QUATERNARY OF SOUTH AMERICA AND ANTARCTIC PENINSULA

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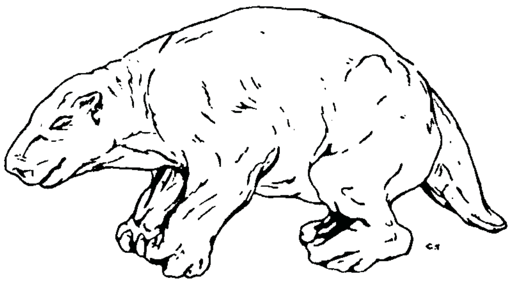
VOLUME 5



LESTODON ARMATUS Gervais

QUATERNARY OF SOUTH AMERICA AND ANTARCTIC PENINSULA

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Obituary

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Daniel Alberto Valencio

Daniel A. Valencio, a pioneer of research on Paleomagnetism and its geodynamic implications, died at Buenos Aires on May 28th, 1987, a few weeks before his 59th birthday. Geophysicists all over the world, and especially his pupils in Bolivia, Brazil, Great Britain and Mexico will join their Argentine colleagues in deploring his ultimately passing away.

A graduate from La Plata University, Valencio started his professional career at the Argentine National Oil Fields Administration as an Exploration Geophysicist in 1952; from 1960 to 1962, he held the position of Head of the Geophysical Department at the Cuban Institute of Oil and Mineral Resources. After his return to Argentina, he became Professor of Geophysics at Buenos Aires University. During the 25 years of his association with the Department of Geological Sciences there, he succeeded in establishing an admirably close interdisciplinary connection between the geological and geophysical aspects of solid earth problems.

In 1964 Valencio laid the foundations of the Laboratory of Paleomagnetism which was to become the centre of an impressive and ever-increasing activity in research and teaching, including several international post-graduate courses. Numerous students of Geology and Physics sought his guidance for their under-graduate and graduate studies, and many of them remained associated with his group as investigators. In addition to his unswerving teaching activities at Buenos Aires, Valencio was visiting Professor in Brazil and Mexico. He was an active, and in some cases, leading participant, both on a national and world-wide scale, in the planning, coordination and execution of several great interdisciplinary projects such as the Upper Mantle Project, the International Geodynamics Project and the International Lithosphere Project, becoming the chairman or cochairman of diverse commitees and working groups as well as organizer of several symposia. He was a member of the Executive Committee of the Inter-Union Commission on Geodynamics (1970-1980) and leader of its Working Group on "Global synthesis of evidence leading to the reconstruction of the distribution of continents and oceans through time."

In the framework of IAGA, Valencio served as a member of its Executive Committee during the 1979-1983 term, as chairman of the Working Group on Paleomagnetism in the following four years period, and also as liaison officer with other bodies of IUGG. At home, he was a top-ranking Research Fellow of the Consejo Nacional de Investigaciones Científicas y Técnicas; member of diverse advisory committees of the "Consejo"; chairman of the National Committee for the Inter-Union Lithosphere Project, and president of the Asociación Argentina de Geofísicos y Geodestas (AAGG) during one four years term. He was the author of a book on "El magnetismo de las rocas" (1980), and co-editor of three other books dealing with the interdisciplinary aspects of Paleomagnetism, as well as member of several editorial boards, Valencio was an Honorary Fellow of the AAGG, an Ordinary Member of the Academia Nacional de Geografía, and a Foreign Member of the Royal Astronomical Society, whose "Geophysical Journal" published several of his papers.

In pondering Valencio's overwhelming productivity in the fields of teaching, research, academic administration, and coordination of interdisciplinary projects, both local and international, one cannot help suspecting that some kind of foreboding may have challenged him to generously give his utmost during the limited span that has fallen to his lot.

Daniel is survived by Nike, his wife, three daughters (including a geologist), and a son, also a student of Earth Sciences.

Otto Schneider
Universidad de Buenos Aires - CONICET

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Magnetostratigraphy and magnetic susceptibility data of the late Cenozoic 'Ensenadense' and 'Bonaerense' sediments of Buenos Aires and La Plata, Argentina

ABSTRACT

Paleomagnetic and magnetic susceptibility data for sequences of late Cenozoic "Ensenadense" and "Bonaerense" sediments exposed by excavations carried out in the Cities of Buenos Aires (lat. 34.5° S; long. 58.5° W) and La Plata (lat. 35° S; long. 58° W) are reported. These geological units are carriers of land mammal fauna assemblages younger than the Great American Faunal Interchange.

The lithology as well as the paleomagnetic and magnetic susceptibility data indicate that the "Ensenadense" and "Bonaerense" sediments from these cities were accumulated under different geological processes.

In Buenos Aires, the accumulation of these late Cenozoic sediments was practically continuous. Only one period of no-accumulation and/or erosion was recorded in the "Ensenadense" sediments at about 13.15 m below ground level. The magnetostratigraphy for this sedimentary sequence suggests a predominantly Brunhes (<0.7 Ma, middle-late Pleistocene) magnetic age for the "Bonaerense" sediments and a Matuyama to late Gauss (>0.7 Ma- <2.84 Ma, late Pliocene-middle Pleistocene) magnetic age for the "Ensenadense" deposits.

In La Plata, the accumulation of the "Ensenadense" and "Bonaerense" sediments was probably discontinuous. The magnetostratigraphy for these sediments suggests two interpretations, which would indicate middle-late Brunhes magnetic age for the "Ensenadense" and "Bonaerense" sediments from the uppermost 14.0 m of the sequence. One of the interpretations suggests a late Gauss-Matuyama magnetic age (<3.0 - >0.7 Ma; late Pliocene-middle Pleistocene) for the

"Ensenadense" sediments from the lowest 14.0 m of the sequence. The other interpretation would indicate, instead, a Matuyama (<2.41 Ma - >0.7 Ma, late Pliocene-middle Pleistocene) magnetic age for these "Ensenadense" sediments.

RESUMEN

Se presentan en este trabajo datos paleomagnéticos y de susceptibilidad magnética obtenidos para secuencias de sedimentos "Ensenadenses" y "Bonaerenses" del Cenozoico Superior, expuestos en excavaciones en las ciudades de Buenos Aires (34°5 lat.S; 58°5 long. W) y La Plata (35° lat. S; 58° long. W). Estas unidades geológicas son portadoras de asociaciones faunísticas de mamíferos terrestres, más jóvenes que el Gran Intercambio Faunístico Americano.

La litología, así como los datos paleomagnéticos y de susceptibilidad magnética, indican que los sedimentos "Ensenadenses" y "Bonaerenses" de estas ciudades fueron acumulados bajo procesos geológicos diferentes.

