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Changes in lithic technology and environment in southern continental Patagonia: The Chico and Santa Cruz River basins

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ABSTRACT

Changes in artifact technology and environment during the Holocene are documented, within an organization of technology framework, for three different regions of Patagonia. Possible relationships between environmental changes and changes in artifact technology are explored. We examine past vegetation and geomorphic evidence of Holocene climate conditions in the three regions studied and what technologies were used during particular wetter and drier intervals. Our results suggest that many of the observed changes in technology use occurred at times of rapid climate change, particularly towards much drier conditions.

1. Introduction

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 (Paruelo et al., 2000; Garreaud et al., 2009). In arid and semi-arid environments, water is an important resource for hunter-gatherer populations (e.g. Smith et al., 2005; Veth, 2005). In Patagonia, variations in water availability have been documented over time (e.g. Heusser and Streeter, 1980; Heusser and Rabassa, 1987; Stine and Stine, 1990; Heusser, 1995; Coronato et al., 1999; Paez et al., 1999) and used by different researchers to explain variations in the frequency of occupation of different areas and to discuss the importance of water availability for hunter-gatherers (i.e. Borrero and Franco, 2000; Goñi et al., 2000–2002; Miotti and Salemme, 2004; Brook et al., 2013). However, there has been little research on possible relationships between technology and climate.

The purpose of this paper is to document chronological and spatial relationships between technological and environmental changes in three different regions of Patagonia, within an organization of technology framework. This is considered as a first step to evaluate the reasons for these changes and by no means implies that we believe there is a direct relationship between changes in human behavior and environmental conditions.

In seeking possible relationships, we will examine the available pollen, sediment, geomorphic and archaeological information at both regional and supra-regional scales. Our time scale is from the earliest to the latest occupations by hunter-gatherers, i.e. from the Pleistocene–Holocene transition until the end of the Holocene. We will not deal here with equestrian hunter-gatherers, present in the area after European contact, because there were changes in mobility and transportability requirements related to horse acquisition (i.e. Kelly, 1995; Goñi, 2000).

2. Methodology

The three regions we will examine are: A) the Southern end of the Deseado Massif (SDM), B) the basaltic plateaus north of the Upper and Middle Santa Cruz River (NSCR), and C) the upper Santa Cruz River basin south of Lake Argentino and the Santa Cruz River (USCRB). To compare the SDM, NSCR and USCRB, we will first summarize the available environmental and technological evidence for each region, in some cases supplementing sparse data with information from nearby areas. New and previously published radiocarbon ages in ^{14}C years BP (^{14}C yr BP) were calibrated using CALIB 7.1 (Stuiver and Reimer, 1993) with the Southern Hemisphere (SHcal13) atmospheric calibration curve of Hogg et al. (2013).

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Calibrated ages at the 2σ level are given in calendar years BP (cal yr BP). OSL ages are converted to cal yr BP.

3. Environmental and technological characteristics of the three regions

3.1. The Southern Deseado Massif

3.1.1. Archaeology

The SDM is a morphostructural region shaped by volcanic activity during the Jurassic (De Giusto et al., 1980). The region has mineral veins that penetrate the volcanic and sedimentary bedrock, numerous caves, and excellent raw materials for high-quality flintknapping (e.g. Panza et al., 1998; Cattaneo, 2000; Panza and Haller, 2002; Cattáneo, 2004; Miotti and Salemme, 2004; Echeveste, 2005; Paunero et al., 2007; Hermo, 2008; Paunero, 2009; Skarbun, 2009). Our study area lies in the southern part of the SDM and is characterized by its heterogeneity, with access to high-quality raw materials, caves and rockshelters, and water varying over distances ranging from ca. 2 km to ca. 25 km -such as between La Gruta and Viuda Quenzana-. For example, while La Gruta is dominated by closed depressions in volcanic and sedimentary rocks that may contain seasonal lagoons and occasionally permanent bodies of water, in the locality of Viuda Quenzana (Fig. 1), seasonal lagoons are less frequent, but there are seasonal streams and even a few large canyons with semi-permanent streams and springs. Water is a critical resource in the region today, and so differences in availability and reliability between areas may have influenced hunter-gatherer groups in the past. Also, sinters which provide good quality rocks have been localized some 1 km to the west of La Gruta 1 site and also 3 km to the north, in La Esperanza area. The earliest evidence of human occupation comes from La Gruta 1 (LG1) archaeological site, with dates from ca. 10,800 to 10,400 ^{14}C yr BP (12,800–12,100 cal yr BP) (Franco et al., 2010a; Brook et al., 2014).

Scarce lithic artifacts from archaeological sites consist mostly of internal flakes, including bifacial reduction and resharpening flakes all of small size. The evidence from La Gruta 1, 2 and 3 archaeological sites reveals important discontinuities in occupation (Franco et al., 2010a, 2013; Brook et al., 2014). These discontinuities, which are also apparent at other sites in the SDM (e.g. Paunero et al., 2007; Paunero, 2009; Skarbun, 2009) are consistent with low population densities, as suggested for Patagonia by other researchers (e.g. Borrero, 1989–1990).

The most abundant evidence of occupation for the Early Holocene dates to the period ca. 9000 to 8000 ^{14}C yr BP (10,500–8500 cal yr BP, Aguerre, 2003; Durán et al., 2003). Sites have been discovered in different environments within the SDM, including La Gruta, La Martita and El Verano cave areas (Fig. 1). Bifacial artifacts, which are probably preforms made from a high quality chert, have been recovered from the oldest deposit at La Martita Cave 4, dating to ca. 8000 ^{14}C yr BP (9000 cal yr BP, Aguerre, 2003). The same high-quality chert was also recovered from deposits at El Verano, Cave 1, with dates between 9000 and 8000 ^{14}C yr BP (10,500–8500 cal yr BP, Durán et al., 2003). A cache of mainly bifacial preforms, similar to those found at La Martita and made of the same high quality chert was recovered in La Gruta area, close to LG1 (Franco et al., 2011). The utilization of the same raw material and the similarities in technological characteristics of the three assemblages allow us to attribute them to the same time interval,

