Quaternary International 375 (2015) 44–54

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Geochemical analysis of obsidian from archaeological sites in northwestern Santa Cruz Province, Argentine Patagonia

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ARTICLE INFO

Article history:
Available online 1 December 2014

Keywords:
Obsidian
Geochemical analysis
NW Santa Cruz
Argentina
Patagonia

ABSTRACT

Obsidian raw material has been widely used in central and southern Patagonia from the beginning of the occupation of this region. In NW Santa Cruz province, Argentina, the geochemical analyses published to date suggest that Pampa del Asador was the main obsidian source. However, both the spatial and temporal limits of the distribution of obsidians from this and other sources in the region remain undefined. The principal goal of this article is to characterize obsidian artifacts from archaeological sites, located in a portion of NW Santa Cruz, from which there is no available geochemical information. ICP-MS analyses were obtained for 49 obsidian artifacts recovered from 24 excavated rockshelters and open-air surface scatters. The results indicate that all the samples of black obsidian came from the Pampa del Asador source, located ~90–160 km to the south. Two samples of grey obsidian discovered on the top of Meseta del Lago Buenos Aires are chemically different from any other archeological obsidian yet analyzed in southern Patagonia. Their origin is still unknown, but they are most likely derived from a local Meseta del Lago Buenos Aires obsidian source. These results contribute to the knowledge about the use of obsidian in NW Santa Cruz, and provide constraints on the communication and material exchange between different environments and basins in this region.

1. Introduction

Obsidian is an excellent material for tool-making as its conchoidal fracture results in extremely sharp edges. For this reason, in the past, it has been transported long distances from sources in different regions of the world. Different obsidians can be identified and their provenience distinguished through geochemical analysis. With this technique, the identification of the presence of obsidians from specific sources in archaeological sites makes it possible to explore variations, over different time intervals, in the indigenous use of it and the role it played in social exchange networks, among other relevant topics.

In central and southern Patagonia (Fig. 1A) obsidian raw material has been widely used from the beginning of the occupation – at >10,000 BP – of many sites studied in this region (e.g. Gradín et al., 1979; Aschero, 1981–1982; Mena and Jackson, 1991; Stern, 1999, 2004a; Civalero, 2009; Méndez et al., 2012). In Santa Cruz province, Argentine Patagonia, geochemical analyses carried out to date for obsidian samples from archaeological sites indicate that multiple sources were used to procure this raw material. The identified provenience sites include: Volcán Chaitén (X Región, Chile), Pampa del Asador (Santa Cruz), Cordillera Baguales (Santa Cruz) and Seno de Otway (XII Región, Chile) (Fig. 1A; Stern, 1999, 2004a; Fernández and Leal, 2014).

In NW Santa Cruz province, the few geochemical analyses published to date from archaeological sites suggest that Pampa del Asador (PDA) is their main source (e.g., Stern, 1999, 2004a). However, the spatial and temporal limits and extent of the distribution and circulation of this obsidian remain undefined. This is because analysis of the obsidian used in all the archaeological sites in the region have not yet been carried out and also because in some cases chronologies associated with the use of this raw material are not available. Therefore, the principal goal of this article is to characterize the obsidian from archaeological sites located in a portion of NW Santa Cruz, Argentina, from which there is no previously

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http://dx.doi.org/10.1016/j.quaint.2014.11.013

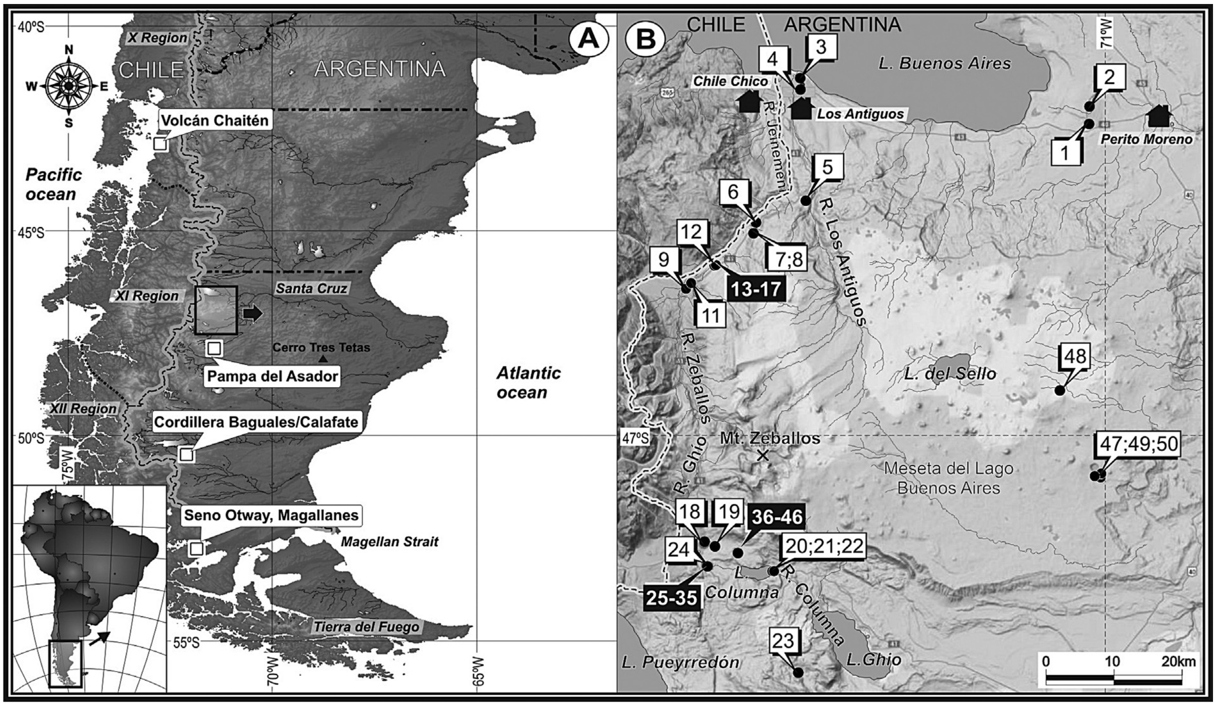

Fig. 1. A) Location of Patagonia obsidian sources, B) Samples per archaeological site in the study area. White squares indicate open air sites. Black squares indicate samples from rockshelter stratigraphic sites. The number inside each square refers to the sample code (Tables 1 and 2).

available geochemical information. With this information we analyze what sources have been used at different time periods, in different portions of the study area, and on this basis discuss possible circulation patterns of this raw material.

