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Climatic fluctuations in the Central Region of Argentina in the last 1000 years

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Abstract

Several lines of evidence concur to explain the climatic fluctuations that occurred in the central region of Argentina during the last millennium. The investigation was advanced in two ways: on the one hand, a geographic model was elaborated; and on the other, a temporal sequence for various climatic situations was developed. During the last 1000 yr, two significant events related to global changes occurred: the Medieval Warm Period (MWP) and the Little Ice Age (LIA). The Medieval Warm Period was characterized by a humid and warm climate in the plains and recession of the Andean glaciers. In contrast, during the Little Ice Age the plains had temperate, semi-arid to arid climates, and Andean glaciers advanced. In the western region, the fluvial-lacustrine systems were more extensive during cold events (LIA) and contracted during warm events (MWP). In contrast, in the eastern region the fluvial-lacustrine systems showed a diminution during cold events and increased their extent during warm episodes. During the LIA, the occurrence of two cold pulses separated by an intermediate period has been established. The first cold pulse extended from the beginning of the XV century to the end of the XVI century; the second cold pulse (the main one) began at the beginning of the XVIII century and lasted until the beginning of the XIX century. Both cold pulses can be related to the Spörer and Maunder Minimums respectively. These climatic changes modified the landforms, influenced the vegetation distribution and were one of the main factors for control of human activities during the last 1000 yr.

1. Introduction

"Since the end of the Last Ice Age, the Earth's climate has been more or less constant, with average surface temperatures varying within a degree or two of their present levels. However, superimposed on this relative constancy has been a succession of shorter term fluctuations that have had geological, biological and even socio-economic impacts" (Murck et al., 1995).

In the first part of the present millennium, between 1100 and 1400 AD, sometimes called the Medieval Warm Period, the global temperatures rose around 0.3°C in comparison to the norm of reference, the year 1900 (Riccardi, 1995).

In the central region of Argentina the Medieval Warm Period (MWP) showed an increase of precipitation, rivers enlarged their flow, lakes expanded and, on the Late Pleistocene and Middle Holocene sediments, pedogenic processes occurred on aeolian landforms (Carignano, 1997).

Later on, a cold global event called Little Ice Age (LIA) was registered in Argentina. It was the most significant alteration that occurred in the evolution of the climate in the course of the last two millennia (De Blij and Muller, 1993). This pulse began at the end of the Middle Ages and even lasted to the main part of the XIX century. The climate suffered a severe deterioration. Temperatures descended around 0.6°C below the norm of reference (year 1900) (Riccardi, 1995). During the LIA, corresponding with the advance of the glaciers in the Andes (Politis, 1984; Rabassa et al., 1984; Iriondo and Kröhling, 1995), dry conditions dominated on the lowlands of the central region of Argentina, repeating on a minor scale the patterns of the Last Glacial Maximum (Iriondo, 1994).

Numerous investigators of Earth sciences have studied the climatic fluctuations which occurred during the last 1000 yr, in many diverse environments and by means of several different approaches (e.g. Mercer, 1970; Heusser, 1961; Politis, 1984; Rabassa et al., 1985; Latrubesse and Ramonell, 1990; Iriondo and Kröhling, 1995; Carignano, 1997). Also, some historians have made important contributions on this theme, reconstructing the climatic conditions during the colonial times through the study of

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historical and cartographic sources (e.g. Herrera and Dussell, 1992; Prieto and Herrera, 1991; Prieto and Jorba, 1990).

The objective of the present work is to examine the various lines of evidence that concur to explain the climatic fluctuations occurred in the central region of Argentina during the last millennium.

2. Methodology

The investigation of the climatic changes which have occurred in the central region of Argentina is based on fieldwork evidence, satellite images and aerial photograph interpretation, historical sources, and meteorological records. Also, previous researches carried out by geologists, archaeologists, and historians were analyzed, in order to provide the bases for the elaboration of the proposed model.

The study advanced along two lines, on the one hand a geographical model was elaborated and for another, a temporary sequence of the climatic conditions was developed.

In the first case the Medieval Warm Period and the Little Ice Age, both two key moments happened during the last millennium was staged. For this, starting from the current climatic conditions, supplemented by information given by the previous research, regional stratigraphic correlation and geomorphological observations, a cartographic comparative study of each element of the landscape was made.

In the second case, a temporary model was based fundamentally on historical, archaeological and glaciological data, that allowed to carry out an sequential analysis of the whole available information, confronting it with the present climate.

3. Location and physical setting

The studied area is located in the central region of Argentina, between 28–36°S and 61–67°W. It comprises two large geomorphologic regions: the Pampean Ranges and Pampean Plain (Fig. 1).

3.1. Pampean ranges

The west sector of the studied area is a mountainous zone that embraces the oriental cordillera of the Sierras Pampeanas System. It is an old crystalline massif that has suffered successive erosive events, forming a landscape characterized by remains of erosional surfaces, fractured and tilted during the Andean movements (Carignano, 1997). This unit can be divided in three main groups: Mountains; inter-mountain depressions (bolsones); and piedmont areas.

3.1.1. Mountains

The group of mountains is formed by the Sierras of Córdoba (500–2790 m a.s.l.), San Luis (500–2150 m a.s.l.), Ancasti-Ambato (500-1624 m a.s.l.) and Chepes-Ulapes (500–1700 m a.s.l). All these ranges present a western abrupt flank, corresponding to large fault scarps, and an oriental extended slope where the old erosion surfaces are preserved, sometimes covered by Tertiary and Quaternary sediments.

The mountain system is within the temperate climate zone. Precipitation increases according to elevation from 500 to 900 mm yr^{-1}. The annual temperature ranges are lower than in the plain and fluctuate between 10 and 16°C. Above 2000 m a.s.l, the lower winters temperatures cause isolated snowfalls.

3.1.2. Inter-mountain depressions (Bolsones)

The inter-mountain depressions are structural forms, relatively flat and filled with sediments, that form closed systems (endhorreic) or bolsones. In some cases, these depressions are connected with fluvial systems that receive their overflows (Iriondo and Ramonell, 1993).

At present, the bolsones are partially occupied by salinas, located around 200 m a.s.l. The main Salinas are: Salinas Grandes (4700 km^2); Ambargasta (4200 km^2); San Bernardo (7.2 km^2); and La Antigua (410 km^2). The group constitutes one of the largest hypersaline systems of the world (Dargám, 1995). These depressions are characterized by arid climates, with rainfall < 400 mm yr^{-1} concentrated in the summer season, wide thermal amplitudes, and high deficit of water (Capitanelli, 1976).

To the southwest is located the (exorreic) depression of Salina del Bebedero (380 m a.s.l.), belonging to the Desaguadero-Salado basin (248,000 km^2). During the present century, this fluvial system has progressively lost its connection with the Atlantic Ocean. At the present time its base level is the Urre Luquen depression, located in Western La Pampa province (Véscovo, 1981).

3.1.3. Eastern piedmont of the Sierras de Córdoba and southern piedmont of the Sierras de San Luis

The piedmont landscape extends from the last oriental extreme of the Sierras de Córdoba and South of San Luis up to around 400 m a.s.l. Here, a change of slope accompanies the morphologic variation.

The eastern piedmont of the Sierras de Córdoba is a 15–20 km wide belt. It is integrated by a series of coalescent alluvial fans. Sediments have fluvial origins with progressively finer grain sizes toward the east, where they gradually mix with the aeolian sediments of the Loessic Plain (Carignano, 1997).

