JOURNAL OF QUATERNARY SCIENCE (2010) **25**(7) 1092–1099

Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/jqs.1352

Lake-level changes in central Patagonia (Argentina): crossing environmental thresholds for Lateglacial and Holocene human occupation

DANIEL ARIZTEGUI,[1]* ADRIAN GILLI,[2] FLAVIO S. ANSELMETTI,[3] RAFAEL A. GOÑI,[4] JUAN B. BELARDI[5] and SILVANA ESPINOSA[5]

[1] Section of Earth and Environmental Sciences, University of Geneva, Geneva, Switzerland
[2] Geological Institute, ETH Zürich, Zürich, Switzerland
[3] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland
[4] Instituto Nacional de Antropología y Pensamiento Latinoamericano, Universidad de Buenos Aires, UNCPBA, Buenos Aires, Argentina
[5] CONICET/Universidad Nacional de la Patagonia Austral, Río Gallegos, Santa Cruz, Argentina

Ariztegui, D., Gilli, A., Anselmetti, F. S., Goñi, R. A., Belardi, J. B. and Espinosa, S. 2010. Lake-level changes in central Patagonia (Argentina): crossing environmental thresholds for Lateglacial and Holocene human occupation. *J. Quaternary Sci.*, **Vol. 25** pp. 1092–1099. ISSN 0267-8179.

Received 30 May 2008; Revised 18 September 2009; Accepted 22 September 2009

ABSTRACT: The role and extent of climate as a cause of the expansion and decline of human cultures is still debatable. It is clear, however, that human–environment interactions are enhanced and interplay more closely in climatically sensitive areas such as around hydrologically closed basins. Lago Cardiel is located at 49° S in the very arid rain shadow east of the Andes, providing an exceptionally receptive system to changes in hydrological balance. Results of a geophysical survey combined with sedimentological and geochemical studies provide a continuous Lateglacial–Holocene record of substantial water-level changes. These variations, combined with archaeological results from the catchment area, offer a unique possibility to explore the pattern of peopling within this remote area of the globe and its possible relation to climate change. Human occupation in Patagonia is well documented towards the Andes throughout the entire Holocene. Archaeological data from the Lago Cardiel basin, however, show an apparent lack of human activity during the first part of this period, which coincides with well-constrained high lake levels. Our results show an intriguing coincidence between low lake level and increasing human occupation, suggesting that the Lago Cardiel basin has focused human use during intervals with relatively lower effective moisture such as during the Late Pleistocene, but its evidence may have been submerged. This interpretation is confirmed by archaeological remains from Lago Strobel, another perennial lake with a comparable catchment located in the same climatic region and thus sharing the same climatic history as Lago Cardiel. Copyright © 2009 John Wiley & Sons, Ltd.

KEYWORDS: eastern Patagonia; Late Pleistocene; Holocene; archaeology; limnogeology; human occupation.

Introduction

The early occupation, further expansion and eventual decline of human groups can be the result of a complex set of factors. Although the role and influence of climate among these causes is still debatable, human–environment interactions are clearly enhanced in climatically sensitive areas such as around hydrologically closed basins.

Human evolution and Earth system science have traditionally developed independently, with limited communication among these academic communities. Lately, there has been an increasing flux of information across these fields in an attempt to obtain more integrated views of the interaction between people and their environment and to elucidate some causal relationships among them (e.g. Costanza *et al.*, 2007). Most of these investigations have concentrated on the last few thousand years during which human history was punctuated by the rise and fall of major civilisations, wars and specific human accomplishments (e.g. Anselmetti *et al.*, 2007; Hodell *et al.*, 1995, 2001; Gómez-Pompa *et al.*, 2003; Diamond, 2005; and references therein). Earlier populations are more difficult to study because of paucity of data and associated uncertainties.

Although ranging between regions the Pleistocene/Holocene transition displays a general pattern of relatively unstable climatic conditions and substantial variability. This

* Correspondence to: D. Ariztegui, Section of Earth and Environmental Sciences, University of Geneva, 13 rue des Maraichers, Geneva 1205, Switzerland.
E-mail: daniel.ariztegui@unige.ch; gonirafael@gmail.com

time interval was critical, however, for the dispersal of human societies worldwide. Depending on regional conditions, people looking for places to settle, even temporarily, had to cope with this often large environmental variability (Borrero, 1996; Coronato *et al.*, 1999).