En Buenos Aires, la acumulación de estos sedimentos fue prácticamente continua. Solamente un período de no-acumulación y/o erosión ha sido detectado en los sedimentos "Ensenadenses", a aproximadamente 13,15 m bajo el nivel del suelo. La magnetoestratigrafía para esta secuencia sedimentaria sugiere una edad magnética Brunhes predominante (<0,7 Ma; Pleistoceno medio a superior) para los sedimentos "Bonaerenses" y una edad magnética Matuyama a Gauss tardía (>0,7 Ma -<2,84 Ma, Plioceno tardío a Pleistoceno medio) para los depósitos "Ensenadenses".

En La Plata, la acumulación de sedimentos "Ensenadenses" y "Bonaerenses" fue probablemente discontinua. La magnetoestratigrafía para estos sedimentos sugiere dos interpretaciones, las cuales indicarían una edad magnética Brunhes media a tardía para los sedimentos "Ensenadenses" y "Bonaerenses" de los 14,0 m superiores de la secuencia. Una de las interpretaciones sugiere una edad magnética Gauss tardía-Matuyama (<3,0 Ma - >0,7 Ma; Plioceno tardío - Pleistoceno medio) para los sedimentos "Ensenadenses" de los 14,0 m inferiores de la secuencia. La otra interpretación indicaría, en cambio, una edad magnética Matuyama (<2,41 Ma - >0,7 Ma; Plioceno tardío - Pleistoceno medio) para estos sedimentos "Ensenadenses".

INTRODUCTION

Throughout most of the Tertiary, South America was an isolated continent. During most of this period, South America had a highly distinctive fauna where unique land mammal faunas developed. It is widely accepted that the isolation of South America ended about 3 million years ago (late Pliocene), when the Panamá Isthmus came into existence, uniting North and South America. This permitted the reciprocal interchange of terrestrial biota between both Americas. This biotic event is known as the Great American Faunal Interchange (Webb, 1976).

Palaeontologist used this evidence to define the age of the New World's mammals; particularly, the age of the South American mammals in pre-(mostly endemic fauna) and post-land bridge times (endemic plus North American fauna). The chronological order of the South American Land Mammal ages are: "Huayqueriense"; "Montehermosense"; "Uquiense"; "Ensenadense" and "Lujanense" (Pascual **et al.**, 1965, Table 1). Pascual and Fidalgo (1972) as well as Marshall and Pascual (1978) suggest different geological ages for these land mammal time-units (Table 1). The beginning of the major faunal interchange occurred during the "Montehermosense" mammal age when North-American fossils (Cricetidae and Tayassuidae) occurred in South America (Pascual **et al.**, 1965). This should be related with the development of the stable corridor between both Americas. Hallam (1972) suggests that this occurred in the late Pliocene, about 3 Ma; Tarling (1981) reports that "the development of such a bridge was critical during the final linkage between North and South America during Miocene-Pliocene times".

Sediments exposed or circumstantially exposed in excavations for building purposes in Buenos Aires Province, have produced one of the richest records of vertebrate life during the Great American Faunal Interchange. These sediments are assigned to geological formations or units: Chapadmalal, Barranca de Los Lobos, Vorohué, San Andrés and Miramar Formations, "Ensenadense"; Arroyo Seco and Arroyo Lobería Formations, "Bonaerense". The ages assigned to these formations and units are summarized in Table 1. These formations and units' relationships as well as the South American Land Mammal Ages are also shown in this table. It is not possible to give a more precise age to these sediments due to the lack of precise biostratigraphic and absolute age controls. Therefore, we have programmed a

Table 1

Formation or Stratigraphic Unit	Age	South American Land Mammal Ages (Pascual **et al.**, 1965)	Geological Ages	
			(Pascual and Fidalgo, 1972)	(Marshall and Pascual, 1978)
"Bonaerense" Arroyo Lobería Fm. Arroyo Seco Fm.	middle-late Pleistocene (Frenguelli, 1957); early Pleistocene (Ameghino, 1908)	Lujanense	late Pleistocene	late Pleistocene
"Ensenadense" Miramar Fm.	middle-Pleistocene (Frenguelli, 1957); Pliocene, (Ameghino, 1908)	Ensenadense	middle Pleistocene	late-middle Pleistocene
San Andrés Fm. Vorohué Fm. Barranca de Los Lobos Fm.	Pleistocene (Kraglievich, 1952)	Uquiense	early Pleistocene	middle Pleistocene-late Pliocene

Table 1. Cont.

Formation or Stratigraphic Unit	Age	South American Land Mammal Ages (Pascual **et al.**, 1965)	Geological Ages	
			(Pascual and Fidalgo, 1972)	(Marshall and Pascual, 1978)
Chapadmalal Fm. (equivalent to the "Hermo- sense" and "Chapadmalense")	late Miocene (Ameghino, 1908); late Pliocene (Kraglievich, 1952); early Pleistocene (Frenguelli, 1957)	Montehermosense	late Pliocene	late-early Pliocene
		Huayqueriense	middle Pliocene	early Pliocene- late Miocene.

systematic paleomagnetic study of sequences of late Cenozoic sediments of Buenos Aires Province. Our purpose is to use the magnetostratigraphy of these sequences to define the absolute age of the sediments. Magnetostratigraphy relies on some basic assumptions: 1) the Earth's magnetic field has reversed its polarity in the past; 2) the timing of these reversals is accurately known; 3) sediments record the direction of the geomagnetic field at or near the time of deposition (primary remanent magnetization, PRM) and 4) this PRM is preserved throughout geological time. In many cases, it is not easy to establish the correlation tie-lines between the magnetostratigraphy for a given sequence and the reversal time scale for the late Cenozoic. This is also valid when datable rocks are available in the sequence, because the uncertainty of the radiometric age is frequently higher than the time-span of an event of polarity of the geomagnetic field. In order to solve that problem, the sequences of "Ensenadense" and "Bonaerense" sediments are being studied. These are among the youngest geological units exposed in Northeastern Buenos Aires Province (Valencio and Orgeira, 1983; Bobbio **et al.**, 1985). Then, a key reference mark, the Brunhes-Matuyama boundary, may be used to establish the correlation. Paleomagnetic data for sequences of the "Ensenadense" and "Bonaerense" sediments exposed in large excavations in the Cities of Buenos Aires (34.5° S, 58.5° W) and La Plata (35° S, 58° W) for building foundation are presented here (Figure 1).

Marshall **et al** (1979, 1982), McFadden **et al** (1983) and Butler **et al** (1984) have reported paleomagnetic data for late Cenozoic sediments exposed in northern Argentina and Bolivia.