The southern piedmont of the Sierras de San Luis show a relief marked by low hills with planar tops, products of the development of two successive levels of pedimentation (Iriondo and Ramonell, 1993). The upper

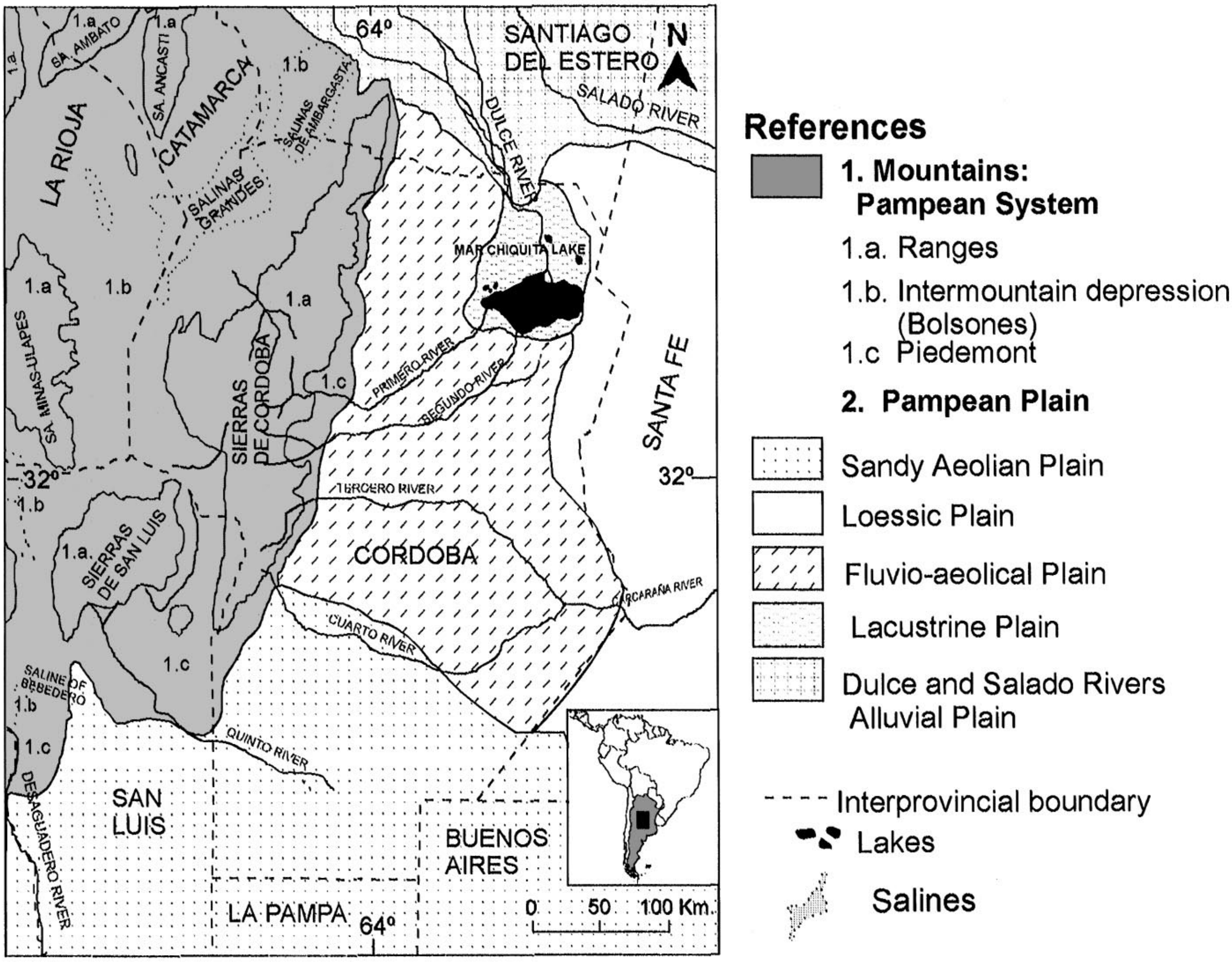


Fig. 1. Location map showing geomorphological regions of Central Argentina.

surfaces are dominated by loess and loess-like sediments, which mix with the sand of the Sandy Aeolian Plain toward the south.

Climatic conditions in the piedmont are directly linked to altitude. This region receives more precipitation than the average of the nearby plain and annual temperatures are between 1 and 3°C lower than the latitudinal equivalent on the plain.

3.2. Pampean plain

The Pampean Plain is a wide surface of 600,000 km^2, with altitudes between 80 and 400 m a.s.l. It is an extensive, very uniform area consisting of medium and fine sediments deposed by aeolian, fluvial, and lacustrine processes.

This sedimentary cover forms the "Pampean Aeolian System", which joins the "Pampean Sand Sea" (Sandy Aeolian Plain) and the "Peripherial Loess Belt" (Loessic Plain), to the south and north respectively (Iriondo and Kröhling, 1995).

The plain has a temperate climate. Annual temperatures increase toward the north, fluctuating between 16 and 18°C. *The mean annual rainfall decreases toward the west, from* 900 *to* 500 *mm*.

The study region embraces the Central and Western sectors of the Pampean Aeolian System. According to origin form, and dominant processes, five sub-units are distinguished (Classification of Plains, Iriondo 1987):

3.2.1. Sandy Aeolian Plain

This is located to the south of the region and belongs to the Pampean Sand Sea. It is located south of the 34°S parallel, which is considered to approximate the external limit of the mobilization of sands during dry events (Iriondo and Kröhling, 1995). It is a sector of the plain where aeolian processes prevailed. They generated deflation forms, dunefields and sand mantles (Carignano, 1997). These geoforms are associated with very wide valleys, which are partially filled palaeochannels of the Quinto River, formed during previous humid events (Iriondo, 1987).

3.2.2. Loessic Plain

This covers the eastern sector of the region and is within the Peripherial Loess Belt. It is a very homogeneous plain, with very low slopes covered by loess of variable thickness (7–10 m) (Iriondo and Kröhling, 1995). The limited relief favours the formation of lakes and swamps, which disappear in times of drought.

3.2.3. Fluvio–Aeolian Plain

This is located in the center of the region and corresponds to the western part of the Peripherial Loess Belt (Iriondo and Kröhling, 1995). It is an extensive continuation of the piedmont of the Mountains of Córdoba, 180 km long and 300 km wide (Iriondo, 1987). The general inclination is toward the east. The plain has been built by the combined work of rivers and wind. The coalescence of alluvial fans of small rivers with headwaters in the mountains of the west (Iriondo, 1986) is a typical pattern. The unit is dominated by fluvial morphology (e.g. palaeochannels, terraces, flood plains, abandoned channels), with interbasins occupied by loess.

3.2.4. Lacustrine Plain — Mar Chiquita Lake

This is a sunken block located in the northwestern area of the region. Its origin is related to climatic and structural conditions. The eastern limit is defined by a regional fracture (the Tostado-Selva Fault), which separates this unit from the Loessic Plain. In the north, it is linked with the alluvial fans of the Dulce and Salado Rivers. To the south, its limit is marked by the Fluvio–Aeolian Plain. The Lacustrine Plain is a large surface located at 100 m a.s.l., with a very low slope on the order of 1 : 1000 (Capitanelli, 1976). It is composed of fine and very fine laminated silts. Local depressions, swamps, and salinas are the dominant forms of the landscape.

The lowest part is occupied by Mar Chiquita Lake (70 m a.s.l.). This extensive body of water is the biggest lake in the country. It is characterized by large fluctuations of level and surface area, which was recently enlarged from 2000 km^2 to 5000 km^2.