The history of the early population of Patagonia has been the centre of controversial discussions provoking heated debates within the archaeological community. Borrero (1999) has reviewed technological and faunal evidence from a number of sites in southernmost Patagonia supporting an early human arrival dating back to at least 13 800 cal. a BP. The availability of a North Pacific coastal corridor around 15 000 cal. a BP suggests that this entry likely happened only after the Last Glacial Maximum (LGM; see Goebel *et al.*, 2008). Further studies in Patagonia assembling existing evidence of population point towards a complex distribution and uneven timing of these early settlers, not only during the transition but also during the Holocene (Borrero and McEwan, 1997; Coronato *et al.*, 1999; Miotti and Salemme, 2003). These studies share the view that the climatic amelioration encompassing the Late Pleistocene/Holocene transition coincided with a progressive spreading of people around the South American hemicontinent. Analysis of the temporal and geographical distribution of these records reinforces the idea that human colonisation in southernmost Patagonia was most probably uneven and somehow patchy for the first Americans (Miotti and Salemme, 2003). Moreover, the complexity of certain records can jeopardise and even prevent any attempt to build up regional patterns of human distribution. The latter is mostly due to their temporal discontinuity and the lack of local palaeoclimatic reconstructions of a high-resolution form. The Patagonian region, specially the central plateau of the Argentinean province of Santa Cruz and the southern Magellan basin, has been one of the most relevant areas for the study of early South American peopling and for the interpretation of human/environment interactions during the Late Pleistocene and Holocene. The archaeology of several Patagonian sites reveals that people arrived in southernmost South America at least towards the end of the Late Pleistocene (Borrero, 1999). They were carrying a technology that allowed them to adapt to the changing environmental conditions of the Lateglacial period. Thus hunter-gatherers colonised extra-Andean Patagonia as well as the piedmont of the Andean ranges, occupying most of the available space where they could get an adequate supply of food, water and raw materials, even though populations were small and dispersed in southern South America at the time of this transition. At present, most of the well-documented archaeological evidence suggests that the direction of peopling was from the north (Borrero, 1999), leading to the presence of early-comers in the Cardiel/Strobel regions.

In this paper we present data for two lake basins in central Santa Cruz Province, Argentina (Fig. 1): limnogeological and archaeological evidence for the Lago Cardiel region as well as archaeological data for Lago Strobel. An intriguing question arises when comparing the recently developed chronology of the archaeological records of both basins to other southern Patagonian lakes: why do the Cardiel–Strobel basins show a striking lack of human activity for the Late Pleistocene as well as the first part of the Holocene and only an extensive late Holocene human occupation? This relatively late arrival is in disagreement with most of the existing regional data and several hypotheses have been proposed to explain this discrepancy (e.g. Goñi *et al.*, 2004, 2005). Combining geomorphological, geophysical, sedimentological and archaeological evidence for Lago Cardiel we propose that the contrasting hydrological conditions dominating both deglaciation and early Holocene intervals may be responsible of this apparent late occupation of the area.

