Climate Change and Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions
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Chapter 3

Mid-Holocene climate and culture change in the South Central Andes

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Abstract

The South Central Andes host a wide range of different habitats from Pacific coastal areas up to extremely harsh cold and dry environments of the high mountain plateau, the altiplano *or the* puna. *Marine resources in habitats along the cold Humboldt current are abundant and very stable through time, whereas terrestrial vegetation, animal, and water resources in the habitats of the intermediate valleys, of the high valleys toward the Andes and of the high* puna *are marginal, scarce, highly variable, and hardly predictable in time. Paleoenvironmental information reveals high amplitude and rapid changes in effective moisture during the Holocene period and consequently, dramatically changing environmental conditions. Therefore, this area is suitable to study the response of hunting and gathering societies (Paleoindian and Archaic Period, between ca. 13,000 and 4500 cal yr BP; 11,000 and 4000* ^{14}C *yr BP) to environmental changes, because smallest variations in the climatic conditions have large impacts on resources and the living space of humans. We analyzed environmental and paleoclimatic information from lake sediments, ice cores, pollen profiles, and geomorphic processes, and put these in relation with the cultural and geographic settlement patterns of human occupation in the different habitats in the area of southern Peru, SW Bolivia, NW Argentina, and North Chile. The time window of 5000 cal yr BP (4300* ^{14}C *yr BP) considered in this context is put in perspective of the early and late Holocene in order to show a representative range of environmental and cultural changes. We found that the time broadly around 5000 cal yr BP (4300* ^{14}C *yr BP) does not show significant environmental or climatic nor rapid cultural changes. The largest changes took place around 9000 cal yr BP when the humid early Holocene conditions were replaced by extremely arid but* *highly variable climatic conditions. The onset of such hostile conditions resulted in a marked decrease of human occupation, in the occupation of alternative habitats ('Ecological refuges'), in increased mobility, in a stronger orientation toward the habitats with relatively stable resources (such as the coast, the* puna seca*, and 'ecological refuges'), and in stepwise technological innovations of artifacts. In the most arid and marginal areas of the* Puna Salada *south of the Río Loa (21°S) and the adjacent valleys, the mid-Holocene aridity resulted in some sites even in a hiatus of human occupation (*'Silencio Arqueológico'*, sensu Grosjean et al., 2005b). Such hostile conditions were repeatedly interrupted by sub-decadal humid spells or by short-lived extreme climatic events (floods, droughts, etc.), and lasted until ca. 3500 cal yr BP when modern conditions were established in a stepwise process. This was also the time when the* puna salada *was re-occupied at large, and irrigated agriculture emerged. Domestication of camelids in the South Central Andes (ca 5500 cal yr BP, 4800* ^{14}*C yr BP) falls roughly into the time of interest around 5000 cal yr BP. Although this process is centered in the mid-Holocene harsh conditions, the climate dictate remains debatable because the onset of such harsh conditions preceded domestication by as much as 2000–3000 years.*

1. Introduction

The Atacama Desert of the South Central Andes is today an area with extremely harsh geoecological conditions and marginal resources. Thus, societies based on subsistence economies are highly susceptible to even smallest changes in the climatic and environmental settings and available resources.

As in other subtropical areas of the world, Holocene climatic changes are mainly manifested as variations in the effective moisture budget, whereas changes in temperature were relatively insignificant. This is a fundamental difference with mid- and high-latitude areas and makes the Holocene, as far as subtropical arid and semi-arid areas are concerned, one of the most interesting time windows for the study of high amplitude and abrupt climate changes.

Holocene climatic changes in the Central Andes affected primarily the water cycle (lake levels, spring flow, river discharge, groundwater tables, soil moisture, etc.) and, consequently, flora and fauna. Thus palaeo-ecological archives that record humidity, vegetation, and animal resources are the best sites to study potential impacts of climate change on early hunting–gathering subsistence societies in the Atacama Desert, which were present between ca. 13,000 and 3400 cal yr BP (11,000 and 3200 ^{14}C yr BP). Culturally, this period of time is known as the Archaic Period. It was the time when supplies of and demand for certain natural resources were in a very delicate balance, with critical implications for the demography of human societies.

It was early recognized (Le Paige, 1965; Lanning, 1967, 1973) that many archaeological sites in the Atacama Desert and elsewhere in South America are found in places with very hostile environmental conditions at present, and that paleoenvironments must have been very different from those of today. Thus, a relatively deterministic interdependence between Paleoindian/Archaic human occupation and the paleoenvironment was postulated and documented in many cases (e.g., Cardich, 1980; Massone and Hidalgo, 1981; Fernández, 1984–85; Lynch, 1990; Santoro et al., 1991; Grosjean and Núñez, 1994; Núñez and Grosjean, 1994; Núñez et al., 1994, 1996, 2001, 2002; Grosjean et al., 1997a, 2005a,b; Borrero et al., 1998; Messerli et al., 2000). In the area of the Central Andes, consensus exists that prolonged and severe droughts and arid periods had particularly strong impacts on early societies at times when buffer and storage capacities were still limited (Binford et al., 1997).

Recent advances in multidisciplinary paleoclimate research on tropical glaciers, lake sediments, geomorphologic features, paleosols, groundwater bodies, rodent middens, and pollen profiles in bogs have provided information about large scale, high amplitude, and rapid climate changes in the Central Andes during the Holocene, and have strengthened the hypothesis about the man–environment relationship. Indeed, paleoenvironments play a key-role in understanding the very complex pattern of Paleoindian and Archaic resource use in space and time, for the human occupation of different habitats from the marine coast up to the high elevation lake environments on the *altiplano* above 4500 m altitude (Grosjean et al., 2005b). The combination of archaeological and paleoenvironmental information may also shed light on the question whether climate and cultural changes were synchronous or not, whether there is a causal relationship between climate and culture, and to what extent early cultures were able to shape and manage the landscape toward more efficient resource use and for mitigating high variability or shifts in resources (Lentz, 2000). We may speculate if changes to the socio-economic and cultural patterns were adaptations to new environmental conditions and thus the result of changing environmental boundary conditions.

The aim of this chapter is to review the paleoclimate information for the mid-Holocene (between ca. 8000 and 4000 cal yr BP) in the South Central Andes, to draw a picture of the different habitats of human occupation (marine coast, valleys and *quebradas*, high elevation *puna* habitats and sites), and to compare the paleoclimate scenario with the regional archaeological information in space and time. Major research questions are:

(1) Why did people occupy or abandon specific habitats? Does a hiatus of human occupation or a change in the habitat reflect overly harsh environmental conditions whereas continuous inhabitation is indicative of stable conditions and hence resources through time?
(2) Are cultural or socio-economic changes (e.g., the beginnings of domestication or the adoption of innovative lithic industries) related to changes in the environment, or were technological and cultural changes the result of internal processes of transformation within hunting and gathering societies and aimed directly at a better management and exploitation of the environment?
(3) Was the period around 5000 cal yr BP a particularly interesting period with significant, rapid and high-amplitude climatic changes and adaptive cultural processes?

We emphasize that the unambiguous interpretation of occupations and settlement patterns is still difficult given the current state of knowledge. In some cases, our interpretations will become more complete when archaeological deposits and artifacts are better documented and dated (usually just the basal and top layers of a stratigraphic column are dated) and incomplete regional survey is clarified. In all cases, developing local and detailed environmental reconstructions, including of the geomorphological processes at every individual site, is a prerequisite to achieving a consistent and holistic view of the human–environment relationship in the past (Grosjean et al., 2005a,b).

For the purpose of this chapter, we put the mid-Holocene arid period into the perspective of the entire Holocene, starting with the swing from humid early Holocene to fully arid mid-Holocene conditions between ca. 9500 and 8500 cal yr BP, and ending with the onset of modern climatic conditions around 4000 cal yr BP. This interval brackets the time window around 5000 cal yr BP under investigation herein (see also Sandweiss et al., 1999). We delineate the research area as extending from the marine coast in the west up to the *altiplano* in the east, and from the tropical summer precipitation area in SE Bolivia and Peru at 17°S in the north to the fully arid southern margin of the *altiplano* at 28° in the south (Fig. 3.1). This area is known as the Atacama Desert, and hosts a broad range of habitats and archaeological sites with different assortments of resources such as high elevation open campsites associated with lakes on the *puna* (*dry puna* and *salt puna*), caves,

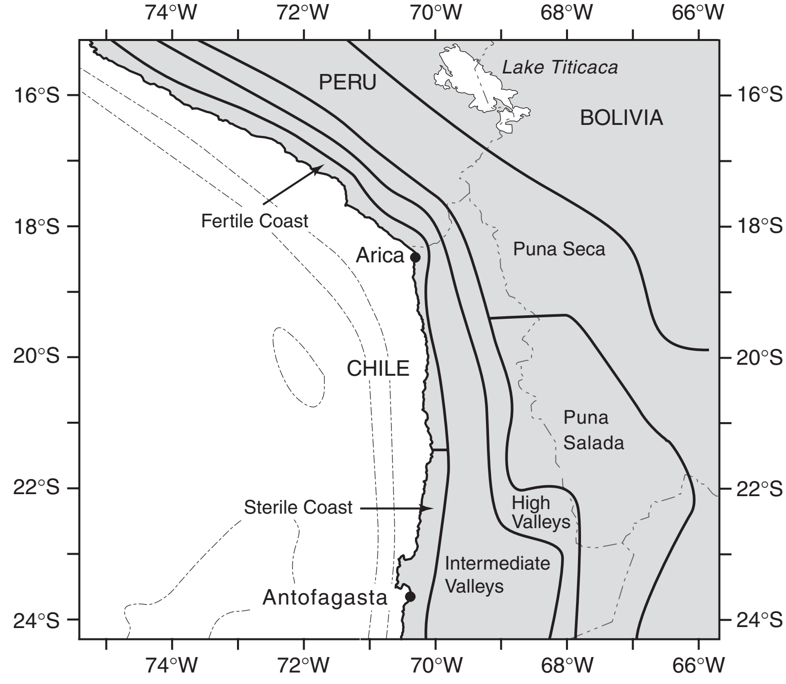


Figure 3.1. Map showing the South Central Andes with different habitats along the fertile and the sterile coast, the intermediate valleys, the high valleys, and the *puna seca* and *puna salada*.

and complex open campsites in intermediate valleys and *quebradas* (dry valleys), and densely occupied sites on the Pacific coast.

Hunters and gatherers in arid areas such as the Atacama Desert were always threatened by the extreme variability of precipitation and unpredictable periods of drought. Therefore, high mobility, and complementary and diversified use of resources in different ecological zones, was an important strategy to live in and to manage a difficult, highly variable environment. This also brought about a regional cultural development with groups that were specialized in certain habitats. However, inter-regional interaction, for instance, between the highlanders and the coastal people, were always very important. This is fundamental when patterns of concentration and dispersion of Archaic settlement in the Atacama Desert are evaluated. In this context it is important to note that a general decrease in resources during times of extreme regional aridity (such as the mid-Holocene) resulted in the formation of ecological refuges where resources were locally still available due to favorable micro-environmental conditions. This in turn led to a major concentration of animals and humans specifically around these areas despite the regional crisis and possibly also regional depopulation. The archaeological sites in these areas are thought to be the nuclei of increasing socio-economic and cultural complexity, semi-sedentarism, and the domestication of flora and fauna (Núñez, 1981; Santoro, 1989; Núñez et al., 1996; Grosjean et al., 1997a; Núñez et al., 2001).

2. The physiogeographical setting

The Andes and the high mountain plateau (*altiplano* or *puna*) form one of the most prominent mountain chains in the world. The unique physiogeographical setting with vertical gradients ranging from sea level up to peaks above 6000 m within less than 150 km horizontal distance is the result of Cenozoic tectonic uplift in the fore-arc region of the active tectonic convergence zone. This created a wide range of geoecological belts with extremely strong and persistent precipitation gradients between the humid windward side and the arid rain-shadow side of the N–S ranging mountain chain. The formation of the Andes led also to a broad vertical range of temperature regimes from hot climates at sea level to continuous permafrost climate above 5600 m, and to a highly variable spatial pattern of topography, slope, aspect, geological, and pedological conditions. All of these variables superposed result in a mosaic of potential habitats with characteristic local water, vegetation, and animal resources. The geoecological conditions may also involve natural hazards such as volcanism, seismic activity, tsunamis, landslides, and debris flows. Some of the variables that combined to form the living space for humans remained constant in time, some others changed very rapidly. However, it was always the humans who decided, based on their subsistence economy, technology, and ideology, whether a given living space at a specific time was regarded as favorable or hostile.

The meso- and macroscale climate of the Atacama Desert is controlled by (1) the SE Pacific Anticyclone (SPA), (2) the cold Humboldt Current, (3) the upper tropospheric Bolivian Anticyclone centered above the eastern Cordillera, and (4) the Westerly circulation belt in the mid-latitudes of Central Chile (Vuille, 1999; Garreaud et al., 2003). The SPA is a quasi-permanent dynamic high-pressure area and forms part of the southern hemisphere Hadley circulation. The all-year-round dry subsiding air masses are largely responsible for the persistent aridity in the coastal areas and the western slope of the Andes in northern Chile and Peru. The SPA also blocks the frontal systems from the zonal Westwind Drift in the mid-latitudes that bring moisture from the Pacific. Eckman upwelling of cold water in the Humboldt current off the Chilean and Peruvian coast stabilizes the SPA, and gives rise to an inversion layer at ca. 800 m altitude with the prominent coastal fog, locally known as *camanchaca*. The coastal range in northern Chile is a very effective local moisture trap for the coastal fog (Schemenauer et al., 1988) and a strong barrier against moisture transport from the Pacific into the interior of the continent. During austral summer, the *altiplano* and the western Cordillera are controlled by the 'Bolivian High' centered above the eastern Cordillera of Bolivia (Hastenrath, 1997). The 'Bolivian High' is regarded as the result of local heating of the high mountain plateau (Gutman and Schwerdtfeger, 1965; Rao and Erdogan, 1989) and latent heat release over Amazonia (Lenters and Cook, 1997). The 'Bolivian High' features strong upper tropospheric divergent flow, lively convection, easterly winds and advection of tropical Atlantic moisture from the continental lowlands east of the Andes (e.g., Hardy et al., 1998; Vuille et al., 1998). Thus the area considered here (i.e., southern Bolivia and Peru, northernmost Chile and NW Argentina) is subject to tropical summer precipitation (*Invierno boliviano*) which decreases with strong gradients from $>450\,\mathrm{mm\,yr^{-1}}$ on the Bolivian *altiplano* to $<200\,\mathrm{mm\,yr^{-1}}$ in adjacent high elevation areas to the west and south in northern Chile, and to $<20\,\mathrm{mm\,yr^{-1}}$ in areas below 2000 m elevation and the coast.

Tropical summer rainfall remains restricted to high elevations above 4000 m in the western Andes (northern Chile), while summer rainfall reaches all elevation belts in the windward very humid eastern slope of the South Central Andes (SE Bolivia and NW Argentina). The western slope of the Andes remains in the fully arid 'rain shadow' but receives some river discharge from the high Andes. A few rivers north of 22°S reach the marine coast. Frontal winter rainfall of the Westwind Drift is the common moisture source for Central Chile (*Invierno chileno*). Frontal systems further north than ca. 28°S are usually blocked by the SE Pacific Anticyclone. However, penetration of fronts is sporadically observed as far north as northernmost Chile and SE Bolivia (Vuille, 1996; Vuille and Ammann, 1997; Vuille and Baumgartner, 1998). Winter precipitation increases toward the south from ca. 100 mm in coastal areas at 27°S to >300 mm at 33°S. Thus, the Atacama Desert is currently located in the extremely dry transition zone between the tropical summer precipitation areas in the north and east (*Invierno boliviano*) and the extratropical winter precipitation areas in the south and west (*Invierno chileno*). The most arid part of this 'Arid Diagonal' crosses the Andes NW–SE at ca. 25°S (Messerli et al., 1993; Arroyo et al., 1998).

Water resources are very scarce today (Grilli, 1989). For instance, the total available water resources for the Región de Antofagasta in northern Chile (126,000 km^2) amounts to 12–18 $\mathrm{m}^3\,\mathrm{s}^{-1}$, the larger proportion being too saline for domestic use. Also most of the endorheic lakes on the Chilean, Argentinean, and Bolivian *altiplano* are seasonally dry, very shallow, and hypersaline (Stoertz and Ericksen, 1974; Chong Diaz, 1984; Vuille and Baumgartner, 1993; Risacher et al., 2003), and the water quality in lakes, springs, groundwater, and rivers is generally affected by naturally high loads of dissolved salt, in particular arsenic. Except the two large freshwater bodies of Lake Titicaca and Lake Chungará which are located in the somewhat more humid ($P > 400\,\mathrm{mm\,yr}^{-1}$) tropical part of the *altiplano* and have a surface or subsurface outflow, the only open water bodies with a surface of a few square kilometers are bound to active geologic fault systems with limited internal drainage (Chong Diaz, 1984; Grosjean, 1994). Small springs (discharge of some 1 $\mathrm{m}^3\,\mathrm{s}^{-1}$) above 2500 m altitude provide water for small bogs and mires with particular ecological conditions (Ruthsatz, 1993, 1995) for animals and humans. Along the ca. 1000 km long coast of northern Chile, there are only five valleys with currently perennial or seasonal rivers connecting the *altiplano* with the Pacific. Besides these estuaries, freshwater is extremely scarce along the coast. At best, there are some small springs fed by the coastal fog, some of them being rather brackish (Núñez and Varela, 1967–68). Some of these places served also as microhabitats combined with nearby marine resources.

In contrast to the scarce terrestrial resources along the coast, the ocean offers stable and predictable resources suitable for permanent human occupation. The coast of northern Chile and southern Peru features the unique arrangement of very hostile fully arid terrestrial conditions with extremely rich marine resources of the cold Humboldt Current. High-nutrient loads of the cold water combined with high solar radiation rates sustain one of the most productive marine ecosystems and food chains in the world, and provide the base for a long tradition of marine subsistence in the coastal areas of the Atacama Desert (Llagostera, 1979, 1982; Sandweiss et al., 1996, 1998).

