

Environmental changes in the Pampean area of Argentina at the Matuyama–Brunhes (C1r–C1n) Chrons boundary

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Abstract

The so-called Pampean sediments are the uppermost sedimentary levels of the Chacopampean basin. They record the sequence of geologic changes that occurred during the late Cenozoic. In the Pampean area, the most important environmental and faunistic changes occurred close to the end of the Matuyama Chron and beginning of the Brunhes Chron. The relatively wet climate recorded in the region at the end of Matuyama Chron turned to drier and colder conditions during the beginning of the Brunhes Chron, which also seems to be characterized by an important volcanic activity in the Cordillera de los Andes. An important faunistic turnover (between *Tolypeutes pampaeus* and *Megatherium americanum* biozones) coincides with lithostratigraphic changes (between the Ensenada and Buenos Aires formations). The change of polarity Matuyama–Brunhes is observed below this boundary.

Keywords: biozones; early–middle Pleistocene; magnetozones; Pampean stratigraphy

1. Introduction

The Pampean region is a well-known area of late Cenozoic loess and loess-like sedimentation (Fig. 1). These kinds of deposits may provide good sequences for the study of climatic changes in continental environments. Loess sediments are mostly located in temperate belts, and the study of their evolution is relevant for understanding the present climate and predicting future changes in these important food-producing areas.

The alternation of loess-like deposits and paleosols in the Pampean area (as well as with marine deposits in the east) are indicators of environmen-

tal changes. Besides these geological features, since the end of the 19th century, biostratigraphical studies have shown faunistic modifications in the Pampean region in the late Cenozoic sequence.

In this paper, we summarize magnetostratigraphical, biostratigraphical and lithostratigraphical information from the Pampean region published in different journals, with the objective to point out the coexistence of different events close to the Matuyama–Brunhes (C1r–C1n) Chrons boundary.

The relationships among different phenomena such as geomagnetic reversals, climate, volcanism, and biological evolution are still not well understood; nevertheless, efforts have been made in addressing these relationships. For example, geolo-

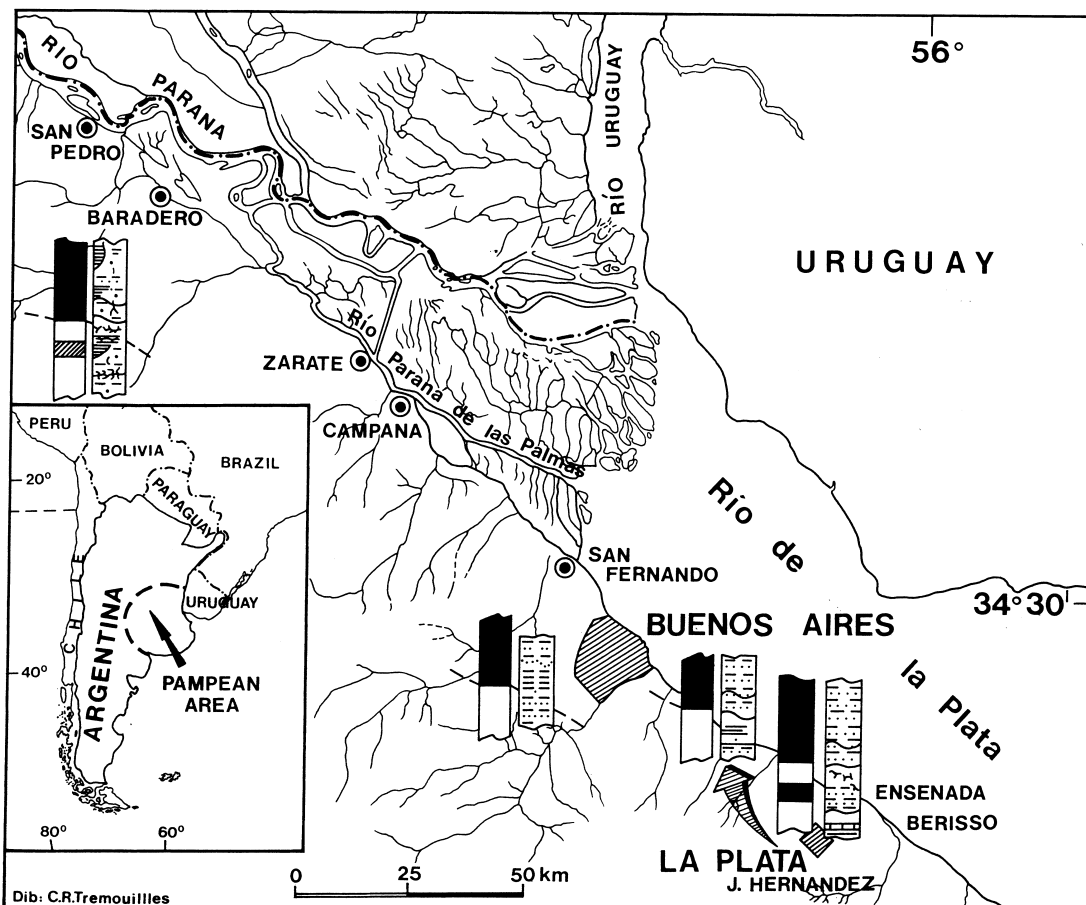


Fig. 1. Northeastern Pampean area of Argentina. Lithological and magnetostratigraphic profiles of several localities are depicted.

dence on the coincidence of geomagnetic reversal with climatic change and biological evolution. In the Chinese plateau, where there is one of the most complete and best-studied loess deposits of the world, the initiation of loess accumulation was established close to the Gauss–Matuyama chron boundary 2.6 Ma (Liu et al., 1985). The coincidence of the geomagnetic field reversal with global climatic change, perhaps caused in part by the accelerated uplift of the Tibetan plateau, is remarkable (Heller and Evans 1995). In addition, the time close to the Gauss–Matuyama boundary is characterized by alternating Pliocene and the early Pleistocene fauna (Liu et al., 1985).

