Paleoclimatic and paleobiological correlations by mammal faunas from Southern America and SW Europe

M.T. Alberdi[1], F.P. Bonadonna[2], E. Cerdeño[1], G. Leone[2], A. Longinelli[3], J.L. Prado[4], B. Sánchez[1,4] & E.P. Tonni[4]

1 - Museo Nacional de Ciencias Naturales, CSIC, Madrid, Spain.
2 - Dipartimento di Scienze della Terra, Università di Pisa, Italy.
3 - Ist. di Mineralogia e Petrografia, Università di Trieste, Italy.
4 - Facultad de Ciencias Naturales y Museo de La Plata, CIC, Argentina.

ABSTRACT

Key words: Correlation; Mammals; Paleoclimatology; Geochemistry; Neogene.

The preliminary results of a research dealing with the study of global changes in the last 5 Ma by correlations of continental records between the Northern and the Southern Hemispheres (SW Europe and Argentina, respectively) are reported. The first analyses of the evolutionary patterns point out, in Argentina, two different turnover times: the first one is characterized by a high percentage of mammal autochthonous extinctions placed in the span of time between the last Chapadmalalan and the first Ensenadan faunas, around 2.5-2.3 Ma. It is possible to identify a high percentage of new immigrant genera from North America in the first turnover, while the second one, associated to the "last Pleistocene megafaunal extinctions", probably occurred at the beginning of the "Glacial Pleistocene", around 1.0-0.8 Ma.

The oxygen isotope composition of phosphate from fossil mammal bones was measured to have a better climatic resolution from faunal elements of two hemispheres and to compare them by results as quantitative as possible. The preliminary efforts are brought out on fourteen deposits from SE Spain. Isotopic and chemical results strongly suggest the existence of a relation between the oxygen isotope composition in various skeletal components and the taphonomic processes of a single deposit. The variations of $\delta^{18}O$ in the mammal teeth of Equidae from SE Spain suggest a shift towards a colder environment from the older one, Huélago, to more recent deposits, as well as from Venta Micena to Fuensanta in agreement with the transition from the Middle to the Upper Villafranchian, around 2.5 Ma, and the transition between the "Preglacial" to the "Glacial" Pleistocene, around 1.9-0.8 Ma.

INTRODUCTION

This work reports the preliminary results obtained during the first stage of a cooperation project among Argentina, Italy and Spain, and funded by the European Community (E.C. grant n° CI1* - CT90 - 0862). The aim of the research is the study of global changes by correlations of continental records between the Northern Hemisphere (SW Europe) and the Southern one (Argentina). The goal of the project is to collect climatic information to get a better chronological location of the studied faunas in the last 5 Ma. The work deals with mammal evolution and includes analyses of oxygen isotopes in phosphate from mammal bones (Longinelli, 1984).

In the Southern Hemisphere we have selected several Atlantic coastal localities between the North of Mar del Plata and the South of Miramar (Buenos Aires province, Argentine, figure 1a). These localities show the best continental series from the Pliocene to the Pleistocene levels, with a great faunal richness. These faunal assemblages are comprised between the Chapadmalalan Age, Pliocene, and the Pleistocene - Holocene boundary.

In the Northern Hemisphere we have used our previous knowledge on the Western Mediterranean area, mainly the Guadix-Baza Basin, Spain, and the correlations with Central Italy (Bonadonna & Alberdi, 1987a,b; Alberdi & Bonadonna, 1988, 1989).

