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CENOZOIC (PRE-PLIOCENE) PALEOENVIRONMENTAL TRENDS BASED ON PALYNOMORPHS FROM THE COLORADO BASIN, ARGENTINA [1]

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ABSTRACT: *CENOZOIC (PRE-PLIOCENE) PALEOENVIRONMENTAL TRENDS BASED ON PALYNOMORPHS FROM THE COLORADO BASIN, ARGENTINA.* Based on palynological studies, paleoclimatic trends were inferred for the Paleocene-Miocene of the marginal part of the Colorado Basin, Argentina. The data show warm and humid conditions during the Late Danian (Paleocene), a decline of temperature and humidity from the ?Mid Eocene to the Oligocene. Warm, humid conditions at the end of the Oligocene and Early Miocene were recorded; dry-temperate periods alternated with warmer humid ones during the Mid and Late Miocene. Temperature and humidity decreases coincide with sea level drops at Eocene/Oligocene, Early/Late Oligocene and Miocene/Oligocene boundaries. These paleoclimatic interpretations are compatible with those derived from calcareous microfossils of Colorado Basin, fossil plants from South America and global paleoclimatic changes inferred by other authors.

RESUMEN: *FLUCTUACIONES PALEOAMBIENTALES DEL CENOZOICO (PRE-PLIOCENO) EN BASE A PALINOMORFOS EN LA CUENCA DEL COLORADO, ARGENTINA.* A partir de estudios palinológicos realizados en el sector marginal de la Cuenca del Colorado, se determinaron las tendencias paleoclimáticas durante el lapso Paleoceno-Mioceno. Para el Daniano tardío (Paleoceno) fueron inferidas condiciones cálidas y húmedas; para el Eoceno medio, templado-cálidas y húmedas; posterior disminución de la temperatura y humedad hasta el Oligoceno temprano; un mejoramiento climático para el Oligoceno tardío y Mioceno temprano; alternancia de períodos húmedos y cálidos con episodios relativamente más secos y fríos, durante el Mioceno medio y tardío. Las principales inflexiones en las tendencias de temperaturas reconocidas presentan una notable correspondencia con los límites estratigráficos convencionales. Los límites Eoceno/Oligoceno, Oligoceno inferior/Oligoceno superior y Mioceno/Plioceno coinciden con disminuciones de temperatura y humedad relacionadas con caídas relativas del nivel del mar. Las tendencias paleoclimáticas propuestas en este trabajo son compatibles con la información disponible acerca de microfósiles calcáreos de la Cuenca del Colorado, tafofloras de América del Sur y con las fluctuaciones paleoclimáticas de carácter global.

KEY WORDS: Argentina, Colorado Basin, Cenozoic pre-Pliocene, Palynology, Paleoenvironment, Paleoclimatical trends.

PALABRAS CLAVE: Argentina, Cuenca del Colorado, Cenozoico pre-Plioceno, Palinología, Paleoambientes, Tendencias paleoclimáticas.

INTRODUCTION

The aim of this contribution was to infer paleoclimatic trends during the Cenozoic (pre-Pliocene), based on previous palynological studies carried out by the authors of this paper in the marginal area of the Colorado Basin, Argentina (Quattrocchio and Guerstein, 1988; Guerstein, 1990 a, b, c; Guerstein and Quattrocchio, 1991; Ruiz, 1994; Ruiz and Quattrocchio, in press).

The samples were collected from six deep boreholes located onshore (figure 1): Nadir Nº 1 (Dresser Atlas), Puerto Belgrano 19 (Dirección Nacional del Servicio Geológico: DNSG); Puerto Belgrano 20 (DNSG) and Sansinena 1 (DNSG); Ombucta x-1 (Yacimientos Petrolíferos Fiscales: YPF) and Pedro Luro x-1 (YPF).

In order to assign the fossil spores and pollen grains to present plant families, the sporomorphs have been compared with modern taxa. The type and frequencies of sporomorphs belonging to different vegetal families reflect the past vegetational communities, including both local and regional vegeta-

