Il Quaternario
Italian Journal of Quaternary Sciences
***15**(1), 2002, 39-44*

MAMMAL SKELETAL REMAINS FROM THE FUMANE CAVE (VERONA, NORTHERN ITALY): AN OXYGEN ISOTOPE STUDY AND ITS PALAEOCLIMATOLOGICAL IMPLICATIONS

S. Davanzo, P. Iacumin & A. Longinelli
University of Parma, Department of Earth Sciences, Parco Area delle Scienze 157/A, 43100 Parma, Italy

ABSTRACT
A stable isotope study of mammal skeletal remains of Palaeolithic age from the Fumane cave (Verona, N. Italy) was carried out to obtain palaeoclimatological information. The studied samples belong to *Capra ibex, Cervus elaphus, Capreolus capreolus and Bos/Bison* sp. and come from various levels of the cave deposits of Upper and Mid Palaeolithic age. The $\delta^{18}O$ of palaeoenvironmental water was calculated from the $\delta^{18}Op$ measured on fossil samples, according to the isotope equations previously calibrated on modern specimens.
The results obtained suggest that teeth must be considered with great caution for palaeoclimatic reconstruction: in the case of this study they yield quite unreliable results. In a general way, isotopically well-preserved bones are preferrable since the interpretation of their results is more straightforward, more reliable and more meaningful, the bone phosphate representing a mean value of a considerable period of the life of each specimen. The $\delta^{18}Ow$ calculated from bone samples indicate that the climatic conditions were colder than at present. Further isotope data are of importance as a database for detailed reconstructions of the past climatic conditions along NS and EW geographic sections in Europe.

RIASSUNTO
Sono state eseguite misure della composizione isotopica del fosfato ($\delta^{18}Op$) su resti di mammiferi fossili provenienti dalla Grotta di Fumane (Verona) allo scopo di ottenere informazioni paleoclimatiche quantitative o almeno semiquantitative per il Paleolitico Medio-Superiore nella zona in esame. I campioni provengono da vari livelli di una successione stratigrafica divisa in quattro unità principali (S, BR, A e D) ed appartengono alle specie Capra ibex, Cervus elaphus, Capreolus capreolus *e* Bos/Bison *sp.. I valori di $\delta^{18}O$ delle "paleo" acque meteoriche sono stati calcolati a partire dai valori di $\delta^{18}Op$ misurati sui campioni fossili utilizzando le equazioni isotopiche preventivamente calibrate su individui recenti. I risultati ottenuti indicano che i denti non sono sempre utilizzabili per ricostruzioni paleoclimatiche e che, in generale, è preferibile utilizzare le ossa, almeno quando si ha a che fare con materiali non interessati da processi diagenetici. I valori di $\delta^{18}Ow$ (acqua paleoambientale) calcolati dai campioni di ossa confermano che il clima, nell'intervallo di tempo relativo alla successione esaminata, era sensibilmente più freddo di quello attuale. Questi risultati costituiscono un utile apporto per dettagliate ricostruzioni delle variazioni climatiche nel passato lungo sezioni NS ed EO in Europa.*

Keywords: Fumane cave, oxygen isotopes, palaeoclimatology, Upper and Mid-Palaeolithic
Parole chiave : Grotta di Fumane, composizione isotopica dell'ossigeno, paleoclimatologia, Paleolitico Medio-Superiore

1. INTRODUCTION

The Fumane Cave (Verona-Northern Italy) has been studied by archaeologists for its deposits from Palaeolithic age. The cave is located at about 350 m.a.s.l. on the Lessini Mountains (Fig.1). It was repeatedly excavated throughout the last century and an extensive excavation (10 m of sediments) was carried out by the Historical Museum of Verona and the Sovraintendenza alle Antichità from 1982 to 1983 and by the Prehistoric and Ethnographic Museum "Pigorini" of Rome from 1987 to recent time (Bartolomei *et al.*, 1992a).