Terrestrial natural vegetation is an important indicator linking climatic patterns with the living space for animals and humans. Arroyo et al. (1988) show that vascular plant diversity and vegetation cover in the western Andes of northern Chile reflects well the precipitation pattern and the vegetation food resources for subsistence societies. Vegetation cover and species number are highest in the *altiplano* of northernmost Chile (18°S), decrease rapidly toward the coast (rain shadow) and toward the south (Arid Diagonal), and increase again as winter rainfall becomes stronger. In the winter rainfall areas, however, the best conditions for vegetation are found in intermediate altitudes, because low temperatures limit plant growth higher up. The occurrence of terrestrial fauna broadly follows the pattern of the vegetation. Camelids, birds, and rodents are the most important animal groups for hunting (Hesse, 1982; Santoro, 1987). Obviously, the high elevation areas and the areas with river runoff from the mountains are generally the most favorable places, whereas terrestrial resources in the low elevation areas are sparse or totally absent. However, the particular combination between the coastal fog and the moisture trapping coastal range may, in some cases, provide enough moisture to sustain surprisingly dense local vegetation (*Loma* vegetation) and the respective animals.

Natural hazards may also play a role in determining whether a given area is selected as a living space for humans. Numerous active volcanoes are found in the Western Cordillera of southern Peru, Bolivia, and northern Chile between 15°S and 27°S (Zeil, 1986). Numerous volcanic eruptions on the Atacama *altiplano* are reported for historic, Holocene, and late-glacial times (Gardeweg et al., 1984; Francis et al., 1985; Glaze et al., 1989). Some of these eruptions resulted in the collapse of large massifs, triggered immense debris flows and lahars, devastated large areas, and changed in some cases completely the hydrological drainage of a watershed. A debris avalanche, for instance, formed Lake Chungará after the late-glacial collapse of Vn. Parinacota, which dammed the earlier westward drainage (Francis and Wells, 1988). Volcanism in the Andes plays also an important role with regard to raw materials for lithic artifacts. Obsidian and basalt are usually found in the high elevation areas with Cenozoic volcanism, whereas the coastal range and the intermediate zone of the Precordillera with low-grade metamorphic rocks, Cenozoic alluvial material, and sedimentary rocks do not provide first-choice raw material for lithic artifacts. Exceptions are Devonian flint stone nodules or fine-grained sandstones.

However, earthquakes, occasional tsunamis, and volcanic eruptions are low-frequency catastrophes of rather local significance. If devastating, the impact is expected to be found in the stratigraphies of archaeological sites, which is, however, hardly observed in the Atacama (Schiappacasse and Niemeyer, 1984). Furthermore, new studies from Middle America suggest that relatively simple societies tended to recover from sudden stress of explosive volcanism more readily than complex societies (Sheets, 2001). In summary, we conclude that natural hazards and low-frequency catastrophes, although present, did not play a major role in the general regional settlement pattern over the time scales of centuries or millennia considered in this chapter.

3. Habitats for human occupation in the Atacama Desert

In order to compare the settlement patterns within and between the different sectors of the South Central Andes, we distinguish several types of habitats. Each one is characterized by a specific combination of ecological conditions (Fig. 3.1). Table 3.1 summarizes the different habitats with a qualitative index for biomass productivity and predictability (stability) of the food and water resources for human populations. We hypothesize that these two criteria were crucial when Archaic hunters and gatherers evaluated an area as a potential living space. We also expect that areas with low to medium productivity or stability were the areas which were first affected by changes in the environmental conditions, and where climatic changes had the largest impact. Thus we hypothesize that, during the mid-Holocene arid intervals, the humans not only in the *puna salada*, in the high valleys and *quebradas* but also in the intermediate

Table 3.1. Different habitats in the Atacama Desert and qualitative indices for freshwater availability, biomass production and resource stability.

Habitat	Freshwater	Biomass	Predictability
Fertile marine coast	Moderate	Marine: very high Terrestrial: very low	High
Sterile marine coast	Very low	Marine: very high Terrestrial: very low	High
Valleys, *quebradas*, oases at intermediate altitude	Low	Very low	Low
Valleys and *quebradas* towards the Andes	Moderate	Medium to high	Medium
Puna seca	Moderate	High	High
Puna salada	Moderate	Medium	Medium

areas would show the strongest impact of climate change in their cultural patterns, whereas decreasing terrestrial resources in the coastal areas and the *puna seca* did not reach the critically low levels to permanently threaten human societies.

3.1. Fertile marine coast

The coast of Peru and Chile has extremely rich and stable marine resources but terrestrial flora and fauna are very scarce. The marine food resources include a broad variety of mollusks, fish and marine mammals such as the sea lion. The marine resources are, despite variability in El Niño-Southern Oscillation (ENSO) and the ocean currents, hardly affected to the extent observed in terrestrial ecosystems, making marine resources a reliable, stable, and predictable food supply (Schiappacasse and Niemeyer, 1984; Santoro, 1987).

Only a few rivers cut through the coastal range between Majes and Pisagua (17–20°S) and convey freshwater from the mountains to the Pacific coast. Particularly favorable habitats are located around their estuaries, where the very rich and stable marine resources are complemented with fresh water, land mammals (camelids, rodents), birds, freshwater shrimp, fruits of trees (*Prosopis* sp., *Geoffrea* c.), and roots of totora (*Typha* sp.). Totora fiber was likely a very important material for construction, rope making, and cloth. The oases along such rivers reach 5–10 km inland (Fig. 3.1).

3.2. Sterile marine coast

Except the Río Loa, there is no river cutting through the coastal range between Pisagua and Chañaral (20–27°S). Thus, the Pacific coast in this area is disconnected from the high Andean freshwater resources and is fully arid. The local freshwater supply is restricted to trapped moisture from the coastal fog or small brackish groundwater wells in the interior (Núñez and Varela, 1967–68). The habitats along the sterile coast are almost exclusively based on marine resources that are as abundant and reliable as in the coastal areas further north (Fig. 3.1).

3.3. Valleys, quebradas (dry valleys), and oases at intermediate altitude

This area stretches from the coastal range to the foot zone of the high Andes and ranges between 500 and 2500 m. In the Precordillera west of the Salar de Atacama – Salar Punta Negra Graben (23–24°S), this zone reaches up to 3500 m (Fig. 3.1). The habitat is characterized by extremely arid conditions in the rain shadow of the Cordillera de los Andes. In the northern sector adjacent to the fertile coast, few oases in the interior of the transversal valleys provide living space, whereas fully arid endorheic basins and salt lakes (*Salar*) are found south of Quebrada Tiliviche (20°S, Fig. 3.1). Most of these habitats are extremely arid today. The oases are located along the few rivers from the high Andes (Arica valleys), around springs in *quebradas* (e.g., Tana and Tiliviche, Aragón, Tarapacá, and El Médano), or groundwater wells in *Salars* such as the Pampa del Tamarugal. These habitats are well-defined ecological refuges with limited resources (food and water) surrounded by extremely hostile conditions (True et al., 1970, 1971; Núñez and Zlatar, 1980; True and Gildersleeve, 1980). These habitats are fully based on scarce terrestrial resources (few camelids, rodents, birds, freshwater crustaceans, fruits of trees, *Totora* roots, etc.) and limited in their extent, which makes them highly vulnerable to climate fluctuations. Resources were very scarce and hardly predictable. However, some locations were important source areas with raw material (quartz nodules, chalcedony) for lithic artifacts.

3.4. Valleys and quebradas toward the Andes

Habitats in this area are located in higher elevation valleys and quebradas (dry valleys), between 2500 and 4000 m and connected with the high Cordillera (Fig. 3.1). In contrast to the lower elevation valleys, these sites benefit from the freshwater resources and higher precipitation rates of the high mountains. Besides many open camp sites, some of the archaeological sites are located in caves or well-protected rock shelters, on ridges, in deep valleys and near wetlands in confluence areas of rivers.

The northern part of this area is located adjacent to the more humid *Puna Seca* of southern Peru and northernmost Chile, and consists of deep valleys, steep and gentle slopes. Precipitation rates are between 200 and 300 mm yr^{-1}. A rather dense vegetation of shrubs (matorral) provides good grazing areas for camelids (guanacos and vicuñas), rodents (e.g., *Vizcacha* sp., *Ctenomis*), and taruca (*Hippocamelus* sp.), a small deer.

Geoecological conditions become harsher in valleys and quebradas toward the south, adjacent to the *Puna Salada* of northern Chile. Among the most important focal points of human occupation is a series of salars in the foot zone of the high Andes (Salar de Atacama, Salar Punta Negra) that receive fresh water from the high Cordillera. Although local precipitation is below 100 mm yr^{-1} today, many springs and groundwater wells provide favorable habitats with a rich flora and fauna. These habitats were located near the *puna* (above 4000 m) where many different geoecological zones and altitudinal belts were readily accessible and best conditions were given for a complementary use of different resources at different times of the year. A transhumant pattern of resource use (e.g., Núñez, 1981) seems obvious, and is in modern times as important as in the past. Although these habitats are favorable in many respects, the overall relative scarcity of resources (particularly in the southern part) and the relatively high variability (and low predictability) puts limits to the suitability of this area as a permanent living space for Archaic hunters and gatherers.

3.5. High puna (puna seca and puna salada)

The high elevation grasslands of the western Andes and the high mountain plateau (*altiplano*, above 4000 m) provide, as far as food and water are concerned, widespread favorable habitats for human occupation. The best places are usually found around the endorheic brackish lakes (some of them with freshwater) and salt lakes, or near the many small freshwater springs with little ponds and wetland vegetation (bogs and mires). Higher precipitation rates in the mountains (>200 mm yr^{-1}) provide enough moisture for disperse grass and herb vegetation (maximum cover 40–60%), and abundant animal life. In contrast to all the other habitats, the resources on the *puna* are not restricted to some favorable sites (linear or point sources), but are rather dispersed.

Following the gradients of rainfall and vegetation, the high elevation area of the South Central Andes includes the more humid *puna seca* in the north and northeast (southern Peru and Bolivia, NW Argentina and northernmost Chile), and the very arid *puna salada* in the southern part of the Atacama Desert (Arroyo et al., 1988; Santoro, 1989; Troll, 1958; Fig. 3.1). Within the *puna seca*, the areas of NW Argentina and SE Bolivia show the highest rainfall rates and the best environmental conditions regarding water and food resources. Thus we expect that these areas are the most stable human habitats (relatively speaking) with relatively low susceptibility to climatic changes, whereas the most vulnerable areas were those of the *puna salada* in the highlands of Chile south of the Río Loa.

In the *puna seca*, the list of hunted animals includes *vicuñas*, small rodents (*vizcacha*, *chinchilla*, *cholulos*), birds (ostrich, *suri*, flamingos, partridge, geese, ducks), and a wide range of plant products. The widespread grass cover (mainly *Stipa* sp. and *Festuca* sp.) provides good grazing areas for animals, and the surprisingly large wetlands (*humedales, bofedales, vegas*) are excellent habitats for camelids and birds

(Aldenderfer, 1989; Santoro, 1989). The habitats in the *puna salada* are similar to those of the *puna se*ca. However, the favorable sites are more local, smaller in size, and isolated from each other.

4. Mid-Holocene aridity: Hostile conditions and scarce resources around 5000 cal yr BP

Lake sediment and ice cores, pollen profiles, plant macrofossils preserved in rodent middens, geomorphic features, and paleosol indicators provide consistent multiproxy evidence of a dramatic decrease in average, century-to-millennial scale effective moisture during mid-Holocene times (roughly between ca. 9000 and 4000 cal yr BP). However, the issue of the mid-Holocene climate in this area has been subject to debate (Betancourt et al., 2000; Grosjean, 2001 and discussion therein; Latorre et al., 2002, 2003, 2007; Rech et al., 2002, 2003; Grosjean et al., 2003; Maldonado et al., 2005). In our view, much of this debate arose because (1) vegetation macrofossils in rodent middens record discrete and (maybe) highly variable (sub)decade-scale humid spells that are not (or poorly) recorded in lake sediments or ice cores; these in turn reflect the smoothed average mid- to long-term climate evolution (for discussion Grosjean et al., 2003) and (2) we interpret the higher groundwater tables in valleys as local features driven by geomorphic processes (Grosjean, 2001) and not as regional features driven by humid climates (Rech et al., 2002, 2003).

At multi-centennial to millennial scales, Mid-Holocene aridity was significantly greater than today, and affected the entire geo-bio-hydrosphere. Model calculations suggest that mid-Holocene annual precipitation rates in the Titicaca area were on average 18% lower than today (Talbi et al., 1999). The amplitude and rate of change at the beginning of the mid-Holocene was unique in the light of the preceding much more humid early Holocene environmental conditions.

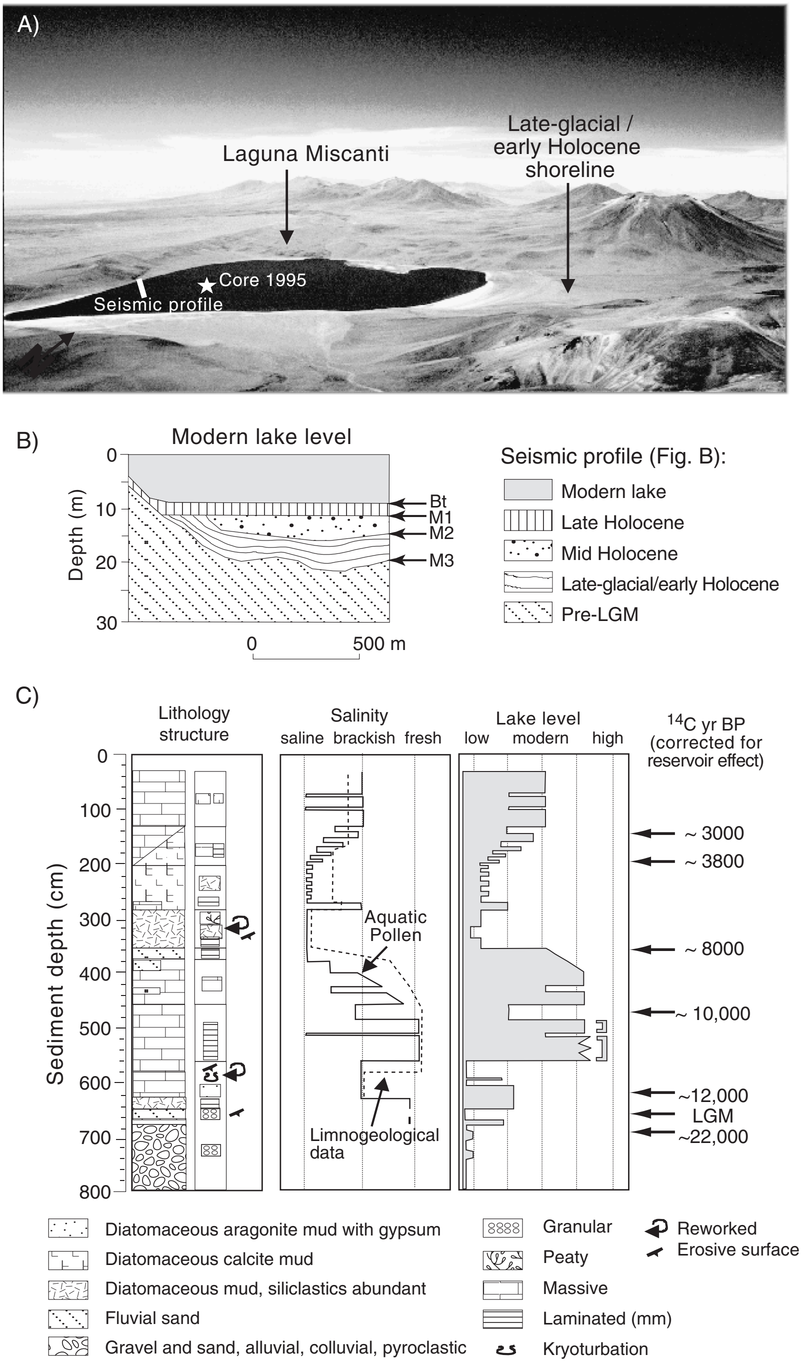
4.1. Lake sediment and ice core records

The small endorheic lakes on the *altiplano* respond very sensitively and in a most direct way to even smallest changes in the effective moisture budget (precipitation–evaporation). Thus chemical, mineralogical, and physical properties of lake sediments and lake level changes provide information about climate change in the past. Laguna Miscanti (23°45′S, 67°45′W, 4000 m) and Laguna del Negro Francisco (27°30′S, 69°14′W, 4125 m) in northern Chile, Lake Titicaca in Bolivia, and a transect of six small Bolivian lakes between 14°S and 20°S lakes are the best studied sites regarding Holocene limnogeological changes in this part of the *altiplano*. All of the these sites show a consistent picture although the timing of the onset and the end of the mid-Holocene drought varies to some extent from site to site because of the time-space transgressive nature of climate change (Abbott et al., 1997, 2003; Grosjean et al., 2001, 2003; Tapia et al., 2003 and references therein); Laguna Miscanti is given as an example here.

Laguna Miscanti (23°44′S, 67°46′W, 4140 m) is a relatively large (15.5 km^2) 10-m deep endorheic lake with brackish (6.4–6.9 $\mathrm{mS\,cm}^{-1}$) alkaline (pH 8.0) water. The catchment area is about 320 km^2. Limited amounts of water seep through a lava flow along the Quebrada Nacimiento Fault into Laguna Miñiques. Seismic data and information about the depositional environment, mineralogical, and chemical compositions of autigenic lake sediments provide detailed insight into the Holocene paleolake history, and the respective climatic changes (Fig. 3.2, for detailed discussion: Grosjean et al., 2001, 2003). We use the ^{14}C reservoir-corrected chronology for regional lake level changes (Geyh et al., 1999). Seismic data show four main reflectors that define three major lake sediment units (Valero-Garcés et al., 1996).

The *lowermost seismic unit* corresponds to the sediments of the late-glacial/early Holocene paleolake transgression between ca. 12,000 and 8000 ^{14}C yr BP (between 14,000 and 9000 cal yr BP). This unit consists mainly of diatomaceous mud with brackish to freshwater calcite. Gypsum concentrations are very low, and the sedimentary facies suggests pelagic conditions. These sediments correspond stratigraphically to algal bioherms and shoreline carbonates of fossil beach deposits 25 m above the current lake level. Similar paleolake features on the Bolivian *altiplano* are known as the 'Tauca' and 'Coipasa' paleolake phases (Servant and Fontes, 1978; Servant et al., 1995; Wirrmann and Mourguiart, 1995; Sylvestre et al., 1996, 1999; Bradbury et al., 2001; Placzek et al., 2006). Model calculations suggest for this time a significant increase in precipitation by a factor of 3 (annual rates of >600 mm at 23°S compared to the modern ca. 200 mm, $\Delta P = 400$ mm), a similar increase in cloudiness and reduction of evaporation rates (Grosjean, 1994). Latorre et al. (2007) found a similar factor of precipitation increase in elevations at 3000 m (from 40 to 120 mm per year). These results compare with earlier estimates for Bolivia (Hastenrath and Kutzbach, 1985; Kessler, 1991) where ΔP was estimated to ca. 200 $\mathrm{mm\,yr}^{-1}$. Long-distance transported pollen from the east side of the Andes, the spatial pattern of the paleolakes, the gradients of equilibrium line altitudes and the geometry of glaciers in southern Bolivia and northern Chile, and the dominance of summer flowering plants in rodent middens (Markgraf, 1989, 1993; Kessler, 1991; Grosjean et al., 1995; Jenny and Kammer, 1996; Clapperton et al., 1997; Kull and Grosjean, 1998, 2000; Kull, 1999; Betancourt et al., 2000; Kull et al., 2002; Latorre et al., 2002, 2003, 2006, 2007; Maldonado et al., 2005) suggest that the increase in effective moisture was mainly due to strengthened tropical summer precipitation from the eastern side of the Andes. This in turn resulted in a strong rain shadow effect and fully arid conditions in intermediate elevations (below ca. 3000 m) on the western slope of the South Central Andes and on the Pacific coast during early Holocene times.