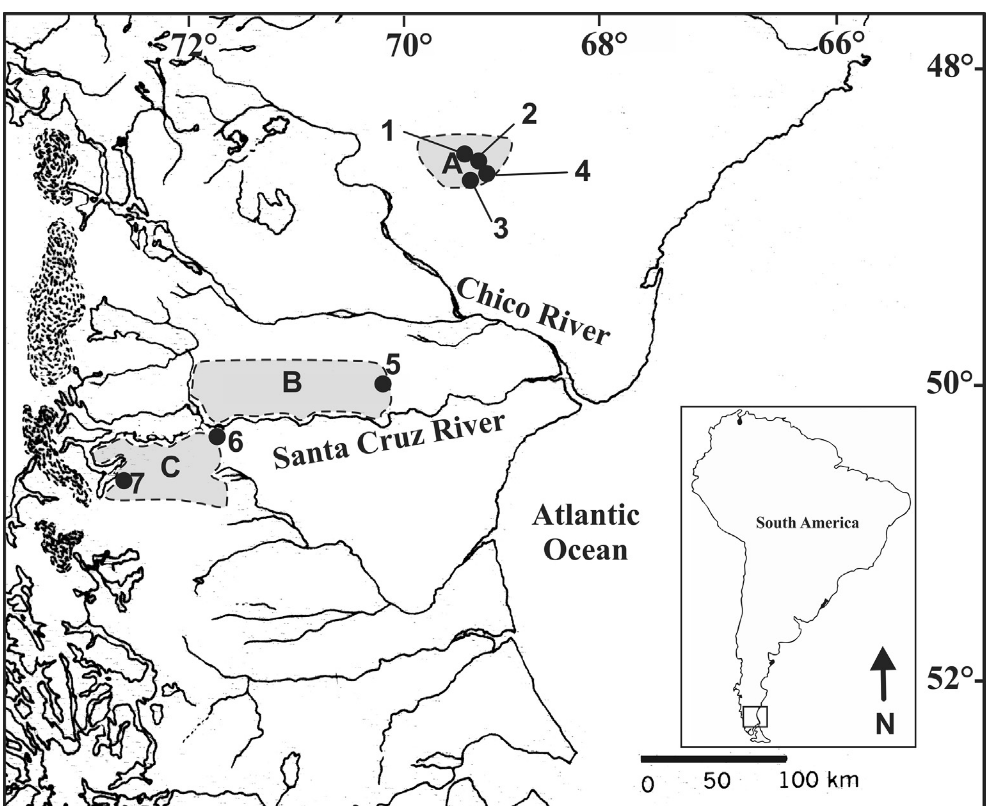

Fig. 1. Map showing main regions and sites mentioned in text. Regions: A. Southern Deseado Massif; B. Basaltic plateaus north of the Upper and Middle Santa Cruz River; C. Upper Santa Cruz River basin south of Lake Argentino and the Santa Cruz River. Sites: 1. La Martita; 2. Viuda Quenzana; 3. La Gruta; 4. El Verano; 5. Yaten Guajen 12 and Mercerat 1; 6. Río Bote 1; 7. Chorrillo Malo 2.

when bifacial technologies of lithic reduction were used in the SDM. These similarities at sites that are less than 25 km apart suggest that they probably fall within the area used by the same human group (Franco et al., 2015b).

Archaeologically, there is a gap in the sequence at La Gruta 1 (Franco et al., 2010a; Brook et al., 2014). According to Aschero, the archaeological sequences in the Deseado Massif show an increase in blade production around ca. 5300 cal yr BP, which includes La Martita Cave 4 (Aschero, 1987). At the nearby site of El Verano, there is a similar increase in blade production that was linked to blade production at La Martita because of its close proximity (Durán, 1990). Similar technological characteristics have also been used to link these sites with sites to the northwest in the Pinturas River area, where blade production dates to 6400–6200 cal yr BP and lasts until 4600–4200 cal yr BP (Gradin et al., 1979).

In older assemblages there are small numbers of blades present, but probably are by-products of other technological strategies. Many authors suggest that there is also a considerable increase in blade frequencies and prepared blade cores by ca. 5500 cal yr BP, although this argument has been challenged by other researchers who suggest that there is no significant change in relation to the development of blade technology (Yacobaccio and Guraieb, 1994; Hermo, 2008; Hermo and Magnin, 2012). To the north of La Gruta 1, in the youngest deposits at Viuda Quenzana 7, dating to 1220 ± 20 ^{14}C yr BP (1177–988 cal yr BP), there are small blades in the lithic assemblage.

3.1.2. Paleoenvironment

Around 12,000 cal yr BP, during the first occupation of the SDM, geomorphic and pollen data indicate a time of greater moisture availability (Brook et al., 2014). Sediments from the base of the La Gruta 1 (LG1) archaeological sequence have a high content of gravel and clay, the former suggesting that water was available for hydration breakdown of the shelter walls or for freeze-thaw weathering and the latter that chemical processes were active. The dark yellowish brown color of the sediments and high clay content suggest stable conditions in the cave and pedogenesis due to increased moisture (Brook et al., 2014). At La Gruta 3, sediments deposited after ca. 8000 ^{14}C yr BP (9000 cal yr BP) contain less gravel but have high percentages of sand, silt and clay, particularly silt, pointing to drier conditions at this time. Younger sediments at La Gruta 3 show that moisture levels increased from at least 5500 cal yr BP, with a maximum between 4500 and 3500 cal yr BP and dropping by 2700 cal yr BP (possibly up to 2200 cal yr BP).