Worm (1997) points out that all polarity boundaries separating chrons and subchrons since the

Gauss–Matuyama field reversal have been recorded in loess, and thus correspond to periods of cold climate. In particular, the Matuyama–Brunhes boundary is mostly located in the loess sections (Heller and Evans, 1995).

Volcanic activity has also been correlated to climate change (Bray, 1977). Recently, McGuire et al. (1997) proposed a mechanism by which the growth and decay of large ice sheets can influence the eruptive timing of volcanoes through changes in sea level. In a like manner, Worm (1997) suggests a mechanism for field reversals caused by lowering of the sea level during glaciations.

Some particular periods in South American history show a concentration of biological and geological phenomena. In this paper, we detail the

geologic, climatic, and biological changes that were detected in Pampean sections deposited in the vicinity of the Matuyama–Brunhes boundary (C1r–C1n Chrons; 0.78 Ma yr BP; Berggren et al., 1995) and discuss the possible coincidence of some of these events.

2. Stratigraphy and paleoclimate

The Pampean area is part of a large sedimentary basin with horizontally arranged strata ranging from at least the Cretaceous to the Recent (Fidalgo et al., 1975; Yrigoyen, 1975; Russo et al., 1979). Stratigraphic survey of the younger beds began in the first half of the 19th century (Ameghino, 1889; see Cione and Tonni, 1995a, 1999). Florentino Ameghino established the standard reference scale for the continental Cenozoic of southern South America and proposed a sequence of stages (*pisos*) grouped into higher order units ('formations' = '*formaciones*', which were chronostratigraphic and not lithostratigraphic units, e.g. Ameghino, 1889, 1909). Later, it was extended to the rest of South America (see Pascual et al., 1965). Ameghino's (1909) scale of stages, largely based on biostratigraphy, remains valid even today in the chronologic local standard scale of at least southern South America (Cione and Tonni, 1995a,c). The late Cenozoic stratigraphy was later studied by other authors (e.g. Frenguelli, 1957; Fidalgo et al., 1975, 1991; Fidalgo, 1983; Rabassa, 1985; among others).

The current local time scale of latest Cenozoic over the Marplatan Stage/Age (Cione and Tonni, 1995a) includes the Ensenadan Stage/Age (from about 2 to less than 0.78 Ma; Ensenadan Stage of Ameghino, 1899), the Bonaerian Stage/Age (younger than 0.78 to about 130 000 yr BP; Lujanian 'Land mammal age' partim of Pascual et al., 1965; Bonaerian Stage of Ameghino, 1889), the Lujanian Stage/Age (from about 130 000 to 8500 yr BP; Lujanian 'Land mammal age' partim of Pascual et al., 1965 = Lujanian Stage of Ameghino, 1889 partim), and the Platan Stage/Age (from 8500 yr BP to the 16th century, when the Spaniards arrived at the Pampas; Cione and Tonni, 1999; Platan partim of Ameghino, 1889). These four

chronostratigraphic units are based on biostratigraphic units: the biozones of *Tolypeutes pampaeus* (Ensenadan), *Megatherium americanum* (Bonaerian), *Equus (Amerhippus) neogaeus* (Lujanian) and *Lagostomus maximus* (Platan; for a discussion, see Tonni and Cione, 1994; Cione and Tonni, 1995a,c, 1999). Ortiz Jaureguizar et al. (1995) correlated the extinction event at the Marplatan–Ensenadan boundary with the beginning of the 'Glacial Pleistocene' at 1.0–0.8 Ma. In the western Mediterranean area, this event is marked by practically total rejuvenation of the fauna (Ortiz Jaureguizar et al., 1995). However, in our region, the beginning of the 'Glacial Pleistocene' at 1.0–0.8 Ma seems to correlate with the upper levels of the Ensenadan, which have been magnetostratigraphically studied and include fauna of arid and cold environments (see below).

Some confusion in the stratigraphic terminology arose from the use of the same names for lithostratigraphic units in place of former chronostratigraphic units. After Ameghino's classification, many other stratigraphic proposals have been performed.

Several authors have included most of the late Cenozoic sediments of the Pampean region in a single lithostratigraphic unit, the '*Pampiano*' or '*Pampeano*' Formation (Tonni and Fidalgo, 1978; Fidalgo, 1983). However, most workers presently recognize the early–middle Ensenada Formation and the middle–late Pleistocene Buenos Aires Formation (see Riggi et al., 1986), among those deposited close to the Matuyama–Brunhes boundary in the central and northern Buenos Aires province. In the southern Buenos Aires province, several other correlated units were distinguished (see Kraglievich, 1952). The Ensenada and Buenos Aires formations coincide with the sediments of Ensenadan and Bonaerian–Lujanian age, respectively, in the central and northern Pampean area (certainly not in other parts of South America). For a more detailed survey of lithostratigraphic units in the area see, Fidalgo (1983) and Fidalgo et al. (1975, 1991).

The Pliocene–Pleistocene boundary (C2n–C1r2r boundary) is located within the lower part of the Ensenada Formation if the date of 1.77 Ma is accepted (Berggren et al., 1995). Attempts to relocate the Pliocene–Pleistocene boundary to

coincide with the late Pliocene climatic change at ca 2.6 Ma were judged to be inappropriate (Berggren et al., 1995). The Matuyama–Brunhes boundary was recognized in different Pampean loess sections in the upper part of the Ensenada Formation (Nabel, 1993; Tonni et al., 1999) (Fig. 2).

An alternation of loess and loess-like deposits and paleosols characterizes both the Ensenadan and Buenos Aires formations, but the sediment is less consolidated in the Buenos Aires Formation than that of the Ensenada Formation. At the top of the Matuyama reversed polarity zone, we have recognized a well-developed paleosol (Hisisa Geosol; Nabel et al., 1990; Nabel, 1993).

