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Spatial and temporal distributions of exotic and local obsidians in Central Western Patagonia, southernmost South America

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ABSTRACT

Central Western Patagonia (CWP) is a key area for assessing long-distance procurement of high-quality obsidians throughout the Holocene given that almost all relevant types represented in the archaeological record are exotic to this region. By using surface and stratigraphic obsidian artifacts from archaeological sites compared to standards from known sources in Patagonia, this paper discusses the spatial and temporal distribution of this lithic material. Sampling was oriented to assemblages from deposits with radiocarbon-based time frames (10,700 – 300 cal BP). This paper presents geochemical (ICP-MS) analyses of 178 samples from 58 archaeological sites at 11 surveyed areas located along the Pacific coast, the Andean forest, and eastern steppe. Out of six potential sources, the Chaitén Volcano source (Los Lagos Region, Chile) dominates exclusively the occurrence of obsidians along the coastal fringe, while the Pampa del Asador source (PDA, Santa Cruz Province, Argentina) largely dominates (86% of samples) obsidian in the eastern steppe and the forest/steppe ecotone. This broad distribution is explained by the presence of the densely forested Andean mountain range acting as a biogeographical barrier. East of the Andes, we recorded an absolute dominance of PDA south of 45°30′S, while more variability prevailed north of this point. The highest diversity of obsidians was recorded in the Cisnes River valley, probably because it is located closer to other alternative northern sources (Telsen/Sierra Negra, Sacanana and Angostura Blanca, all in Chubut Province, Argentina) and because it also hosts a local low-quality obsidian type. Based on this distribution, we discuss obsidian procurement behaviors by considering obsidian frequency and tool/debitage-class representation with increasing distance. We use the analysis of fall-off curves based on the distance of studied locations from the sources and include the use of least-cost paths for providing the most likely procurement routes. No obsidian diversification was recorded during the Holocene, hence the main driver for its procurement seems to be the distance from the source rather than the antiquity of its knowledge. Alternative procurement behaviors are discussed, specifically direct acquisition, exchange, and/or sporadic visits as mechanisms for explaining the archaeological patterns throughout the Holocene.

1. Introduction

The procurement and circulation of goods is closely tied to the movement of people and the transmission of ideas. Since archaeologists seldom access to these domains, we must rely on material proxies such as the distribution of exotic items and try to define their movement patterns to attempt to interpret them in behavioral terms (i.e., Gamble, 1999; Meltzer, 1989; Salomon, 1985). Central Western Patagonia (CWP; Aisén Region, Chile; 44° to 49°S) is a key area for assessing long-distance procurement of toolstones in the broader region of the southern cone of South America since all high-quality obsidians used by past hunter-gatherers are exotic (Méndez et al., 2008–9, 2012). Thus, obsidian samples, independent of their abundance, tool/debitage class or technological attributes, are regarded as highly relevant in the assemblages from

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which they were obtained, given that they provide information on specific decisions related to high-quality toolstone procurement, group mobility, and territoriality. Patagonia has a total of nine major geochemically recognizable obsidian sources that have been analyzed following the same methods (Stern, 2017 see this issue). Only a very minor percentage of obsidian artifacts from archaeological assemblages come from a limited number of minor or unknown sources (Méndez et al., 2012; Stern, 2017); thus, they should be considered of less importance in comparative trends. Additionally, the Patagonian region was occupied by mobile societies throughout the Holocene (e.g., Borrero, 1994–5; McEwan et al., 1997), and as such, it provides a suitable context for assessing the evolution of procurement behaviors among groups with similar decision-making regarding the use of landscapes at different temporal and spatial scales. However, it is worth noting that pedestrian movement was not exclusive to this region, given that mobility along the Pacific coast was accomplished using canoes (Reyes et al., 2015) and that horse was adopted during the seventeenth century AD by inland societies (Nuevo Delaunay et al., 2017). Hence, this paper targeted contexts with known time frames for discussing such behavioral patterns.

During the last decade, archaeological research teams working in CWP have managed to compile a series of obsidian provenance analyses from locations both along the Pacific coast and inland along the forest/steppe margin and the eastern plains (e.g., Stern, 1999; Stern and Porter, 1991; Stern et al., 2013; Reyes et al., 2017). However, this information, based on both surface-averaged (Méndez et al., 2008–9) and chronologically constrained stratigraphic assemblages (Méndez et al., 2012), featured only a limited distribution. This paper presents new and previously published geochemical analyses of obsidian artifacts from archaeological locations in CWP (Fig. 1), including areas with no prior sampling, and compares them to values of known sources that have been used in discussions of the spatial distribution of this exotic lithic material in broader Patagonia (e.g., Stern, 2004, 2017). Whenever possible, we selected samples from radiocarbon-dated contexts instead of surface artifacts. These data are used to discuss the spatial and temporal distributions of exotic and local obsidians in CWP and their implications for disentangling different procurement behaviors.

This paper discusses the variability in assemblages as a function of the distance from the source and the implications of having alternative sources at equivalent distances represented in the archaeological record (e.g., Barberena et al., 2011; Cortegoso et al., 2016; Méndez, 2004). By comparing these spatial trends with chronologically constrained assemblages, we investigate the antiquity of the use of obsidian in CWP and whether preferred sources varied over time (Méndez et al., 2012; Stern, 2017). In addition to distance and time, other variables such as the knapping quality of the specific obsidians are considered, though the large dominance of specific types across the region make this variable only relevant for specific areas. Finally, we discuss whether the frequency and tool/debitage class representation of obsidian artifacts in CWP meets the expectations for direct procurement, systematic exchange or other sporadic mechanisms that may account for the decisions involved in the manufacturing, use and discarding of high-quality exotic raw materials.

2. Regional setting and obsidian artifact distribution in CWP

The main geographic feature of CWP is the Andean mountain range (Fig. 2). To the west, a series of archipelagos and fjords form an abrupt and fragmented landscape, while to the east, the landscape is composed of extensive sedimentary plains, lakes and other glacial and volcano-related landforms. The almost continuous presence of the southern westerly winds produces a strong west-east precipitation gradient due to the rain shadow effect over the Andes (Garreaud, 2009). Because of this rainfall distribution, evergreen forests occur along the coast and western continental mountains, deciduous forests occur on the lee side of the Andes, and open semiarid steppes occur to the east (Luebert and Pliscoff, 2006). The paleoenvironmental records for the continental area suggest that the most significant climate and landscape changes occurred during the Pleistocene/Holocene transition and that the current phytogeographical distribution has not changed substantially since the early Holocene, except for minor fluctuations in the maximum easterly position of the forest steppe ecotone and changes in the density of the forest canopy (de Porras et al., 2012; 2014; Villa-Martínez et al., 2011). Coastal records also indicate a relative stable period in terms of forest distribution, coverage and species variability during the Holocene (Haberle and Bennett, 2004). Thus, for all human trajectories discussed in this paper we consider that no substantial changes in landscape and climate affected the overall access to obsidian sources or constrained the mobility of hunter-gatherers relative to the modern conditions.

The sources for obsidian in this region are either Andean or extra-Andean, and each of these types are chemically distinctive based on XRF and ICP-MS analyses of both source and extra-source samples (e.g., Stern, 2017). We discuss the distribution of obsidian from six sources (major and minor) of known geographical location between 42° and 48°S plus four potential unknown sources. Although other sources for obsidian are available in Patagonia both to the south and the north of the study area (Stern, 2017), the six obsidian types considered here are the only ones found among archaeological samples. The main obsidian type represented in CWP is the black-colored alkaline rhyolitic obsidian from Pampa del Asador (PDA; 47°49′S; 70°48′W; Stern, 1999, 2017). PDA cobbles (secondary sources) are found distributed over a large area in excess of 2000 km^2 in Santa Cruz Province, Argentina (Belardi et al., 2006; Espinosa and Goñi, 1999; Franco et al., 2017). Repeated analyses have concluded that there are four distinctive variants: PDA1, PDA2, PDA3ab, and PDA3c (Stern, 1999, 2004, 2017; García-Herbst et al., 2007). PDA obsidian artifacts have been recorded between 42° and 54°S from the eastern rim of the Andes to the Atlantic coast and from 12,100 calibrated years before present (cal BP) to historical times (Méndez et al., 2012; Morello et al., 2012; Stern, 2004, 2017; Stern et al., 2000; Paunero, 2003). PDA is by far the most represented source in Patagonia, and the PDA1 subtype accounts for the majority of archaeological artifacts, the widest distribution and the greatest antiquity (Stern, 2017). Within CWP, obsidian from this source has shown a strong relationship between increased distance and decreased frequency when comparing south-to-north equivalently sampled surface units (Méndez, 2004). This assessment considered the relative proportion of obsidian debitage versus other toolstones in assemblages recorded through surface surveys (in the range between 110 and 150 km^2) at sections of the Cisnes, Ibáñez, Jeinemeni and Chacabuco valleys (Méndez et al., 2008–9).