Excavations in four lagoons in La Gruta area reached gravel at shallow depth, suggesting that prior to sediment deposition, beginning around 6500 cal yr BP, there was a period of dry, windy conditions when deflation removed fine sediments from the lagoon basins (Brook et al., 2014). This may correlate with La Gruta 3 evidence of drier conditions after ca. 9000 cal yr BP. The youngest sediment ages from three of the lagoons, La Barda, La Gruta 1, and La Gruta 2, from 10, 15, 14, and 25 cm depth, show that deposition of lacustrine sediment in these basins continued until at least 2150–2329, 2548–2842 and 2783–2958 cal yr BP, respectively (2250 ± 30, 2660 ± 30, and 2820 ± 30 ^{14}C yr BP; Table 1). In contrast to these lagoons, sediments overlying gravel in the Melisa lagoon were much younger, dating to 1310 ± 20 ^{14}C yr BP (1106–1272 cal yr BP). This suggests that conditions in the period prior to ca. 1270 cal yr BP might have been dry, resulting in deflation of the lagoon basin floor concentrating gravel there.

Table 1
Radiocarbon ages of lagoon sediments in La Gruta area of the SDM.

Lagoon	UGAMS Lab. ID	Depth (cm)	Sample ID	δ^{13}C ‰	Age (^{14}C yr BP)	Calibrated age (2σ cal yr BP)	Median probability (cal yr BP)
La Barda	14755	10–15	EB-8	−24.4	2250 ± 30	2150–2329	2231
	14754	35–40	EB-3	−24.9	5690 ± 35	6311–6525	6429
La Gruta 1	14759	14	GRUT2-2	−24.9	2660 ± 30	2548–2842	2751
	14758	55	GRUT2-1	−24.9	4900 ± 30	5482–5657	5601
La Gruta 2	14700	25	LGLAG2-4	−24.5	2820 ± 30	2783–2958	2874
	14700	65	LGLAG2-1	−25.0	4710 ± 35	5310–5576	5403
Melisa	11081	65–60	MELISA-2	−26.2	1310 ± 20	1106–1272	1225

Pollen data from La Gruta area, and from other areas of the Deseado Massif (Paez et al., 1999; de Porras et al., 2012; Mancini et al., 2013), indicate drier conditions prior to ca. 13,000 cal yr BP and slightly wetter conditions with grass steppe and dwarf shrub vegetation from ca. 13,000 to 11,500 cal yr BP. The vegetation changed to grass steppe after ca. 11,500 cal yr BP until ca. 8800 cal yr BP indicating wetter conditions during this period (Brook et al., 2013, 2014; Mancini et al., 2013).

During the Early Holocene grass became more dominant in the steppe vegetation around La Gruta area indicating a higher moisture level than during the Late Pleistocene. Similar vegetation is indicated at La Martita (Mancini, 1998) until ca. 9000 cal yr BP, when there was a change to shrub steppe. This change occurred earlier in the northern part of the Massif, at Los Toldos (47°S, 68°W; ca. 11,500 cal yr BP) and Piedra Museo (47°S, 67°W; 10,800 cal yr BP) (Mancini et al., 2013).

Evidence from La Martita (Mancini, 1998) and La Gruta (Brook et al., 2014) shows an increase in moisture in the SDM from the Middle to the Late Holocene, beginning ca. 5700 cal yr BP and ending ca. 2000 cal yr BP, after which temperature and precipitation were similar to modern.

The implication of these results is that when humans first entered La Gruta area around the time of the Pleistocene–Holocene transition (ca. 12,000 cal yr BP), the climate was slightly wetter than today but moisture levels increased further after ca. 11,500 cal yr BP and remained so until the onset of dry conditions lasting from ca. 8800 to 6500 cal yr BP. After this, climate was relatively moist until at least 2150 cal yr BP when there may have been a short dry period lasting until ca. 1270 cal yr BP. Based on the paleoenvironmental evidence and available chronological data, humans may have used the area less frequently in the Early Holocene due to much drier conditions from ca. 9000–6500 cal yr BP when the lagoons were largely bare windblown surfaces with no water (Brook et al., 2013). In addition, along the eastern margin of La Gruta Lagoon 1 there is a beach ridge about 1 m high that records a period of increased flooding of the lagoon basin. An auger sample from a depth of 55 cm in this ridge (sample LGE-1) has provided a feldspar OSL age of 1.07 ± 0.07 ka (1020 ± 70 cal yr BP) for ridge formation. This age is close to the radiocarbon age obtained from Melisa Lagoon and suggests that the period 1100–1300 cal yr BP was wetter than present.

3.2. The basaltic plateaus north of the Upper and Middle Santa Cruz River

3.2.1. Archaeology

Streams draining north to south across the NSCR area dissect the basalt plateaus before joining the Santa Cruz River. Unfortunately, archaeological excavations in numerous shallow rock shelters in this area frequently have not exposed dateable evidence of human occupation, although rock art is often abundant (Franco et al., 2007a,b; 2014). Earliest human use of the canyons is indicated by findings at a shallow rock shelter site, Yaten Guajen 12 (Fig. 1). This site was first occupied in the Early Holocene ca. 7700 ^{14}C yr BP or 8600–8400 cal yr BP (cf. Franco, 2008; Brook et al., 2014), possibly at the end of an Early Holocene wet interval ca. 8500 cal yr BP to the north in the SDM, defined by pollen data (Fig. 2M), when conditions became much drier. It is possible that humans occupied the basalts at this time because they had perennial springs, fed by ground water from the basalt aquifer. These springs would have been a much more reliable source of water than, for example, the seasonal lagoons of the SDM and may have attracted human groups during times of drought, a hypothesis that remains to be tested.

The evidence of human presence obtained so far is discontinuous. A human burial, dating to ca. 2500 ^{14}C yr BP (2376–2718 cal yr BP; Franco et al., 2010b), has been discovered in a shallow volcanic lava tube cave, but a major period of human occupation of the canyons is indicated between ca. 1700 to 1000 ^{14}C yr BP (932–773 cal yr BP) (Franco et al., 2007a,b; 2014). Blade production has been identified, which included subprismatic cores and crested blades.