MATERIAL AND METHODS

The mammal assemblages come from the following "Formations": Epecuén (Huayquerian age), Monte Hermoso (Montehermosan Age), Chapadmalal

(Chapadmalalan Age), Barranca de Los Lobos, Vorohué and San Andrés ("Uquian" Age), Miramar (Ensenadan age) and Arroyo Seco, Santa Isabel and Lobería of the Lujanian Age (Tonni *et al.*, 1992; Alberdi *et al.*, 1993). The chronological assignement of the stratigraphic scheme showed in Tonni *et al.* (1992: fig.8) is reviewed according to new data. Concerning the temporal range of the different mammal ages there are differences with respect to the previous geochronological scale of Marshall *et al.* (1983, 1984).
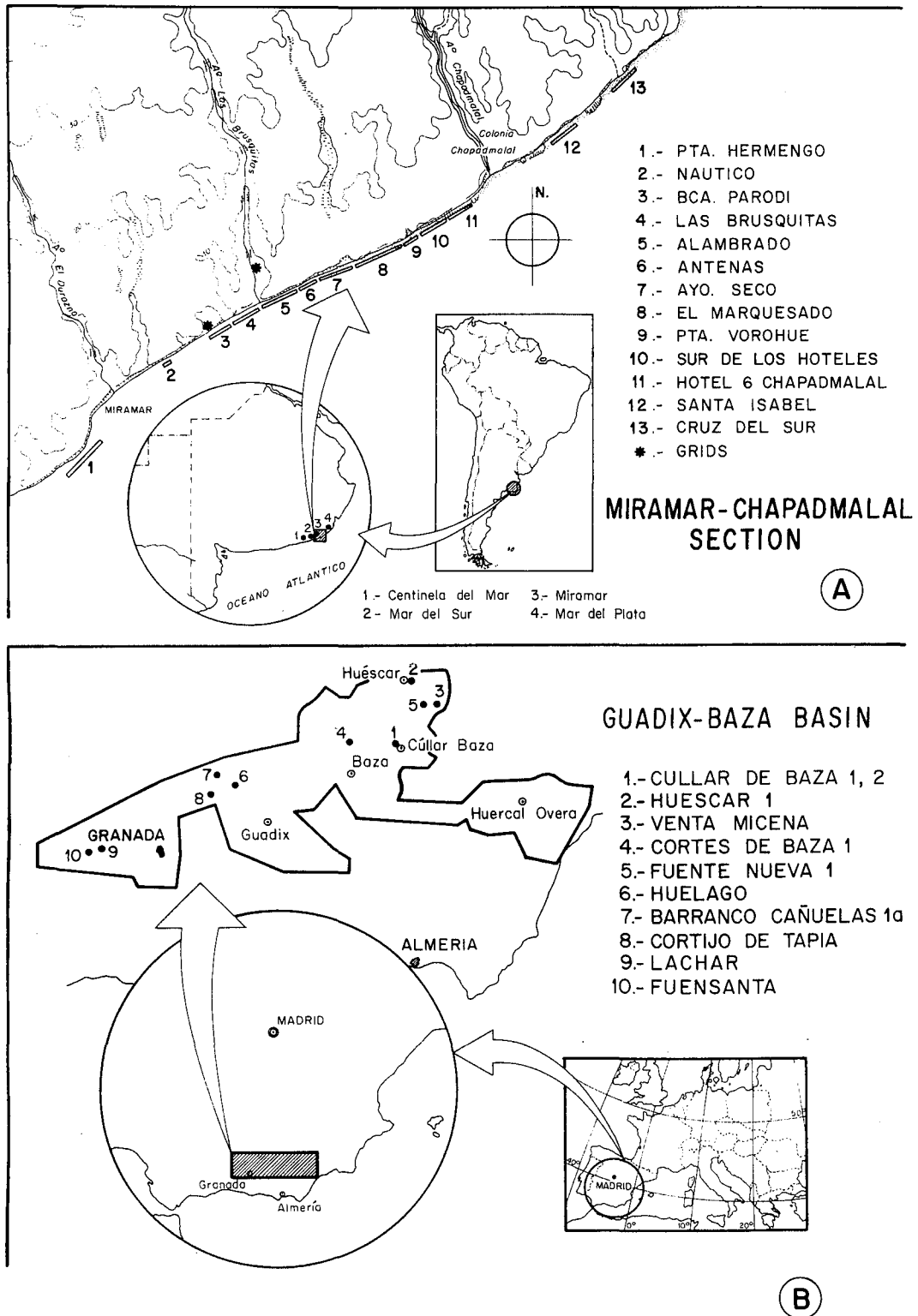

Fig. 1 — Geographical map of the studied areas. A, the Miramar-Chapadmalal Section (Argentina, Southern Hemisphere); B, the Guadix-Baza Basin (SE Spain, Northern Hemisphere).