In northern CWP, especially in the Cisnes River valley, obsidian from the Somuncurá Plateau is also present. Metaluminous black obsidian from Sacanana (S; 42°30′S; 68°36′W) and translucent grey-green obsidian from Telsen/Sierra Negra (T/SN, previously referred to as T/SC; 42°18′S; 66°36′W) have been described in this area (Méndez et al., 2008–9, 2012). S obsidian is a crystal-free peralkaline rhyolite, and artifacts composed of this material have been observed from 40°50′ to 45°20′S and from the eastern rim of the Andes to the Atlantic coast with ages no older than 2700 cal BP (e.g., Favier Dubois et al., 2009; Gómez Otero and Stern, 2005; Stern, 2017; Stern et al., 2000, 2013). T/SN is a crystal-free peralkaline rhyolitic obsidian with a similar distribution as that of S, except for its southernmost occurrence at 44°30′S (Stern, 2017;

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Stern et al., 2000, 2013) and a maximum age of 10,200 cal BP from stratified deposits in its south-easternmost distribution area (Méndez et al., 2012). Much less common, the Angostura Blanca perlite obsidian (AB, also referred to as DesX) from Piedra Parada locality (42°39′S; 70°07′W) (Bellelli and Pereyra, 2002; Stern et al., 2007; Stern, 2017) has been located in CWP, as reported in this paper. AB obsidian artifacts occur mainly near the source and east of the Andes at 41°S and were manufactured during the last millennium (Bellelli et al., 2006; Boschín and Massaferro, 2014; Stern, 2017).

The only local obsidian type in CWP corresponds to a dark grey-black brittle variety cropping out from within a rhyolitic pyroclastic flow in two locations in the upper Cisnes River valley (CIS; 44°32′S, 71°13′W and 44°29′S, 71°11′W). Four subtypes are available (CIS1, CIS2, CIS3 and CIS?), although they do not correlate with particular outcrops. At first, this type was considered to be of limited prehistoric use and was thought only to be used in artifacts close to the source because of its poor knapping quality (Méndez et al., 2008–9). However, later findings have shown that it was used starting at 5400 cal BP within the source (Méndez et al., 2012) and at least at 8500 cal BP approximately 100 km to the southeast at the Casa de Piedra de Roselló site in Aldea Beleiro, some 30 km east of Coyhaique Alto (Castro Esnal et al., 2017).

Another common obsidian in CWP is the porphyritic grey to black calc-alkaline obsidian with distinctive plagioclase crystals derived from the Chaitén Volcano (CH; 42°55′S, 74°42′W). Artifacts from this Andean source are recorded along the Pacific coast, archipelagos, and fjords on the western side of the Andes from 39°31′ to 45°30′S, with a maximum antiquity of 6500 cal BP at its northernmost site of occurrence, the Chan Chan site of the Araucanía coast, north of Patagonia (Reyes et al., 2007; Stern and Porter, 1991; Stern and Curry, 1995; Stern et al., 2002). Given that no artifacts have been recorded on the eastern side of the Andes, this densely forested mountain range has been regarded as a potential barrier between the western coasts and the eastern steppe populations at this latitude (Méndez and Reyes, 2008). However, recent findings of this obsidian at the southernmost Atlantic coast (50°21′S) and inland in the Pali Aike region (51°50′S) suggest the coastal transport of artifacts circumnavigating the south of the continent, most likely through the Magellan Strait (Stern et al., 2012).

3. Material and methods

This paper presents 178 ICP-MS geochemical analyses on 169 samples (nine duplicates were conducted in cases where verification was needed) from sites covering the entire Holocene within CWP, an area of ~108,000 km^2 (see Supplementary Material Table 1 and Supplementary Material KMZ file). Ninety-six of these analyses have been previously published (Méndez et al., 2008–9, 2012, 2016b; Nuevo Delaunay et al., 2013; Reyes et al., 2007; Stern et al., 2013). This set also includes 16 geological (unmodified) samples from the CIS obsidian outcrops. Altogether, 153 analyzed archaeological artifacts were obtained from 58 locations (including sites and isolated surface findings) from 14 surveyed areas located along the Pacific coast, in Andean forests, and in the forest-steppe ecotone (Table 1). The studied artifacts belong to both surface lithic scatters (N = 72; 47.1%) and stratified (N = 81; 52.9%) deposits (Fig. 3), although special emphasis was put on sampling archaeological deposits with known radiocarbon-based timeframes. Either direct ages or ranges were assigned based on the specific location of the samples within the excavations or their proximity (see Supplementary Material Table 1, ages are expressed in ka or thousand calibrated years BP). Color, translucency, and inclusions were recorded for all samples, although these criteria were not used in the selection of samples for geochemical analyses based on previous experiences that suggest these characteristics may not be reliable indicators of variability.

ICP-MS analyses were conducted at the Laboratory for Environmental Geochemistry at the University of Colorado (Boulder, CO, USA) using an ELAN DCR-E instrument. The results are considered to be precise to ±10% at the parts-per-million (ppm) scale based on repeated analyses of selected obsidian samples and available U.S. Geological Survey standards (Saadat and Stern, 2011). Analyses of samples from unknown sources were replicated and provided similar results. Given that geological and archaeological obsidian samples from Patagonia south of 42°S have been analyzed following the same protocol in the same laboratory, the assigning of these samples to individual types/sources is regarded as reliable (Stern, 2017). Obsidians from these sources are also highly homogeneous (Stern, 2004). The average compositions of these obsidians are presented in Stern (2017, Tables 1 and 2) and elsewhere (Franco et al., 2017; Méndez et al., 2012; Stern, 2004).

For assessing temporal variability in procurement behaviors, all radiocarbon age determinations from sites discussed in this paper were calibrated into years before present (cal BP) with Calib 7.0.4 (Stuiver et al., 2013) using the ShCal13 curve (Hogg et al., 2013) and are expressed rounded to the nearest hundred. These are available in regional syntheses (Mena and Stafford, 2006; Méndez et al., 2016a; Reyes et al., 2015; and references therein). For evaluating spatial variability, Euclidean distances were measured in linear kilometers between selected sites and central points within the obsidian sources (Méndez, 2004). Additionally, in this case, least cost paths (LCP) were compared to the Euclidean distances (see supplementary material KMZ file). LCP are assumed to be better routes because they account for adjacent points with less slope, thereby minimizing the theoretical energy expenditure in the displacement between two points (Anderson and Gilliam, 2000; Miotti and Magnin, 2012; Rademaker et al., 2012). LCP were produced using a digital elevation model (DEM) with data from the NASA Shuttle Radar Topography Mission with a 90-m cell resolution.

4. Results

4.1. Geochemistry of obsidians in CWP

Fig. 4 is a plot of the Ba and Zr values (in ppm) of the analyzed archaeological artifacts from CWP, showing the variability in the obsidian types represented in the assemblage, which is further summarized in Table 1. The analyses confirm the variability in the obsidian samples outlined in previous regional studies and provide data on types and new subtypes previously not described in this region (Méndez et al., 2008–9, 2012; Stern et al., 2013). The new types represented in CWP are AB (N = 2) plus four unknown sources (N = 6), which represent only 3.92% of the studied assemblage. Unknown types were compared to all known sources in Patagonia and confirmed by duplicate analysis (Stern, 2017). These were recorded at four sites in northern CWP and one in southern CWP (Fig. 1).