The 10 m of sediments were divided into four units (D, A, BR and S), each one in turn being subdivided into various levels and sublevels. 29 radiocarbon dates are available for 9 of the stratigraphic levels of the D and A units of the Fumane cave. The D unit dates approximately from 27,000 to 32,000 BP and the A unit from 32,000 to 38,000 BP. (for a complete review see Bartolomei *et al.*, 1992a,b; Cassoli and Tagliacozzo, 1994; Cremaschi *et al.*, 1986; Peresani and Sartorelli, 1996). Three thermoluminescence dates were carried out on burnt flint stones from levels BR11, BR12 and S7 yielding ages of about 55, 57 and 80 ka BP respectively (Broglio, personal communication).

Deer and ibex are the most abundant faunal remains at Fumane Cave followed by roe deer, chamois and bovines with subordinated marmot and fox. These remains are essentially human food refuse. Micromammals are also well represented. The study of mammal assemblages and sedimentary analyses from the A and D units point to a wooded landscape and a cool climate at lower levels (A13-A3) and to an open landscape with a cold and arid climate at higher levels (A2-D1) (Bartolomei *et al.*, 1992b).

While the analyses of faunal assemblages from archaeological sites can yield only qualitative palaeoclimatological information, oxygen isotope analyses can provide a quantitative or semi-quantitative information of past climatic conditions in the case of suitable material. Mammal bone and tooth oxygen isotope data enable the calculation of the mean oxygen isotope composition of environmental water throughout the period covered by the samples studied. In fact, the δ^{18}Op values can be converted into δ^{18}O of palaeoenvironmental water by means of isotope equations calibrated on living specimens of the same species from different climatic areas (e.g. Longinelli, 1984; Longinelli, 1995; Delgado Huertas *et al.*, 1995). These equations take into consideration the different metabolic processes characteristic of each species and the overall isotope fractionation of the oxygen taken in. In turn, the mean δ^{18}O value of environmental water is related quantitatively to the yearly mean temperature at the ground. Consequently, the δ^{18}Op values can be considered variables quantitatively related to palaeoclimatological conditions.

Fig.1 - Location of the Fumane Cave, North-Eastern Italy.
Ubicazione della Grotta di Fumane.

2. MATERIALS AND METHODS

The study was carried out on 119 mammal bone and tooth enamel samples belonging to *Cervus elaphus, Capra ibex, Capreolus capreolus and Bos/Bison* sp. In the case of teeth, the enamel sample portion analysed was collected in such a way as to represent the whole period of tooth accretion. Consequently, the intra-tooth variation related to seasonal climatic changes is considerably reduced.

The samples were prepared according to well established procedures (Crowson and Showers, 1991 and Lécuyer *et al.*, 1993). The final sample of the chemical treatment is Ag_3PO_4.The phosphate oxygen is extracted from the samples by reacting the Ag_3PO_4 with BrF_5 at 600°C for about 15 hours. The oxygen is then purified and converted to CO_2 by cycling over hot graphite in the presence of a platinum catalyst; the CO_2 is measured for its $^{18}O/^{16}O$ ratios by means of a mass spectrometer (in this case a Finnigan Delta S). The isotope results are reported in the δ terminology versus the international V-SMOW standard.

3. ISOTOPE RESULTS AND DISCUSSION

The phosphate oxygen isotope composition (δ^{18}Op) of the measured samples and the oxygen isotope composition of local environmental water (δ^{18}Ow) are reported in Table 1 along with their stratigraphic position in the cave sedimentary sequence. The δ^{18}Ow was calculated from the δ^{18}Op values according to the equations suggested by D'Angela and Longinelli (1990) for *Cervus* and *Bos* and by Delgado Huertas *et al.* (1995) for *Capra and Capreolus*.