The study area in NW Santa Cruz (Fig. 1B) has been proposed as a natural corridor limited by the Andean Range (Chile) on the west and the western edge of the Meseta del Lago Buenos Aires and Mt. Zeballos (Argentina) on the east (Figuerero Torres and Mengoni Goñalons, 2010). This corridor links two major lake basins: lake Buenos Aires in the north and lakes Pueyrredón-Posadas in the south (Fig. 1B). Also, this circulation zone connects the steppe, forest and forest-steppe ecotones, which change according to the gradient of precipitation that increases significantly to the west and decreases eastward over a relatively short distance of only 20 km on average. Finally, throughout this area, the territories extending west to the Pacific are relatively easy to access (Figuerero Torres and Mengoni Goñalons, 2010). Recent publications have provided background information concerning the history and occupation dynamics of this portion of Patagonia (e.g., Figuerero Torres and Mengoni Goñalons, 2010; Mengoni Goñalons et al., 2013). The chronology so far places the earliest occupation detected at 6120 BP and the presence of indigenous people has continued into historic times to the present (Fernández, 2013; Mengoni Goñalons et al., 2013; San Martín, 2013).

Until now, it has been assumed that the obsidian used in the study area came from PDA because it is the closest and most accessible source (e.g., Fernández, 2013) and was the main source in other archaeological areas around the study area (e.g., Stern, 2004a). However, obsidian geochemical analyses have not yet been carried out in this specific portion of NW Santa Cruz. Not knowing the source or sources of this raw material leaves it unexplained if native people used more than one source, from when the different possible sources were used, and whether the presence of a particular type of obsidian is ubiquitous or if distribution is directed towards any particular portion of the space, especially in view of the potential communication that this study area has with different environments and basins.

This paper presents geochemical data which characterizes 49 obsidian samples from 24 sites in NW Santa Cruz in order to determine their probable origin (Fig. 1B; Tables 1 and 2). The sites include both excavated rock shelters with chronologies and open-air surface scatters, and are located in the valleys of Los Antiguos, Jeinemeni, Zeballos and Ghío-Columna rivers, along the southern coast of Buenos Aires lake, and on the Meseta del Lago Buenos Aires plateau (Fig. 1B). The geochemical results are compared with published obsidian analysis from other areas of central and southern Patagonia to determine their provenience (Stern, 1999, 2004a). With these results, we have a better understanding of how past populations used the obsidian resources, and are in a better position to contrast this new information with the previous lithic artifact technological analyses, and thereby identify possible circulation pathways and/or exchange circuits.

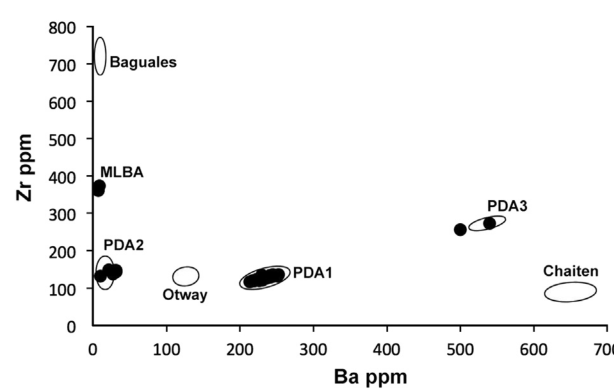

Fig. 2. Graph of parts-per-million (ppm) Ba vs. Zr contents of the different types of obsidians from NW Santa Cruz (solid circles; Table 3; PDA-Pampa del Asador; MLBA = Meseta del Lago Buenos Aires). Fields for PDA1, 2 and 3, Baguales, Otway and Chaiten are the 2sigma ranges from previously published data (Table 4; Stern, 1999, 2004a,b; Stern et al., 2012).

Table 1
Samples from the northern section of the study area: provenance sites, kind of context, chronology, lithic and obsidian frequency, obsidian proportions and type of identified obsidian. Radiocarbon dates from Mengoni Goñalons et al. (2013).

Sample code	Site	Context	^{14}C y BP	N lithic	N obsidian					Obsidian type
					Total (%)	Tools (%)	Cores (%)	Flakes (%)	Cortex flakes (%)	
1	Bloques Erráticos	Surface	–	8	1 (12.5)	0	0	1 (100)	0	PDA1
2	Los Manantiales I	Surface	–	134	29 (21.6)	4 (13.8)	1 (3.4)	24 (82.8)	8 (33.3)	PDA1
3	Chacra Messina, lote 10	Surface	–	1	1 (100)	0	0	1 (100)	0	PDA1
4	Los Antiguos, Usina - 378	Surface	–	59	33 (55.9)	1 (3.0)	0	32 (97.0)	4 (12.5)	PDA1
5	El Refugio talud	Surface	–	6	33.3	–	–	–	–	PDA1
6	Toscas Bayas talud	Surface	–	12	2 (16.7)	1 (50.0)	0	1 (50.0)	0	PDA1
7	Los Moscos 1, Transecta 3	Surface	–	76	13.1	–	–	–	–	PDA1
8	Mallín Álvarez	Surface	–	33	3 (9.1)	0	0	3 (100)	3 (100)	PDA1
9	Río Zeballos II	Surface	–	180	3 (1.6)	0	0	3 (100)	1 (33.3)	PDA1
11	Alero Mauricio I Jeinemeni-Confluencia	Surface	–	1	1 (100)	0	0	1 (100)	1 (100)	PDA1
12	Alero Mauricio II, talud, transecta tramo 4	Surface	–	78	13 (16.7)	–	–	–	–	PDA2
13	Alero Mauricio II	Layer 9 (1) quadrant 1	930 ± 40 (UGAMS-01297)	48	10 (20.8)	1 (10.0)	0	9 (90.0)	1 (11.1)	PDA2
14	Alero Mauricio II	Layer 9 (3) quadrant 2	1000 ± 40 (UGAMS-01298)	208	17 (8.2)	0	0	17 (100)	2 (11.8)	PDA1
15	Alero Mauricio II	Layer 10 (1) quadrant 2	2590 ± 25 (UGAMS-3175)	183	21 (11.5)	0	0	21 (100)	1 (4.8)	PDA2
16	Alero Mauricio II	Layer 10 (1) quadrant 1	2590 ± 25 (UGAMS-3175)	223	27 (12.1)	0	0	27 (100)	7 (25.9)	PDA1
17	Alero Mauricio II	Layer 10 (2) quadrant 2	–	70	10 (14.3)	0	0	10 (100)	1 (10.0)	PDA1

Table 2
Samples from the southern section of the study area: provenance sites, kind of context, chronology, lithic and obsidian frequency, obsidian proportions and type of identified obsidian. Radiocarbon dates from Mengoni Goñalons et al. (2013).