Elsewhere, we proposed that the Hisisa Geosol be used as a regional indicator of the upper boundary of the Matuyama polarity zone in the Pampean area (Nabel et al., 1997; Tonni et al., 1999). The base of the Brunhes polarity zone in the area is characterized by loessic sedimentation, suggesting a change to drier environmental conditions (Nabel et al., 1990).

There are no accurate absolute ages for Buenos Aires Formation. The exact age of the Ensenadan–Bonaerian boundary is unknown, but it is younger than 0.78 Ma (Tonni et al., 1999; Cione and Tonni, 1999). The Buenos Aires Formation includes a large part of the Brunhes polarity zone, representing the middle–late Pleistocene.

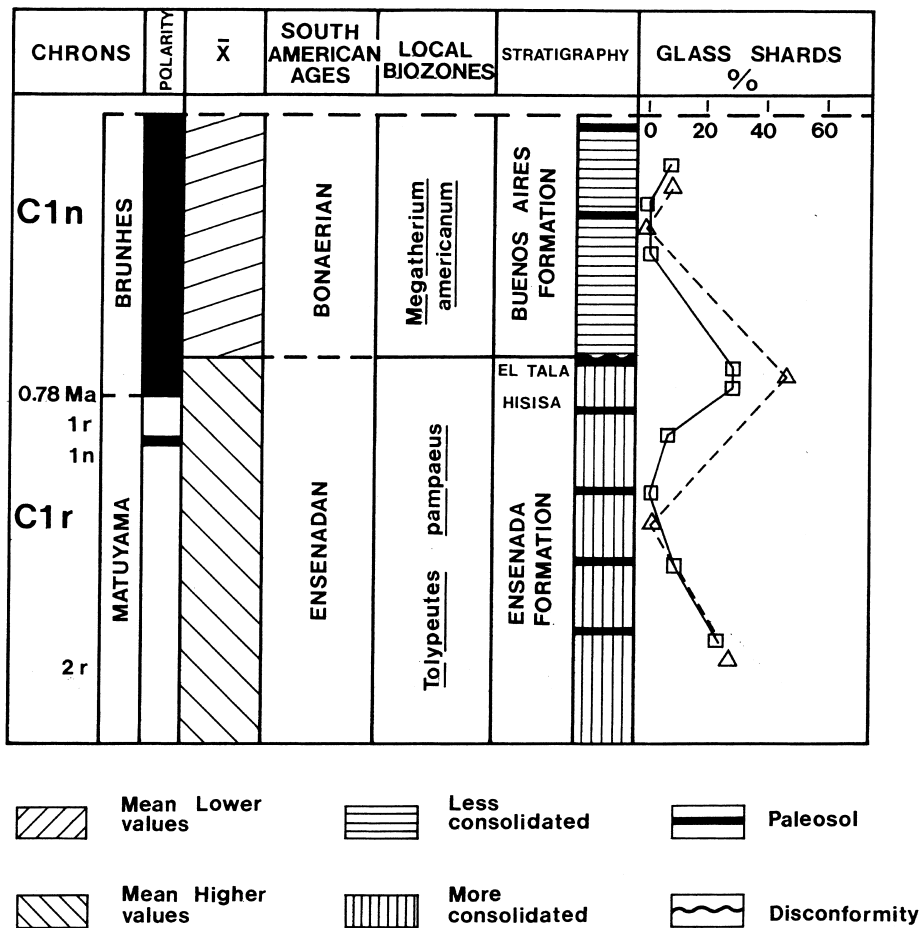


Fig. 2. Magnetic, stratigraphic, mineralogical and biostratigraphic evidences of changes at the Matuyama–Brunhes boundary in the northeastern Pampean area.

The mean magnetic susceptibility (X) values of Buenos Aires Formation are usually slightly, but systematically, lower than those of the Ensenada Formation (Fig. 2).

The Cordillera de los Andes, located along the west border of Argentina, as well as the North Patagonian river deposits, have been recognized as the main sources of the loess and loess-like sediments that cover the Pampean region (Teruggi, 1957; Karlsson, 1990; Zarate and Blassi, 1993). The strong west and south-western winds are the most important transport supply.

For both units the source of sedimentation has been the same and the main mineralogical content are similar, and the observed differences in main magnetic susceptibility values require the study of the mineralogical changes on a more accurate scale in order to identify the behavior of the iron oxides.

The differences in consolidation observed between the Ensenada and Buenos Aires formations, but their similar mineralogical contents, suggest a time span between their deposition. A paleosol that guides the recognition of the discontinuity found between them, named El Tala Geosol, has developed over the upper section of the Ensenada Formation (Nabel et al., 1993) and has been proposed as a stratotype of the upper boundary of the Ensenada Formation (Nabel et al., 1997; Tonni et al., 1999).

It is interesting to note that in a different geological environment, in California soil chronosequences, it was observed that magnetic susceptibility values increase with age (Fine et al., 1992). A progressive transformation of iron oxides has been used to explain this phenomenon (Aniku and Singer, 1990). The search for an answer to the differences in main magnetic susceptibility values between Buenos Aires and Ensenada formations could be addressed in a similar direction.

Glass shards of the Pampean sediments have been found extensively, and their relative variations give important environmental and climatic information. The base of the Brunhes polarity zone shows a peak of glass shards (Nabel et al., 1990, 1993, 1999; Nabel, 1993; Tonni et al., 1999) (Fig. 2). This correlation suggests that the Matuyama–Brunhes turnover coincided with intense volcanic activity in the Cordillera. The

large volcanic deposits in the Chilean Andes, where the Matuyama–Brunhes polarity transition has been recorded (Brown et al., 1994; Singer and Pringle, 1996), is evidence of the volcanic activity in the Andes and agrees with our results.