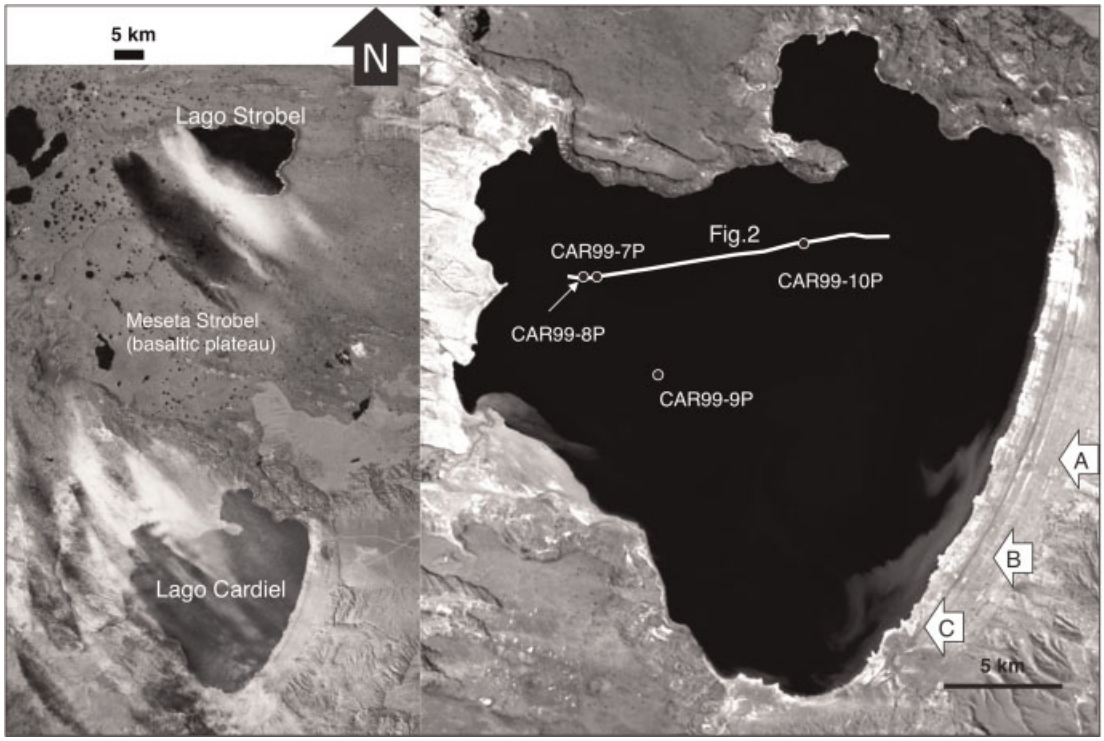

Figure 1 The Landsat 7 satellite image (left) shows the location of lakes Cardiel and Strobel. Note the basaltic plateau that joins both basins. The close-up (right) shows a detailed satellite image of Lago Cardiel. Arrows indicate dated palaeoshorelines. White lines and dots show the location of the seismic profile and sediment cores depicted in Fig. 2.

DOI: 10.1002/jqs

Study area: the Cardiel and Strobel basins

Lago Cardiel is a closed lacustrine basin centrally located on the southern Patagonia plateau at ~100 km east of the Andean cordillera and ~200 km west of the Atlantic coast. At an elevation of 276 m above sea level (a.s.l.) this heart-shaped lake has today an average diameter of approximately 20 km and a maximum water depth of 76 m. The Cardiel river is the principal perennial inflowing river to the system within a total catchment area of about 4500 km^2 (Gilli *et al.*, 2005a). A more detailed description of the morphology of the lake basin can be found elsewhere (e.g. Gilli *et al.*, 2001, 2005a,b).

A basaltic plateau reaching a maximum altitude of 1100 m a.s.l. – Meseta Strobel – joins the Lago Cardiel catchment with that of another perennial closed basin, Lago Strobel, located at an elevation of ~733 m a.s.l. To our knowledge there is neither modern limnological nor sedimentological data available for Lago Strobel, except for a preliminary chemical and isotopic characterisation of the lake water (Schwalb *et al.*, 2002). Lakes Cardiel and Strobel are, however, the only major permanent water bodies among hundreds of non-perennial ones in the region.

Both lakes and their catchments lie in the orographic rain shadow of the Patagonian Andes, with a present mean annual precipitation of ~150 mm near the lake, reaching maximum averages of ~500 mm a^{-1} to the west and northwest of the basin. The present climate of the region is dominated by the Southern Westerlies, winds that create sharp and contrasting seasonal intensities and which are particularly high during the austral summer (Prohaska, 1976). A more detailed description of the modern climatic conditions of the region can be found elsewhere (e.g. Gilli *et al.*, 2001, 2005a,b; Markgraf *et al.*, 2003; and references therein).

