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Palaeoenvironment and early human occupation of southernmost South America (South Patagonia, Argentina)

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ABSTRACT

Pollen and archaeological records from two areas of southern Patagonia, one in the southern part of the Deseado Massif, the other south of Lago Argentino, suggest an important influence of climate on human movements into new areas. Pollen spectra record a significant dry climate throughout the region prior to ca. 12,900 cal BP that may correlate with the Antarctic Cold Reversal (ACR) from ca. 14,500 to 12,700 cal BP. The earliest archaeological sites date the initial exploration (sensu Borrero, 1994–95) of the Deseado Massif between 13,081 and 12,141 cal BP at the time of the Northern Hemisphere Younger Dryas (YD) cold interval (ca. 12,700–11,500 cal BP), which in the Southern Hemisphere was a time of gradually increasing temperatures. When humans set foot into the Deseado Massif, vegetation was grass steppe, indicating that conditions were wetter than during the ACR. The area south of Lago Argentino was occupied somewhat later around 11,000 cal BP, also when the vegetation changed to grass steppe. As temperatures increased during the early Holocene, forest replaced grass steppe in southwest Santa Cruz. A mix of forest and grass steppe persisted until ca. 9400 cal BP, when there was a return to drier conditions as those of today in the Deseado Massif.

1. Introduction

Patagonia, including Tierra del Fuego, was the last South American region to be explored and colonized by humans as the environment changed following the Last Glacial Maximum (e.g. Borrero et al., 1998; Borrero, 2004; Coronato et al., 2011). On the plateau east of the Andes in Patagonia (Deseado Massif) the earliest archaeological sites date the initial phase of exploration (sensu Borrero, 1994–95) definitely back to the period ca. 13,000–12,000 cal BP and possibly earlier (e.g. Cardich et al., 1973; Miotti, 1996; Miotti and Cattáneo, 1997, 2003; Miotti and Salemme, 2004; Paunero et al., 2007; Frank and Paunero, 2009; Paunero, 2009). The earliest dates from Cerro Tres Tetas are 13,733–13,162 cal BP (11,560 ± 140 ^{14}C BP; Frank and Paunero, 2009) and Piedra Museo has an accepted date of 13,087–12,687 cal BP (11,000 ± 65 ^{14}C BP; Miotti and Salemme, 2004). There is also a date of 16,163–14,977 cal BP (12,890 ± 90 ^{14}C BP) for Piedra Museo (Miotti and Salemme, 2004) but whether this dates human occupation is still under discussion. The Andean area was explored later. For example, early occupation in the Lake Burmeister basin (CCP 7) is indicated by a guanaco bone with cut marks, which dates to 12,758–12,432 cal BP (10,690 ± 72 ^{14}C BP; Aschero et al., 2007). Other archaeological studies suggest that hunter-gatherers were on the plateau east of the Andes by the beginning of the Holocene (Civalero and Aschero, 2003; Civalero and Franco, 2003; Franco and Borrero, 2003; Belardi et al., 2010). These populations were affected directly or indirectly by variations in climate and they had to continually adapt their subsistence activities to the ever-changing conditions.

There are few Holocene palaeoenvironmental records for the area east of the Andes in Patagonia mainly because of the limited availability of suitable deposits. In fact much of what is known has come from archaeological sites. The only continuous high-resolution records for the Pleistocene–Holocene transition are from Lago Cardiel (48° 48′ S; 71° 13′ W) in the west (Gilli et al., 2001; Markgraf et al., 2003) and Laguna Potrok Aike (51° 58′ S; 70° 23′ W) in the south (Haberzettl et al., 2007; Wille et al., 2007).

This paper examines the vegetation and climate history in two areas of southern Patagonia during the Pleistocene–Holocene transition and the early Holocene, namely the Deseado Massif (Figs. 1 and 2) and the region south of Lago Argentino (50° S). It also

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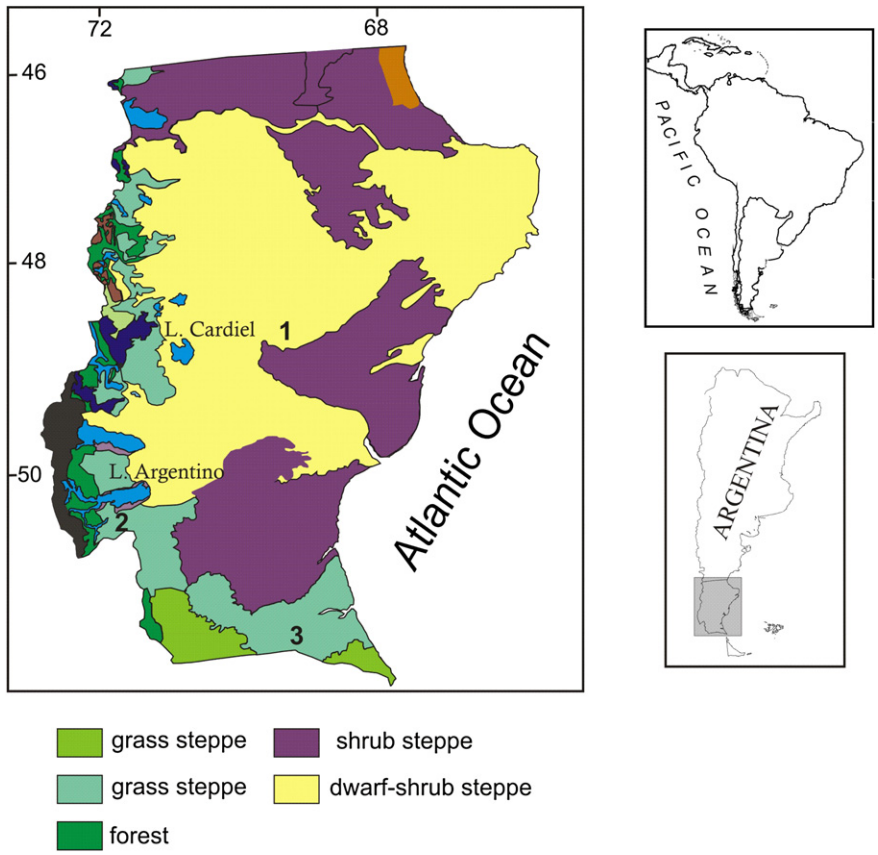

