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# MAMMAL CHANGES AND ISOTOPIC BIOGEOCHEMISTRY. AN INTERDISCIPLINARY APPROACH TO CLIMATIC-ENVIRONMENTAL RECOSTRUCTIONS AT THE LAST PLENIGLACIAL/LATE-GLACIAL TRANSITION IN THE PAGLICCI CAVE SECTION (GARGANO, APULIA, SE ITALY)

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RIASSUNTO - *Cambiamenti nei mammiferi e biogeochimica isotopica. Un approccio interdisciplinare alle ricostruzioni climatico-ambientali dell'ultimo Pleniglaciale Tardiglaciale nella sezione di Grotta Paglicci (Gargano, Puglia)* - Il Quaternario *Italian Journal of Quaternary Sciences*, **9**(2), 1996, 573-580 - Le variazioni di abbondanza degli isotopi stabili dell'ossigeno, carbonio e azoto, sono state verificate nei resti scheletrici di grandi mammiferi (*Equus, Bos* e *Cervus*) rinvenuti nella sezione stratigrafica di grotta Paglicci (Gargano, Puglia). Il deposito di questa località documenta un intervallo di tempo di circa 17 ka nel quale è contenuto il passaggio tra l'ultimo Pleniglaciale e il Tardiglaciale. Le variazioni percentuali nella composizione dei grandi mammiferi ben illustrano i cambiamenti climatico-ambientali che si sono verificati in questo intervallo di tempo. Questo lavoro rappresenta un primo tentativo di applicare le analisi isotopiche ai resti fossili per ricostruire antichi climi e ambienti, integrando questi dati con le informazioni dedotte dalle variazioni della composizione faunistica.

ABSTRACT - *Mammal changes and isotopic biogeochemistry. An interdisciplinary approach to climatic-environmental recostructions during the last Pleniglacial/Late-Glacial in the Paglicci cave section (Gargano, Apulia)* - Il Quaternario *Italian Journal of Quaternary Sciences*, **9**(2), 1996, 573-580 - Changes in stable isotope abundances of oxygen, carbon and nitrogen, have been measured in the fossil skeletal remains of large mammals (*Equus, Bos* and *Cervusi*) recovered from the stratigraphical section of Paglicci cave. The deposit found in this locality records a time interval of about 17 ka, which includes the last Pleniglacial/Late-Glacial transition. Percentage changes in the large mammals assemblage are indicative of the climatic-environmental variations that occurred during that time. This work is a first attempt to apply isotopic investigation to fossil remains in order to reconstruct ancient climate and environments, by taking into account the information deduced from the changes in faunal composition.

Key-words: Late Pleistocene, large mammals, isotope, climatic-environmental changes, Gargano, Southern Italy,
Parole chiave: Pleistocene superiore, grandi mammiferi, isotopi, variazioni climatico-ambientali, Gargano, Italia meridionale

## 1. INTRODUCTION

Several works (Longinelli 1973; 1984; Longinelli & Peretti Padalino, 1983; Van der Merwe, 1978; Lee-Thorp & Van der Merwe, 1987; Bocherens *et al.*, 1995) suggested the possibility of carrying out quantitative palæoclimatic, palæoenvironmental and palæodietary studies by measuring the isotopic ratio of oxygen, carbon and nitrogen of mammal teeth and bones.

The phosphate oxygen isotopic composition of teeth and bones of recent mammals have been experimentally demonstrated to be closely related to the mean $\delta^{18}O$ of local meteoric water (Longinelli, 1984; Luz *et al.*, 1984; DAngela & Longinelli, 1990; Bryant *et al.*, 1994) *via* the existing quantitative relationship between the mean oxygen isotopic composition of body water and the mean oxygen isotopic composition of total ingested water. This relationship is reliable in the case of mammal species since the body temperature of all the specimens of the same species is practically constant and metabolically controlled. In the case of the mammal species studied, the biogenic phosphate is precipitated in isotopic equilibrium conditions with body water with the only exception of milk teeth (Longinelli, 1973). The fractionation factor between $\delta^{18}O$ of ingested water and $\delta^{18}O$ of phosphate, has been established empirically for several groups of mammals and follows a linear behaviour, although the slope and intercept of the calculated equation show interspecific variability (Longinelli, 1995). The existence of a relationship between phosphate $\delta^{18}O$ and meteoric water $\delta^{18}O$ suggests the possibility of studying the palæoclimatic changes on continental areas by means of oxygen isotope analyses of fossil skeletal remains of mammals (Ayliffe *et al.*, 1992; D'Angela & Longinelli, 1993; Bryant *et al.*, 1994; Sanchez Chíllon *et al.*, 1994; Iacumin *et al.*, in press). However, it must be considered that the oxygen isotope ratio is affected by factors other than temperature. A marked isotope effect may be related to the amount of evapotranspiration of the consumed plants. Under environ-