Identifying and dating lake-level changes in Lago Cardiel

Results of geomorphological investigations indicate that the entire lake catchment area was not affected by icefield outlet glaciers during the last glaciation (Rabassa and Clapperton, 1990; Wenzens, 2002, 2004) and hence the lake was mostly disconnected from massive glacial or meltwater inputs. Previous studies have also shown that Lago Cardiel is very sensitive to hydrological changes, as confirmed by several palaeoshorelines that were first described and dated by Galloway *et al.* (1988), followed by detailed studies of Stine and Stine (1990). More recent geophysical studies have further ruled out possible structural causes and associated processes of water leaking as a cause of lake-level changes, reinforcing the role of climate behind them (Beres *et al.*, 2008). A radiocarbon-based chronology on bulk carbonates of the outcropping palaeoshorelines indicates major lake-level highstands of +55 m and +21.5 m above present lake level at ca. 10 900 and 5900 cal. a BP, respectively (arrows A and B in Fig. 1; Stine and Stine, 1990). Four minor lake-level fluctuations were further identified during the last 2500 a (arrow C in Fig. 1), but a complete lake-level reconstruction can only be attained in the deepest part of a lake basin, where continuous sedimentation records the full spectra of lake-level fluctuations. Recent studies in several lacustrine basins throughout the Americas have shown the advantage of combining seismic data and a sedimentological multiproxy approach to achieve robust palaeoclimatic reconstructions (e.g. Ariztegui *et al.*, 2001, 2008). The combination of high-resolution seismic profiles further calibrated with sedimentary core data allowed identification, mapping and dating of former lake-level fluctuations in Lago Cardiel, particularly the intervals when the lake was substantially lower than today. Figure 2 shows a high-resolution seismic profile summarising the main seismic sequences that were separated by applying the concept of seismic sequence stratigraphy. The methodological details behind these analyses and their sedimentological significance are extensively discussed elsewhere (Gilli *et al.*, 2001, 2005a,b; Ariztegui *et al.*, 2008). The onlap geometries of the seismic reflections in sequence IV indicate a lake's water depth of only a few metres. The peat and gravel lithology capping this succession at the sequence IV–III boundary implies a desiccation period of a few hundred years after 13 160 cal. a BP (Fig. 3). The presence of well-dated tephra layers allowed the development of a good chronology for the sharp stepwise climate development at this latitude during this time. The existing age model, however, is still too broad to discern whether this arid interval represents the Antarctic Cold Reversal (ACR), the Younger Dryas Chronozone (YDC) and/or the Huelmo/Mascardi Cold Event (HMCE; Hajdas *et al.*, 2003; Gilli *et al.*, 2005a). A major change in the hydrological balance followed this desiccation phase at the base of sequence III. This sequence is found throughout the entire basin even at shallow depths, implying a large lake-level rise after ca. 12 600 cal. a BP up to at least the modern lake level. This fast-evolving transgressive phase rising lake level of at least 80 m occurred within a few hundred years and also in a stepwise fashion. Gilli *et al.* (2005a) identified a series of buried beach ridges during this transgression and proposed a stepwise lake-level rise, arguing that only such a mechanism would prevent erosion of the palaeoshorelines by wave action so that they are preserved in the geological record. This transgression exceeded modern lake level, reaching a highstand of 55 m during the early Holocene (Stine and Stine, 1990). During the subsequent recession, lake levels never

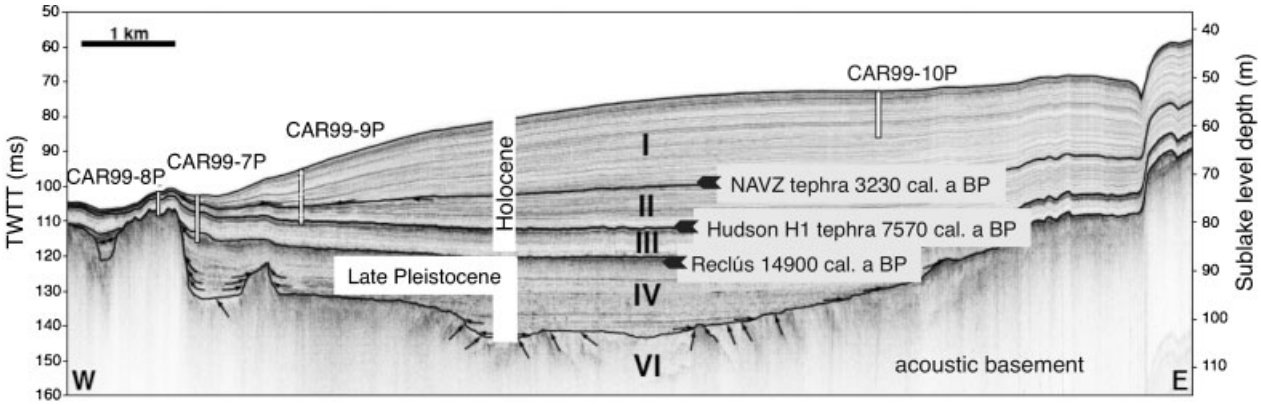

Figure 2 Seismic profile showing the different seismic units as well as the location of the sedimentary cores used to calibrate the geophysical data. Vertical exaggeration is ~50×. Note the position of the main tephra layers and their respective chronology. See text for more details