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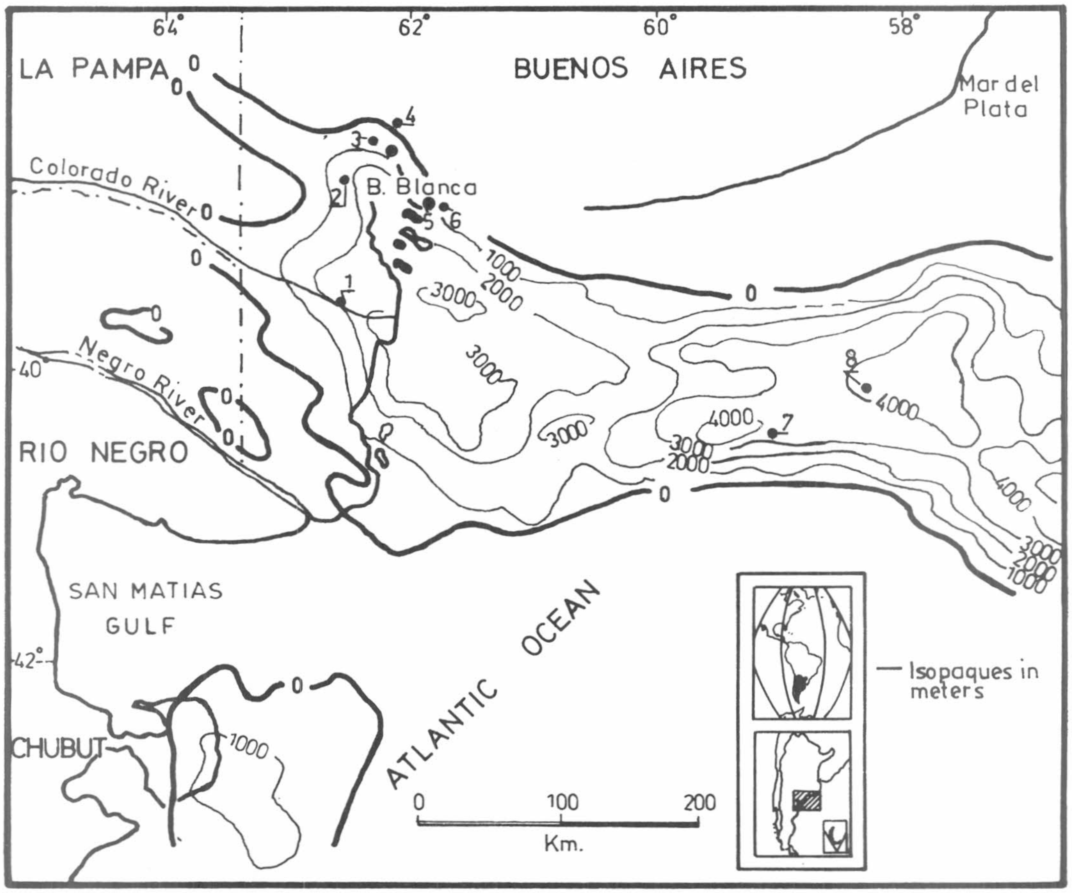


Figure 1. Location map. Boreholes: YPF Pedro Luro 1 (1); YPF Ombucta x-1 (2); DNSG Sansinena (3); Dresser Atlas Nadir Nº 1 (4); DNSG Puerto Belgrano Nº 20 (5); DNSG Puerto Belgrano Nº 19 (6); YPF Puelche x-1 (7); YPF Ranquel x-1 (8).

tion, growing around the site of deposition. The evolution of these paleocommunities, which are related to paleoclimatic changes, have been used to define "climatic zones" sensu Chateâuneuf and Reyre (1974). The climatic zones for the Colorado Basin have been established by Quattrocchio and Guerstein (1988), Quattrocchio *et al.* (1988) and Ruiz (1994).

Breaks in the paleoclimatic trends, as climatic reference marks, have also been considered following the concept of "Global climatic events" (Zubakov and Borzenkova, 1990). The empirical evidence shows that changes in the trends in different natural zones on land and in the ocean turn out to be geologically synchronous.

The proportions of marine microplankton to terrestrial derived spores and pollen have been employed as a quantitative method for approximating the distance from shore (Harker *et al.*, 1990). Considering the environmental controls on dinoflagellate cyst morphology, general dinocyst types (chorate, proximochorate, proximate, etc.) have been used to infer paleoenvironmental conditions. According to Davey and Rogers (1975) spines and processes appear to be developed as buoyancy controls; they become longer and more elaborate in open water conditions. Oceanic and warmer-water cysts typically possess longer and more delicate processes than nearshore forms. Guerstein and Quattrocchio (1991) have determined seawater paleotemperature trends based on the ratio between the frequencies of chorate and proximate dinocysts.

In order to present a paleoenvironmental model for the pre- Pliocene Cenozoic, the results have been compared with paleoclimatic conditions inferred from calcareous microfossils (Malumián, 1970; Malumián and Náñez, 1991; Boltovskoy, 1980; Krasheninnikov and Basov, 1983) and Paleogene taphofloras of South America (Romero, 1986). Our data have also been confronted to the global

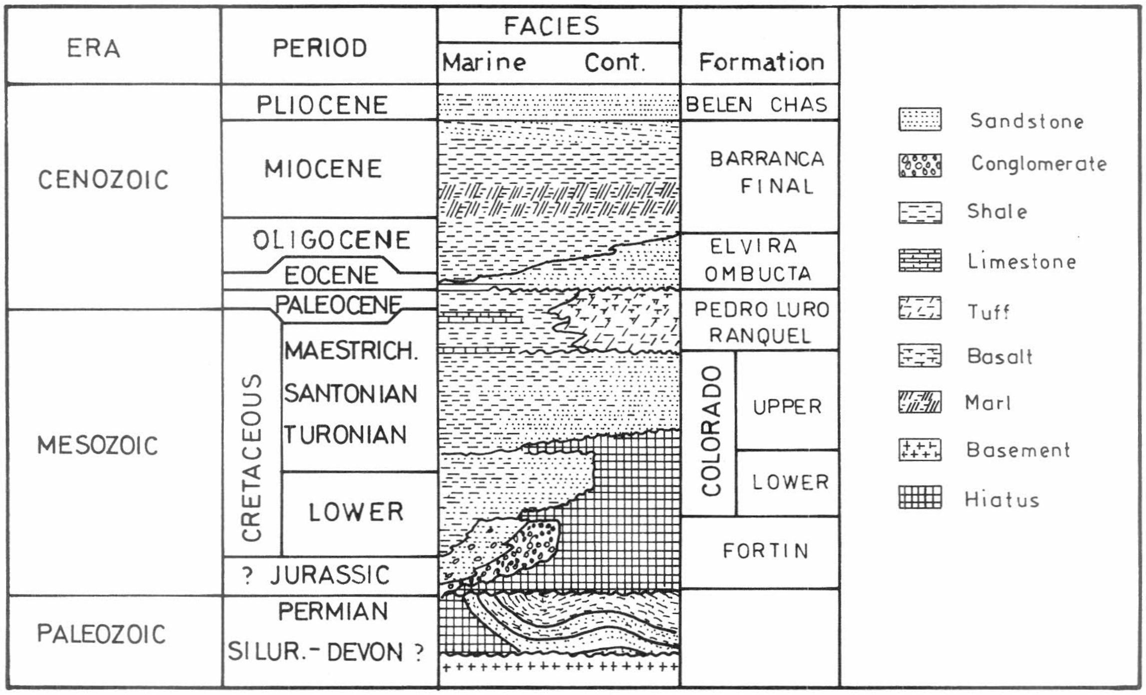


Figure 2. Stratigraphic column for the Colorado Basin (from Lesta *et al.*, 1978).

