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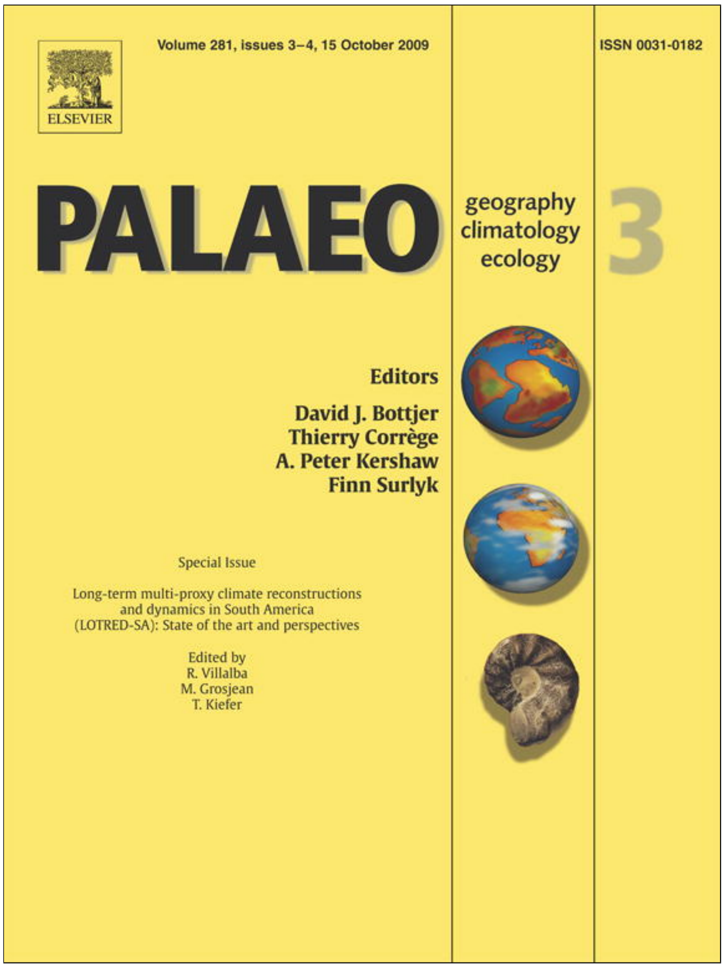

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Reviewing human–environment interactions in arid regions of southern South America during the past 3000 years

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ABSTRACT

Interactions between human societies and the environment that they inhabit have been a controversial topic in archaeology for at least the past fifty years. Currently, modern theoretical approaches take this subject as a key issue in their research agenda. This paper presents a review of the main outcomes of several archaeological and multidisciplinary South American projects related to this theme. The case-studies discussed here are all located within arid settings, and can be grouped into three broad geographic areas: Puna (or Altiplano) of northwestern Argentina, Cuyo (west-central Argentina), and southern Patagonia. These regions cover a wide latitudinal range extending from 22° to 52° S. They were selected for comparison due to environmental similarities, and a common record of past climate impacts mainly related to the Medieval Climatic Anomaly (MCA) and the Little Ice Age (LIA). Although the impacts of these climatic changes were locally heterogeneous in their intensity and the quality of the available information is regionally variable, they provide a base-line for comparison and supra-regional integration.

The integration of archaeological and palaeoenvironmental data on this broad supra-regional spatial scale allows us to identify interesting historical trajectories associated with particular time periods. As an example, there are some spatial rearrangements of large populations during the MCA, in the three areas. Additionally, there are variable patterns in the changes associated with the different social contexts that impose specific demographic and economic constraints. Finally, this study sets the basis for new questions and provides a guide to the methodological and theoretical issues that we need to address in order to answer them.

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1. Introduction

Interactions between humans and their surrounding environments have been discussed in anthropological and archaeological literature over the past fifty years (i.e., Baker, 1962; Dincauze, 2000). Up to the 1970s, the development of this subject was guided by a deterministic approach, suggesting that human ways of life were mechanically determined by environmental features and local resource availability (see review in Trigger, 1971). Since then, this rather simplistic concept has been increasingly contended by the scientific community and, consequently, the approach has grown in complexity and interest (Messerli et al., 2000; Brenner et al., 2001). Current views assume that climatic and ecological conditions provide the context in which all human decisions are made, and need to be accounted for in the construction of archaeological models and hypothesis (Jones et al., 1999; Sandweiss et al., 1999).

The environment does not determine the social organisation of human societies, but sets the frame to which they must adapt, establishing boundaries for the range of social strategies that can be selected and applied (Dearing, 2006; Leroy, 2006). One possible long-term historical trajectory is that adverse climatic conditions and/or maladaptive human behaviour drive some societies, or parts thereof, to crisis or collapse, eventually leading to local extinction (Borrero, 1994–95; Brenner et al., 2001).

On a global scale, several archaeological and ethnographic studies try to understand the spatial distribution of hunter–gatherer, pastoralist, and farming societies in relation to environmental parameters, like effective moisture, primary and secondary biomass (see reviews in Binford, 2001; Marlowe, 2005). This recent research

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has shown the existence of some global-scale patterns which may underlie particular social and historical configurations. Finally, a relatively recent avenue of research, fostered by the changes that the world has experienced during the last two centuries, aims to disentangle the complex relationship between natural and human-induced environmental change (Dearing, 2006; Piovano et al., 2006). The emerging picture shows a dynamic connection, where human societies need to respond to environmental changes, and also produce an impact on the landscape that they inhabit. The theoretical scheme of niche construction appears to adequately define this interaction (Odling-Smee et al., 2003).

In this paper we present a review of archaeological and palaeoclimatic information relevant to the analysis of these issues from three South American regions (Puna, Cuyo, and southern Patagonia) that correspond to arid environments on a wide latitudinal range extending from 22° to 52° S (Fig. 1). This wide geographical scope allows us to compare different historical processes including the persistence of hunter–gatherer societies up to historical times, the local emergence of pastoralist and/or farming groups, and the late contact of the Inka Empire with the Southern Andes and Spanish conquerors.

2. Methodological and theoretical issues

There are two main ways that climate changes affect human populations. The most obvious is the short-term impact of abrupt changes of a cataclysmic nature, like floods or droughts (Oliver-Smith, 1996; Piovano et al., 2006). These events can be repeatedly observed in the span of a few human generations. On the other hand, there are the less obvious long-term climatic changes (e.g. gradual changes in insolation or precipitation regimes) that substantially modify the ecological landscapes inhabited by humans (Sandweiss et al., 1999; Dincauze, 2000). These long-term changes may have taken centuries

Fig. 1. South American regions reviewed.

or thousands of years to fully develop, but their impact on human evolution and the organisation of human societies can be far-reaching.

Knowledge on the spatio-temporal abundance and distribution of resources is a basic requirement for the study of human decisions and processes of cultural change, and can only be soundly established in the light of an environmentally informed perspective. Past human decisions of whether to repeatedly move around or to settle on particular spots of the landscape, whether to invest on storage devices or not, or whether to control the reproductive process of the animal and plant species used as food staples, all partially depend on resource abundance and predictability.

Finally, we arrive at the issue of temporal and spatial *scales*, which underlie all the above-mentioned lines of research (Dincauze, 2000). Obviously, the spatial and temporal scale of the information needed will depend on the questions we are trying to answer. To understand broad social processes we may find little use for fine-scale climatic data, and greatest relevance from the broadest climatic patterns. On the other hand, there are a number of specific archaeological issues that require equally high-resolution palaeoenvironmental data, which may not be addressed on the basis of more general information. One last point regarding scales, the importance of which cannot be overstated, is how to interpret the temporal relationship between climatic and social events as inferred from the archaeological record. We ask, as examples: "How long is the time involved in human responses–which usually imply social or technological change–to climatic fluctuations?" or, "What is the magnitude of the temporal lag associated with these responses?" These are problems of causality that clearly depend on the magnitude of the environmental changes and the nature of the social responses observed, and may have different expressions, such as geographical relocation, participation in regional networks or changes in subsistence.