Fig. 1. Map of major vegetation units in southernmost South America (modified from Mancini et al., 2012) showing the location of the sites La Gruta (1), Chorrillo Malo 2 (2), and Laguna Potrok Aike (3).

seeks to understand how the changing climate during this critical period influenced human occupation and human activities. In both areas, the earliest evidence of human occupation probably corresponds to their initial exploration (sensu Borrero, 1994–95). The environmental reconstructions presented are based on pollen spectra from two archaeological sequences at La Gruta and at Chorrillo Malo 2 and are compared with other palaeoenvironmental records for the region. Uncalibrated radiocarbon ages referred to in this paper are in radiocarbon years BP (^{14}C BP). All calibrated radiocarbon ages, including previously published ages, are in calendar years BP (cal BP) and were calibrated using CALIB 6.0 (Stuiver and Reimer, 1993). The SHCal04 Southern Hemisphere calibration curve of McCormac et al. (2004) was used to calibrate samples younger than 11,000 cal BP and the IntCal09 calibration curve based on Northern Hemisphere data was used for samples older than this (Reimer et al., 2009).

2. Study areas: geomorphology, climate and vegetation

The Patagonian plateau is a stepped tableland ranging in altitude from 1000 to 100 m a.s.l. with erosion scarps, rotational slumps, pediments and deflation hollows breaking a generally flat landscape (Pereyra et al., 2002). Rising from this tableland is the Deseado Massif, an irregular landscape with isolated hills and volcanic cones alternating with small rounded hills and plateaus (Fig. 2). Fluvial, wind and gravitational erosional and depositional features dominate especially deflation and mass-wasting forms, the latter including rockfalls and landslides (Pereyra et al., 2002). Notable in the area are caves or cavities in ignimbrites, some of which were used by humans (e.g. in the Los Toldos, La María, La Martita and La Gruta localities).

The Deseado Massif has abundant silicified ignimbrites, silicified wood, tuffs and epithermal quartz veins of the Chon Aike and La Matilde Formations (e.g. Panza and Marin, 1998; Panza and Haller, 2002; Echeveste, 2005). Chalcedonies, jasper and opal are available in some areas. Overall, the region has excellent raw material for high-quality flint knapping (e.g. Cattáneo, 2000, 2004; Hermo, 2008; Franco and Cirigliano, 2009; Franco et al., 2009, 2012; Skarbun, 2009). In addition, the Pampa del Asador obsidian source is located west of the Massif (e.g. Stern, 2000).

The second area of study is located south of Lago Argentino in the western part of Santa Cruz province. It is characterized by a system of smaller connected lakes with occasional rock shelters. One rock shelter, Chorrillo Malo 2, has provided evidence of early occupation of the area (Civalero and Franco, 2003; Franco and Borrero, 2003). Dacites are the most frequent raw material in the area (e.g. Franco, 2004, 2008), but are not of the quality of raw materials available in the Deseado Massif. The western and southern parts of Santa Cruz province were glaciated and are dominated by steep-sided glaciated valleys, moraines, glaciofluvial terraces and glaciolacustrine plains (Coronato et al., 2008).

The climate of the Patagonian plateau is temperate semi-arid with autumn–winter rainfall that ranges from 180 mm in the eastern and central parts of the area to 400 mm at the foot of the Andes. Mean annual temperature values are between 8° and 10 °C in the central plateaus and from 6 °C to 8 °C in the southwest. The dryness of the Patagonian plateau is due to the combined effects of the low annual precipitation and strong prevailing winds. The Southern Westerly Winds (SWW) are stronger during the summer, peaking between 45° S and 55° S latitude but weaken in winter, particularly at 50° S (Paruelo et al., 2000; Garreaud et al., 2009).