paleoclimatic changes summarized by Kennett (1980) and Zubakov and Borzenkova (1990).

GEOLOGICAL SETTING

The Colorado Basin lies on the Atlantic margin of Argentina, between 38°S and 41.5°S latitudes and 57°W and 64°W longitudes. The northern and southern limits are fault-bounded and therefore was defined as a taphrogenic basin (Zambrano, 1980). Urien *et al.* (1981) have pointed out the irregular basement subsidence, that controlled a series of highs and lows within the basement.

Main normal block faulting with E-W, NW-SE and ESE-WNW dominant trends occurred within the Upper Jurassic and the Middle Cretaceous. The fault lenghts are generally over 100 km with throws of about 500 m, though locally can reach 1800 m (Zambrano, 1980). Some basement blocks are elongated along the basin axis (like the one underlying Bahía Blanca), defining a series of horsts (Bonorino *et al.*, 1986).

Cretaceous and Cenozoic sedimentary filling up to 7000 m, derived mainly from the zocle erosion (which was exposed until the Eocene-Oligocene) and Paleozoic rocks of Sierras Australes (Bonorino, 1988), lies unconformably over the basement complex capped by Pleistocene graben terraces and eolian sands (Urien *et al.*, 1981).

The Cenozoic basin overlaps the Cretaceous limits and therefore Cretaceous sediments do not outcrop in the study area. Our knowledge is based almost exclusively on subsurface data. The samples come from deep boreholes.

The stratigraphic scheme for the Colorado Basin used in this paper (figure 2) has been proposed by Lesta *et al.* (1978).

The ?Jurassic-Cretaceous sequence begins with the Fortín Formation. The lithology suggests a mature alluvial plain deposit with lacustrine episodes. The Colorado Formation overlies the former. The depositional environment was a subaerial floodplain. The older marine deposits recorded in the basin belong to the Upper Member of Colorado Formation. According to Uliana and Biddle (1988), the Late Cretaceous flooding of the Argentine margin during a period of tectonic quiescence, produced a spectacular increase in the size of the areas under marine influence. Development of epeiric flooding started before Maastrichtian time, through limited marine incursions in the Colorado Basin (Turonian?, Lesta *et al.*, 1978).

The Pedro Luro Formation (marine) is composed of ?Maastrichtian-Lower Paleocene greenish-grey siltstones and claystones with subordinated, sometimes glauconitic, sandstones. The Upper Paleocene has not been registered in the basin.

The Eocene - Oligocene is represented by neritic, sandy and calcareous beds of Elvira Formation

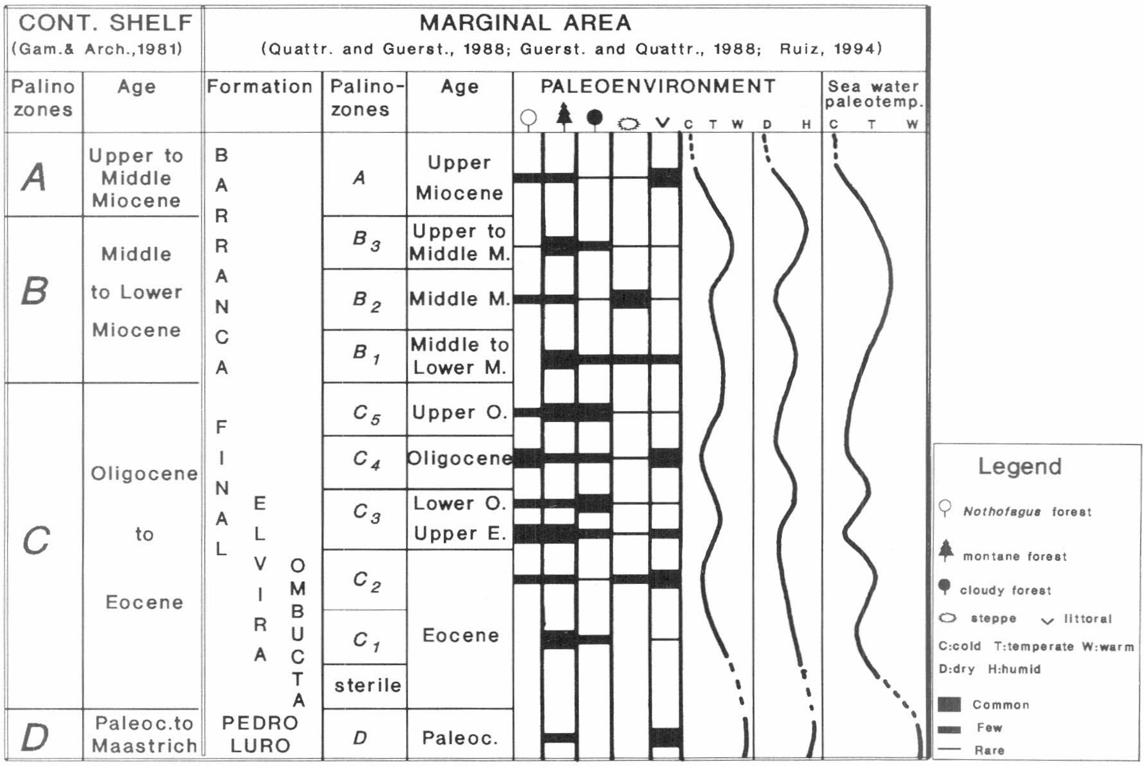


Figure 3. Chronostratigraphy and paleoenvironments inferred throughout the study of palynomorphs from the pre-Pliocene Cenozoic of the Colorado Basin.