Fig. 1 - Location map of Paglicci cave.
*Localizzazione geografica di Grotta Paglicci.*

mental conditions characterised by low mean values of the atmospheric relative humidity, a large $^{18}O$ enrichment of plant water will be paralleled by a similar enrichment in mammal body water and, consequently, by an $^{18}O$ enrichment of tooth and bone phosphate (Luz *et al.*, 1990; Delgado Huertas *et al.*, 1995). This piece of information should be taken into account in the interpretation of the results.

The carbon isotope composition of the biogenic tissue (*e.g.* collagen and carbonate hydroxylapatite) is dependent upon the carbon isotope composition of local vegetation. Such an analysis, recently used for palæodietary and palæoenvironmental reconstructions, refers to the photosynthesis mechanism. In modern ecosystems, two broad classes of plants are known: plants using $C_3$ photosynthetic pathway (or Calvin-Benson cycle), which are all the trees and herbs from cold and temperate climates, have low $^{13}C/^{12}C$ values, whereas plants using $C_4$ photosynthetic pathway (Hatch-Slack cycle), which are the grasses common in the tropical and subtropical climate dominated by summer rainfall, have higher $^{13}C/^{12}C$ values. However, carbon isotope variations do not arise only from the presence of $C_4$ or $C_3$ plants. $C_3$ plants in fact display a fairly wide carbon isotope range in response to a number of factors including moisture stress and soil $CO_2$ trapping under forest canopies. Due to $^{13}C$-depleted $CO_2$ originating from organic matter, decay and low light intensity in closed canopy forest, understory plants are also significantly $^{13}C$-depleted (Vogel, 1978; Van der Merwe & Medina, 1989).

Nitrogen isotopic abundances in collagen are linked to trophic level: they increase at each trophic step reflecting dietary values with an isotope shift of about +3‰(De Niro, 1985). However, $\delta^{15}N$ values of terrestrial mammals may be directly affected by local climatic conditions. $\delta^{15}N$ of mammal bones was found to increase with decreasing amount of precipitation (Heaton *et al.*, 1986). Such an effect is probably related to water retention in animals living in arid areas and excretion of urine depleted in $^{15}N$ (Ambrose & De Niro, 1989; Sealy *et al.*, 1987).

The preservation of isotopic values in fossils is absolutely necessary for reliable palæoecological and palæoenvironmental information from these data. Fossil biogenic phosphate and particularly bones and dentine are known to undergo post-depositional changes such as increased crystallinity and exchange or adsorption of ions from the environment. These diagenetic modifications can alter the original isotopic signal.

In this work tooth and bones samples belonging to ungulates recovered from the stratigraphical sequence of Paglicci cave, have been analysed. The isotopic values derived from this investigation were compared to the abundance of large mammals and than tentatively correlated to the climatic-environmental changes suggested for the studied time interval by palæontological, palæobotanical and palæoclimatic considerations.

## 2. THE LOCALITY AND THE FAUNAL ASSEMBLAGE

Paglicci cave, located in the south-western edge of the Gargano promontory (south-eastern Italy; Fig.1), is an important site for defining the human cultural evolution in Italy during latest Pleistocene. Sediments yielded artefacts and human remains that pertain to the interval from Gravettian to final Epigravettian (Bartolomei *et al.*, 1979; Palma di Cesnola, 1975; 1988; Palma di Cesnola *et al.*, 1983).

Radiometric $^{14}C$ data (conventional ages) span from about 28 ka (level 22) to about 11 ka (levels 3-2) (cfr. Palma di Cesnola, 1988; Palma di Cesnola *et al.* 1983). The succession clearly illustrates the changes in mammal assemblages during this time interval, even though hiatuses have been recognized. In detail, an important hiatus occurs between levels 17 and 18, while the hiatus recognized around 13-14 ka seems to have wiped out a small section of the stratigraphical record.

The large mammal assemblage studied by Sala (1983) is related to man hunting activity, and is characterised by the occurrence of variable percentages of *Bos primigenius, Capra ibex, Rupicapra pyrenaica, Cervus elaphus, Capreolus capreolus, Sus scrofa, Equus hydruntinus* and a caballine horse. The remains come from 22 stratigraphic levels subdivided into several stratigraphic cuts for a total of 50 units. The high number of remains recovered, greater than 100 in most of cuts and in some cases greater than 700 (*e.g.* cuts 20e and 20d) guarantees the reliability of the observed percentage changes.