A similar concentration was observed in the Southern Pacific Ocean (Kennett and Watkins, 1970), Alaska (Westgate et al., 1990) and New Zealand (Shane et al., 1995). In the western and central United States, the widespread Bishop ash bed has been found above (Liddicoat, 1985) and below (Hillhouse and Cox, 1976) the Matuyama–Brunhes boundary (Sarna-Wojcicki et al., 1987), addressing the idea of a possible relationship between them.

The fresh condition of the glass shards in the Pampean loessic sedimentation suggests a colder and more arid climate. A relation between field reversals and cold stages has also been observed in other places (Heller and Evans 1995; Worm, 1997).

3. Mammal record

The evolution of mammal fauna in the Pampean region since the Pliocene has been analyzed elsewhere, taking into account the Chapadmalalan (Pliocene), lower, middle and upper Marplatan (which replaces the former ‘Uquian’ Pliocene), Ensenadan (latest Pliocene–middle Pleistocene), Bonaerian (middle–late Pleistocene), Lujanian (late Pleistocene–early Holocene) and Platan (middle–late Holocene) stages (Tonni et al., 1992; Cione and Tonni, 1995a). A very high degree of extinction of autochthonous taxa (e.g. Microtragulidae, Hegetotheridae, Echimyidae in the Pampean area, *Pithanotomys*) has occurred in the top of the Marplatan. Authors have attributed this faunal event to the impact occasioned by the supposed massive and sudden immigration of Holarctic mammals in ‘Uquian’ times or by climatic changes (Pascual and Fidalgo, 1972; Webb, 1976). However, the arrival of Holarctic mammals into the Pampean region was not as sudden as previously envisioned. The biomass and diversity of Holarctic immigrants were reduced in the Pampean region during Chapadmalalan and Marplatan times. As a consequence, the faunal turnover observed between the Marplatan and

Ensenadan would be due to other causes. The influence of northern mammals was certainly much more important during Ensenadan, Bonaerian and Lujanian times (Tonni et al., 1992). Notwithstanding that no new autochthonous family appeared after the end of the Chapadmalalan, many new genera of autochthonous families occur in the Ensenadan, paralleling the abrupt increase of Holarctic taxa. It is only in the latest Lujanian that we observe a high degree of extinction of genera of autochthonous families. Most genera that dominated during the Pleistocene in the Pampean area occur for the first time in the Ensenadan but are represented by other species in the Bonaerian and Lujanian. However, notwithstanding that several Ensenadan, Bonaerian and Lujanian taxa are presently in revision, there was certainly a very important turnover at the species level between these ages (Cione and Tonni, 1999; Cione et al., 2000). Based on these differences, Ameghino (1908) suggested that an important hiatus existed between both (including the marine beds of the 'Belgranense' at the coast).

4. Discussion

The climatic conditions in the Pampean area during the early Pleistocene (most of the Ensenadan) were relatively wet and warm according to the mammal record and lithology. The Ensenada Formation sediments show more evidence of being deposited under water and record a higher number of paleochannels than the overlying sediments of the Buenos Aires Formation (Frenguelli, 1925). The Ensenadan fauna includes species of the families Tapiridae, Procyonidae and Echimyidae, inhabitants of relatively warm areas that have not been recorded in younger sediments. The present southernmost ranges of these species (*Tapirus terrestris*, *Nasua nasua*, *Procyon cancrivorus*, *Euryzygomatomys spinosus*, *Kannabateomys amblyonyx*) reach the subtropical north-eastern Argentina (Misiones Province; Chebez and Massoia, 1996). Furthermore, today, the species of the echymid genus recorded in the Ensenadan, *Clyomys laticeps*, has its southernmost distribution in Paraguay. All these warm climate indicators disappear in the upper sections of the Ensenadan, during the beginning of the Brunhes Chron.

The loessic sedimentation at the beginning of Brunhes Chron, with marked immaturity of minerals, abundant and fresh plagioclase and glass shards, carbonated globules and calcretes, as well as the mammal assemblage that characterize the sediments deposited between Matuyama–Brunhes boundary and the upper boundary of the Ensenada Formation, suggest a climatic change to drier and colder conditions.

Under arid or semi-arid conditions, the 'normal' order of mineral stability may be modified, or even reversed, thus permitting the attainment of a high textural maturity coupled with mineralogical immaturity. In particular, it is accepted that feldspars are good indicators of the climatic conditions during weathering and transport (Mackie, 1899).

In Argentine loess sediments, the abundance of fresh feldspars is an indicator of arid and cold paleoclimates (Teruggi and Andreis, 1971). Also, the fresh glass shards with jagged shapes do not show transport reworking and suggest a direct deposition from the eruptive cordillera centers.

The dry and cold event identified in Pampa region at the onset of Brunhes Chron was related to an important glaciation in the east and south-east region. Paleomagnetic studies in tills of southern Argentina (Morner and Sylwan, 1989; Sylwan, 1989) have shown a close correlation of the onset of Brunhes Chron with the third main glaciation or 'ice age' in Patagonia, corresponding with the 'Daniglacial' of Caldenius (1932), who first, and accurately, studied the glaciations in that region. Present names of the glaciations recognized in the east and south-east regions of the country for the early Middle Pleistocene are: for the Mendoza region, 'Uspallata' glaciation (Espisúa, 1989; Clapperton, 1993), and for the Bariloche region, 'El Condor' (Rabassa and Evenson, 1989). This glaciation might be correlated to the Illinoian North America glaciation (Rabassa, 1990).

Certainly, in upper Ensenadan beds, there are many mammals adapted to arid and/or cold climates: *Lestodelphys halli*, *Eligmodontia* sp. (Tonni et al., 1993), *Microcavia*, *Ctenomys*, *Reithrodon*, *Zaedyus* and *Tolypeutes* (Tonni and Cione, 1994, 1995; Verzi and Lezcano, 1996; Tonni et al., 1999). Besides, an extinct species of the furnariid *Pseudoseisura* was recently recorded in correlative levels in the north-eastern Pampean area (Tonni

et al., in press). The present species of *Pseudoseisura* inhabit semiarid and forested areas such as the Chacoan Dominion of northern and central Argentina and the Caatinga of Brazil, excluding the Pampean area (EPT and Jorge Noriega, personal observation).