In order to represent the faunal turnover in the Southern Hemisphere, we take the percentage of first and last records in the faunistic assemblages (%FR and %LR) from the Huayquerian Age to the Lujanian Age. The %FR and %LR are discriminated between autochthonous and immigrant mammal genera, since through this span of time, families are scarcely modified and species are not taxonomically well established.

RESULTS

Results of Faunal Analysis in Southern Hemisphere

Two faunal turnovers are verified: the first one, placed between the Chapadmalalan and "Uquian" Ages, is characterized by a high percentage of autochthonous extinctions and new immigrant genera from North America, mainly in the last part of this time scale (figs. 2 and 3).

During the Chapadmalalan Age (assemblage 3) a maximum of last records occurs. Some clades become partially extinct and the Thylacosmilidae, a very specialized carnivorous marsupial family, disappear. Most of these extinctions correspond to forms whose morphological type is not replaced until the beginning of the Ensenadan age (assemblage 7), when probably the environmental status became once more comparable to the previous period. This is the case for the middle sized Glyptodontidae as *Plohophorus* and *Plohophoroides*, whose niches are occupied by *Sclerocalyptus* and *Lomaphorus*.

The largest Glyptodontidae such as *Eleutherocercus*, lastly recorded in the Montehermosan age (assemblage 2), are also replaced in the Ensenadan.

The Chapadmalalan giant Dasypodidae, *Macroeuphractus outesi* and *Macrochorobates chapadmalensis*, show a similar pattern, being replaced by *Eutatus seguini* and *Propraopus grandis* during the Middle and Late "Uquian" (assemblage 5+6) and the Ensenadan, respectively.

Macraucheniidae are represented by two genera in the Huayquerian (assemblage 1). One of them (*Macrauchenidia*) becomes extinct in the Huayquerian; the other one, *Promacrauchenia*, persists until Early "Uquian" (assemblage 4). These forms are replaced by *Macraucheniopsis* and *Macrauchenia* in the Ensenadan and Lujanian, respectively.

These and other punctual examples reveal a faunal turnover only within the autochthonous mammals. It is evident that these changes imply pseudoextinctions or migrations, since some lineages disappear from one area but they come back in later times.

Carnivores have been mentioned as a model of active replacement of autochthonous forms (marsupials) by placental Carnivora from the Stratum III (Webb, 1985; Marshall & Cifelli, 1990). Although this necessarily implies the simpatry of both lineages, this situation is not verified from the critical faunal analysis and new findings.

Borhyaenidae is an important carnivorous marsupial group which is well diversified during most part of the Middle Cenozoic, and becomes extinct in the Montehermosan (last record of *Borhyaenidium*, *Notocynus*, *Parahyaenodon* and *Eutemnodus*). In addition, the last record of Thylacosmilidae (*Thylacosmilus*) occurs in the Chapadmalalan. The active replacement of these forms should be performed by placental carnivores with similar characteristics as Felidae and, in a lesser degree, Canidae. However, the first record of Felidae happens in the Ensenadan (Berman, 1989; Tonni et al., 1992), and Canidae are firstly recorded in the Middle-Late "Uquian".