3.2.2. Paleoenvironment

There are no palynological data for this area but pollen data from La Tercera wet meadows, locally known as "mallines", further to the west, at Lake San Martín (Bamonte and Mancini, 2011), indicate lower humidity during the Middle Holocene (ca. 8000–3000 cal yr BP) and wetter conditions after ca. 3000 cal yr BP. This suggests environmental conditions that were similar to those in the SDM. We have obtained geomorphic evidence of climate change for this area from one lagoon and two stream deposits in river canyons. The lagoon, in a broad, shallow basalt canyon, has a small rock shelter on the western cliffed margin that was used by humans (Yaten Guajen Lagoon 1). The shelter faces east so is protected from the prevailing westerly winds. There was a dense

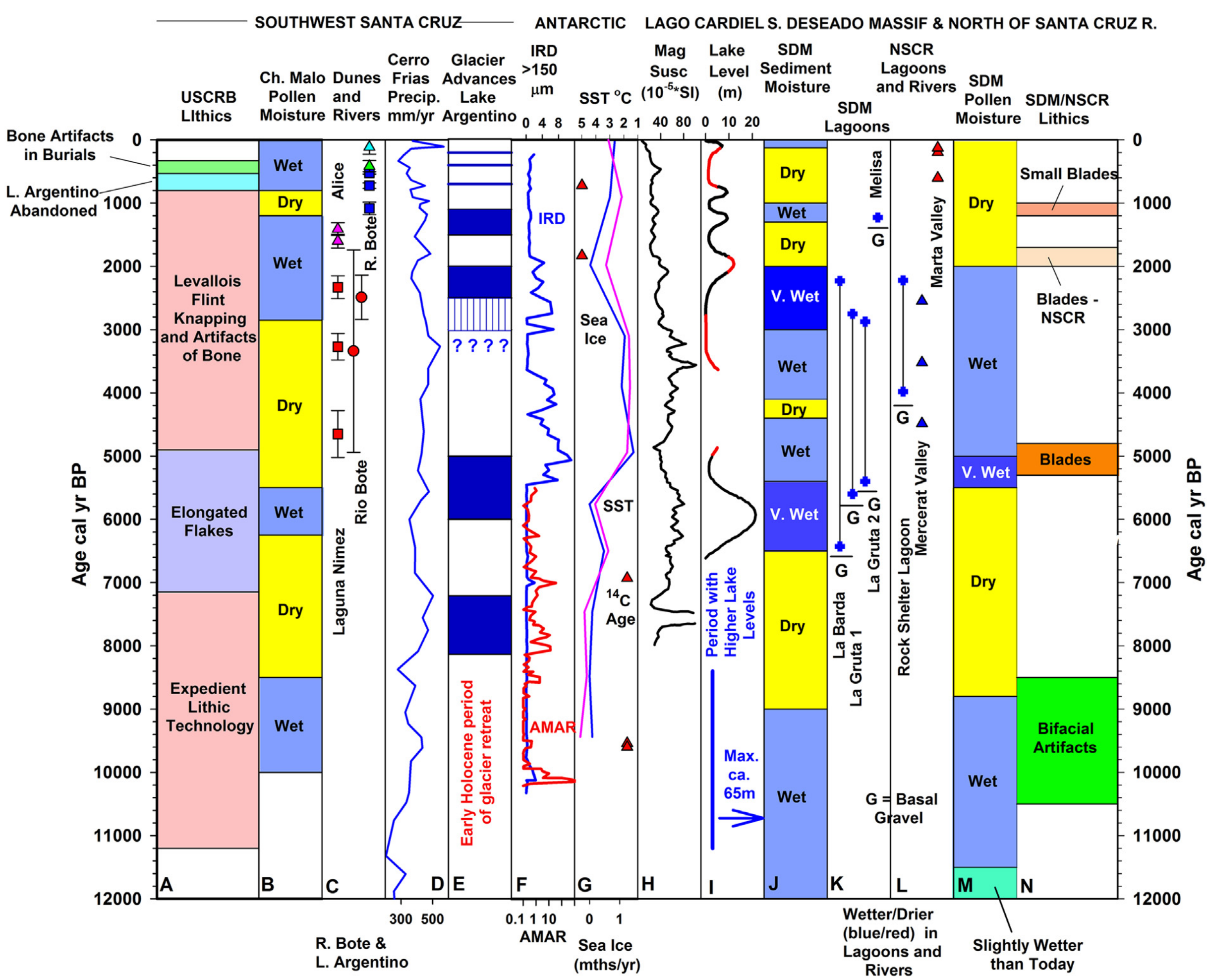

Fig. 2. Changes in lithic technology and climate in the USCRB and SDM/NSCR regions and comparison with glacier advances west of Lake Argentino, conditions in Antarctica, and levels of Lake Cardiel west of the SDM region. (A, B, J, L, M and N) – this paper; (C) – Franco et al., 2015a (in revision); (D) – Tonello et al., 2009; (E) – Strelin et al., 2011, 2014; (F and G) – Hodell et al., 2001; (H and I) – Stine and Stine, 1990; Gilli et al., 2001, 2005; (K) – Brook et al., 2014.

scatter of cores, flakes, and some tools in front of the rock shelter along the margin of the lagoon sediments. To determine when the lagoon contained water, a pit was dug to a depth of 36 cm at which depth gravel was encountered. The gravel may record the last time the pan was blown free of sediment during a major dry interval. The overlying sediments, which contained organic matter, are believed to record a period when in most years there was a lake, probably seasonal, which filled the lagoon basin. Organic-rich sediments from 18 to 20.5 cm and 33.5–36 cm depth provided AMS radiocarbon ages of 3700 ± 25 and 2220 ± 25 ^{14}C yr BP, respectively (3891–4086 and 2099–2309 cal yr BP). It is possible that the artifacts close to the rock shelter, and only ca. 30 m from the dug pit, date to the period 4100–2100 cal yr BP when the pan regularly contained water (Table 2).

incised by the present small stream. Samples of organic-rich sediment from 46 to 137 cm above the base provided AMS radiocarbon ages of 240 ± 25 ^{14}C yr BP (297–154 cal yr BP) and 170 ± 25 ^{14}C yr BP (271–0 cal yr BP), respectively. These ages suggest drier conditions in the basalt canyons from ca. 600–120 cal yr BP, including the Little Ice Age (LIA). Incision of the fill may have occurred after the LIA around AD 1850 under somewhat wetter conditions.