The local obsidian type reported in the upper Cisnes valley of CWP was further analyzed by including a new set of unworked samples. CIS obsidian nodules occur naturally at the surface of the sites El Chueco 1 and La Cantera 1 as unworked clasts with sizes of <2 cm (Gómez and Méndez, 2015). These nodules also occur within a tuff ash stratum outside the El Chueco 1 cave, underlying the levels with anthropogenic material (Méndez et al., 2011). Combined archaeological and geological data have identified four subtypes on the basis of their geochemical variability (Fig. 5). CIS1 (originally CIS) is represented in both archaeological and geological samples,

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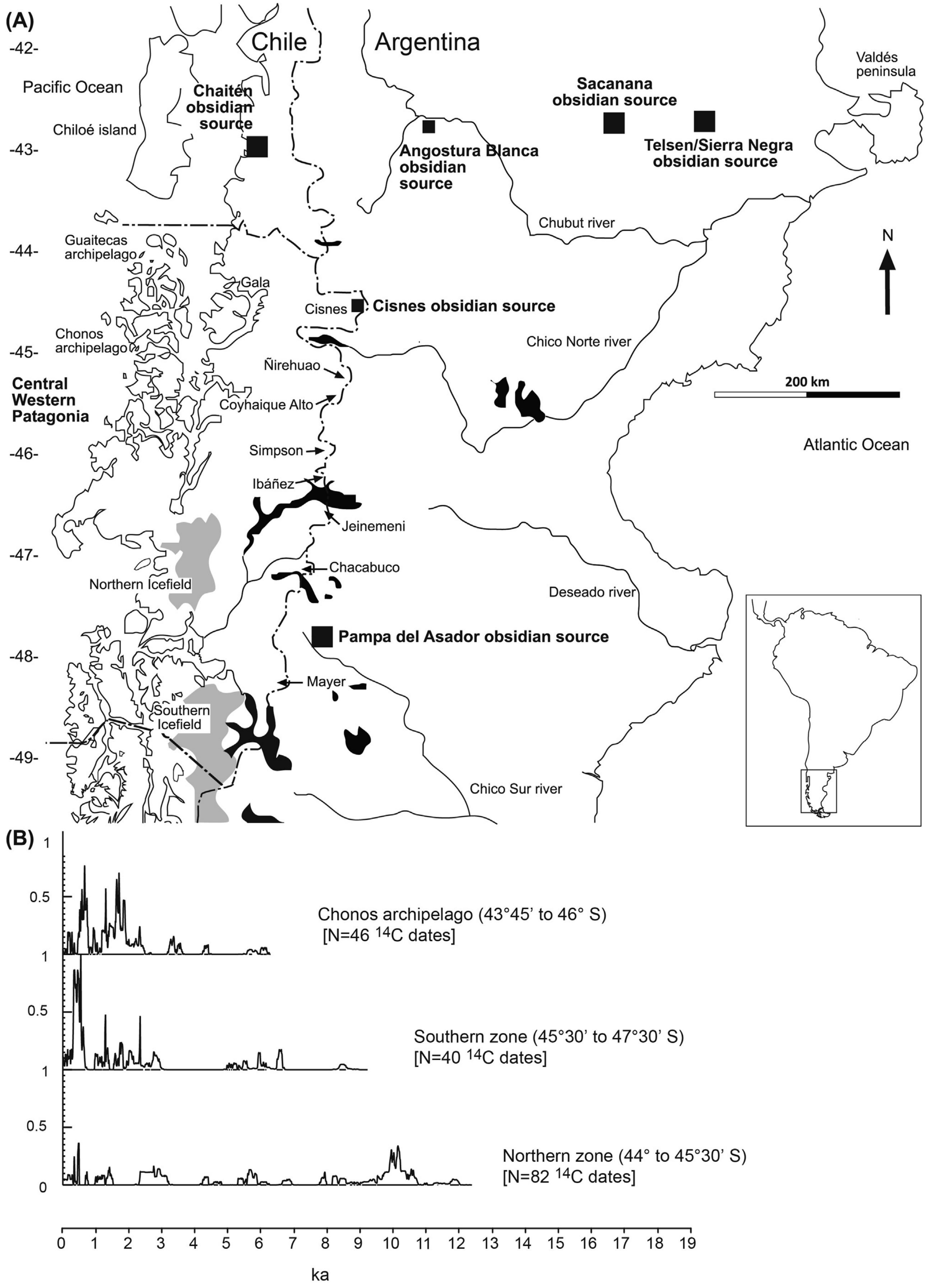

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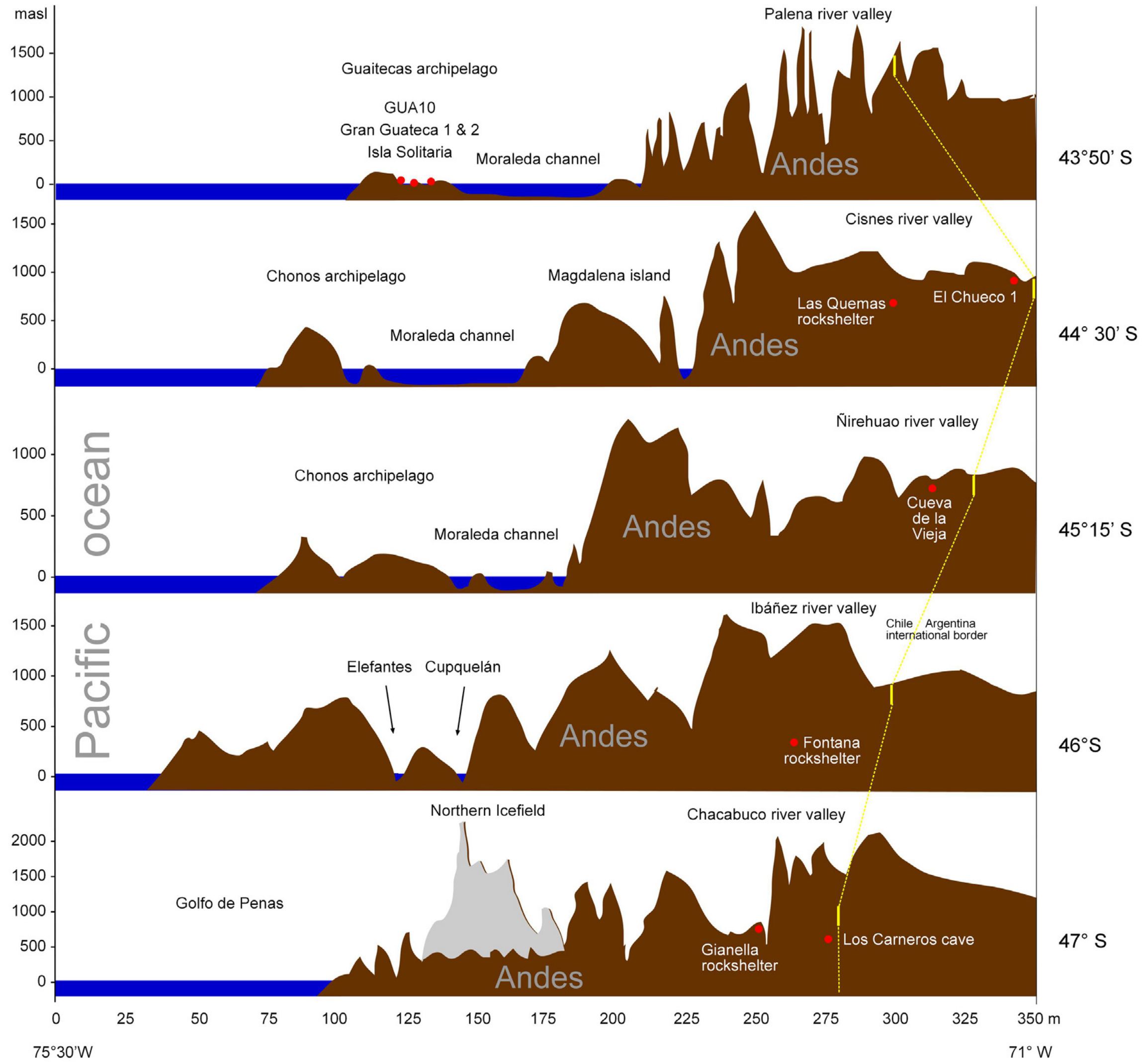

Fig. 2. Schematic cross sections of CWP at latitudes with representative sites discussed in this paper.