3.2.5. Alluvial Plain of the Dulce and Salado Rivers

This plain forms the northeastern end of the region and comprises a small sector of the Southern Chaco. The unit is formed by the coalescence of large alluvial fans of both rivers (Iriondo, 1987, 1992). The Dulce River has its headwaters in the Nevado del Aconquija Range, and the basin has a surface of 34,620 km^2. The Salado River has its heads in the snowy eastern region of the Puna, and its basin covers a surface area of 247,000 km^2. The sediments in the plain are fine to medium-grained materials transported by the mentioned rivers. The general pattern is a distributary system, with abandoned beds, lobes of flooding and splaying, swamps, and alluvial plains (Iriondo, 1987). This constitutes a plain with very low relief, which favors the mobility of the sediment and channel migration. In historical times, both river courses have suffered changes and bifurcations.

4. Reconstruction of the main scenarios occurring in the last 1000 yr

During the last 1000 yr, two main climatic events have been detected: the Medieval Warm Period (Fig. 2), corresponding to a climate similar or perhaps more humid than the present one; and the Little Ice Age (Fig. 3), characterized by climatic conditions drier than the present.

4.1. The Medieval Warm Period

Several climatic indicators suggest warm and humid conditions for the period 1400–800 yr BP (Iriondo, 1999). This interval corresponded to a climatic improvement in the central region of the country, registered by an incipient soil development, expansion of the fluvial and lacustrine systems, and formation of swamps in depressions. The inherited aeolian forms (formed during the dry period of the Upper Holocene) were dissipated and partially stabilized (Carignano, 1997).

In the Sandy Aeolian Plain partial erosion of the landforms in all dunefields occurred. Large deflation depressions were transformed into permanent lakes (due to rising of the water tables). The shores of these water bodies were colonized by human groups (Iriondo, 1994).

In the Loessic Plain, the rise of the water table allowed the development of swamps and small lakes in the depressed sectors, and permitted pedogenic activity in the highest parts. In fact, all deflation depressions became permanent lakes (Kröhling, 1993).

In the Fluvio–Aeolian Plain, favorable conditions appeared for soil development. This established the current configuration of the zonal soils (typical of the sector) with B horizons enriched in organic matter and clays (Carignano, 1997).

The Lacustrine Plain underwent an increment of the fluvial systems (Primero River, Segundo River and Dulce River), expanding the lake area and depth up to approximately the current level and perceptibly diminishing the concentration of salts. In the margins (on high terraces) the establishment of cultures occurred (Carignano, 1997).

The northwestern region was colonized by the phytogeographic province of the Oriental Chaco (Boninsegna et al., 1987), which is now located one hundred

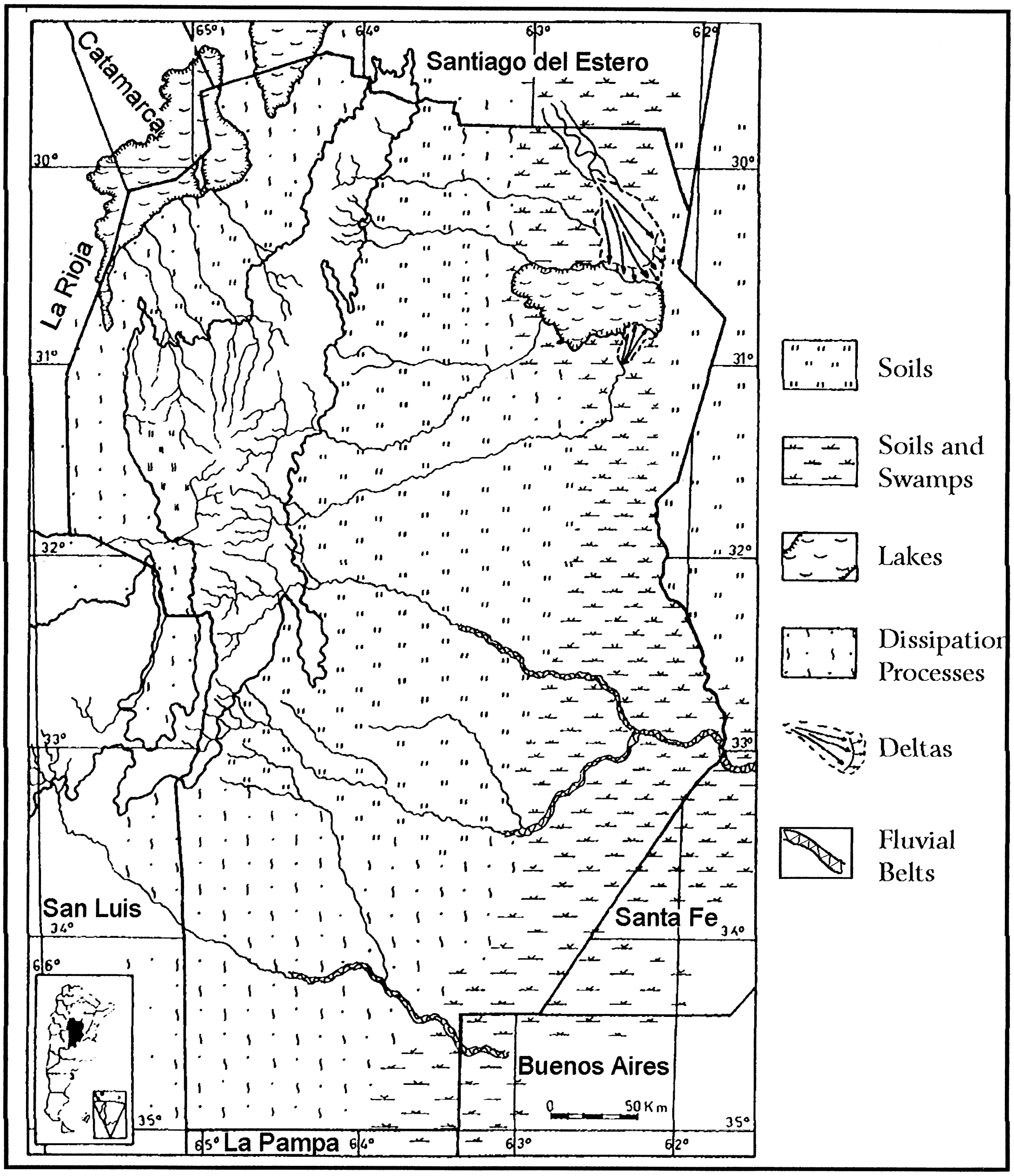


Fig. 2. Geomorphological scheme showing the scenario from ca. 1000 yr BP to before the Little Ice Age (modified from: Carignano, 1997).

kilometers to the northeast, under subtropical conditions. The large salinas located to the west (Salina Grande, Ambargasta, La Antigua) were partially occupied by ponds, favoring human establishment at the margins. The cultivation line was displaced several kilometers toward the salt, in zones totally devoid of water at present. Archaeological evidence indicates that to the southeast of the Salinas Grandes, the expansion of human occupation would have occurred at approximately 1000 yr BP (Laguens and Bonnin, 1987).

The main rivers of the region increased their flows. They cut the inherited fans generated during the dry period of the Late Holocene. In many cases, small rivers changed their direction of flow.

This heating is explained, from the climatological point of view, as an enhancement of the South Atlantic Anticyclone. Iriondo (1994) postulated a significant increment of the temperature (approximately 2.5°C), with the displacement of the bands of tropical climate toward the south.