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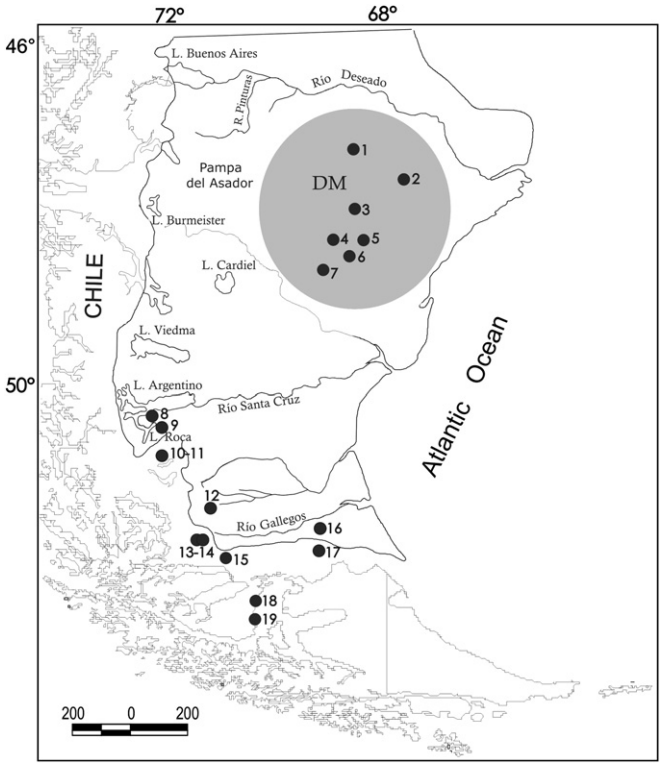

Fig. 2. Map showing the locations of sites mentioned in the text. 1) Los Toldos, 2) Piedra Museo, 3) Cerro Tres Tetas, 4) La Martita Cave 4, 5) La María 6) El Verano, 7) La Gruta 1 and La Gruta 2, 8) Cerro Frías, 9) Chorrillo Malo 2, 10) Torres del Paine, 11) Vega Ñandú, 12) Meseta Latorre, 13) Cueva Mylodon, 14) Cueva Lago Sofía 1, 15) Río Rubens, 16) Laguna Potrok Aike, 17) Cueva Fell, 18) Punta Arenas, 19) Puerto del Hambre. DM: Deseado Massif.

The vegetation of southernmost South America (Fig. 1) is related to the precipitation gradient at the regional scale but also to topography, edaphic characteristics and slope orientation at the meso and local scales. Dwarf-shrub steppe, the most widely distributed vegetation unit, is dominated by dwarf shrubs such as *Nassauvia glomerulosa, Nassauvia ulicina* and *Ephedra frustillata*, cushion plants (*Azorella caespitosa*, *Acantholippia seriphioides*), bunch grasses (*Stipa speciosa, Stipa humilis, Stipa chrysophylla, Stipa ibari*) and isolated patches of shrubs (*Junellia tridens*, *Berberis heterophylla*, *Nardophyllum obtusifolium*) (Mancini et al., 2012). At the regional scale the dwarf-shrub steppe is generally considered a homogeneous unit although it is quite heterogeneous at the meso and local scales and presents important differences in composition as a consequence of the complex geomorphologic features of the Patagonian plateau (Roig, 1998).

In the Andean region, in areas with 400–800 mm of annual precipitation, the vegetation is Subantarctic forest of *Nothofagus* with *Nothofagus pumilio* and *Nothofagus antarctica.* In areas of lower precipitation (300–400 mm/y) the forest grades into *Festuca pallescens* grass steppe. Shrublands of *Maytenus magellanica, Embothrium coccineum, Ribes magellanicum, Pernettya mucronata, Empetrum rubrum* and *Escallonia rubra* occur locally, whereas *Baccharis patagonica, B. >heterophylla* and *Mulinum spinosum* grow in drier areas (Pisano Valdés and Dimitri, 1973). In rocky places protected from the wind, there is increased humidity and organic matter accumulates so that *Adesmia boronioides* is found.

3. Archaeological sites

In the area of La Gruta, in the extreme southern part of the Deseado Massif, radiocarbon ages indicate human occupation 12,895–12,141 cal BP based on five radiocarbon ages (Table 1). The presence of small charcoal concentrations as well as small flakes produced during the final stages of stone tool production, suggest that during the Pleistocene–Holocene transition, La Gruta 1 (previously, Lagoon 2, Cave 1, see Franco et al., 2010a,b) was used repeatedly for short periods by a few to several people. Most likely, the cave was used during hunting trips for shelter and to sight prey (Franco et al., 2010a,b). The cave is located in a cliff close to the shore of a seasonal lagoon. Old shorelines around the lagoon, up to a few meters above present lake levels (Fig. 3), suggest that the lagoon was much larger and possibly more permanent in the past. In this relatively dry environment, variations in the availability of water in lagoons similar to that at La Gruta, may have affected human populations over time and possibly at the Pleistocene–Holocene transition. A 1 × 1 m square test pit excavated in the cave floor exposed four stratigraphic–sedimentological units and provided chronological data on use of the shelter by humans (Fig. 4).

Radiocarbon ages for Unit 1, at the base of the excavation, date it to the Pleistocene–Holocene transition (Table 1). Small flakes and charcoal concentrations were identified throughout the sequence and artifacts include black and grey obsidian (Franco et al., 2010b). Geochemical data for Patagonia indicate that the obsidian probably came from Pampa del Asador 158 km to the north (e.g. Stern, 2000).

The early Holocene use of the rock shelter is indicated by an age of 9026–8770 cal BP (8090 ± 30 ^{14}C BP) on charcoal from a hearth in the sequence (Table 1). Small flakes were also recovered from the sediments at this depth.