CIS2 is only recognized in geological samples mainly from La Cantera 1 site in the upper Cisnes River valley, and CIS3 and CIS? are represented by archaeological samples recorded at sites far from the source. CIS1 artifacts (N = 2; 1.3%) with ages of 5400 and 3200 cal BP have been found in small quantities in the El Chueco 1 site located immediately on the source (Méndez et al., 2012). CIS3 includes 2 individual pieces (1.3%) belonging to a level dated between 8800 and 5700 cal BP in Baño Nuevo 1 site in the upper Ñirehuao river valley, 94 linear km south of the source. These samples were previously assigned to an unknown type (Méndez et al., 2012). This subtype also occurs at 8500 cal BP around 100 linear km to the southeast of the source, at the Casa de Piedra de Roselló site in Aldea Beleiro, some 30 km east of Coyhaique Alto (Castro Esnal et al., 2017). A fourth subtype, CIS? (N = 2; 1.3%), occurs 57 linear km west of the source in the Las Quemas site (middle Cisnes) with ages between 3000 and 2400 cal BP (Méndez et al., 2016b), and in a 9400 and 8500 cal BP level of the Cueva de la Vieja site (Fig. 3D) in the upper Ñirehuao River valley, also 94 linear km south of the source (Méndez et al., 2017) (see Fig. 6).

More than 80% of all analyzed values from CWP correspond to subtypes of the PDA source. This confirms that this is the single most common source of obsidian in the region and that it dominates obsidian circulation patterns. PDA1 (N = 87; 56.9%) occurs in sites east of the Andean mountains and within Andean valleys up to 370 linear km north of the source at 10,200 cal BP in El Chueco 1 site. It features a maximum antiquity of 10,700 – 9900 cal BP in the Baño Nuevo 1 site at 286 linear km north of the source. A similar trend is expressed by the less common PDA2 (N = 27; 17.7%), which is mostly distributed within less than 200 linear km north of the source. Though even rarer, PDA3ab (N = 9; 5.9%) is distributed in a similar geographical range as the other two types and features a maximum age of 10,300 cal BP, suggesting that there are no particular procurement constraints when comparing the spatial and temporal distributions of these geochemical subtypes. These proportions correspond to those of the geological samples randomly selected from the PDA source area (Stern, 1999, 2017).

Fig. 1. A. Map of Central Patagonia and the study area (CWP) showing major and minor obsidian sources (large and small squares, respectively) and the river valleys and areas sampled for obsidian artifacts discussed in this paper. B. Summed probability plots of calibrated radiocarbon dates of CWP per sub-regions expressed in ka (thousand calibrated years BP, based on Méndez et al., 2016a).

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Table 1
ICP-MS determinations of types and subtypes of obsidian artifact samples from CWP.

	Sites	CH	S1	T/SN	T/SN?	AB	CIS1	CIS3	CIS?	PDA1	PDA2	PDA3ab	UK	Total
Guaitecas Archipelago	GUA10	1												1
	Gran Guaiteca 1	2												2
	Gran Guaiteca 2	2												2
	Isla Solitaria	3												3
Gala	Seno Gala 1	2												2
Upper Cisnes	El Chueco 1			1			2			2			1	6
	El Deshielo									5				5
	Appeleg 1		3							9			1	13
	Appeleg 2			1							1			2
	CIS100									1				1
Middle Cisnes	Las Quemas								1	2				3
	Altos del Moro 1					1								1
	Altos del Moro 2					1						2		3
	Altos del Moro 3				1									1
Upper Ñirehuao	Cueva de la Vieja								1	4			1	6
	Baño Nuevo 1							2		17	7	1	2	29
	Lago Coichel 1									4		1		5
	BN76									1				1
	BN8									1				1
Coyhaique Alto	Punta del Monte cave									1	1			2
	Punta del Monte workshop									3		1		4
Upper Simpson	La Frontera										1			1
	La Veranada 2									1				1
	Tapera Sandoval									1				1
	BAL039									1				1
Middle Ibáñez	Fontana									2				2
	Alero Alto									2				2
	Las Mellizas									2				2
	RI5A									2				2
	RI6West									1				1
Lower Ibáñez	Juncal Alto									1				1
	Levicán 1											1		1
	Los Maitenes										1			1
	PAL21										1			1
	PAL24									1				1
	PAL25									1				1
	PAL29									1	1			2
	PAL33											2		2
	RI37									1				1
Lower Jeinemeni	Alero Jeinemeni									1				1
	RJ28									1				1
	RJ31										1			1
	RJ44										1	1		2
	RJ53									1				1
	RJ70									1				1
	RJ9										1			1
	2E-HA6										1			1
Upper Chacabuco	Entrada Baker									4	4			8
	Cueva Los Carneros									5				5
Middle Chacabuco	Gianella									2	3			5
	RCH4										1			1
	RCH5										1			1
Lower Chacabuco	Alero Doble Lili									1				1
	Alero Mano 1												1	1
	Laguna Cisnes Sur									1	1			2
	Nacientes Tulín 1									1				1
	1-HA5									1				1
Mayer	Mayer									1				1
Total		10	3	2	1	2	2	2	2	87	27	9	6	153

PDA obsidian occurs in 100% of the cases closer to the source (i.e., 100 linear km), such as at the Los Carneros site (Fig. 3C), and this proportion starts to diminish beyond 270 linear km of the source, although it is present at the northernmost sampled site, El Chueco 1.

Obsidian samples from the S and T/SN sources only occur in the Cisnes River valley, the northernmost sampled area in CWP. S1 (N = 3; 2%) was recorded only in the surface assemblage of the Appeleg 1 site with a known age of 1300 – 400 cal BP, located 310 linear km southwest of the source (Méndez et al., 2016a). T/SN (N = 2; 1.3%) obsidian, with Zr contents of >2000 ppm (Fig. 4), was recorded in the surface assemblage of the Appeleg 2 site located 445 linear km from the source and presumed to be of late Holocene age and in a level dated to 10,200 cal BP in the El Chueco 1 site, located at the same distance from the source (Méndez et al., 2012). A subtype T/SN? (N = 1; 0.7%) was recorded in the Altos del Moro 3 site in the middle Cisnes River valley. This sample yielded high Zr and rare earth element (REE) values. These values were not as high as those reported for T/SN but higher than any other known Patagonian obsidian type; hence, its identification as T/SN obsidian

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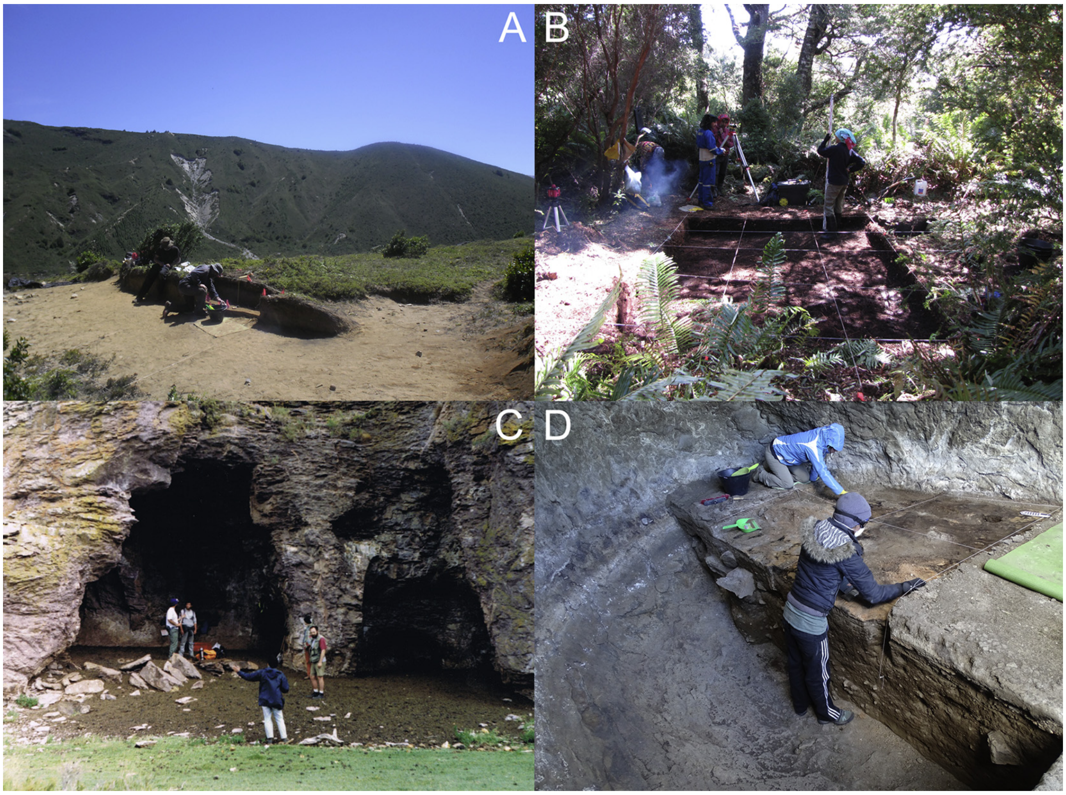