(marine). Toward the northwest, Elvira Formation interfingers with and oversteps the continental beds of the Ombucta Formation which is hitherto palynologically sterile. Eastward Elvira Formation interfingers with Barranca Final Formation. Relations between Elvira and Barranca Final Formations in the marginal area of the basin have been presented in Guerstein and Quattrocchio (1988).

Upwards fine grained deposits of Barranca Final Formation (grey to greenish-grey claystones, shales and siltstones) continued until the Early Pliocene and the upper contact is transitional from neritic to continental (Urien *et al.*, 1981). More stratigraphic information can be found in Kaasschieter (1965), Rolleri (1975), Yrigoyen (1975), Zambrano (1980), Lesta *et al.* (1978), among others.

BIOZONATION OF THE MARGINAL AREA AND ITS CORRELATION WITH THE PLATFORM AREA (PRE - PLIOCENE CENOZOIC)

Gamerro and Archangelsky (1981) have defined five palynozones on the Argentine continental shelf in the Colorado Basin, from the Ra-X1 (Ranquel) and Pu-X1 (Puelche) YPF boreholes. These authors have compared the biozones of Puelche borehole with those defined on foraminifers by Becker and Bertels (1980).

The microfloras from Puerto Belgrano 20 borehole (Guerstein, 1990c; Ruiz, 1994) have been calibrated with calcareous microfossils from Puerto Belgrano 20 and 23 boreholes (Malumián, 1970, 1972). Microfloras from the continental shelf reflect the major climatic fluctuations, whereas microfloras from the marginal area show also the smaller changes related to climatic and environmental modifications. Therefore, in the marginal area of the Colorado Basin, Guerstein and Quattrocchio (1988) have defined subzones for the preliminar zonation of Gamerro and Archangelsky (1981).

Figure 3 shows the chronostratigraphic correlation between palynozones defined by Gamerro and Archangelsky (1981) on the continental shelf and the climatic zones determined on the marginal area of the basin (Guerstein and Quattrocchio, 1988; Ruiz, 1994; Quattrocchio and Sarjeant, *ms.*). The correlation points out the following common elements:

Palynozone D (?Maastrichtian - Paleocene): *Palaeocystodinium australinum* (Cookson) Lentin and

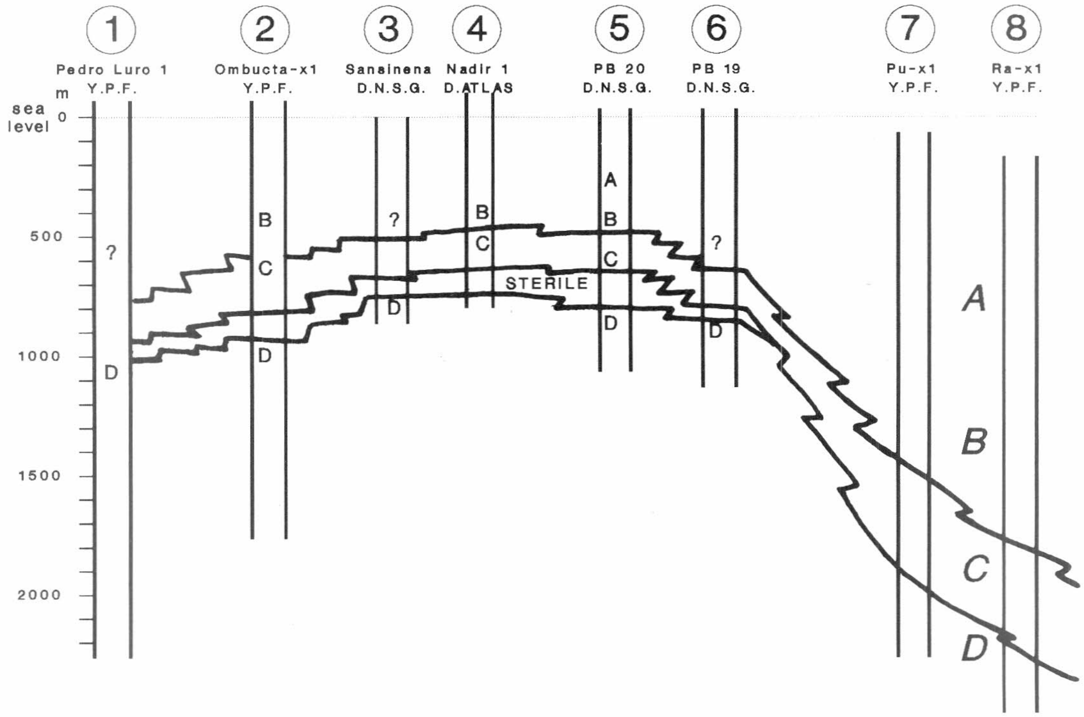


Figure 4. Chronostratigraphic correlation based on palynomorphs and calcareous microfossils from the Cenozoic of the Colorado Basin.