Sixty kilometers northeast of La Gruta area (Fig. 2), in La María locality, sites occupied during the Pleistocene–Holocene transition include Casa del Minero 1 and Cueva Túnel, where the earliest dates are 13,081–12,692 cal BP (10,999 ± 55 ^{14}C BP) and 12,669–11,509 cal ka BP (10,420 ± 180 ^{14}C ka BP), respectively (Paunero, 2009). Approximately 83 km northeast of La Gruta, the initial occupation of Cerro Tres Tetas has been dated at 13,733–13,162 cal BP (11,560 ± 140 ^{14}C BP; Frank and Paunero 2009). The oldest deposits in Cave 4 at La Martita date to 9092–8595 and 9026–8417 cal BP (8050 ± 90 and 7940 ± 260 ^{14}C BP, Aguerre, 2003) and at El Verano to 10,268–9551 and 8781–7733 cal BP (8960 ± 140 and 7500 ± 250 ^{14}C BP, Durán et al., 2003). These sites are only 32 and 21 km north and northeast from La Gruta, respectively, indicating that a number of different sites in this large area were occupied during the early Holocene (e.g. Aguerre, 1997, 2003; Aguerre and Pagano, 2003; Durán et al., 2003). Black obsidian was also recovered from both sites (Aguerre, 2003; Durán et al., 2003). In addition, there is evidence of human occupation during the early Holocene at La Gruta, Lagoon 1, Cueva Puntos, where a date of 8393–8203 cal BP (7560 ± 30 ^{14}C BP) was obtained (Franco et al., 2011; Table 1).

Table 1
Radiocarbon and calendar ages for charcoal and Guanaco bone from the oldest deposits at La Gruta 1, La Gruta 2, and Chorrillo Malo 2.

Site	^{14}C yr BP	Cal yr BP (2σ)	Laboratory sample	Material
La Gruta 1	8090 ± 30	9123–8986	UGAMS 7540	Charcoal
	10477 ± 56	12,579–12,141	AA-84225	Charcoal
	10656 ± 54	12,706–12,438	AA-76792	Charcoal
	10790 ± 30	12,792–12,577	UGAMS 7538	Charcoal
	10840 ± 62	12,893–12,594	AA-84223	Charcoal
	10845 ± 61	12,895–12,597	AA 84224	Charcoal
La Gruta 2	7560 ± 30	8393–8203	UGAMS 7119	Guanaco bone[a]
Chorrillo Malo 2	9690 ± 80	11,237–10,776	AMS 71152	Guanaco bone[b]
	9740 ± 50	11,247–10,884	GX-25279 AMS	Guanaco bone[b]

[a] Guanaco bone with anthropical marks (Franco et al., 2012).
[b] Guanaco bone with anthropical marks (Franco and Borrero, 2003).

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Fig. 3. Environments near the La Gruta and Lago Argentino archaeological sites. A. High lake strandlines visible from the La Gruta 1 entrance. B. View from Chorrillo Malo 2 in the direction of Lago Argentino and Cerro Frías.

Early Holocene occupation of the area south of Lago Argentino is indicated by dates of 11,247–10,884 and 11,237–10,776 cal BP (Table 1) for basal sediments at the Chorrillo Malo 2 rock shelter, east of Lago Roca (Franco and Borrero, 2003). This archaeological site is located in the area of grass steppe (Figs. 1 and 2). The entrance to the shelter faces south and so the shelter receives pollen from the forest and the forest-shrub steppe ecotone (Mancini, 2002; Franco et al., 2004).

Only one artifact, a small black obsidian flake, was recovered from below the ca. 11,247–10,776 cal BP level (Franco, 2004). XRF and neutron activation analysis indicate that the obsidian came from Pampa del Asador, more than 260 km to the north (Stern, pers. comm.). This obsidian was probably part of a tool-kit carried by early inhabitants (Civalero and Franco, 2003).

4. Pollen evidence of changing conditions

Pollen sampling, processing and results from Los Toldos, La Martita, Chorrillo Malo 2 and Cerro Frías have been discussed previously by Paez et al. (1999) and Mancini (1998, 2002, 2009). For these sites and for La Gruta 1, approximately 20 g of sediment was treated using standard pollen extraction methods outlined in Gray (1965) and Faegri and Iversen (1989). Pollen diagrams showing the frequencies (%) of the main pollen taxa were plotted using TG View 2.0.2 (Grimm, 2004).

Pollen data from sites in the central plateau region east of the Andes in Patagonia have been used to reconstruct regional palaeoenvironment conditions prior to and contemporaneous with the human use of the La Gruta rock shelter (Fig. 5). Prior to ca.

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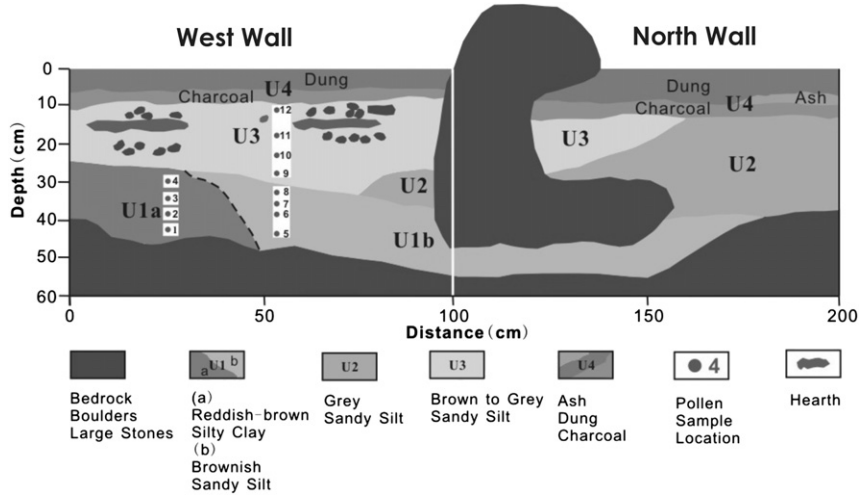

Fig. 4. Stratigraphy of the west and north wall of the 1 × 1 m square excavated at La Gruta 1. Sediment units U1-U4 are shown along with the most prominent hearths and pollen sampling locations. Only pollen data from Unit 1 are presented in this paper.