Fig. 3. Images of selected sites sampled for obsidian artifacts in CWP. A. Altos del Moro 1 (CIS081, AB obsidian, mid Holocene, Cisnes River valley); GUA-010 (CH obsidian, mid Holocene, Guaitecas Archipelago); C. Cueva Los Carneros (PDA1 obsidian, late Holocene, Chacabuco River valley); D. Cueva de la Vieja (BN15, CIS and PDA1 obsidians, early through late Holocene, Ñirehuao River valley).

Table 2
Obsidian frequency from selected assemblages in inland CWP. SSC: systematic surface collection; E: excavation; SS: surface survey. *frequencies based only in debitage classes.

	Method	Site	Obsidian frequency (N)	Total lithics (N)	% Obsidian	Reference
Upper Cisnes	SSC	Appeleg 1	7	623	1.1	Contreras et al., 2016
	E	El Chueco 1	3	88	6.7	Méndez et al., 2011
Middle Cisnes	E	Las Quemas	12	306	3.9	Méndez et al., 2016b
Upper Ñirehuao	E	Cueva de la Vieja	11	394	2.8	Méndez et al., 2017
	E	Baño Nuevo 1	163	1609	10.1	García, 2007
Coyhaique Alto	SSC	Punta del Monte cave	5	173	2.9	Nuevo Delaunay et al., 2013
Upper Simpson	SS	Various sites	1	33	3.0	Contreras et al., 2016
Middle Ibáñez	SS	Various sites	92	258	35.7	Gómez, 2013
Lower Ibáñez	SS	Various sites	96	746	12.9	Méndez, 2004
Lower Jeinemeni	SS	Various sites	34	355	9.6	Contreras, 2012
Upper Chacabuco	SS	Various sites*	313	1142	27.4	Méndez et al., 2003
	E	Entrada Baker (exterior)	172	360	47.8	Méndez and Velásquez, 2005
	E	Entrada Baker (interior)	136	224	60.7	Méndez and Velásquez, 2005
Middle Chacabuco	E	Gianella	35	228	15.4	Fuentes-Mucherl et al., 2012

remains preliminary. This new find is presumed to be of late Holocene age and was located 496 linear km west of the source. Just 2 linear km west from this last site, along the edge of the Cisnes river, AB obsidian artifacts (N = 2; 1.3%) were recorded in the surface of the Altos del Moro 1 (Fig. 3A) and two sites, which have ages of 5800 cal BP (unpublished date, 5046 ± 27 BP, D-AMS 017339, charred material, $\delta^{13}C$: -25.5) and 1800 cal BP, respectively (Thompson and Méndez, 2017). These new finds suggest southward transport over an approximate distance of 265 linear km from the Angostura Blanca area (Piedra Parada).

All samples from the coastal area yielded values consistent with obsidian from the Chaitén Volcano. CH obsidian (N = 10; 6.5%) artifacts and/or nodules were transported by watercraft 140 linear km along the Corcovado Gulf to islands in the Guaitecas Archipelago and to continental coastal sites, such as Seno Gala 1. The maximum antiquity for this transport was recorded at the GUA10 site (Fig. 3B) at a level between 5800 and 6100 cal BP (Reyes et al., 2017), but this obsidian occurs in dated deposits up to the contact with western peoples (Reyes et al., 2015).

4.2. *The obsidian archaeological assemblages of the eastern Andean flank of CWP*

To characterize the main aspects of obsidian procurement strategies, we assumed a basic distance-decay principle, in which a particular raw material should become less represented and stages in the reduction sequence should be more advanced with increased distance between the source and the sampled location. We present

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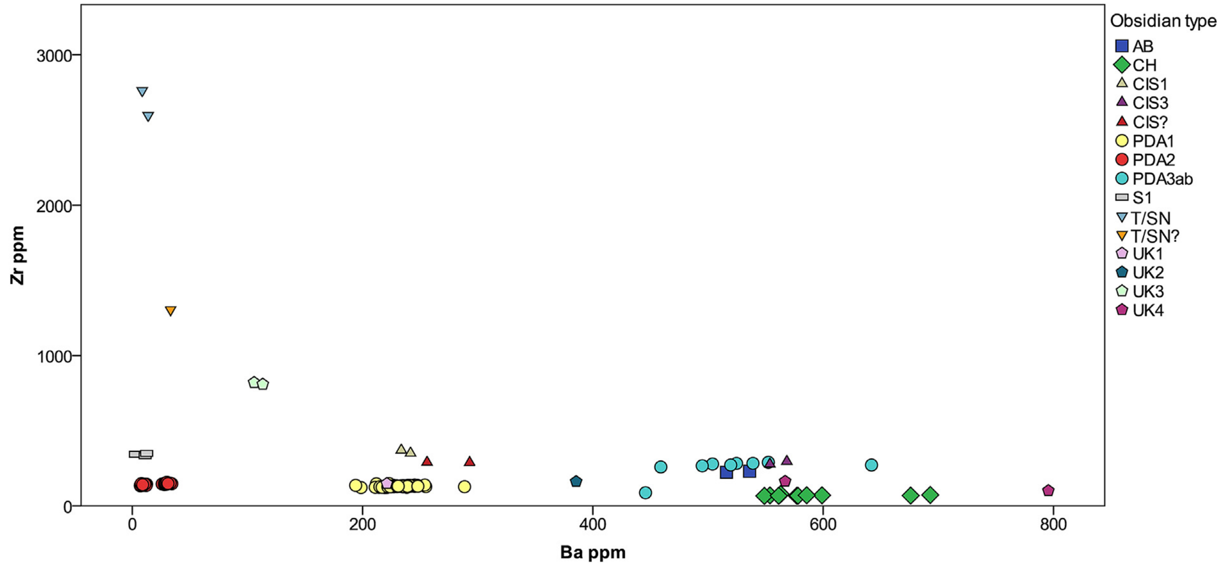

Fig. 4. Plot of Ba versus Zr concentrations in parts-per-million (ppm) for obsidian artifacts from archaeological sites sampled in CWP. The geochemical assignation to types and subtypes of obsidians from known sources follows Stern (2004, 2017).