Sample code	Site	Context	^{14}C y BP	N lithic	N obsidian					Obsidian type
					Total (%)	Tools (%)	Cores (%)	Flakes (%)	Cortex flakes (%)	
18	Cerro Bayo II	Surface	–	21	3 (14.3)	1 (33.3)	0	2 (66.7)	1 (50.0)	PDA1
19	Los Cóndores I	Surface	–	60	17 (28.3)	5 (29.4)	0	12 (70.6)	6 (50.0)	PDA1
20	Lago Columna II	Surface	–	67	24 (35.8)	6 (25.0)	1 (4.2)	17 (70.8)	9 (52.9)	PDA3
21	Lago Columna II	Surface	–	67	24 (35.8)	6 (25.0)	1 (4.2)	17 (70.8)	9 (52.9)	PDA1
22	Transecta Columna III	Surface	–	30	7 (23.3)	1 (14.3)	0	6 (85.7)	4 (66.7)	PDA1
23	La Misteriosa	Surface	–	10	2 (20.0)	1 (50.0)	0	1 (50.0)	0	PDA1
24	Sol de Mayo 1, talud	Surface	–	63	27 (42.8)	–	–	–	–	PDA1
25	Sol de Mayo 1	Layer 1 and 2	–	107	75 (69.1)	1 (1.3)	0	74 (98.7)	11 (14.9)	PDA1
26	Sol de Mayo 1	Layer 3	370 ± 25 (UGAMS-3176)	573	340 (59.3)	4 (1.2)	0	336 (98.8))	27 (8.0)	PDA1
27	Sol de Mayo 1	Layer 4	1060 ± 30 (UGAMS-3705)	1497	776 (51.8)	6 (0.8)	1 (0.1)	769 (99.1)	53 (6.9)	PDA1
28	Sol de Mayo 1	Layer 5	1210 ± 30 (UGAMS-3706)	428	159 (37.1)	2 (1.3)	3 (1.9)	154 (96.8)	24 (15.6)	PDA1
29	Sol de Mayo 1	Layer 6	2790 ± 25 (UGAMS-3176)	220	67 (30.5)	1 (1.5)	1 (1.5)	65 (97.0)	13 (20)	PDA1
30	Sol de Mayo 1	Layer 7 (1)	2960 ± 25 (UGAMS-7604)	617	246 (39.9)	4 (1.6)	4 (1.6)	238 (96.8)	61 (25.6)	PDA1
31	Sol de Mayo 1	Layer 7 (2)	3200 ± 30 (UGAMS-5031)	174	57 (32.8)	2 (3.5)	0	55 (96.5)	19 (34.5)	PDA1
32	Sol de Mayo 1	Layer 8 (1)	–	136	37 (27.2)	4 (10.8)	0	33 (89.2)	4 (12.1)	PDA2
33	Sol de Mayo 1	Layer 8 (5)	–	193	136 (70.5)	0	0	136 (100)	2 (1.5)	PDA1
34	Sol de Mayo 1	Layer 8 (6)	6120 ± 30 (UGAMS-8762)	463	371 (80.1)	1	0	370 (99.7)	9 (2.4)	PDA2
35	Sol de Mayo 1	Layer 8 (7)	–	221	199 (90.0)	0	0	199 (100)	3 (1.5)	PDA1
36	Colmillo Sur 1	Layer 2	–	103	23 (22.3)	3 (13.0)	0	20 (87.0)	–	PDA1
37	Colmillo Sur 1	Layer 3	–	585	174 (29.7)	4 (2.3)	1 (0.6)	169 (97.1)	–	PDA1
38	Colmillo Sur 1	Layer 4 (2)	2209 ± 58 (UGAMS-00935)	763	228 (29.9)	6 (2.6)	1 (0.4)	221 (96.9)	–	PDA1
39	Colmillo Sur 1	Layer 4 (2)	2209 ± 58 (UGAMS-00935)	763	228 (29.9)	6 (2.6)	1 (0.4)	221 (96.9)	–	PDA1
40	Colmillo Sur 1	Layer 4 (3)	–	799	202 (25.3)	3 (1.5)	1 (0.5)	198 (98.0)	–	PDA3
41	Colmillo Sur 1	Layer 4 (4)	–	668	181 (27.1)	1 (0.6)	0	180 (99.4)	–	PDA1
42	Colmillo Sur 1	Layer 5 (1)	3160 ± 25 (UGAMS-8761)	593	193 (32.5)	2 (1.0)	1 (0.5)	190 (98.5)	–	PDA1
43	Colmillo Sur 1	Layer 5 (2)	–	599	165 (27.5)	2 (1.2)	0	163 (98.8)	–	PDA2
44	Colmillo Sur 1	Layer 5 (3)	–	454	122 (26.9)	5 (4.1)	0	117 (95.9)	–	PDA1
45	Colmillo Sur 1	Layer 6 (1)	–	442	119 (26.9)	1 (0.8)	1 (0.8)	117 (98.3)	–	PDA1
46	Colmillo Sur 1	Layer 6 (2)	–	279	81 (29.0)	0	0	81 (100)	–	PDA1
47	Meseta Lago Buenos Aires, P2	Surface	–	–	–	–	–	–	–	Unknown
48	Meseta Lago Buenos Aires, P6	Surface	–	–	–	–	–	–	–	PDA1
49	Meseta Lago Buenos Aires, P4	Surface	–	–	–	–	–	–	–	Unknown
50	Meseta Lago Buenos Aires, P1	Surface	–	–	–	–	–	–	–	PDA2

2. Obsidian sources

From previous geochemical analyses of obsidian artifacts, it was concluded that the sources that the Santa Cruz inhabitants exploited correspond to Volcán Chaitén (e.g., Cruz et al., 2011; Stern et al., 2012), Pampa del Asador (e.g., Stern, 2004a), Cordillera Baguales (e.g., Stern and Franco, 2000) and Seno de Otway (e.g., Stern and Prieto, 1991; Fig. 1A). We describe these four sources below because they are those that were used by the inhabitants of Santa Cruz province in the past. These sources are known to have been exploited by the occupants of archaeological sites not only in Santa Cruz, but also in Tierra del Fuego (Argentina and Chile) and in the XI and XII Regions of southern Chile. The obsidians from these four sources are visually (Fernández and Leal, 2014) and geochemical distinct (Fig. 2; Stern, 2004a). We briefly describe below the main characteristics of each of these sources, from north to south, and summarize their presence in the archaeological record to provide a complete setting of obsidian availability and use in this area of Patagonia.

2.1. Volcán Chaitén (42°50′S; 72°40′W)

Volcán Chaitén is located on the western margin of the Andean Cordillera, in X region of Chile, west of the drainage divide that separates Chile from Argentina (Fig. 1A). This volcano is associated with arc volcanism involving oceanic plate subduction (Stern, 2004b; Bellelli et al., 2006). The Chaitén volcano is a rhyolitic dome within a collapsed caldera located on the west flank of the much larger Michinmahuida volcano, northeast of the town of Chaitén (López-Escobar et al., 1993; Naranjo and Stern, 2004; Stern et al., 2007). The calc-alkaline obsidian from Chaitén was first geochemically characterized by López-Escobar et al. (1993) and has been constrained in age as <0.1 Ma (Stern, 2004a). It was most likely derived from the rhyolite dome that formed within the volcano's crater during the last large pre-historic eruption *ca.*10,000 BP (Naranjo and Stern, 2004). This pre-historic dome was destroyed in a new eruption that began in May 2008 (Major and Lara, 2013), and has now been totally replaced by a new rhyolite dome with very similar chemical attributes. Optically, this rhyolite obsidian is translucent grey, with banded textures of variable thickness. Its most conspicuous feature is the presence of feldspar and quartz as phenocrysts (Fernández and Leal, 2014).