The carnivorous role in South America was played also by the running birds of the families Phororhacidae, Psiliopteridae and Brontornithidae (Tonni, 1977; Tonni & Tambussi, 1986). These birds, as well as Thylacosmilidae, have their last record in the Chapadmalalan. Phororhacidae participate in the Great American Biotic Interchange, and the genus *Titanis* is coeval with the placental carnivores in North America until Early Pleistocene (Vuilleumier, 1985; Webb, 1991). As Webb (1991) states, this situation — and that shown by the Argentinian record — appears to contradict Marshall's (1977) and Marshall & Cifelli's (1990) hypotheses, who atribute the extinction of "phororhacoids" to the arrival of holarctic carnivores.

The native "ungulates" were also considered as an example of active replacement by the holarctic ungulates (Webb, 1991). Most of the former clades have an important adaptative radiation during Middle Cenozoic, but they show an abrupt decline in the Chapadmalalan, although most of them survive. Proterotheriidae reach the Chapadmalalan with the genus *Brachytherium* and the family still exist in the Pleistocene (Frenguelli, 1921; Alvarez, 1974). Within Toxodontidae, *Palaeotoxodon* becomes extinct in the Huayquerian, *Trigodon* and *Alitoxodon* in the Montehermosan, and *Chapadmalodon* and *Xotodon* in the Chapadmalalan. Only one genus, *Toxodon*, appears in the last Age and still exists in the Lujanian.

Hegetotheriidae are represented by five genera from the Huayquerian, but only one of them, *Paedotherium*, reaches the "Uquian". Webb (1991) suggested that the decrease of this genus and its final extinction could be due to the competition with the lamine Camelidae. However, these kinds of comparisons must be done among taxa with similar size and trophic habits, which is not observed between *Paedotherium* and any Camelidae.

A second turnover (figs. 2 and 3) includes the Ensenadan and Lujanian faunas. It is characterized by a great increase of immigrant genera; there is also an increase of the autochtonous genera, but they don't reach again their previous diversity. Among the autochthonous forms, a diversification of Cingulata (Glyptodontidae and Dasypodidae) and Tardigrada (Scelidotheriinae and Mylodontinae) occurs during that time.

Among the immigrant elements, the orders Artiodactyla (Camelidae and Cervidae), Perissodactyla (Equidae), Proboscidea and Carnivora became very diversified. Felidae, Ursidae and the large-sized *Canis* (Canidae) are firstly recorded in the Ensenadan.

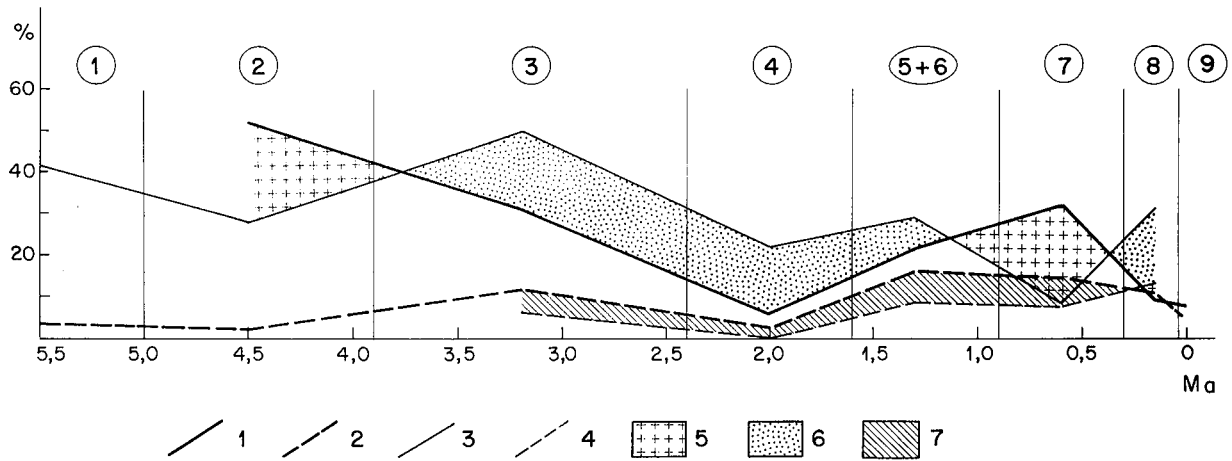The mammal communities of this period are characterized