The same δ^{18}Ow values are also reported graphically in Figure 2. The δ^{18}Ow calculated from bone samples range from -10.2 to -6.2 per mil with a mean value of -7.8±0.8. The mean δ^{18}Ow calculated from tooth samples (-9.6±2.3) is surprisingly lighter than that of bone samples ranging between -13.4 and -3.9 per mil. In general, tooth enamel is considered the most reliable material for δ^{18}Op analyses due to its capability of retaining the pristine isotope value throughout long periods (e.g. Ayliffe *et al.*, 1994). However, tooth phosphate is not renewed during the lifetime of an individual and, consequently, it records the isotopic signature of climatic conditions referring to a very short period of the individual's life (Bryant *et al.*, 1996; Fricke and O'Neil, 1996). This is particularly true for the teeth that mineralise during the weaning period which are affected by the nursing processes.

In the case of our samples and particularly for the *C. ibex* from which a number of teeth were measured in the lower units (BR and S) the δ^{18}Ow values calculated from teeth δ^{18}Op are systematically ^{18}O-depleted when compared to δ^{18}Ow calculated from bone values, even from the same level (Fig.2). Only very few teeth values behave in the opposite way being ^{18}O-enriched. Since diagenetic processes normally affect preferentially bones leading to an ^{18}O-depletion, this effect can hardly be ascribed to post-depositional processes. Therefore, according to the results obtained the time period represented by the BR and S units could be considered slightly colder than the period represented by the D and A units. However, this hypothesis is not confirmed by the measurements obtained from other species and, particularly, by the deer samples, several of which were analysed from the BR and S levels. It may be inferred that: 1) the ibex fawns lived at a higher elevation; 2) they lived in an area where streams carried down isotopically lighter water from the nearby alpine glaciers; 3) that they were born in a given period so that the permanent teeth mineralised preferentially during the cold season.

The ^{18}O-enriched teeth values may be ascribed to the weaning period since milk water is considerably ^{18}O-enriched when compared to environmental water (Luz *et al.*, 1984).