Williams, *Palambages morulosa* O. Wetzel and other dinoflagellate cysts are characteristic of this palynozone in the continental shelf and they are also present in the marginal area. *Spinidinium macmurdoense* (Wilson) Lentin and Williams, *Operculodinium bergmanii* (Archangelsky) Stover and Evitt, *Palaeoperidinium pyrophorum* (Ehrenberg) Goch and Netzel, *Cerodinium diebelii* (Alberti) Lentin and Williams are abundant in Late Danian beds of the marginal area (Quattrocchio and Sarjeant, *ms.*). The subzone D_1 has been defined based on terrestrial species from the uppermost Upper Danian (Ruiz, 1994).

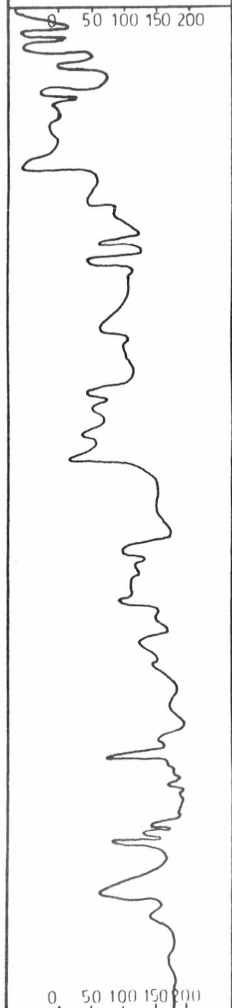
Palynozone C (Eocene to Oligocene): It is characterized by the presence of the following dinoflagellate cysts: *Pentadinium taeniagerum* Gerlach, *Cannosphaeropsis utinensis* (O. Wetzel) Marheinecke, *Hystrichokolpoma rigaudiae* Deflandre and Cookson, *Nematosphaeropsis densiradiata* (Cookson and Eisenack) Stover and Evitt, *Spiniferites membranaceus* (Rossignol) Sarjeant and *Operculodinium centrocarpum* Deflandre and Cookson, both in the continental shelf and in the marginal area. Five climatic subzones (C_1 - C_5) determined in Nadir Nº 1, Puerto Belgrano Nº 20 and Ombucta x-1 boreholes correspond chronostratigraphically to this palynozone.

Palynozone B (Lower to Middle Miocene): The age of this palynozone has been defined by foraminifers (Malumián, 1970, 1972). Sediments of this age from the marginal area do not bear paleomicroplankton elements in common with Palynozone B from Ranquel and Puelche boreholes. However, as Gamerro and Archangelsky (1981) have pointed out, it shows greater abundance and diversity of marine species with respect to Palynozone A. Climatic zones B_1, B_2 and B_3 from the marginal part of the basin correspond to palynozone B.

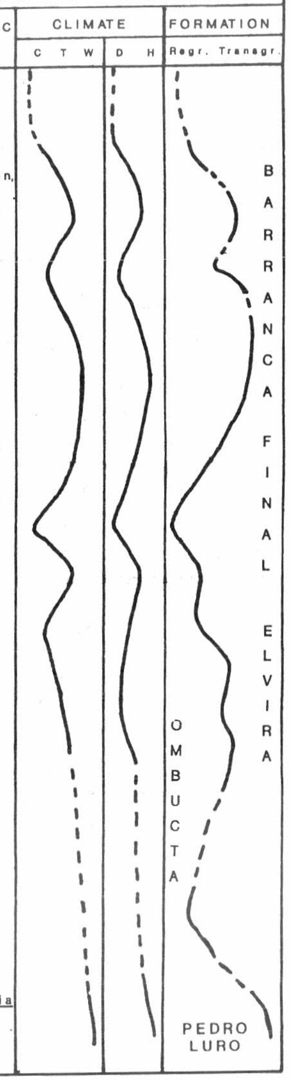
Palynozone A (Upper Miocene) : This palynozone is dominated by terrestrial elements. The following taxa have been recognized in the marginal area: pollen grains of Chenopodiaceae, Compositae, Ephedraceae, and species of the genera *Nothofagidites* and *Podocarpidites*. This palynozone, characterized by a strong decrease in the abundance and diversity of dinoflagellate cysts, has only been recorded in the uppermost fertile sample from Puerto Belgrano 20 borehole.

Figure 4 shows the chronostratigraphic correlation based on Cenozoic palynomorphs and calcareous microfossils of the Colorado Basin.

Table I. Paleoenvironmental model proposed for the pre-Pliocene. Cenozoic. C: cold; T: temperate; W: warm; D: dry; H: humid. I-IV: Andean Orogenic Movements; + Presence.