In Europe, the Villafranchian–Galerian transition (about 0.9–0.8 Ma) involved an important faunal turnover, with massive extinctions. The late Pleistocene and living fauna of Eurasia took its origin at this time (Zanchetta et al., 1995). In South America, the extant fauna can be traced to the Bonaerian, notwithstanding that at the boundary between Lujanian and Platan, an important massive extinction occurred, especially affecting the megamammals.

A regional paleosurface overlies the El Tala Geosol at the top of the Ensenada Formation. This regional unconformity and the differences in compaction between Ensenada and Buenos Aires Formations suggest that a significant time span separates these two units.

Notwithstanding that the presence of paleosols intercalated in the Buenos Aires Formation indicates moments of a relatively higher humidity, in the *Megatherium americanum* biozone (recognized in the Buenos Aires Formation) as well as in the overlying *Equus (Amerhipus) neogeus* biozone of the Pampean area, there is no mammal indicator of a wet and warm climate. *Lama gracilis*, *Lama guanicoe*, *Reithrodon auritus*, *Microcavia* sp., *Eligmodontia* (in the *Equus (Amerhipus) neogeus* biozone), *Graomys* sp., *Ctenomys lujanensis*, *Zaedyus* sp., *Tolypeutes* sp., *Lestodelphys halli* are abundant in comparison with most of the *Tolypeutes pampaeus* biozone, indicating arid and cold climate.

5. Conclusions

- Several important environmental changes were detected close to the Matuyama–Brunhes boundary in the Pampean area.
- The Brunhes onset, detected in the upper part of the Ensenada Formation in the Pampean region, is characterized by a new pulse of loessic sedimentation.

- The high content of fresh feldspars, as well as fresh and sharp shaped glass shards and the biogeographic faunistic change, indicates a climatic change to drier and colder conditions.
- The loessic deposits at the Brunhes onset in Pampa area is related to the establishment of a new glaciation in eastern and south-eastern regions.
- The high fresh and sharp shaped glass shard content of the loess sediments indicates that at the time of the geomagnetic polarity turnover, intense volcanic activity in the cordillera took place.
- Notwithstanding that the major faunal turnover occurs between the *Tolypeutes pampaeus* and *Megatherium americanum* biozones and seems to be younger than the Matuyama–Brunhes boundary (0.78 Ma), it is possible to recognize a shift of the mammal taxa in accordance with drier environmental conditions since then. The boundary between both biozones coincides with the short upper boundary between the Ensenada and Buenos Aires Formations.
- Consequently, in the Pampean area, there seems to be some coincidence between climatic and paleomagnetic change and volcanic activity, but there is no close coincidence between the major evolutive faunistic turnover between Ensenadan and Bonaerian and the paleomagnetic change in the area.
- The unconformity that separates the Ensenada and Buenos Aires formations could represent a relatively long period of time on account of their marked consolidation differences and the important faunal turnover between them.

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Appendix A

Mammal content of the *Tolypeutes pampaeus* and *Megatherium americanum* biozones in the Pampean area (Cione et al., 2000).

Tolypeutes pampaeus biozone (Cione and Tonni, 1995a)

Taxa exclusive to this zone are *Tolypeutes pampaeus*, *Daedicuroides*, *Panochthus intermedius*, *Glyptodon munizi*, *Glyptodon principalis*, *Glyptodon gemmatum*, *Glyptodon laevis*, *Plaxhaplous ensenadensis*, *Sclerocalyptus pseudornatus*, *Sclerocalyptus perfectus*, *Sclerocalyptus scrobiculatus*, *Sclerocalyptus ornatus*, *Diheterochnus holmbergi*, *Nothropus carcaranensis*, *Neothoracophorus elevatus*, *Lomaphorus compressus*, *Neuryurus rudis*, *Megalonychops*, *Scelidothierium n. sp.*, *Scelidodon*, *Machrauchenioipsis*, *Megatherium gallardoi*, *Megatherium silenum*, *Megalonychops carlesi*, *Glossotherium n. sp.*, *Mylodon n. sp.*, *Antifer ensenadensis*, *Epieurycerus*, *Galictis hennigi*, *Lyncodon bosei*, *Cyonasua meranii*, *Dusicyon ensenadensis*, *Theriodictis*, *Protocyon scagliarum*, *Canis gezi*, *Microcavia robusta*, *Galea laeviplicata*, *Ctenomys kraglievichi*, *Ctenomys orthognathus*, *Ctenomys laetidens*, *Ctenomys intermedius*, *Myocastor minor*, *Bolomys nov. sp.*, *Eligmodontia nov. sp.*, *Graomys nov. sp.*, *Toxodon ensenadensis*, *Machrauchenioipsis*, *Arctodus angustidens*, *Arctodus candiotti*. Taxa with the last records in this zone are: *Stipanicia pettoruti* and *Mesotherium cristatum*. Taxa with pseudoextinction in the Pampean area are: Dasyproctidae and Echimyidae. Taxa ranging from this zone to younger levels are: (1) several new families of North American origin (Cervidae, Ursidae, Tapiridae, Gomphotheriidae, Felidae); (2) the autochthonous genera and species *Neolicaphrium*, *Propraopus*, *Dasypus*, *Glyptodon*, *Panochthus*, *Neuryurus*, *Doedicurus*, *Plaxhaplous*, *Neothoracophorus*, *Lomaphorus*, *Scelidothierium*, *Mylodon*, *Lestodon*, *Pampatherium typum*, *Dusicyon cultridens*, *Ctenomys*, *Myocastor*, *Nechoerus*, *Holochilus*, and *Clyomys*; and (3) genera and species unknown in older beds of previously recorded North American families such as *Akodon azarae*, *Lundomys*, *Necromys*, *Oligoryzomys*, *Oxymycterus*, *Phyllotis*, *Catagonus*, *Megatherium tarijensis*, *Lama guanicoe*, and *Hemiauchenia*. It remains to be demonstrated whether *Conepatus* is older than Ensenadan. This zone (and the younger zones) is characterized by the abundance of specimens of families of North American origin.