In the following section we present brief descriptions of the climate dynamics in the areas under study (see details on Clapperton, 1993; Garreaud et al., 2009-this issue) followed by descriptions of the geographic and ecologic settings summaries of relevant palaeoenvironmental records, and reviews of the available Late-Holocene archaeological information. On this basis, we perform a series of comparisons of the different historical trajectories inferred and evaluate their association with locally recorded climatic changes. This information is then used to develop a preliminary analysis of human–environment interactions in these regions of southern South America during the last 3000 years.

3. Archaeological case studies

The area considered here covers a wide latitudinal range of almost 30°, from 22° S to 52° S (Fig. 1), and is characterised by an arid climatic regime. This situation constrains several general geographic and ecologic properties of relevance for human organisation. Garreaud et al. (2009-this issue) present a summary of the regional climate dynamics.

The following regions were selected for comparison because they share some general current environmental similarities including an arid/semi-arid climatic regime, and the presence of some of the main food staples, like the wild species of camelids, which were obtained by hunting strategies. These settings show a heterogeneous structure where water and the main food sources tend to appear clustered on favoured patches. Additionally, there is a shared record of the past occurrence of important Late Holocene climatic fluctuations, mainly related to the periods of the Medieval Climatic Anomaly (MCA) and the Little Ice Age (LIA). Although these shifts are locally expressed with different intensities and the quality of the available information is regionally variable, they provide a basis for comparison in a supra-regional integration.

Another relevant characteristic that was taken into account when selecting an area is the existence of a largely similar demographic profile, given that the communities in these three regions started with low demographic levels, which correspond to the category of so-called

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“low scale” extractive societies. This last criterion excludes the valleys of northwestern Argentina, adjacent to the Puna region, where demographic levels were noticeable higher, thereby conditioning different kinds of social responses to ecological or social stress.

3.1. The Puna (Andean Highlands–northwestern Argentina)

The Puna region comprises the arid highland of Argentina, between 22° and 27° S and 3000 to 4500 m (Fig. 2). This area is defined as a highland desert biome dissected by several NE-SW oriented mountain chains (Fig. 3). This biome also comprises altitudinal variation in vegetation from tolar (shrub steppe) to pajonal communities (highland grasslands), with patches of *vegas* (wetlands) in both of them (Olivera, 1997; Morales, 2004).

The Puna is characterised by high solar radiation due to its high altitude, wide daily thermal amplitude, marked seasonality in rainfall, and low atmospheric pressure. Primary productivity is mainly concentrated in stable hydrological systems like primary basins, high valleys (Olivera, 1997), and wetlands. Several permanent freshwater basins, salt lakes, pans and playas constitute the general hydrological net. A few rivers and several springs, irregularly distributed in the landscape, are the main sources of freshwater, which is a critical resource for human populations. The summer precipitation in northern Argentina, including Puna region, is largely governed by the so-called South American Monsoon-like System (Garreaud et al., 2009-this issue). This system produces about 80% of the annual precipitation occurring in the Andes highlands (ca. 200 mm/yr in Puna region) between December and February (Vuille and Keimig, 2004). In turn, these conditions determine a heterogeneous distribution of plant and animal resources. Some patches defined as ‘nutrient concentration zones’ (Yacobaccio, 1994) contain the majority of the available regional biomass. The most important animal food sources for humans in the Puna include several mammals (e.g., the vicuña *Vicugna vicugna* and the guanaco *Lama guanicoe*), rodents (e.g., viscachas *Lagidium viscacia* and chinchillas), and a cervid (Taruca, *Hippocamelus antisensis*).

Palaeoenvironmental research in the Argentinean Puna is in its infancy compared to that from northern Chile and southern Bolivia. Data from pollen studies (Markgraf, 1985; Lupo, 1998), lake level changes (Valero Garcés et al., 2003; Olivera et al., 2007), diatom studies (Grana and Morales, 2005), and multi-proxy approaches (Lupo et al., 2006) are the only available information for the Late Holocene. For this reason, information obtained at similar environmental settings from neighbouring countries is commonly used to understand local processes.

Fig. 2. Geographical setting, archaeological sites and palaeoenvironmental records from the Puna region.

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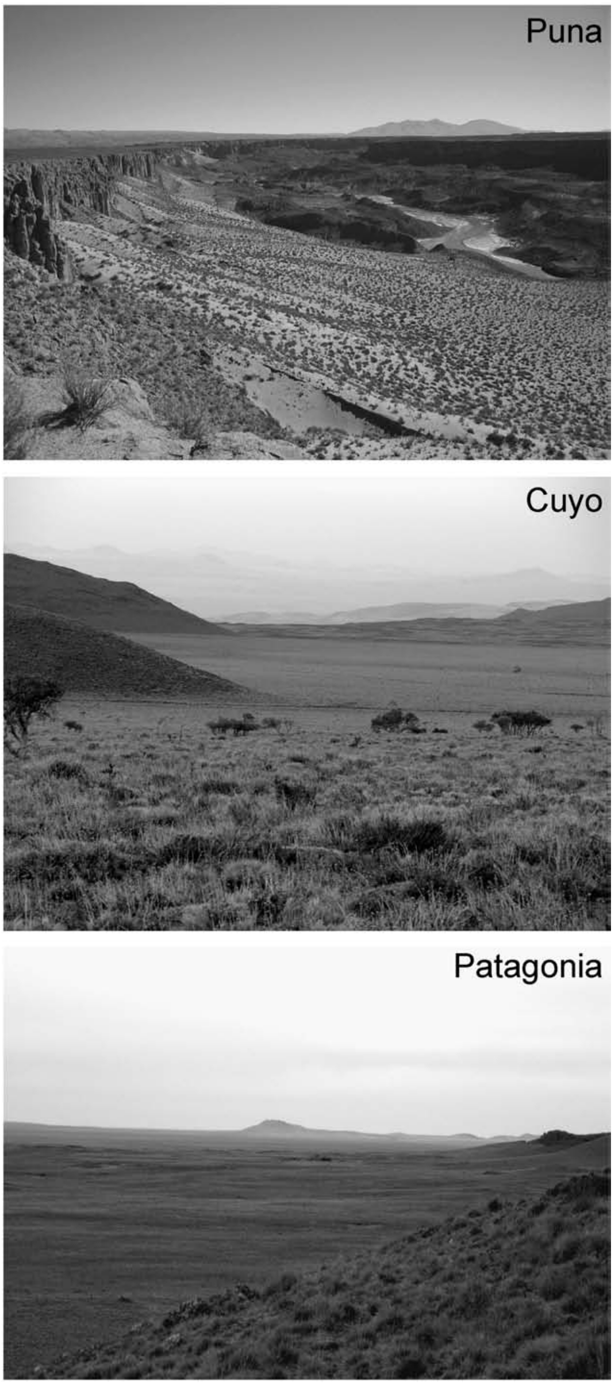

Fig. 3. Environmental setting of the Puna, Cuyo, and Patagonia regions.