GEOLOGICAL SETTING AND SAMPLING SITES

Late Cenozoic sediments, bearing characteristic fossil mammal assemblages, are exposed in different sites of Argentina. The lithology of these sediments is remarkably homogeneous in Buenos Aires Province (Figure 1). On the basis of lithology and stratigraphic relationships, these sediments have been included in formations or units (Table 1); however, it is not always easy to define accurately the transitions between these formations or units. Characteristic fossil mammal assemblages have been found in these sediments. Paleontologists used them to define land mammal ages for these sediments (Table 1).

Late Cenozoic sediments are poorly exposed in the Cities of Buenos Aires and La Plata. However, sequences of these sediments are uncovered by excavations. The "Ensenadense" was defined by Ameghino (1889) at the City of Ensenada, 7.5 km NE of La Plata (Figure 1). The "Ensenadense" and the underlying "Pre-ensenadense" are, according to Ameghino, the oldest units of the "Pampeano". This lays upon the "Puelchense" sands; Ameghino suggested a Miocene age for the latter. The classification used in this paper is that of Frenguelli (1957) who included the upper part of the "Pre-ensenadense" of Ameghino within the "Ensenadense". Frenguelli (1957) presented a detailed description of the "Ensenadense" sediments; it is roughly constituted by a thick brown unit of loessic silts with calcareous nodules of different forms and an intercalation of greenish lacustrine sediments. It generally presents irregular stratification at its base which disappears toward the top. Ameghino (1908) assigned the "Ensenadense" to the Pliocene, whereas Frenguelli (1957) suggested a middle Pleistocene age for this unit. Pascual **et al** (1965), Pascual and Fidalgo (1972) and Marshall and Pascual (1978) correlated the "Ensenadense" and "Bonaerense" with the middle Pleistocene and middle-late Pleistocene, respectively, on basis of its fossil mammal fauna.

Frenguelli (1957) described the "Bonaerense" as a thick, homogeneous, fine-grained, light reddish brown unstratified unit, with small holes left by roots and homogeneous distribution of calcareous nodules. There is general agreement to assign the "Bonaerense" to the late Pleistocene (Fidalgo **et al**, 1975); however, Frenguelli (1957) and Ameghino (1908) suggested a middle-late Pleistocene and an early Pleistocene age, respectively, for this unit. Pascual and Fidalgo (1972) and Marshall and Pascual (1978) correlated the "Bonaerense" with the late Pleistocene on basis of its fossil mammal fauna.

Fidalgo **et al** (1975) indicated that from the geological point of view it is not possible to distinguish all the sedimentary units from the Lower Pliocene to the Upper Pleistocene in Buenos Aires Province; however, they have observed unconformities between Tertiary and Quaternary sediments.

Samples for this study were collected from the walls of two excavations in the City of Buenos Aires (A) and one in the City of La Plata (B; Figure 1).

The two excavations in the City of Buenos Aires were situated at different topographic levels. The relationship between these

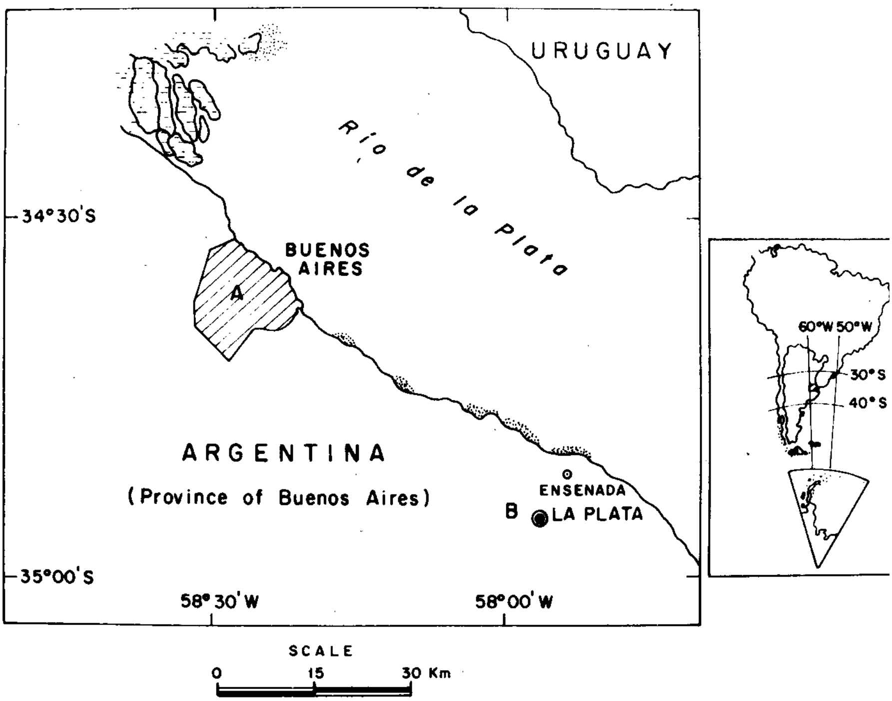

Figure 1. Locations of sampling sites; A: City of Buenos Aires and B: City of La Plata, Buenos Aires Province. Samples are collected from excavations carried out for building foundation.

and the depths of these excavations was such that it was possible to sample a continuous sequence 23 m thick of sediments assigned to the "Bonaerense" and "Ensenadense". In this city it is not easy to define accurately the "Ensenadense"-"Bonaerense" transition (González Bonorino, 1965). This transition is defined in the sequence of sediments exposed in the excavation situated at the higher stratigraphic level (Valencio and Orgeira, 1983). However, the depth of this transition is not precise; these authors suggested that this transition is situated at about 10,5 m below ground level. In the other excavation only sediments assigned to the "Ensenadense" were found (Nabel and Valencio, 1981). The lithology of the sediments of the "Ensenadense" and "Bonaerense" of these two excavations is shown in Figure 5.

Samples of the "Ensenadense" and "Bonaerense" from La Plata were collected from the walls of the excavation, about 30 m deep, carried out for the foundation of the Nuevo Teatro Argentino (B; Figure 1). The "Ensenadense"-"Bonaerense" boundary is there at 8 m below ground level (F. Fidalgo, Universidad Nacional de La Plata, personal communication). The lithology of these sediments (Figure 6) is remarkably different from that of the sequence of Buenos Aires. On the basis of the lithology the sequence of the "Ensenadense" and "Bonaerense" from La Plata was subdivided into 15 geological sections (A through N; Bobbio, 1983, and Devicenzi, 1983). The boundary between the sections J and K, at about 14 m below ground level and within the "Ensenadense", is an unconformity (F. Fidalgo, personal communication).