Because of the great difference between bone and

level	specimen	skeletal remains	$\delta^{18}O$ p	$\delta^{18}O$ w	level	specimen	skeletal remains	$\delta^{18}O$ p	$\delta^{18}O$ w
D1e	*C. ibex*	bone	17.2	-7.9	BR7c	*C. elaphus*	bone	17.4	-7.3
D1e	*C. ibex*	bone	17.7	-7.3	BR7f	*C. elaphus*	bone	17.6	-7.0
D1e+D1d	*C. ibex*	bone	16.8	-8.4	BR7f	*C. elaphus*	bone	17.7	-6.9
D1e+D1d	*C. ibex*	tooth	12.3	-13.4	BR7f	*C. capreolus*	bone	16.7	-9.2
D1d	*C. ibex*	bone	17.7	-7.3	BR7f	*C. capreolus*	bone	15.9	-9.3
D1d	*C. ibex*	bone	17.5	-7.5	BR8	*C. ibex*	bone	17.2	-7.8
D1c	*C. ibex*	bone	16.9	-8.2	BR8	*C. elaphus*	bone	17.3	-7.3
D1c	*C. ibex*	bone	16.9	-8.2	BR9	*C. ibex*	bone	16.9	-8.2
D1c	*C. ibex*	bone	18.2	-6.7	BR9	*C. elaphus*	bone	18.5	-6.2
D1a	*C. ibex*	bone	15.1	-10.2	BR9	*C. elaphus*	bone	17.1	-7.5
D1a	*C. ibex*	tooth	20.7	-3.9	BR9	*C. elaphus*	tooth	16.5	-8.1
D3b	*C. ibex*	bone	17.4	-7.6	BR9	*C. capreolus*	bone	16.6	-8.5
D3b	*C. ibex*	bone	17.9	-7.0	BR10	*C. ibex*	bone	17.5	-7.5
D3b	*C. ibex*	tooth	19.4	-5.4	BR10	*C. ibex*	tooth	12.4	-13.4
D5	*C. ibex*	bone	17.2	-7.8	BR10	*C. ibex*	tooth	18.0	-7.0
D5	*C. ibex*	bone	18.4	-6.5	BR11d	*C. ibex*	tooth	15.9	-9.3
D6	*C. ibex*	bone	18.2	-6.7	BR11d	*C. elaphus*	bone	17.0	-7.7
D6	*C. ibex*	tooth	15.2	-10.1	BR11d	*C. elaphus*	bone	17.6	-7.0
D6	*C. ibex*	tooth	15.9	-9.3	BR11d	*C. elaphus*	bone	15.9	-8.6
D6	*Bos/Bison sp.*	bone	16.7	-8.2	BR11d	*C. capreolus*	bone	17.3	-7.8
D6	*Bos/Bison sp.*	bone	15.7	-9.1	BR11d	*C. capreolus*	bone	17.7	-7.3
D6	*Bos/Bison sp.*	bone	17.9	-6.9	BR12	*C. elaphus*	bone	16.6	-8.0
D6	*Bos/Bison sp.*	bone	15.5	-9.3	BR12	*C. elaphus*	bone	17.8	-6.9
A1	*C. ibex*	bone	17.6	-7.4	BR12	*C. elaphus*	bone	17.4	-7.3
A1	*C. ibex*	bone	17.6	-7.4	BR12	*C. elaphus*	tooth	16.1	-9.1
A1	*C. ibex*	bone	17.6	-7.4	BR12	*C. capreolus*	tooth	14.2	-11.3
A1	*Bos/Bison sp.*	bone	17.3	-7.6	BR12	*C. capreolus*	bone	15.7	-9.6
A1	*Bos/Bison sp.*	tooth	12.8	-12.0	S2	*C. elaphus*	bone	16.5	-8.0
A2	*C. ibex*	bone	17.7	-7.3	S2	*C. elaphus*	bone	17.1	-7.5
A2	*C. ibex*	tooth	16.7	-8.4	S2	*C. elaphus*	bone	17.0	-7.6
A2	*C. ibex*	tooth	15.2	-10.2	S2	*C. ibex*	tooth	14.9	-10.5
A3	*C. ibex*	bone	17.0	-8.1	S2	*C. ibex*	tooth	14.8	-10.6
A3	*C. ibex*	tooth	17.8	-7.2	S2	*C. capreolus*	bone	17.5	-7.6
A3	*Bos/Bison sp.*	tooth	15.1	-9.7	S2	*C. capreolus*	bone	17.9	-7.0
A4	*C. elaphus*	bone	16.5	-8.1	S2	*C. capreolus*	bone	17.6	-7.4
A5+6	*C. ibex*	bone	16.5	-8.6	S3	*C. elaphus*	bone	16.8	-7.7
A5+6	*C. ibex*	tooth	17.4	-7.7	S3	*C. elaphus*	bone	16.9	-7.7
A5+6	*C. elaphus*	bone	16.3	-8.2	S3	*C. elaphus*	bone	16.1	-8.4
A5+6	*C. elaphus*	bone	16.9	-7.7	S3	*C. elaphus*	bone	17.3	-7.3
A6	*C. ibex*	bone	16.8	-8.3	S3	*C. ibex*	tooth	14.8	-10.6
A6	*C. capreolus*	bone	17.9	-7.1	S3	*C. ibex*	tooth	14.3	-11.1
A6	*C. capreolus*	bone	17.7	-7.3	S4	*C. elaphus*	bone	17.0	-7.6
A7	*Bos/Bison sp.*	bone	15.0	-9.8	S4	*C. elaphus*	bone	16.3	-8.2
A10	*C. ibex*	bone	18.4	-6.5	S4	*C. elaphus*	bone	16.8	-7.7
A10	*Bos/Bison sp.*	tooth	14.2	-10.6	S4	*C. ibex*	tooth	12.5	-13.2
A11	*Bos/Bison sp.*	tooth	15.1	-9.7	S4	*C. capreolus*	bone	18.4	-6.5
A11	*Bos/Bison sp.*	tooth	16.2	-8.7	S5	*C. elaphus*	bone	15.3	-9.1
BR1	*C. ibex*	bone	17.6	-7.4	S5	*C. elaphus*	bone	16.3	-8.2
BR1	*C. elaphus*	bone	17.7	-7.0	S5	*C. ibex*	tooth	14.8	-10.6
BR3	*C. ibex*	bone	16.8	-8.3	S6	*C. elaphus*	bone	16.0	-8.5
BR4	*C. ibex*	bone	17.4	-7.7	S6	*C. elaphus*	bone	17.4	-7.2
BR5	*C. ibex*	bone	17.0	-8.1	S6	*C. elaphus*	bone	17.0	-7.6
BR5	*C. elaphus*	bone	16.8	-7.8	S7	*C. elaphus*	bone	17.2	-7.4
BR5	*C. elaphus*	bone	17.5	-7.2	S8	*C. elaphus*	bone	16.5	-8.0
BR6	*C. elaphus*	bone	17.1	-7.5	S8	*C. elaphus*	bone	16.8	-7.7
BR6	*C. capreolus*	bone	16.7	-8.4	S8	*C. elaphus*	bone	17.8	-6.9
BR7b	*C. elaphus*	bone	17.4	-7.3	S8	*C. elaphus*	bone	14.1	-10.2
BR7b	*C. elaphus*	bone	17.2	-7.4	S9	*C. elaphus*	bone	16.8	-7.7
BR7b	*C. elaphus*	bone	16.1	-8.4	S9	*C. elaphus*	bone	14.4	-9.9