The percentage frequency of large mammals species is reported against the stratigraphic levels and the $^{14}C$ ages in Figure 2.

At the base of the sequence (levels 21d and 22a) the mammal assemblage is characterised by abundant *Rupicapra pyrenaica,* horse and *Bos primigenius.* The occurrence of *R. pyrenaica,* an ungulate strictly adapted to montainous environment, suggests a rather open environment and a fresh humid climate. The first faunal change is recorded at levels 21d-21c and resulted in the establishment, during Gravettian and part of the early Epigravettian, of an assemblage in which horse and *Capra ibex* are by far the dominant species. This faunal composition, characterising the maximum of the last Pleniglacial and part of the Late-Glacial, indicates a dominant deforested environment. In fact, the occurrence of

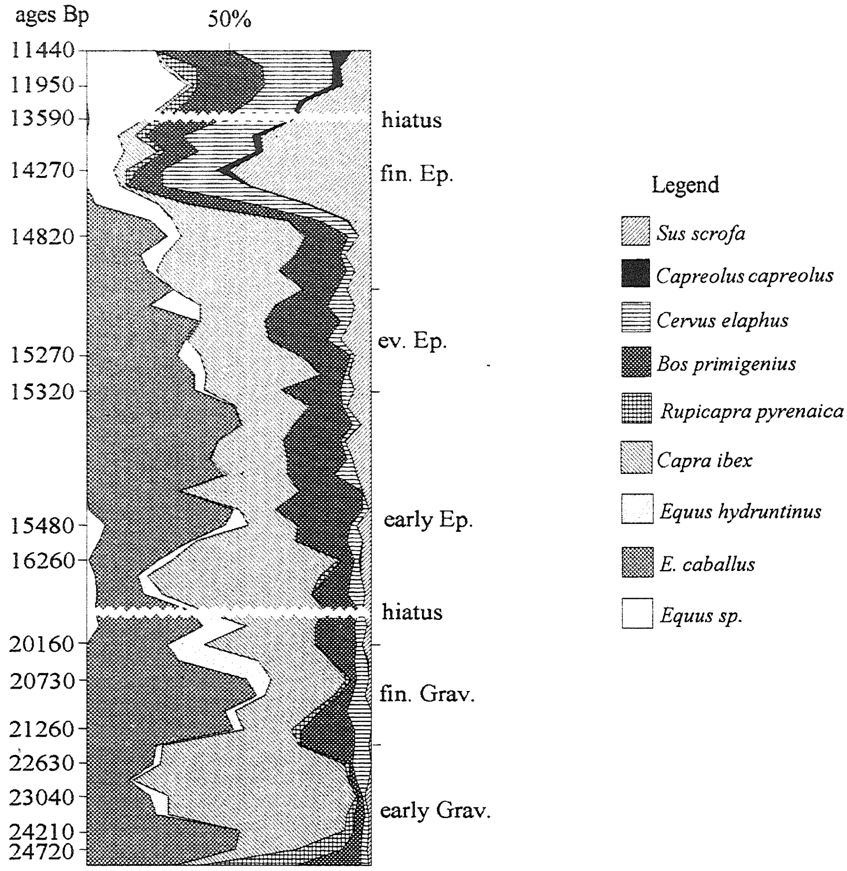


Fig. 2 - Percentage variation of large mammals *vs* the stratigraphical succession. On the left, $^{14}C$ ages are reported.

*Variazione percentuale dei grandi mammiferi lungo la successione stratigrafica. A sinistra sono riportate le età $^{14}C$.*

horse is related to an open landscape, and the most favourable conditions for the *ibex* coincide with episodes of deforestation during arid climatic oscillations (see also Masini & Abbazzi, 1997 - in press). The diffusion of *ibex* seems also strongly related to rough grounds (Ronchitelli *et al.*, 1995); then the Paglicci area should have a suitable *habitat* to the diffusion of this ungulate. *Capra ibex* is dominant on horse at least during two wide oscillations of the faunal composition, in the lower-middle part of the section. These oscillations, where *Rupicapra pyrenaica* also occurs, could be the consequence of an increase of forested areas in the most elevated sections of the Gargano mountain, that may have forced the *ibex* towards less elevated zones. Alternatively, the decrease of the horse might have forced the hunters towards the mountain zones. However, the finding of marmot skeletal remains from the same levels (Palma di Cesnola, 1988) suggests episodes of climatic deterioration.