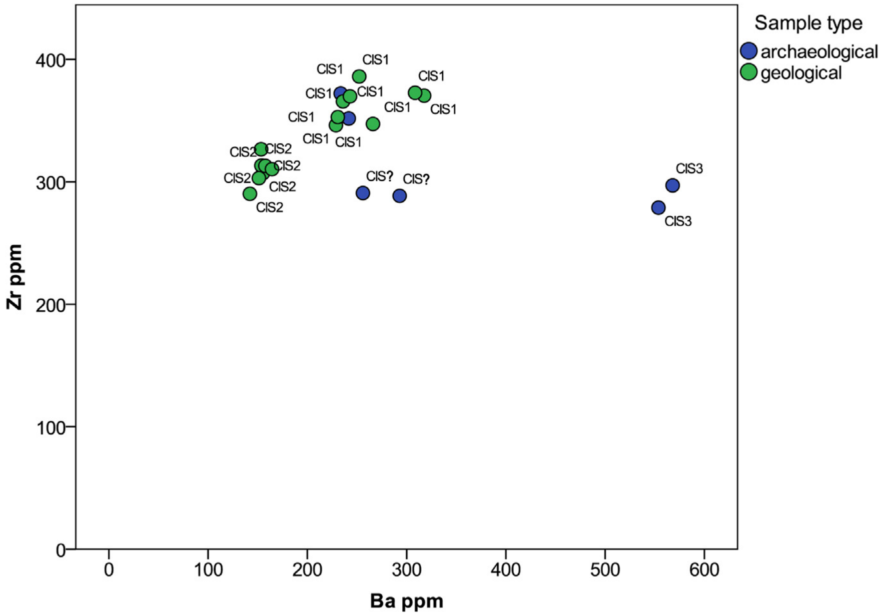

Fig. 5. Plot of Ba versus Zr concentrations in parts-per-million (ppm) for geological and archaeological samples assigned to CIS obsidian types following Méndez et al. (2012) and Stern (2017).

frequency data and a qualitative assessment of the available tool and debitage classes based on different locations in the steppe and forest-steppe ecotone of CWP. These assemblages vary in that they were obtained over a long period using different methods, i.e., surface surveys, systematic surface collection of specific sites, and stratigraphic excavations (Table 2 and references therein). Although we acknowledge that the diverse nature of the techniques influences comparability, we discuss each result considering some potential biases.

Obsidian in the lithic assemblages on the eastern Andean flank of CWP vary between 61% and 1% of the total raw materials. Assemblages closer to PDA usually include more obsidian, as evidenced by the surface records at the upper Chacabuco, lower Jeinemeni and lower Ibáñez valleys (~100, ~150 and ~190 linear km from PDA, respectively) which were surveyed with the aim of producing comparative samples (Méndez, 2004). Other similarly sampled valleys in northern CWP, such as the upper Simpson and the upper Cisnes, contain sites with very low frequencies and commonly lack obsidian entirely (Contreras et al., 2016; Méndez et al., 2006). Information based on assemblages from individual sites varies accordingly, as shown by selected sites from Andean valleys in the region (Table 2).

By combining available surface and stratigraphic assemblages with obsidian artifacts in the region, it is possible to observe a broad decreasing trend in the representation of tool/debitage classes with increased distance from the PDA source, which is related to advances in the stages of the reduction sequence of lithics. In order words, the organization of technology over variable distances

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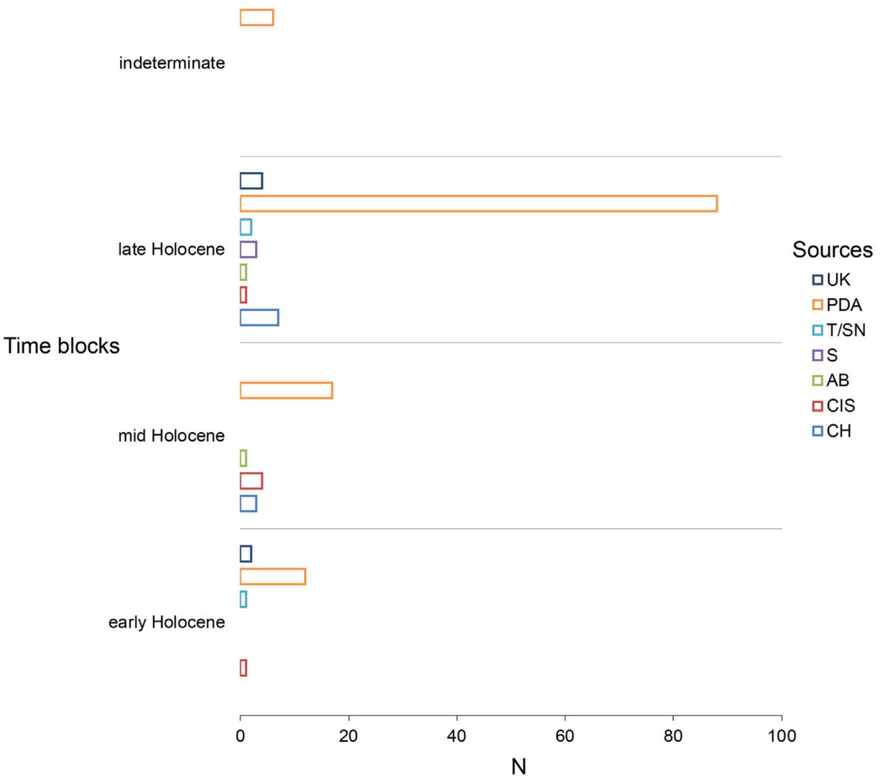

Fig. 6. Distribution of obsidian type groups of analyzed samples of CWP per time blocks based on the temporal assignation on Supplementary Material Table 1.

dictates the distribution of tool/debitage groups across space. Thus, the areas closest to the source exhibit all expected tool/debitage groups, i.e., cores (or their fragments), bifacial tools (or their fragments), edge tools, blades, flakes, bifacial thinning flakes, and edge/retouch debitage (~<1 cm). This is the case of the upper Chacabuco and lower Jeinemeni River valleys, where despite the differences in assemblage size and obsidian frequency they exhibit the same tool/debitage class variability (Contreras, 2012; Méndez and Velásquez, 2005; Méndez et al., 2003). This closely resembles the tool/debitage class variability suggested for areas to the east at a similar latitude (Fernández, 2013). The disappearance of specific tool/debitage classes starts in the lower and middle Ibáñez River valley. However, when combined, these two areas also show examples of each of the tool/debitage class groups. Most marked changes occur beyond ~230 linear km from PDA, in the upper Simpson River valley and the Coyhaique Alto area, where only bifacial tools (or their fragments) and edge/retouch debitage have been recorded. In other words, beyond this point only curated tools or final-stage debitage classes are common among artifacts manufactured in obsidian. This area has been acknowledged to show archaeological discontinuity when compared to equivalently sampled areas (Méndez et al., 2013). The upper Cisnes River valley has also yielded heavily curated artifacts, such as bifacial tools and blades, plus the last stages in the reduction sequence (Méndez et al., 2011). The upper Ñirehuao River valley (~290 linear km from PDA) stands as an exception in this broad decreasing trend in variability because, except for cores, it has produced artifacts in all the tool/debitage classes described. Spatial redundancy in conspicuous sites, and therefore higher discard throughout the Holocene, may partly explain this exception (e.g., Mena and Stafford, 2006; Méndez et al., 2017).

The only securely dated sequences spanning the Holocene in CWP that have been analyzed for raw material and tool/debitage class variability are the sites El Chueco 1 in Cisnes and Cueva de la Vieja and Baño Nuevo 1 in Ñirehuao River valleys (García, 2007; Méndez et al., 2011, 2017). Las Quemas rockshelter in the middle Cisnes River valley with middle and late Holocene assemblages, and the Entrada Baker rockshelter (interior and exterior) in the upper Chacabuco River valley with late Holocene assemblages also contain data for obsidian frequency and tool/debitage class variability. By considering broad time periods and direct ICP-MS analyses, the tool/debitage classes manufactured from PDA obsidian exhibit a similar behavior to that outlined for averaged surface and stratigraphic assemblages. Early Holocene assemblages in northern CWP show edge/retouch debitage in the case of Cisnes, and flakes, blades and edge/retouch debitage in the case of Ñirehuao. Middle Holocene assemblages in the Cisnes River valley show bifacial tools and edge/retouch debitage, whereas in Ñirehuao, the assemblages include both these classes and bifacial thinning flakes. As expected, the late Holocene assemblages of upper Chacabuco River valley, the closest to PDA, exhibit all tool/debitage groups except for cores and blades. The Ñirehuao assemblages include flakes and edge/retouch debitage for the same period, whereas the Cisnes sites have not produced any obsidian. Other determinations by ICP-MS analyses indicate edge debitage on T/SN obsidian in the early Holocene assemblage of El Chueco 1 (Méndez et al., 2012). Obsidian from CIS source was distributed throughout northern CWP, yet it has only been recorded as debitage classes in the early Holocene and middle Holocene assemblages of Ñirehuao and in the middle and late Holocene assemblages of Cisnes.