The past 3000 years show moister conditions than those observed for the arid Mid-Holocene (Grosjean, 2001). The Huascarán and Sajama Ice Cores show clear evidence of wetter and probable colder conditions starting ca. 4000 yr BP, and Titicaca lake levels, which reflect the moisture balance resulting from the easterly flow moisture transport, show a strong rise from the previous low stand conditions near 3000 yr BP (Abbott et al., 1997). Recent high-resolution records allow us to include the high frequency signals (i.e., short-term variability) within the previous general palaeonvironmental characterisation. The Quelccaya Ice Cores (Thompson et al., 2006) offer a detailed isotopic and dust particle archive of the past two millennia that points to two noticeable phases. The first one is characterised by modest δ^{18}O enrichment between AD 300 to 500 and AD 1100 to 1300, corresponding with the MCA. The second one shows a δ^{18}O isotopic depletion from AD 1400 to 1900, probably corresponding to the LIA (Thompson et al., 2006).

Pollen and lake sediment studies show broadly similar trends. A pollen record from the Sajama Ice Cap shows two different phases during the LIA: a wet phase from AD 1500 to 1700 followed by a dry period from AD 1700 to 1880. Recent results from Laguna Polulos (Lupo et al., 2006) in the Jujuy province of Argentina (Fig. 2) display similar trends to Sajama during the LIA, and also to the two phases recorded in the Quelccaya Ice Cap isotopic data. Titicaca lake levels also show a severe drought ending ca. AD 1350 (Abbott et al., 1997), matching the driest period recorded in Polulos. A significant palaeohydrological change is recorded in lakes from the Puna Salada (e.g. Laguna El Peinado, Fig. 2) at the end of the 19th century, coinciding with that observed in Laguna Polulos, and coeval with the termination of the LIA (Valero Garcés et al., 2003).

3.1.1. Human–climate interactions in the Puna archaeological record

The relationship between environmental change and human strategies during the past 3000 years has been poorly studied in the area compared to the Early and Mid-Holocene when strong environmentally induced changes in mobility patterns and social organisation in hunter–gatherer societies took place. Nevertheless, there is relevant palaeoclimatic information available for analysis of the interactions between Late Holocene climatic changes and patterns of human organisation.

Archaeological evidence between 3000 and 2100 yr BP is scarce; however, there are some important data. Ceramic technology is introduced into the region at 2900 yr BP, as shown by the evidence from Cueva de Cristóbal and Inca Cueva 1 sites. This innovation is important for the development of new cooking techniques, which allowed a more efficient consumption of corn, and their possible use as storage devices. Data can also be retrieved from burials (i.e., Morro del Ciénego Chico) and suggests that technology linked to the exploitation of domesticated llamas was widespread in the region between 2600 and 2400 yr BP. Additionally, evidence of the first village-settled communities appears by 2100 yr BP in the Puna, with small settlements between ca. 500 and 2000 m^2, with circular stone structures (as Casa Chavez 1), compounds, and courtyards (kanchas) used as agricultural fields (as in Matancillas and Piscuno sites, Fig. 2). Finally, several lines of evidence indicate that quinoa (*Chenopodium quinoa*), maize (*Zea mays*), and potatoes (*Solanum* sp.) were cultivated, showing the expansion of agriculture-based people of lowlands valleys, or an intensive inter-regional exchange with them.

No attempts to correlate these phenomena with environmental changes have yet been made. To this end, we can suggest a hypothesis for future testing; that ENSO, which established its current average frequency and intensity at ca. 3000 yr BP, is a possible modifying agent of resources predictability, consequently affecting economic risk. The increased frequency and periodicity of droughts, usually assigned to ENSO anomalies in the Puna area, could have triggered several strategies to buffer those “bad years”. Archaeological evidences suggest an economic risk management strategy starting at this time, based on a reduced residential mobility (i.e., related to abundant architectural features and the inferred pastoralist strategy), the development of storage technology, an increased efficiency in consumption of resources, and an installed intensification process at the level of subsistence.

Regarding the impact of drought, data available from the driest sector of the area, the Salt Puna of Catamarca Province, indicate that human occupations correlate closely with resource availability and diversity. Dated archaeological layers from several sites in Antofagasta de la Sierra show a differential pattern of diachronic occupation of the upper, middle and lower parts of the Quebradas (Fig. 2, Olivera et al., 2004). These occupations are chronologically associated with abundances and locations of several peat deposits along those Quebradas, suggesting a strong relationship between residence placement and availability of water and pastures. Moreover, site abandonment in the

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extensively occupied valleys of permanent rivers, like Rio Las Pitas and lower sectors of tributary quebradas, occurs concurrently with regional dry periods.

This kind of community-based agro-pastoral system-change is noticeable at about 1000 yr BP, when palaeoenvironmental records (i.e., Laguna Polulos; Lupo et al., 2007) suggest the installation of MCA conditions. At least three main cultural and socio-political systems are evident at this time in the Dry Puna of Jujuy: Yavi in the northeast, Casabindo–Agua Caliente in the centre, and pastoral people in the Susques area in the southwest (Fig. 2). The economy of the former two systems was agro-pastoral during this period, whilst in Susques the emphasis was on llama pastoralism. Notwithstanding, the role of agriculture seems to have complemented a fully developed pastoralist economy (Albeck, 2007). As examples of northeastern Yavi archaeological sites we can mention Yavi Chico (with a surface area of 6 ha), Pueblo Viejo de la Quiaca and Cerro Colorado (Raffino, 2007). In the central area of Casabindo–Agua Caliente, sites with large agricultural facilities, as Rinconada with 2 ha, Casabindo, Sorcuyo, Queta, Cochinoca and Rachaite, with almost 3000 ha of agricultural fields, have been studied (Raffino, 2007). The presence of these agricultural sites suggests the possibility of higher demographic levels in the eastern part of the Puna of Jujuy. Conversely, the southwest section seems to show a different picture of pastoralist societies with lower population levels.

Studies focused on age mortality patterns of livestock related to short- and long-term droughts were recently conducted with the archaeological record of pastoralist societies from Susques (Lupo et al., 2007). Preliminary results coincide with ethnoarchaeological data suggesting noticeable herd reduction during arid palaeoenvironmental events. This would be due to both high mortality and killing of elder individuals and also by a fall in birth rate, directly recognised in the zooarchaeological record between AD 1000 and 1500 (Lupo et al., 2007).

The impact of short-term droughts in pastoralist demography has been also studied. Gil Montero and Villalba (2005) suggest that events with high livestock mortality and reduced availability of water and pastures produced a population concentration during the 19th century favouring disease transmission and, consequently, increasing human mortality rates. At the beginning of the 15th century the Inkas conquered the region, introducing several socio-political changes. New multi-proxy data from Laguna Polulos and Sajama Ice-Cap pollen suggest an important increase in regional moisture coinciding with this imperial expansion, but there are no supportable relationships. This is a supra-regional process of imperial expansion that can be partially detached from local climatic fluctuations in virtue of its inherent scale.

3.2. Cuyo (central-western Argentina)

This area is located between 30° and 37° S, and can be subdivided into three environments: the western mountain area, the central plains (which are the driest biome with a mean annual precipitation below 250 mm), and the southeastern volcanic plateau of La Payunia, characterised by a mean annual precipitation ranging between 200 and 400 mm (Capitanelli, 1972; Abraham and Rodríguez, 2000). The mountain area includes two vegetation provinces: the Altoandina Province above 4000 m and the Puneña Province between 2200 and 4500 m (Cabrera, 1971; Roig et al., 2000). The Central plains belong to the *Monte* phytogeographic province, presenting xerophytic vegetation (*Larrea* sp.) and an arboreal stratum dominated by *Prosopis flexuosa* (Roig et al., 2000). Cabrera (1971) defined La Payunia as a particular district of the Patagonian phytogeographic province. The animal food sources can be divided into two main provinces within this region: the *Fauna de Montaña* and the *Fauna de Llanura* (Roig, 1972). The first is characterised by the presence of camelids (*Lama guanicoe* and *Vicugna vicugna*), carnivores, such as the grey fox (*Dusicion griseus*) and puma (*Felis concolor*), small rodents, and several birds. The *Fauna de Llanura* is more diverse, including the previously mentioned taxa plus other small mammals and big flightless birds like *Pterocnemia pennata* and *Rhea americana*.