The most evident faunal change is observed at the beginning of final Epigravettian (around 14.8 ka in the Paglicci cave section) where, after a quick reduction, the horse disappears, and *Capra ibex* decreases to an insignificant presence. At the same time, *E. hydruntinus* increases, whereas wild-boar and red deer become the dominant species. In this phase, *C. capreolus* also occurs, and the presence of *R. pyrenaica* becomes constant.

*C. elaphus* is an ubiquitous species in the Late Pleistocene of the Italian regions, and is quite common in the more wooded Tyrrhenian side (cfr. also Torre *et al.*, 1996). This deer, though able to adapt itself to very diversified environments, becomes rare when arid conditions strongly reduce the forested zone. Its scant occurrence in the lower and middle levels of Paglicci cave confirms the palæoenvironmental recostruction deduced from other evidences (e.g. horse abundance). *Equus hydruntinus,* like extant ass, was a species apparently adapted to Mediterranean conditions, and, unlike other equids, was probably a solitary form, which did not strictly depend on widely open landscape. Roe deer and wild-boar also indicate temperate-humid climate and the development of vegetated areas.

Therefore, the faunal composition that characterises the upper levels of the Paglicci deposit, suggests a climatic-environmental change with the development of a relatively more wooded landscape. This dramatic change in the large mammal assemblage occurs in a very short time interval, about 500 years, as indicated by the results of the Q-mode factor analysis reported in Figure 3.

In the uppermost part of the section, *E. hydruntinus* reaches its maximum abundance and *S. scrofa* again becomes a subordinate presence. This change in the percentage composition of the fauna suggests a drier phase in the climatic amelioration of the Late-Glacial. An increased percentage of the former species is also documented in the "terre brune" of Romanelli cave, dating back to 10,640±100 ÷ 9,880±100 (cfr. Palma di Cesnola *et al.*, 1983).

Important data supporting the climatic-environmental picture derived by large mammals come from the study of the micromammal fauna (Bartolomei, 1975; Bartolomei *et al.*, 1977). The small mammal remains are embedded in owl pellets drapped when man did not dwell in the cave.

During Gravettian rodents are dominated by *Microtus (Microtus) arvalis* (Bartolomei *et al.*, 1977). This species spread in the southern part of the Italian peninsula during the more rigid climatic phases of the last glacial cycle (Masini & Abbazzi, 1997 - in press). The most important change in the rodent assemblage occurs at levels 10-6, when *M. (M.) arvalis* disappears and *Microtus (Terricola) savii* becomes the dominant species. *M. (T.) savii,* which is at the present time one of the more abundant arvicolids in the Southern Italy regions, can be considered as an indicator of temperate climatic phases. Therefore, the variation in the micromammal fauna suggests a climatic transition towards warmer conditions.