DOI: 10.1002/jqs

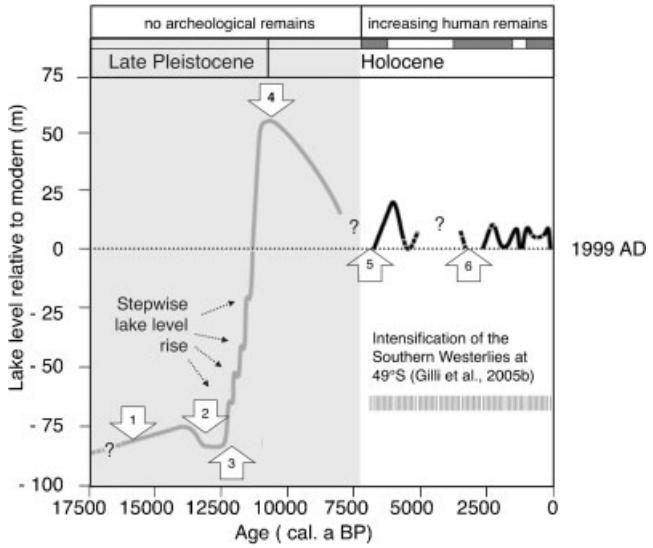

Figure 3 Reconstructed lake-level curve for Lago Cardiel combining geophysical and sedimentological data. The grey area indicates the time interval of possible submerged archaeological evidence. Numbered arrows indicate radiocarbon or tephra ages as follows: (1) Reclús tephra 15 330 cal. a BP; (2) 13 160 cal. a BP; (3) 12 320 cal. a BP; (4) 10 800 cal. a BP; (5) Hudson tephra 7570 cal. a BP; and (6) 3230 cal. a BP (after Ariztegui *et al.*, 2008, and references therein). Note the coincidence between the interpreted intensification of the Southern Westerlies at this latitude and human occupation in the lake catchment (see text)

dropped significantly below modern values (Markgraf *et al.*, 2003; Gilli *et al.*, 2005a). The geometries of seismic sequences II and I display sensible lateral changes, revealing a large drift mound in the central part of the basin that is displayed in Fig. 2 by an increase in thickness towards the right in seismic sequence II and particularly sequence I. The chronology provided by well-determined volcanic tephras indicates that this conspicuous shape was deposited over the last 6800 cal. a BP (Figs 2 and 3). This sedimentation pattern has been interpreted to be a product of strong lake circulation that must have been triggered by an intensification of the Southern Westerlies at a latitude of 49° S since the mid Holocene (Fig. 3; Gilli *et al.*, 2005b). Present short-term fluctuations in precipitation patterns of the region are mostly dependent on the intensity of these winds bringing moisture from the west.

At present there is no equivalent limnogeological study for Lago Strobel as for Lago Cardiel. However, since both lakes have comparable catchments and are located in the same climatic region, it is sensible to assume that they share the same climatic history.

The archaeological record of Lago Cardiel and Lago Strobel catchments

Since the late 1990s a systematic and detailed sampling of archaeological materials in the lakes Cardiel and Strobel catchments has provided new data in an area of Patagonia that most probably acted as a corridor for early hunter-gatherer populations (Borrero, 1999). The foci of this first survey were the identification of the archaeological evidence, its relationship with present-day geomorphology and the development of a local chronology of human occupation.

Palaeocene–Eocene basaltic plateaus and Mesozoic sandstones dominate the northern and western areas of the lake (Ramos, 1982, 1989; Beres *et al.*, 2008), whereas sand dunes are prevailing features on the eastern and southeastern sections of the lakeshores. Using geomorphological criteria the lake catchment was divided into various sections for sampling (Goñi *et al.*, 2005). Transects and excavations in selected sites enabled the determination of distributional patterns of evidence within the archaeological landscape (Belardi *et al.*, 2003). Four distinctive sectors were separated as follows (Fig. 4(a)): (A) Small N–S-oriented canyons cut through the western outcropping sandstones containing many rock shelters; (B) low basaltic plateaus – *mesetas bajas* – located in a wide sector of the north shore of Lago Cardiel at $\leq$400 m a.s.l.; (C) sand dunes from the eastern and southern shores of the lake basin; and (D) high basaltic plateaus – *mesetas altas* – at an altitude of $\geq$900 m a.s.l. that join the meseta that host Lago Strobel. These basaltic plateaus presently host numerous water bodies with a strong seasonality, providing sources of water and shelter. In contrast to the other sectors the climatic conditions in these high basaltic plateaus are quite harsh during winter, which may have limited human occupation to only spring and summer (Belardi and Goñi, 2006).

Archaeological finds, particularly lithic artefacts, are distributed within the entire catchment, displaying variations in terms of frequency, morphology and raw material (Goñi *et al.*,