4.2. The Little Ice Age

The reconstruction of this scenario shows the environmental conditions during the maximum cold pulse of the LIA (late XVIII century) and the geomorphologic processes that occurred at that time as an answer to a global climatic event (Fig. 3). In general terms, the central region

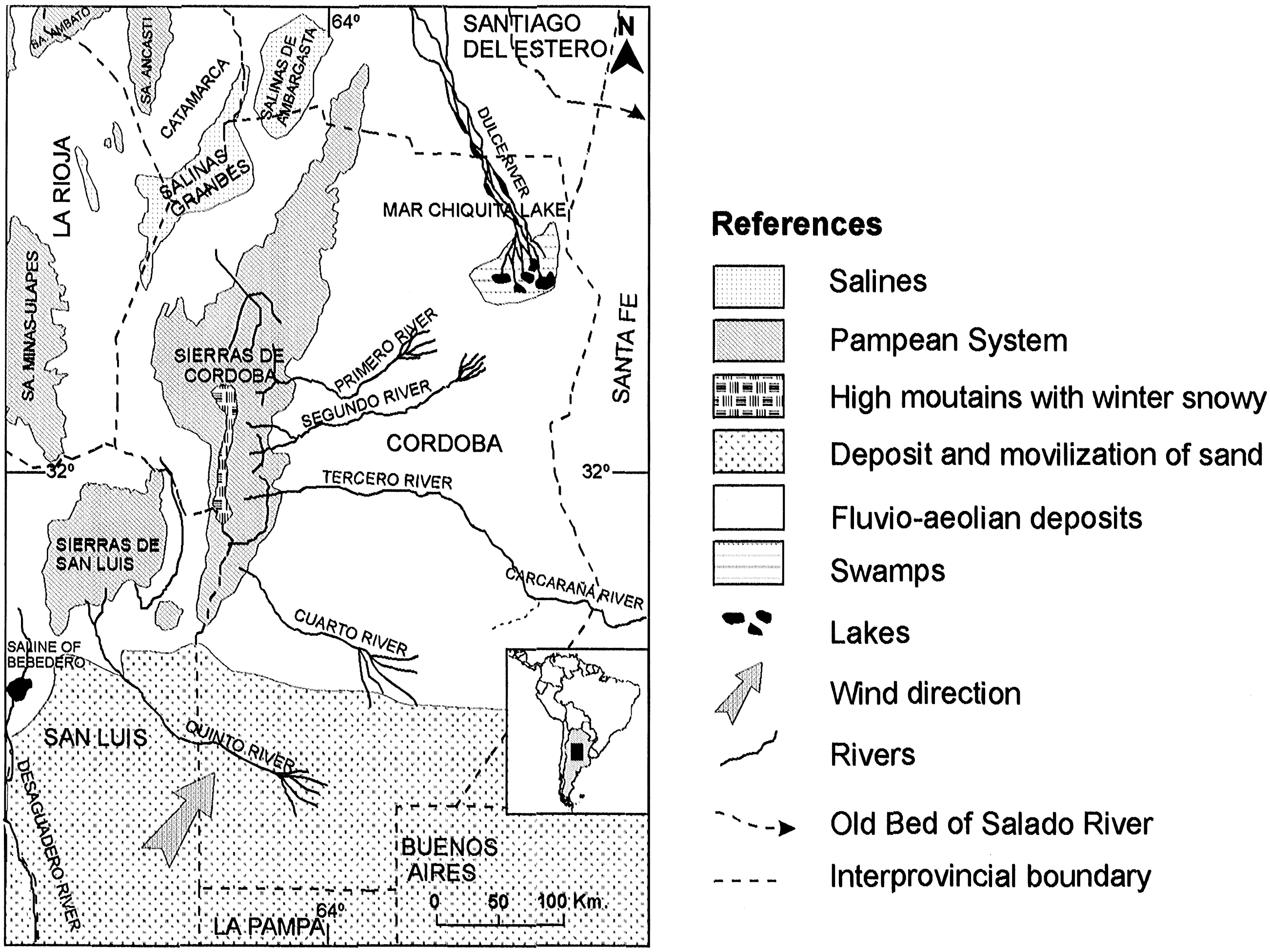


Fig. 3. Geomorphological scheme showing the scenario of the Second Cold Pulse of the Little Ice Age (18–19th centuries).

of Argentina underwent a sensitive climatic deterioration during this time. The climate was more arid and cold than that today (Politis, 1984; Rabassa et al., 1984; Iriondo and Kröhling, 1995; Iriondo and García, 1993). Climatic oscillations were intensified, with a succession of extreme drought and flood events (Prieto and Jorba, 1990).

Intense aeolian processes occurred in the Sandy Aeolian Plain, as recorded by a thin mantle of sand and landforms developed under conditions of an arid to semiarid climate, provoked by strong SW winds (Iriondo and Kröhling, 1995). These geomorphologic dynamics repeated, with lesser intensity, the patterns of a preceding arid period that had occurred during the Late Holocene in the region (Iriondo, 1994; Carignano, 1997). Numerous authors have described sediments of LIA age in the Sandy Aeolian Plain. In almost all localities, these sandy materials were deposited discordantly above a soil formed in the Hypsithermal Period; or cover soils or lacustrine sediments formed during the Medieval Warm Period (1400–800 AD) (see Table 1).

Beyond the study area, toward the south and southeast (the continuation of the Sandy Aeolian Plain), similar conditions have been observed by several authors (Politis, 1984; Rabassa et al., 1984; Gentile, 1990; Tonni and Fidalgo, 1978; Fidalgo, 1991). The Quinto River, the main river crossing the Sandy Aeolian Plain, flows into a depression occupied by a swamp or lake, according to the intensity of the summer rain (Furlong, 1946).

On the Loessic Plain, the dry environment provoked a recession of the fluvial systems. Channels reduced their flow, which disappeared by infiltration in the plain many kilometers further upstream than at present. The Primero and Segundo Rivers infiltrated before arriving at Mar Chiquita Lake, developing alluvial fans upstream (Furlong Cardiff, 1937).

The Carcarañá-Tercero system maintained its direction, but it underwent an increase in salt content (Iriondo and Kröhling, 1995). The Jesuitic Cartography (Furlong Cardiff, 1937) and the colonial chronicles describe (Lozano, 1873) the Tercero as the main river of the region. In all the cartographic registrations (Furlong Cardiff, 1937;

Table 1
Sedimentary evidences of the Little Ice Age in central region of Argentina

Place	Formation	Litotology	Age	Lower layer	Author
San Luis	Fm. Algarrobito	2.30 m Gravels and sands	> 1536 AD	Lacustrine Sediment 1000 yr BP (MWP)	Latrubesse and Ramonell (1990)
		1.30 m Silts and sands		Los Toldos Soil (Hypsithermal)	
La Pampa	Fm. III	0.60 m Fine and very fine sand	LIA	Toay Soil (Hypsithermal)	Ramonell et al. (1993)
Córdoba NW	Fm. Zanjas Hondas	0.10–1.75 m Sands and silts with fine gravels	> 1536 AD	Paleosoil (MWP) (1000 yr AP–XIV)	Carignano (1997)
Southern Santa Fe and NW Buenos Aires	Fm. Las Lilas	0.10–0.30 m Sands	LIA	Paleosoil 1155 $\pm$ 145 (MWP) yr BP	Panigatti (1981)

Torres Revello, 1938; Leviller, 1927) appear similar representations. Having the largest basin of the region, and originating at high altitudes in the Sierras de Córdoba (> 2000 m a.s.l.), it constitutes the least affected system.

The Carcarañá River began with the confluence of the Tercero and Saladillo streams, at this time not linked to the Cuarto River. This river flowed toward the SE and infiltrated within a local depression, sporadically occupied by a lake (Torres Revello, 1938; Furlong Cardiff, 1937).