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Fig. 2 — Graphic representation of faunal evolution in the Chapadmalal sections through time in Ma. The ordinate axis represents the percentage ratio between first occurrence of taxa and the total number of taxa in each assemblage, for autochthonous (1) and immigrants (2), and the percentage ratio between last appearance of taxa and the total number of taxa in each assemblage, for autochthonous (3) and immigrants (4). 5 represents the ratio between appearances and extinctions > 1. 6 represents the ratio between appearances and extintions < 1. 7 represents the difference between the first and last appearances of immigrant faunal elements. Encircled numbers: 1 = Huayquerian, 2 = Montehermosan, 3 = Chapadmalal "Fm.", 4 = Bca. Los Lobos "Fm.", 5+6 = Vorohué + San Andrés "Fms.", 7 = Miramar "Fm.", 8 = Luján Fm., 9 = recent.
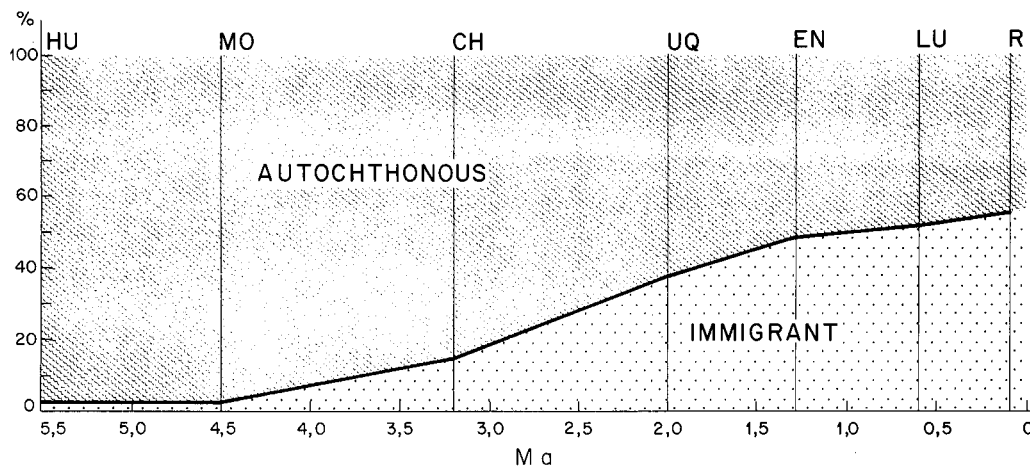

Fig. 3 — Graphic representation of the percentage relation between autochthonous and immigrant faunal elements through time in Ma. HU = Huayquerian, MO = Montehermosan, CH = Chapadmalalan, UQ = "Uquian", EN = Ensenadan, LU = Lujanian, R = Recent. The correlations between the ages (Ma) and the Land Mammal Ages (M=, CH, UQ, EN, LU) are wrong. The correct correlation is in Fig. 2.

by the high frequency of megamammals, weighing over 1000 kg (i.e.: *Toxodon, Megatherium, Lestodon, Doedicurus, Panochthus, Glyptodon, Stegomastodon, Macraucheniopsis*). This situation is unique, and involves mainly the autochthonous herbivores (except *Stegomastodon*) whose tendency to giantness reaches its maximal expression in the Ensenadan (Scillato Yané*et al.*, 1989). All these overweighted species disappear from the South American record in the late Pleistocene-Holocene.

In this work, according to the correlation of the global climatic changes between both Hemispheres (Shackleton & Kennett, 1975; Shackleton & Hall, 1984; Haq *et al.*, 1987), we try to correlate these global changes with those succesive faunal turnovers (figs. 2 and 4).