The *middle lacustrine seismic unit* of Laguna Miscanti (Fig. 3.2) encompasses the sediments deposited during the fully arid mid-Holocene period (between <9000 and ca. 4000 cal yr BP, Grosjean et al., 2001). The irregular and poorly stratified reflectors suggest heterogeneous deposition in a fluctuating shallow water environment. Aragonite precipitation, high gypsum contents, hardpans, and evaporite crusts suggest conditions of an ephemeral saline pan–saline lake with sub-aerial


A)
Laguna Miscanti
Late-glacial / early Holocene shoreline
Core 1995
Seismic profile
B)
Modern lake level
Depth (m)
0
10
20
30
Bt
M1
M2
M3
0
500 m
Seismic profile (Fig. B):
Modern lake
Late Holocene
Mid Holocene
Late-glacial/early Holocene
Pre-LGM
C)
Lithology structure
Salinity
saline brackish fresh
Lake level
low modern high
^{14}C yr BP (corrected for reservoir effect)
Sediment depth (cm)
0
100
200
300
400
500
600
700
800
Aquatic Pollen
Limnogeological data
~ 3000
~ 3800
~ 8000
~ 10,000
~12,000
LGM
~22,000
Diatomaceous aragonite mud with gypsum
Diatomaceous calcite mud
Diatomaceous mud, siliclastics abundant
Fluvial sand
Gravel and sand, alluvial, colluvial, pyroclastic
Granular
Peaty
Massive
Laminated (mm)
Kryoturbation
Reworked
Erosive surface

exposure of the sediments at times. The early Holocene lake sediments were exposed to erosion and truncated in the littoral part of the lake, washed into the central part of the basin or blown out. In light of the fact that levels of endorheic lakes are among the best and most direct indicators for effective moisture budgets of the past, the truncation of the sediments and the substantially lower lake level of Miscanti is one of the strongest arguments showing mid-Holocene aridity at centennial and millennial scales in this part of the Andes. However, it is important to note that the mid-Holocene sediments of Laguna Miscanti do record pronounced climate variability at the multi-decadal to decadal or shorter scale because of the inertia of the system. However, it is most likely and suggested by middens data (Latorre et al., 2003, 2006) that interannual to subdecadal variability was also high. The lake sediment data currently available are not able to provide such information. A distinct humid spell is noted around 6000–5500 cal yr BP (Grosjean et al., 2003).

Dramatic drops in lake levels are also reported for Lago Wiñaymarka, the southern sub-basin of Lake Titicaca in Bolivia. Using transfer-functions for ostracod assemblages Mourguiart and Roux (1990), Mourguiart and Carbonel (1994), and Mourguiart et al. (1998) provided quantitative evidence for extremely low lake levels (15 m lower than today) and high salinity ($30\,\mathrm{mg\,l^{-1}}$ compared to modern ca. $1\,\mathrm{mg\,l^{-1}}$) between 9000 and 4400 cal yr BP (8100 and 3900 ^{14}C yr BP). This included also a very dry event centered around 6200–6000 cal yr BP (5300 ^{14}C yr BP) and compares favorably with earlier sedimentological evidence for low mid-Holocene lake levels in the southern basin of Titicaca (Wirrmann and De Oliveira, 1987). Pollen analysis shows that algae are almost missing in this section of the lake sediment core (Ybert, 1992). Detailed seismic profiles suggest that the level in the northern basin of Lake Titicaca dropped by as much as –85 m during this period of time (Seltzer et al., 1998; Tapia et al., 2003). Interestingly, lake sediment cores from the tropical eastern side of the Bolivian Andes (Siberia Lake 18°S, 64°45′W, 2920 m, Sifeddine et al., 1998), and the only studied lake in the southernmost *altiplano* (Laguna del Negro Francisco at 27°30′S, 69°14′W, 4125 m, Grosjean et al., 1997b), also provide convincing evidence of macro-regional mid-Holocene aridity.

The *upper lacustrine seismic unit* in Laguna Miscanti (Fig. 3.2) extends from ca. 4000 cal yr BP to the present. The sediments consist of banded to laminated diatomaceous calcitic mud rich in charophytes. Aragonite is again replaced by

Figure 3.2. View of Laguna Miscanti from Cerro Miñiques showing the location of the seismic profile (Fig. 3.2b) and the site of the sediment core (Fig. 3.2c). Figure 3.2b shows the schematic seismic profile with the late-glacial/early Holocene, mid-Holocene and late Holocene lake sediments (after Valero-Garcés et al., 1996). Figure 3.2c shows the sedimentology and lithology of the sediment core, the major mineralogical components (XRD), and SO_4 concentrations as an indicator of gypsum content and thus salinity. The reconstruction of the salinity and lake level changes is based on limnogeological and pollen data (Grosjean et al., 2001).

magnesian calcite, and gypsum contents are low. This suggests increasing lake levels and the formation of the modern brackish perennial 8–9 m deep lake. This is consistent with the on-lap geometry of the upper seismic sediment unit, which was deposited on top of the mid-Holocene sediments in the central part of the basin, and on top of the truncated early Holocene sediments with the erosion surface in the littoral part of the lake. The ^{14}C reservoir-corrected chronology of the lake level changes suggests that the swing from the saline mid-Holocene to the brackish late Holocene lake took place in several steps back and forth between ca. 3600 and 3000 ^{14}C yr BP (between 4000 and 3200 cal yr BP). A broadly similar timing for increasing lake levels was also found in Laguna del Negro Francisco (Grosjean et al., 1997b), in Lake Titicaca (Wirrmann and De Oliveira, 1987; Martin et al., 1993; Abbott et al., 1997; Binford et al., 1997; Mourguiart et al., 1997, 1998; Tapia et al., 2003), in the eastern Cordillera (Abbott et al., 2003) and on the eastern slope of the Bolivian Andes (lake Siberia 2900 m, Sifeddine et al., 1998) suggesting that this marked increase in lake levels and humidity was a supra-regional climate signal that started first in the northeast, extended progressively to the southwest, and terminated the mid-Holocene aridity in the South Central Andes at large.

The history of humidity changes as drawn from lake sediment records is also well reflected in the paleoclimatic archives of ice cores from tropical glaciers in the South Central Andes (e.g., Thompson et al., 1995, 1998). In particular, the ice core from Sajama (Thompson et al., 1998) shows high accumulation rates and low sulfate and chloride concentrations, which is indicative of relatively humid climatic conditions with large paleolakes and small atmospheric loads of evaporite minerals from the *altiplano* lake basins. Accumulation rates decrease and ion concentrations increase with the onset of mid-Holocene arid conditions suggesting that humidity decreased, the paleolakes disappeared, and the former paleolake basins were exposed to aeolian erosion. The mid-Holocene section of the ice core shows numerous extraordinary peaks of dust and soluble ions, again suggesting highly variable climatic conditions with extreme events at a generally very arid background climate. The time window around 5000 cal yr BP shows a significant peak in dust and nitrate. However, comparable peaks are found throughout the mid- and late Holocene period. Thus the ice core of Sajama does not seem to provide information about a significant change in climatic conditions around 5000 cal yr BP.

4.2. Vegetation records

The vegetation history as recorded in pollen profiles shows a picture of mid-Holocene aridity in the western South Central Andes and the Chilean coast between 18°S and 35°S. The database has substantially increased in recent years.

The pollen profile of Laguna Seca (18°11′S, 69°15′W, 4500 m, Fig. 3.3) in northernmost Chile shows the vegetation history of a high elevation site in the tropical summer rainfall regime. Baied (1991) described three different pollen zones. The chronology, however, is poor (two ^{14}C dates). Gramineae are dominant

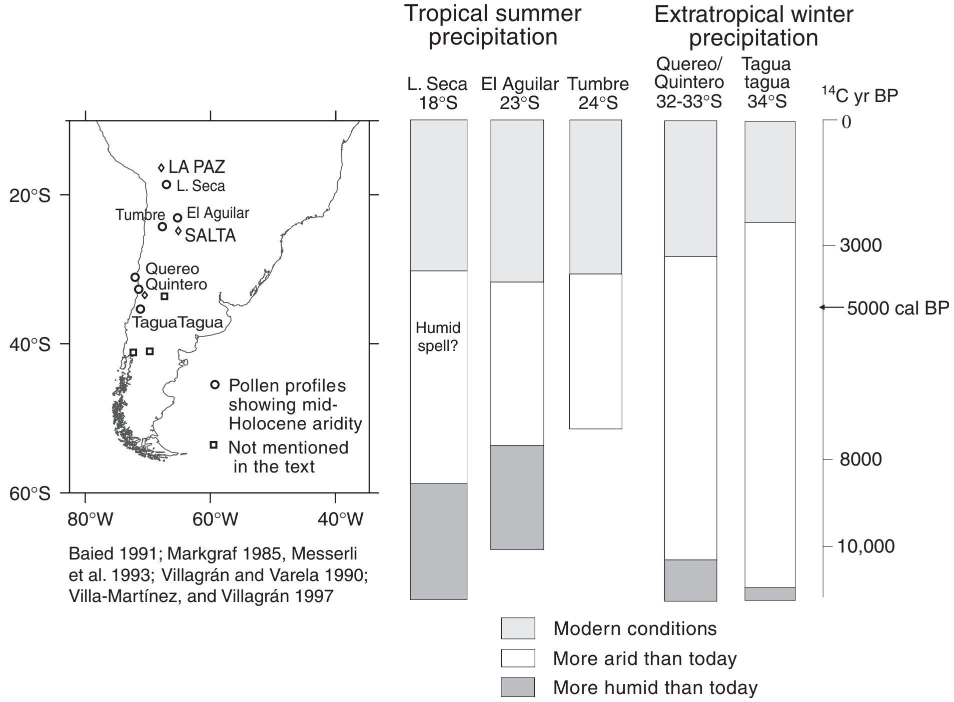


Figure 3.3. Pollen profiles in the South Central Andes and adjacent areas showing the mid-Holocene aridity. Modern vegetation patterns were established largely around 3200 cal yr BP (3000 ^{14}C yr BP). The marked shift from humid to arid conditions is observed at the end of the Pleistocene in areas with extratropical winter rainfall and around 9000 cal yr BP (8000 ^{14}C yr BP) in areas with tropical summer rainfall.

($>$55%) in the late-glacial and early Holocene section (Zone 1) and long-distance transported pollen (ca. 5%) from the subtropical montane and lowland forest east of the Andes is relatively abundant. These features suggest moister conditions than today with strengthened easterly airflow and tropical summer rainfall. Long-distance pollen decreases in pollen Zone 2 (after ca. 9000 cal yr BP) suggesting increasing aridity. This trend culminated in pollen Zone 3 (after ca. 8000 cal yr BP) when the lake was replaced by peat land, and generally arid and warm mid-Holocene conditions were established. This compares with the general lake level history as described above. However, pollen from aquatic taxa and long-distance arboreal pollen from the East suggest a spell of increased moisture tentatively assigned to ca. 5800–5500 cal yr BP, which was also found in Laguna Miscanti (Grosjean et al., 2003). The first human impact on the vegetation is estimated to ca. 3500 cal yr BP (Baied, 1991), which is broadly synchronous with the rise of the lake levels.

The vegetation history of a high elevation site in NW Argentina (El Aguilar, 23°05′S, 65°45′W, 4000 m, Markgraf, 1985) suggests that relatively moist conditions lasted until ca. 8300 cal yr BP (7500 ^{14}C yr BP). Long-distance pollen from the east side of the Andes disappeared at around this time. Dry mid-Holocene conditions prevailed until ca. 4500 cal yr BP (4000 ^{14}C yr BP) when modern conditions were established.

The pollen profile at Tumbre (23°19′S, 67°47′W, 3880 m, Graf, 1992) east of the Atacama basin covers the last 8300 cal yr BP (basal date 7500 ± 80 ^{14}C yr BP). The chronology is relatively well-constrained with seven ^{14}C dates. Graf (1992, pp. 36–106) concluded from the high percentage of Gramineae pollen (70–85%) that more humid conditions than today prevailed between 7400 and 2000 cal yr BP (between 6500 and 2000 ^{14}C yr BP). This finding is based on pollen percentages and not on pollen concentrations and disagrees with all the other available paleodata. However, based on Graf's data, we argue that the almost complete absence of wetland taxa (e.g., Cyperaceae) between 7200 and 4200 cal yr BP (6200 and ca. 3800 ^{14}C yr BP) speaks clearly for local dry mid-Holocene conditions instead, when the moisture supply for the peat bog was limited, and the wetlands were much smaller or partly absent.

Pollen in the sediments of nearby Laguna Miscanti (23°44′S, 67°46′W, 4140 m) provides a detailed high-resolution record of vegetation history covering the last 22,000 ^{14}C yr BP (Grosjean et al., 2001, analyst J. van Leeuwen). The mid-Holocene aridity is clearly found in the pollen record as aquatic freshwater taxa (*Myriophyllum* and *Ranunculus*-type) decreased gradually after ca. 9000 cal yr BP (ca. 8000 ^{14}C yr BP), and disappeared completely after ca. 8000 cal yr BP until 6900 cal yr BP, suggesting that the lake desiccated. However, Cyperaceae pollen implies patches of swamps in littoral areas and wetlands in the exposed bottom of the former lake. Subsequently, *Ruppia* returned while Cyperacea disappeared. We think that a saline shallow lake or wetlands was established (between ca. 6900 and 4000 cal yr BP) as it was also found in the limnogeological data (Fig. 3.2). The gradual initial swing to the modern aquatic vegetation is observed around or after 4000 cal yr BP.

Interestingly, the percentages of terrestrial pollen (relative abundance of the different pollen groups) in the lake sediments do not show the mid-Holocene aridity. Terrestrial pollen percentages show for some groups (e.g., Adesmia-type) the humid early and late Holocene; most other groups show no significant difference compared to the mid-Holocene. It is suggested that the overall species composition did not change much, which is consistent and expected under a persistent summer rainfall regime throughout the Holocene (e.g., Betancourt et al., 2000). However, the pollen concentration and the pollen flux rate (which we use as a proxy indicator of vegetation density and thus biomass productivity) show for most groups significantly reduced values during the mid-Holocene compared with the early and late Holocene (Grosjean et al., 2003). Pollen concentrations thus suggest overall reduced mid-Holocene vegetation cover (and biomass productivity), while the species composition remained largely the same. This would be indicative of more arid conditions relative to the present days. Rodent midden records (e.g., Betancourt et al., 2000; Latorre et al., 2002) provide vegetation information comparable to 'species compositions' and 'pollen percentages' (in the 'pollen language') but do not inform about midden production rates, rodent population density, and vegetation density (biomass productivity) as revealed by 'pollen concentration' and 'pollen flux'. It is, therefore, not surprising that the midden data show a picture comparable to that of the pollen percentages. Thus no indication for a marked dry period during the mid-Holocene is expected. But if the number of midden samples per unit time (production rate of middens) is regarded as a proxy of rodent population density, which in turn is a function of food availability, biomass productivity, and ultimately humidity (Lima et al., 2002), the midden data set (Latorre et al., 2002, 2003, 2007) shows indeed a marked mid-Holocene decline (Núñez et al., 2002).

Very interesting is the study of pollen in rodent middens along an altitudinal transect at Quabrada del Chaco (25.5°S) between 2670 and 3500 m elevation (Maldonado et al., 2005) showing that the timing of humid phases is very different in the upper elevation zone (summer precipitation regime) and the lower zone (winter precipitation regime). While the pluvial in the winter precipitation regime lasted until ca. 14,000 cal yr BP, late-glacial humid conditions related to summer precipitation prevailed exclusively in the upper elevation zone (14,000–11,000 cal yr BP). The Holocene record is very scarce at Quebrada del Chaco (Maldonado et al., 2005) suggesting overall very low primary production and, consequently, very low midden production.

Further south in the winter rainfall areas of the north-central Chilean coast 31–32°S, Cyperaceae, aquatic taxa, and arboreal pollen suggest humid conditions during late-glacial times. Aquatic taxa and arboreal pollen disappeared almost completely during the arid period between ca. 11,200–9900 and 3200 cal yr BP (10,000 and ca. 3000 ^{14}C yr BP). In some places, Cyperaceae pollen suggest that humidity returned slowly after ca. 4500 cal yr BP (4000 ^{14}C yr BP, Villagrán and Varela, 1990; Villa-Martínez and Villagrán, 1997; Maldonado and Villagrán, 2002; Maldonado and Villagran, 2006). Aquatic taxa returned by ca. 3200 cal yr BP (3000 ^{14}C yr BP), and re-colonization by forest taxa is observed after ca. 2000 cal yr BP. The period with scarce vegetation falls well into the time of coastal dune mobilization observed between 5800 and 4200 cal yr BP (5000 and 3800 ^{14}C yr BP, Villa-Martínez and Villagrán, 1997). Modern vegetation patterns were established broadly after ca. 4000 cal yr BP (around 3700 ^{14}C yr BP) at Quereo 31°55′S, Quintero 32°47′S, Quintero II 32°47′S, and Santa Julia 32°49′S (Villagrán and Varela, 1990; Villa-Martínez and Villagrán, 1997).

Particular and very powerful paleobotanic archives thus are the plant macrofossils preserved in rodent middens (Latorre et al., 2002, 2003, 2006, 2007). While the late-glacial early Holocene pluvial is consistently found in all the sites, the onset of Holocene aridity differs at the various sites, with a general trend toward progressively earlier desiccation to the south (Latorre et al., 2006). The mid-Holocene records show large variability that is not recorded in the lake sediment archives.