This rhyolite obsidian has been identified in archaeological sites by Stern and Porter (1991), Stern and Curry (1995), Stern et al. (2002, 2012), Bellelli et al. (2006), Reyes et al. (2007) and Cruz et al. (2011), and is found in high densities in coastal sites, occupied by groups that utilized canoes to support a marine based economy, located as far as 400 km to the north and south of this source (Stern and Curry, 1995; Stern et al., 2002; Reyes et al., 2007). In these kinds of contexts, Volcán Chaitén obsidian occurs in occupational levels as old as 5610 BP (Stern et al., 2002; Stern, 2004a). It has not been found at similar latitudes to the volcano in terrestrial hunter–gatherer sites east of the Andean drainage divide in Argentina. Recently, however, archaeological materials made with this obsidian have been identified as far as 1000 km southeast of the source, on the southeastern Atlantic coast, south of the Santa Cruz river and near the Magellan Strait at sites in the Monte León National Park and Pali Aike volcanic field (Cruz et al., 2011; Stern et al., 2012).

2.2. Pampa del Asador (47°53′S; 71°19′W)

Pampa del Asador is located in Argentina, Santa Cruz province, and is part of the fluvial–glacial sedimentary plateaus of the pampas of Patagonia (Ramos and Kay, 1992; Fig. 1A), within which metaluminous obsidian pebbles occur (Espinosa and Goñi, 1999). Samples of this obsidian are found concentrated in the creeks that cut the plateau and in small drainage basins on the plateau (Stern, 1999; Belardi et al., 2006). This obsidian has also been carried down by numerous drainage channels to areas of the pampas with lower elevation southeast of Pampa del Asador. The general distribution suggests that the primary source is located within the Patagonian plateau lavas of Meseta del Águila, west of Pampa del Asador, but this primary source either no longer exists or has not been found. Some samples have been dated in a range of 4.9–6.4 Ma (Stern, 1999, 2004a), which coincides with the formation of some basaltic plateau lavas from Meseta del Águila area (Ramos and Kay, 1992). At least three chemically different types of obsidian (PDA1, PDA2 and PDA3; Figs. 2 and 3) have been described from Pampa del Asador (Stern, 1999, 2004a; García-Herbst et al., 2007).

This obsidian is present in the form of rounded black to translucent grey pebbles and cobbles up to 20 cm in diameter with a brown or gray weathering/alteration surface a few millimeters thick (Fernández and Leal, 2014). Although most samples present massive homogeneous textures, banding also frequently occur (Fernández and Leal, 2014). Chemical types PDA1 and PDA2 are crystal free and indistinguishable visually (e.g., Stern, 2004a). Small crystals of plagioclase feldspar occur in chemical type PDA3 so it does not fracture as well as the two crystal-free obsidian types (e.g., Stern, 2004a). The presence of obsidian with crystals is less common among the geologic pebbles and cobbles of obsidian found around Pampa del Asador (Fig. 3; Stern, 1999; Fernández and Leal, 2014).

In terms of archaeological representation, samples from the Pampa del Asador source are widely distributed in south-central Patagonia in space and time. Artifacts of this obsidian have been found 800 km to the northeast from the source, as far as Valdés Peninsula (Stern et al., 2000, 2013; Stern, 2004a), or 600 km south along the Magellan Strait and further south on Tierra del Fuego (Stern et al., 1995a, 1995b; Stern, 2004a; Morello et al., 2012). This glass has been used in some archaeological sites since at least 10,260 BP (Stern, 2004a). This is the case for the Cerro Tres Tetas archaeological site, in the central plateau of Santa Cruz, 200 km east from the Pampa del Asador source (Paunero, 2003).

2.3. Cordillera Baguales (50°40′S; 72°15′W)

Geological deposits of this variety of obsidian have not yet been found (Stern and Franco, 2000). This peralkaline obsidian to date has only been identified on the basis of geochemical analyses of archaeological artifacts. The age of this obsidian is constrained around 2.3 Ma, similar to the basaltic lavas of the Vizcachas plateau

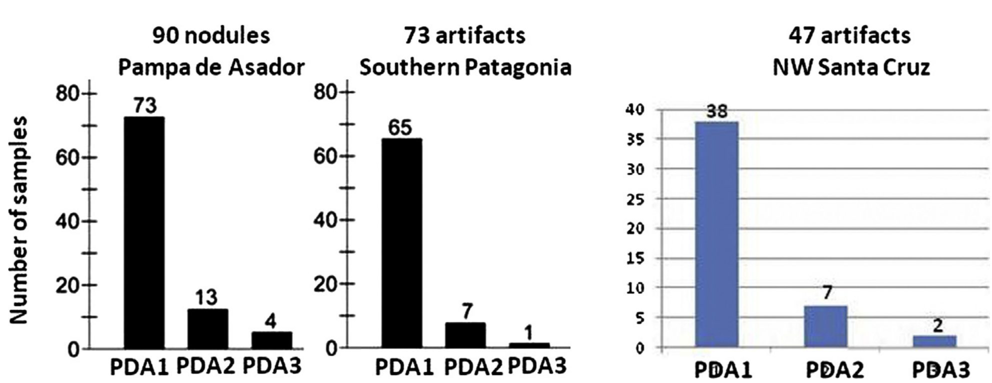

Fig. 3. Histograms of the observed frequency of each type of obsidian (PDA1, PDA2 and PDA3) in three different groups: a random collection of 90 samples of geologic obsidian nodules from Pampa del Asador source area (Stern, 1999), 73 samples of obsidian artifacts previously analyzed from other areas of southern Patagonia (Stern, 1999) and 49 samples from Los Antiguos-Paso Roballos area in NW Santa Cruz.

and Cordillera Baguales range in the upper Santa Cruz river basin. The most remarkable feature is the banded light gray to greenish color. Thin sections of this glass present dark bands of about 0.1 and 0.9 mm inside a colourless background (Fernández and Leal, 2014).

The known distribution of the analyzed fragments is along the southern and eastern edge of Argentino lake, in the upper Santa Cruz river basin and near the Atlantic coast (Stern and Franco, 2000; Fig. 1A). Their proportion in the archaeological assemblages increases towards the Cordillera Baguales range (Stern and Franco, 2000). In Pali Aike and Cueva Fell archaeological localities, this obsidian is present from 8500 to 6500 BP (Stern, 2000, 2004a,b). In the Pali Aike area this obsidian is the most abundant compared to other obsidian types and its use persists until historic times (Charlin, 2009).

2.4. Seno de Otway (52°50′40″S; 71°56′00″W)

The geological source of this obsidian is still unknown. Its age of about 17.1 Ma (Stern and Prieto, 1991; Morello et al., 2001; San Román and Prieto, 2004) and its Sr isotopic composition suggest a relationship between Seno de Otway obsidian and the southern Andean Miocene magmatic belt that includes the Fitz Roy and Torres del Paine massifs, as well as volcanic rocks exposed to both north and south of the Otway sea (Stern and Prieto, 1991; Morello et al., 2001; San Román and Prieto, 2004). This obsidian occurs as individual dark green, or less commonly dark grey, fragments (Stern and Prieto, 1991; San Román and Prieto, 2004). It also presents banding textures composed of colourless and greenish glass, as well as some minor devitrification textures (Fernández and Leal, 2014).