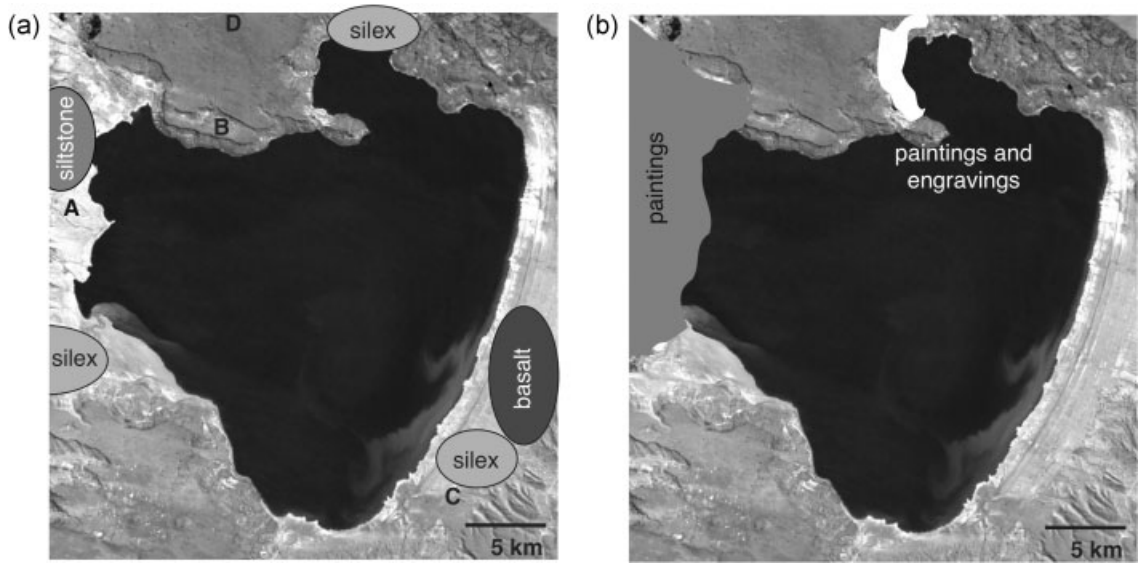

Figure 4 Landsat 7 satellite image of Lago Cardiel and its catchment area showing: (a) dominant lithological nature of the artifacts; (b) geographical distribution of main rock art motives

DOI: 10.1002/jqs

2006). The design of most of the lithic assemblages such as projectile points and endscrapers, and to a lesser extent small ceramic remains, are comparable to others in the region that have been previously attributed to the late Holocene. The distributional pattern and frequency of raw material used for the lithic artefacts varied throughout the catchment (Fig. 4(a)). Artefacts made of the locally available siltstone are mostly restricted to the western sector of the canyons (A). There are also artefacts of exotic rocks such as obsidian, of which the closest source area in Patagonia Austral is located at Pampa del Asador, ~100 km north of Lago Cardiel (Espinosa and Goñi, 1999; Stern, 1999). The latter is an excellent indicator of the mobility of these early humans, suggesting a sustained use of all resources within the entire basin. Artefacts of different kinds of siliceous material are found everywhere, whereas those on basalt are concentrated in those areas of the catchment dominated by basaltic plateaus (B and D) as well as in the sand dunes (C). In summary, the spatial distribution of the raw material of the lithic assemblages indicates a continuous use of the lake catchment during the last part of the Holocene, showing a close relationship not only among the different geomorphological sectors but also with extra-regional areas located at least as far as 100 km.

Another important aspect dealing with the technology used by these hunter-gatherer groups is the presence of two different rock constructions: burial mounds or *chenques*, and hunting blinds or *parapetos de caza*, located in the low and high areas (B and D), respectively. Radiocarbon dating of these structures has delivered ages no older than 1200 cal. a BP (Goñi and Barrientos, 2004). Thus the entire archaeological evidence points toward a late Holocene technology for the whole basin.

Archaeofaunal analyses indicate that the subsistence and diet of these human groups were clearly dominated by the guanaco (*Lama guanicoe*). Other animals such as the choique (*Pterocnemia pennata*) and smaller animals are very scarce and not significant (Savanti *et al.*, 2005).

The rock art in both lakes Cardiel and Strobel shows similarities but also several differences. Two different techniques have been identified between sites located at relatively short distances (25 km). Paintings dominate the canyons in the sandstone and low plateau sections (A and B), whereas engravings prevail in the high plateau of the Strobel catchment (D; Gradin, 1959–1960; Belardi and Goñi, 2002). This difference has been interpreted as associated with the local availability of material to hold up these representations such as sandstone walls in the canyons and basaltic blocks surrounding the numerous water bodies in the high basalt plateau as well as the hunter-gatherer use of these areas (Belardi and Goñi, 2002). The paintings comprise negative images of hands (stencilled) and some zoomorphic themes, although abstract geometric motives are largely dominant. The engravings of the Strobel area (Fig. 5) display a variety of themes and art designs that

Figure 5 Lago Strobel basaltic plateau: (a) anthropomorphs (1) and puma footprints (2) from Laguna del Faldeo Verde; (b) guanacos (3), ñandu footprints (4) and geometric forms from Laguna Uli; (c) engraved lizards (5) from Laguna Uli; (d) geometric forms and puma footprints (6) from Laguna del Faldeo Verde