4.3. Geomorphic and paleosol records

Although the records of geomorphic processes and paleosol formation are often discontinuous and heterogeneous, they add important information about paleoclimatic conditions. Geomorphological records, particularly alluvial deposits, may also register short-lived climatic events of a few hours or days of duration, whereas vegetation and lake systems usually integrate seasons, years, or decades of paleoclimatic information.

Alluvial deposits in the Puripica valley of northern Chile (22°50′S, 68°04′W, 3250 m, Grosjean et al., 1997a) provide insight into mid-Holocene storm activity and climate variability. Deposits of more than 30 individual debris flows were identified between ca. 7200 and 3300 cal yr BP (between 6200 and 3100 ^{14}C yr BP). The individual deposits are interpreted as the result of low-frequency heavy storms during a hyperarid background climate with poor vegetation erosion control. The heaviest storms seem to have occurred every 500–1500 years, i.e., around 5900 cal yr BP (5080 ^{14}C yr BP), a short time before 4300–4000 cal yr BP (3790 ^{14}C yr BP), and at ca. 3500 cal yr BP (3300 ^{14}C yr BP), while moderate storms are registered every 100–200 years.

These mid-Holocene storms were of regional significance. In the Salar de Atacama, southwest of Puripica, these events are recorded in sediment profiles as fine-grained flood deposits embedded in aeolian sand. The earliest documented flood occurred at ca. 6400 cal yr BP (5605 ± 65 ^{14}C yr BP), close to the beginning of the Puripica stratigraphy (Grosjean and Núñez, 1994). Such episodic floods may also explain mid-Holocene groundwater recharge in the low-elevation areas of the Atacama Desert (Aravena, 1995), which is difficult to interpret in the light of hyperarid climate at that time. Siliciclastic inwash in the mid-Holocene sediments of Laguna Miscanti (Valero-Garcés et al., 1996) provides further evidence of regional storm activity. We also interpret the sandy matrix in the lower section of the Tumbre pollen profile (23°30′S, 3880 m, Graf, 1992) as the result of a geomorphologically unstable valley floor and alluvial activity ending around 4300 cal yr BP (3800 ^{14}C yr BP). Afterwards, peat started to dominate the Tumbre profile, suggesting that the alluvial activity decreased and stable groundwater-fed wetlands were established. The repeated short-term cycles of flooding and desiccation in the mid-Holocene sediments of Laguna del Negro Francisco (27°S) between ca. 7000 and 3900 cal yr BP (6000 and 3600 ^{14}C yr BP, Grosjean et al., 1997b) suggest a similar highly variable climate in the southwest of the *puna salada*. However, a causal link with the storms at Puripica and with the ENSO-phenomenon in general remains, in our view, inconclusive and speculative. Strong alluvial activity, scarce vegetation cover, and a hiatus in soil formation were also observed in the coastal range and the Andes of Central Chile 27–33°S between 5800 and 4000 cal yr BP (5100 and 3700 ^{14}C yr BP, Veit, 1995, 1996), and on the coast of southern Peru (Fontugne et al., 1999). Lowest lake levels in this area date to the time between 9500 and 5700 cal yr BP modern levels were reached 3200 cal yr BP (Jenny et al., 2002). Also in the *Puna Seca* of southern Peru (17°S, 3450 m), the sediment stratigraphy shows evidence of successive alluvial deposition between ca. 7800 and 6000 cal yr BP (7000 and 5200 ^{14}C yr BP, Aldenderfer, 1993).

A typical feature of mid-Holocene geomorphological activity is the infilling of steep valleys with fine-grained siliciclastic and organic (peat, diatoms) sediments. Such sediments are observed in the Salar de Atacama area (Grosjean et al., 1997a;

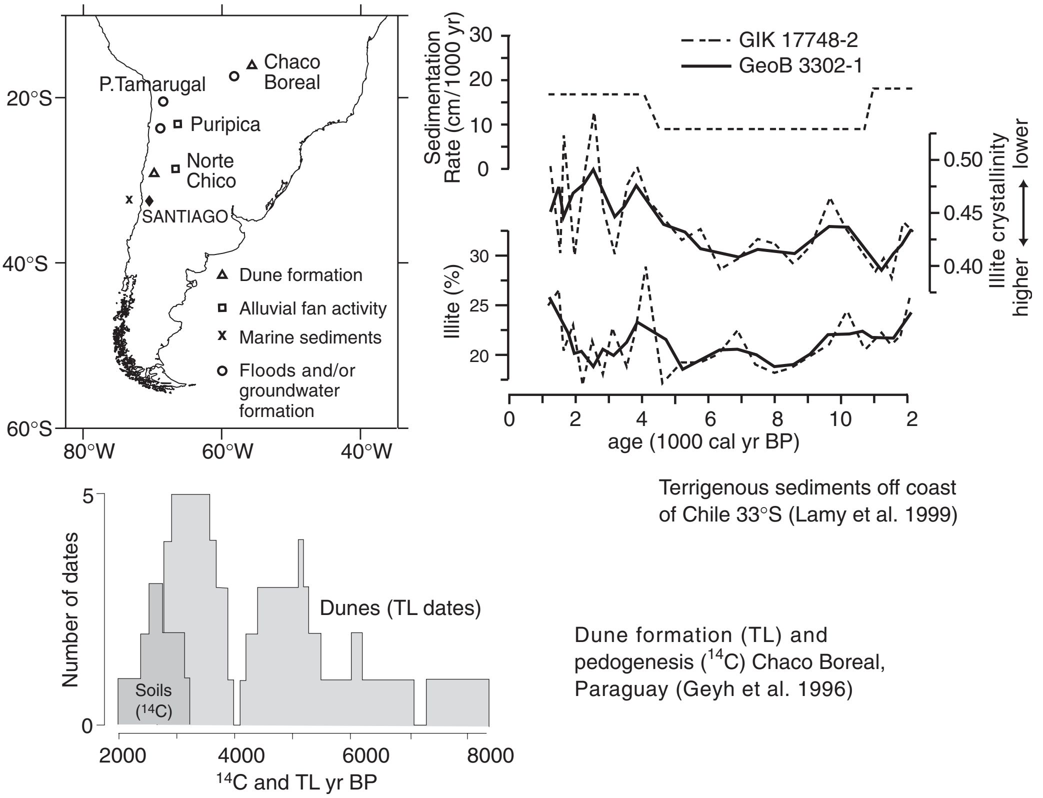
Rech et al., 2002, 2003) and in many other steep valleys as far north as Peru (Rech et al., 2002). Indeed, the widespread occurrence of these features suggests rather a regional climatic than a local tectonic forcing. The paleoclimatic interpretation, however, remains controversial. Whereas these deposits are mostly interpreted as a result of sediment accumulation in an overall low-energy hydrological environment with very limited surface runoff (less than today), limited river incision and thus high local aquifers but generally arid climatic conditions (humid climates would lead to surface runoff and river incision; Grosjean, 2001, P. Baker, C. Rigsby, R. Aravena, B. Warner, personal communications, 2001), and are indicative of dry climates elsewhere (e.g., in Southern Africa; I. Stengel, personal communication, 2003), Rech et al. (2002) interpret these features as a result of generally more humid climatic conditions.

In the South Central Andes, glaciers and permafrost bodies play a vital role with regard to steady freshwater supply for human consumption (e.g., Ribstein et al., 1995; Schrott, 1998). Except for the still controversial glacier advance prior to 5100 cal yr BP in Argentina 33°S (Garleff and Stingl, 1994), glaciers in Bolivia, Peru, and NW Argentina were generally at minimum extents between the late-glacial deglaciation and neoglacial advances younger than ca. 3800 cal yr BP (< 3500 ^{14}C yr BP, Seltzer, 1990; Clapperton, 1993, 1994; Abbott et al., 1997; Grosjean et al., 1998).

Evidence of pronounced arid mid-Holocene conditions is also provided by terrigenous sediments in marine sediments off the Central Chilean coast 33°S (Lamy et al., 1999, Fig. 3.4). The overall low sedimentation rate throughout the early and mid-Holocene until 4160 cal yr BP suggests low river discharge rates. Clay mineralogical data show that the major river sediment sources and places of erosion were in the high Andes, whereas the coastal range remained inactive with regard to erosion. Lamy et al. (1999) also conclude for the coastal range that physical weathering was more important than chemical weathering, which is indicative of hyperarid early and mid-Holocene climatic conditions in the lower elevation areas and thus highly consistent with the findings by Maldonado et al. (2005).

Dune mobilization is a good long-term indicator for arid conditions with scarce vegetation cover. On the coast of Central Chile 32°S, dune mobilization is observed between 5800 and 4200 cal yr BP (5000 and 3800 ^{14}C yr BP, Villa-Martínez and Villagrán, 1997). Also in the tropical lowlands of the Chaco Boreal (Paraguay, Geyh et al., 1996, Fig. 3.4), TL dates of dune sands range between 7700 and 2900 TL yr BP, indicating widespread eolian processes during mid-Holocene times. The ^{14}C dates on fossil soils suggest that these dunes were stabilized after 3200 cal yr BP, right around the time when lake levels in the South Central Andes started to increase, and modern vegetation patterns were established.

Also the lack of pedogenesis on geomorphologically stable surfaces in the Salar de Atacama (e.g., at Tambillo) is a strong indicator for persistent arid conditions since ca. 9000 cal yr BP. In the more humid eastern Cordillera of the Atacama Desert 22°S (Cordillera Santa Victoria, 4500 masl), Zipprich et al. (1999) observed a mid-Holocene hiatus in soil formation (Eutric Regosol) between 9000 and 4100 cal yr BP.



Terrigenous sediments off coast of Chile 33°S (Lamy et al. 1999)

Dune formation (TL) and pedogenesis (^{14}C) Chaco Boreal, Paraguay (Geyh et al. 1996)

Figure 3.4. Map showing the locations with mid-Holocene geomorphological and paleosol information. In marine sediments off the Chilean coast, mid-Holocene aridity is expressed as reduced terrigenous sediment input and high Illite crystallinity. In the Chaco Boreal of Paraguay, dune mobilization is observed during the mid-Holocene until about 3200 cal yr BP (3000 ^{14}C yr BP) when the dunes were stabilized by soil formation and vegetation.

In summary, a broad range of paleolimnological, vegetation, geomorphological, and pedological information draws a consistent picture of persisting very dry climatic and harsh environmental conditions during the mid-Holocene. Such conditions are observed in the entire area of the South Central Andes at large, from the Pacific coast in the west to the high Cordillera of the Andes in the east, and from the tropical summer rainfall in the north to the extratropical winter rainfall areas in the south.

5. Archaic settlement patterns and paleoenvironmental variability

The currently available data on mid-Holocene water, floral and faunal resources show a picture of relatively very hostile environmental conditions for human societies based on pre-agricultural/pre-irrigation subsistence economies at around 5000 cal yr BP. The *puna*, a favorable living space during the early Holocene, experienced a severe persisting multi-millennia drought. The few lakes desiccated, vegetation suffered from a quantitative decrease, and glaciers reached minimum extents or disappeared. Such harsh climatic conditions resulted in a pronounced concentration of life around small very specific places, named 'ecological refuges' (Grosjean et al., 2005b), where resources were still available due to groundwater and spring discharge from regional and/or fossil Early Holocene aquifers. We hypothesize that the food and water resources were critically scarce in the *Puna* of the Atacama Desert in northern Chile (south of the Río Loa, 22°S and near the modern Arid Diagonal), whereas conditions further north in southern Bolivia, northernmost Chile, southernmost Peru, and northwestern Argentina were still rich enough to sustain a low-density, possibly highly mobile hunting and gathering population.

The fully arid conditions on the *puna salada* also affected to some extent the habitats in the intermediate zone and the longitudinal valleys because river discharge from the high Andes was reduced. Relatively stable conditions persisted in the coastal habitats where marine food resources were stable and abundant, and terrestrial food and atmospheric water supply are subordinate. Along the marine coast, the most drastic change in the habitat was most likely the rapid global rise of the sea level during the early Holocene until ca. 6000 cal yr BP when modern levels were reached (Fairbanks, 1989). A regional sea level curve is not available so far. However, the sea level rise on the order of 60–80 m during the early Holocene implies that all the archaeological sites previously located next to the beach were progressively submerged until 6000 cal yr BP and disappeared. Thus caution is needed when early and mid-Holocene coastal settlement patterns are compared.

Here, we evaluate 106 archaeological sites (with about 300 ^{14}C dates, Table 3.2; database state, 1999) in the South Central Andes in the different habitats in order to identify settlement patterns, and to relate continuous or interrupted human occupation in time to changing environments between ca. 9000 and 4500 cal yr BP (8000 and 4000 ^{14}C yr BP).

5.1. Occupation of the fertile marine coast

The 34 ^{14}C dated Archaic sites (21 in southern Peru, 13 in northern Chile) in the habitat of the fertile marine coast cover the sequence between 13,000 and 3200 cal yr BP (11,000 and 3000 ^{14}C yr BP; Figs. 3.5–3.8, Table 3.2). The initial latest lateglacial human occupation took place during a time when the humid environments in the highlands and high river discharge provided this part of the coast with fresh water. This created exceptional habitats near estuaries where complementary marine and freshwater resources were available (Núñez and Varela, 1967–68).

The first people were highly specialized on marine resources including net-fishing practice and recollection of wedge clams (*Mesodesma donacium*) as found in

Table 3.2. Uncalibrated ^{14}C dates of late Pleistocene and Holocene Archaic sites in the South Central Andes (S Peru, N Chile, and NW Argentina). Database status as of 2002.

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
			A. Fertile marine coast		
Peruvian sites					
Q. Jaguay-280	11,105 ± 260	BGS-1942	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	11,088 ± 220	BGS-2024	Charcoal	Early Archaic	Sandweiss et al. (1998)
Tacaguay	10,770 ± 150	BETA-95869-C	Charcoal	Early Archaic	Keefer et al. (1998)
Q. Jaguay-280	10,770 ± 130	BGS-1702	Charcoal	Early Archaic	Sandweiss et al. (1998)
Tacaguay	10,750 ± 80	Beta-108692-A	Charcoal	Early Archaic	Keefer et al. (1998)
Q. Jaguay-280	10,725 ± 175	BGS-1937	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	10,700 ± 300	BGS-1940	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	10,600 ± 135	BGS-1939	Charcoal	Early Archaic	Sandweiss et al. (1998)
Ring site	10,575 ± 105	SI-6783	Shell	Early Archaic	Sandweiss et al. (1989)
Q. Jaguay-280	10,560 ± 125	BGS-1938	Charcoal	Early Archaic	Sandweiss et al. (1998)
Tacaguay	10,530 ± 140	Beta-108860-C	Charcoal	Early Archaic	Keefer et al. (1998)
Q. Jaguay-280	10,507 ± 125	BGS-2025	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	10,475 ± 125	BGS-1936	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	10,274 ± 125	BGS-1943	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	10,200 ± 140	NR	Charcoal	Early Archaic	Engel (1981), Sandweiss et al. (1998)
Q. Jaguay-280	10,190 ± 220	BGS-1957	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	9850 ± 170	BGS-1956	Charcoal	Early Archaic	Sandweiss et al. (1998)
Los Burros (Cañón)	9830 ± 140	10628	Charcoal	Early Archaic	Lavallée et al. (1999)
Los Burros (Test 2b)	9820 ± 80	10723	Shell	Early Archaic	Lavallée et al. (1999)
Q. Jaguay-280	9657 ± 220	BGS-2023	Charcoal	Early Archaic	Sandweiss et al. (1998)
Tacaguay	9630 ± 60	Beta-108859-A	Shell	Not cultural	Keefer et al. (1998)
Q. Jaguay-280	9597 ± 135	BGS-1960	Charcoal	Early Archaic	Sandweiss et al. (1998)
Los Burros (Cañón)	9545 ± 55	10403	Shell	Early Archaic	Lavallée et al. (1999)
Q. Jaguay-31	9393 ± 160	BGS 1966	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-1	9385 ± 140	BGS 1998	Charcoal	Early Archaic	Sandweiss et al. (1998)

Q. Jaguay-22	9340 ± 340	BGS 1965	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-1	9227 ± 110	BGS 1962	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-16	9200 ± 115	BGS 1967	Shell	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	9120 ± 300	BGS-1701	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-4	9115 ± 130	BGS 1993	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-21	9105 ± 115	BGS 1997	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-37	9039 ± 110	BGS 2020	Shell	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	9020 ± 170	BGS-1703	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-8	9015 ± 120	BGS 1991	Charcoal	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-1	8906 ± 115	BGS 1963	Charcoal	Early Archaic	Sandweiss et al. (1998)
Los Burros (Test 2b)	8890 ± 70	10406	Shell	Early Archaic	Lavallée et al. (1999)
Los Burros (Test 2b)	8860 ± 130	10400	Shell	Early Archaic	Lavallée et al. (1999)
Los Burros (Test 2)	8780 ± 70	10401	Shell	Early Archaic	Lavallée et al. (1999)
Q. Jaguay-20	8765 ± 180	BGS 1996	Charcoal	Early Archaic	Sandweiss et al. (1998)
P. Chira	8765 ± 160	HV 1090	Soil	Early Archaic	Ziolkowski (1993)
Q. Jaguay-43	8757 ± 110	BGS 2021	Shell	Early Archaic	Sandweiss et al. (1998)
Ring site	8755 ± 120	SI-6931	Shell	Early Archaic	Sandweiss et al. (1989)
P. Chira	8730 ± 115	BGS 1961	Shell	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-45A	8704 ± 115	BGS 2022	Shell	Early Archaic	Sandweiss et al. (1998)
Q. Jaguay-19	8615 ± 135	BGS 1995	Charcoal	Early Archaic	Sandweiss et al. (1998)
Los Burros (Cañón)	8470 ± 65	10407	Shell	Early Archaic	Lavallée et al. (1999)
Los Burros (Test 2b)	8430 ± 90	10405	Shell	Early Archaic	Lavallée et al. (1999)
Tacaguay	8430 ± 60	Beta-110330-A	Root	Not cultural	Keefer et al. (1998)
Q. Jaguay-3	8275 ± 130	BGS 1990	Charcoal	Early Archaic	Sandweiss et al. (1998)
Puyenca	8070 ± 145	Hv-1084	Charcoal	Late archaic	Ravines (1972)
Q. Jaguay-280	8053 ± 115	BGS-1944	Charcoal	Middle Archaic	Sandweiss et al. (1998)
Los Burros (Test 2b)	8040 ± 105	10634	Organic material	Early Archaic	Lavallée et al. (1999)
Kilómetro 4	8030 ± 100	Beta-77947	Charcoal	Early Archaic	Wise (1999)
Los Burros (Excavation)	8020 ± 65	10402	Shell	Early Archaic	Lavallée et al. (1999)
Tacaguay	7990 ± 80	Beta-109354-C	Charcoal	Early Archaic	Keefer et al. (1998)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
Tacaguay	7920 ± 80	Beta-108861-A	Root	Not cultural	Keefer et al. (1998)
Los Burros (Excavation)	7880 ± 55	10626	Shell	Early Archaic	Lavallée et al. (1999)
Los Burros (Test 2b)	8730 ± 70	10632	Organic material	Early Archaic	Lavallée et al. (1999)
Los Burros (Profile "Capilla")	8650 ± 70	10642	Organic material	Early Archaic	Lavallée et al. (1999)
Los Burros (Test 2b)	8160 ± 70	10633	Organic material	Early Archaic	Lavallée et al. (1999)
Los Burros (Profile "Capilla")	8125 ± 30	10646	Shell	Early Archaic	Lavallée et al. (1999)
Puyenca	7855 ± 150	Hv-1086	Charcoal	Middle Archaic	Ravines (1972)
Ring site	7810 ± 105	SI-6930	Shell	Middle Archaic	Sandweiss et al. (1989)
Los Burros (Excavation)	7735 ± 40	11004	Shell	Middle Archaic	Lavallée et al. (1999)
Q. Jaguay-280	7690 ± 100	BGS-1959	Charcoal	Middle Archaic	Sandweiss et al. (1998)
Ring site	7675 ± 60	SI-4784	Shell	Middle Archaic	Sandweiss et al. (1989)
Q. Jaguay-280	7620 ± 100	BGS-1958	Charcoal	Middle Archaic	Sandweiss et al. (1998)
Q. Jaguay-17	7540 ± 110	BGS 1999	Shell	Middle Archaic	Sandweiss et al. (1998)
Q. Jaguay-280	7500 ± 130	BGS-1700	Charcoal	Middle Archaic	Sandweiss et al. (1998)
Ring Site	7415 ± 65	PITT-0142	Charcoal	Middle Archaic	Sandweiss et al. (1989)
Los Burros (Profile "Capilla")	7390 ± 50	10643	Organic material	Middle Archaic	Lavallée et al. (1999)
Los Burros (Profile "Corral")	7320 ± 80	10635	Organic material	Middle Archaic	Lavallée et al. (1999)
Q. Jaguay-5	7300 ± 105	BGS 1992	Charcoal	Middle Archaic	Sandweiss et al. (1998)
Los Burros (Excavation)	7195 ± 45	11002	Shell	Middle Archaic	Lavallée et al. (1999)
Los Burros (Profile "Capilla")	7160 ± 80	10647	Shell	Middle Archaic	Lavallée et al. (1999)
Ring site	7155 ± 180	PITT-0147	Charcoal	Middle Archaic	Sandweiss et al. (1989)