13,000 cal BP pollen sequences from the Los Toldos and La María archaeological localities – in the north and central Deseado Massif – show a dwarf - shrub steppe with high values of *Ephedra* suggesting arid conditions with annual precipitation less than 200 mm (Paez et al., 1999; de Porras, 2010). These ancient communities have no present-day analogues at the regional (Mancini, 1998), meso or local scales (de Porras, 2010). At the Piedra Museo rock shelter, the vegetation at this time was shrub steppe with Asteraceae subf. Asteroideae and halophytic plants (Borromei, 2003).

The pollen data from north of La Gruta reveal that during the Pleistocene–Holocene transition from ca. 13,000 to 10,900 cal BP when humans first occupied this area, there was steppe vegetation dominated by grass with low shrubs, mainly *Nassauvia* (Figs. 5 and 6). Between 13,000 and 10,800 cal BP pollen records from Los Toldos (Paez et al., 1999) and Piedra Museo localities (Borromei, 2003) indicate grass steppe with local variations in the proportions of shrubs and dwarf-shrubs (Fig. 5). The vegetation at this time resembled patches of grass that are found in the present-day dwarf-shrub vegetation of the Deseado Massif above 700 m. The same plant communities are indicated by pollen spectra from La María locality (Casa del Minero, de Porras, 2010), suggesting an increase in effective moisture probably due to an increase in precipitation under cold and semi-arid conditions (Mancini et al., 2008). Probably, temperature during this time was lower than today (de Porras, 2010).

During the early Holocene grass became even more dominant in the steppe vegetation in La Gruta area (Figs. 5 and 6) suggesting higher moisture than during the late Pleistocene. There was similar vegetation at La Martita until ca. 9000 cal BP when there was a change to shrub steppe. This change occurred earlier at Los Toldos (ca. 11,500 cal BP) and Piedra Museo (10,800 cal BP), where the vegetation was steppe with shrubs, dwarf-shrubs and Poaceae from

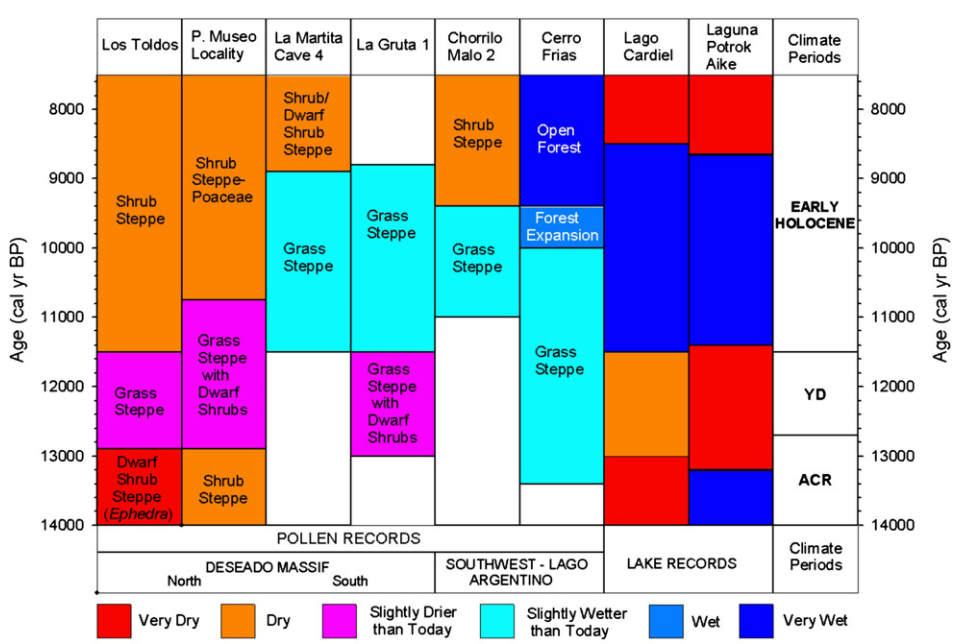

Fig. 5. Plant physiognomy inferred from pollen records for sites mentioned in the text (from Mancini, 1998, 2002, 2009; Paez et al., 1999; Borromei, 2003) compared with lake level changes at Lago Cardiel and Laguna Potrok Aike.