The Cuyo region is located over the South American Arid Diagonal and within the inversion zone of precipitation regimes (Bruniard, 1982). It is located in a temperate zone with an arid to semiarid climate with average annual precipitations of around 250 mm. It is exposed to the action of the Atlantic anticyclone (piedmont, depressions and oriental plains) and the Pacific Ocean anticyclone (western mountains). From the morpho-climatic aspects, the subregions within Cuyo are highly contrasting due to their relief, dominant masses of maritime air and the season of dominant precipitation. Because of the great distance travelled, the humid winds of the Atlantic produce little precipitation, while the winds from the Pacific precipitate at the mountain range of the Andes, arriving at this region generally dry and warm (Abraham and Rodríguez, 2000). The Andes, under the action of the Pacific anticyclones, belong to the Andean phytogeographic province, and the central and oriental plains, influenced by the Atlantic anticyclones, form the Monte phytogeographic province (Roig, 1972). Cuyo contains two main hydrographic systems: the Desaguadero River, which shows high summer flow, and the Colorado River, which is mainly fed by mountain winter precipitations (Fig. 4).

Cuyo palaeoenvironmental history derives from records located in different settings, including the High Andes, the Precordillera mountain ranges, and the fluvial systems of the Andean piedmont and eastern plains. Major constraints for palaeoenvironmental reconstructions are the local environmental heterogeneity and the still limited number of studied localities. The general palaeoclimatic conditions of the Mid- and Late-Holocene are inferred from two peat pollen records: the upper Uspallata valley (2000 m) and the upper basin of the Salado river (2400 m) (Markgraf, 1983). Pollen assemblages, along with sedimentological changes, suggest a decrease in summer rains (implying an increase in temperature) between 8500 and 5000 yr BP; increased precipitations (presumably in the form of winter rains and lower temperatures) between 5000 and 3000 yr BP, and the establishment of modern climatic conditions by 3000 yr BP, with summer rain precipitation in the lowlands and more favourable temperatures in the uplands (Markgraf, 1983).

Other lines of evidence used to reconstruct Mid- to Late-Holocene environmental conditions come from glacial records. A neoglacial advance is reported from Glaciar de los Cipreses on the Chilean side at 5200 yr BP (Clapperton, 1993), and in the Mendoza River valley at an age of 5000–2500 yr BP, attributed to the Confluencia drift (Espizúa, 1993). Evidence of glacier fluctuations during the Mid- to Late-Holocene was recently reported from the Valenzuela area in the upper basin of the Grande River, with advances at 5700, 4700–4300, 2500–2200 yr BP, and most recently, that which corresponds to the LIA, culminating at ca. 400–350 yr BP (1435–1660 cal. yr AD; Espizúa, 2005).

The distal piedmont and the eastern plains are characterised by extensive dune fields with evidence of dune superposition. In the dune field of Médanos Grandes, in San Juan province (Fig. 4), Tripaldi and Forman (2007) report repeated dune activation at ca. 4000 yr BP, 2500–2100 yr BP and 400–600 yr BP, this last coinciding with the LIA. During the past 4000 yr BP, dune reactivation in western Argentina might reflect a greater deficit in austral spring to summer precipitations than historically recognised (Tripaldi and Forman, 2007). The Central Chile precipitation patterns are relevant for the understanding of Cuyo climatic dynamics, since the Pacific Anticyclone have an influence on the Cordillera, but not on the oriental plain.

3.2.1. Human–climate interactions in the Cuyo archaeological record

One of the earliest Argentinean archaeological projects framed within a palaeoecological perspective was developed in Cuyo (Lagiglia, 1971; D'Antoni, 1980; Markgraf, 1983). Recent lines of

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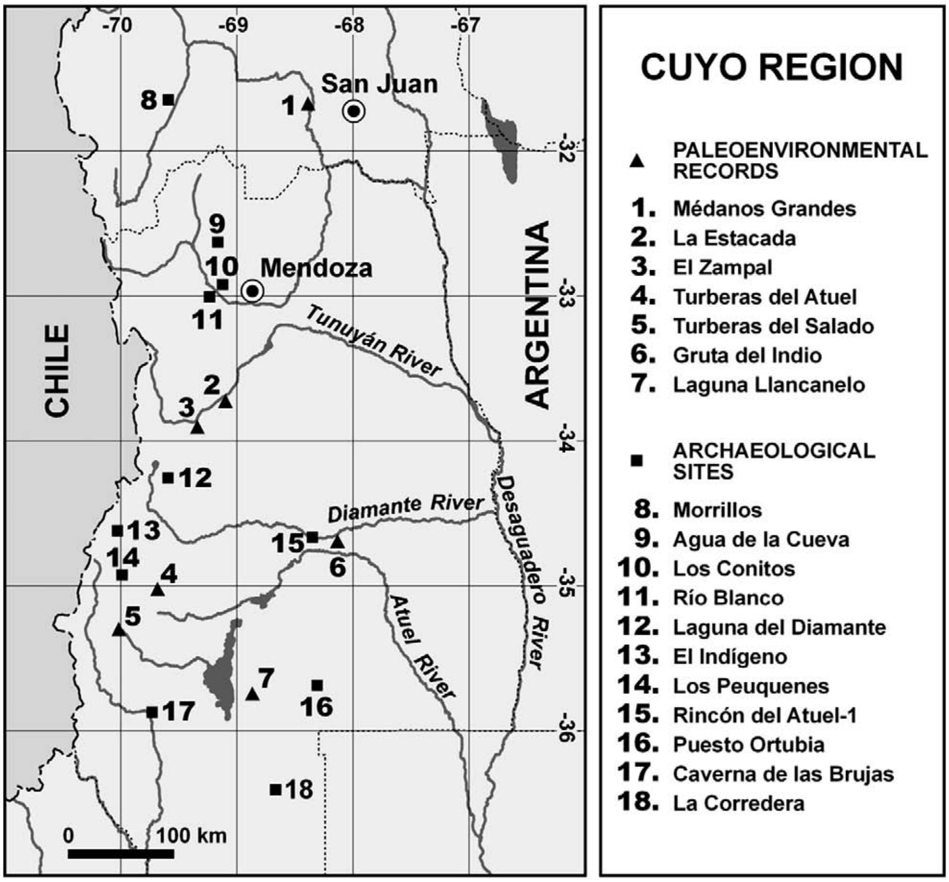

Fig. 4. Archaeological and palaeoenvironmental localities from Cuyo.

research also use palaeoecological information as a key element in the explanation of the archaeological variability. In historic times, the area was occupied by two ethnic groups known as Huarpes and Puelches (Michieli, 1983; Prieto, 1989). These groups have been described by contrasting cultural and demographic characteristics. The Huarpes are described demographically as a medium-scale society with a sedentary settlement pattern and a farming economy. On the other hand, the Puelches were hunter–gatherers with low demography and high mobility. Therefore, during historic times, this region appears to be a boundary area between farming and hunter–gatherer societies. The relation between ecological conditions and predominant subsistence mode is beginning to be studied within evolutionary frames (Johnson et al., 2007).