Los Burros (Profile "Capilla")	7105 ± 55	10644	Organic material	Middle Archaic	Lavallée et al. (1999)
Los Burros (Profile "Corral")	6940 ± 60	10636	Organic material	Middle Archaic	Lavallée et al. (1999)
Los Burros (Excavation)	6845 ± 30	10689	Shell	Middle Archaic	Lavallée et al. (1999)
Los Burros (Excavation)	6640 ± 50	10649	Shell	Middle Archaic	Lavallée et al. (1999)
Los Burros (Excavation)	6630 ± 70	10625/GifA 97289	Charcoal	Middle Archaic	Lavallée et al. (1999)
Los Burros (Profile "Capilla")	6595 ± 75	10645	Organic material	Middle Archaic	Lavallée et al. (1999)
Los Burros (Excavation)	6510 ± 60	10624/GifA 97288	Charcoal	Middle Archaic	Lavallée et al. (1999)
Los Burros (Excavation)	6460 ± 60	10623/GifA 97287	Charcoal	Middle Archaic	Lavallée et al. (1999)
Kilómetro 4	6220 ± 70	Beta-77951	Charcoal	Middle Archaic	Wise (1999)
Los Burros (Profile "Corral")	6180 ± 60	10637	Organic material	Middle Archaic	Lavallée et al. (1999)
Los Burros (Excavation)	6110 ± 80	10399	Shell	Middle Archaic	Lavallée et al. (1999)
Los Burros (Profile corral)	5390 ± 100	10638	Organic material	Middle Archaic	Lavallée et al. (1999)
Ring site	5060 ± 65	PITT-0144	Charcoal	Late Archaic	Sandweiss et al. (1989)
Kilómetro 4	4620 ± 90	Beta-27417	Wood-Charcoal	Late Archaic	Wise et al. (1994)
Los Burros (Profile "Corral")	4555 ± 50	10639	Organic material	Late Archaic	Lavallée et al. (1999)
Tacaguay	4550 ± 60	Beta-108536-A	Sediment	Not cultural	Keefer et al. (1998)
Carrizal	4390 ± 110	Beta-18920	Charcoal	Late Archaic	Wise (1989)
Los Burros (Profile "Corral")	4010 ± 55	10640	Organic material	Late Achaic	Lavallée et al. (1999)
Kilómetro 4	3970 ± 80	Beta-77948	Charcoal	Late Archaic	Wise (1999)
Q. Jaguay-32	3895 ± 80	BGS 1995	Shell	Late Archaic	Sandweiss et al. (1998)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
Kilómetro 4	3760 ± 70	Beta-52797	Wood-Charcoal	Late Archaic	Wise et al. (1994)
Kilómetro 4	3750 ± 60	Beta-52796	Wood-Charcoal	Late Archaic	Wise et al. (1994)
Los Burros (Test 2b)	3700 ± 40	10648	Organic material	Late Archaic	Lavallée et al. (1999)
Kilómetro 4	3680 ± 70	Beta-77946	Charcoal	Late Archaic	Wise (1999)
Los Burros (Cañón)	3595 ± 90	10722	Shell	Late Archaic	Lavallée et al. (1999)
Kilómetro 4	3340 ± 70	Beta-77950	Charcoal	Late Archaic	Wise (1999)
Kilómetro 4	3240 ± 60	Beta-77943	Charcoal	Late Archaic	Wise (1999)
Los Burros (Profile "Corral")	3220 ± 50	10641	Organic material	Late Archaic	Lavallée et al. (1999)
Los Burros (Cañón)	3120 ± 80	10629	Charcoal	Late Archaic	Lavallée et al. (1999)
Los Burros (Cañón)	2825 ± 80	10631	Charcoal	Late Archaic	Lavallée et al. (1999)
Los Burros (Cañón)	2760 ± 80	10630	Charcoal	Late Archaic	Lavallée et al. (1999)
Chilean sites					
Acha-2	8970 ± 255	KE-15082	Human muscle	Early Archaic	Muñoz and Chacama (1993)
Acha-2	8900 ± 150	Teledyne SR	Charcoal	Early Archaic	Muñoz and Chacama (1993)
Acha-3	8380 ± 60	Beta-88041	Human muscle	Early Archaic	Standen and Santoro (2006)
Acha-3	8120 ± 90	Beta-40956	Human muscle	Early Archaic	Standen and Santoro (2006)
Camarones-14	7420 ± 225	I-999	Charcoal	Middle Archaic	Schiappacasse and Niemeyer (1984)
Camarones-14	7000 ± 135	I-11431	Human tissue	Middle Archaic	Schiappacasse and Niemeyer (1984)

Camarones-17	6930 ± 140	GX-15081	Wood	Middle Archaic	Muñoz et al. (1993), Aufderheide et al. (1993)
Camarones-17	6780 ± 110	GX-15080	Wood	Middle Archaic	Muñoz et al. (1993), Aufderheide et al. (1993)
Camarones-14	6650 ± 155	I-9817	Charcoal	Middle Archaic	Schiappacasse and Niemeyer (1984)
Camarones-14	6615 ± 390	I-9816	Charcoal	Middle Archaic	Schiappacasse and Niemeyer (1984)
Quiani 9	6370 ± 540	GaK-8782	Charcoal	Middle Archaic	Muñoz and Chacama (1982)
Camarones Pta. Norte	6270 ± 130	Gak-7135	Charcoal	Middle Archaic	Alvarez (1980)
Camarones Pta. Norte	6240 + 160	Gak-7132	Charcoal	Middle Archaic	Alvarez (1980)
Quiani-1	6170 ± 220	I-1348	Charcoal and bone	Middle Archaic	Mostny (1964)
Quiani-9	6115 ± 280	I-11.643	NR	Middle Archaic	Muñoz and Chacama (1982)
Chinchorro-1	6070 ± 285	I-15084	Wood	Middle Archaic	Muñoz et al. (1993)
Camarones Pta. Norte	5950 + 130	Gak-7137	Charcoal	Middle Archaic	Alvarez (1980)
Camarones Pta. Norte	5880 + 160	Gak-7134	Charcoal	Late Archaic	Alvarez (1980)
Camarones Pta. Norte	5750 + 170	Gak-7133	Charcoal	Late Archaic	Alvarez (1980)
Camarones Pta. Norte	5670 + 140	Gak-7136	Charcoal	Late Archaic	Alvarez (1980)
Camarones Pta. Norte	5640 + 160	NN	Charcoal	Late Archaic	Alvarez (1980)
Camarones-Sur	5640 ± 160	GaK-8645	Charcoal	Late Archaic	Rivera (1984)
Quiani-1	5630 ± 130	I-1349	Charcoal and bone	Late Archaic	Mostny (1964)
Chinchorro-1	5560 ± 175	I-15083	Wood	Late Archaic	Muñoz et al. (1993)
Quiani-9	5250 ± 430	GaK-8781	Charcoal and bone	Late Archaic	Muñoz and Chacama (1982)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
Camarones Pta. Norte	5230				Alvarez (1980)
Morro-1	5240 ± 230	GaK-9902	Wood	Late Archaic	Vera (1981)
Pisagua Viejo-4	5220 ± 245	IVIC-170	Wood	Late Archaic	Núñez (1976)
Morro-1	5160 ± 110	I-13539	Human tissue	Late Archaic	Allison et al. (1984)
Morro-1	5010 + 110	GaK-71309903	Wood	Late Archaic	Vera (1981)
Camarones-Punta	4950 ± 210	GaK-9903	Wood	Late Archaic	Alvarez (1980)
Pisagua Viejo-4	4880 ± 320	IVIC-170	Wood	Late Archaic	Núñez (1976)
Maderas Enco	4750 ± 155	GX-17464	Wood	Late Archaic	Arriaza (1995)
Camarones 8	4635 ± 90	GX-15079	Human tissue	Late Archaic	Muñoz et al. (1993), Aufderheide et al. (1993)
Morro-1	4570 ± 100	I-13542	Human tissue	Late Archaic	Allison et al. (1984)
Morro-1	4520 ± 90	Beta-40956	Wood	Late Archaic	Standen (1997)
Morro-1	4350 ± 280	I-13650	Human tissue	Late Archaic	Allison et al. (1984)
Morro-1/6	4310 ± 145	GX-	Human muscle	Late Archaic	Focacci and Chacón (1989)
Camarones 15b	4240 ± 145	GX-18256	Human tissue	Late Archaic	Muñoz et al. (1993), Rivera (1994)
Morro-1	4200 ± 100	I-13541	Human tissue	Late Archaic	Allison et al. (1984)
Morro-1	4120 ± 75	GX-17019	Human tissue	Late Archaic	Guillén (1992)
Playa Miller 8	4090 ± 105	GaK-5811	Wood	Late Archaic	Rivera (1977–78)
Morro-1	4040 ± 100	I-13543	Wood	Late Archaic	Allison et al. (1984)
Morro-1/6	4010 ± 75	GX-	Human muscle	Late Archaic	Focacci and Chacón (1989); Rivera (1994)
Camarones 15b	4010 ± 75	GX-18258	Human tissue	Late Archaic	Muñoz et al. (1993), Rivera (1994)
Lluta 13	3900 ± 100	charcoal	charcoal	Late Archaic	Santoro (1999)
Morro-1/6	3895 ± 75	GX-	Human tissue	Late Archaic	Focacci and Chacón (1989)

Morro-1/6	3880 ± 70	GX-	Human tissue	Late Archaic	Focacci and Chacón (1989)
Morro-1	3830 ± 100	I-13652	Human tissue	Late Archaic	Allison et al. (1984)
Morro-1	3790 ± 140	I-13656	Human tissue	Late Archaic	Allison et al. (1984)
Morro-1/6	3780 ± 100	I-14957	Human tissue	Late Archaic	Focacci and Chacón (1989)
Morro-1/6	3750 ± 140	GX-	Human tissue	Late Archaic	Focacci and Chacón (1989)
Morro-1	3670 ± 100	I-13651	Human tissue	Late Archaic	Allison et al. (1984)
Camarones 15d	3650 ± 200	RL-2054	Human tissue	Late Archaic	Rivera (1994)
Quiani- 7	3590 ± 100	GaK-5814	Wood	Late Archaic	Rivera (1977–78)
Morro-1/6	3560 ± 100	I- 14958	Human tissue	Late Archaic	Focacci and Chacón (1989)
Quiani- 7	3280 ± 90	I-13654		Late Archaic	Unpublished
Quiani- 7	3240 ± 90	I-13655		Late Archaic	Unpublished
Camarones-Sur	3060 ± 290	RL-2055		Late Archaic	Rivera (1994)
Camarones 15	3060 ± 100	GaK-5813	Wood	Late Archaic	Rivera et al. (1974)
			B. Sterile marine coast		
Chilean sites					
La Chimba 13	9680 ± 160	P-2702	Charcoal	Early Archaic	Llagostera (1977)
La Chimba 13	9400 ± 160	P-2702	Charcoal	Early Archaic	Llagostera (1977)
La Chimba 13	9170 ± 80	TO-5631	Otoliths	Early Archaic	Costa Junqueira (2001)
Cobija-1	6030 ± 70	Beta-3933	Charcoal	Late Archaic	Bittmann (1984)
Caramucho-1	5980 ± 120	GaK-8375	Shell	Late Archaic	Sanhuesa (1980)
Cobija-13	5510 ± 60	Beta-3934	Shell	Late Archaic	Bittmann (1984)
Cobija-S1	5460 ± 140	Beta-3114	Charcoal	Late Archaic	Bittmann (1984)
Cobija-S1	5440 ± 150	Beta-3115	Charcoal	Late Archaic	Bittmann (1984)
Abtao-1	5350 ± 120	Gif-1660	NR	Late Archaic	Boisset et al. (1969)
Abtao-1	5100 ± 130	IVIC681	Shell	Late Archaic	Boisset et al. (1969)
Abtao-1	5090 ± 80	IVIC682	Shell	Late Archaic	Boisset et al. (1969)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
Cobija-13	5060 ± 120	Beta-3117	Charcoal	Late Archaic	Bittmann (1984)
Abtao-2	5030 ± 70	IVIC-679	Shell	Late Archaic	Boisset et al. (1969)
Cobija-S1	4880 ± 90	Beta-3114	Charcoal	Late Archaic	Bittmann (1984)
Abtao-2	4820 ± 70	IVIC-680	Shell	Late Archaic	Boisset et al. (1969)
Abtao-1	4800 ± 70	IVIC-683	Shell	Late Archaic	Boisset et al. (1969)
Caleta Huelén-42	4780 ± 100	GaK-3546	Charcoal	Late Archaic	Núñez (1971)
Punta Guasilla-1	4730 ± 180	Beta-3121	Charcoal	Late Archaic	Bittmann (1984)
Cáñamo	3960 ± 80	GaK-102	Charcoal	Late Archaic	Núñez and Moragas (1983)
Caleta Huelén-42	3780 ± 90	GaK-3545	Wood	Late Archaic	Núñez (1971)
Abtao-1	3550 ± 100	Gif-1658	Shell	Late Archaic	Boisset et al. (1969)
Punta Guasilla-1	3490 ± 290	Beta-3112	Charcoal	Late Archaic	Bittmann (1984)
C. Valleys, *quebradas*, and oases at intermediate altitude					
Chilean sites					
Tiliviche 1(B)	9760 ± 365	SI-3116	Charcoal	Early Archaic	Núñez and Moragas (1977–78)
Aragón-1	8660 ± 230	GaK-5966	Charcoal	Early Archaic	Núñez and Zlatar (1977)
Tiliviche 1(B)	7850 ± 280	GaK-052	Vegetal fiber	Early Archaic	Núñez and Moragas (1977–78
Tiliviche 1(B)	6905 ± 65	SI-3115	Charcoal	Middle Archaic	Núñez and Moragas (1977–78)
Tarapacá 14-A	6830 ± 270	GaK-2432	Material	Middle Archaic	True et al. (1971)
Tarapacá 14-A	6430 ± 430	WSU-987	Charcoal	Middle Archaic	True et al. (1971)
Tiliviche 1(B)	6060 ± 60	SI-3114	Charcoal	Middle Archaic	Núñez and Moragas (1977–78)
Tarapacá 12	5970 ± 120	GaK-2205	Charcoal	Late archaic	True et al. (1971)
Tarapacá 12	5250 ± 340	GaK-3895	Charcoal	Late archaic	Tartaglia (1980)
Aragón-1	5170 ± 200	GaK-5965	Charcoal	Late archaic	Núñez and Zlatar (1977)