Age in M.y.	Epoch/Serie		Diastrophic phases	Paleogeographic and paleoclimatic global changes (Kennett, 1980; Zub. & Borz., 1990)		Colorado Basin: Phytogeographic changes	Colorado Basin: Formation
0	Pleistocene		IV Movement				
0–5	Pliocene	Upper	III Movement				
	Pliocene	Lower					
5–10	Miocene	Upper		Expansion of Antarctic ice-cap Global cooling. Sea level drop.	ICEHOUSE	Forest retraction Savanna, steppes and littoral environ, / Montane & cloudy forest	BARRANCA FINAL
10–16		Middle	3 Phase, 2 Phase, 1 Phase } II	Development of major ice-cap on east Antarctica. / Major Neogene optimum Melting of Antarctic glaciers Oceanic transgression		Decrease of tree pollen. Steppes	
16–24		Lower		Thermal Miocene optimum		Montane forest	
24–30	Oligocene	Upper		Drop in surface water temperatures Global aridization		Montane & cloudy forest / Littoral environm. Increase of *Nothofagus* flora	
30–36		Lower	2 Phase, 1 Phase } I			Montane & cloudy forest	
36–41	Eocene	Upper		Opening of the Drake Passage Bottom water temperature drop		Increase of *Nothofagus* flora	ELVIRA
41–49		Middle		Heavy bottom waters formation Global cooling / Mountain glaciation in Antarctica	GREENHOUSE	Grassland and littoral environm. + *Nothofagus* / Retraction of Ulmaceae forest northward	OMBUCTA
49–55		Lower	I Movement Prephase	Australia moving northward. Circum Antarctic flow restricted			
55–60	Paleocene	Upper					
60–65		Lower	Larámica	Australia and Antarctica were joined. Surface waters warm in middle latitudes		End <u>Mtchedlishvilia</u>	PEDRO LURO



COLORADO BASIN PALEOENVIRONMENTS AND PALEOCLIMATIC INFERENCES

As is well known, the palynomorphs are very useful for paleoclimatic reconstructions. The vegetational changes inferred from the microfloristic associations (figure 3) determine paleoclimatic trends which are compared with the information obtained through the study of calcareous microfossils, taphofloras and with the global climatic changes. This is the first attempt at such a paleoenvironmental reconstruction for the Colorado Basin during the pre-Pliocene Cenozoic (Table I).

The percentage of each vegetal family has been obtained considering only the derived terrestrial spores and pollen grains. Climatic oscillations during the Paleocene are inferred from the relationships between the Ulmaceae forest and the temperate-forest. The numeric relations between the montane forest and the *Nothofagus* flora reflect the climatic oscillations from temperate to cool-temperate since the Middle Eocene until the Upper Miocene. For the same interval, an increase of subtropical cloudy forest components suggests warmer temperatures and humid conditions.

UPPER DANIAN: PALYNOZONE D_1

Age: Due to the evolutive characteristics in *Globoconusa daubjergensis* Brönnimann (foraminifer present above 826-27 m in Puerto Belgrano 20 borehole) a Late Danian age is given to this interval (Malumián, 1970).

Pedro Luro Formation was deposited during a transgressive event, inferred from high frequencies of dinoflagellate cysts (up to 66% considering the total of palynomorphs). Its microfloristic associations are characterized by high percentages of Cheirolepidaceae (up to 77% calculated as a percentages of pollen + spores sum) reflecting a littoral environment, elements from the transitional forest (Ulmaceae: cf. *Phyllostylon*, up to 31%, not included in figure 3) and montane forest (Podocarpaceae up to 9%). There are also palustrine environment indicators (*Mtchedlishvilia* sp.). Warm-humid climatic conditions are inferred from the microfloristic assemblages for the Upper Danian (Ruiz, 1994).

The dinocyst assemblages are dominated by chorate and proximochorate cysts, which suggest that Pedro Luro Formation was deposited under relative warm, open marine conditions (Quattrocchio and Sarjeant, *ms.*).

Global paleoclimate considerations: Plant microfossils from this interval in the Argentine Northwest reflect warm-humid climatic conditions which were interrupted in the Early Eocene. This change is suggested by the decrease in the Ulmaceae Forest elements (Quattrocchio and Volkheimer, 1990).

The floras and palynofloras of Salamanca Formation in San Jorge Gulf (46°S) show that the climate during the Upper Danian would have been humid subtropical (Petriella and Archangelsky, 1975), in accordance with the finding of crocodiles, which suggest that by this time the 10°C isotherm passed across the area. Nowadays, it is some 1500 km further north (Volkheimer, 1971).

Romero (1986) has pointed out a progressive temperature increase from the Maastrichtian to the Lower Eocene, considering the percentage of entire-margined leaves, in the South American Paleogene taphofloras.

During the Paleocene (65-55 Ma) the Antarctic continent was in a high-latitude position as it had been through the Middle and Late Mesozoic. The continent was largely non-glaciated and it was joined to Australia (Kennett, 1980).

?MIDDLE TO UPPER EOCENE: SUBZONES C_1, C_2 AND LOWER PART OF C_3

Age: The first occurrence of *Globigerina brevis* Jenkins at 500 - 503 meters drilling depth (m d.d.) in Puerto Belgrano 23 borehole indicates that Eocene marine sediments are present between 500 and 563 m d.d (Malumián, 1972). The microfauna studied in the sediments from Nadir 1 borehole, between 520 and 577 m d.d. (Elvira Formation), determines that these sediments can not be older than Late Eocene (Malumián, oral communication, 1994).

A transgression, inferred from the presence of marine paleomicroplankton, is recorded from 596 m d.d. in Nadir 1 borehole (Elvira Formation), on the continental deposits of Ombucta Formation. This transgression was lesser extended than the Danian transgression considering the lower percentages of dinoflagellate cyst in Elvira Formation (up to 43%) with regard to the percentages recorded in Pedro Luro Formation (up to 66%).

The temperate forest (Podocarpaceae, Gunneraceae and Anacardiaceae) replaces the subtropical transitional forest of Ulmaceae, frequent in the Upper Danian, suggesting less favourable conditions for the ?Middle Eocene.

The microfloristic associations from subzone C_1 (Elvira Formation) reflect the existence of forested areas (Podocarpaceae 8%, Araucariaceae 4%, Gunneraceae 9.3%), indicating a temperate-warm and humid climate. The sea water paleotemperature would be temperate-cool, based on the chorate/proximate dinocysts rate (1.8).