Tab.1 - δ^{18}Op of the samples measured, their stratigraphic position and calculated δ^{18}Ow values.

Valori di δ^{18}Op dei campioni misurati, la loro posizione stratigrafica e i valori calcolati di δ^{18}Ow.

tooth values and the uncertainty on the meaning of the observed difference, teeth were not used for the reconstruction of the palaeoclimatic curve.

Apart from a few cases the $\delta^{18}Ow$ values calculated from the $\delta^{18}Op$ of *C. ibex, C. capreolus, C. elaphus and Bos/Bison* sp. bone samples are rather similar along the stratigraphic sequence (Fig.3). The observed similarity suggests similar $\delta^{18}O$ values for the water taken in by the specimens of the different species despite their different behaviour. If the mean $\delta^{18}Ow$ values of all the samples measured are taken into consideration the solid curve can be traced through the sequence (Fig.3). This curve is characterised by very small $\delta^{18}Ow$ oscillations and does not show a significant trend, most of the samples yielding results that are not very far from modern mean values of atmospheric precipitation and of environmental water in that area (about -7.5 / -8.0 per mil). This consideration is not acceptable since the time interval considered is known as a cold period belonging to the last glacial. To explain this apparent inconsistency in the results it must be assumed that during glacial periods the isotope composition of ocean water was considerably enriched in heavy isotopes (^{18}O and D) when compared to modern ocean water (Shackleton and Kenneth, 1975). This enrichment is related to the storage of huge amounts of isotopically light water in the thick and expanded ice caps covering large areas of the northern hemisphere. Since the Mediterranean basin is known to amplify the climatic effects considerably, it can be assumed that, during the last glacial period, oceanic water was at least 1 to 1.5 per mil heavier than now and the Mediterranean water was, very likely, heavier by 1.5 to 2 per mil than now. Accordingly, the oxygen isotope composition of the atmospheric water vapour and the atmospheric precipitation were ^{18}O enriched by about the same amount. This means that the mean $\delta^{18}Ow$ value obtained from most of the samples measured should be shifted by about 2 per mil towards lighter (colder) values. Such a shift corresponds to a temperature decrease of about 5°C that can be reasonably accepted to represent the mean difference between the average conditions of the last glacial in this area and modern conditions.