Tarapacá 14-A	4780 ± 130	GaK-2529	Charcoal	Late archaic	True et al. (1971)
Tarapacá 12	4690 ± 80	UCLA-1293	Charcoal	Late archaic	True et al. (1971)
Tarapacá 2-A	4160 ± 80	UCLA-1834A	Wool	Late archaic	Tartaglia (1980)
Tarapacá 12	4480 ± 170	GaK-5867	Charcoal	Late archaic	Tartaglia (1980)
Conanoxa W(a)	4020 ± 110	IVIC-875	Charcoal	Late archaic	Schiappacasse and Niemeyer (1969)
Conanoxa W(a)	3970 ± 120	IVIC-876	Charcoal	Late archaic	Niemeyer and Schiappacasse (1963)
Tarapacá 18	3910 ± 170	GaK-2433	Charcoal	Late archaic	True and Gildersleeve (1980)
Tiliviche-2	3870 ± 100	GaK-3772	Human coprolite	Late archaic	Standen and Núñez (1984)
Conanoxa W(a)	3740 ± 130	IVIC-175	Coprolites	Late archaic	Niemeyer and Schiappacasse (1969)
		D. Valleys and *Quebradas* towards the Andes			
Peruvian sites					
Asana	9820 ± 150	Beta 40063	NR	Early Archaic	Aldenderfer (1993)
Asana	9580 ± 130	Beta-24628	Wood	Early Archaic	Aldenderfer (1993)
Toquepala	9580 ± 160	I-1325	Charcoal	Early Archaic	Ravines (1972)
Toquepala	9490 ± 140	I-1372	Charcoal	Early Archaic	Ravines (1972)
Asana	8790 ± 170	Beta-24630	Wood	Early Archaic	Aldenderfer (1993)
Asana	8780 + 90	Beta-43920	NR	Early Archaic	Aldenderfer (1999)
Asana	8720 + 110	Beta-3303	NR	Early Archaic	Aldenderfer (1999)
Asana	8720 + 110	Beta-35599	NR	Early Archaic	Aldenderfer (1993)
Asana	8720 + 120	Beta-43922	NR	Early Archaic	Aldenderfer (1999)
Asana	8620 + 110	Beta-47057	NR	Early Archaic	Aldenderfer (1999)
Asana	8530 ± 240	Beta-18924	Charcoal	Early Archaic	Aldenderfer (1993)
Asana	8330 ± 60	Beta-43919	NR	Early Archaic	Aldenderfer (1999)
Asana	8250 ± 80	Beta-43921	NR	Early Archaic	Aldenderfer (1999)
Caru	8190 ± 130	Hv-1087	Charcoal	Early Archaic	Ravines (1967)
Asana	8080 ± 110	Beta-24627	NR	Early Archaic	Aldenderfer (1993)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
Asana	8000 ± 280	Beta-47058	NR	Early Archaic	Aldenderfer (1999)
Asana	7930 ± 80	Beta-43923	NR	Middle Archaic	Aldenderfer (1999)
Asana	7860 ± 110	Beta-23363	Wood	Middle Archaic	Aldenderfer (1993)
Asana	7070 ± 110	Beta-47056	NR	Middle Archaic	Aldenderfer (1999)
Coscori	7610 ± 130	NR	NR	Middle Archaic	Aldenderfer (1989)
Asana	7100 ± 70	Beta 24633	NR	Middle Archaic	Aldenderfer (1993)
Asana	6850 ± 70	Beta-25049	NR	Middle Archaic	Aldenderfer (1988 (1993
Asana	6550 ± 110	Beta-24629	Wood	Middle Archaic	Aldenderfer (1988, 1993)
Asana	6040 ± 90	Beta-24634	NR	Middle Archaic	Aldenderfer (1988, 1993)
Asana	5345 ± 70	B35596/ETH6328	NR	Late Archaic	Aldenderfer (1993)
Asana	4760 ± 90	Beta-27413	NR	Late Archaic	Aldenderfer (1993)
Asana	4640 ± 230	Beta-27414	NR	Late Archaic	Aldenderfer (1993)
Asana	4610 ± 60	Beta-24632	Wood	Late Archaic	Aldenderfer (1993)
Asana	4600 ± 80	Beta-35597	NR	Late Archaic	Aldenderfer (1993)
Asana	4580 ± 60	Beta-24631	Wood	Late Archaic	Aldenderfer (1993)
Asana	4570 ± 60	Beta-35598	NR	Late Archaic	Aldenderfer (1993)
Asana	4330 ± 70	Beta-43918	NR	Late Archaic	Aldenderfer (1999)
Asana	4330 ± 130	Beta-27415	NR	Late Archaic	Aldenderfer (1993)
Asana	3640 ± 80	Beta-23364	Charcoal	Late Archaic	Aldenderfer (1993)
Chilean sites (Arica)					
Tojotojone	9580 ± 1950	GaK-7958	Charcoal	Early Archaic	Dauelsberg (1983)
Ticnamar	9090 ± 75		Charcoal	Early Archaic	Rech (2001)
Patapatane	8160 ± 160	I-12.837	Charcoal	Early Archaic	Santoro and Chacama (1984)
Toconce-Confl.	7990 ± 125	Beta-1995	Charcoal	Middle Archaic	Aldunate et al. (1986)
Patapatane	7970 ± 10	Beta-43019	Charcoal	Middle Archaic	Santoro et al. (2005)
Patapatane	5910 ± 90	Beta-24634	Human bone	Middle Archaic	Standen and Santoro (1994)

Patapatane	4890 ± 130	I-12.838	Charcoal	Late archaic	Santoro and Chacama (1984)
Guañure	4330 ± 105	I-11.873	Charcoal	Late archaic	Santoro and Chacama (1982)
Puxuma	4240 ± 95	I-11.872	Charcoal	Late archaic	Santoro and Chacama (1982)
Puxuma	4010 ± 100	I-11.645	Charcoal	Late archaic	Santoro and Chacama (1982)
Quevilque	4000 ± 50	Beta-24355	Charcoal	Late archaic	Núñez and Santoro (1988)
Piñuta	3750 ± 140	I-11.832	Charcoal	Late archaic	Santoro and Chacama (1982)
Tojotojone	3740 ± 130	GaK-7959	Charcoal	Late archaic	Dauelsberg (1983)
Puxuma	3510 ± 80	Beta-24357	Charcoal	Late archaic	Santoro (1989)
Chilean sites (Puna Atacama)					
PN 99	12,251 ± 478	89-117	Obsidian Hydr.	Early Archaic	Lynch and Stevenson (1992)
PN 101	10,875 ± 450	89-121	Obsidian Hydr.	Early Archaic	Lynch and Stevenson (1992)
Tuina-1	10,830 ± 630	SI-3112	Charcoal	Early Archaic	Núñez (1983b)
San Lorenzo-1	10,400 ± 130	N-3423	Charcoal	Early Archaic	Núñez (1983b)
San Lorenzo-1	10,280 ± 120	HV-299	Charcoal	Early Archaic	Spahni (1967)
PN 71	10,154 ± 355	89–109	Obsidian Hydr.	Early Archaic	Lynch and Stevenson (1992)
Tuina-5	10,060 ± 70	Beta-107120	Charcoal	Early Archaic	Núñez et al. (2002
San Lorenzo-1	9960 ± 125	N-3423	Charcoal	Early Archaic	Núñez (1983b)
Tuina-5	9840 ± 110	Beta 107121	Charcoal	Early Archaic	Núñez et al. (2002)
PN 99	9603 ± 434	89–115	Obsidian Hydr.	Early Archaic	Lynch and Stevenson (1992)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
Tambillo-2/4-a	9590 ± 110	Beta-105687	Organic sediment	No cultural	Núñez et al. (2002)
Chulqui-1	9590 ± 60	Beta-6845	Charcoal	Early Archaic	Sinclaire (1985)
PN 115a	9569 ± 445	89–113	Obsidian Hydr.	Early Archaic	Lynch and Stevenson (1992)
Tulán-68	9290 ± 100	Beta-25532	Charcoal	Early Archaic	Núñez et al. (2002)
PN 71	9127 ± 337	89–108	Obsidian Hydr.	Early Archaic	Lynch and Stevenson (1992)
Tuina-1	9080 ± 130	NR	Charcoal	Early Archaic	Lanning (1967)
Tambillo-1	9590 ± 110	Beta-105687	Charcoal	Early Archaic	Núñez et al. (2002)
Tambillo-1	8870 ± 70	Beta-63365	Charcoal	Early Archaic	Núñez (1983b)
Tambillo-1	8590 ± 130	Beta-25536	Charcoal	Early Archaic	Núñez et al. (2002)
Tulán-67	8190 ± 120	Beta-25535	Charcoal	Early Archaic	Núñez et al. (2002)
PN 115a	7961 ± 405	89–111	Obsidian Hydr.	Middle Archaic	Lynch and Stevenson (1992)
Chulqui-1	7180 ± 80	Beta-7324	Charcoal	Middle Archaic	Sinclaire (1985)
Puripica-3/P16	6460 ± 230	Beta-63366	Charcoal	Middle Archaic	Núñez et al. (2002)
PN 99	6184 ± 341	89–116	Obsidian hydr.	Middle Archaic	Lynch and Stevenson (1992)
Puripica-3/39	6150 ± 150	Beta-87200	Charcoal	Middle Archaic	Núñez et al. (2002)
Puripica-3/P13-14	6130 ± 80	Beta-63359	Charcoal	Middle Archaic	Núñez et al. (2002)
Isla Grande	6008 ± 130	NR	Charcoal	Middle Archaic	Lanning (1967)
Tulan-67	5940 ± 50	Beta-142174	Charcoal	Late Archaic	Núñez et al. (2002)
Chulqui-4	5730 ± 90	Beta-7323	Charcoal	Late Archaic	Sinclaire (1985)
Confluencia-1	5380 ± 130	NR	Charcoal	Late Archaic	Lanning (1967)
Puripica-3/P34	5130 ± 110	Beta-88951	Charcoal	Late Archaic	Núñez et al. (2002)
Calarcoco-1	5120 ±	NR	Collagen	Late Archaic	Serracino and Pereyra (1977)
Tulán-51	4990 ± 110	N-2486	Charcoal	Late Archaic	Núñez (1981)

Puripica-3/P33	4880 ± 100	Beta-45478	Charcoal	Late Archaic	Núñez et al. (2002)
Puripica-1	4815 ± 70	SI-3113	Charcoal	Late Archaic	Núñez (1980)
RanL92/Chiuchiu	4565 ± 110	I-5173	Charcoal	Late Archaic	Druss (1977)
RanL140/Chiuch.	4530 ± 110	NR	NR	Late Archaic	Druss (1977)
RanL15140/Ch.	4500 ± 116	NR	Charcoal	Late Archaic	Druss (1977)
PN 112	4387 ± 310	89–114	Obsidian hydr.	Late Archaic	Lynch and Stevenson (1992)
Kalina/Morteros-1	4370 ± 220	Beta-12977	Charcoal	Late Archaic	Aldunate et al. (1986)
Tulán-52	4340 ± 95	N-2487	Charcoal	Late Archaic	Núñez (1981)
Puripica-1	4290 ± 60	Beta-32390	Charcoal	Late Archaic	Núñez et al. (2002)
RanL92/Chiuchiu	4280 ± 170	I-7017	Charcoal	Late Archaic	Druss (1977)
Tulán-52	4270 ± 80	N-2488	Charcoal	Late Archaic	Núñez et al. (2002)
RanL133(A)/Chi.	4250 ± 105	I-5175	Charcoal	Late Archaic	Druss (1977)
Puripica-1	4160 ± 90	Beta-85226	Charcoal	Late Archaic	Núñez (1981)
Calarcoco-1	4120 ± 170	NR	Collagen	Late Archaic	Serracino (1975)
RanL4(A)/Chiu.	4115 ± 105	I-6741	Apatite	Late Archaic	Druss (1977)
RanL104(B)/Chi.	4050 ± 105	NR	NR	Late Archaic	Druss (1977)
Puripica-1	4050 ± 95	Beta-2360	Charcoal	Late Archaic	Núñez (1981)
Punta Negra-59	4040 ± 70	Beta-12908	Charcoal	Late Archaic	Lynch (1986)
Kalina/Morteros	3950 ± 50	Beta-6844	Charcoal	Late Archaic	Aldunate et al. (1986)
PN 115f	3881 ± 285	89–133	Obsidian hydr.	Late Archaic	Lynch and Stevenson (1992)
RanL118/Chiuch.	3675 ± 470	I-6742	Charcoal	Late Archaic	Druss (1977)
Tulan-67	3640 ± 120	Beta-142175	Charcoal	Late Archaic	Núñez et al. (2002)
RanL276(A)/Chi.	3625 ± 85	I-7016	Charcoal	Late Archaic	Druss (1977)
PN 36	3413 ± 111	89–132	Obsidian hydr.	Late Archaic	Lynch and Stevenson (1992)
PN 72	3257 ± 93	89–119	Obsidian hydr.	Late Archaic	Lynch and Stevenson (1992)
PN-122	3180 ± 252	89–122	Obsidian hydr.	Late Archaic	Lynch and Stevenson (1992)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
PN 105	3086 ± 255	89–128	Obsidian hydr.	Late Archaic	Lynch and Stevenson (1992)
PN 36	3050 ± 142	89–131	Obsidian hydr.	Late Archaic	Lynch and Stevenson (1992)
E. High *puna*					
Dry *puna*					
Peruvian and Chilean sites					
Hakenasa	9840 ± 40	Beta-187535	Bones	Early Archaic	LeFebvre (2004)
Las Cuevas	9540 ± 160	T-12.835	Charcoal	Early Archaic	Santoro and Chacama (1982)
Hakenasa	9520 ± 70	Beta-187534	Charcoal	Early Archaic	LeFebvre (2004)
Quebrada Blanca	9510 ± 70	Beta-139632	Charcoal	Early Archaic	Santoro and Standen (2000)
Hakenasa	9260 ± 60	Beta-187533	Charcoal	Early Archaic	LeFebvre (2004)
Hakenasa	9170 ± 70	Beta-187532	Charcoal	Early Archaic	LeFebvre (2004)
Hakenasa	8789 ± 60	Beta-187531	Charcoal	Early Archaic	LeFebvre (2004)
Hakenasa	8340 ± 300	I-13.287	Charcoal	Early Archaic	Santoro (1989)
Las Cuevas	8270 ± 250	I-13.128	Charcoal	Early Archaic	Santoro and Chacama (1984)
Quelcatani	7250 ± 170	NR	NR	Middle Archaic	Aldenderfer (1989)
Quelcatani	7100 ± 130	NR	NR	Early Archaic	Aldenderfer (1989)
Hakenasa	5140 ± 70	Beta-187530	Charcoal	Late Archaic	LeFebvre (2004)
Hakenasa	4270 ± 70	Beta-187529	Charcoal	Late Archaic	LeFebvre (2004)
Hakenasa	4380 ± 130	I-13.230	Charcoal	Late Archaic	Santoro (1989)
Hakenasa	3700 ± 60	Beta-187528	Charcoal	Late Archaic	LeFebvre (2004)
Argentine sites					
Barro Negro	12,530 ± 160	AC-735	Peat	No cultural	Fernández (1984–85)

Barro Negro	12,300 ± 170	AC-744	Peat	No cultural	Fernández (1984–85)
Barro Negro	10,740 ± 140	AC-677	Peat	No cultural	Fernández (1984–85)
Inca Cueva-4	10,620 ± 140	LP-137	Charcoal	Early Archaic	Aschero and Podestá (1986)
Leon Huasi-1	10,550 ± 300	GAK-13.402	Charcoal	Early Archaic	Fernández Distel (1980)
Cueva Yavi	10,450 ± 55	CSIC-1101	Charcoal	Early Archaic	Kulemeyer and Laguna (1996)
Huachichocana	10,200 ± 420	GAK-5847	Charcoal	Early Archaic	Fernández Distel (1986)
Barro Negro	10,200 ± 170	AC-672	Peat	No cultural	Fernández (1984–85)
Barro Negro	10,200 ± 140	AC-745	Peat	No cultural	Fernández (1984–85)
Inca Cueva 4	9900 ± 200	AC-564	Charcoal	Early Archaic	Aschero and Podestá (1986)
Cueva Yavi	9790 ± 100	CSIC-1074	Charcoal	Early Archaic	Kulemeyer and Laguna (1996)
Cueva Yavi	9760 ± 160	AC-1088	Charcoal	Early Archaic	Krapovickas (1987)
Inca Cueva-4	9650 ± 110	LP-102	Charcoal	Early Archaic	Aschero and Podestá (1986)
Huachichocana	9620 ± 130	P-2236	Charcoal	Early Archaic	Fernández Distel (1986)
Cueva Yavi	9480 ± 220	AC-1093	Charcoal	Early Archaic	Krapovickas (1987)
Quebrada Seca-3	9410 ± 120	LP-881	Charcoal	Early Archaic	Aschero (personal communication)
Quebrada Seca-3	9250 ± 100	LP-895	Charcoal	Early Archaic	Aschero (personal communication)
Inca Cueva-4	9230 ± 70	CSIC-498	Charcoal	Early Archaic	Aschero (1984)
Quebrada Seca-3	9050 ± 90	Beta-59930	Charcoal	Early Archaic	Aschero (personal communication)
Barro Negro	9200 ± 140	AC-743	Peat	No cultural	Fernández (1984–85)
Pintoscayoc	9080 ± 50	CAMS39041		Early Archaic	Hernández (2000)
Barro Negro	9050 ± 140	AC-742	Peat	No cultural	Fernández (1984–85)
Huachichocana	8930 ± 360	GAK-5847	Charcoal	Early Archaic	Fernández Distel (1986)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
Quebrada Seca-3	8670 ± 350	AC-1118	Wood	Early Archaic	Aschero and Podestá (1986)
Huachichocana	8670 ± 550	P-2280	Wood	Early Archaic	Fernández Distel (1986)
Quebrada Seca-3	8660 ± 80	Beta-77747	Charcoal	Early Archaic	Aschero (personal communication)
Quebrada Seca-3	8640 ± 80	Beta-59929	Charcoal	Early Archaic	Aschero (personal communication)
Cueva Yavi	8420 ± 70	CSIC-887	Charcoal	Early Archaic	Kulemeyer and Laguna (1996)
Quebrada Seca-3	8330 ± 110	LP-267	Charcoal	Early Archaic	Aschero (personal communication)
Cueva Yavi	8320 ± 260	CSIC-908	Charcoal	Early Archaic	Kulemeyer and Laguna (1996)
Quebrada Seca-3	7760 ± 80	Beta-77746	Charcoal	Middle Archaic	Aschero (personal communication)
Cueva Salamanca-1	7410 ± 100	LP-615	Charcoal	Middle Archaic	Aschero (personal communication)
Quebrada Seca-3	7350 ± 80	Beta-59928	Charcoal	Middle Archaic	Aschero (personal communication)
Quebrada Seca-3	7220 ± 100	SMU-2364	Charcoal	Middle Archaic	Aschero (personal communication)
Quebrada Seca-3	7130 ± 110	LP-269	Charcoal	Middle Archaic	Aschero (personal communication)
Quebrada Seca-3	6160 ± 100	AC-1117	Charcoal	Middle Archaic	Aschero (personal communication)
Quebrada Seca-3	6080 ± 70	Beta-77745	Charcoal	Middle Archaic	Aschero (personal communication)
Quebrada Seca-3	5400 ± 90	LP-270	Charcoal	Late Archaic	Aschero (personal communication)