4.3. Distribution of obsidian in CWP

Obsidian representation in the studied assemblages varies mainly according to the distance from the source. In provenance studies, distances are generally measured as Euclidean distances (linear km; Méndez, 2004; Pallo and Borrero, 2015). In this paper, we also produced LCP from known source locations to conspicuous sites representative of the sampled areas in which they are located to assess more likely procurement routes. Fig. 7 plots Euclidean (Fig. 7A) and LCP (Fig. 7B) distances vs. the relative frequency of obsidian in the studied assemblages. In contrast to sites, which provide more precise locations, in the case of surface surveys, distances were calculated from a representative site in the middle of the surveyed polygon. Given the dominance of PDA, whenever this source did not represent 100% of the provenance data, the frequency of different types was corrected by a factor of the percentages corresponding to the different sources based on the ICP-MS results (Table 3).

Although the difference between Euclidean and LCP distances is fairly constant (average LCP to Euclidean ratio: 1.51, s.d.: 0.13), the results from our analysis suggest that the latter provide a better explanation for the obsidian frequencies in the studied assemblages. The values of the compared correlations indicate that LCP explain 73% ($p < 0.005$) of the variation in obsidian frequencies, whereas linear distances explain only 68% ($p < 0.005$). Thus, both ways of measuring distance result in similar observations. The fall-off curves show that beyond ~100 linear km or ~150 km following LCP routes, obsidian is infrequent, and the decreasing slope changes abruptly. Beyond 200 linear or 300 LCP km, the exponential decline shows that most assemblages comprise obsidian in minimal frequencies (<3%). Only the middle Ibáñez River valley surface survey sample corresponds to a major outlier for this trend. However, two sites in this area are considered to be anomalous, and it should thus be regarded with caution. At RI-41 site only obsidians were recorded and no artifacts on local raw materials were observed, and RI-55 accounts for 35.9% of the obsidian of the entire survey, thus influencing the overall frequency in the middle Ibáñez River valley.

5. Discussion

As in other cases of Andean obsidian artifacts transported by hunter-gatherers, the Patagonian cases indicate that this type of high-quality toolstone was transported beyond the expected spatial scale of home ranges (Cortegoso et al., 2016; Pallo and Borrero, 2015; Rademaker et al., 2012; Stern et al., 2013). When considering the overall representation within the CWP assemblages, obsidian artifacts can only be considered frequent up to ~100 linear km (~150 LCP-km) from the source. Within this range, they comprise 45.3% of the total assemblages on average. Between 100 and 210 linear km (~330 LCP km), the average decreases to 17.8%. Beyond 210 linear km, their frequencies are less than 3% (with a notable exception of Baño Nuevo 1), and they are considered extremely rare. Distances beyond 360 linear km (~490 LCP km) can be suggested as a starting point for the combination of multiple sources, as evidenced by the results presented. Obsidian tool and debitage classes also vary with increasing distance. Close to the source all expected tool and debitage classes are common and the overall number of classes decreases with distance until only the last stages of reduction are observed beyond ~230 linear km from the sources, although exceptions to this pattern are observed.

The first occurrence of obsidian artifacts in each area in CWP is highly variable; however, in the Cisnes and Ñirehuao River valleys, where obsidian types are most diverse, different types occur in the deposits dated to the early Holocene. In the rest of the areas, obsidian appears in association with the first occupations during the middle Holocene. Since there is no major increase in variability over time, especially in northern CWP, these patterns suggest that distance from the source is a more significant factor than time (i.e., age of the knowledge of a source) in explaining the exotic lithic procurement behavior. Only seven sites sampled in this study show dated occupational ranges overlapping the historical period. Though these cases, as well as some surface lithic scatters of undefined chronology (see Supplementary Material Table 1), may have been created in times when the horse was integrated to mobility in eastern Patagonia (Nuevo Delaunay et al., 2017), the contribution of this animal in the distribution of archaeological obsidian patterns in CWP is low given the scarse record attributed to historical times (Mena and Lucero, 2004).

Combining the spatial and temporal information, we have outlined three broad distribution configurations: (a) the absolute dominance of obsidian from the Chaitén Volcano along the Pacific coast and archipelagos since the middle Holocene; (b) the absolute

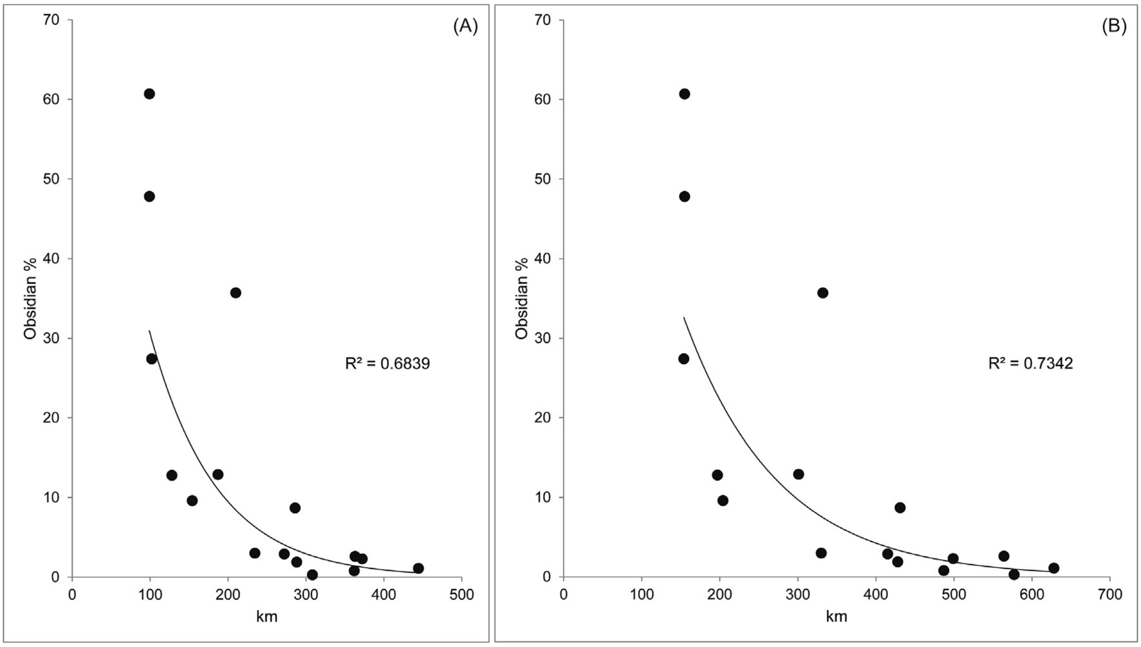

Fig. 7. Plots of (A) Euclidean and (B) LCP distances versus the proportion of obsidian in the assemblages they occur based on data in Table 3.

Table 3
Distances between sources and sampled units for obsidian artifacts in inland CWP and obsidian frequencies; *corrected for obsidians from different sources based on ICP-MS analyses.

	Euclidean distance (lkm) from sources	LCP distance (km) from sources	LCP to Euclidean ratio	Obsidian %	Source frequency
S to Appeleg 1	308	577	1.87	0.3*	S1 23.1%
T/SN to El Chueco 1	444	628	1.41	1.1	T/SN 16.7%
PDA to Appeleg 1	362	487	1.35	0.8*	PDA 69.2%
PDA to El Chueco 1	372	499	1.34	2.3	PDA 33.3%
PDA to Las Quemas	363	564	1.55	2.6*	PDA 66.7%
PDA to Cueva de la Vieja	288	428	1.49	1.9*	PDA 66.7%
PDA to Baño Nuevo 1	286	431	1.51	8.7*	PDA 86.2%
PDA to Punta del Monte cave	272	415	1.52	2.9	PDA 100%
PDA to BAL039 (midpoint upper Simpson)	234	330	1.41	3	PDA 100%
PDA to RI5a (midpoint middle Ibáñez)	210	332	1.58	35.7	PDA 100%
PDA to PAL33 (midpoint lower Ibáñez)	187	301	1.61	12.9	PDA 100%
PDA to RJ28 (midpoint lower Jeinemeni)	154	204	1.32	9.6	PDA 100%
PDA to Los Carneros (midpoint upper Chacabuco)	102	154	1.51	27.4	PDA 100%
PDA to Entrada Baker (exterior)	99	155	1.57	47.8	PDA 100%
PDA to Entrada Baker (interior)	99	155	1.57	60.7	PDA 100%
PDA to Gianella	128	197	1.54	12.8*	PDA 83.3%

dominance of PDA obsidian along the eastern Andean flank south of 45°30′S since the middle Holocene (southern CWP); and (c) a variety of obsidian types also along the Eastern Andean flank north of this boundary throughout the Holocene (northern CWP). This distribution is explained by the presence of the densely forested, north-south-oriented Andean mountain range with ice fields, which acted as a biogeographical barrier that exert major influences on hunter-gatherer movement along the western channels and along the forest steppe ecotone and the steppe plains (Méndez and Reyes, 2008). Though obsidian is a chief argument supporting this pattern, the location and distribution of sites, chronological patterns, artifact design, and debitage size independently support this (Méndez et al., 2008–9, 2016a,b; Reyes et al., 2007, 2015). Along the eastern Andean slope, differences are explained by increasing distances from the PDA source and the role of alternative sources in northern CWP.