The Late Holocene archaeological record needs to be interpreted in light of Mid-Holocene evidence that shows a very limited signature of human presence (Zárate, 2002; Cortegoso, 2005; García, 2005; Gil et al., 2005; Zárate et al., 2005). Since the fourth millennium BP, the archaeological record shows important economic changes on a regional scale, followed by divergent trajectories for northern and southern Cuyo peaking at ca. 2000 yr BP, and resulting in two different subsistence patterns: northern Mendoza was characterised by the presence of farming populations, which adopted cultigens already present in northwestern Argentina (like maize), while southern Mendoza shows the persistence of societies living in a hunter–gatherer subsistence mode (Lagiglia, 1979; Gil et al., 2005). This divergence is also reflected in some aspects of the associated human remains (Novellino and Guichón, 1997–1998).

There is no clear evidence of farming production between 4000 and 2500 yr BP, and guanaco exploitation is the most significant dietary staple for humans during this period. This is followed by an economic intensification peaking during the last 2000 years, associated with changes on settlement patterns, technological organisation, a widening of the subsistence base, and an expansion of inter-regional interactions (Neme, 2007). In southern Mendoza, the intensification process helps to explain the late human occupation of ecologically marginal environments, like the La Payunia volcanic area and the highest mountain settings (Neme et al., 2005; Gil, 2006). Similar intensification processes, with decrease in mobility and changes in technological organisational properties, were also studied in northern Mendoza, where inter-mountain valleys were intensively occupied for 1500 yr BP by farmers that used small semi-subterranean houses and who also sustained their economy with the extraction of wild resources (Cortegoso, 2004). An effective occupation of all the available environments had already taken place in Mendoza between 2000 and 1000 yr BP (Neme et al., 2005; Cortegoso, 2006; Gil, 2006). In the case of San Juan, Gambier (1976) reported substantial changes at AD 1100 and suggested that they were linked to warmer environmental conditions and extensive melting of ice in the Cordillera, which allowed the exploitation of lands that are deserts today (e.g., in the Bermejo river basin). According to Gambier (1976), this period was characterised by a progressive population growth and the displacement toward lower lands with the advances in irrigation technology.

These processes of intensification could be interpreted as the consequence of an unbalance between environment carrying capacity and an increasing human demography. Nevertheless, the association with climatic changes has not yet been evaluated in detail. It is significant enough to remark that there are some methodological difficulties for disentangling climatic and anthropic agency in ecologic change (see Methodological and theoretical issues).

The distribution of calibrated ^{14}C dates on archaeological materials provides a proxy for human palaeodemography and intensity of occupation of different parts of the landscape (Rick, 1978). As argued by Shennan and Edinborough (2007), given representative sample sizes, the distribution of the summed probabilities for a set of ^{14}C date

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distributions should generate a reasonably good population proxy. In the Cuyo region, this approach was used to assess human demography from the Mid-Holocene onwards (Gil et al., 2005; Neme et al., 2005). We analysed the distribution of ^{14}C dates for human occupations in high-altitude settings, providing a sensitive tool to explore the relation between Late-Holocene warm (MCA) and cold (LIA) climatic fluctuations and human occupation patterns (Durán et al., 2006; Gil et al., 2006). The resultant distributions show changes in the probability of human occupations. Clearly, the number of radiocarbon dates is too small ($n = 13$) to make stronger inferences, and the local MCA and LIA's chronology needs to be improved.

Although the incidence of humans in the configuration of the landscape has not been treated in detail so far, available evidence suggests that a strong human impact over the regional resource structure could have occurred since ca. 2000 yr BP. This impact was probably caused by landscape over-exploitation that reduced the availability of highly-ranked resources, and drove subsistence towards the inclusion of foods with lower caloric returns and higher processing costs (Gil, 2006; Neme, 2007). This intensification process may have stimulated the local adoption of domestic plants like maize (Gil et al., 2006).

3.3. Southern Patagonia (Argentina and Chile)

This large territory is located between 46° and 53° S (Fig. 5). Atmospheric circulation patterns are controlled by strong westerly storm tracks that shift seasonally on a latitudinal axis (Lamy et al., 2001). The interaction of the Andean topographic 'wall' and the prevailing westerly winds imposes a strong west–east gradient on precipitation, and therefore, on effective moisture. Precipitation on the western side of the Andes reaches levels of 4000 mm/yr, whereas the eastern steppes show mean annual precipitation in the order of 200/300 mm (Oliva et al., 2001).

The eastern side of Patagonia is characterised by large dissected plateaus that give way to low steppe plains up to the Atlantic Ocean (Clapperton, 1993; McCulloch et al., 1997). Water availability is spatially heterogeneous and restricted to the main fluvial valleys, which constitute 'unearned' water conditioned by shifts in discharge amount from the Andes, and to permanent lakes (i.e., Buenos Aires, Cardiel, Viedma, Argentino and Potrok Aike). This water restriction is also present in the Puna and Cuyo areas, and may have been a key constraint for human populations in arid areas of southernmost South America.

The main sources of food for humans include terrestrial and marine mammals and birds, and most of these species have a relatively ubiquitous distribution. The terrestrial animals with highest biomass are the guanaco (*Lama guanicoe*) and the choique (*Pterocnemia pennata*). On the other hand, marine species usually consumed by humans in the past include birds, such as shags (*Phalacrocorax atriceps*) and penguins (*Spheniscus magellanicus*), mammals, such as the southern sea lions (*Arctocephalus australis*, *Otaria flavescens*), and several species of mussels. Guanacos are abundant almost everywhere in the hinterland and have a territorial behaviour (Franklin, 1982), therefore, they are easy to predict in time and space. In contrast, marine resources are not ubiquitous, being available only at selected times and locations (Schiavini et al., 2004).

In southern Patagonia, palaeoclimatic studies have mostly been based on archives located in settings west of the continent and Tierra del Fuego Island (i.e., Markgraf et al., 2000), which are more humid and prone to the preservation of relatively continuous palaeoclimatic signals. This has been recently complemented by the multi-proxy study of the geomorphology and deep lacustrine sediments from lakes located at different latitudes on the steppe (i.e., Cardiel Lake at 49° S and Laguna Potrok Aike at 52° S, Stine and Stine, 1990; Gilli et al., 2005; Zolitschka et al., 2006). All these studies provide a well-informed