The Loessic Plain was under a semiarid climate, characterized by long droughts, which hindered travel between Santa Fe and Córdoba. During winter times, it was necessary to wait for rains in order to have water for the horses (Parras, 1943).

The Dulce and Salado Rivers suffered important modifications. Through analysis of the Jesuitic Cartography (Furlong Cardiff, 1937), it has been established that during the period 1609–1756 the Salado River flow was similar to that at present, that is, flowing to the Parana. Later, maps made in 1760, 1770, and 1772 show the Salado outflowing into the Mar Chiquita depression. These maps evidently show the old direction of the Salado River (Fig. 5). It is probable that such an important change in the basin occurred about 1750/1752, when extraordinary rains caused large floods in both rivers (Herrera and Dussell, 1992).

A map of 1774 shows the Salado River draining simultaneously to the Dulce and to the Paraná rivers. In 1789, it was again arriving in Mar Chiquita Lake (Furlong Cardiff, 1937).

There is no cartographic evidence documenting at what precise time the Salado River finally shifted to the Paraná. By the middle of the XIX century, it was already in its present position (Herrera and Dussell, 1992). The rapid dynamic of this river is also registered in the alluvial plain, in the form of numerous palaeochannels and overflows. The landscape is completed by deflation depressions (Iriondo, 1987).

The Lacustrine Plain (today the Mar Chiquita Lake) was a large playa with interconnected minor salt lakes, partially covered by dunes in the second half of the XVIII century (Parras, 1943; Furlong Cardiff, 1937). Kröhling (1993) recognized a reduction of the lake and the accumulation of important amount of salts in the sediments at that time.

Numerous rivers and streams flowing from the mountains arrived at the piedmont of the Sierra de Cordoba, an area with a more benign environment than that in the nearby oriental plain. Most streams did not reach the plain, except during extraordinary summer rains. In their final reaches, rivers frequently changed their courses, forming alluvial fans. Such geoforms, at the present time, have been cut and constitute the top of terraces. It is common to find remains of European fauna in such sandy layers, together with remains of human activity (pottery, pieces of metal, etc.).

Undoubtedly, in the colonial times, the piedmont sector was the more appropriate for the development of the new populations due to the amount and quality of water. In this region were located cities and Jesuit stays, such as Córdoba, Alta Gracia, and Jesus María. In his description of the rivers of Córdoba in 1773, Concolorcorvo referred to the Primero River, indicating "waters that are clear and they don't cause annoyance to the palate". (Leviller, 1927).

In the Sierras de Córdoba, torrential summer rains and intense winter snowfalls were common, particularly above 1500 m a.s.l. Cartography of 1789 identifies the mountains of Córdoba as "Montañas nevadas de Córdova" (Snowy Mountain of Córdoba) (Torres Revello, 1938). Snow is very rare today.

The lakes of the inter-mountain depressions disappeared completely and their bottoms were occupied by salt playas (e.g. Salinas Grandes, Ambargasta) (Carignano, 1997). Human groups living in the region suffered the consequences of an important climatic deterioration, modifying their behaviors and economy (Laguens and Bonnin, 1987). However, the Salina del

Bebedero depression was occupied by a lake and received waters from the Desaguadero River. González (1987) dated a lacustrine level there to approximately 350 yr BP.

Gez (1938) established that the transformation of this lake into a salina occurred at the end of the last century, provoked by the interruption of the water flow from the Desaguadero River. It is noteworthy to remark that during the LIA, Bebedero Lake (located in the west of the region) reached a high level, while the Mar Chiquita Lake became a swamp skirted by salinas and dunes in the east. This east–west connection confirms in this region the model proposed by Iriondo (1999), which establishes inverse correlations among different South American plains.

The physiognomy of the vegetation suffered variations owing to the climatic deterioration. Two important changes have been verified: (a) the substitution of the Association of the Eastern Chaco (corresponding to more humid climates) by the Association of the Western Chaco which responds to a more dry climate (Bonnin et al., 1987); and (b) the development of palm trees, a plant linked to the use of fire (Díaz et al., 1987). Palms are favored by conditions of drier climate with freezing and strong winds, factors increasing the probability of occurrence of fire (Lutti et al., 1976).

5. Climatic fluctuations during the last 1000 yr

Within the Medieval Warm Period, a climatic improvement was reported between 1400–800 yr BP (Iriondo, 1999). This interval was characterized by a temperate, humid to semi-humid climate, with a pluviothermal regime either similar to the present or probably more humid (Carignano, 1997).

Archaeological evidence in several places of the region suggests a general climatic improvement, with a marked increase of environmental suitability, under a relatively homogeneous climate. Dates from several localities of the region certify the improvement produced in the first centuries of the present millennium. Two ^{14}C dates on lacustrine sediments west of the region studied in this paper (near San Luis city) gave determinations of 1440 ± 60 and 1030 ± 90 yr BP. An abandoned branch of the Quinto River (^{14}C on wood) was dated at 1220 ± 90 yr BP (Iriondo and Kröhling, 1995).

In the center of Santa Fe province, in the east of the region, Panigatti (1981) dated pedogenetic carbonate in a C-horizon (corresponding to a humid climate) with an age of 1155 ± 145 yr BP. Outside the study area, such a warming was identified in several areas. In the basin of the Uruguay River, 300 km to the east of the region, paleontological and archaeological indicators confirm a tropical climate between the XIII and the XIV centuries (Iriondo, 1994).

Archaeological studies made in the Central Andes (Peru), indicate a strong thermal increment over 300 yr. The population located in the lower valleys ascended to higher areas in the Andes, as a result of an improvement of the climatic conditions about 1000 AD. During that time the hillsides were cultivated in many places up to 4300 m a.s.l. Around 1320 AD, the cold climate of the LIA began (Cardich, 1980). In the southern Andes, glaciers retreated and an intermediate period occurred between two main cold pulses: 2000–3000 and 300–400 yr BP (Wayne, 1981; Mercer, 1970; Malagnino and Strelin, 1996).

The LIA in the central region of Argentina was not a homogeneous event. It was formed by two cold pulses (Fig. 4), separated by an intermediate period of more benign conditions, similar to the present or perhaps more humid (Fig. 5).

The *First cold pulse of LIA* extended from the first decades of the XV century until the end of the XVI century. Archaeological data obtained in the northwest

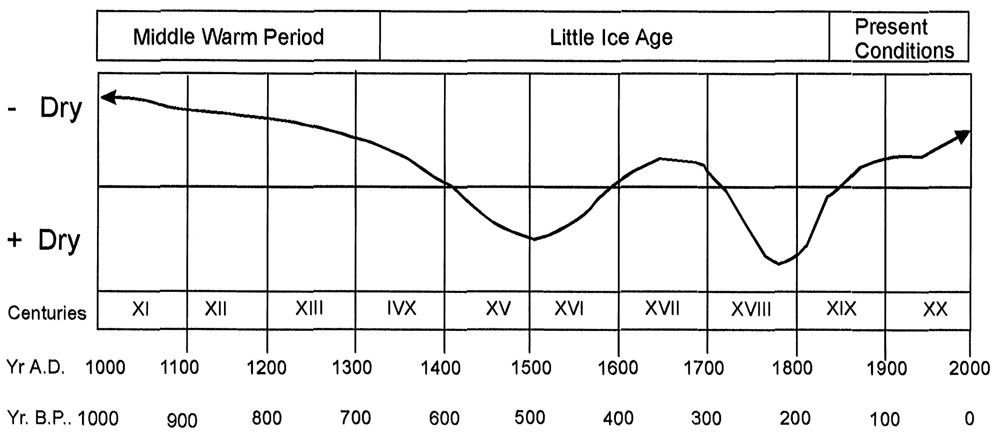


Fig. 4. Climatic fluctuations in Central Region of Argentina during the last 1000 yr.