If the most negative values obtained are taken into account the $\delta^{18}Ow$ obtained from levels S8 and D1a are lighter than the modern mean isotope composition of local meteoric water by about 2/2.5 per mil. On the basis of the modern Mediterranean temperature gradient (0.39 per mil) the difference between the modern value and the lowest results obtained would correspond to a negative gradient in the yearly mean air temperature of about 9.0/11.0°C if the variation of 1.5/2 per mil of the oxygen isotope composition of the Mediterranean water is taken into account. These values seem to be too high and in this case it is worth suggesting once more the possibility that these very negative values may be related to specimens that drank stream water from alpine glaciers or, at least, from high mountains.

It is also possible that, given the incompleteness of our curve, the coldest periods are not documented because the cave was not occupied.

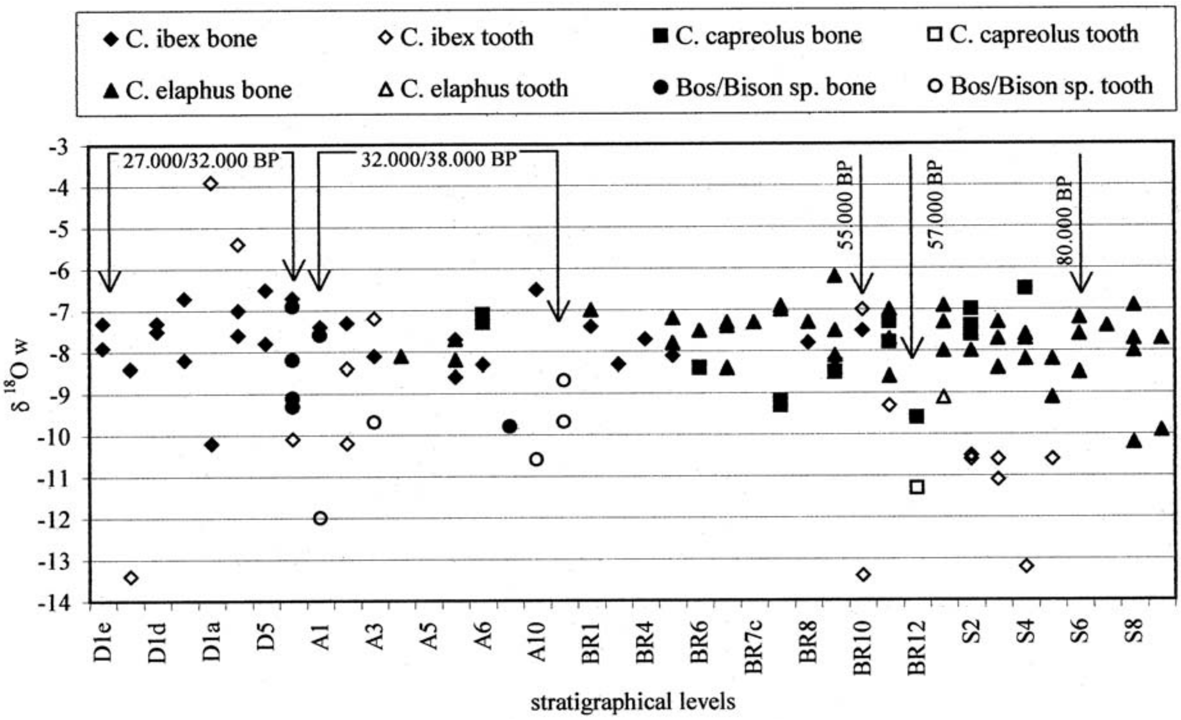

Fig.2 - Oxygen isotope composition of palaeoenvironmental waters calculated from the measured $\delta^{18}Op$ values reported according to the stratigraphic position of the samples. Solid symbols are bones, open symbols are teeth.