In this way, the first turnover which happened during the Chapadmalalan-"Uquian" Ages can be correlated with

the cooling which took place around 3.2 - 2.4 Ma. The second one, found during the Ensenadan -Lujanian Ages, occurs after 1.0 - 0.8 Ma (see figs. 2 and 3). This event could be explained as linked to a long sequence of climatic oscillations which are short in time but of great amplitude. Therefore they could be correlated with the beginning of the "Glacial Pleistocene".

Another interpretation regarding this second turnover considers it as linked to a climatic improvement followed by a quite long time of stable climatic conditions, in this case the quoted event could be older.

Around the Pleistocene-Holocene boundary there is one important extinction involving mainly autochthonous mammals (Tonni, 1990). On the other hand, the families of immigrant mammals are well represented in recent faunas, except as concern Equidae and Gomphotheriidae.

Geochemical analysis results

Oxygen isotope analyses on mammals have been performed in order to check the application of this methodology on bones of such an old age, and to develop a paleoclimatic interpretation of the results.

The oxygen isotope compositions of the phosphate from fossil bones coming from fourteen Spanish deposits were measured. These deposits, mainly located in the Guadix-Baza area, SE Spain, have a good stratigraphical position and permit us a certain control on the methodology itself, see fig. 1b. Results provide evidence of a quite large variability for the samples belonging to the same deposit and also a peculiar feature: the $\delta^{18}O(PO_4)$ values of bones are often depleted in heavy isotope with respect to teeth of the same species and from the same locality. The isotopic difference ranges from a few tenths of one per mil to several δ units. In a few cases, namely Puebla de Valverde, Fuentenueva, Huéscar-1 and Cúllar-1 deposits, the opposite behaviour, $\delta^{18}O_{(tooth)} \le \delta^{18}O_{(bone)}$, takes place for almost all the measured species: Equus stenonis cfr. vireti, Equus stenonis intermediate granatensis-altidens, Equus altidens, E. sussenbornensis, Capra sp., Dolichodoryceros savini, Stephanorhinus etruscus. This strongly suggests the existence of a relation between the oxygen isotope composition, which is now found in the different portions of the skeleton, and the taphonomic processes of a single deposit. Mineralogical (XRD) and chemical (XRF) analyses were performed on bones of horses belonging to two deposits, Huélago and Cúllar-1. Huélago deposit is the oldest studied one, Middle Villafranchian in age; Cúllar-1 is younger, Galerian in age. The results show a major degree of cristallinity of carbonate apatite in bones from the Cúllar-1 deposit; moreover, some trace elements, Ba and Sr, result to be very enriched in the analysed bone and dentine teeth from Cúllar-1: 3700-3500 versus 1200-1800 ppm for strontium, and 240-350 versus 160-330 ppm for barium. Differences of the same order were also found in Sr by analysing separately enamel and dentine of the teeth from these two deposits; the Sr and Ba values are about ten times larger than the ones we found in bones of Spanish modern horses. Chemical alteration and oxygen isotope anomalies appear to be distinctive for a single deposit.