3.3. The upper Santa Cruz River basin south of Lake Argentino and the Santa Cruz River

3.3.1. Archaeology

The earliest evidence of human occupation of the USCRB area comes from Chorrillo Malo 2, a small rockshelter facing southwest

Table 2
Radiocarbon ages of lagoon and fluvial sediments in the NSCR region.

Lagoon or river Valley	UGAMS Lab. ID	Depth (cm)	Sample ID	δ^{13}C ‰	Age (^{14}C yr BP)	Calibrated age (2σ cal yr BP)	Median probability (cal yr BP)
Yaten Guajen Lagoon 1	11072	10–12.5	RSLAG-10	−25.1	2220 ± 25	2099–2309	2221
	11071	33.5–36	RSLAG-1	−25.4	3700 ± 25	3891–4086	3980
Mercerat	11079	53	MA-1	−20.8	2500 ± 30	2364–2706	2547
	11080	33	MA-2	−20.8	3330 ± 25	3449–3607	3522
	11078	79	MER-1	−20.8	4060 ± 30	4415–4778	4484
Marta	11075	91	MARTA-5[a]	−28.6	240 ± 25	149–303	198
	11076	15	MARTA-5B	−28.7	170 ± 25	0–278	126
	11077	76	MARTA-6	−25.7	680 ± 20	559–654	602

The Mercerá stream valley in which the Mercerat 1 archaeological site is located has a broad, flat alluviated floor that has been incised along narrow channels by the present small stream. Localized areas of the valley sediment fill have also been eroded by wind, leaving hollows with vertical walls that expose sections of the sediments. At three locations, MA1-1, MA2 and MER-1, within 1–2 km of the Mercerat 1 archaeological site, stream incision has exposed sections of fluvial sediments 76 cm, 89 cm, and 94 cm high, respectively. In all three profiles there are organic-rich sediments near the base that are overlain by aeolian sand towards the top. The organic layers had too little organic material for reliable AMS radiocarbon dating but each section had guanaco bones embedded and we used these to provide chronological data for the sediments. At MA1-1, a guanaco bone in sand overlying an organic layer provided an age of 2500 ± 30 ^{14}C yr BP (2364–2706 cal yr BP). At MA2, a guanaco bone in aeolian sand 25 cm above an organic layer dated 3330 ± 25 ^{14}C yr BP (3449–3607 cal yr BP). At MER-1 a guanaco bone from an organic layer dated to 4060 ± 30 ^{14}C yr BP (4415–4778 cal yr BP). The present stream at MER-1 has incised the ca. 1 m of sediment suggesting a hydrological regime characterized by flash floods. The ages we obtained from MA1-1 and MA2 were from sand above organic layers so they represent minimum ages for these deposits that indicate increased moisture. Overall, the three ages suggest wetter conditions and higher ground water tables in this area from ca. 4800–2400 cal yr BP.

Several fluvial sediment sections in the Yaten Guajen River valley, upstream of the Yaten Guajen 2 archaeological site, which is located in a rock shelter above the stream, included dateable organic deposits. These sequences suggest valley alluviation at a time when stream discharge could not accommodate the volume of sediment available for transport. Typically, such conditions record drier intervals characterized by flash floods. The sediments at the MARTA-6 fluvial sediment site are an example. Here the sediments are 110 cm thick and consist of stream channel gravel cobble layers and light grey organic sands and clays. One of the organic layers provided an AMS radiocarbon age of 680 ± 20 ^{14}C yr BP (559–654 cal yr BP). At MARTA-5, 140 cm of sediments have been

that is close to Lake Roca. The oldest occupations date from ca 9700 ^{14}C yr BP (11,066–11,233 cal yr BP). This evidence was obtained from a small test pit and artifacts were scanty. Human occupation was discontinuous until ca. 4380 ^{14}C yr BP (4530–5314 cal yr BP). However, by ca. 6270 ^{14}C yr BP (7000–7260 cal yr BP) elongated flakes and cores were being produced. Similar artifacts of approximately the same age are present at Río Bote 1, a rockshelter located ca 80 km to the northeast of Chorrillo Malo 2. The archaeological sequence at Río Bote 1 is also discontinuous because the people using the shelter excavated pits in the floor at different times, largely for burials. In addition, the rockshelter faces a meandering river, which has eroded the deposits over time. Most of the buried individuals date between ca. 3800 (4200–4000 cal yr BP) and 3620 ^{14}C yr BP (4000–3700 cal yr BP), but the youngest has an age of ca. 2100 ^{14}C yr BP (2000–1900 cal yr BP). Some of the burials have lithic and bone goods associated with them (Franco et al., 2010b).

The adoption of the Levallois method at both Chorrillo Malo 2 (Franco, 2004a,b) and Rio Bote 1, at approximately the same time, shows the start of a new trend, represented by Levallois cores and tools made of Levallois flakes and of other flakes obtained as by-products from the cores. The tool blanks obtained from Levallois cores contrast with blades or laminar flakes in that they tend to be larger and more rounded, and are regular in the shape and size of the butt of the flakes. This change occurs at ca. 4380 ^{14}C yr BP (4530–5314 cal yr BP) at Chorrillo Malo 2 and 4100 ^{14}C yr BP (4760–4800 cal yr BP) at Río Bote 1. Side-scrapers and knives made from flakes of this kind are present at Chorrillo Malo 2 until ca. 1070 ± 60 ^{14}C yr BP (1058–797 cal yr BP), when there is no evidence of human occupation in the area (Borrero and Franco, 2000). The utilization of the Levallois method is less common after ca. 2800 ^{14}C yr BP (3050–3060 cal yr BP) but it is present in rockshelters and open air sites, like Laguna Nimez (Franco, 2008). The reasons for the utilization of the Levallois method are not clear, but it implies a considerable amount of time and energy for core preparation to control the size and shape of the flake (Boëda, 1993). Microwear studies might provide useful information in future.