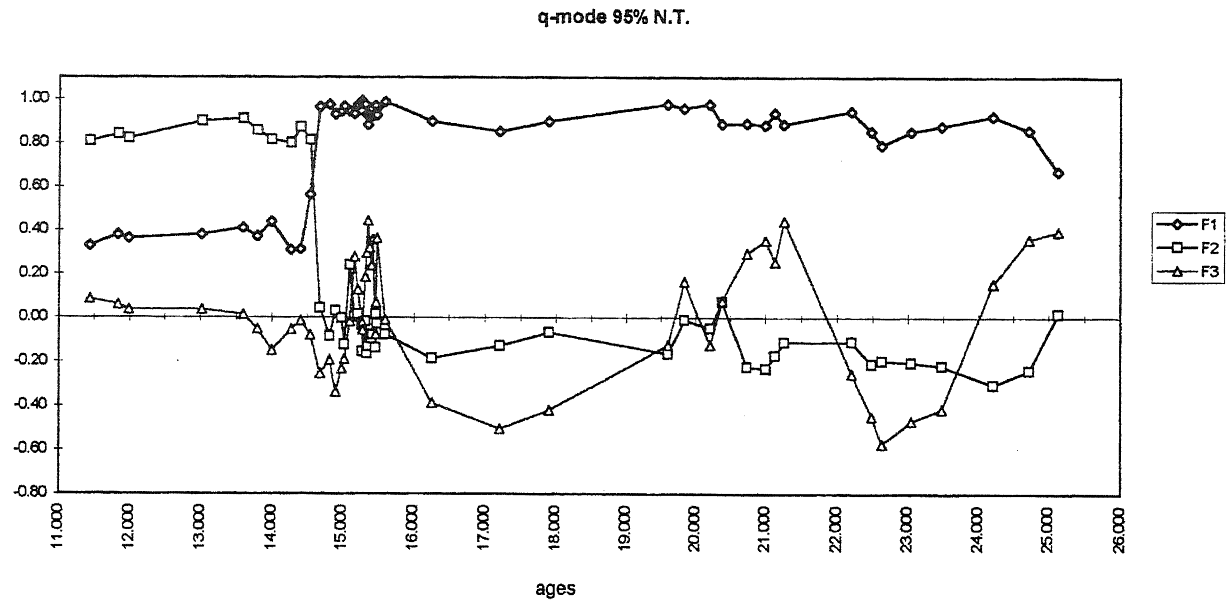


Fig. 3 - Q-mode factor analysis on mammal abundances. Legend: Factor 1 (70.7% of variance) is correlated to *Equus* and *Capra ibex* and may be interpreted as a marker of open environment. Factor 2 (16.1% of variance) is correlated to the faunal elements indicating forested environment, as *Cervus elaphus* and *Sus scrofa*. Factor 3 (7.4 of variance) is related to the relative abundance between *Equus* and *Capra ibex*. High values of Factor 3 indicate *Equus* dominating on *Capra*, and vice-versa. One can observe the abrupt inversion between factor 1 and factor 2 at 6d-6c transition, at around 14.5 ka BP, that indicates the change from an open to a wooded landscape.

*Analisi fattoriale Q-mode delle abbondanze dei mammiferi. Il fattore 1 (70.7% della varianza) è correlato con* Equus *e* Capra ibex *e può essere interpretato come un indicatore di un ambiente aperto. Il fattore 2 (16.1% della varianza) è correlato agli elementi faunistici che indicano un ambiente forestato come* Cervus elaphus *e* Sus scrofa. *Il fattore 3 (7.4 della varianza) è correlato all'abbondanza relativa tra* Equus *e* Capra ibex. *Alti valori di questo fattore indicano la dominanza di* Equus *su* Capra, *e vice-versa. Si osservi l'improvvisa inversione tra il fattore 1 e il fattore 2 in corrispondenza del passaggio 6d-6c a circa 14.5 ka BP, che indica la variazone da un ambiente aperto ad un ambiente forestato.*

## 3. RESULTS OF ISOTOPE ANALYSES

### 3.1 Materials and Methods

Tooth and bone samples were used for this study: in the case of former samples both dentine and enamel were measured.

A portion of each sample, after mechanical cleaning, was finely ground in an agate mortar, the amount of material varying from a few hundred milligrams in the case of enamel or dentine, to 2 or 3 grams for bone. For the measurement of the oxygen isotope composition of apatite-phosphate, 100-120 mg of the powdered sample were dissolved in 10 M nitric acid after a preliminary treatment by means of 30% $H_2O_2$. This solution was then treated according to the chemical procedure reported by Tudge (1960) and slightly modified by Longinelli (1965) and by Kolodny *et al.*, (1983). The final product of chemical treatment ($BiPO_4$) was dried overnight at about 90°C and then heated in vacuo at 450°C (Kahru & Epstein, 1986) to obtain the $BiPO_4$-β form (Mooney-Slater, 1962) with no structural water, thus avoiding subsequent rehydration of the samples. The samples were then reacted with $BrF_5$ at 300°C for 3 hours in nickel reaction vessels to separate quantitatively the oxygen. After conversion of $O_2$ to $CO_2$, the isotopic measurements were carried out by means of a Finnigan Delta S mass spectrometer. The standard deviation of the measurements is, on average, about ±0.2 to ±0.25 ‰ (1σ). All the samples were run at least in double and the reported data (*vs.* V-SMOW isotopic standard) are the mean values of consistent results.

For the measurements of $\delta^{15}N$ and $\delta^{13}C$ of collagen, this material was extracted from about 1 to 2 g of powdered bone or dentine by decalcification in 1M HCl for 20 min at about 20°C. After filtration, the insoluble residue, containing collagen, was treated at room temperature for 20 hours with 0.125 N NaOH. Collagen was then filtered again, rinsed with distilled water, solubilised in $10^{-2}$ M HCl (pH=2) in closed tubes at 100°C for 17 hours, and after centrifugation, the supernatant containing solubilised collagen was freeze dried.

Extraction yield (mg/g) is expressed as the ratio of the freeze dried organic matter to the dry weight of the tooth or bone sample. The isotopic composition of nitrogen and carbon of collagen was analysed by means of an EA-IRMS elemental analyser on line with a VG Optima mass spectrometer which also allowed for the calculation of %C and %N and consequently, the C/N ratios. The standard deviation of the measurements is about ±0.1‰ for carbon and 0.2‰ for nitrogen (1σ). The $\delta^{13}C$ values are reported versus PDB-1 and the $\delta^{15}N$ values versus atmospheric $N_2$ international standards.