DOI: 10.1002/jqs

range from zoomorphic representations (guanaco, huemul, lizards, etc.), abstract and geometric forms (circles, lines, dots, etc.), and animal and human footprints (Re *et al.*, 2005; Belardi and Goñi, 2006). A comparison of these art representations with those from other studied regions in Patagonia indicates that most of them can be attributed to the late Holocene, except for those containing guanacos, which could correspond to the middle Holocene (see Gradin *et al.*, 1979). This late Holocene age has been confirmed by a series of radiocarbon dates that deliver ages always younger than 1500 cal. a BP (Goñi *et al.*, 2004). A continuous occupation of the Strobel catchment during the late Holocene is further sustained by the type, distribution and frequency of different technologies. The presence of hundreds of hunting blinds containing the highest frequency of projectile points in the region suggests its preferential use for hunting during summer months (Belardi *et al.*, 2005). Topographically lower – and climatically milder – zones close to Lago Cardiel may have been occupied on an annual basis.

In summary, the archaeological record for the Cardiel and Strobel basins indicates a dominant late Holocene human occupation, although a first colonisation is also evident at ca. 6700 ^{14}C a BP (Fig. 3). Additionally, there is a clear pattern in the distribution of lithic assemblages, paintings, engravings and rock structures. This distribution suggests that the surroundings of Lago Cardiel were mostly used as a residential area, whereas the Strobel catchment for logistical reasons may have been used seasonally in concert with the topographically lower areas around Cardiel as well as other extra-regional areas (Belardi and Goñi, 2006).

The chronology of equivalent archaeological records in the well-studied area of Lago Argentino and the Perito Moreno National Park (PMPN; Aschero *et al.*, 2005) (Fig. 6) shows human occupation towards the Andes throughout the entire Holocene. A further integration of existing datasets allows extension of the chronology of human settlements to most of the Patagonian ensemble (e.g. Coronato *et al.*, 1999; Borrero, 1999). Archaeological data from the Cardiel and Strobel lake basins, however, show a striking lack of human activity for the Late Pleistocene as well as the first part of the Holocene, coinciding with well-constrained high lake levels (grey area in Fig. 6).

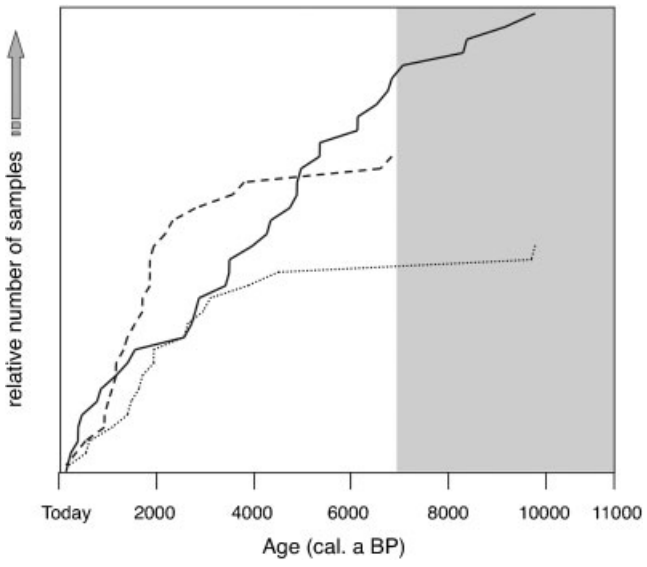

Figure 6 Distribution of ages in well-dated archaeological samples: average distribution for the entire eastern Patagonia (solid line); Lago Argentino region (dotted line; see Fig. 1 for lake location); Cardiel–Strobel basins (broken line). Grey area highlights the time interval without human remains in the Cardiel and Strobel basins

Discussion

Until now the archaeological record in the vicinity of Lago Cardiel and Lago Strobel basins has shown no evidence of human remains covering both the Late Pleistocene and the early Holocene (Fig. 6). Thus in these two basins the archaeological record alone only permits a certain number of speculations to explain the causes behind this intriguing situation. The limnogeological dataset, however, indicates major changes in the hydrological balance of the region, providing key evidence to understand the apparent discrepancy with the rest of the Patagonian plateau. Based on the sedimentary record of Lago Cardiel, this extra-Andean region experienced a substantial drought during the Late Pleistocene. This climatic degradation most probably had a strong impact on the human populations already present in Patagonia. If they were exposed to harsh conditions, even though they may have been milder than the cold YDC condition dominating the Northern Hemisphere, displacement or extinctions were probably occurring (Borrero, 1999). Lago Cardiel is presently the largest natural water reservoir outside the Andean range for this latitude. Hence during this desiccation phase the lake may have attracted both fauna and early hunter-gatherer populations, since water resources at the time were quite scarce considering that the large lakes on the west were still glaciated. Conversely, the early Holocene with positive hydrological balances in the Cardiel basin coincides with a noticeable increase in water resources throughout the rest of the Patagonian plateau. This change in the hydrological cycle had major local and regional implications, since the high lake water levels may have submerged the existing archaeological evidence of early occupation (Late Pleistocene) in the Cardiel basin. Additionally, hunter-gatherer societies may have increased their residential mobility during this time, crossing the previous environmental thresholds due to the higher water availability.