SAMPLING

The "Ensenadense" and "Bonaerense" sediments were sampled using plastic cylinders (0.025 m in diameter; 0.025 m in height). They were introduced into the walls by hand or using special tools according to the hardness of the sediment.

In Buenos Aires, samples were collected from two excavations (item 2). In the excavation situated at the higher topographic level, 129 samples were obtained from a sedimentary sequence 14.5 m thick (Valencio and Orgeira, 1983). In the excavation situated at the lower topographic level, 119 samples were collected from a sequence 10 m thick of sediments of the "Ensenadense" (Nabel and Valencio, 1981). Most of the samples were recovered from different stratigraphic positions. The mean stratigraphic interval between the axes of two consecutive cylinders was 0.10 m; that is, the mean of the unsampled stratigraphic interval between two consecutive cylinders was 0.075 m. Several samples were also taken at the same stratigraphic level in some sections of the sequence in order to test the consistence of the paleomagnetic data.

In La Plata, 228 samples were collected from a sedimentary sequence 28 m thick. Sampling was carried out following the same technique used in Buenos Aires. The mean stratigraphic distance between the axes of two consecutive cylinders was 0.12 m (Bobbio **et al.**, 1985).

THE PALEOMAGNETIC AND MAGNETIC STUDIES

The intensity of natural remanent magnetization (NRM) was measured using a fluxgate slow speed spinner magnetometer (Vilas, 1979). Susceptibility measurements were made using a balanced double coil susceptibilimeter type RMSH III manufactured at the Tata Institute, Bombay. The stability of the NRM was investigated by alternating field (AF) demagnetization. Pilot samples were demagnetized successively in 25, 50, 75, 100, 125, 150, 175, 200, 225, 250 and 300 Oe; some of them were also demagnetized in 350 and 400 Oe. NRM directions of most of the samples showed either no systematic change on AF demagnetization or a viscous magnetization which could easily be removed by AF demagnetization in 25 or 50 Oe. Median destructive fields (MDFs) fell in the range 75-200 Oe; samples with higher MDF values were observed to exhibit smaller changes in NRM direction. Typical demagnetization curves for the "Ensenadense" and "Bonaerense" from Buenos Aires and La Plata are shown in Figure 2. Bulk demagnetization of not-pilot samples was carried out in 150-200 Oe peak fields.

The directions of the NRM and stable remanence for the collected samples from Buenos Aires and La Plata are shown in Figure 3 and 4, respectively. On the basis of the latter directions, virtual geomagnetic poles (VGPs) for each of these samples were calculated. Two mean poles were computed from these VGPs; one for samples from Buenos Aires and the other for samples from La Plata. VGPs situated more than 40° from these mean poles were rejected and two new mean poles were calculated. In this way, two populations of VGP's were obtained all within 40° of the mean poles for the samples from Buenos Aires and La Plata, respectively. These populations of VGP's yield two paleomagnetic poles for the "Ensenadense" and "Bonaerense": one for Buenos Aires at lat. 88.7° S, long. 254.7° E (N= 154, K= 10.3, A_{95}= 3.6°) and the other for La Plata at lat. 88° S, long. 264° E (N= 136, K= 12, A_{95}= 3.5°). The rejected VGP's were classified as oblique.

The magnetic stratigraphies for the "Ensenadense" and "Bonaerense" from Buenos Aires and La Plata, consisting of logs of stratigraphic level-value of cleaned declination (D) and inclination (I), are plotted alongside the logs of distances of VGP's from the mean polar positions in Figures 5 and 6, respectively. The distance of a VGP from the mean pole defines the polarity of the stable remanence of the sample: 0-40°,

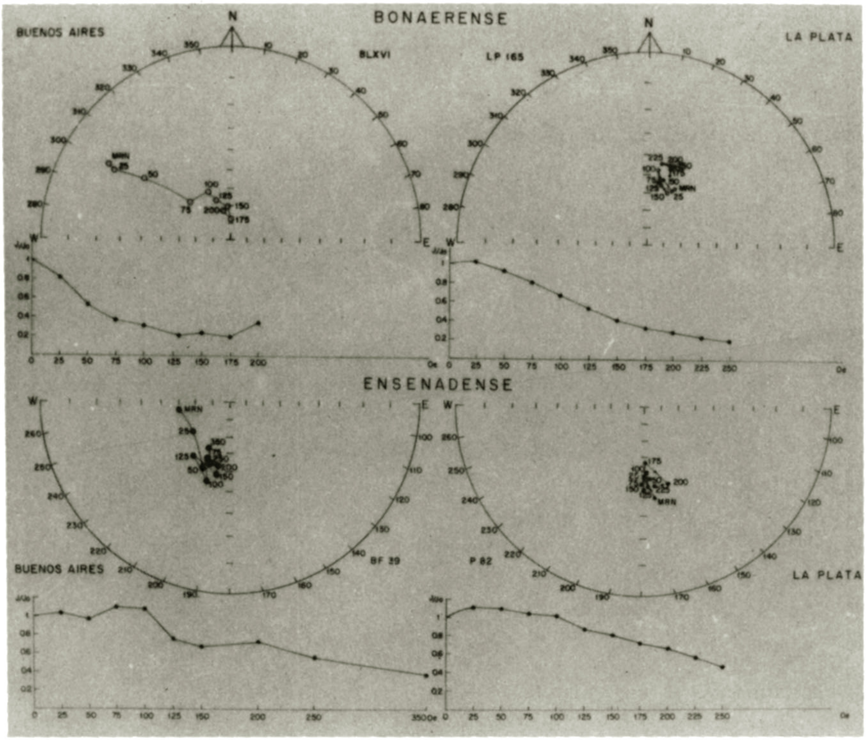

Figure 2. Changes in direction and intensity of magnetization by progressive AF cleaning for one specimen of the "Bonaerense" and the "Ensenadense" from each of the sampling sites. Solid symbols indicate downward dipping directions.

normal polarity; 40°-140°, oblique polarity, and 140°-180°, reversed polarity. The polarity of the stable remanence of samples defines the magnetostratigraphy of each sequence of sediments (Figures 5 and 6).

Logs of stratigraphic level-value of intensity of NRM (Jn) and magnetic susceptibility (χ) are also plotted for the "Ensenadense" and "Bonaerense" sedimentary sequences throughout the studied excavations. The patterns of these logs for the same excavation show a remarkable similarity, though they differ from one excavation to another (Figures 5 and 6).