### 3.2 Oxygen isotopic ratio

A set of 106 samples was studied for the oxygen isotopic composition of bone and tooth phosphate. The samples belong to *C. elaphus, Bos primigenius,* and to

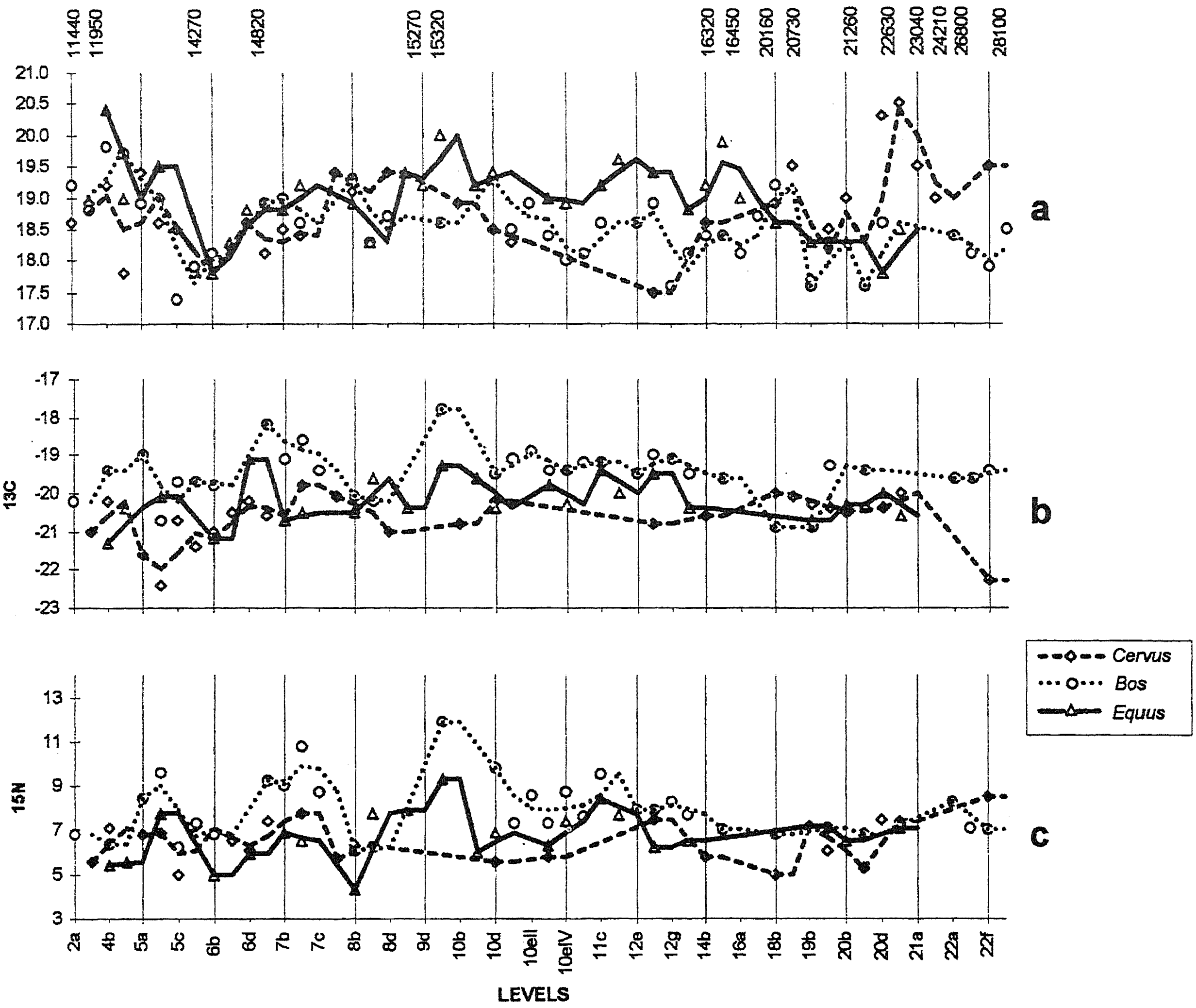


Fig. 4 - Oxygen isotopic composition of phosphate (a), and of carbon (b) and nitrogen (c) isotopic composition of collagen of skeletal remains of *Cervus elaphus, Bos primigenius* and caballine horse (‰ values) *vs.* their stratigraphic position and the conventional $^{14}C$ ages. A moving average of period 2 has been performed for smoothing the curves.