Upwards, a regressive event is recorded at 554-559 m d.d. from Puerto Belgrano 20 borehole (subzone C_2). This event is associated with the development of littoral environments, inferred from the increasing percentages of Chenopodiaceae-Amaranthaceae (10.3%) and Cyperaceae (1.3%). The presence of extra-regional pollen grains of Fagaceae (*Nothofagidites* spp. 4%) suggests temperate-cool climatic conditions.

The lower part of the subzone C_3 corresponds to a transgressive event of probable Late Eocene age, characterized by high proportions of dinoflagellate cysts (40 to 32%) and dinoflagellate species number (up to 16). The microfloristic associations point out a relative cooling in the Upper Eocene, with an increase in the proportions of the *Nothofagus* flora (up to 5%). The chorate/proximate dinocyst rates indicate temperate - cool sea waters (1.2 to 1.8).

Global paleoclimate considerations: Malumián (1970, 1972) studied the calcareous microfossils from Puerto Belgrano 23 borehole (Upper Eocene to Miocene, Colorado Basin) and he did not find typical elements from warm waters for this interval. This author remarks that the species mainly belong to cool-temperate waters. Malumián and Náñez (1991) have found the *Spirosigmoilinella-Martinottiella* assemblage in the basal deposits of Barranca Final Formation from (DNGM) Pedro Luro borehole. Malumián (oral communication, 1995) has also found a well developed assemblage of *Spirosigmoilinella-Martinottiella* at 551-554 m .d.d from Puerto Belgrano 23 borehole. This cold water assemblage suggests the existence of cold bottom waters in the Late Eocene of the Colorado Basin.

Mercer (1977) has pointed out that during the Late Eocene-Early Oligocene the South American tropical flora began to retract northwards and it was replaced by the *Nothofagus* cool-temperate flora.

Romero (1986) has concluded that the sequence of floras in Patagonia would imply variations from the equivalents of a Paratropical Rain Forest (Lower Eocene) to a Subtropical Forest (Middle Eocene). This author has also recognized a transition from the equivalents of a Mixed Mesophytic Forest (Upper Eocene) to a Mixed Northern Hardwood Forest (Oligocene).

Kennett (1980) has indicated that during the Early Eocene (55 Ma) Australia began to drift northwards from Antarctica, forming an ocean, although Circum-Antarctic flow was blocked by the South Tasmania Rise and Tasmania. During the Eocene (55-38 Ma) the Southern Ocean was relatively warm and Antarctica was still largely non-glaciated. Cool-temperate vegetation existed in some regions.

According to Zubakov and Borzenkova (1990), a worldwide cooling of sea water started 48 Ma ago. There is evidence indicating a mountain glaciation in Antarctica in the Early/Middle Eocene. The mammal marsupials, lizards and even crocodiles inhabiting Seymour Island, Antarctica (South of 60°S) in the Late Eocene indicate that the extent of such glaciation should be limited. However, this glaciation would be responsible for the formation of cold bottom waters in the Eocene.

Near the Eocene/Oligocene boundary a rapid bottom water temperature drop has been indicated by several authors (Savin *et al.*, 1975; Savin, 1977; Kennett, 1977). The sharp climatic deterioration has been related to the formation of the Antarctic ice cover (Kennett *et al.*, 1975) and to the appearence of a circumpolar current around Antarctica as a result of the opening of the Drake Passage (Zubakov and Borzenkova, 1990).

Malumián and Náñez (1991) have indicated that a "jet effect", capable to introduce dense water on the Argentine Atlantic shelf, would have been the consequence of a dismemberment of the circumantarctic current due to the partial aperture of the Drake Passage. Such current would have affected the continental climate and ecosystem.

According to Pomerol (1981), the Eocene/Oligocene boundary is the first and possibly the largest step towards a glacier climatic regime. That was the time when the present patterns of atmospheric and vertical circulations evolved.

OLIGOCENE: UPPER PART OF THE SUBZONE C_3, SUBZONES C_4 AND C_5

Age: Malumián (1970) has found the assemblage of *Globorotalia opima opima* Bolli and *Globigerina ouachitensis ciperoensis* Bolli and *Globigerina angulioff icinalis* Blow in Puerto Belgrano 23 borehole. These assemblages determine that the sediments between 500 and 450 m d.d. are not younger than Oligocene.

The presence of Compositae pollen type (*Tubulifloridites antipodica* Cookson) indicates that the age of the sediments which are bearing these kind of palynomorphs cannot be older than Oligocene (Müller, 1981).

In the Colorado Basin, the uppermost part of the subzone C_3 corresponds to a temperature and humidity increase. This event of probable Early Oligocene age, has been inferred from the development of the cloudy forest (Myrtaceae, 5% and Juglandaceae, 9%) and the retraction of the montane forest (Podocarpaceae and Fagaceae) in the extrabasinal areas. The chorate/proximate dinocyst rates (3.3-3.5) show a sea water temperature rise.

The microfloristic assemblages belonging to the subzone C_4 reflect a regressive event within the transgression of Barranca Final Formation. Minimum values of relative and absolute abundance of marine paleomicroplankton (4.3%, 45 individuals/g sediment) and low number of dinocyst taxa (4 species) are recorded in Ombucta x- 1 borehole (616 m d.d.). A climatic deterioration is associated with the cool forest expansion. An increase in the Fagaceae pollen percentages (up to 19%) suggests cool and dry conditions, whereas the percentages of Podocarpaceae 14 - 12%, Gunneraceae 3% and Anacardiaceae 2% (components of the temperate forest) decrease in this subzone. The development of littoral environment indicated by higher percentages of Chenopodiaceae-Amaranthaceae (up to 10.6%), Cyperaceae (2%) and Sparganiaceae (2%) is related to this regressive event. Low chorate/proximate dinocyst rates indicate a sea water temperature decrease (1.2 to 2.8).