The magnetic susceptibility is not related to the intensity of the geomagnetic field during the physicochemical processes in which sediments acquire their NRM. On the other hand, it is

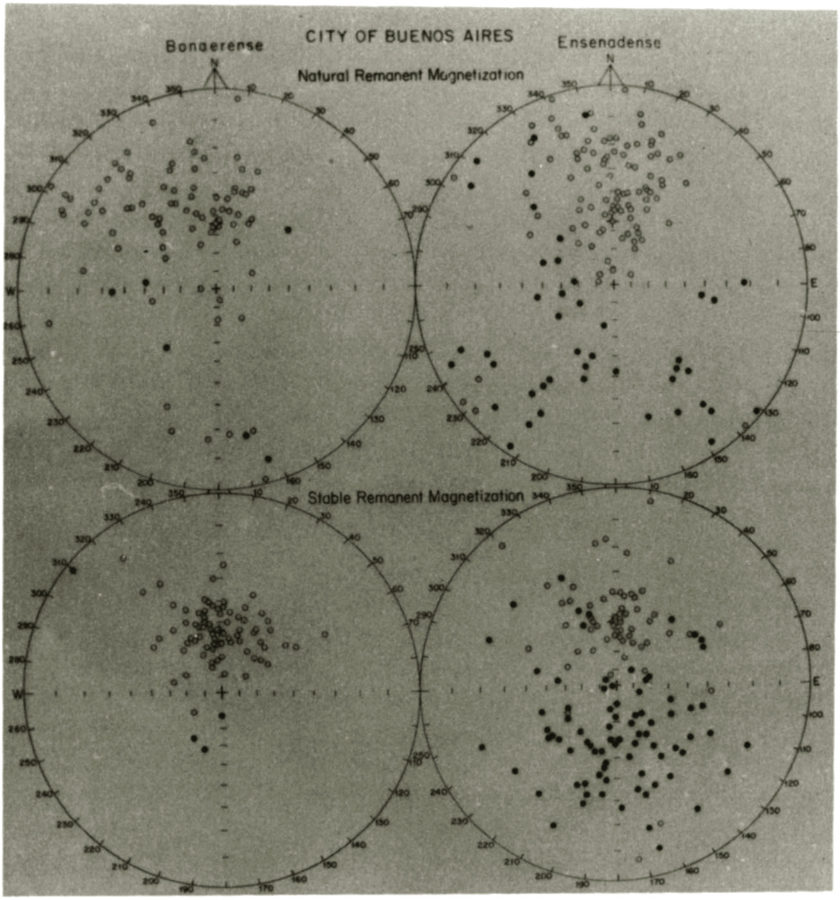

Figure 3. Directions of natural and cleaned remanent magnetization for "Ensenadense" and "Bonaerense" specimens from Buenos Aires. The direction of the present geomagnetic field is shown by -φ-. The key of the symbols is the same given in Figure 2.

related to the number, chemical composition and/or size of their magnetic minerals. Therefore, the comparison of logs of χ and Jn for each excavation indicates that their variations in time are due to variations in the number, chemical composition and/or size of the accumulated magnetic minerals.

THE REVERSAL TIME SCALE FOR THE LATE CENOZOIC

In the last years, new polarity events of the geomagnetic field

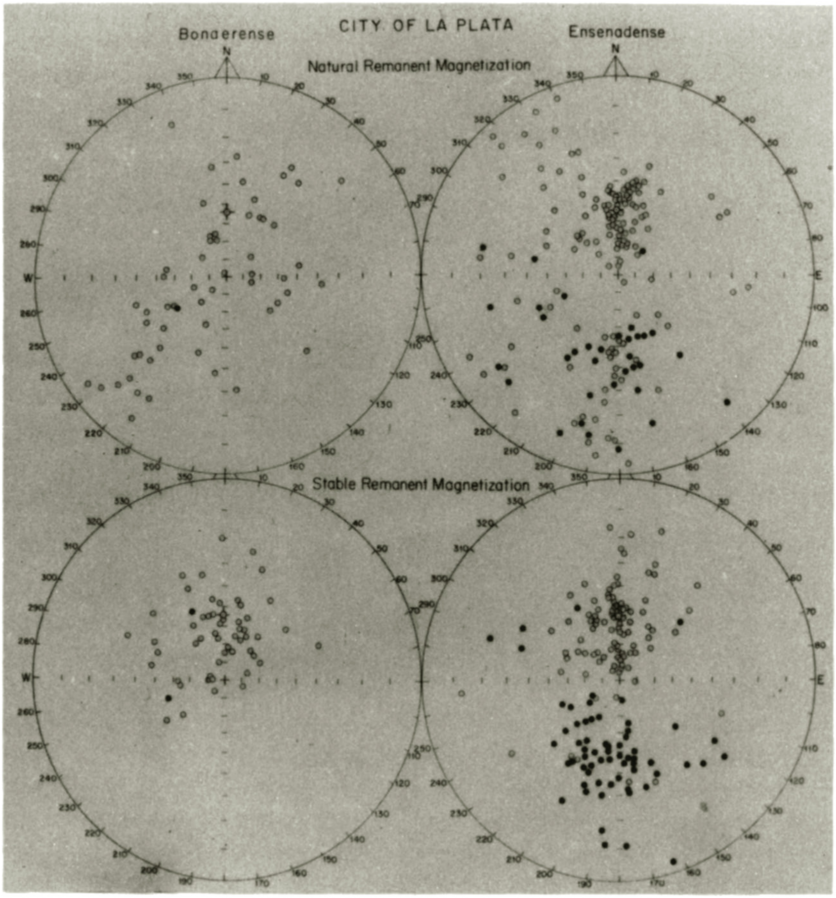

Figure 4. City of La Plata. Directions of natural and stable remanent magnetization for "Ensenadense" and "Bonaerense" specimens. The key of the symbols is the same given in Figure 2.

within the Brunhes Normal and Matuyama Reversed Epochs have been proposed.