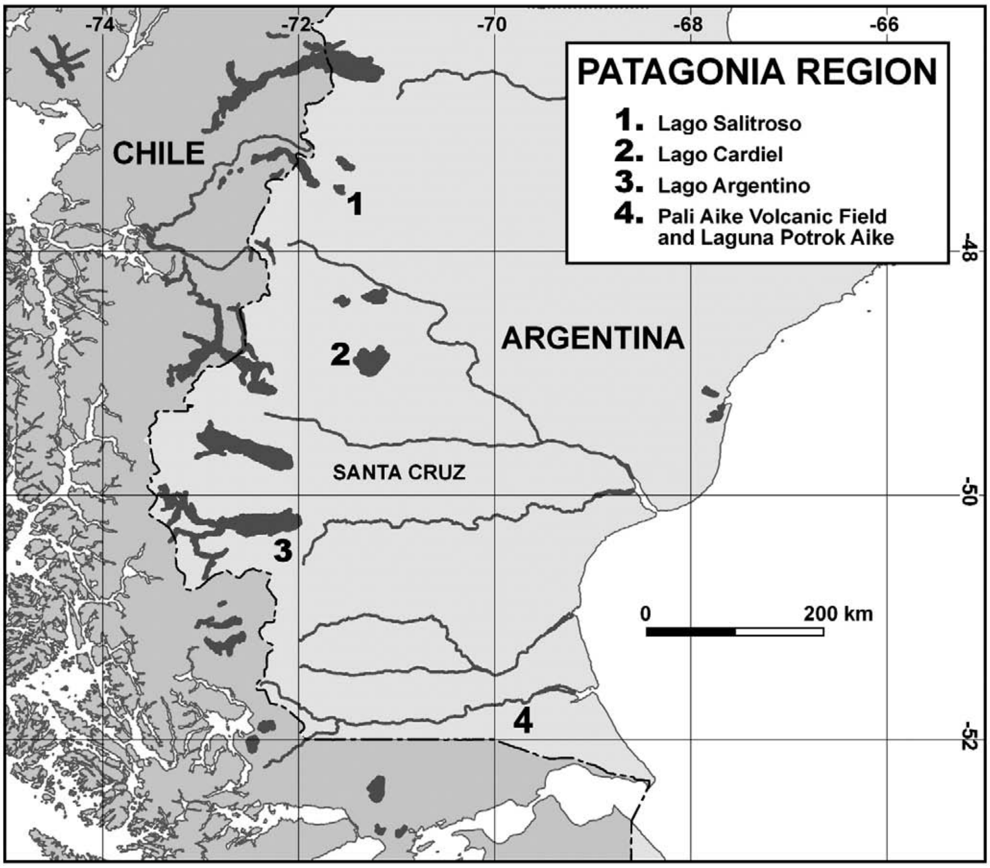

Fig. 5. Archaeological and palaeoclimatic localities from southern Patagonia.

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picture of the climatic and ecological evolution of southern Patagonia since Late Glacial times.

In the Laguna Potrok Aike continuous sedimentary record (Fig. 5), the Late Holocene shows a series of cold and wet periods occurring at ca. 4800, 3900–3700, 3000, 2500, 1980, 950–750 and 530–20 cal yr BP, separated by longer dry intervals (Haberzettl, 2006). The last two sets of events are related to global processes previously recorded in the northern hemisphere. At 950–750 cal yr BP, there is a local record attributed to the MCA. On the basis of geomorphic and dendrochronological studies conducted on southern Patagonia and the North American Great Basin, Stine (1994) suggested the existence of an inter-hemispheric connection during these times. The local climatic signature of the MCA is highly variable and is related to atmospheric circulation patterns (Villalba, 1994; Luckmann and Villalba, 2001). In southern Patagonia the MCA is associated with predominantly hot and dry conditions punctuated by at least two short humid events probably occurring on a decadal scale (Haberzettl et al., 2005). There are different opinions regarding the precise chronology of the local expression of the MCA. Originally, Stine (1994) proposed a range extending from 850 to 1350 cal yr BP. More recently, on the basis of the analysis of the continuous record from Potrok Aike, a chronology has been proposed for the Medieval droughts in southern Patagonia, which would extend its time range up to the 15th century when the Medieval Warm Period had already ended in Europe (Haberzettl et al., 2005).

A set of events attributed to the LIA has also been recorded. The Neoglacial advances that culminated in LIA were evaluated by Mercer (1976) in the Argentino Lake area. Following this, evidence related to this cold and wet period has been recorded in many glacial systems of southern and northern Patagonia (Luckmann and Villalba, 2001; Glasser et al., 2004). Studies on sediment cores from Laguna Potrok Aike and Laguna Azul also recorded this event, beginning in the late 15th century and extending to the early 20th century (Haberzettl et al., 2005; Mayr et al., 2005). According to the total inorganic carbon record from Potrok Aike, the LIA represents the longest period of constant wet conditions in southern Patagonia since the Early Holocene (Haberzettl, 2006), although there appears to be inter-regional variation not yet fully understood. The earlier chronology for the MCA may be related to the lake transgression recorded in Cardiel Lake, which resulted in the drowning of trees grown during the MCA low stands (Stine, 1994). During this wet period the systematic contact between indigenous and European populations took place, an event that has sensitive markers on the pollen record, such as the introduction of *Rumex* sp. (Huber et al., 2004).

3.3.1. Human–climate interactions in the Patagonian archaeological record

Strong connections between Late-Holocene climatic variations and fluctuations in human geographical distribution and organisation are only recorded during the dry periods associated with MCA times. Archaeological research on these issues has been centred on several lacustrine basins, which may have acted as demographic attractors (Goñi, 2000). Borrero and Franco (2000) suggested two alternative hypotheses to account for the nearly total absence of humans in the Argentino Lake region (200 m, Fig. 6) during and after these dry times: either human populations completely abandoned the area, perhaps moving to eastern locations, or they dramatically rearranged their pattern of use of the area, producing an almost invisible archaeological signature. In this context, the Santa Cruz River has been proposed as the main circulation corridor between the hinterland and the Atlantic Ocean during the MCA (Franco et al., 2004). Conversely, other large southern Patagonian basins show a signal of intense human presence during the MCA.

On the basis of the abundant archaeological evidence from Cardiel Lake (270 m, Fig. 6), Goñi (2000) suggested that, in the predominantly dry Late Holocene context, low lake basins were strong attractors for human populations that inhabited them for permanent residential purposes. On a local scale, the gradual lowering of the lake level generated new spaces available for human use, which are integrated into the hunter–gatherer geography. This is exemplified by the sand dunes located at southern and eastern coasts of Cardiel Lake; where there is a widely distributed archaeological record associated with berms of different radiocarbon dates (Stine and Stine, 1990; Belardi et al., 2003).

Other basins show similar records of strong human presence during the Late Holocene. The smaller Salitroso basin (150 m), located in north-western Santa Cruz province (Fig. 6), shows an unusually high frequency of human burials and large artefactual concentrations in open air locations with evidence of site furniture, suggesting intensive and redundant human use. This has been explained as the consequence of a reduction in mobility and population clustering after MCA (Goñi et al., 2000–2002). Additionally, burials show a higher percentage of sub-adults and females in comparison to the period before the MCA (García Guráieb et al., 2007). This population clustering may have influenced the prevalence of infectious diseases that have been detected. So far, there are no other southern Patagonian records showing such a marked clustering of mortuary sites, also pointing to very a heterogeneous distribution of human populations on the steppe landscape (although there is a case on the Atlantic coast of northern Santa Cruz province that may be comparable; Castro and Moreno, 2000).

The high-altitude Strobel Lake plateau (900–1100 m) is a very different setting, characterised by strong seasonality, high resource availability and productivity, and strategic location due to its position in the middle of natural circulation corridors. The distribution and diversity of engraved motifs on rocks, the high frequency of projectile points, and the presence of site furniture exemplified by the so-called “parapetos” that are hunting blinds, all point to functionally specific occupations, associated with guanaco hunting on a logistical and seasonal basis. These high basins may have been connected with the lower basins, like the Cardiel, where the archaeological record shows a functionally more diverse human use. Given the existence of strong similarities with the rock art of nearby areas, the Strobel Plateau was explained as a space where macro-regional population convergence took place, and where rock art played an important role as a social mechanism for information exchange (Belardi and Goñi, 2006).

In summary, there is a spatially heterogeneous demographic scenario at the scale of southern Patagonia. Human populations appear to have been irregularly distributed on the landscape, where some basins, like the Argentino Lake basin, were abandoned and others concentrated humans to an extent not seen before, like the Cardiel and Salitroso located further north. The archaeological record from the Pali Aike volcanic field, located southeast of the cordilleran basins, shows a somewhat continuous signal of human presence that becomes more intense during the last 1000 cal yr (Barberena and Borrero, 2007), and the same can be postulated for coastal habitats, like the central and eastern Strait of Magellan. Consistently, available radiocarbon dates show an important clustering in the Late Holocene (Goñi et al., 2004; Barberena, 2008).