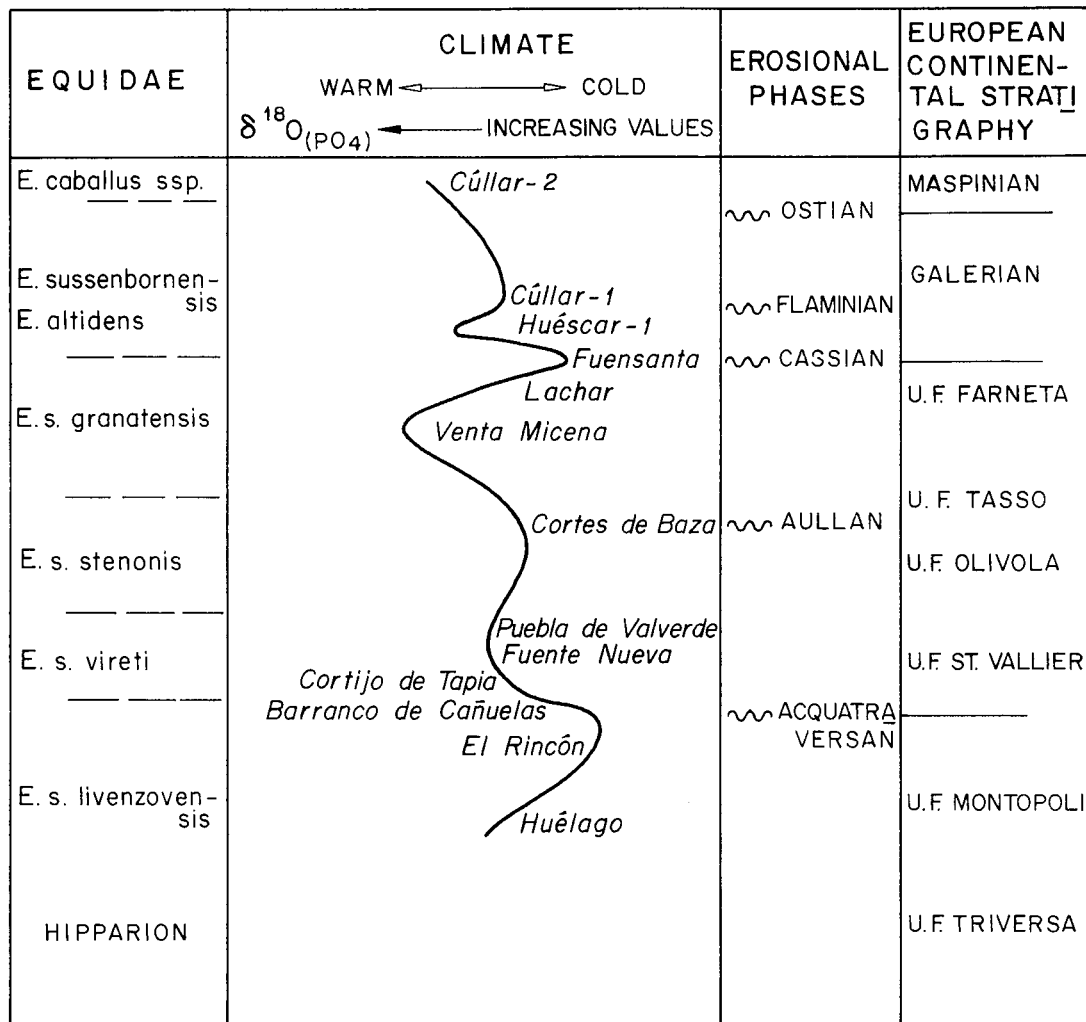| EQUIDAE	CLIMATE WARM ⟵————⟶ COLD $\delta^{18}O_{(PO_4)}$ ⟵————INCREASING VALUES		EROSIONAL PHASES	EUROPEAN CONTINENTAL STRATIGRAPHY
E. caballus ssp.	Cúllar-2		∿ OSTIAN	MASPINIAN
E. sussenbornensis E. altidens	Cúllar-1 Huéscar-1		∿ FLAMINIAN	GALERIAN
	Fuensanta		∿ CASSIAN	
E. s. granatensis	Lachar Venta Micena			U.F. FARNETA
				U.F. TASSO
E. s. stenonis	Cortes de Baza		∿ AULLAN	U.F. OLIVOLA
E. s. vireti	Puebla de Valverde Fuente Nueva Cortijo de Tapia Barranco de Cañuelas El Rincón		∿ ACQUATRA VERSAN	U.F. ST. VALLIER
E. s. livenzovensis	Huélago			U.F. MONTOPOLI
HIPPARION				U.F. TRIVERSA

Fig. 4— Stratigraphy of Spanish deposits studied from remains of equids. The curve shows the variations of maximum isotopic values measured in teeth phosphate from each deposit (after Sánchez Ph.D., unpublished). Erosional phases after Ambrosetti et al. (1972).