*Composizione isotopica dell'ossigeno nel fosfato (a) e del carbonio (b) e dell'azoto del collagene dei resti scheletrici di* Cervus elaphus, Bos primigenius *e di* Equus *rispetto alla posizione stratigrafica e alle età $^{14}C$ convenzionali. Le curve sono state smussate utilizzando una media mobile di periodo 2.*

the caballine horse. The results of these analyses are reported in Figure 4a, where isotopic data are given against the stratigraphical levels and time, respectively.

The lower part of the section (Gravettian) is not well documented because of some discontinuities, so that it is difficult to identify a clear trend in the isotopic signal. On the other hand, the upper part (Epigravettian) is detailed, as shown by the frequent sampling.

The diagram shows that the isotopic values measured on *Cervus, Bos* and *Equus* are weakly correlated to one another (see also Table 1). In detail, some sections of the isotopic curve obtained from *Cervus* results show a quite different behaviour when compared to the *Bos* and *Equus* curves. Moreover the *Equus* isotopic values are, in general, slightly higher than those of the other two taxa. These results suggest that the $\delta^{18}O$ signal could be influenced by factors other than temperature. In fact the *Equus* values and some sections of the *Cervus* curve could be related to diet differences. Equids, and grazers in general, show enriched $^{18}O$ values when compared to browsers. Bocherans *et al.* (1994), Quade *et al.* (1995) and Land *et al.* (1980) found that the oxygen isotopic composition of carbonate in tooth and bone apatite of grazers is $^{18}O$ enriched. Since both carbonate and phospate are precipitated in equilibrium with body water (Iacumin *et al.,* in press) the *Equus* $^{18}O$ enriched values may be easily accepted when compared to *Cervus* values. Moreover *C. elaphus* can easily move to higher or lower elevations and the $\delta^{18}O$ of drinking water at different altitudes could also be another factor influencing the oxygen isotopic composition of phosphate. According to this last consideration, the oxygen isotopic composition of *Cervus* at level 20e, could result from a migration of this ungulate to less elevated zone (isotopically heavier water), at a time during which a generalized forestation took place.

Table 1 - Matrix of correlation among the oxygen isotope values measured on the phosphate of the skeletal remains of *Cervus elaphus, Bos primigenius* and *Equus*. The coefficient of the correlation, the number of cases and the significance of correlation are shown.

*Matrice di correlazione tra i valori isotopici dell'ossigeno misurati nel fosfato dei resti di* Cervus elaphus, Bos primigenius *e* Equus. *Sono riportati i coefficienti di correlazione, il numero di casi e la significatività della correlazione.*

| | *C. elaphus* | *B. primigenius* | *Equus* |
|---|---|---|---|
| *Cervus elaphus* | 1.000 | | |
| *Bos primigenius* | 0.290<br>(22)<br>P= .099 | 1.000 | |
| *Equus* | -0.041<br>(22)<br>P=.428 | 0.510<br>(20)<br>P=.011 | 1.000 |

Considering the section of the curves where the isotopic signals have parallel trends, it is possible to define four phases with light isotopic values at about 22.2, 21, around 16.2 and 13.6 ka. Four episodes with heavy isotopic value may be identified at about 22.7 (only *C. elaphus*), 20.7, 15 and 12 ka, even though, there is no strict agreement between the results of the three species. In a very general way, these $^{18}O$ depleted or enriched values may be interpreted, respectively, as the isotopic "translation" of climatic deteriorations or improvements. Despite the relatively low latitude of the studied area, and its central position in the Mediterranean basin, it seems that the major climatic changes left their signature in the isotopic composition of the studied samples.

The overall climatic picture that can be suggested according to the reported results is the following. The base of the studied section (levels 22a to 20d) should correspond to rather favourable and humid conditions, quickly evolving towards a considerably cooler and still humid episode, which could identify the final stage of the glacial. The central section of our curve should refer to the end of Last Pleniglacial and the beginning of Late-Glacial with variable and less humid climatic conditions. During this episode (levels 18b to 9a) there is the relatively large discrepancy between the horse on one side and the cattle plus deer on the other. This discrepancy could perhaps result from the relatively quick climatic changes and from some peculiar difference in the behaviour of diverse species. After the climatic deterioration, recorded by levels 8a to about 5b which may, perhaps, be referred to the the Oldest Dryas, there is an apparent evolution towards warmer and, possibly, more arid climatic conditions. According to the result obtained from the last sample measured, this climatic scenario is again switching towards a rapid cooling, which could tentatively be referred to the beginning of the Younger Dryas episode.

### 3.3 Carbon and nitrogen isotope ratio

First of all, it should be mentioned that the C/N ratios of the extracted organic matter are of importance to check whether or not the sample preserved its pristine isotopic value. Well preserved collagen samples are thought to yield C/N ratios between 2.9 and 3.6 (De Niro, 1985).