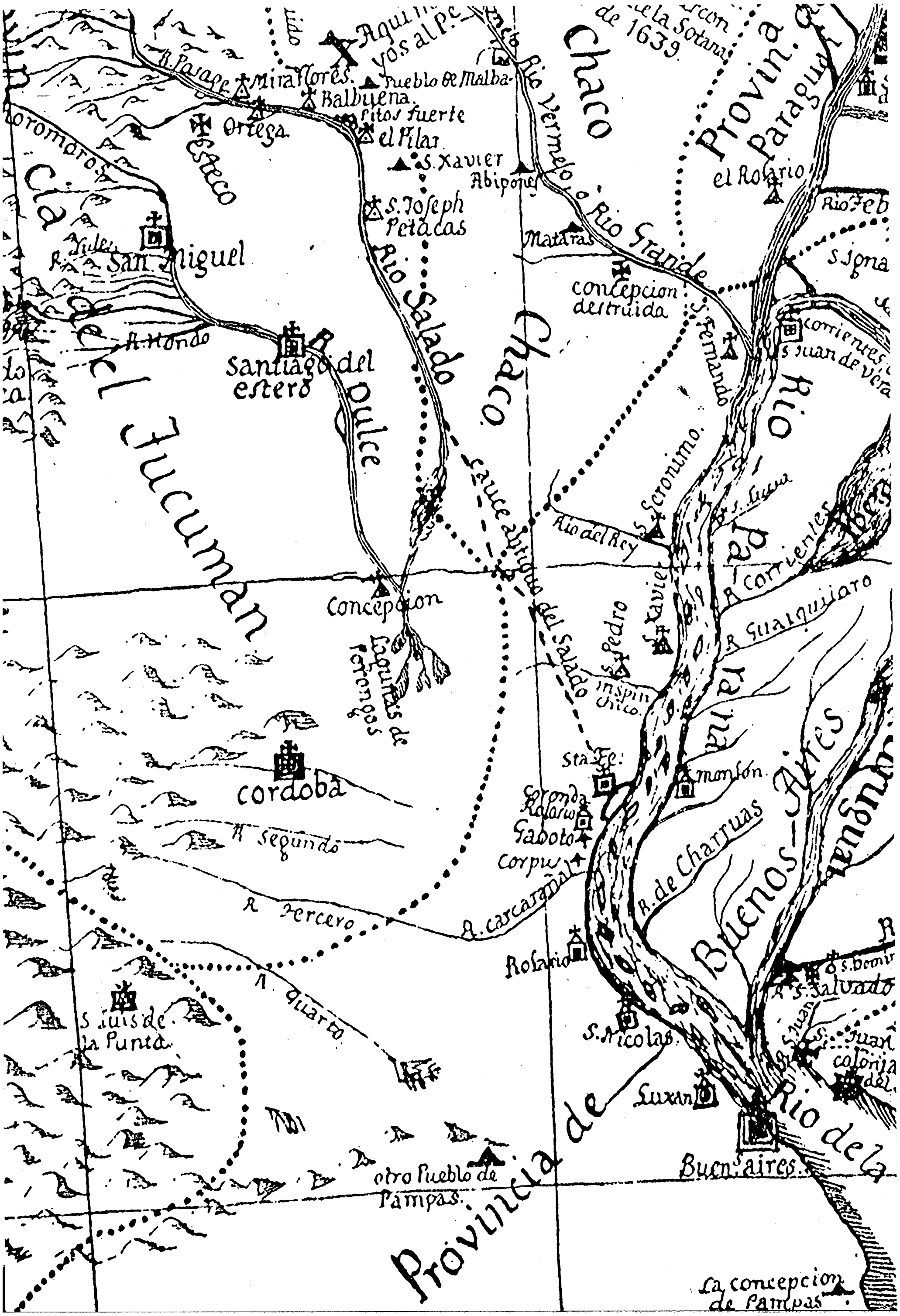


Fig. 5. Reproduction of 1760 yr Jesuitical map (from Furlong Cardiff, 1937).

of the region, have established that the XV century was marked by a clear decline of the indigenous system. A generalized crisis existed before the contact with the Spanish conquerors (Laguens and Bonnin, 1987). Demographic analysis of the period 1500–1700 AD shows a situation characterized by a population stress provoked by a decrease in environmental suitability (Laguens, 1993).

At the same time, a change in the storage of food was detected in the region. These indigenous peoples used to build underground structures of baked earth, locally termed "hornitos", that were used as true silos. Two generations of hornitos have been identified. Older "hornitos" are smaller than the younger "hornitos". The change occurred at the middle of the XVI Century (1550 AD by ^{14}C dating). The increment of volume of such storage structures is interpreted as a way of minimizing risks and trying to increase the capacity of supply during winters (Laguens, 1993).

Historical data registered droughts in Santa Fe province during 1592–1593 AD (Prieto and Jorba, 1990). The vegetation began to suffer the consequences of this climatic deterioration. The flora of the Oriental Chaco was replaced by the Western Chaco Association, in equilibrium with more arid climates (Bonnin et al., 1987).

This event is correlated with the observations made by Cardich (1980) in the Central Andes (Perú). It also coincides with the well-known global cooling named Minimum Spörer (minimum of solar activity), which lasted from 1420 to 1570 AD (Riccardi, 1995).

The *Intermediate period* began at the end of the XVI Century and was prolonged until the beginning of the XVIII Century. During this period a more benign climate (similar to the present one) occurred, with some drier years. Under these conditions, the installation of the Spanish colony took place. The cartography corresponding to this period (Furlong Cardiff, 1937) shows all the fluvial systems with flows sufficient to arrive at their respective base levels, as well as an expansion of lakes.

By means of the analysis of historical data, it was verified that the climate in the central Argentina during the XVII century was more humid than in the XVIII century. This event was characterized by an episode of major climatic stability, with very scarce extraordinary floods and few droughts (Prieto and Herrera, 1991). Numerous references to abundant precipitation have been detected, with a peak between AD 1650 and 1660. Another precipitation peak occurred between AD 1720 and 1740 (Prieto and Jorba, 1990).

A catastrophic flood of the Dulce River caused important losses in the city of Santiago del Estero. In consequence, the Church transferred the Bishopric from that city to Córdoba in 1690 (Herrera and Dussell, 1992). The Dulce River area had its maximal economic and political expansion during the XVI and the XVII centuries (Assadurian, 1983).

In 1660 AD the Salado River flooded and later maintained a high level. Consequently, the colonial administration resolved to transfer the city of Santa Fe from its original location to the present place (Prieto and Jorba, 1990). Outside the study area, in the province of Buenos Aires, an improvement of the climatic conditions in this period was also determined. Through investigation of the archives of the Extinguished Council of Buenos Aires, it was verified that during the XVI and XVII centuries the climate was similar to the present. Records from 1589 to 1697 AD show that 85% of the years were "normal" (Politis, 1984).

This improvement coincided with a recession of the glaciers in the Southern Andes. Heusser (1961) determined that a recessive state existed during the last decade of the XVI century. This event was also noted in the Peruvian Andes. Cardich (1980) makes reference to a climatic improvement between the two temperature minima. On a global level, the indices of solar activity indicate a thermal maximum embracing the XVI and XVII centuries (Riccardi, 1995).