3.3.2. Paleoenvironment

Vegetation during the Early Holocene was grass steppe indicating increased moisture. To the west higher levels of *Nothofagus* pollen suggest the beginning of the forest expansion in Andean areas. Pollen records suggest a grass-shrub steppe with intermediate levels of moisture between ca. 5800 and 3000 ^{14}C yr BP (6400–3000 cal yr BP) at Chorrillo Malo 2, but records from eastern Andean Patagonia show the prevalence of *Nothofagus* forest under wet conditions in these areas during the mid-Holocene. These records come from Peninsula Avellaneda (Echeverría et al., 2014), Brazo Sur (Wille and Schäbitz, 2009), Cerro Frías (Mancini, 2009) in the Lake Argentino area and Vega Ñandú (Villa-Martinez and Moreno, 2007) in South Chile.

In the steppe to the east at Rio Bote 1, the relationship between grass (Poaceae) and shrub (mainly Asteraceae subf. Asteroideae) pollen in the sediments suggests higher moisture levels before 5800 ^{14}C yr BP (6600–6400 cal yr BP). After this, moisture decreases until 4300 ^{14}C yr BP (4846–4654 cal yr BP) and then increases again after 4260 ^{14}C yr BP (4846–4624 cal yr BP).

A feldspar OSL age of 4650 ± 370 cal yr BP for basal sediments in a coastal dune at Laguna Nimez, Lake Argentino, overlaps the timing of a glacier advance at 6000–5000 cal yr BP to the west (Strelin et al., 2014). Younger feldspar OSL ages of 2330 ± 180 and 3270 ± 210 cal yr BP for other dune sediments at Laguna Nimez correlate with a glacier advance at ca. 3000–2000 cal yr BP (Fig. 2C and E). At Estancia Alice on the south shore of Lake Argentino, feldspar OSL ages of 1410 ± 100 and 1600 ± 110 cal yr BP for dune sand over lake sediments correspond with a glacier advance at ca. 1500–1100 cal yr BP. Coastal dunes may have developed during glacier advances west of Lake Argentino as the advances may have been associated with low lake levels (reduced melting of ice) and strong winds that increased wave action along the shore forming beach ridges and coastal dunes (Strelin et al., 2014; Franco et al., 2015a).

Our studies of fluvial sediments near Rio Bote 1 (RB1) have also provided paleoenvironmental information. Quartz OSL ages of 3340 ± 1600 and 2490 ± 350 cal yr BP for a major fluvial sediment deposit upstream of RB1 are evidence of drier conditions between 3300 and 2500 cal yr BP, corresponding with a glacier advance west of Lake Argentino ca. 3000–2000 cal yr BP and thus drier conditions in the steppe to the east (Fig. 2C and E). From 1182 to 500 cal yr BP sediment deposition on the floodplain near RB1 was by gradual vertical accretion, which was periodically interrupted by significant floods that cut channels across the floodplain that were later buried by sand. Organic matter from the buried channels defines two periods of flooding, the first prior to 1180–985 cal yr BP and the second before 770–680 cal yr BP; these periods precede glacier advances west of Lake Argentino at 1500–1100 and ca. 700 cal yr BP (Strelin et al., 2014) when conditions would have been wetter in the steppe. Evidence of increased flooding of the Bote River area before ca. 540–330 cal yr BP may be associated with increased precipitation on the steppe prior to a minor glacier advance >400 cal yr BP (Strelin et al., 2014).

The end of the occupation of the area south of Lake Argentino seems to be related to the Medieval Climatic Anomaly ca. 1200–800 cal yr BP (Borrero and Franco, 2000), which was a particularly severe arid interval (Stine and Stine, 1990). A dry period is also indicated in the pollen record for extra-Andean areas at ca. 1000 cal yr BP. After this there is a change in burial techniques. Bone beads continue to be manufactured and stair rods appear in burials, while lithic artifacts are scarce and don't show clear technological trends.

4. Discussion

Comparing changes in lithics in the three regions with environmental changes is difficult because the USCR area has perennial fluvial and lake resources (e.g. Lake Argentino and the Santa Cruz River) that are not as available in either the SDM or NSCR regions. However, the basalt areas of the NSCR do have groundwater-fed springs that are a more reliable source of water than seasonal lagoons and so we might expect the SDM to be impacted more severely than the basaltic canyons by changes in water availability. In addition, simply comparing the environmental datasets for each region presents problems because each dataset has chronological uncertainties that might change slightly the estimated age of an event and also, the time lag between environmental change and sediment deposition will be different from that between environmental change and vegetation (pollen). Because of these issues, sediment and pollen data may record the length and timing of a climate-change event differently. In addition, most archaeological sites are palimpsests (Bailey, 2007). Therefore, it is unlikely that perfect matches between technological and environmental evidence of change will be observed. Instead, we can only hope to see "probable" correlations, which will need to be tested further in the future.

The climate of Patagonia is strongly influenced by the latitudinal location of the core of the Southern Westerly Winds (SWW), which is influenced by conditions in Antarctica. In general, cooler conditions in Antarctica push the SWW north and intensify the winds by increasing the pole-equator temperature gradient. Marine core TTN057-13-PC4, in the South Atlantic sector of the Southern Ocean at 53ºS (Hodell et al., 2001), documents variations in ice-rafted debris (IRD) and sea surface temperature (SST) at 53ºS. As Fig. 2 (D, E, F and G) shows, periods of increased IRD and lower SST in Antarctica are related to glacier advances west of Lake Argentino and higher precipitation at Cerro Frias in the eastern Andean foothills. Strelin et al. (2014) have documented phases of glacier advance in the Lake Argentino area at 7730–7210, 6000–5000, 2500–2000, 1500–1100, ca. 700, and >400 and <300 to the 1900s. It is possible that these glacial intervals correlate with our documented environmental changes and the shifts we have seen in lithic assemblages. We presume that the glacier advances occurred because of an increase in precipitation over the Andes west of Lake Argentino and cooler summer temperatures. Such changes in climate would have led to short-term drier conditions in SW Santa Cruz but possibly slightly wetter conditions in the SDM and basalt areas north of the Santa Cruz River.