Megatherium americanum biozone (c) (Cione and Tonni, 1995c)

Exclusive taxa of this biozone are: *Arctodus (Pararctotherium) pamparum*, *Conepatus mercedensis*, *Protocyon n. sp.*, *Toxodon gracilis*, *Epieurycerus proximus*, *Morenelaphus brachyceros*, *Antifer ultra*, *Megatherium lundii*, *Mylodon darwini*, *Nothropus priscus*, *Scelidothierium floweri*, *Neothoracophorus depressus*, *Sclerocalyptus migoyanus*, *Lomaphorus elegans*, *Lomaphorus elevatus*, and *Doedicurus poucheti*. Taxa with the first record in this zone are: *Macrauchenia patachonica*, *Toxodon burmeisteri*, *Toxodon platensis*, *Morenelaphus lujanensis*, *Paraceros fragilis*, *Necromys benefactus*, *Ctenomys lujanensis*, *Nechoerus aesopi* (?), *Lyncodon patagonicus*, *Dusicyon avus*, *Pecari tajacu*, *Lama gracilis*, *Hemiauchenia paradoxa*, *Megatherium americanum*, *Lestodon armatus*, *Lestodon trigonidens*, *Mylodon darwini*, *Scelidothierium leptocephalum*, *Sclerocalyptus migoyanus*, *Glossotherium robustum*, *Glossotherium myloides*, *Glyptodon reticulatus*, *Glyptodon elongatus*, *Lomaphorus elevatus*, *Panochthus tuberculatus*, *Panochthus frenzelianus*, *Panochthus morenoi*, *Plaxhaplus canaliculatus*, *Zaedyus minimus*, *Clamyphorus truncatus*, *Tolypeutes matacus*, *Paraceros lujanensis*. *Panochthus morenoi* could be a junior synonym of *P. tuberculatus* (G. Scillato Yané and A. Carlini, personal communication). Several clades of holarctic origin greatly expand in diversity in this zone (v.gr. Cricetidae and Cervidae).

References

- Ameghino, F., 1889. Contribución al conocimiento de los mamíferos fosiles de la República Argentina. Actas Academia Nacional de Ciencias, Córdoba 6, 1–1027.
- Ameghino, F., 1908. Las formaciones sedimentarias de la region litoral de Mar del Plata y Chapadmalán. Anales del Museo Nacional de Historia Natural 10, 343–428.
- Ameghino, F., 1909. Le Diprothomo platensis: un précurseur de l'homme du Pliocene inférieur de Buenos Aires. Anales del Museo Nacional de Historia Natural de Buenos Aires 19, 107–209.
- Aniku, J.R.F., Singer, M.J., 1990. Pedogenic iron oxide trends in a marine terrace chronosequence. Soil Science Society American Journal 54 (1), 147–152.
- Berggren, W.A., Hilgen, F.J., Llagostera, C.G., Kent, D.V., Obradovich, J.D., Raffi, I., Raymo, M.E., Shackleton, N.J., 1995. Late Neogene chronology: new perspectives in high-resolution stratigraphy. GSA Bulletin 11, 1272–1287.
- Bray, J.R., 1977. Pleistocene volcanism and glacial initiation. Science 197, 251–254.
- Brown, L., Pickens, J., Singer, B., 1994. Matuyama–Brunhes transition recorded in lava flows of the Chilean Andes: Evidence for dipolar fields during reversals. Geology 22, 299–302.
- Caldenius, C., 1932. Las glaciaciones cuaternarias en la Patagonia y Tierra del Fuego. Min. Agric., Dirección General de Minas y Geología 95, 150.
- Chebez, J.C., Massoia, E., 1996. Mamíferos de la provincia de Misiones. In: Chebez, J.C., (Ed.), Fauna Misionera. L.O.L.A., Buenos Aires, pp. 181–206.
- Cione, A.L., Tonni, E.P., 1995a. Chronostratigraphy and 'Land-mammal ages' in the Cenozoic of southern South America: Principles, practices and the 'Uquian' problem. Journal of Paleontology 69, 135–159.
- Cione, A.L., Tonni, E.P., 1995b. Bioestratigrafía y cronología del Cenozoico superior de la región pampeana. In: Alberdi, M.T., Leone, G., Tonni, E.P. (Eds.), Evolución biológica y climática de la región pampeana durante los últimos cinco millones de años. Un ensayo de correlación con el Mediterráneo occidental 12. Museo Nacional de Ciencias Naturales, Consejo Superior de Investigaciones Científicas, Monografías, Madrid, pp. 47–74.