Quebrada Seca-3	5380 ± 70	Beta-59927	Charcoal	Late Archaic	Aschero (personal communication)
Inca Cueva-4	5200 ± 110	AC-1112	Charcoal	Late Archaic	Aschero and Podestá (1986)
Quebrada Seca-3	4930 ± 100	AC-1115	Charcoal	Late Archaic	Aschero and Podestá (1986)
Quebrada Seca-3	4770 ± 80	Beta-27802	Charcoal	Late Archaic	Aschero (personal communication)
Quebrada Seca-3	4510 ± 100	Beta-27801	Charcoal	Late Archaic	Aschero (personal communication)
Tomayoc	4250 ±	GIF-8710	Charcoal	Late Archaic	Lavallée et al. (1997)
Inca Cueva-7	4080 ± 80	T-1173	Charcoal	Late Archaic	Aguerre et al. (1973)
Punta de la Peña-4	4060 ± 90	Beta-77749	Charcoal	Late Archaic	Aschero (personal communication)
Peñas Chicas-1.1	3660 ± 60	LP-261	Charcoal	Late Archaic	Aschero (personal communication)
Peñas Chicas-1.1	3590 ± 55	LP-263	Charcoal	Late Archaic	Aschero (personal communication)
Tomayoc	4250 ± 50	GIF-8710	Charcoal	Late Archaic	Lavallée et al. (1997)
Tomayoc	3480 ± 40	GIF-8707	Charcoal	Late Archaic	Lavallée et al. (1997)
Tomayoc	3390 ± 50	GIF-8371	Charcoal	Late Archaic	Lavallée et al. (1997)
Tomayoc	3360 ± 50	GIF-8708	Charcoal	Late Archaic	Lavallée et al. (1997)
Tomayoc	3310 ± 40	GIF-8372	Charcoal	Late Archaic	Lavallée et al. (1997)
Tomayoc	3250 ± 60	GIF-7335	Charcoal	Late Archaic	Lavallée et al. (1997)
Salt Puna					
Chilean sites					
Aguas Calientes I	8720 ± 100	Beta-105696	Charcoal	Early Archaic	Núñez et al. (2002)
Tuyajto 1(B)	8210 ± 110	Beta-105692	Charcoal	Early Archaic	Núñez et al. (2002)
Tuyajto 1(B)	8130 ± 110	Beta-105691	Charcoal	Early Archaic	Núñez et al. (2002)

Continued

Table 3.2. continued

Sites	^{14}C yr BP	Laboratory	Material	Period	Reference
San Martín-4-a	8130 ± 50	Beta-116573	Charcoal	Early Archaic	Núñez et al. (2002)
Huasco-2	6320 ± 50	Beta-142171	Charcoal	Middle Archaic	Núñez et al. (2002)
Meniques-1	5470 ± 60	Beta-105689	Charcoal	Late Archaic	Núñez et al. (2002)
Capur-3	3390 ± 60	Beta-114536	Charcoal	Late Archaic	Núñez et al. (2002)
Capur-3	3320 ± 60	Beta-105690	Charcoal	Late Archaic	Núñez et al. (2002)
Ollague-3	3170 ± 60	Beta-114537	Charcoal	Late Archaic	Núñez et al. (2002)

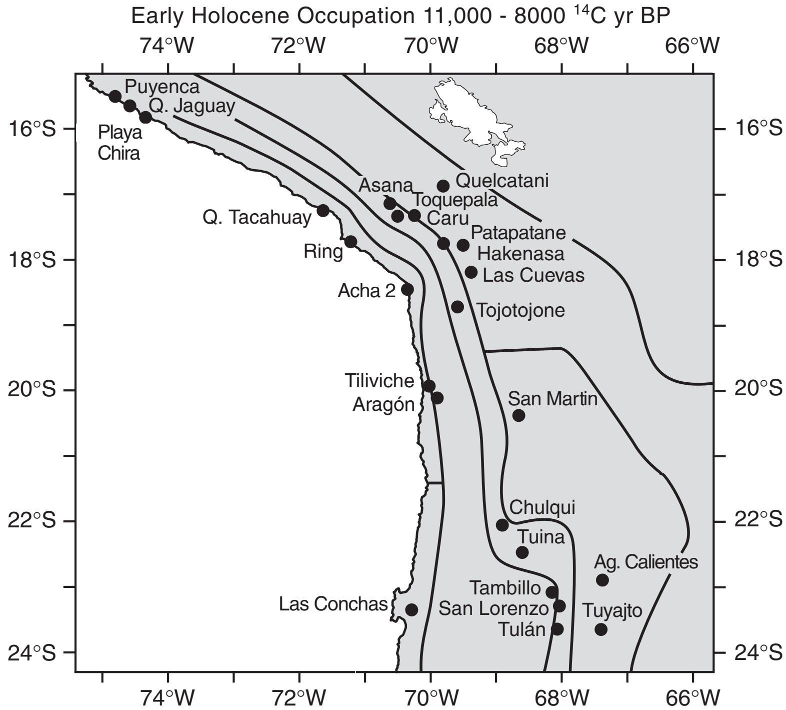


Figure 3.5. Map showing the locations of archaeological sites with early Holocene human occupation between 11,000 and 8000 ^{14}C yr BP. The black lines delineate the different habitats (Fig. 3.1).

Quebrada Jaguay (Sandweiss et al., 1998), hunting of seabirds (Quebrada Tacahuay, Keefer et al., 1998) and marine mammals. The earliest coastal sites also yielded lithic artifacts made from obsidian, which crops out 130 km inland at an altitude of 2850 m (Keefer et al., 1998; Sandweiss et al., 1998).

The Archaic settlement sequence is generally continuous. At the site-scale, however, a hiatus is observed in the south Peruvian sites between ca. 7800 and 5700 cal yr BP (7000 and 5000 ^{14}C yr BP, *Quebradas* Jaguay and Tacahuay, Ring Site, Puyenca, Figs. 3.5 and 3.8). Human occupation was restricted to ephemeral stream sites and a link with decreasing humidity in the adjacent highlands between 8000 and 3600 cal yr BP has been suggested by Sandweiss (2003). Near Arica, the sites of the Chincorro Culture (after ca. 9000 cal yr BP, Figs. 3.6 and 3.8) show considerable cultural innovations compared with the pre-Chinchorro (early) sites. Examples are the development of sophisticated procedures for human mummification, technological innovations as demonstrated in the use of harpoons, different kinds of fishhooks made of *Choromytilus* shell and bone, or the complementary use of terrestrial food resources such as camelids. This shows that major cultural changes began around 9000 cal yr BP. Also the number of coastal sites and most likely the population density increased (Fig. 3.7). However, we point to the fact that the

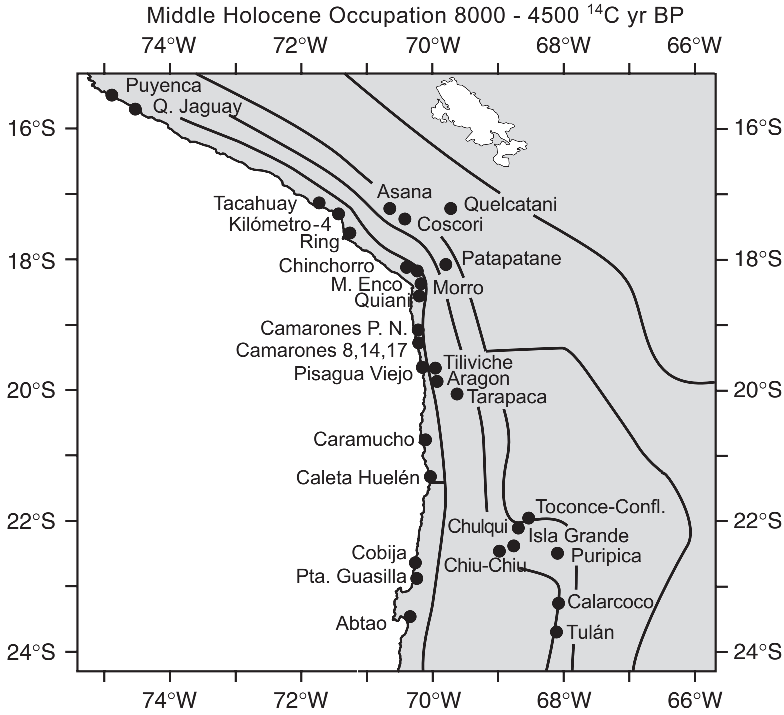


Figure 3.6. Map showing the locations of archaeological sites with mid-Holocene human occupation between 8000 and 4500 ^{14}C yr BP. The black lines delineate the different habitats (Fig. 3.1).

known early sites are all found on high terraces or in estuaries (Núñez and Moragas, 1983; Núñez and Zlatar, 1977, 1980; Múñoz et al., 1993) that were some kilometers away from the early Holocene coastline. In contrast to possibly many other unknown sites located immediately next to the previous coastline, these sites were not affected by the rising sea level prior to ca. 7000 cal yr BP. Thus, we hypothesize that the increase in the number of permanent sites after that time might also be an 'artifact' due to the stabilization of the sea level and the coast line around that time. The same observation is also made in the coastal area further to the south (sterile coast).

The coastal sites were extended open campsites with large shell middens, whereas the sites inside the *quebradas* were smaller. It is suggested that the latter ones were used sporadically, maybe as transitory logistic camps related to the rock outcrops with raw material for lithic artifacts, to collect reed fiber, or to gather terrestrial plants and hunt animals. Aragon and Tiliviche are two representatives of that type of site (Núñez and Zlatar, 1977).

The beginning of artificial mummification of the Chinchorro Culture (Guillén, 1992, 1997; Arriaza, 1994; Standen, 1997), and the diversification/intensification of resource exploitation suggests significantly increasing socio-cultural complexity on the coast

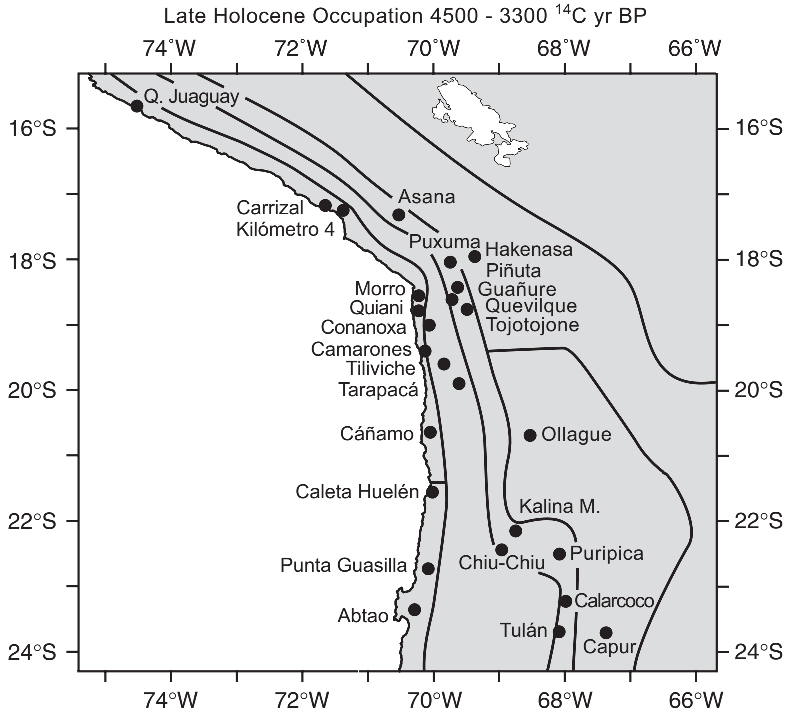


Figure 3.7. Map showing the locations of archaeological sites with late Holocene human occupation between 4500 and 3000 ^{14}C yr BP. The black lines delineate the different habitats (Fig. 3.1).

with the onset of mid-Holocene conditions. Such changes took place between ca. 9000 and 8000 cal yr BP and lasted throughout the Archaic period. There is no significant cultural or environmental change around 5000 cal yr BP (4300 ^{14}C yr BP). Interestingly, the technology and artificial mummification of the Chinchorro culture did not change much during several millennia, which suggests a rather closed, traditional, and conservative society, and is maybe even a mechanism for cohesion and socio-cultural defense (Arriaza, 1995; Santoro, 1999). The Chinchorro culture disintegrated after 4000 cal yr BP when new types of burials gradually replaced mummification. Individualism (e.g., hair dress) became more important, the society more structured and new technologies with wooden tools and cotton fabric emerged. However, the marine subsistence economy and the settlement pattern on the coast remained pretty constant during the time of such transformation.

5.2. Occupation of the sterile marine coast

Las Conchas (23°33′S) is the only known and ^{14}C dated Early Holocene site along the sterile marine coast south of 22°S (Figs. 3.5 and 3.8; Table 3.2). Like the early sites further north, Las Conchas was always located several kilometers away from the

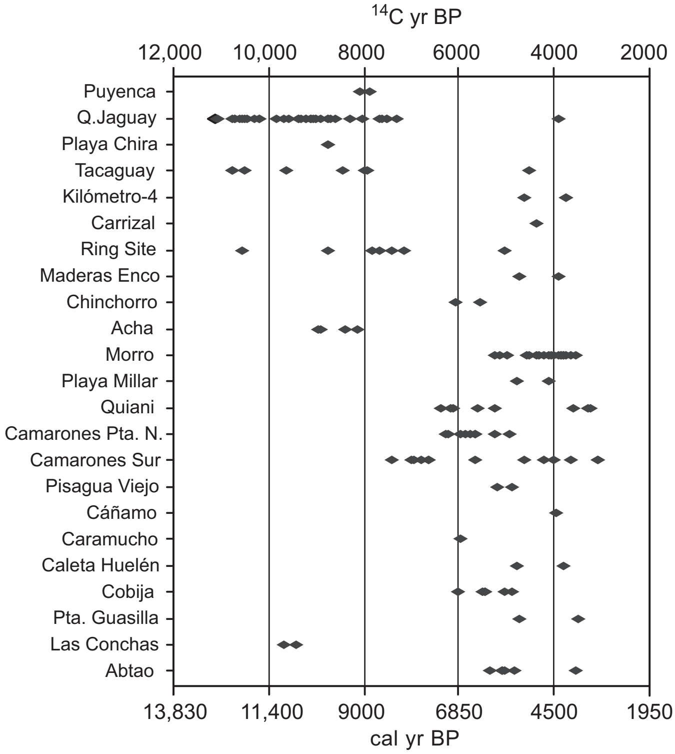


Figure 3.8. Radiocarbon chronostratigraphy of archaeological sites in the habitat of the fertile and the sterile coast. The sites are listed from north (top) to the south (bottom).

coast, and thus not affected by Holocene sea level changes. The cultural complex of this site known as the Huentelauquen Pattern (Llagostera, 1977, 1979) was based on a wide variety of marine resources (mammals, fish, and mollusks) and complementary birds and camelids. Techniques included net fishing (for Sciaenidae and Serranidae), harpoons, and collecting of mollusks (*Concholepas* and *Fissurella*). Interestingly, the variety of fish in this early site includes species of the Panamic Province that are indicative of warm water conditions along the northern Chile coast at that time (Llagostera, 1979). People seem to have lived permanently on the coast. The distinctive cultural features are geometric sandstone artifacts that are also known from areas south of Antofagasta and in Central Chile (Llagostera, 1979).

There seems to be an occupational hiatus between ca. 9000 and 6000 ^{14}C yr BP (Fig. 3.8), when a second phase of human habitation began. However, we point again to the problem of sea level rise during the early Holocene, which might have submerged many of the early coastal sites, and the fact that archaeological survey is incomplete in this area. It also remains unclear whether or not the end of Las Conchas is triggered by desiccation of the local springs at the end of the early Holocene.

Coinciding with the stabilization of sea level, the sterile coast was re-colonized by open campsites between 6700 and 3200 cal yr BP (6000 and 3000 ^{14}C yr BP;

Figs. 3.6–3.8). Although the hunting–fishing–gathering practices remained the same, the introduction of a variety of new harpoon types suggests cultural changes. Interestingly, the warm water fish species disappeared and were replaced by cold-water species (such as *Choromytilus*) by 6000 cal yr BP, whereas *Trachurus* (a warm-water fish) was absent until 4500 cal yr BP and increased afterwards (Llagostera, 1979).

Some elements of the Chinchorro culture (such as artificial mummification and technology) were introduced as far south as Antofagasta (23°S) from ca. 4500 cal yr BP (4000 ^{14}C yr BP). The presence of obsidian fragments and feathers of Andean parrots in a site at the Río Loa estuary on the one hand, and marine fish remains in sites of the middle course of the Rio Loa (Druss, 1977) and marine shells in sites of the western Andean slope (Tulán 52, Núñez and Santoro, 1988) on the other show that the cultural exchange between the coast and the high *puna* was already intensified around 5500 cal yr BP (4780 ^{14}C yr BP; Núñez et al., 1974). This falls well into the period of greatest environmental stress in the adjacent highlands. We see this as evidence of high regional mobility between the coast and the highlands and as evidence of intense exchange between peoples living in adjacent habitats largely around 5000 cal yr BP, the time window considered in the context of this chapter. However, this interpretation remains somewhat speculative because the database and the archaeological survey in this habitat are still far from complete.

5.3. Occupation of valleys, quebradas, and oases at intermediate altitude

The archaeological sites in the intermediate valleys are usually open campsites and show features of a mixed subsistence economy based on marine and terrestrial resources. The chronosequence spans between 12,000 and 4200 cal yr BP (10,000 and 3800 ^{14}C yr BP) without a significant hiatus (Fig. 3.9; Table 3.2). The early sites of Tiliviche and Aragón show strong bonds to the coast. The small size and the

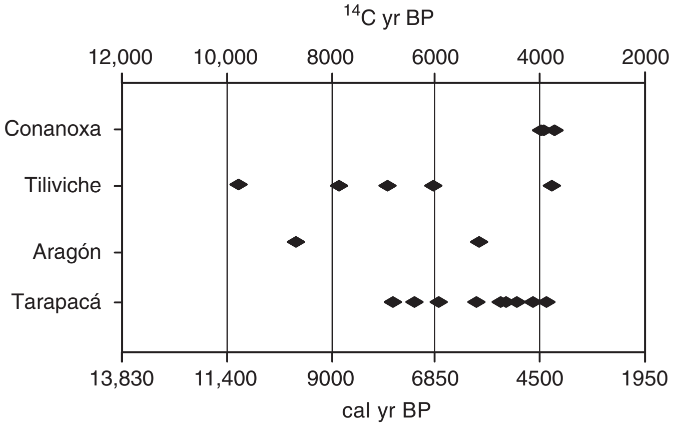


Figure 3.9. Radiocarbon chronostratigraphy of archaeological sites in the habitat of the intermediate valleys. The sites are listed from north (top) to the south (bottom).

low-density of the sites also suggest that they were rather complementary transitory camps than semi-permanent settlements observed at the coast. All of the known campsites/workshops (Figs. 3.5–3.7) are located in areas where local vegetation and water resources, reed fiber, wood, and in some cases lithic raw material were available. However, macrofossils of marine fauna and the technology of the tools suggest strong cultural bonds to the coast and the need for complementary food supplies (Niemeyer and Schiappacasse, 1963; Schiappacasse and Niemeyer, 1969; True et al., 1970, 1971; Núñez and Moragas, 1977–78; Núñez and Zlatar, 1977, 1980; Núñez et al., 1979–81, 1994; Standen and Núñez, 1984).