Rapid climate changes (RCC) can have more impact on humans than slower changes even if these are of greater eventual magnitude (e.g. Mayewski et al., 2004). This appears to be the case in our study areas for the period of the Holocene. A particularly good example of this occurs ca. 5500–5000 cal yr BP when there is a marked drop in Southern Ocean SST and a sharp increase in the extent and persistence of sea ice in the Antarctic region (Fig. 2F and G). Ice rafted debris >150 μm increases from 0 to ca. 8 weight % over less than a thousand years. The colder conditions in Antarctica intensified the SWW and pushed them further north bringing increased precipitation to the glaciers west of Lake Argentino resulting in glacier advances ca. 6000–5000 cal yr BP (Fig. 2E) and affecting our areas of study via climatic teleconnections.

Considering uncertainties in dating, the correlations between IRD amount, SST value, period of glacier advance and higher precipitation at Cerro Frias are remarkable. This is particularly apparent for the glacier advances at 7700–7200 and 6000–5000 cal yr BP, which correlate with high IRD percentages in marine core TTN057-13-PC4, higher precipitation at Cerro Frias, dry conditions at Chorrillo Malo 2, and the beginning of the presence of elongated flakes in the SW Santa Cruz area.

Despite the problems facing any correlation between lithic characteristics and environmental change, we have been able to identify several "possible" or "probable" correlations between the two variables. The proposed relationships are shown in Fig. 2, which summarizes both environmental and lithic technology changes in our study areas. These relationships are outlined below in chronological order from Late Pleistocene to Late Holocene:

i) The Chorrillo Malo 2 and SDM pollen records, and the SDM sediment record, suggest that prior to ca. 8500 cal yr BP conditions were relatively wet – at least as wet as today – in both the USCRB and SDM areas. This evidence of increased moisture corresponds with a major Early Holocene period of glacier retreat west of Lake Argentino, and lower precipitation at Cerro Frías, during the Holocene Climate Optimum, suggesting more southerly and weaker SWW allowing more Atlantic Ocean moisture to enter the eastern parts of Patagonia. Data from marine core TTN 057-13-PC4 indicate high SSTs in the Southern Ocean and reduced sea ice in Antarctica (Hodell et al., 2001) and higher levels of Lake Cardiel at 49ºS from ca. 11,450–7800 cal yr BP, with a maximum level of about 55 m above present at ca. 10,700 cal yr BP (Stine and Stine, 1990; Gilli et al., 2001), are further evidence of this widespread wet interval east of the Andes in southern Patagonia.

In the SDM, bifacial artifacts appear at ca. 10,500 cal yr BP during this early wet climate phase, and expedient lithic technology artifacts appear in the USCRB region around 11,200 cal yr BP. We cannot be sure if conditions at Chorrillo Malo 2 were wetter than today when humans first entered the USCRB area because the pollen record does not go beyond 10,000 cal yr BP. However, wet and dry periods in the USCRB and SDM correlate quite well between 10,000 and 6000 cal yr BP and so it is possible that conditions at Chorrillo Malo 2 were wet 11,000 cal yr BP as they appear to have been in the SDM. It is difficult not to argue that conditions wetter than today during the Early Holocene were part of the reason humans were able to occupy these areas at this time (Brook et al., 2013); particularly in the SDM region where seasonal lagoons represent what is currently an unreliable water source.

ii) After ca. 8500 cal yr BP the Chorrillo Malo 2 and SDM pollen and sediment evidence all indicate dry conditions, as does the very low level of Lake Cardiel ca. 7500 cal yr BP, which dropped below 0 m (Stine and Stine, 1990). These dry conditions were accompanied by glacier advances west of Lake Argentino ca. 6500–5500 cal yr BP (Strelin et al., 2014) and higher precipitation at Cerro Frias (Tonello et al., 2009). Glacier advances and higher precipitation at Cerro Frias suggest increased precipitation in the Andes but reduced precipitation east of the Andes.

The shift to dry conditions in the SDM around 8500 cal yr BP corresponds with a period when there is no evidence of human occupation in the area (Brook et al., 2013). The change from expedient lithic technology to elongated flakes in the USCRB area occurred around 7150 cal yr BP, close to the time of maximum glacier advances west of Lake Argentino at ca. 7500 cal yr BP when precipitation may have been at a minimum (Fig. 2A and E). In the SDM, human occupation dates from ca. 12,800–8500 cal yr BP. The lack of evidence for occupation of this area after ca. 8500 cal yr BP coincides with a change from wet to dry conditions in the pollen record at ca. 8500 cal yr BP and in the sediment record at 9000 cal yr BP (Brook et al., 2013). The absence of evidence for human occupation after this period can be related to the abandonment or less intense use of this area.

iii) The dry interval in the USCRB and SDM regions came to an end around 6500–5500 cal yr BP with a shift to wet conditions evident in the pollen records at ca. 6200–5500 cal yr BP at Chorrillo Malo 2 in the USCRB, and ca. 5500–5000 cal yr BP in the SDM. The SDM sediment record shows conditions probably wetter than today from 6500 to 5400 cal yr BP (Fig. 2J). During this period, glaciers retreated west of Lake Argentino, there was less precipitation at Cerro Frias, and the level of Lake Cardiel rose to 20 m at ca. 6000 cal yr BP (Stine and Stine, 1990; Gilli et al., 2001). Southern Ocean SSTs increased, and there was less Antarctic sea ice as evidenced by low IRD and low apparent mass accumulation rates (AMAR) for quartz in the 150 μm to 2 mm size fraction (Hodell et al., 2001). All of these changes suggest weaker and more southerly SWW that allowed an increase in precipitation east of the Andes.