A brief interval of relatively low human occupation started around 7300 cal. a BP but was interrupted during minor rising lake-level intervals between ca. 6800 and 4200 cal. a BP. Human activity in the lake catchment reappeared ca. 4200 cal. a BP, to be finally enhanced since 2000 cal. a BP and sustained during historical times (Fig. 3). Thus it appears that the increasing activity of the Westerlies (i.e. increasing moisture in eastern Patagonia) during the middle and late Holocene (Gilli *et al.*, 2005b) have had less impact on human distribution than during more arid periods such as the Late Pleistocene and also the Medieval Climatic Anomaly (MCA), since water availability was more regionally distributed (e.g. Goñi *et al.*, 2000–2002; Goñi *et al.*, 2007).

The archaeological record of the Posadas/Salitroso lakes – two closed lakes located northwards of the study region – displays similar chronological features to those from the Cardiel and Strobel basins (Goñi *et al.*, 2000–2002; De Nigris *et al.*, 2004; Goñi and Barrientos, 2004). One interesting observation is that, while peopling in certain areas of Patagonia started relatively late during the Holocene (e.g. Cardiel/Strobel and Posadas/Salitroso lake basins), at the same time interval other sites were less visited and/or the remains have a more logistic than residential imprint (e.g., PNPM). Thus the dynamic and successive re-accommodation of populations in Patagonia would not always necessarily be synchronous with climatic variations (Borrero and Franco, 2000; Goñi *et al.*, 2000–2002). Furthermore, this apparent population dynamic might not only be tied to a demographic growth but also to the appearance of new physical scenarios.

DOI: 10.1002/jqs

Finally, the occupation and/or desertion of large spaces by hunter-gatherer populations are a constant feature in Patagonia during all the Holocene. Thus, in a regional context, a dominant late Holocene peopling of lakes Cardiel and Strobel remains a plausible alternative. The combination of archaeological and limnogeological data as presented here can be very helpful and even critical in selecting between several possible scenarios.

Conclusions

Combining archaeological and limnogeological datasets for the Cardiel/Strobel basins, the following conclusions can be drawn:

- Extremely low lake levels reconstructed for the Lateglacial–Holocene transition may have concentrated aboriginal populations highly dependent on water availability around sources of water.
- This Late Pleistocene human presence is well described in western Patagonia, whereas its evidence may have been submerged in the Lago Cardiel catchment.
- A subsequent major rise in water level occurred in a few hundred years through a series of pulses that reached a maximum extent at the beginning of the Holocene. A brief period of relatively low human occupation started ca. 6800 cal. a BP and was interrupted during minor rising lake-level intervals between 6000 and 4000 cal. a BP.
- Evidence for increasing human activity in the lake catchment reappears ca. 4000 cal. a BP, was further enhanced from 2000 cal. a BP and sustained during historical times.
- A strong interrelationship between low-altitude (Lago Cardiel) and high-altitude (Lago Strobel) occupational spaces was developed during the late Holocene.

The striking coincidence between low lake level and increasing human occupation suggests that the Lago Cardiel and perhaps Lago Strobel basins have focused human use during intervals with relatively lower effective moisture. The comparison of these unique archaeological and limnogeological datasets points towards the existence of significant differences in the use of diverse environmental settings across the region by hunter-gatherer populations. It further shows the advantage of using different datasets to obtain converging evidence of human–environment interactions. This approach can be extended to other basins at different geographical and temporal scales.

Acknowledgements We would like to thank to all the Patagonian Lake Drilling Project PATO/PALATRA team members. Funding from the Swiss National Science Foundation, grants 21-50862.97 and 20-61704.0/1, Agenda Nacional de Promoción Científica y Tecnológica PICT 4511 and PICT 26295 and the Universidad Nacional de la Patagonia Austral, grant 29/A114, are kindly acknowledged. Comments and suggestions of S. Leroy and an anonymous reviewer on an earlier version of this manuscript are very much appreciated.

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DOI: 10.1002/jqs