This type of hydrated calc-alkaline obsidian has also been identified solely from the analysis of artifacts found in both coastal maritime archaeological sites around the Otway Sea, the Magellan Strait and Tierra del Fuego (Fig. 1A), and, in smaller amounts, in terrestrial hunter–gatherer sites in the Magellanic region (Stern and Prieto, 1991; Stern, 2000, 2004a; Morello et al., 2001, 2012). Its frequency in archaeological sites increases towards the Otway Sea area (Stern and Prieto, 1991; Morello et al., 2001). Samples from the Cueva Fell and Pali-Aike terrestrial hunter–gatherer sites indicate that Seno de Otway obsidian was used, at least, for the last 8500 years (San Román and Prieto, 2004; Stern, 2004a; Prieto et al., 2013).

3. Studied localities and samples analyzed

The study area has been divided into sections encompassing two independent river basins (Fig. 1B). The northern section includes the Los Antiguos and Jeinemeni-Zeballos river valleys and the southern coast of lake Buenos Aires. The southern section contains the Ghío-Columna rivers that successively drain into lake Columna and lake Ghío. The Meseta del Lago Buenos Aires has been divided according the direction of the main draining system into northern and southern portions. The Laguna del Sello (Fig. 1B) is the division point, so all the samples from the meseta analyzed in this work were found in the southern section.

The three stratified archaeological sites from which analyzed obsidian artifacts come from are: Alero Mauricio II, Alero Sol de Mayo I and Alero Colmillo Sur I (Figuerero Torres and Mengoni Goñalons, 2010; Mengoni Goñalons et al., 2013). Alero Mauricio II (AMII hereafter, 46°47′S, 71°48′ W, altitude: 670 m) is located in the north section of the study area in a forest-steppe ecotone environment (Fig. 1B, black square with samples number 13–17). The rockshelter is 18 m by 3 m with NW exposure. It was occupied over the last three millennia (Mengoni Goñalons et al., 2013) and contains eleven layers whose combined thickness is 200 cm. Cultural evidence is concentrated in layers 6–10, with available dates coming from the layers 9 and 10 (Table 1). Layer 11 is a non-basaltic volcanic impure ash, most probably derived from the Hudson volcano (Stern, unpublished data).

Alero Sol de Mayo I (SMI hereafter, 47°47′S, 71°48′W, altitude: 660 m) is located in the south section of the study area in an arid steppe environment (Fig. 1B, black square with samples number 25–35). This rockshelter was formed at the foot of an outcrop of El Quemado volcanic complex. Some fallen blocks shaped a shelter of 100 linear meters, with exposure to the NW. Eight layers were identified whose combined thickness is 190 cm. Archaeological materials were recovered in all layers except at the base of the lower layer composed of weathered wall rock. The radiocarbon dates range from the 6100 BP (the earliest date in the study area) until historic times (Fernández, 2013; Mengoni Goñalons et al., 2013; Table 2).

Alero Colmillo Sur I (CSI hereafter, 47°10′S, 71°45′ W, altitude: 730 m) (Fig. 1B, black square with samples numbers 36–46) is also located in a steppe environment, on a rockshelter formed at the foot of an outcrop that frames a canyon that runs N–S, south of the mountain of the same name. This provides a shelter of 10 m with W exposure. Six natural layers have been identified. The depth reached is 120 cm, but this excavation has not yet reached the lowest occupational level of this shelter. Layers 2–6 include archaeological materials and were dated from ca. 3100 until ca. 1200 BP (Mengoni Goñalons et al., 2013; Table 2). The amount of obsidian cortex flakes present in this site has not yet been calculated (Table 2).

The twenty-one open air surface sites are located in both sections of the study area (Fig. 1B, white squares with sample number; Tables 1 and 2) and their topographical contexts show a great variety. All the south section surface sites are located in an arid steppe environment. The north section surface sites are in a forest-steppe environment, except the provenance sites of samples #1 and #2, in Buenos Aires lake head steppe environment (Fig. 1 B). We use the term “site” to refer to the field location of the artifacts, whether isolated or in concentrations (*sensu* Beck and Jones, 1994). The sampling methodology for these kind of sites varied over the years between targeted samples and random sampling. Materials were collected from these sites in the period 2005–2010 and since 2011 we have employed a methodology for *in situ* analysis of materials, collecting only some specimens of interest to test in the laboratory (Fernández and Rocco, 2013).

In all of these sites, we found different proportions of obsidian (Tables 1 and 2, sixth column). We have consigned the obsidian percentage of each site to see if differences exist between both sections which might reflect the distance to the potential source, between open air surface sites and stratified sites, and between different dated occupations in stratified sites to explore its use through time. We also registered the obsidian percentage of tools, cores and flakes in each site, as well as the percentage of flakes with cortex residuals (Tables 1 and 2). In a few of the sites, the analysis of the proportion of each kind of obsidian artifacts is still being carried out (sites of samples #5, #7, #12, in northern section, and #24, in southern section; Tables 1 and 2). The amount of lithic material and obsidian percentage for the recently collected archaeological samples from Meseta del Lago Buenos Aires has not yet been calculated (Table 2).

4. Methods

We analyzed 49 obsidian archaeological flakes from all of these stratigraphic and open air surface sites (Tables 1 and 2). We selected at least one sample from each layer or site and we preferred those with macroscopic differences. Finally, we selected those samples equal to or greater than 1 g. All the selected samples except two are macroscopically similar: black and with massive texture. Samples of black obsidian have in some cases reddish banding. Two small samples from the top of Meseta del Lago Buenos Aires (#47 and #49) are distinctive, being grey rather than black.

The samples were powdered in a shatterbox utilizing a tungsten–carbide container, dissolved in a mixture of HF and HCl and analyzed by standard ICP-MS techniques using an ELAN DCR-E instrument in the Laboratory of Environmental and Geologic Sciences at the University of Colorado. Methods for ICP-MS are similar to those described by Briggs (1996). Precision for this analytical technique is generally better than 10% at the 95% confidence level as indicated by repeated analysis of an alkali olivine basalt (VMD), an andesite (AND) and a rhyolite sample (PC1; Saadat and Stern, 2011), and confirmed by the standard deviations of the 38 samples of PDA1 obsidian analyzed in this study (Tables 3 and 4).

5. Results

5.1. Obsidian distribution

In the southern section of the study area the proportion of obsidian is greater than in northern section, both in open air and stratified sites (Tables 1 and 2, sixth column). In the sites located in the southern section, obsidian represents on average 37.8% of the lithic material, while in northern section it only represents on average 17.7% in both kinds of contexts, excluding the sites where only one obsidian artifact was recovered. In SM1 (south section) the proportion of obsidian artifacts is greater at the beginning of the occupation and decreases until 1060 ± 30 BP, when obsidian artifacts show an increase in their proportion, but in a lower magnitude in comparison with earlier layers (Table 2). In CS1, the other stratified site in the southern section, the obsidian proportion is relative constant during all the occupation (Table 2). In general, its proportion is notably lower than in SM1, but if we compare the layers with similar ages, the proportions are almost identical (Table 2). In contrast, AMII (northern section) exhibits lower proportions of obsidian in all the layers (Table 1). Notably, when comparing the layers with similar ages in AMII and SM1 and CS1, the obsidian proportion in AMII is less than the half of the southern section sites (Tables 1 and 2).