These events have not been accepted unanimously by the paleomagneticians. The most important purpose of this paragraph is mainly to review and discuss data related with the existence of normal events in the lower Matuyama Reversed Epoch, between the base of the Olduvai Event and the Gauss-Matuyama Epochs transition (Figure 7). For the Gauss-Matuyama boundary, an age of 2.41$\pm$0.01 Ma (McDougall and Aziz-Ur-Rahman, 1972) is accepted; this was derived from K/Ar ages calculated by means

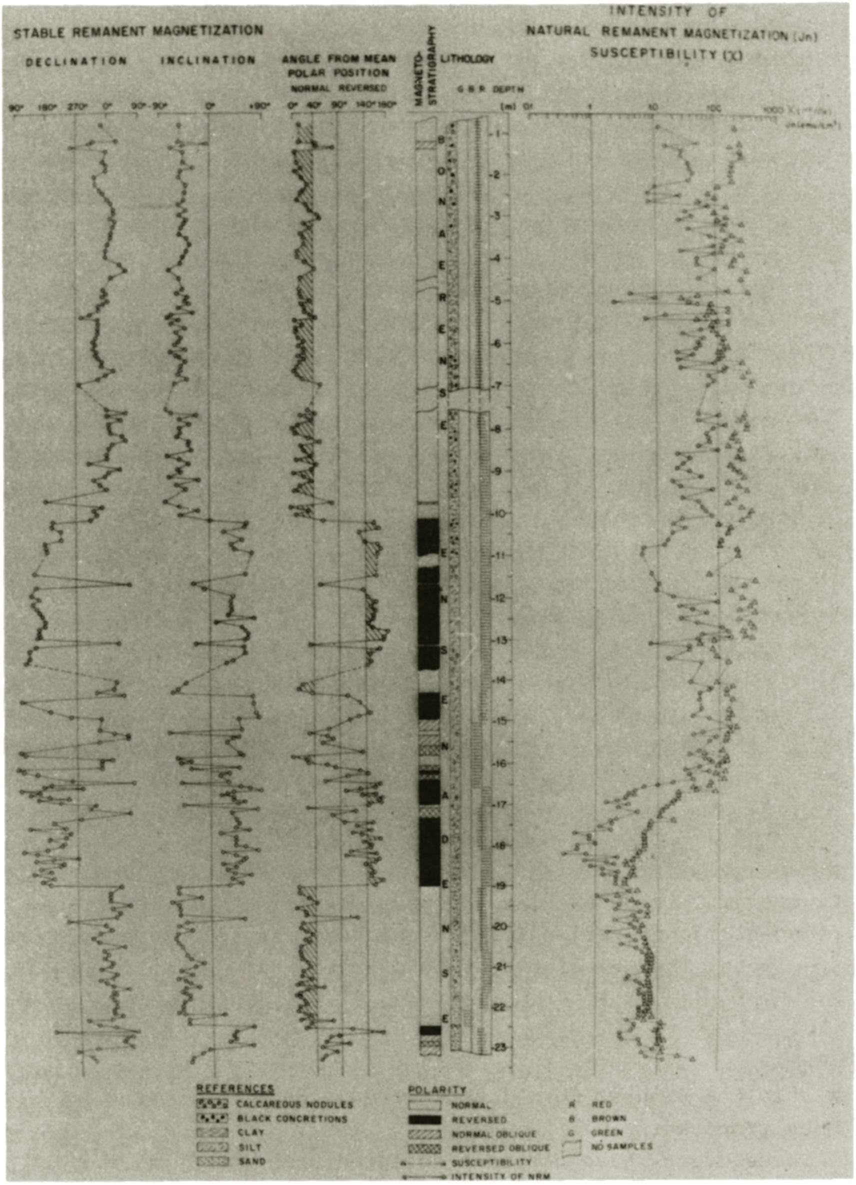

Figure 5. City of Buenos Aires. Declination and inclination of stable remanence and angle between the VGP for each stratigraphic level and the paleomagnetic pole through the "Ensenadense" and "Bonaerense" sequence. The magneto-stratigraphy, the lithology, and the intensity of natural remanent magnetization (J_n) and susceptibility (χ) logs for this sequence are also shown.

of ^{40}K decay constant proposed by Aldrich and Wetherill (1958; quoted in McDougall, 1979).

Data for the time scale of reversals of the geomagnetic field in the late Cenozoic are provided by: 1) oceanic magnetic anomalies; 2) the K/Ar age and the polarity of the stable magnetic remanence of subaerial volcanic rocks; 3) the magnetostratigraphy of sequences of rocks exposed on continents and dated by fossil assemblages and other techniques, and 4) the magnetostratigraphy of sequences from deep-sea cores. We must keep in mind that short polarity events of the geomagnetic field, on account of various causes, are not recorded by rocks of roughly the same age exposed in different sites.

Oceanic magnetic anomalies do not determine by themselves the reversal time scale because, frequently, the age of the magmatic rocks from the bottom of the oceans is unknown. But, when they are calibrated against known points of the radiometric time scale, the oceanic magnetic anomaly profiles provide a nearly continuous record of the geomagnetic field. Heirtzler **et al.** (1968) reported a magnetic anomaly (X anomaly), associated with a normal polarity remanence narrow zone, slightly older than the Olduvai Normal Event (Figure 7). This was probably the first evidence of a short normal within the lower Matuyama. Emilia and Heinrichs (1972) indicated an average age of 2.3 Ma (standard deviation 0.1 Ma) for the X anomaly. McDougall (1979) quoted an age of 2.17 Ma for this anomaly, whereas Rea and Blakeley (1975) suggested an age of 2.25 Ma.

The time scale for the late Cenozoic reversals of the geomagnetic field achieved on basis of the K/Ar age and the magnetic polarity of subaerial rocks requires precisely radiometric dates. However, it is not possible to obtain a complete time scale of reversals using this technique because of the episodic character of the volcanic activity. Valencio **et al.** (1970a, 1970b) reported stable remanence of normal polarity for two basaltic lava flows from the extra-Andean area of Neuquén Province (Argentina), which yielded K/Ar ages within the early Matuyama (2.30 ± 0.15 Ma and 2.31 ± 0.09 Ma). The standard deviations for these radiometric ages are larger than those quoted by other authors for rocks of equivalent age. However, the paleomagnetic data and the K/Ar age for the latter lava flow imply one normal event in the lower Matuyama Reversed