The south-to-north diminishing pattern of obsidian frequency and variability in tool and debitage classes along the eastern Andean flank of CWP is explained by the paramount role that PDA obsidian played in Southern Patagonia and adjacent areas (Fernández et al., 2015; Stern, 2017). The area parallel to the eastern Andean flank can be considered one of the main vectors of movement through the steppe, which is confirmed by the LCP analysis. The routes outlined here indicate that the transport of obsidian artifacts occurred across the steppe, an area where hunter-gatherers dwelled more repeatedly and intensely, and not through a connection between different valleys in CWP. This conclusion lends support to the idea that Andean valleys in CWP acted as "dead ends" or marginal areas in a geographical sense and were occupied in connection to more populated cores in the eastern steppes (Borrero, 2004).

Larger distances, plus the equidistant presence of alternative sources, such as T/SN, S, and AB, resulted in a wider diversity in obsidian use in the Cisnes River valley, the northernmost area of CWP. It is now clear that the presence of local low-quality CIS obsidian in this valley had a role in the development of localized (<100 linear km) circuits of transport, which included Ñirehuao and Aldea Beleiro since the early Holocene (Castro Esnal et al., 2017; Méndez et al., 2017). These sites can be considered within the spatial scale of expected hunter-gatherer home ranges (Borrero and Barberena, 2006). The results also suggest that minor quality/quantity sources, such as CIS or AB (Bellelli et al., 2006), provide information on complementary toolstone transport along a second, less-important, north-to-south vector of mobility along the eastern flank of the Andes.

The interpretation of fall-off curves has been used to assess the different mechanisms of resource acquisition in archaeology (e.g., Renfrew, 1977; Pallo and Borrero, 2015). Although linear distances have been used far more in the discussion of obsidian transport (e.g., Méndez, 2004), LCP analysis provides more likely procurement routes that can be used to construct hypotheses of the use of space and its resources (Cortegoso et al., 2016). We presented decline frequencies of obsidians using data from sixteen assemblages at various distances from different sources. These values indicate significant changes due to an exponential decrease at 100 linear km or ~150 LCP km from the obsidian sources. Based on a broader-scale assessment, Pallo and Borrero (2015) have recently proposed that the fall-off limit corresponds to the most probable radial distance to where direct procurement was confined during the late Holocene in continental Patagonia south of 45°S. The sharp decrease in obsidian proportions beyond ~150 km was suggested to be the product of incidental transport, probably attributable to objects moving along hunter-gatherers in a visiting regime or another mechanism characteristic of open-social formations (Pallo and Borrero, 2015). Cases for systematic exchange, expected to be associated with the occurrence of considerable amounts of exotic material over long distances, have not been recorded in CWP or elsewhere in Patagonia; thus, it should not be regarded as a primary mechanism for exotic toolstone acquisition.

In the case of southern CWP, the absolute dominance of a high-quality and highly abundant source, (i.e., PDA), constrained alternative choices for high-quality toolstone procurement over long distances. This area has also been described as a source for high-quality siliceous toolstones, factor that should be considered in the overall sum of arguments for its dominance in procurement strategies (Espinosa and Goñi, 1999). The remarkably high obsidian frequencies in some sites, such as the Entrada Baker rockshelter, and the diversity in tool and debitage classes represented suggest occupants of the upper Chacabuco River valley may have applied direct procurement strategies in obsidian acquisition. As such, they must have participated in year-round seasonal mobility circuits that included areas in the eastern steppes and the forest steppe ecotone of the southern part of CWP (Méndez et al., 2003; Méndez and Velásquez, 2005). Beyond this area, the transport of obsidian must have occurred mainly as part of the personal equipment of hunter-gatherers and were obtained through a visiting a regime,

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sporadic (non-systematic) exchange or other mechanisms. Heavily curated artifacts and late-stage debitage, most likely related to tool resharpening, indicate obsidian was transported over the course of long use-lives (Shott, 1989).

6. Conclusions

The systematic sampling of obsidian artifacts for ICP-MS analyses at a regional scale has been used to discuss the spatial and temporal dimensions of obsidian procurement among hunter-gatherers throughout the Holocene in CWP. In this paper, we combined these data with technological information from the assemblages from which the samples were obtained to address some of the following issues:

(1) The first evidence for obsidian use in inland CWP occurs between one to two millennia after the first human presence, which was recorded at 12,000 cal BP in the Cueva de la Vieja site in the Ñirehuao River valley (Méndez et al., 2017). Along the Pacific coast and archipelagos, the first human presence at 6000 cal BP recorded in GUA-10 site is associated with an assemblage containing obsidian (Reyes et al., 2017).

(2) By almost doubling the size of the obsidian samples with ICP-MS data from earlier work, the broad obsidian distributional trends described were confirmed (Méndez et al., 2008–9, 2012). This is particularly true regarding the suggested role of the Andean mountain range as a biogeographical barrier that separated obsidian circulation patterns along the coast and archipelagos (CH obsidian) from those occurring along the eastern flank and the steppes of CWP (all other obsidian types discussed) (Méndez and Reyes, 2008; Méndez et al., 2008–9). The fact that no obsidian from either side of the Andes has been recorded on the opposite flank at this latitude (see Supplementary Material Kmz File) lends further support to the idea that CH obsidian along the southern Atlantic and in the Pali Aike volcanic field must have been transported through the southernmost part of the continent (Stern et al., 2012).

(3) Obsidian procurement and use patterns on the coast were dominated exclusively by the CH source, while on the eastern Andean flank of CWP 86% of the sampled obsidian artifacts were obtained from the PDA source.

We reached the following conclusions regarding the eastern Andean flank:

(4) We recorded an absolute dominance of PDA south of 45°30′S (southern CWP) and at linear distances of <280 km (<420 LCP km), while more variability prevailed north of 45°30′S (northern CWP). These two areas have also been observed to exhibit different temporal trends throughout the Holocene based on the radiocarbon data (Méndez et al., 2016a).

(5) No significant increase in source selection or diversification was recorded during the Holocene. By the early Holocene, artifacts of all three subtypes of PDA, T/SN and CIS, plus two unknown sources, were represented in assemblages in northern CWP where variability prevailed.

(6) The main driver for obsidian procurement in CWP thus seems to be the distance from the source rather than the antiquity of its knowledge, given that sources at equivalent distances show similar patterns both in quantitative and qualitative dimensions (e.g., PDA vs. T/SN in the Cisnes River valley).

(7) The main vector of human movement, as suggested by the obsidian geochemical data and LCP analysis, is south-to-north and through the extra-Andean steppe, although other minor circuits in northern CWP have been preliminarily recognized.

(8) The data discussed here also suggest that once a procurement route was established, it was likely maintained over time since most sources were exploited since the initial occupations of different areas.

The interpreted behavior of obsidian at the regional scale is suggestive of direct procurement patterns at distances of less than 100 linear km or within the areas closest to the PDA obsidian source in southern CWP. The abrupt decrease in the fall-off curve and the remarkably small amounts of obsidian in the studied assemblages are not indicative of systematic exchange at distant locations; rather, the patterns beyond this threshold are better explained by heavily curated obsidian artifacts transported in the personal toolkits of hunter-gatherers involved in sporadic visits or other mechanisms.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2017.08.062.

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