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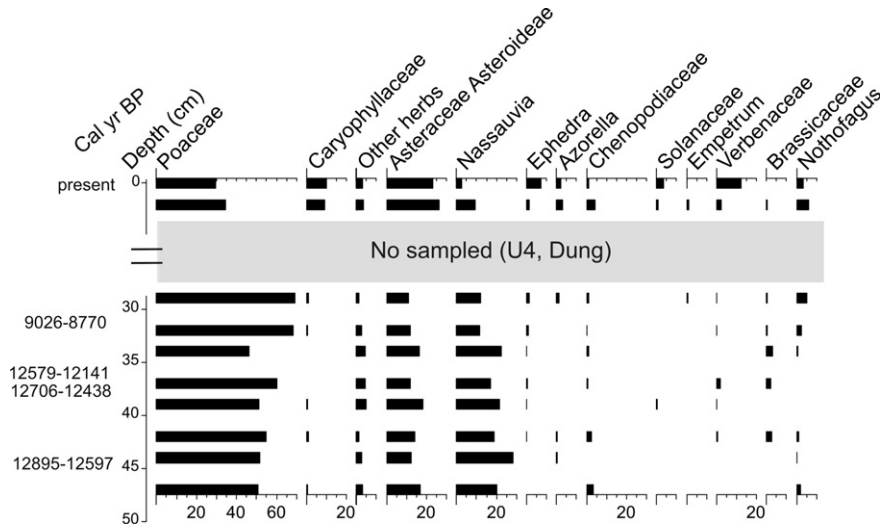

Fig. 6. Pollen diagram for samples taken from stratigraphical unit U1 (a, b) at La Gruta 1.

the early Holocene until at least 7800 cal BP (Mancini, 1998; Paez et al., 1999; Borromei, 2003; de Porras, 2010) (Figs. 1 and 5). These shrub physiognomies suggest higher temperatures and less moisture. The earliest appearance of shrubs on sites further north in the Deseado Massif is also associated with evidence of higher average temperatures.

The earliest evidence for human occupation of the southern part of the Deseado Massif comes from basal sediments at La Gruta 1, and suggests that the first humans to use the rock shelter had occupied it only for short periods of time (Franco et al., 2010). The presence of obsidian from Pampa del Asador indicates that this raw material was probably part of a "tool-kit" which was transported as they explored new areas.

Archaeological evidence for human occupation of the southern part of the Deseado Massif increases after about 9000 cal BP and excavations at several sites have revealed that human groups in the area had very similar tool assemblages that often included obsidian most likely from Pampa del Asador (Durán et al., 2003).

Although grass steppe covered a huge area of the central plateau at the end of the Pleistocene, human populations in Patagonia east of the Andes had to deal with variable environmental conditions as temperature increased and shrinking glaciers allowed humans to occupy areas closer to the Andes (Glasser et al., 2004; Mancini et al., 2008).

With only minor local differences, all pollen records from southernmost Patagonia suggest a similar palaeoenvironmental history (Fig. 5). South of Lago Argentino, pollen spectra from Cerro Frías (Fig. 5) show grass steppe between ca. 13,500 and 10,000 cal BP (Mancini, 2009). Grass steppe was also dominant in pollen spectra from sites located between latitudes 50° S and 52° S (Torres del Paine, Cueva Lago Sofıa 1, Cueva Mylodon, Cueva Fell and Rio Rubens) in the period 12,000–10,000 cal BP. This indicates an open landscape with relatively humid and cold conditions (Markgraf, 1993; Heusser, 1995; Huber and Markgraf, 2003; Villa-Martínez and Moreno, 2007).

There was a change from grass steppe to forest at Cerro Frías ca. 10,000 cal BP in response to increased precipitation and higher temperatures. The expansion of *Nothofagus* forest during the early Holocene is documented in several pollen sequences from southwestern Patagonia including Vega Ñandú (Villa-Martínez and Moreno, 2007), Torres del Paine, Puerto del Hambre, Punta Arenas (Heusser, 1995) and Meseta Latorre (Schäbitz, 1991). During this period temperatures and mean annual precipitation increased (from 200 mm to ca. 300–350 mm) compared to conditions in the preceding period (Tonello et al., 2009).

Pollen records from the Chorrillo Malo 2 archaeological site also indicate forest expansion during the early Holocene into western areas that were previously dominated by grass steppe (Mancini, 2002). The earliest human artifacts at Chorrillo Malo 2, date to around 11,000 cal BP and probably record the first human exploration (sensu Borrero, 1994–95) of this area close to the Andes (Franco, 2004). Most of the artifacts recovered were of local raw material but they did include one obsidian flake similar in composition to obsidian from Pampa del Asador (Franco, 2004). At about 9500 cal BP (8,5 ^{14}C ka BP) pollen spectra from Chorrillo Malo 2 indicate a change from grass steppe to shrub steppe. Occupation of this rock shelter appears to have been discontinuous until at least ca. 6500 cal BP, when a large rock fell the floor of the shelter (Mehl and Franco, 2009). There are other smaller rocks in this part of the sequence, which may have fallen at the same time as the large boulder but could equally have accumulated gradually over a period of time. By ca. 6500 cal BP another rock shelter – Río Bote 1 – located about 50 km to the east was also being utilized by humans (Mehl and Franco, 2009).