In the SDM, blade artifacts are evident at ca. 5250–4800 cal yr BP, coincident with this wet interval, which lasted from ca. 5400–5000 cal yr BP in the SDM pollen record and from ca. 6500–5400 cal yr BP in the SDM sediment record. The end of blade production in this area is still not well dated. However, the evidence we have so far shows that the last date for blade presence in the SDM is around 4800 cal yr BP, corresponding closely with a change to a slightly drier but still moist climate dating to ca. 5000 cal yr BP in the SDM pollen record and ca. 5400 cal yr BP in the SDM sediment record (Fig. 2J, M and N).

In the USCRB area the utilization of expedient technology is followed by an interval from 7150 to 4850 when elongated flakes were used by human groups. The beginning and end of this period correlate extremely well with glacier advances west of Lake Argentino (ca. 7700–7200 and 6000–5000 cal yr BP; Fig. 2E) and related peaks in rainfall at Cerro Frias (ca. 7150 and 5500 cal yr BP; Fig. 2D). Glacier advances in the Andes and higher rainfall at Cerro Frias would have been associated with much drier conditions east of the Andes at for instance Rio Bote, and this may have led to the changes in the way humans were using these spaces and changes from, at first, expedient lithic technology to elongated flakes, and later from elongated flakes to the utilization of Levallois method and bone artifacts. These changes may have occurred for different reasons, either internal or external. The first case can be related to a change from the initial exploration of this environment (sensu Borrero, 1994–95; see Franco, 2004b) to its colonization, as reflected in the archaeological record. In the last case, Levallois methods could have been introduced to the area by new human groups but it can also be related to the effective occupation of these spaces (sensu Borrero, 1994–95), as indicated by an increase in the number of archaeological sites, the use of different environments and a change in raw material utilization (Franco, 2004a,b). The correlation between the chronological boundaries of the period when elongated flakes were utilized and the Chorrillo Malo 2 pollen record is not as clear as that between the lithic boundaries and the glacier record. This is not unexpected, as the timing of maximum glacier advance can sometimes be more exact than the timing of changes in pollen data sets, which at Chorrillo Malo 2 may represent eastern steppe communities. Nevertheless, the glacier advances mark periods when moisture brought by the SWW reached a maximum resulting in droughts east of the Andes, and the beginning of these periods correlate well with the change to elongated flakes and then the change to Levallois method. We do not think these relationships are a coincidence because it is possible that the climate changes that led to glacier advances also brought about a change in the way humans were using these spaces and, as a consequence, in lithic technology use. However, proving linkages between environmental change and lithic use is difficult. For example, the Chorrillo Malo 2 pollen record shows that both elongated flakes and Levallois artifacts were used during both relatively wet and relatively dry periods.

iv) The end of the wet phase in the USCRB and SDM regions around 5000 cal yr BP witnessed major changes with the onset of the Neoglacial. However, the evidence suggests that these changes were not always in the same direction. From ca.

5000–2900 cal yr BP the USCRB area seems to have been drier than today while the SDM area, although slightly drier than previously, appears to have remained wetter than today (Fig. 2B, J, and M). A rise in the level of Lake Cardiel ca. 3500 cal yr BP is implied by high lake sediment magnetic susceptibility values and lake terraces (Stine and Stine, 1990; Gilli et al., 2005) when Southern Ocean SSTs were slightly higher and Antarctic sea ice less persistent. However, what is perhaps most noticeable about this period is that from ca. 5000–3000 cal yr BP SSTs in the Southern Ocean were lower and the extent and persistence of Antarctic sea ice greater than during any other period in the last ca. 9000 years of the Holocene (Fig. 2G). Glaciers did not retreat or advance much during this lengthy cold period (from ca. 5000–3500 cal yr BP) and no new lithic technologies appeared in the USCRB in the interval 5000–800 cal yr BP). This suggests that climate changes were not significant enough to affect human groups, who could adapt to them.

v) Glacier advances west of Lake Argentino around 2200 cal yr BP are evidence that climate change became more severe after this time. Although the record is discontinuous, blades are present in the NSCR after ca 2000 cal yr BP, which is coincident with a shift to dry conditions evident in both the pollen and sediment records for the SDM.

vi) Small blades have been recovered from our excavations at Viuda Quenzana in the SDM. They date between 1200 and 1000 cal yr BP, and so coincide with a slightly wetter climate than today in the SDM. The archaeological deposits at Viuda Quenzana have not been excavated fully and so the use of small blades in this area may be older than present evidence suggests.

vii) A dry period in the Chorrillo Malo 2 pollen record (1200–800 cal yr BP; Fig. 2B) appears to correlate with the end of the utilization of the Levallois method. Again, the technological change seems to have occurred at the time of rapid climate change to drier conditions. The end of occupation south of Lake Argentino seems to be related to the severe dry conditions associated with the Medieval Climatic Anomaly (MCA) (Stine, 1994), as previously noted by Borrero and Franco (2000).

viii) The most recent period of human occupation of the USCRB area from 700 to 300 cal yr BP corresponds approximately to the Little Ice Age (LIA), which may have been slightly wetter than the preceding MCA. Changes in human burial techniques and in the associated goods could suggest that a different human group moved into the area during the LIA, possibly to occupy spaces vacated by the previous occupants as the climate improved slightly, a hypothesis that must be tested.

5. Conclusions

i) Comparison of lithic technology use and environmental change in three large areas of Patagonia suggests that changes in lithic technology may have occurred at times of rapid climate change, particularly when changes were from moist to much drier conditions. The effect of dry conditions on human populations in South Patagonia has been mentioned previously by other researchers (i.e. Goñi et al., 2000–2002; Borrero and Franco, 2000).

ii) It is unclear why the lithic changes we have documented actually occurred. The changes may have been brought about by endogenous changes or those related with the introduction of people or ideas. We hope future research will allow us to fill the gaps in the archaeological record.

iii) Our findings must be treated only as a beginning, much more research will be needed to test the relationships between technology and climate change suggested here, and even more research will be needed to understand how and why the technological changes were made.

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