Valori di $\delta^{18}O$ *dell'acqua paleoambientale, calcolati dai valori di* $\delta^{18}Op$ *dei diversi campioni riportati in funzione della loro posizione stratigrafica. I simboli pieni si riferiscono a campioni di ossa, gli altri a campioni di denti.*

4. CONCLUSIONS

The reported stable isotope study suggests that:

- when possible, it is better to avoid the use of fossil teeth for palaeoenvironmental reconstruction along a stratigraphic sequence because they record the conditions existing during a short period of the individual's life. This short period can be "isotopically" different in comparison to their overall life;
- the studied samples recorded the climatic conditions during a period considerably colder than the present one with colder climatic episodes;
- the temperature gradient between the studied period and recent time was not lower than about 5°C, with, probably, considerably colder episodes;
- these results are of importance as database of the oxygen isotope composition of mammal skeletal remains of Palaeolithic age. By comparing all the samples from Europe, measured up to now, these new data may help the detailed reconstruction of the impact of each climatic event along NS and EW geographic sections.

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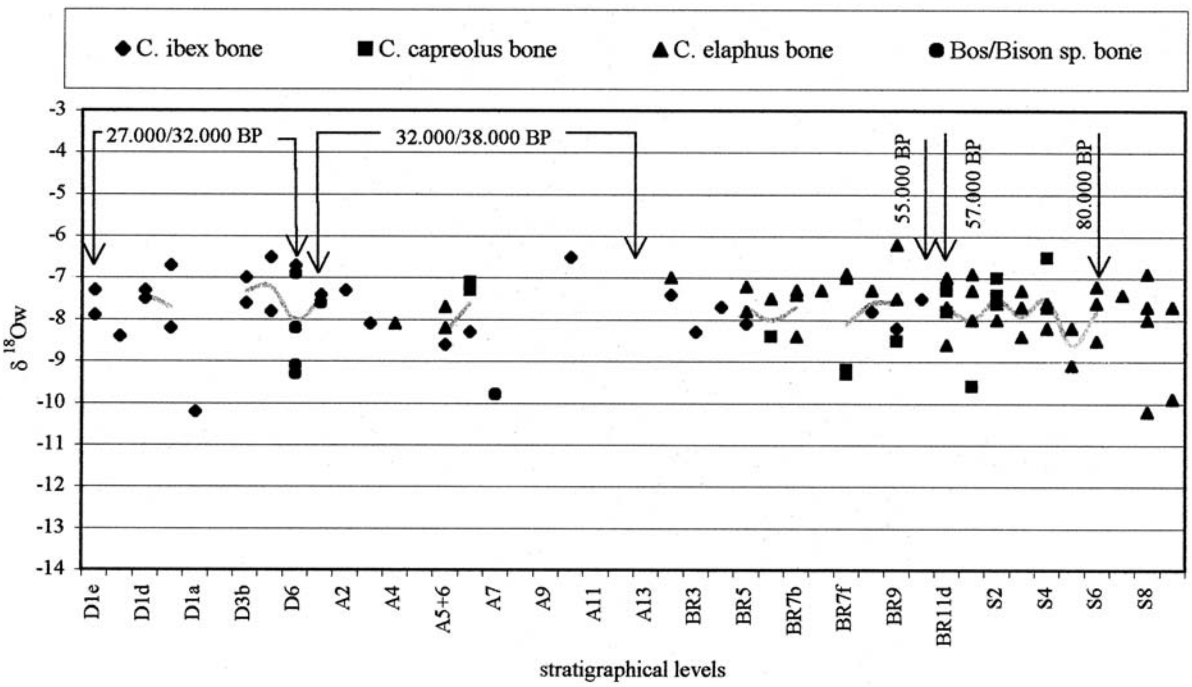

Fig.3 - Oxygen isotope composition of palaeoenvironmental waters calculated from the δ^{18}Op of bone samples reported according to the stratigraphic position of the samples. The curve suggests the possible trend of the "mean" climatic conditions.

Valori di δ^{18}O *dell'acqua paleoambientale, calcolati dai valori di* δ^{18}Op *delle ossa riportati in funzione della posizione stratigrafica. La curva è l'unione dei punti che rappresentano il valore medio dei campioni di ossa presenti nel medesimo strato ed indica il possibile andamento climatico.*

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Ms. ricevuto il 31 ottobre 2001
Testo definitivo ricevuto il 19 dicembre 2001

Ms. received: October 31, 2001
Final text received: December 31, 2001