In general, flakes are the most abundant type of obsidian artifacts in both kinds of sites (Tables 1 and 2, ninth column). If we exclude the sites with less than 3 artifacts, obsidian flakes represent more than 66% of the obsidian artifacts in northern section sites and this proportion add up to 80% in southern section contexts (Tables 1 and 2). In stratified sites of both sections, flakes represent more than 80% (Tables 1 and 2).

With regard to the tools, in all the sites obsidian was selected to make a wide variety of tools, particularly end-scrapers (Fig. 4k–l) and projectile points (Fig. 4b–j), but also sidescrapers (Fig. 4m) and knives (Fig. 4a). In southern section more tools have been registered, perhaps associated with larger sample size, and therefore a greater variety of tool types (Mengoni Goñalons, 2009; Fernández, 2013).

The principal difference between open air sites and stratified sites is that in the former there are almost no obsidian cores, except for one in the northern section (Tables 1 and 2, eighth column). In the northern stratified site obsidian cores have not been discovered while in the southern stratified sites cores are scarce, but appear in stratigraphic levels both as exhausted (Fig. 4n–p) and sometimes of the bipolar kind (Fig. 4q).

Obsidian flakes with cortex residuals have been observed in both sections (Tables 1 and 2, tenth column). In the northern

Table 3
Full data of geochemical composition of the 49 samples analyzed. (PDA1, 2, 3 = Pampa del Asador1, 2. 3; MLBA = Meseta del Lago Buenos Aires).

Type	PDA1																								
Sample	1	2	3	4	5	6	7	8	9	11	14	16	17	18	19	21	22	23	24	25	26	27	28	29	30
Ti*	722	727	706	781	721	791	820	758	714	806	815	797	849	855	845	845	776	758	887	749	848	782	790	773	795
Mn	283	275	275	293	265	285	293	276	263	278	307	282	298	287	292	284	279	265	302	262	295	275	276	258	271
Rb	197	192	183	200	181	194	200	187	181	193	194	190	197	195	200	194	186	180	201	179	197	187	192	183	189
Sr	36	37	33	37	32	34	35	33	31	33	35	35	37	34	35	34	32	31	35	31	35	33	32	31	32
Y	33	32	32	34	31	33	34	32	31	32	33	33	34	33	34	33	31	31	34	30	33	31	31	30	31
Zr	135	125	123	136	121	127	133	125	122	128	132	128	131	130	134	131	121	120	135	119	131	125	126	120	126
Nb	31	26	25	27	24	26	26	24	23	36	26	25	25	26	25	37	25	23	27	22	25	23	23	22	29
Cs	10.4	10.1	9.8	10.8	9.8	10.1	10.4	9.8	9.4	10.4	10.3	10.0	10.4	10.0	10.4	10.3	9.6	9.2	10.5	9.2	10.0	9.6	9.7	9.3	9.7
Ba	230	233	222	245	219	236	241	226	221	235	246	241	251	242	248	241	231	226	253	217	242	230	229	219	228
Hf	6.0	5.5	5.1	5.6	5.0	5.2	5.4	5.1	4.5	7.7	4.8	5.0	4.9	5.0	5.2	7.4	4.8	4.6	5.0	4.3	5.2	4.4	4.8	4.5	4.4
Pb	20.8	20.6	19.9	21.7	19.0	20.5	20.7	19.7	18.7	20.1	20.5	20.2	20.6	20.4	20.8	20.1	18.8	18.3	20.7	18.5	20.2	19.2	18.9	18.1	18.9
Th	20.0	18.7	17.8	19.1	17.3	18.0	18.5	17.8	16.5	22.1	18.1	17.9	18.6	18.4	18.6	22.3	17.1	16.5	19.1	16.4	18.1	16.8	17.1	16.5	17.1
U	5.7	6.0	5.2	6.2	5.1	5.7	5.6	5.3	5.2	5.2	5.6	5.2	5.5	5.5	5.4	5.8	5.3	5.3	5.9	5.2	5.6	5.5	5.6	5.3	5.7
La	42.3	41.0	38.4	43.1	36.7	39.1	39.4	37.2	35.5	37.0	38.0	37.7	38.6	37.9	39.4	37.9	35.5	35.0	39.3	35.1	38.6	36.1	36.2	34.4	36.3
Ce	80.6	83.6	74.6	85.4	72.6	79.0	78.0	74.9	70.8	73.9	76.8	75.1	77.2	76.9	78.2	75.5	72.1	69.6	77.4	69.2	75.1	72.1	72.2	68.5	71.4
Pr	9.77	9.38	8.79	9.73	8.36	8.76	8.69	8.13	7.76	8.18	8.37	8.35	8.55	8.35	8.75	8.28	7.98	7.83	8.79	7.55	8.26	7.97	8.05	7.54	7.76
Nd	34.6	33.3	30.3	35.1	29.6	31.8	31.3	29.6	28.1	29.9	29.5	30.0	31.0	30.7	30.4	30.4	28.0	28.3	31.7	27.3	30.2	28.7	28.9	28.3	29.3
Sm	7.55	7.45	6.81	7.37	6.29	7.02	6.89	6.38	6.29	6.68	6.87	6.61	7.05	6.81	6.65	6.69	6.21	6.19	6.80	6.07	6.36	6.32	6.62	5.98	6.43
Eu	0.57	0.62	0.52	0.62	0.45	0.49	0.51	0.42	0.41	0.40	0.44	0.41	0.48	0.43	0.43	0.50	0.45	0.43	0.46	0.36	0.40	0.42	0.39	0.44	0.41
Gd	10.00	9.87	9.25	9.84	9.04	9.34	9.65	8.84	8.82	8.78	9.52	9.21	9.18	9.26	9.74	9.25	8.52	8.63	9.68	8.28	9.54	9.03	8.87	8.12	8.94
Tb	1.19	1.18	1.13	1.25	1.07	1.13	1.13	1.07	0.97	1.00	1.08	0.98	1.08	1.04	1.06	1.04	0.92	0.90	1.10	0.89	1.03	0.99	0.99	0.95	0.95
Dy	6.33	6.34	6.16	6.45	5.82	6.11	6.46	5.84	5.55	6.07	6.21	5.89	6.31	6.38	6.22	6.12	5.79	5.65	6.44	5.63	5.86	5.62	5.42	5.32	5.62

(continued on next page)

Table 3 (*continued*)