The *Second Cold Pulse* started at the beginning of the XVIII Century and extended until the beginning of the XIX Century. It is the coldest part of the LIA. Glaciers in the Southern Andes underwent their main advance and the plains of the central region of the country suffered intense droughts (Politis, 1984; Rabassa et al., 1985; Iriondo, 1994; Iriondo and Kröhling, 1995).

The Jesuitic cartography of this time (Furlong Cardiff, 1937) shows important changes in the fluvial systems (reduction of the length of the active river beds, change of channels, bifurcations) and the decrease or disappearance of lakes and swamps. The maps also make reference to snow in the mountains of Córdoba, and to steppes in the south and southeast sector of the region, which today receive moderate rainfall.

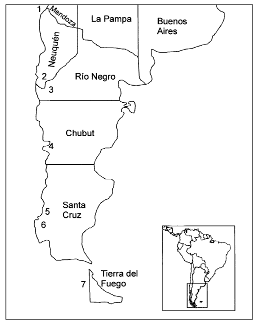
The historical data reveal an important deficit of precipitation during the XVIII Century and the beginning of the XIX Century (Prieto and Jorba, 1990), combined with large interannual oscillations and marked cycles of drought and humid periods (Prieto and Herrera, 1991). In this period began the decline of the northern sector (Santiago del Estero province). A dry climate, together with deep changes in political-economic structures finished the society established during the two previous centuries (Herrera and Dussell, 1992). The maximum series of droughts occurred in the decade of 1770, before the great drought of 1786–1787 in the west of the region (Prieto and Herrera, 1991).

In the east of Buenos Aires Province (outside of the study area), the climate during the XVIII century was more arid than the present one. Analysis of the Proceedings of the Extinguished Council of Buenos Aires indicate that 72.6% of the years in the interval 1698–1791 AD were relatively dry (Politis, 1984).

Information on the southern Andes indicates that glaciers reached their maximum extension during the LIA (Table 2). In the Central Andes (Peru) this event was also detected. The intense cold caused a lowering of the upper limits of cultivation in the basin of the Titicaca Lake, and residents abandoned the towns in the moun-

Table 2
Glaciers advances in Patagonia during the Little Ice Age

	Place	Advances glaciers Age	Author
1	Blanco River Mencoza province	300 años AP	Wayne (1980)
2	Cerro Tronador Rio Negro province	1650–1770 AD	Rabassa et al. (1984) Rabassa et al. (1985)
3	Cerro Tronador Rio Negro province	XVII–1795 AD	Lawrence and Lawrence (1959)
4	Southern Chile	350 años AP	Heusser and Streeter (1980)
5	Continental Ice Field (Argentina-Chile)	1750–1800 AD	Mercer (1965)
6	Argentino Lake Santa Cruz province	1730–1820 AD	Malagnino and Strelin (1996)
7	Tierra del Fuego province	1750 AD	Boninsegna et al. (1990)



tains and settled in the proximity of the lake (Cardich, 1980).

During the main pulse of the LIA, the Patagonian climatic province (arid and cold) advanced between 300 and 400 km to the northeast, approximately up to the parallel of 34°S (Iriondo and García, 1993). This cold pulse can be related to the Minimum Maunder (Minimum of solar activity), which includes the interval between 1650 and 1770 AD (Riccardi, 1995).

5.1. Variations of the present climate

The current climatic conditions began around the middle of the XIX century. In the central region of Argentina more benign conditions were established, corresponding to a recorded retreat of the Andean glaciers (Malagnino and Strelin, 1996). This succession repeated the conditions of the Intermediate Period of the LIA.

At the middle of the XIX century began the continuous registration of climatic data in the center of the country. The series of annual rainfall data in the city of Córdoba in the period 1860–1986 shows various tendencies. Annual rainfalls remained stable between 1860 and 1950 AD. At the beginning of the 1960s a progressively rainier cycle began, characterized by an incremental rate in the order of 8.5 mm yr^{-1} (Lucero, 1995). The Andean glaciers remained in a stationary state up to 1850 and started a slow retreat from 1855 to 1910, with periodic advances. Then, the glaciers continued to regress quickly between 1910 and 1940, with few changes and some advances in the 1950s decade (Heusser, 1961). Detailed studies made on the Uppsala glacier (Santa Cruz province, south Patagonia) established a retreat of 60 m yr^{-1}, starting in the year 1800 (Malagnino and Strelin, 1996).

6. Conclusions

Two significant events related to global changes occurred during the last 1000 yr the Medieval Warm Period (MWP) and the Little Ice Age (LIA). The Medieval Warm Period was a humid and warm climate in the plains; the Andean glaciers retreated. In contrast, during the Little Ice Age the plains had temperate and semi-arid to arid climates, and Andean glaciers advanced.

In the west of the region, the fluvio-lacustrine systems were larger during cold events (LIA) and shrank during warm events (MWP). In contrast, in the eastern region the fluvio-lacustrine systems showed a diminution during cold events and increased their extent during warm episodes.

During the LIA, the occurrence of two cold pulses separated by an intermediate period has been established. The first cold pulse extended from the beginning of the XV century to the end of the XVI century. The second cold pulse (the main one) began at the initiation of the XVIII century and lasted until the beginning of the XIX century. Both cold pulses can be related to the Spörer and Maunder Minimums, respectively. These climatic changes modified the landforms, influenced the vegetation distribution, and were one of the main factors controlling human activities during the last 1000 yr.

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References

Assadurian, C.S., 1983. El sistema de la economía colonial. El mercado interior regiones y espacio económico. Mexico. Editorial Nueva Imagen. 130 pp.

Boninsegna, J., Keegan, G., Jacoby, R., D'arrigo, R., Holmes, R., 1990. Dendrocronological studies in Tierra del Fuego, Argentina. Quaternary of South America and the Antarctic Peninsula 7, 305–326.

Bonnin, M., Laguens, A., Díaz, S., 1987. Ambiente actual y pasado en la cuenca del Río Copacabana (Dpto. Inschilín, Pcia de Córdoba, Argentina). Una primera aproximación. Pub. Inst. de Antrop. Fac. de Fil. y Human. Univ. Nac. de Cba. XLV. 29–66.

De Blij, H.J., Muller, P.O., 1993. Physical Geography: The Global Environment. Wiley, New York, 576 pp.

Dargám, M., 1995. Geochemistry of waters and brines from Salinas Grandes basin, Córdoba, Argentina. 1. Geomorphology and hydrochemical characteristics. International Journal of Salt Lake Research 3, 137–158.

Díaz, S., Bonnin, M., Laguens, A., Prieto, M., 1987. Estrategias de explotación de los recursos naturales y procesos de cambio de la vegetación en la cuenca del Río Copacabana. Pub. Inst. de Antrop. Fac. de Fil. y Human. Univ. Nac. de Cba. XLV, 63–133.

Capitanelli, J.C., 1976. Geomorfología. In: Vázquez, J.B. Miatelo, R.A., Roqué R.A. (Eds.), Geogr. Fís. de la Prov. de Cba. pp. 213–296.

Cardich, A., 1980. El fenómeno de las fluctuaciones de los límites superiores del cultivo en los Andes: Su importancia. Rel. de la Soc. Arg. de Antrop. XIV, 1 (N.S.), 7–31.

Carignano, C., 1997. Caracterización y Evolución, durante el Cuaternario Superior, de los ambientes geomorfológicos en el noroeste de la provincia de Córdoba. Tesis Doctoral. Unpublished.

Fidalgo, F. 1991. Provincia de Buenos Aires - Continental. In: Iriondo, M. (Ed.) Holoceno en la Argentina-CADINQUA. Vol. 1, pp. 23–38.