- Cione, A.L., Tonni, E.P., 1995c. Los estratotipos de los pisos Montehermosense y Chapadmalalense (Plioceno) del esquema cronológico sudamericano. *Ameghiniana* 32, 369–374.
- Cione, A.L., Tonni, E.P., 1999. Biostratigraphy and chronological scale of uppermost Cenozoic in the Pampean Area, Argentina. In: *Quaternary of South America and Antarctic Peninsula* 12, 23–51.
- Cione, A.L., Tonni, E.P., Bond, M., Carlini, A., Pardiñas, U.F.J., Scillato Yané, G., Vucetich, M.G., Verzi, D., 2000. Occurrence charts of Pleistocene mammals in the Pampean area eastern, Argentina. In: Tonni, E.P., Cione, A.L. (Eds.), *Quaternary Vertebrates of Southern South America*. *Quaternary of South America and Antarctic Peninsula*.
- Clapperton, C., 1993. *Quaternary Geology and Geomorphology of South America*. Elsevier, Amsterdam. 779 pp.
- Espisúa L., 1989. *Estratigrafía glacial pleistocena en la región del Río Las Cuevas*. Ph.D. thesis, Universidad Nacional de San Juan, unpublished.
- Fidalgo, F., De Francesco, F.O., Pascual, R., 1975. Geología superficial de la llanura bonaerense. In: *Relatorio del VI Congreso Geológico Argentino, Bahía Blanca*, 103–138.
- Fidalgo, F., 1983. Algunas características de los sedimentos superficiales en la cuenca del río Salado y en la Pampa Ondulada. *Coloquio Internacional sobre Hidrología de Grandes Llanuras*. Olavarría, Buenos Aires. 19 pp.
- Fidalgo, F., Riggi, J.C., Gentile, R., Correa, H., Porro, N., 1991. Los 'Sedimentos postpampeanos' continentales en el ámbito sur bonaerense. *Revista de la Asociación Geológica Argentina* 46, 239–256.
- Fine, P., Singer, M.J., Verosub, K.L., 1992. Use of magnetic-susceptibility measurements in assessing soil uniformity in chronosequence studies. *Soil Science Society American Journal* 56 (4), 1195–1199.
- Freguelli, J., 1925. Loess y limos pampeanos. *Anales de la Soc. Arg. de Estudios Geográficos GAEA* 1, 7–91.
- Freguelli, J., 1957. Neozoico Geografía de la República Argentina. *GAEA* 2 (3), 1–115.
- Heller, F., Evans, M.E., 1995. Loess magnetism. *Reviews of Geophysics* 33 (2), 211–240.
- Hillhouse, J.W., Cox, A., 1976. Brunhes–Matuyama polarity transition. *Earth and Planetary Science Letters* 29, 51–64.
- Karlsson, A., 1990. Aspectos del material piroclástico de los loess, Córdoba, Argentina. In: *Actas XI Congreso Geológico Argentino*, I, 434–438.
- Kennett, J.P., Watkins, N.D., 1970. Geomagnetic polarity change, volcanic maxima and faunal extinction in the South Pacific. *Nature* 207, 283–293.
- Kraglievich, J.L., 1952. El perfil geológico de Chapadmalal y Miramar, provincia de Buenos Aires. Resumen preliminar. *Revista del Museo Municipal de Ciencias Naturales y Tradición de Mar del Plata* 1 (1), 8–37.
- Liddicoat, J.C., 1985. Matuyama/Brunhes polarity transition recorded in lake sediment near Bishop, California. *EOS Abstracts* 63 (18), 304
- Liu, T., et al., 1985. In: *Loess and the Environment*. China Ocean Press, pp. 1–251.
- McGuire, W.J., Howarth, R.J., Firth, C.R., Solow, A.R., Pullen, A.D., Saunders, S.J., Stewart, I.S., Vita-Finzi, C., 1997. Correlation between rate of sea-level change and frequency of explosive volcanism in the Mediterranean. *Nature* 389, 473–476.
- Mackie, W., 1899. The feldspar present in sedimentary rocks as indicators of contemporaneous climates. *Transactions of the Edinburgh Geological Society* 7, 443–468.
- Morner, N.A., Sylwan, C., 1989. Magnetostratigraphy of the Patagonian moraine sequence at Lago Buenos Aires. *Journal of South American Earth Science* 2, 385–389.
- Nabel, P.E., Machado, G., Luna, A., 1990. Criterios diagnósticos en la estratigrafía de los 'Sedimentos Pampeanos' del NE de la Provincia de Buenos Aires. In: *Actas XI Congreso Geológico Argentino*, 2, 121–124.
- Nabel, P.E., 1993. The Brunhes–Matuyama Boundary in Pleistocene Sediments of Buenos Aires Province, Argentina. *Quaternary International* 17, 79–85.
- Nabel, P.E., Camilión, M.C., Machado, G.A., Spiegelman, A.T., Mormeneo, L., 1993. Magneto y litoestratigrafía de los sedimentos pampeanos en los alrededores de la Ciudad de Baradero, Provincia de Buenos Aires. *Revista de la Asociación Geológica Argentina* 48, 3/4, 193–206.
- Nabel, P.E., Etchichuri, M.C., Tófaló, R.O., 1997. Estratotipo del límite superior de la formación Ensenada: Geosuelo El Tala. In: *Actas del 1° Taller sobre Sedimentología y Medio Ambiente*, 11–12.
- Nabel, P.E., Morrás, H.J.M., Petersen, N., Zech, W., 1999. Correlation of magnetic and lithologic features from soils and Quaternary sediments from the undulating Pampa, Argentina. *Journal of South American Earth Science* 12, 311–323.
- Ortiz Jaureguizar, E., Prado, J.L., Alberdi, M.T., 1995. Analisis de las comunidades de mamíferos continentales del Plio-Pleistoceno de la region pampeana y su comparacion con las del area del Mediterraneo occidental. In: Alberdi, M.T., Leone, G., Tonni, E.P. (Eds.), *Evolucion biologica y climatica de la region pampeana durante los ultimos cinco millones de anos. Un ensayo de correlacion con el Mediterraneo occidental Vol. 12*. Museo Nacional de Ciencias Naturales Monografías, Madrid, pp. 383–406.
- Pascual, R., Ortega Hinojosa, E.J., Gondar, D., Tonni, E., 1965. Las Edades del Cenozoico mamalífero de la Argentina con especial atención a aquellas del territorio bonaerense. *Anales Comisión de Investigaciones Científicas de la provincia de Buenos Aires* 6, 165–193.
- Pascual, R., Fidalgo, F., 1972. The problem of the Plio-Pleistocene boundary in Argentine (South America). In: *International Colloquium on the Boundary between Neogene and Quaternary*, Coll. Papers 2. Moscú, 1–25.
- Rabassa, J., 1985. Geología de los depósitos del Pleistoceno superior y Holoceno en las cabeceras del río Sauce Grande, Prov. de Buenos Aires. In: *Abstracts de las I Jornadas Geológicas Bonaerenses*: 9 Tandil, 102–104.
- Rabassa, J., Evenson, E.B., 1989. Revisión de la estratigrafía glacial del área del Lago Nahuel Huapi. *Reúmenes del XI Congreso Geológico Argentino*, San Juan.