Type	PDA1																							
Sample	1	2	3	4	5	6	7	8	9	11	14	16	17	18	19	21	22	23	24	25	26	27	28	29	30
Ho	1.22	1.15	1.10	1.24	1.11	1.19	1.20	1.08	1.02	1.10	1.16	1.18	1.13	1.13	1.20	1.07	0.96	1.03	1.17	0.96	1.09	1.06	1.05	0.93	1.03
Er	3.99	3.67	3.62	3.87	3.66	3.50	3.83	3.52	3.54	3.37	3.57	3.57	3.52	3.59	3.50	3.69	3.53	3.27	3.70	3.23	3.80	3.37	3.32	3.29	3.46
Tm	0.50	0.47	0.46	0.51	0.44	0.51	0.43	0.44	0.38	0.42	0.42	0.40	0.42	0.39	0.40	0.46	0.39	0.39	0.45	0.41	0.40	0.37	0.40	0.36	0.40
Yb	3.71	3.29	3.13	3.47	3.20	3.46	3.46	3.36	3.24	3.25	3.16	3.33	3.37	3.18	3.16	3.37	2.93	3.19	3.37	2.98	3.37	3.17	3.25	2.97	2.92
Lu	0.51	0.44	0.45	0.49	0.46	0.45	0.44	0.44	0.37	0.39	0.45	0.43	0.40	0.40	0.43	0.43	0.39	0.38	0.44	0.38	0.40	0.40	0.34	0.33	0.36

Type	PDA1													PDA2							PDA3		MLBA	
Sample	31	33	35	36	37	38	39	41	42	44	45	46	48	12	13	15	32	34	43	50	40	20	47	49
Ti*	771	795	815	840	791	843	752	813	814	818	808	757	778	718	718	692	701	738	691	763	1316	1414	735	710
Mn	271	271	282	281	277	277	262	263	263	256	267	247	254	267	236	227	217	235	200	230	363	394	424	409
Rb	186	187	187	197	190	193	185	180	189	183	188	176	184	244	212	206	201	214	222	219	159	171	231	228
Sr	32	32	33	34	33	34	31	31	32	31	32	30	31	2	5	6	4	5	2	5	59	61	0	0
Y	32	31	31	33	32	33	30	30	31	31	32	29	30	49	43	41	39	41	44	42	26	28	87	87
Zr	125	123	123	129	126	126	119	124	123	120	122	116	121	149	148	143	137	145	132	147	255	273	373	360
Nb	34	23	22	25	24	25	22	33	25	23	23	22	24	36	30	28	28	29	29	29	28	30	173	168
Cs	9.7	9.7	9.5	10.0	9.9	9.7	9.6	9.6	9.6	9.2	9.7	8.8	9.1	13.3	11.5	11.0	10.7	11.2	11.8	11.5	5.0	5.6	4.6	4.2
Ba	228	231	230	237	234	236	221	224	231	222	229	213	220	21	31	31	27	31	9	30	500	540	8	7
Hf	7.4	4.9	4.7	5.0	4.9	4.7	4.4	7.2	4.9	4.8	5.0	4.4	4.7	6.5	5.8	5.5	5.6	5.7	5.9	6.1	6.7	7.1	15.6	15.3
Pb	19.0	19.0	19.1	19.9	20.0	55.0	18.4	19.0	19.0	18.7	19.1	18.2	18.8	23.4	21.3	20.1	19.6	20.3	20.8	20.9	18.0	19.4	23.2	22.6
Th	20.8	17.2	16.8	17.6	17.3	17.4	16.3	20.3	17.6	16.5	16.9	16.2	16.5	20.3	18.1	17.4	16.7	17.1	17.9	17.9	18.6	20.2	29.4	28.2
U	5.7	5.6	5.5	6.0	5.8	5.8	5.5	5.7	5.6	5.6	5.7	5.2	5.5	6.8	6.0	5.5	6.0	6.0	6.6	6.3	5.8	5.8	6.5	6.2
La	36.1	36.0	35.3	37.5	36.6	36.9	35.1	35.3	35.9	34.9	36.1	33.9	35.1	23.8	28.2	27.2	25.0	27.1	21.0	28.5	39.3	42.5	52.9	46.2
Ce	70.8	71.3	70.6	75.0	72.8	73.0	68.5	69.0	71.3	69.2	72.0	66.9	69.0	56.3	62.9	61.2	57.3	60.6	50.2	63.4	74.3	80.6	118.0	105.1
Pr	7.90	7.86	7.94	8.28	7.93	8.24	7.57	7.53	7.79	7.77	7.95	7.37	7.74	7.10	7.59	7.51	7.10	7.43	6.18	7.83	7.97	8.66	14.47	13.03
Nd	28.4	28.2	27.7	29.0	28.8	30.7	28.2	28.4	28.2	27.9	29.4	27.7	28.6	28.0	30.4	29.2	27.7	30.0	26.6	29.7	27.9	29.8	56.5	52.1
Sm	6.45	6.50	6.25	7.15	6.61	6.53	6.10	6.32	6.48	6.24	6.40	5.75	6.12	8.08	7.07	7.19	6.99	7.21	7.15	7.44	5.92	6.59	15.1	14.48
Eu	0.41	0.48	0.37	0.36	0.41	0.47	0.42	0.42	0.45	0.42	0.45	0.39	0.42	0.06	0.06	0.08	0.06	0.07	DL	DL	1.09	1.17	0.21	0.21
Gd	8.97	8.54	8.70	9.55	8.96	9.19	8.42	8.81	8.61	8.33	9.12	8.34	8.57	10.74	9.78	9.81	9.25	9.67	9.35	10.27	8.34	8.60	19.99	19.76
Tb	0.98	0.98	0.96	1.08	1.00	1.09	0.86	1.01	0.96	0.98	1.03	0.90	0.97	1.49	1.28	1.35	1.22	1.24	1.30	1.41	0.82	0.88	2.82	2.76
Dy	5.64	5.56	5.40	6.00	5.77	6.07	5.49	5.60	5.54	5.55	5.60	5.23	5.74	9.08	7.91	7.33	7.30	7.08	8.11	7.93	4.49	4.90	16.52	15.91
Ho	1.08	1.08	1.05	1.11	1.07	1.09	1.01	1.04	1.03	1.03	1.08	1.00	1.07	1.76	1.43	1.42	1.33	1.44	1.56	1.52	0.84	0.90	2.98	2.97
Er	3.37	3.49	3.35	3.49	3.23	3.38	3.13	3.36	3.56	3.25	3.48	3.22	3.26	5.21	4.46	4.56	4.18	4.40	4.73	4.68	2.84	3.12	8.94	8.54
Tm	0.40	0.37	0.36	0.48	0.41	0.39	0.37	0.33	0.40	0.35	0.38	0.39	0.38	0.62	0.54	0.60	0.53	0.57	0.59	0.55	0.30	0.35	1.18	1.09
Yb	3.19	3.16	3.16	3.10	3.19	3.23	3.09	2.91	3.38	3.09	3.25	2.87	3.03	4.78	4.16	4.11	3.83	4.20	4.53	4.22	2.80	2.83	8.01	8.08
Lu	0.38	0.43	0.37	0.38	0.36	0.36	0.42	0.39	0.42	0.37	0.37	0.37	0.36	0.59	0.53	0.51	0.44	0.49	0.60	0.57	0.33	0.37	1.02	0.92

Table 4
Average compositions of the four types of obsidian found in the study area, in NW Santa Cruz, compared to published values of other obsidians from southern Patagonia. (PDA1, 2, 3 = Pampa del Asador 1, 2. 3; MLBA = Meseta del Lago Buenos Aires; Ave = average; st dev = standard deviation; * = Stern (1999); ** = Stern (2004a,b); ***Stern et al. (2012); n.d. = no data available).