Upwards, a transgressive episode has been recorded with high percentages of dinoflagellate cysts (up to 70%) and dinoflagellate species diversity (up to 32 species). The subzone C_5 is characterized by elements from the cloudy forest (Gunneraceae 7-10%, Hamamelidaceae 1.3-2% and Myrtaceae 5.3%) and montane forest (Podocarpaceae 20-28% and Anacardiaceae, up to 7%). Pollen grains from littoral environments are also present (Chenopodiaceae-Amaranthaceae 5-9.3% and Sparganiaceae 2.7%). These microfloristic assemblages, with low percentages of Fagaceae (4%) and high percentages of Gunneraceae and Hamamelidaceae, would indicate an increase of temperature and moisture.

Batiacasphaera compta-Tuberculodinium vancampoae assemblage has been found in deep facies correlated with subzone C_5 (Quattrocchio and Guerstein, in preparation). This assemblage has been mentioned by Manum (1976) in *Thalassiphora delicata* Zone (Late Oligocene).

Global paleoclimate considerations: A major shift during the Oligocene was recorded in Europe, western Siberia, New Zealand, and western North America. Romero (1986) has indicated that it was marked during the middle Oligocene and produced a spectacular transformation in the high latitude floras, which changed from having high percentages of large, evergreen broad leaves with entire margins to high percentages of dentate, small, deciduous leaves.

Krasheninnikov and Basov (1983) have indicated that the basal Oligocene layers at the Falkland Plateau contain a poor foraminiferal fauna (cold episode) followed by an increase of diversity (temperate episode) in the Lower Oligocene. This warming changed to a period of cooling resulting in the sharp decrease of the species diversity of foraminifers and even their complete disappearance in the Late Oligocene. This deterioration of climate has been regarded by these authors as a reflection of the Late Oligocene glaciation in Antarctica.

According to Zubakov and Borzenkova (1990), the Lower/Upper Oligocene boundary would be concurrent with the largest drop of the Cenozoic sea surface temperatures in lower latitudes, associated with the global aridization of the climate. On the other hand, the Oligocene/Miocene boundary would be concurrent with the shaping of a strong Antarctic Circumpolar Current, which thermally isolated Antarctica and foreordained a new rise of sea surface temperatures in low latitudes and subsequent thermal Miocene optimum.

MIOCENE: SUBZONES B_1, B_2, B_3 AND PALYNOZONE A

The subzone B_1, recognized in Nadir 1 borehole in the Colorado Basin, is characterized by the expansion of transgressive deposits of Barranca Final Formation. The microfloristic assemblages indicate the development of the cloudy forest (Myrtaceae 3%, Gunneraceae 10%, Podocarpaceae, 9% and Anacardiaceae 3%), gramineous steppe (Gramineae 3%) and littoral halophytic vegetation (Chenopodiaceae-Amaranthaceae 9.4%). These assemblages suggest warm-temperate and humid conditions, probably for the Lower to Middle Miocene. Warm-temperate sea water have been inferred from the chorate/proximate dinocyst rates (3.5 - 3.7).

Age: At 446-449 m d.d. in Puerto Belgrano 23 borehole, Malumián (1970) has indicated the last occurrence of *Cribrorotalia hornibrooki* Malumián and Masiuk. At 431-37 m d.d. typical ostracods associated with the Entrerriense marine stage occur, interval not younger than the *Globorotalia mayeri* Zone, Middle Miocene (Malumián, 1970).

The microfloristic assemblages from subzone B_2, corresponding to the interval mentioned above, show a noticeable decrease of pollen grains indicating a forest retraction and development of steppes. This vegetational change suggests a dry and temperate climate during the Middle Miocene in the Colorado Basin.

Upwards, warm-temperate and humid conditions have been inferred from the subzone B_3 (of probable Middle to Late Miocene age), characterized by elements from the cloudy and montane forest. The Palynozone A shows a decrease of sea water temperature and an increase of the components of steppe and littoral environments indicating a climatic deterioration towards the end of the Miocene.

Global paleoclimate considerations: Boltovskoy (1980) has suggested that fossil benthic microfauna studied in the Upper Oligocene to Lower Miocene sections from Gil 1 borehole (Colorado Basin), show an influence from Brazilian warm water fauna and lack of cold water fauna.

Krasheninnikov and Basov (1983) have suggested that the foraminiferal data on the Falkland Plateau are consistent with the well-known warming trend for the end of the Early Miocene and the beginning of the Middle Miocene. The cold climate conditions of the Late Miocene are strongly expressed by the foraminiferal assemblages.

Zubakov and Borzenkova (1990) have indicated that evidence of a major Neogene optimum occurred 17.2-16.5 million years ago in coincidence with an oceanic transgression. It was accompanied by a worldwide more humid climate, by the melting of at least one-third of Antarctic glaciers.

According to Kennett (1980) during the Middle Miocene a drop in the surface-water temperatures occurred. Since this time the East Antarctica ice cap has remained an essentially permanent feature although exhibiting some changes in volume. During the Late Miocene (5 Ma) the Antarctic ice cap volume increased. This event was also related to a global climatic cooling and to an eustatic sea level drop.

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