Furlong Cardiff, G., 1937. Cartografía Jesuítica del Río de La Plata. Buenos Aires. Pub. Inst. de Inv. Hist. LXXI, 125 pp.

Gentile, R.O., 1990. Suelo enterrado por depósitos postconquista en la cuenca del A° Azul (curso superior), Provincia de Buenos Aires" Simp. Inter. sobre Loess, pp. 127–130.

Gez, J.W., 1938. Geografía de la Provincia de San Luis. Bs. As. Ed. Peuser, 235 pp.

González, M.A., 1987. El paleoclima del Cuaternario en el territorio de la República Argentina. Evolución histórica de su estudio. Estado actual de los conocimientos. Serie Didáctica N° 1. Fundación Cari C: zon Caldenius, 1–23.

Herrera, R., Dussell, A., 1992. Eventos climáticos extremos y ambientes en el Santiago del Estero de la segunda mitad del siglo XVIII. Junta de Andalucía. Proyecto NOA 3, 7–33.

Heusser, C.J., 1961. Some comparations between climatic changes in North-Western North America and Patagonia. Annals, New York Academy of Science 95 (1), 624–757.

Iriondo, M., 1986. Modelos sedimentarios de cuencas continentals: Las llanuras de agradación. Primer Congreso Latinoamericano de Hidrocarburos, Actas 1, 81–98.

Iriondo, M., 1987. Geomorfología y Cuaternario de la Provincia de Santa Fe (Argentina) D Orbignyana 4, 1–54.

Iriondo, M., El Chaco. 1992. In: Iriondo, M. (Ed.), Holoceno en la Argentina, Vol. 1, Cadinqua pp. 50–63.

Iriondo, M., 1994. Los climas cuaternarios de la región pampena. Com. Mus. Prov. Cs. Naturales "Florentino Ameghino" 4 (2), 1–48.

Iriondo, M., 1999. Climatic changes in the South American plains: records of a continent — scale oscillation. Quaternary International 57/58, 93–112.

Iriondo, M., García, N., 1993. Climatic varations in the Argentine plains during the last 18,000 years. Palaeogeography, Palaeoclimatology, Palaeoecology 101, 209–220.

Iriondo, M., Kröhling, D., 1995. El Sistema Eólico Pampeano. Com. Mus. Prov. Cs. Naturales "Florentino Ameghino" 5 (1), 1–68.

Iriondo, M., Ramonell, C., 1993. San Luis. In: Iriondo, M., (Ed.), Holoceno en la Argentina, Vol. II, CADINQUA, pp. 131–162.

Kröhling, D., 1993. Geomorfología del tramo inferior del Río Segundo. Inf. final Beca de Iniciación CONICOR. Unpublished, 181 pp.

Laguens, A., 1993. Locational structure of archaeological underground storage pits in northwest Córdoba, Argentina. Rev. do Mus. de Arq. e Etnol., S. Paulo 3, 17–33.

Laguens, A., Bonnin, M., 1987. Espacio, paisaje y recursos. Estrategias indígenas alternativas y complementarias en la cuenca del Río Copacabana (Dto. Ischilín, Córdoba, Argentina). Sitio el Ranchito. 1000 a.C–1600 d.C. Pub. Inst. de Antrop. Fac. de Fil. y Human. Univ. Nac. de Cba. XLV, 159–201.

Latrubesse, E., Ramonell, C., 1990. Formación Algarrobito: Registro de la Pequeña Edad del Hielo en San Luis. 2ª Reunión PICG-281. Publ. Esp. 2, 1–7.

Lawrence, D., Lawrence, E.G., 1959. Recent glacier variations in Southern South America. Technical Report, Office of Naval Research Contract 167 No. 641 (04), American Geographical Society, pp. 1–39.

Leviller, R., 1927. Extensión de la Conquista hacia el Sur, IIª parte. Nueva crónica de la conquista del Tucumán, T. II, pp. 47–104.

Lozano, P., 1873. Historia de la Conquista del Paraguay, Río de la Plata y Tucumán. Imp. Pop. Bs. As. Tomo1.

Lucero, OA., 1995. Characteristics of rainfall climate change on an urban watershed: The case of Córdoba city (Argentina). Ninth Conference on Applied Climatology, American Meteorological Society, Dallas, TX, pp 1–3.

Lutti, R., Bertrán, M.A., Galera, F.M., Müller, N., Serzal, S., Nores, N., Herrera, M.A., Barrera, J.C., 1976. Vegetación. In: Vázquez, J.B., Miatelo, R.A., Roqué R.A. (Eds.), Geogr. Fís. de la Prov. de Cba. Córdoba, pp. 297–368.

Malagnino, E.D., Strelin, J., 1996. Oscilacions del englazamiento en el brazo Norte del Lago Argentino y península Herminita desde el Holoceno Tardío hasta la actualidad. XIII Congr. Geol. Arg, Actas IV. pp. 290–308.

Mercer, J.H., 1970. Variations of some Patagonian glaciers since the late-glacial: II. American Journal of Science 269, 1–25.

Murck, B.W., Skinne, B.J., Porter, S., 1995. Environmental Geology. Wiley, New York, 535 pp.

Panigatti, J., 1981. Molisoles del Norte de la zona pampeana — géneneis y morfología. INTA-EERA, Rafaela. Public. Téc. 13, 1–22.

Parras, P., Diario y Derrotero de sus viajes.1943. Solar Ed. Bs. As, 251 pp.

Politis, G., 1984. Climatic variations during historical times in Eastern Buenos Aires Pampas. Argentina. Quater. of South Amer. and Ant. Pen. Vol. 2, 133–161.

Prieto, M. Del R., Herrera, R.G., 1991. Las perturbaciones climáticas de fines del siglo XVIII en el área andina. Junta de Andalucía. Proyecto NOA 1, 7–35.

Prieto, M. Del R., Jorba, R.A., 1990. Las anomalías climáticas en la Cuenca del Plata y NOA y sus consecuencias socioeconómicas. Siglos XVI-XVII y XVIII. Sep. Leng. Revista Argentina de Geografía. 1, 41–103.

Rabassa, J., Brandani, A., Boninsegna, J., Cobos, D., 1984. Cronología de la Pequeña Edad del Hielo en los glaciares Río Manso, Castaño Overo y Tronador, Provincia de Río Negro. IX Con. Geol. Arg. Actas. III, pp. 624–639.

Rabassa, J., Brandani, A., Salemme, M., Politis, G., 1985. La Pequeña Edad del Hielo (siglos XVII a XIX) y su posible influencia en la aridización de áreas marginales de la Pampa Húmeda (Provincia de Buenos Aires) Actas 1ª Jor. Geol. Bon, pp. 560–577.

Ramonell, C., Tulio, J., Calmels, A., Carballo, O., 1993. Unidades litoestratigráficas del Cuaternario superior en el área de Santa Rosa, Prov. de La Pampa. Actas del Cur. de Posgrado Introduc. al Est. del Cuaternario, pp. 233–242.

Riccardi, C., 1995. Paleoclima. Cambio Global. Publ. Esp. Acac Nac. de Geogr 10, pp. 91–126.

Tonni, E., 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. XV (1–2), 235–252.

Torres Revello, G., 1938. Mapas y Planos referentes al Virreynato de Río de La Plata (Archivo de Simancas). Bs. As. Ed. Peuser, 251 pp.

Véscovo, A.M., 1981. La cuenca del Desaguadero. Atlas Total de la República Argentina. 22, 344–348.

Wayne, R., 1981. La evolución de glaciares de escombros y morenas en la cuenca del Río Blanco, Mendoza. VIII Cong Geol. Arg. Actas IV, pp. 153–166.