Finally, during the LIA, better conditions for humans are present in southern Patagonia due to an increase in effective moisture (Haberzettl et al., 2005). During the last five centuries water was more homogeneously distributed on the landscape, resulting in a less rigid localisation factor for human populations. Archaeological information shows human presence in the western lacustrine basins, the different habitats of the Pali Aike volcanic field (Fig. 6), the headwaters of the Santa Cruz River, the coasts of the Strait of Magellan, and the Atlantic coast (Franco et al., 2004). Temporal distribution of ^{14}C dates, which can be used as a proxy for intensity of human presence, shows a significant increase in intensity in most of the southern Patagonian regions, suggesting high demographic levels in comparison to the MCA (Barrientos et al., 2005; Barberena, 2008), although the late

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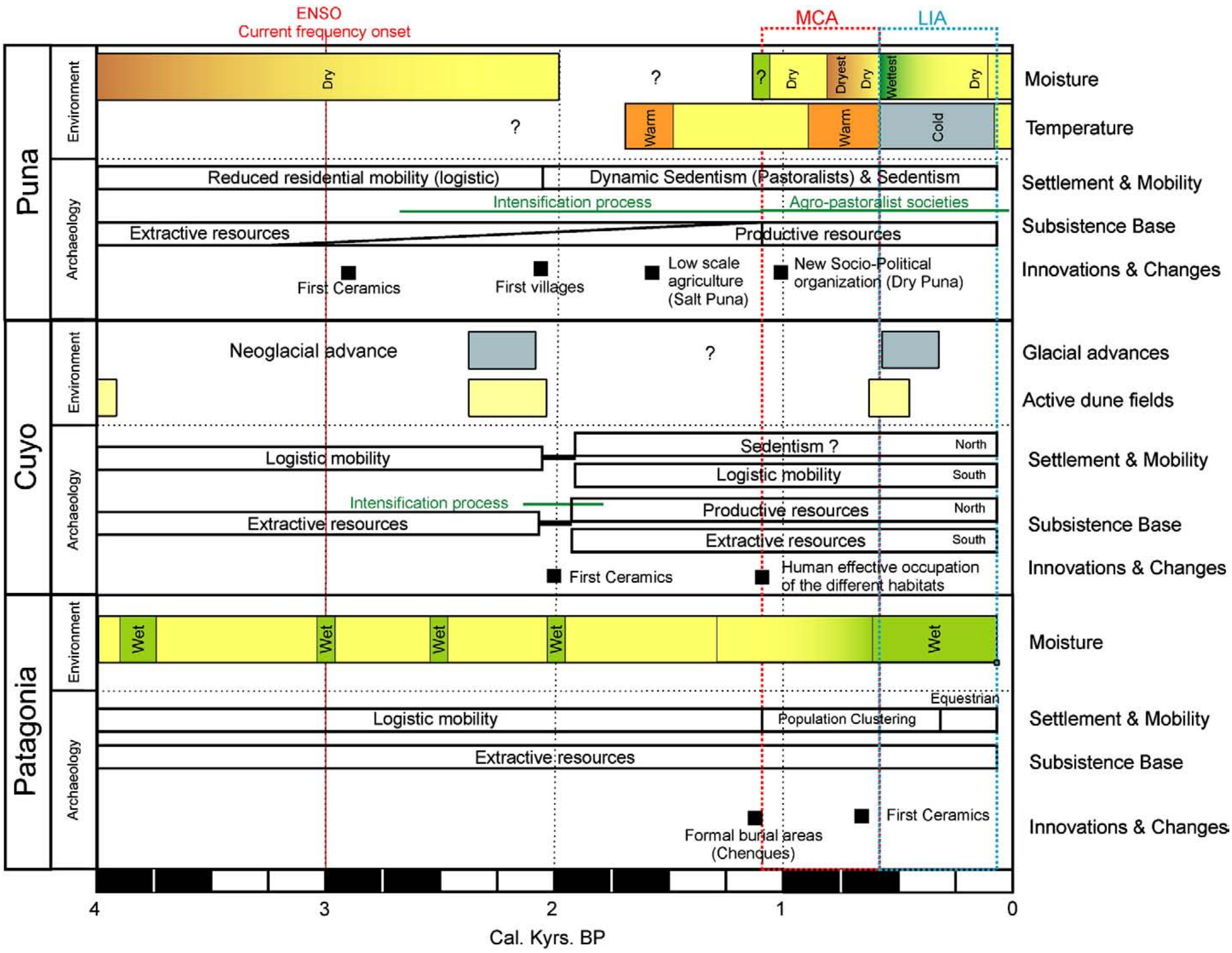

Fig. 6. Late Holocene comparative diagram for Puna, Cuyo and southern Patagonia.

Neoglacial advances may have produced a less intense occupation on the cordilleran side of Patagonia (Goñi, 1988). The incidence of taphonomic factors on the apparent inter-regional increase seen in the archaeological record needs to be assessed on a wider basis (Surovell and Brantingham, 2007).

4. Discussion and conclusions

On the basis of the current state-of-the-art archaeology of Puna, Cuyo and Patagonia, some specific and general patterns in the relationship between cultural and environmental change have been identified and are discussed below.

4.1. Puna

As we have previously presented, the relationship between environmental change and human strategies during the past 3000 years has been poorly studied. However, we were able to outline some suggestive correlations between several archaeological patterns that point towards a strategic management of economic risk during periods of increased risk due to change or modification in drought frequency or intensity. The intensification process in camelid exploitation, which started in the Mid-Holocene, is reinforced with the onset of current ENSO dynamics. As we have shown, towards ca. 2900 yr BP new technologies are locally recorded, like ceramics that allowed more efficient consumption and storage of foods, two aspects related to risk buffering. Also, a fully developed pastoralist economy was installed around 2600 yr BP, implying a different pattern in mobility and resource management. Notwithstanding, as several zooarchaeological studies show, during this time hunting of wild camelids was an ongoing practice in these pastoralist societies, suggesting that herds could also be used as a way of food storage. On the other hand, changes in mobility patterns could have affected ancient communities in other ways. Societies with reduced mobility, such as pastoralist ones, are prone to nucleate during drought events, increasing the probability of disease transmission and population mortality. Other aspects related to a reduced mobility, such us effective population growth or relative higher demographic levels, usually associated to increases in territorial behaviours and inter-personal violence, have not been systematically examined yet in the Puna archaeology. This must be kept in mind as a future issue for research, particularly in the light of the changes that occurred during the MCA in the highly populated pre-Puna area of Quebrada de Humahuaca. Remarkable changes in settlement patterns occurred in this area (Rivolta, 2005), and a process of endemic violence has been suggested (Nielsen, 1996), coinciding with MCA chrono-zone. The evidence that suggests higher demographic levels in these developing agricultural societies from northern and southern Puna regions coincides with MCA, and may have contributed to trigger similar processes that need to be addressed in future research.

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The reason why the archaeological research focus in northwestern Argentina has not been oriented to human–environment interactions remains elusive. We think that it may be related to theoretical and methodological issues. The current use of obsolete, essentialist and chronologically arbitrary culture-historical concepts makes the identification of reliable archaeological patterns difficult. On the other hand, the usual anthropocentric perspectives applied in the area (i.e., where the main cause of organisational changes is always endogenous to society) have intentionally undermined the role of exogenous variables, like climate, that could have affected human cultural change.