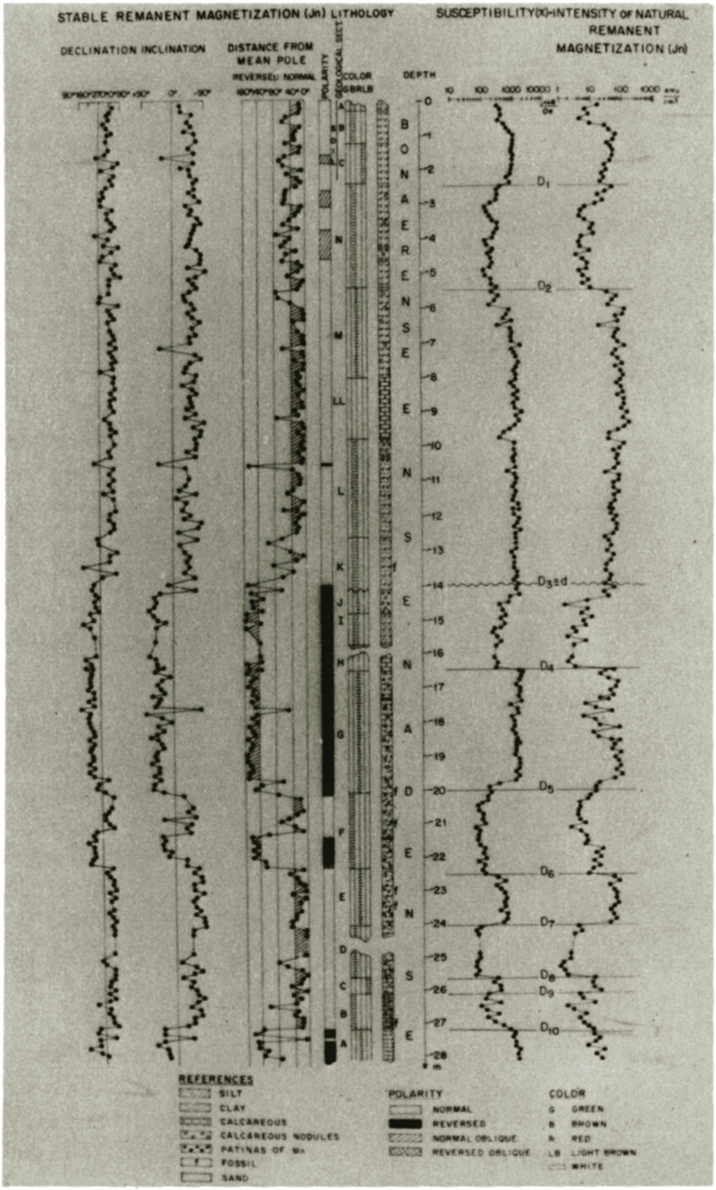

Figure 6. City of La Plata. Declination and inclination of stable remanence and angle between the VGP for each stratigraphic level and the paleomagnetic pole through "Ensenadense" and "Bonaerense" sequence. The magneto-stratigraphy, the lithology, and the intensity of n.r.m (Jn) and susceptibility (χ) logs for this sequence are also shown.

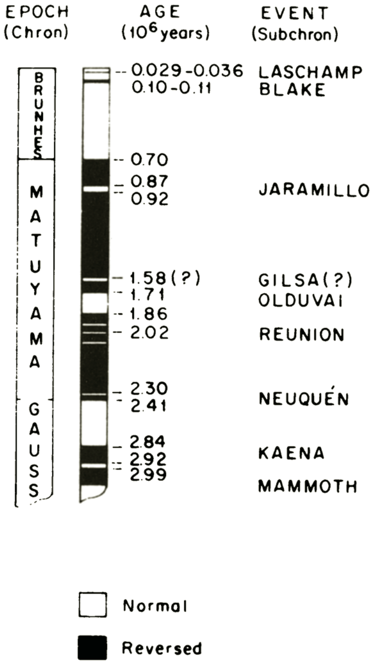

Figure 7. The reversal time scale for the late Cenozoic adopted in this paper.

Epoch (Valencio **et al.**, 1975) if the standard deviation of the date is accepted as an absolute error and an estimate of 2.41 Ma is accepted for the Gauss-Matuyama polarity transition.

The paleomagnetism of sequences of sediments exposed on continents provides another source of information about short polarity events. However, the record of short polarity events can be obscured due to stratigraphic gaps, variations in the rate of deposition and delays in the time between deposition and magnetization of sediments. The paleomagnetic chronology for a Pliocene-early Pleistocene sequence of marine sediments from New Zealand revealed three events of normal polarity within the lower Matuyama Epoch (Kenneth and Watkins, 1971). Shuey **et al.** (1974) and Brown **et al.** (1978) reported four or possibly five such zones in sediments from southwestern Ethiopia which could be interpreted as short normal events in early Matuyama time (one is nearly 2.32 Ma). Kochegura and Zubakov (1978) reported two normal polarity events at 2.13 and 2.30 Ma, respectively, recorded in marine sediments of the

USSR (the oldest was dated by the fission-track method). Liddlicoat **et al.** (1980) reported a zone of normal-magnetic inclination near the beginning of the Matuyama Epoch from the study of one 930 m long core from California, USA. Kristjansonn **et al.** (1980) reported two normal events which occurred in the lower Matuyama in Pliocene and Plio-Pleistocene sequences of volcanic rocks from Iceland. Christoffel and Mak (1981) reported normal polarity events occurred near the Gauss-Matuyama transition in sequences of sediments from New Zealand that were deposited on the continental shelf or shelf slope.

Briefly, information from oceanic magnetic anomalies, sequences of sediments and subaerial lava flows strongly suggests that, at least, a short event of normal polarity occurred in early Matuyama times. These data are not conclusive to indicate the precise age of that event. As the different techniques agree in suggesting a normal polarity event at 2.3 Ma, this age is tentatively suggested for that event. The late Cenozoic events of the geomagnetic field have been usually named after the name of the collecting sites for the paleomagnetic studies. Consequently, the name of Neuquén Normal Event has been suggested for the normal event at the base of the Matuyama Reversed Epoch (Valencio, 1981).

The time scale of the late Cenozoic reversals used in this paper is shown in Figure 7.

INTERPRETATION OF RESULTS

The key to establish the correlation tie-lines of the magnetostratigraphy for a sequence of rocks and the time scale of reversals of the geomagnetic field is to have, at least, one reliable link between them. In this case, this link is the "Bonaerense", the youngest unit of the "Pampeano" sediments, because there is a general agreement in correlating it with the Upper Pleistocene (Brunhes magnetic age; normal polarity NRM). Therefore, we started the correlation of the magnetostratigraphies for the sequences from Buenos Aires and La Plata and the time scale of reversals for the late Cenozoic from the top of these sequences.

The correlation tie-lines adopted for the sequence of the "Ensenadense" and "Bonaerense" sediments from Buenos Aires are shown in Figure 8. They suggest a predominantly Brunhes magnetic age (< 0.7 Ma; middle to late Pleistocene) for the

"Bonaerense". However, at the base of the "Bonaerense" (from 10.15 to 10.35 m; Figure 5) three samples are carriers, from the top to the base, of oblique normal and reversed polarity (two samples) remanences. This suggests a late Matuyama magnetic age (> 0.7 Ma) for the latter two samples. However, we should remind here that the transition "Ensenadense"- "Bonaerense" is not precisely defined in the studied excavation; that is, these three samples might have been erroneously assigned to the "Bonaerense".