5. Discussion

The late glacial and early Holocene was a time of rapid and profound climate change as humans entered the southernmost parts of South America. Several distinct periods of climate are recognized including the Antarctic Cold reversal (ACR), Bølling–Allerød (B–A), and the Younger Dryas (YD). Bianchi and Gersonde (2004) note that the ACR was a thermal reversal, of much lower amplitude relative to the YD cooling in the North Atlantic region, that can be observed in marine and land climate records from the Southern Hemisphere but the exact time of this reversal is still under debate. Blunier et al. (1997) synchronised the GRIP, Vostok and Byrd ice core records using CH_4 content to show that the ACR of the Southern Hemisphere preceded the YD by at least 1800 years lasting from ca. 14,500 to 12,700 cal BP, while the YD lasted from ca. 12,700 to 11,500 cal BP.

It has been suggested that the ACR was triggered by warming in the southern high latitudes that produced an Antarctic meltwater event into the Southern Ocean shortly after 14,600 cal BP (Bianchi and Gersonde, 2004). This meltwater event increased Atlantic Ocean thermohaline circulation producing Northern Hemisphere

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warming associated with the B–A warm period from ca. 14,500 to 13,000 cal BP. The meltwater input triggered continuous warming of the Northern Hemisphere into the B–A time interval until the onset of YD cooling, forced by Northern Hemisphere processes. As YD cooling shut down the Atlantic thermohaline circulation the YD coincides with a period of Southern Hemisphere warming that reached a postglacial maximum temperature around 11,500 cal BP (Bianchi and Gersonde, 2004). Importantly, throughout the YD Antarctic temperature increased.

A major factor in the climate of southern South America is the location and speed of the Southern Westerly Winds (SWW). Seasonal forcing drives the SWW north in winter and south in summer relative to the core region of strongest wind speeds (~50° S), resulting in a winter dominant rainfall climate north of ~50° S and a summer dominant rainfall climate south of this latitude (Fletcher and Moreno, 2011). However, the core region of the SWW varied significantly during the late glacial and early Holocene making some areas drier than today and others wetter. The pollen records in this study allow determination of the likely magnitudes of these SWW migrations and the relation between them and spatial patterns of human occupation.

Pollen data from the southern part of the Deseado Massif indicate drier conditions than present before about 12,900 cal BP during the ACR. Between 12,900 and 11,000 cal BP, roughly centered on the Northern Hemisphere YD cold episode, when Antarctic temperatures increased, conditions at Los Toldos, Piedra Museo and La Gruta were all somewhat wetter than during the ACR and supported grass steppe or grass steppe with dwarf shrubs. Significantly, the start of this slightly wetter period during the YD saw the first humans enter these areas. At the more northerly sites of Los Toldos and Piedra Museo shrub steppe replaced grass steppe with dwarf shrubs after the YD, around 11,500 cal BP and 10,800 cal BP, respectively, signaling the onset of more arid conditions. However, grass steppe persisted at the more southerly sites of La Martita and La Gruta although it was replaced by shrub steppe at La Martita around 8900 cal BP suggesting a return to more arid conditions. Thus, during the early Holocene, the vegetation on the plateau east of the Andes was a mosaic of dwarf shrub, shrub and grass steppes very much like the pattern seen today.

Pollen spectra from southwest Santa Cruz record moist conditions with grass steppe from the middle of the ACR to the early Holocene (13,400–10,000 cal BP at Cerro Frías and 11,000–9400 cal BP at Chorrillo Malo 2). Moisture levels increased after ca. 10,000 cal BP and there was expansion of forest at Cerro Frías until 9400 cal BP when conditions became somewhat drier in the Chorrillo Malo 2 area.

Other records from southern Patagonia support the pollen data presented here, particularly the Lago Cardiel and Laguna Potrok Aike lake level records (Fig. 5). For example, conditions were extremely dry at Lago Cardiel prior to about 13,000 cal BP when the lake level dropped below 75 m but by 11,500 cal BP the lake was at present levels and by 10,800 cal BP it had risen possibly as high as +55 m (Stine and Stine, 1990; Gilli et al., 2001; Markgraf et al., 2003). Stine and Stine (1990) also concluded that the lake remained below +10 m and may even have fallen below the present-day level between ca. 8400 and 5800 cal BP (7700 and 5100 ^{14}C BP) suggesting a dry climate at this time. The record from Laguna Potrok Aike in southeastern Patagonia, approximately 340 km SSE of Lago Cardiel, shows generally wetter conditions from 16,000 to 8700 cal BP with a much warmer and drier interval from 13,200 to 11,400 cal BP. After 8650 cal BP a major drought may have caused the lowest lake level of the record (Haberzettl et al., 2007).

The YD and early Holocene (ca. 13,000–7500 cal BP) records for Lago Cardiel and Laguna Potrok Aike are almost identical with dry intervals from 13,200 to 11,500 and 8600 to 7500 cal BP and high lake levels from 11,500 to 8600 cal BP (Fig. 5). Furthermore, the lake records and the southern Deseado Massif pollen records correlate extremely well during the YD and early Holocene and there is even fairly good agreement with the pollen records from southwest Santa Cruz (Fig. 5). In all these records the YD appears drier and an interval centered on ca. 10,000 cal BP appears wetter, with dry conditions returning sometime between 9400 and 8600 cal BP.

In contrast, although the northern Deseado Massif pollen data show the same vegetation/climate trends as do the other sites, with an early dry phase, and afterwards a wetter interval that is followed by increased aridity, these stages occur 1000–1500 years earlier than in the southern Deseado, and at Lago Cardiel and Laguna Potrok Aike. A further difference among the records is the wet interval at Laguna Potrok Aike during the ACR when all other sites appear to have been more arid.