At this stage of the research only a very preliminary interpretation of the oxygen isotope results may be attempted from a climatic point of view. The $\delta^{18}O$ values, mainly in fossil equid teeth, from the Southeast Spanish area, show differences as large as two δ‰ units when the maximum measured values in each deposit are considered; mean teeth values vary in the same way. Otherwise $\delta^{18}O$ variations in bones do not follow with regularity the trend shown by teeth data. In a paleoclimatic reading of the isotopic results of these mammal fossil remains, higher ^{18}O content of bones corresponds to higher average air temperature. Accordingly these data suggest a short cooling after the oldest deposit, Huélago, followed by an apparently marked climatic improvement which culminates with Venta Micena deposit, where we found the highest isotopic values, $\delta^{18}O$ 18.6 ‰ vs.SMOW, in an *Equus* fossil tooth. A new cold stage, Fuensanta deposit, precedes the trend towards a better climate that characterizes the younger studied deposits (see Fig. 4).

The biostratigraphy of these deposits (Bonadonna & Alberdi, 1987a,b) shows that Huélago, El Rincón, Barranco de Cañuelas-1a and Cortijo de Tapia belong to the Faunal Unit of Montopoli which begins just before the first cooling in the Northern Hemisphere and culminates during it; Fuentenueva and Puebla de Valverde belong to the following Faunal Unit of St.Vallier. This cold event marks the beginning of the same climatic improvement in the Lower Pleistocene we observe in the Venta Micena deposit; moreover, the $\delta^{18}O$ values obtained in bones from El Rincón seem to agree with its attribution to the Faunal Unit of Montopoli previously obtained by studying the $\delta^{18}O$ in freshwater shells and carbonates (Leone, 1985). The reasonable agreement between isotopic and biochronologic data seems to be encouraging for the development of this kind of study.

CONCLUSIONS

We can correlate the global climatic changes (Shackleton & Kennett, 1975; Shackleton & Hall, 1984; Haq *et al.*, 1987) with the succesive faunistic turnovers verified in Southern South America.

The first turnover, verified during the Chapadmalalan - "Uquian" Ages, can be correlated with the cooling around 3.2 - 2.4 Ma.

The second turnover occurs specially during the Ensenadan - Lujanian Ages. It can be correlated with the beginning of the "Glacial Pleistocene", around 1.0 - 0.8 Ma. Another explanation would be to link this second turnover to a climatic improvement followed by a long period of stable climatic conditions, around 2.0 - 1.5 Ma

These turnovers can also be correlated with the similar ones verified in the Western Mediterranean region (Suc & Zagwijn, 1983; Bonadonna & Alberdi, 1987a,b; Alberdi & Bonadonna, 1988). The Chapadmalalan - "Uquian" turnover would correspond to the Huélago deposit in the Northern Hemisphere. Huélago reflects a cold climate, and it is included in the Montopoli Faunal Unit, around 2.5 Ma. A faunal turnover occurs between Montopoli and Triversa F.U.; *Hipparion* is replaced by *Equus* and *Mastodon* by *Elephas*. Therefore, it can be stated than a faunal turnover between 3.5 and 2.5 Ma happened in both Northern and Southern Hemispheres.

On the other hand, the second turnover established for the Ensenadan - Lujanian Ages in Argentina can be compared with the Villafranchian - Galerian time span in Western Europe, represented in the Guadix-Baza area by deposits of Venta Micena, Láchar, Fuensanta, Huéscar-1 (Fig 4). In the Northern Hemisphere, a climatic change and the arrival of a modern fauna occur in this time period.

ACKNOWLEDGEMENTS

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