The remanence of sediments of the section of the "Ensenadense" from 10.40 m to 19.00 m is of predominantly reversed polarity; therefore, they were correlated with the Matuyama Reversed Epoch. The normal polarity subsections within this predominantly reversed section were correlated with the subchrons within the Matuyama chron (Figure 8).

Finally, the sediments of the "Ensenadense" section from 19.00 m to 23.00 m have remanence of predominantly normal polarity; at the base of this section, some samples are carriers of remanence of oblique polarity and one of them, reversed polarity. The sediments of this section were correlated with the late Gauss Chron and the Kaena Subchron, respectively. That is, our interpretation suggests a late Gauss to Matuyama (2.84->0.7 Ma, late Pliocene to middle-late Pleistocene) magnetic age for the sequence of "Ensenadense" sediments from Buenos Aires.

Briefly, the magnetic age for the "Bonaerense" from this site is consistent with the age suggested for this unit by Frenguelli (1975) and older and partially consistent with that assigned to the Lujanense Mammal Age (Table 1). The magnetic age for the "Ensenadense" is partially consistent with the ages suggested for this unit by Ameghino (1908) (Pliocene) and Frenguelli (1975) (middle Pleistocene) and older and partially consistent with that assigned to the Ensenadense Mammal Age (Table 1).

The correlation tie-lines adopted for the sequence of the "Ensenadense" and "Bonaerense" from Buenos Aires and the time scale of reversals (Figure 8), suggest two rates of accumulation: 14 mm/1000 years for the upper 13 m and 7.5 mm/ 1000 years for the lower 10 m of sediments. They also suggest a discontinuity in the accumulation of sediments at about 13.15 m. Sharp changes in the lithology, the intensity of NRM and magnetic susceptibility and a change of polarity of the geomagnetic field occur at this depth (Figure 5). These are

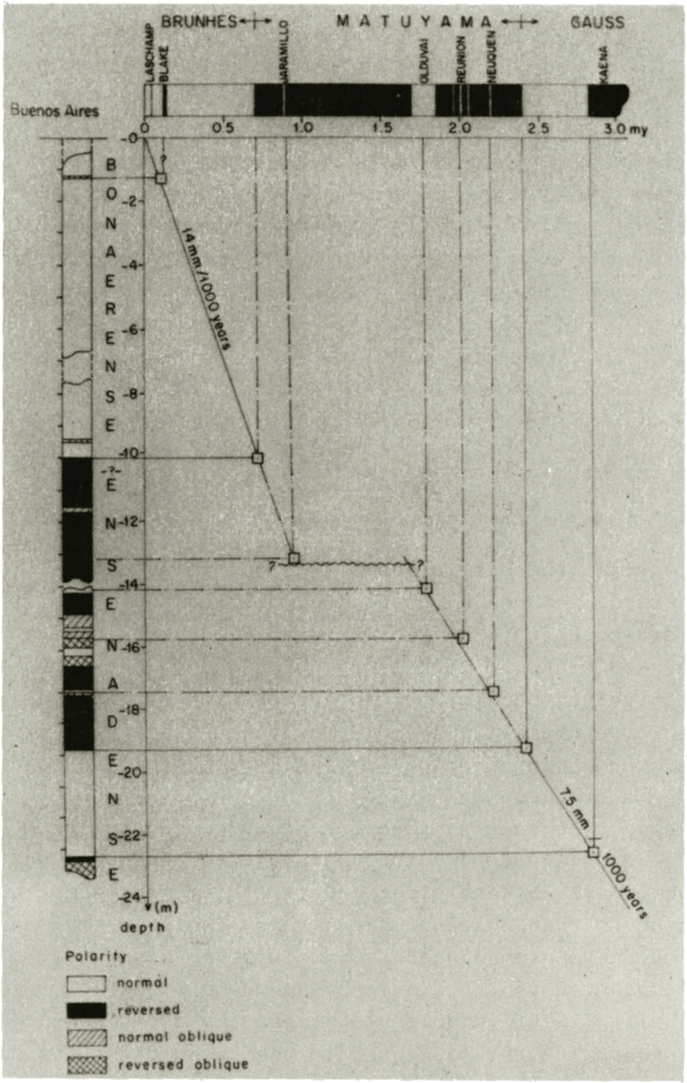

Figure 8. City of Buenos Aires. Correlation tie-lines adopted for "Ensenadense" and "Bonaerense" sequence and the late Cenozoic time scale of reversals.

interpreted as evidence of a discontinuity in the accumulation of sediments, as it will be discussed later. That is, two different lines of reasoning agree in suggesting a discontinuity in the Buenos Aires "Ensenadense" sediments.

The magnetostratigraphy for the "Ensenadense" and "Bonaerense" sediments from La Plata is rather different from that of Buenos Aires (Figures 6 and 5, respectively). There are also remarkable differences in the lithology and the patterns of the intensity of NRM and magnetic susceptibility logs. As it has been mentioned (item 2), the La Plata sequence was subdivided into 15 geological sections on basis of their lithology. Particularly, field geological data indicate that the boundary between the lithologic sections J and K is an unconformity (d). This unconformity is also coincident with changes in the values of the intensity of NRM and magnetic susceptibility, and a reversal of the geomagnetic field, from reversed to normal polarity (D_3). It is difficult to explain that sharp changes in the lithology and in the number, chemical composition and/or size of magnetic mineral of sediments are coeval with a reversal of the geomagnetic field because their causes are entirely different. We interpret this as an evidence of a discontinuity in the sediment accumulation; that is, the lithology and the scalar and vectorial magnetic variables agree with the field geology defining a discontinuity in the sediment accumulation at the J-K transition ($d=D_3$).

Three other coincident sharp variations in the lithology and in the scalar and vectorial magnetic variables are defined in the sequence of La Plata "Ensenadense" sediments. They have been named D_5, D_6 and D_{10} (about 20.0; 22.5 and 27.0 m deep, respectively); the latter is coincident with an irregular surface between the lithological sections A and B. They are also interpreted as discontinuities in the sediment accumulation; perhaps, some of them can be minor unobservable unconformities. Coincident variations in the lithology and the scalar magnetic variables are also defined in the sequence; they have been named D_1, D_2, D_4, D_7, D_8 and D_9. They could be evidence of minor discontinuities in the accumulation of the "Ensenadense" and "Bonaerense" sediments in La Plata as well.

Briefly, field geological data, the lithology and the scalar and vectorial magnetic variables suggest that the accumulation of the "Pampeano" sediments from La Plata may have been interrupted several times during periods of unknown duration. This constitutes a serious difficulty for the correlation of the magnetostratigraphy of these sediments and the time scale of reversals.

The two patterns of correlation tie-lines adopted for the sequence of the La Plata "Ensenadense" and "Bonaerense"