. J.-C.) dans le nord-ouest de la Méditerranée. Approche par l'utilisation des isotopes stables ($\delta^{13}C$ et $\delta^{15}N$) du collagène. PhD Thesis, Univ Bordeaux 1/Univ Leipzig, 415 p.

Heinz C, Figueiral I, Terral J-F, Claustre F 2004. Holocene vegetation changes in the northwestern Mediterranean: new palaeoecological data from charcoal analysis and quantitative eco-anatomy. *Holocene* 14: 621-627.

Helmer D, Vigne JD 2004. La gestion des cheptels de caprinés au Néolithique dans le midi de la France. *In* Bodu P, Constantin C eds, La gestion des cheptels de caprinés au Néolithique dans le midi de la France. Société préhistorique française, Paris, France: 397-407.

Helmer D, Gourichon L, Sidi Maamar H, Vigne JD 2005. L'élevage des caprinés néolithiques dans le sud-est de la France : saisonnalité des abattages, relations entre grottes bergeries et sites de plein air. *Anthropozool* 40: 167-189.

Herrscher E 2003. Alimentation d'une population historique. Analyse des données isotopiques de la nécropole Saint-Laurent de Grenoble (XIIIe-XVe siècle France). *Bull Mem Soc Anthropol Paris* 15: 149-269.

Herrscher E, Le Bras-Goude G 2008. Viande, laitage, poissons ou végétaux. Approche biochimique de l'alimentation néolithique en Toulousain. *In* Vaquer J, Gandelin M, Remicourt M, Tchérémissinoff Y eds, Viande, laitage, poissons ou végétaux. Approche biochimique de l'alimentation néolithique en Toulousain. Archives d'Écologie préhistorique, Carcassonne, France: 199-208.

Jay M, Fuller BT, Richards MP, Knusel CJ, King SS 2008. Iron Age breastfeeding practices in Britain: Isotopic evidence from Wetwang Slack, East Yorkshire. *Am J Phys Anthropol* 136: 327-337.

Katzenberg MA 1993. Age differences and population variation in stable isotope values from Ontario Canada. *In* Lambert J B, Grupe G eds, Age differences and population variation in stable isotope values from Ontario Canada. Springer-Verlag, Berlin, Germany: 39-62.

Katzenberg MA 2000. Stable isotope analysis: a tool for studying past diet demography and life history. *In* Katzenberg MA, Saunders S eds, Biological anthropology of the human skeleton. Wiley-Liss, New York, USA: 305-328.

Le Bras-Goude G, Billy I, Charlier K, Loison G 2006. Contribution des méthodes isotopiques pour l'étude de l'alimentation humaine au Néolithique moyen méridional : le cas du site chasséen ancien du Crès (Béziers, Hérault, France). *Antropol* 11: 167-175.

Longin R 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230: 241-242.

Marinval P 1988. L'alimentation végétale en France du Mésolithique jusqu'à l'Age du Fer. CNRS, Paris, 192 p.

Minagawa M, Wada E 1984. Stepwise enrichment of ^{15}N along food chain: further evidence and the relation between $\delta^{15}N$ and animal age. *Geochim Cosmochim Acta* 48: 1135-1140.

Murray ML, Schoeninger MJ 1988. Diet, status, and complex social structure in Iron Age Central Europe: some contributions from bone chemistry. *In* Gibson DB, Geselowitz MN eds, Diet, status, and complex social structure in Iron Age Central Europe: some contributions from bone chemistry. Plenum Press, New York, USA: 155-176.

Noe-Nygaard N 1988. ^{13}C values of dog bones reveal the nature of changes in man's food resources at the Mesolithic-Neolithic transition, Denmark. *Isot Geosci* 73: 87-96.

Noe-Nygaard N, Price TD, Hede SU 2005. Diet of aurochs and early cattle in southern Scandinavia: evidence from ^{15}N and ^{13}C stable isotopes. *J Archaeol Sci* 32: 855-871.

O'Connell TC, Hedges REM 1999. Investigations into the effect of diet on modern human hair isotopic values. *Am J Phys Anthropol* 108: 409-425.

Park RB, Epstein S 1960. Carbon isotope fractionation during photosynthesis. *Geochim Cosmochim Acta* 21: 110-26.

Polet C, Orban R, Herbosch A 1994. Différences sexuelles des teneurs en zinc et en strontium dans les ossements humains de quelques échantillons médiévaux de Belgique (résultats préliminaires). *In* Buchet L ed, La femme pendant le Moyen Âge et l'époque moderne. CNRS, Paris, France: 173-188.

Prowse T, Schwarcz HP, Saunders R , Macchiarelli R, Bondioli L 2005. Isotopic evidence for age related variation in diet from Isola Sacra. *Am J Phys Anthropol* 128: 2-13.

Richards MP, Hedges R 1999. Stable isotope evidence for similarities in the types marine food used by late Mesolithic humans at sites along the Atlantic coast of Europe. *J Archaeol Sci* 26: 712-722.

Schoeninger MJ, DeNiro MJ 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochim Cosmochim Acta* 48: 625-639.

Schurr MR 1997. Stable nitrogen isotopes as evidence for the age of weaning at the Angel site: comparison of isotopic and demographic measures of weaning age. *J Archaeol Sci* 24: 919-927.

Sponheimer M, Robinson T, Ayliffe L, Roeder B, Hammer J, Passey BH, West A, Cerling TE, Dearing MD, Ehleringer JR 2003. Nitrogen isotopes in mammalian herbivores: hair $\delta^{15}N$ values from a controlled feeding study. *Int J Osteoarchaeol* 13: 80-87.

Valentin F, Donat R, Claustre F 2003. La gestion de l'espace sépulcral néolithique moyen de la grotte de Montou (Pyrénées-Orientales) : un essai d'interprétation. *Bull Soc Pre Fr* 23: 301-314.

Valentin F, Bocherens H, Gratuze B, Sand C 2006. Dietary patterns during the late prehistoric/historic period in Cikobia island (Fiji): insights from stable isotopes and dental pathologies. *J Archaeol Sci* 33: 1396-1410.

van Klinken GJ, van der Plicht H, Hedges REM 1994. Bone $^{13}C/^{12}C$ ratios reflect palaeoclimatic variations. *Geophys Res Lett* 21: 445-448.

Received October 2, 2008
Accepted November 21, 2008
Associate Editor: F Charles