The (non-seasonal?) mobility pattern of the early occupants of these sites (Fig. 3.5) continues without major change until ca. 4500 cal yr BP (4000 ^{14}C yr BP), whereas major changes in the resource use are suggested. For instance, the early occupation at Aragón (pre-8600 ^{14}C yr BP, 30 km away from the coast) shows that mostly terrestrial resources were exploited (small land mammals and *Prosopis*). It is suggested that local food and river water were sufficient to sustain a (low-density?) highly mobile population, whereas the late occupation of the site after 5000 cal yr BP (4400 ^{14}C yr BP) relied strongly on marine food components. Reduced mid-Holocene river runoff from the Andes might have produced harsh conditions in these microenvironments. Other than at Aragon, the sites in Quebrada Tiliviche showed always a mixed marine-terrestrial subsistence economy throughout the early and middle Holocene (including camelids, Núñez, 1983a,b; Núñez and Moragas, 1977–78), and thus the changes were less pronounced. However, local terrestrial resources became more important after 4200 cal yr BP, (3800 ^{14}C yr BP), which coincides largely with the onset of modern more humid conditions in the high Andes, and supports the hypothesis about the importance of Andean water supply to the intermediate and coastal parts of the valleys.

Most sites at intermediate elevation are found in valleys north of the Río Loa, adjacent to the 'fertile' coast, along the waterways between the Andes and the coast. However, there are sites and lithic workshops adjacent to the 'sterile' coast ca. 40 km inland of the coast between Antofagasta and Taltal. The chronostratigraphy and paleoenvironmental context of these sites, however, is not yet known.

With regard to the mid-Holocene climate and cultural changes we emphasize the high mobility of the people (low-density population, and small transitory camps), the concentration of human activities in river oases and ecological refuges (such as Aragón, Tiliviche, and Tarapacá), and the coastal sites as a buffer zone with stable food resources and where the main camps were located. We interpret this as adaptive strategies to an environment with generally very low biomass productivity and relatively high resource variability (Table 3.1).

5.4. Occupation of valleys and quebradas toward the Andes

This habitat connects the coast with the Andes and shows also scarce precipitation, vegetation, and animal resources, but it is closer to the *puna* where the water resources are located.

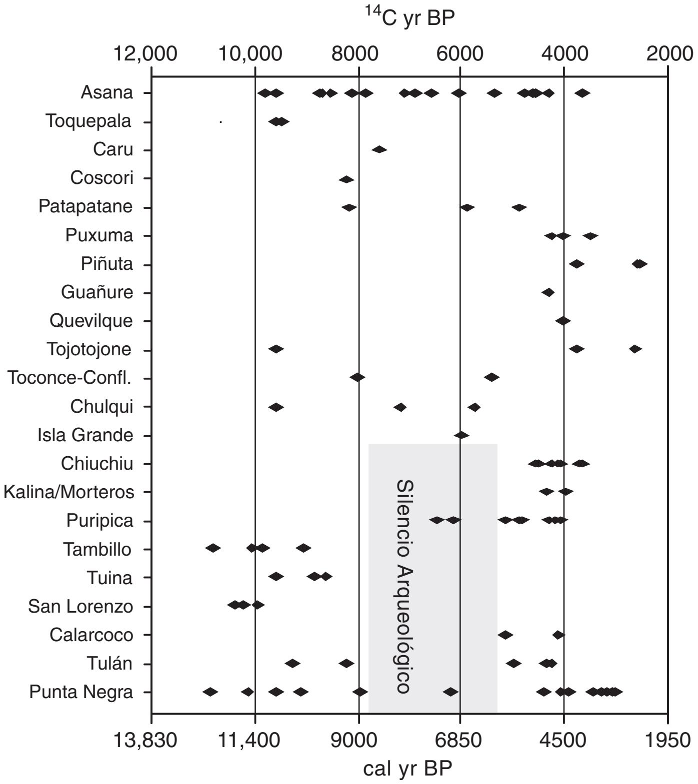


Figure 3.10. Radiocarbon chronostratigraphy of archaeological sites in the habitat of the high valleys. The sites are listed from north (top) to the south (bottom).

Asana, the most important site in southern Peru, was used continuously between 11,000 and 4000 cal yr BP (9800 and 3600 ^{14}C yr BP; Figs. 3.5 and 3.10, Table 3.2, Aldenderfer, 1993, 1999), whereas other less-well-documented sites suggest discontinuous habitation (Fig. 3.10; Table 3.2, Ravines, 1967, 1972). However, the Early Archaic occupation of Asana shows strong bonds to the lower elevation belts and the coast as suggested by the presence of lithic artifacts from outcrops at lower elevation and a settlement pattern with circular 'houses' of 2–3 m in diameter similar to what is found at coastal sites (e.g., Acha 3). At the same time, lithic materials document some links to the *puna* (Aldenderfer, 1993). Materials from the *puna* became increasingly important after ca. 10,000 cal yr BP (8800 ^{14}C yr BP) and especially between 8600 and 6900 cal yr BP (7800 and 6000 ^{14}C yr BP; Middle Archaic Period), which is thought to reflect a fundamental orientation of the mobility pattern toward the *puna*. The first architecture with circular constructions made of posts, brush-walls, and consolidated floors at wind-protected sites are dated ca. 7700 cal yr BP (6850 ^{14}C yr BP, Aldenderfer, 1988).

Aldenderfer (1993) observed a collapse in the overall number and density of artifacts (particularly the *puna* elements) particularly between 6700 and 5700 cal yr

BP (6000 and 5000 ^{14}C yr BP), which coincided with the desiccation of the local wetlands (*bofedal*) and likely with a substantial decrease in local food and water resources. Asana is thought to have been almost abandoned as it become a temporary camp site within the logistic radius of a (semi)permanent base located in the adjacent *dry puna*, possibly the Quelcatani site (Aldenderfer, 1989). However, no *puna* material has been found at Asana between 6700 and 5700 cal yr BP (6000 and 5000 ^{14}C yr BP). The major cultural change during that time is observed in the architecture, which suggests a trend toward a sporadic use of the site during short periods of time (Aldenderfer, 1993).

Intense reactivation of the site and re-establishment of strong links to the *puna* are observed around 5000 cal yr BP (4400 ^{14}C yr BP; Late Archaic). At that time, the most likely seasonal transhumant mobility pattern across various altitudinal belts and geoecological zones included pasturage of domesticated animals. Also seed processing, new oval forms, and functions of domestic architecture, ceremonial structures, and stone fences for animals suggest major cultural changes after 5000 cal yr BP (Aldenderfer, 1993).

Further to the south in northern Chile, the archaeological record of the high valleys includes six sites covering the Archaic Period between 10,900 and 2500 cal yr BP (9600 and 2400 ^{14}C yr BP; Figs. 3.5–3.7, Table 3.2). The Early Archaic sites show a highly diverse lithic industry. Faunal remains include camelids and rodents. Few marine gastropod shells (*Choromytilus*, likely of ceremonial character) suggest interaction with the coastal habitats. However, the sites are much smaller compared to Asana in Peru, and located in rock shelters and caves. Interestingly, the Middle Archaic Period starts with a 2000-year period of low human activity or even with an occupational hiatus between 9000 and 7000 cal yr BP (Fig. 3.10), which coincided with the severe regional mid-Holocene drought as recorded in nearby Laguna Seca in the *Puna* of Arica (Baied, 1991). Whereas Aldenderfer (1988) considers mainly the incomplete archaeological survey as a possible explanation, Santoro (1987, 1989) favored environmental stress, which may also have resulted in a stronger orientation toward the *puna* or the coastal sites. This might help to explain the observed increase in coastal sites, although the early Holocene sea level fluctuations remain a problem when population density on the coast is interpreted. Resolving this controversy requires a more complete archaeological survey and database.

Human occupation of the high valleys in northern Chile recovered after 6300 cal yr BP (5500 ^{14}C yr B.P; Fig. 3.10). People used a broad variety of materials and tools. Although the introduction of some tuber crops such as *ullucu* or *papalisa* (*Ullucus* sp.) and *isaño* (*Tropaelum*) is documented, the subsistence economy remained mainly based on camelids and rodents (Santoro and Núñez, 1987; Núñez and Santoro, 1988; Santoro, 1989). Other important cultural elements include rock painting. The already previously established seasonal transhumant pattern of resource use in different geoecological zones between the coast and the high *puna* remained the key-strategy for the subsistence economy.

Further to the south in the Puna de Atacama, the habitat of the high valleys is documented by 43 Archaic sites (Figs. 3.5–3.7) covering the period between 13,000 and 3200 cal yr BP (11,000 and 3000 ^{14}C yr BP; Fig. 3.10, Table 3.2). The most important archaeological areas south of the Río Loa are the Quebrada de Tulán, the Quebrada de San Lorenzo, Quebrada Puripica, and Tuina (Núñez et al., 2002). All of them connect the habitat of the *puna* ($>$4000 m) with the habitat in the low elevation basins of the Salar de Atacama (2500 m), the Salar Punta Negra (Lynch, 1986; Lynch and Stevenson, 1992), or with the Río Loa valley and further connections to the Pacific coast. The Early Archaic sites (Fig. 3.5) are all located in rock shelters and caves. Lithic artifacts (typical triangular points) made of exotic basalt and obsidian suggest intense transhumance with a strong orientation toward the *puna* that was readily accessible at a short distance. Many of the caves show a well-developed stratigraphy of Early Archaic archaeological deposits, and show multiple uses of these sites over a long period of time by highly mobile but likely small groups of people.

The surprisingly dense record of early sites experiences a dramatic decline with the onset of arid mid-Holocene conditions around 9000 cal yr BP (8000 ^{14}C yr BP; Fig. 3.10, Núñez et al., 2001, 2002). Due to the constant sedimentation of sterile geologic material from the ceiling, the caves of Tuina-4 and San Lorenzo are perhaps the best sites to document the mid-Holocene occupational hiatus (known as '*Silencio Arqueológico*', Núñez and Grosjean, 1994) between 9000 and $<$5700 cal yr BP (8000 and $<$5000 ^{14}C yr BP; Fig. 3.10, Table 3.2). The mid-Holocene sediments in some of the caves are totally devoid of archaeological remains, clearly separating the Early Holocene/Early Archaic archaeological strata rich in plant macrofossils, charcoal, mammal, and bird bones from the post-Archaic archaeological strata (supplement material in Núñez et al., 2002). This occupational hiatus coincides with the extremely arid mid-Holocene environmental conditions in the Salt Puna, when lake levels reached lowest stands, river discharge decreased substantially, and water resources became critically scarce. Compared with the more stable and continuously occupied high valleys further north (such as Chulqui in the Río Loa basin, Aldunate et al., 1981; Sinclaire, 1985), the valleys in the Atacama basin were always relatively poor in resources, and thus responded most sensitively to climate changes. Therefore, we think that the environmental conditions in this sector dropped below critical levels for hunting and gathering societies, as they were present during the early Holocene. This resulted in a clear hiatus in this specific area, whereas a comparable decline in water resources led to a decrease in population density, but not necessarily to a visible hiatus north of the Río Loa. This feature is typical for areas with marginal and critically scarce resources, and will repeat itself in the Salt Puna (*puna salada*), the most marginal and arid part of the *puna* (see Section 5.5.).

The mid-Holocene fully arid conditions resulted in some cases in the formation of 'ecological refuges', small atypical oases, where water was still available, resources were concentrated, and where people found the living space for discrete habitation. Such an example is documented in Quebrada Puripica (Grosjean et al., 1997a, Núñez et al., 2001). Twenty fireplaces that are physically separated by individual debris flows on the alluvial fan record in detail the stepwise cultural transformation of a hunting/gathering Early Archaic society into a very complex Late Archaic society, and thus fill the 'gap of evidence' of the regional '*Silencio Arqueológico*'. The early hunting tradition prior to 7000 cal yr BP (6200 ^{14}C yr BP) changed by 6700 cal yr BP (5900 ^{14}C yr BP) into a cultural system with large campsites, intense exploitation of wild camelids, and an innovative lithic industry with microliths and perforators, some of them made of exotic raw material. This process culminated in the Late Archaic classic site of Puripica-1 (5500 cal yr BP, 4800 ^{14}C yr BP) that showed parallel hunting and domestication of camelids, the use of local lithic materials, and the development of structured semi-sedentary settlements and naturalistic rock art (Núñez, 1981; Hesse, 1982; Grosjean and Núñez, 1994; Grosjean et al., 1997a; Núñez et al., 2001). Although human occupation at Puripica continued through the agricultural period (after ca. 3500 cal yr BP), the site lost the unique importance as an 'ecological refuge' after ca. 4200 cal yr BP (3800 ^{14}C yr BP), when modern (i.e., better) conditions were established, lake levels rose again, and widespread re-occupation of the area is observed (Tilocalar Phase beginning 3500 cal yr BP, Núñez et al., 1996).

5.5. Occupation of the high **puna**

The numerous sites in the habitat of the high *puna* reflect in general what has been observed in the sites of the high valleys in adjacent areas to the west. This is not surprising because the *puna* and the high valleys were always complementary ecosystems within the same economic unit. Early Archaic ($<$12,000 cal yr BP, 10,000 ^{14}C yr BP) human occupation in the *puna seca* is documented in three sites, Quelcatani in southern Peru, and Las Cuevas and Hakenasa in northernmost Chile (Fig. 3.11, Aldenderfer, 1989; Santoro, 1989). Interestingly, the known sites are all located in caves, which is very different from the numerous open campsites in the *puna salada* further south. The sites in the *puna seca* were repeatedly used during short intervals. As expected, there is no clear evidence of a mid-Holocene hiatus, although the density of artifacts and likely also human activity decreased significantly between ca. 9000 and 6700 cal yr BP (8000 and 6000 ^{14}C yr BP; Table 3.2). The mid-Holocene sites do not show any evidence of coastal artifacts, suggesting that the mobility pattern was restricted to the *puna* and the adjacent valleys, possibly with (or maybe due to) domesticated camelids (Núñez, 1981; Aldenderfer, 1993).

In contrast to the sites in the *puna seca* with rather continuous occupation, the sites in hydrologically sensitive areas of the *Puna Salada* of northern Chile show a distinct hiatus (*Silencio Arqueológico*) between ca. 9000 and 4500 cal yr BP (8000 and 4000 ^{14}C yr BP), which coincided with the hyperarid mid-Holocene conditions. The Early Archaic sites in the *puna salada* prior to 9000 cal yr BP (8000 ^{14}C yr BP) are small open campsites with abundant local lithic material (basalt, obsidian), typical triangular artifacts. The sites are usually strictly related to the fossil shorelines of the late-glacial/early Holocene paleolakes. The few ^{14}C dated sites (Salar Aguas Calientes I, Salar Tuyajto, Salar San Martin, Fig. 3.5; Table 3.2, Núñez

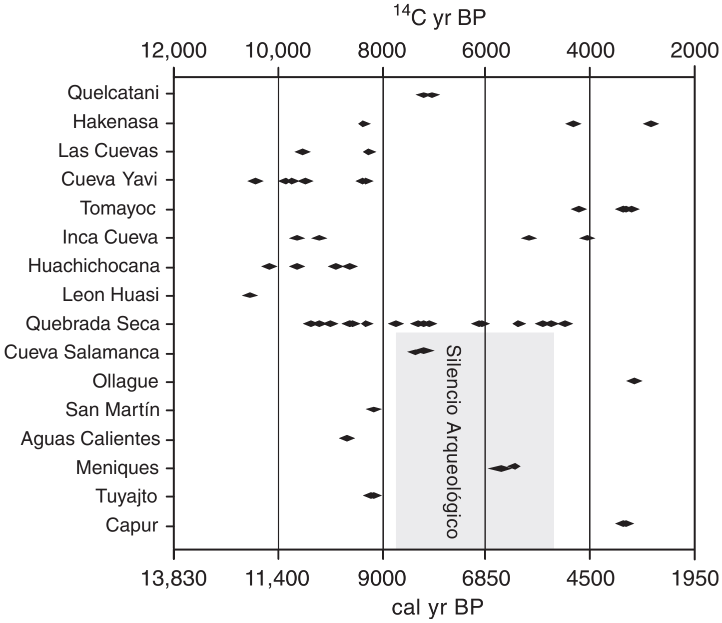


Figure 3.11. Radiocarbon chronostratigraphy of archaeological sites in the habitat of the *puna seca* and *puna salada*. The sites are listed from north (top) to the south (bottom).

et al., 2001, 2002) and the numerous sites with diagnostic triangular artifacts suggest that human occupation was widespread between 12,000 and 9000 cal yr BP (10,000 and 8000 ^{14}C yr BP), whereas there is no evidence of human occupation in the *puna salada* during the mid-Holocene between 9000 and 6200 cal yr BP (8000 and 5500 ^{14}C yr BP; Fig. 3.6). However, as a result of changing climate and geomorphological processes, alternative habitats with very favorable conditions were created in flat bottoms of desiccated lakes or in steep valleys where wetlands were formed (Grosjean et al., 2005b). In light of the well-documented paleoenvironmental scenario, we interpret this occupational re-organization (i.e. not always a hiatus) as a clear signal of extremely harsh environmental conditions. Interestingly, ^{14}C dated open camp sites document reoccupation of the lakesides at the time when regional lake levels started to increase, and modern (i.e., more humid than before) conditions were established after 4000 cal yr BP (3600 ^{14}C yr BP). The two ^{14}C dated sites showing Late Archaic reoccupation of lake shorelines are Salar Ollagüe and Salar Capur (Fig. 3.7).

Our climate–culture model for the *Puna Seca* and *Puna Salada* in Peru and Chile also applies successfully to NW Argentina (Fig. 3.11, Table 3.2). As expected, the environments in the more arid and marginal part of the NW Argentinean *Puna* were seriously affected by the mid-Holocene drought. Particularly the time between 9000 and 7000 cal yr BP (8100 and 6100 ^{14}C yr BP) was very arid (Kulemeyer et al., 1999), and resources dropped below a critical level for hunting and gathering societies. This resulted in a mid-Holocene occupational hiatus in the Archaic sites of

Inca Cueva-4, Leon Huasi, Yavi and Huachichocana, all located above 3000 m in the Argentinean *Dry Puna.* The sites of Cueva Salamanca-1 and Quebrada Seca-3 (Aschero, 1994; Rodríguez, 1999; Núñez et al., 2001) show continuous occupation.

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