There can be little doubt that the vegetation and lake level changes shown in Fig. 5 were caused by broad-scale changes in atmospheric circulation over southern Patagonia (Mancini, 2009; Tonello et al., 2009; Sottile et al., 2012). For example, it is possible that the meltwater pulse that triggered the ACR pushed the Polar Front northwards and brought moisture to the Laguna Potrok Aike area. Laguna Potrok Aike is south of the modern core of the SWW and because of its proximity to both the Andes and Atlantic Ocean, it receives precipitation today from both the SWW and from the South Atlantic under weak westerly flow (Fletcher and Moreno, 2011). Therefore, it seems likely that easterly sources of moisture were important in raising lake levels during the ACR when the SWW were further north than they are today as evidenced by widespread aridity elsewhere in southern Patagonia.

Only sites in the northern Deseado Massif show definite evidence of wetness during the YD implying a more northerly position for the core of the SWW at this time. Cool-temperate conditions at Lago Condorito in Chile (41° 45′ S) between 13,800 and 11,500 cal BP support this view and suggest that the SWW were most effective between latitudes ca. 41° and 48° S during the later part of the ACR and during the YD.

The prominent wet interval from ca. 11,500 to 8500 cal BP that is recorded at sites from the southern Deseado Massif through southwest Santa Cruz (Lago Argentino area) to Laguna Potrok Aike in the south, suggests that the SWW core area during the early Holocene was further south than previously and further south even than today, extending between latitudes 48°–52° S. Sites further north were drier at this time so the SWW influence did not extend as far as 47° S. Moreno (2004) notes that at Lago Condorito at 41° 45′ S, the period 10,000–7600 cal BP was extremely warm suggesting a significant poleward movement of the SWW. This period corresponds with the major phase of wetness in southern Patagonia between 11,500 and 8500 cal BP supporting the view that the SWW were focused between 48° and 52° S at this time. A more southerly position of the SWW than today is indicated because Laguna Potrok Aike (52° S; Fig. 2), lies south of the modern core of the SWW and it appears to have been within the zone of influence of the SWW in the early Holocene.

La Gruta 1 was first utilized by humans between 13,000 and 12,000 cal BP during the YD chronozone from 12,700 to 11,500 cal BP when temperatures in the Southern Hemisphere were increasing. Lago Cardiel data indicate rising lake levels so that the climate was becoming gradually wetter. The northern part of the Deseado Massif was wetter with grass steppe during this period and as the SWW core area moved polewards La Gruta 1 and La Martita Cave 4 became wetter with the establishment of grass steppe, which facilitated human use of the area. In fact the main use of these sites by humans corresponds with a time of significantly increased moisture over broad areas of southern Patagonia during the early Holocene from ca. 11,500 to 8500 cal BP (Fig. 5).

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The earliest human use of the Chorrillo Malo 2 site in southwest Santa Cruz was a little later, around 11,000 cal BP. One reason for this may have been cold conditions that triggered glacial advances west of Lago Argentino evidenced by the Puerto Bandera II moraines, with two ages of 12,900 and 12,300 cal BP (Strelin and Malagnino, 2000). However, Mercer (1968) shows that by about 12,000 cal BP the snout of the Moreno glacier was about 25 km from Chorrillo Malo 2, essentially in about the same position as today. Rapidly increasing temperatures at the beginning of the Holocene caused glaciers to retreat and brought increased moisture due to migration of the SWW core into the area. It was only after these changes that humans were able to utilize areas nearer to the Andes.

6. Conclusions

Pollen records from La Gruta 1 and Chorrillo Malo 2 suggest that the initial occupation (ca. 12,900–11,000 cal BP) of the southern Deseado Massif and the area south of Lago Argentino corresponded with improved environmental conditions, related to higher temperatures and greater moisture availability than previously. After ca. 10,000 cal BP the plant communities reconstructed from pollen analysis suggest higher vegetation heterogeneity (grass, shrub and dwarf shrub on the plateau and steppes and forest expansion to the west). Undoubtedly, variations in moisture availability affected occupation and mobility of small groups of humans within the arid and semiarid environments of these regions as changes would determine the distribution of the resources (plants, animals) available to them.

Although there is more evidence for the presence of humans in the southern part of the Deseado Massif by ca. 9000 cal BP at the height of a major wet phase that affected large parts of southern Patagonia, there is no conclusive evidence that the area south of Lago Argentino was used continuously, at least between ca. 11,200 and 6000 cal BP. This difference may reflect the fact that human occupation of new spaces is influenced by climatic and environmental conditions in areas that could be occupied.

The shift to shrub communities on the plateau east of the Andes and the expansion of forest in the Andean region appear to have been related to an increase in temperature at the beginning of the Holocene. In the dry environment of the plateau the rising temperatures reduced the availability of water in small ponds and ephemeral streams, while in the Andean region they led to the shrinkage of glaciers and the opening up of new spaces for occupation and use. Thus, increased aridity in the plateau immediately east of the Andes accompanied by improved conditions in the Andean region and a steady increase in the ranges of human groups (Borrero, 1994–95), may have encouraged them to explore the Andean sector at this time. However, although the Patagonian hunter-gatherers were highly dependent on water availability, population dynamics in Patagonia would not necessarily have been synchronous with climatic variations (Borrero and Franco, 2000).

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