4.2. Cuyo

The Cuyo region lacks detailed palaeoclimatic reconstructions for the Late Holocene, and the available information has a coarse-grained resolution. However, this information provides a palaeoecological basis for the explanation of archaeological patterns and its variability, and has started to be used in this way during the last decade. Recent studies focused on human–environment relationships stressed the analysis of human demography and settlement systems on the basis of the spatial and temporal distribution of ^{14}C dates (Gil et al., 2005). These studies initiated a productive research line, but it is necessary to develop other issues, including human subsistence, mobility, and goods exchange. In conjunction with a stronger palaeoclimatic basis, which is also being developed, this will allow for a deeper understanding of human–environment interactions in central west Argentina.

Two main human processes that occurred during the last 3000 years that were significantly related to environmental modifications can be identified. The first is the economic intensification process proposed as a human response to environment degradation, although human activity may have contributed to this degradation (Gil, 2006; Neme, 2007). The second general process is the incorporation of several domestic plants to the subsistence base of these human populations (Bárcena et al., 1985; Gambier, 2000; Lagiglia, 2001; Gil, 2006).

There are several remarkable trends that must be taken into account in our future research agenda in terms of hypotheses construction. On the one hand, during the MCA times, a noticeable increase in the intensity of human occupations was recorded in the lowland areas of Laguna Llancanelo and in some areas of the Cuyo region (Durán et al., 2006; Gil et al., 2006). This pattern can be associated to the drier conditions that affected the surrounding more marginal areas, pushing human groups to moister areas with higher water availability. On the other hand, a marked change in settlement patterns in highland cordillera during LIA times is not indicated by the spatial and temporal distribution of radiocarbon dates. Unfortunately, there is no detailed palaeoecological information on resource structure and its local variations in these different settings of this region during both periods that will significantly help to test and improve these ideas.

4.3. Patagonia

The Late Holocene in southern Patagonia shows oscillations between some of the driest and wettest periods of the Holocene (Stine, 1994; Haberzettl et al., 2005). Importantly, these climatic oscillations occur very quickly, apparently on a decadal scale. As indicated by the chronology of human occupations, their impact on hunter–gatherer societies was strong, given that very sharp fluctuations are recorded in the evidence of human presence during the last 1000 years. The MCA prompted different responses from human populations, like the abandonment of vast areas of southern Patagonia (Argentino Lake basin) and the concentration in other lacustrine basins (Cardiel Lake basin), where the archaeological record reaches levels of abundance not seen before. Further, high concentrations of human burials on particular spots of the landscape are first recorded (Salitroso Lake basin). Southeastern locations, like the Pali Aike volcanic field, show a more continuous archaeological signature for the last 1000 years, although a decrease in human presence is also inferred (Barberena and Borrero, 2007). Therefore, one of the main features of the MCA archaeological landscape is its spatial heterogeneity. Drought duration may have been a key climatic factor given that, as Stine (2000) stressed, its impact on the landscape is progressive, implying different human responses as water availability becomes more restricted and favourable places act as refuges.

After the MCA, and apparently in association with the moist LIA conditions, the record shows a demographic increase, inferred from the presence of humans in most southern Patagonian settings. Even areas that are marginal in terms of productivity and geographic position were incorporated within hunter–gatherer home ranges.

4.4. Integration of regional cases

The MCA appears to be a key period in terms of the integration of the three regional cases; it had an important effect on human populations from Patagonia, Puna and, apparently also Cuyo (Fig. 6). This is, therefore, a short time period where important social and economic changes are taking place across a large transect across southern South America. The subsistence and social basis of the societies inhabiting these three areas during the past 1000 years were quite different. Foremost, there is a variable degree of importance of domesticated foods on local economies, from northwestern Argentina agricultural and pastoral cases to exclusive hunter–gatherer Patagonian societies, with Cuyo showing an intermediate situation, but where domesticates were not subsistence staple. Nevertheless, geographical relocations were recorded in these three settings and changes in relative demographic levels due to population nucleation or growth took place in association with the MCA. In fact, there was geographically enough space to allow for mobility as a strategy: large areas were abandoned and other areas functioned as refuges. Given that, on average, large tracts of these semi-arid lands were impoverished, there are two possible demographic scenarios working at the scale of southern South America (which have already been treated in smaller scales): human populations modified their spatial arrangement, or they contracted and became smaller than during previous times.

The first scenario was operating in the three regions in order to deal with the MCA changes, expressed in a process of population aggregation that took place particularly in the Puna and Patagonia. The archaeological record of these three regions also indicates that several large areas were temporarily abandoned. As a consequence, higher levels of relative demography were reached, probably resulting in changes in human organisational strategies. In the Puna this process was accompanied by marked changes in the subsistence base associated with an intensification in the use of domestic plants that was synchronous with the MCA. The increase in the scale of agricultural production in several areas of the northern Puna, as shown by the sites of Casabindo and Yavi areas (Raffino, 2007) and most part of the southern Puna, seems to have produced an effective population growth, and consequently deep social changes.

The cold conditions associated with the LIA resulted in less frequent use of high settings in the Andes of Patagonia and Cuyo. Additionally, the associated increase in humidity may have improved the carrying capacity of lowland settings, like the Patagonian steppe, allowing for the relaxation of the spatial constraints imposed by the MCA arid events. The actual impact of LIA in these societies is difficult to disentangle firstly from that produced by the Inka expansion into northwestern Argentina and Northern Cuyo, and secondly from the European conquest in the three regions. It is important, therefore, to understand native demographic history. In this sense, historically recorded human extinctions were superimposed on these prehistoric trajectories (Goñi et al., 2000–2002). This issue also deserves a detailed historical analysis that exceeds the aim of this archaeological review, particularly due to the availability of a broad corpus of chronicles, explorers' diaries and historical documents.

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The role of human agency in the modelling of the ecosystems is another side of this history that may be seen as an active process of niche construction (Odling-Smee et al., 2003). Given that humans actively interact with the ecosystems they inhabit, we can assume that they modified them to some extent. In these three regions, there is evidence of a low degree of human impact in the environment during prehistoric times. This can be shown with the increase in charcoal deposition probably related to human-induced fires (Huber et al., 2004), and with modifications on the demographic structure, behaviour and morphology of wild and domesticated animals (Yacobaccio, 2001; L'Heureux, 2007). Starting with the European colonisation, a deeper impact on the environment was induced by the introduction of European domestic animals (Haberzettl et al., 2005) and the expansion of agriculture. An effort towards a systematic approach to this topic will help us to understand this important interaction (like the PHAROS initiative of PAGES, Dearing and Battarbee, 2007). Given their consequences, these types of interaction–in addition to other anthropogenic environmental impacts i.e., water management for irrigation, the domestication process and packing effects due to population aggregation (Redman, 1999)–need to take prime place in future archaeological research agendas.

We have identified interesting patterns of interaction between climatic change and human organisation in the three South American regions reviewed. In particular, the trends associated with the MCA provide a promising basis for a comparative inter-regional approach. On the other hand, we have also identified the main limiting factors that we face in integrating palaeoclimatic, palaeoecological, and archaeological data in the context of a strong research design. What is needed is an increase in the development of interdisciplinary projects that are able to deal with human–environment interactions on selected and comparable scales. On a spatial level, current climatic information gives a clear picture of the large existing inter-regional variation (Garreaud et al., 2009-this issue). This is a serious limitation to the use of non-local palaeoclimatic data when correlating with archaeological evidence and needs to be improved to strengthen our conclusions. On a temporal level, it is crucial to substantiate the relevance of palaeoclimatic data on certain scales to answer anthropological questions that also have an inherent temporal scale. In the most fortunate cases, this may imply the need for coarse-grained climatic information, which is more compatible with the available archaeological data that is usually of an averaged nature. The trends presented are clearly preliminary and in some cases even tentative, but they have the important merit of clarifying how we can develop stronger inter-disciplinary archaeological research.

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