Almost all our samples yielded correct values for this ratio and, consequently, the obtained isotopic data can be consider as reliable.

The $\delta^{13}C$ and $\delta^{15}N$ values are reported graphycally in Figures 4b and 4c. The carbon isotope results of collagen from the three species are characteristic of animals feeding on $C_3$ plants. These values are higher than those of recent mammals living in a closed canopied forest (Chisholm *et al.,* 1983; Vogel, 1978). It follows that the studied species probably lived in an open environment. Taking into account the $^{13}C$ enrichment of collagen with respect to the mean $\delta^{13}C$ of food (about 5‰) the mean isotopic composition that may be calculated for the plants eaten is -25.5‰ for deer, -25.2‰ for horse and -24.5‰ for wild ox.

The $\delta^{15}N$ values from horse and wild ox display rapid variations as large as 5.8‰ (Fig. 4c). Taking into account the period from about 12 ka to 16 ka BP, the number of samples measured is particularly useful for the interpretation of the isotopic variations along the Paglicci stratigraphic sequence, and for drawing palæoenvironmental conclusions in some detail. The succession through time of light and heavy nitrogen isotopic values in short time intervals should be related to rapid shifts from humid to arid conditions related to changing climatic and/or meterological parameters during the deglaciation. The mean $\delta^{15}N$ values measured are close to the mean value of African herbivores rather than to that of central Europe herbivores. This may, perhaps, be related to mean environmental conditions in the Paglicci area more arid than at present with two main arid episodes at about 15.3 ka and 13.2 ka and with a humid event at about 15.1 ka.

A general trend toward lighter values is apparent in the curve of $\delta^{13}C$ (Fig. 4b) even though, as in the case of $\delta^{15}N$ values, large and fast oscillations take place. The evolution towards a forest habitat is also supported by the common finding among cave skeletal remains, after 14.8 ka BP, of typical forest mammals, such as wild boar and deer.

With respect to the lower section of the sequence, the oldest samples measured suggest arid environmental conditions between about 28 and 26 ka BP (levels 22g and 22f) and a humid event between 22 and 21 ka BP (levels 20a-20d).

It must be pointed out that the $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ values are complementary for a correct interpretation of the data obtained. As an example we can take into account the isotopic results from level 10a at about 15.3 ka BP: the $\delta^{18}O$ enrichment of phosphate is obviously related to a climatic warming. However, since $\delta^{15}N$ and $\delta^{13}C$ clearly suggest arid conditions, an $^{18}O$ enrichment of the water ingested by herbivors should be taken into account because of increasing evapotranspiration effect. As a result, the oxygen isotope effect is proportionally amplified. The "climatic improvement" is then partially related to the effect of water oxygen fractionation because of increased evapotranspiration. A correct evaluation of the phosphate $\delta^{18}O$ values in terms of climatic changes is then strictly related to the simultaneous measurements of $\delta^{15}N$ and $\delta^{13}C$ of collagen.

## 4. CONCLUSION

Palæoclimatological and palæoenvironmental reconstructions should take into account as many variables as possible to improve the reliability and the accuracy of the models which may be suggested. From this point of view, no doubt that interdisciplinary studies may help. In the case of the fossil fauna from the Paglicci cave, we have developed at our best palæontological and geochemical studies with the aim of obtaining all the technically available information. The results obtained, and their interpretation, may be summarized as follow:

1) In the mammal assemblage the major change (Fig. 2) takes place between levels 6d and 6b, and it is preceded by a variation (reduction of horse and *Microtus (Microtus) arvalis*) starting from level 10. The settlements of the renewed fauna is paralleled by the apparent isotopic evolution of $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ values of level 10a to the isotopically depleted peaks of level 5c. This episode should correspond to the increased humidity that allowed the establishment of a wide arboreal cover;

2) indipendent of less important details, all the information obtained confirm a climatic and environmental evolution from humid conditions at the base of the section to a variable and less humid environment through cool and humid episode. The minor fluctuations in the large mammal fauna (occurring at levels 20b-20c; level 18-17, around level 10, at level 8c and at level 6c), which forestall the main change, are in agreement with the changes in the C and N isotope ratios, indicating more humid events.

The upper section shows the aforementioned strong evolution towards cooler and humid conditions, followed by the last episode recorded by the uppermost section of the sequence towards warmer and dry conditions;

3) the $\delta^{15}N$ and $\delta^{13}C$ mean values of the Paglicci samples are closer to the mean value of African herbivors rather than to those of herbivors from central Europe. According to these data, it should be concluded that the mean environmental conditions in the Paglicci area were, on average, definitely more arid than at present.

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