- Rabassa, J., 1990. Quaternary Glaciations of the Southern Andes. *Quaternary Science Review* 9, 153–174.
- Riggi, J.C., Fidalgo, F., Martinez, O., Porro, N., 1986. Geología de los 'Sedimentos Pampeanos' en el Partido de La Plata. *Revista de la Asociación Geológica Argentina* 44, 316–333.
- Russo, A., Ferello, R., Chebli, G., 1979. In: Llanura Chaco Pampeana II Simposio de Geología Regional Argentina, Anonymous. Academia Nacional de Ciencias, Córdoba, pp. 139–184.
- Sarna-Wojcicki, A.M., Morrison, S.D., Meyer, C.E., Hillouse, J.W., 1987. Correlation of upper Cenozoic tephra layers between sediments of the western United States and eastern Pacific Ocean and comparison with biostratigraphic and magnetostratigraphic age data. *Geological Society of America Bulletin* 98, 207–223.
- Shane, P., Froggatt, P., Black, T., Westgate, J., 1995. Chronology of Pliocene and Quaternary bioevents and climatic events from fission track ages on tephra beds, Wairarapa, New Zealand. *Earth and Planetary Science Letters* 130, 141–154.
- Singer, B., Pringle, M.S., 1996. Age and duration of the Matuyama–Brunhes geomagnetic polarity reversal from $^{40}\text{Ar}/^{39}\text{Ar}$ incremental heating analyses of lavas. *Earth and Planetary Science Letters* 139, 47–61.
- Sylwan, C.A., 1989. Paleomagnetism. Paleoclimate and Chronology of Late Cenozoic Deposits in Southern Argentina, No. 277. Department of Geology, Stockholm University, Stockholm. 110 pp.
- Teruggi, M.E., 1957. The nature and origin of Argentine loess. *Journal of Sedimentary Petrology* 27 (3), 322–332.
- Teruggi, M.E., Andreis, R.R., 1971. Composición, estabilidad mineral y acción climática en sedimentos argentinos. *Revista del Museo de La Plata*.
- Tonni, E.P., Fidalgo, F., 1978. Consideraciones sobre los cambios climáticos durante el Pleistoceno tardío–Reciente en la provincia de Buenos Aires. Aspectos ecológicos y zoogeográficos relacionados. *Ameghiniana* 15, 1/2, 235–253.
- Tonni, E.P., Cione, A.L., 1995. Los mamíferos como indicadores de cambios climáticos en el Cuaternario de la región pampeana de la Argentina. In: Argollo, J., Mouguiart, Ph. (Eds.), *Los climas cuaternarios en América del Sur*. ORSTOM, La Paz, Bolivia, pp. 319–326.
- Tonni, E.P., Alberdi, M.T., Prado, J.L., Bargo, M.S., Cione, A.L., 1992. Changes of mammal assemblages in the pampean region (Argentina) and their relation with the Plio-Pleistocene boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology* 95, 179–194.
- Tonni, E.P., Verzi, D.H., Bargo, M.S., Pardiñas, U.F.J., 1993. Micromammals in owl pellets from the lower–middle Pleistocene in Buenos Aires Province, Argentina. *Buenos Aires Ameghiniana* 30 (3), 342.
- Tonni, E.P., Cione, A.L., 1994. Los mamíferos y el clima en el Pleistoceno y Holoceno de la provincia de Buenos Aires. In: *Actas de la Jornadas de Arqueología e Interdisciplinas*, Buenos Aires: Programa de Estudios Prehistóricos, 127–142.
- Tonni, E.P., Nabel, P.E., Cione, A.L., Etchichury, M.C., Tófaló, R., Scillato, J.G., San Cristóbal, J., Carlini, A., Vargas, D., 1999. The Ensenada and Buenos Aires Formations (Pleistocene) in a Quarry near La Plata Argentina. *South American Earth Science* 12, 273–291.
- Verzi, D., Lezcano, M.J., 1996. Status sistemático y antigüedad de *Megactenomys kraglivichi* Rusconi, 1930 (Rodentia, Octodontidae). *Revista del Museo de La Plata* 60, 239–246.
- Webb, S.D., 1976. Mammalian faunal dynamics of the Great American Interchange. *Paleobiology* 2, 220–234.
- Westgate, J.A., Stemper, B.A., Pewe, T.L., 1990. A 3 m.y. record of Pliocene–Pleistocene loess in interior Alaska. *Geology* 18, 858–861.
- Worm, H.-U., 1997. A link between geomagnetic reversals and events and glaciations. *Earth and Planetary Science Letters* 147, 55–67.
- Yrigoyen, M., 1975. Geología del Subsuelo y Plataforma continental. In: *Relatorio del VI Congreso Geológico Argentino*, Bahía Blanca, 139–168.
- Zanchetta, G., Alberdi, M.T., Bonadonna, F.P., Leone, G., 1995. Escenario de la evolución climática entre la región pampeana y el área mediterránea occidental durante el Cuaternario. In: Alberdi, M.T., Leone, G., Tonni, E.P. (Eds.), *Evolución biológica y climática de la región pampeana durante los últimos cinco millones de años un ensayo de correlación con el Mediterráneo occidental*. Museo Nacional de Ciencias Naturales Consejo Superior de Investigaciones Científicas Monografías, Madrid, pp. 407–423.
- Zarate, M., Blassi, A., 1993. Late Pleistocene–Holocene Eolian Deposits of the Southern Buenos Aires Province, Argentina: A preliminary model. *Quaternary International* 17, 15–20.