	Published			Published			NW Santa Cruz		NW Santa Cruz		NW Santa Cruz		NW Santa Cruz	
Type	PDA1 (**)	PDA2 (**)	PDA3 (*)	Chaiten (***)	Baguales (**)	Otway (**)	PDA1		PDA2		PDA3		MLBA	
	Ave	Ave	Ave	Ave	Ave	Ave	Ave	st dev	Ave	st dev	Ave	st dev	Ave	st dev
No.	132	20	3	18	37	10	38	38	7	7	2	2	2	2
Ti	743	703	1279	594	540	561	792	42.9	721	24.3	1365	48.9	723	12.4
Mn	292	241	395	457	214	238	276	13.6	229	18.0	379	15.6	417	7.8
Rb	195	237	173	125	321	181	189	6.5	216	12.3	165	5.9	230	1.2
Sr	34	1.9	63	154	2.3	24	33	1.8	4.1	1.3	60	1.4	0.4	0.1
Y	35	50	28	12	146	42	32	1.3	43	2.9	27	1.2	87	0.0
Zr	137	132	260	88	724	130	126	5.1	143	5.4	264	9.0	367	6.2
Nb	25	28	27	11	153	39	26	3.8	31	3.6	29	1.0	170	2.7
Cs	10.2	12.7	5.9	7.7	11.6	6.9	9.8	0.4	11.6	0.7	5.3	0.3	4.4	0.2
Ba	242	7.8	559	660	8.5	126	232	9.8	27.7	3.8	520	19.8	7.7	0.4
Hf	5.6	6.3	7.6	2.9	27.2	6.2	5.2	0.8	6.2	1.0	6.9	0.2	15.4	0.2
Pb	*n.d.*	*n.d.*	*n.d.*	19.5	*n.d.*	*n.d.*	19.7	1.3	20.8	1.1	18.7	0.7	22.9	0.3
Th	19.1	19.5	21.2	13.4	45.1	23.1	17.9	1.5	18.4	1.6	19.4	0.8	28.8	0.6
U	5.4	6.1	5.6	3.5	12.7	5.3	5.6	0.3	6.2	0.4	5.8	0.0	6.3	0.1
La	38.6	23.2	42.9	28.2	41.8	31.2	37.1	2.1	26.0	2.4	40.9	1.6	49.6	3.3
Ce	69.2	55.1	78.6	50.3	98.0	70.4	73.7	4.2	59.1	4.1	77.5	3.1	112	6.4
Pr	*n.d.*	*n.d.*	*n.d.*	5.49	*n.d.*	*n.d.*	8.21	0.56	7.26	0.47	8.31	0.35	13.7	0.7
Nd	31.9	27.1	27.7	18.7	50.6	34.7	29.7	1.8	28.8	1.2	28.9	1.0	54.3	2.2
Sm	6.79	7.94	5.92	2.96	17.9	7.58	6.56	0.40	7.34	0.33	6.26	0.34	14.8	0.3
Eu	0.29	0.1	0.69	0.56	0.58	0.17	0.45	0.06	0.07	0.02	1.13	0.04	0.21	0.00
Gd	*n.d.*	*n.d.*	*n.d.*	3.71	*n.d.*	*n.d.*	9.03	0.48	9.86	0.45	8.47	0.13	19.9	0.1
Tb	1.1	1.39	0.82	0.4	3.85	1.21	1.02	0.09	1.32	0.09	0.85	0.03	2.79	0.03
Dy	*n.d.*	*n.d.*	*n.d.*	2.08	*n.d.*	*n.d.*	5.86	0.35	7.81	0.59	4.70	0.21	16.2	0.3
Ho	*n.d.*	*n.d.*	*n.d.*	0.41	*n.d.*	*n.d.*	1.09	0.07	1.50	0.12	0.87	0.03	2.97	0.00
Er	*n.d.*	*n.d.*	*n.d.*	1.18	*n.d.*	*n.d.*	3.49	0.20	4.61	0.28	2.98	0.14	8.74	0.20
Tm	*n.d.*	*n.d.*	*n.d.*	0.21	*n.d.*	*n.d.*	0.41	0.04	0.56	0.04	0.33	0.02	1.13	0.04
Yb	3.66	4.88	3.07	1.29	9.98	4.01	3.21	0.18	4.22	0.29	2.82	0.01	8.04	0.04
Lu	0.49	0.72	0.51	0.19	1.32	0.58	0.40	0.04	0.53	0.05	0.35	0.02	0.97	0.05

section open air surface sites, particularly those sites with more than 3 artifacts, the proportion of these flakes ranges from 12.5% to 33.3% of the total obsidian flakes, while in the southern section this proportion ranges from 50% to 66.7%, as expected according to the lower distance from the probably source (Tables 1 and 2). In the stratified sites the proportion of obsidian flakes with cortex exhibits greater variability in the southern section, ranging from 1.5% to 34.5% (Table 2). In the northern section, this proportion ranges from 4.8% to 25.9% (Table 1). Despite this difference, comparing layers with similar ages in both sections, the proportion of obsidian cortex flakes are similar (Tables 1 and 2, fourth and tenth columns).

In summary, in the stratified sites located in the south section of the area, all stages of obsidian reduction are present, including flakes (some with cortex), tools, and cores. In contrast, in the northern sites only flakes and tools, but not cores, have been found, with the exception of Los Manantiales I surface site where we found an exhausted obsidian core (Tables 1 and 2; Fig. 4n). These differences both in the relative abundance and in the lithic reduction of the obsidian suggest that the potential location of the source is to the south in PDA, because the sites in the southern section are closer to this source.

5.2. *Obsidian geochemistry*

Practically all the samples analyzed ($n = 47$) do correspond to the three chemically different types of obsidian from Pampa del Asador (Tables 1–4). The PDA obsidian was used from the beginning of the occupation in the study area (6120 BP) and persists until historic times, as indicated in the SMI obsidian analyses (Table 2).

All three different chemical types of obsidian from Pampa de Asador were found among the samples analyzed (Fig. 2). The Zr and Ba values are only the most obvious of a number of chemical differences among these three types of obsidian (Tables 3 and 4; Stern, 1999, 2004a,b; García-Herbst et al., 2007). Most of the PDA samples ($n = 38$) are type PDA1, with 116–135 ppm Zr and 213–253 ppm Ba (Fig. 2; Tables 3 and 4). A small proportion ($n = 7$) are type PDA2 with 132–149 ppm Zr and <31 ppm Ba. Only two samples are type PDA3 with 255–273 ppm Zr and 500–540 ppm Ba. Both PDA1 and PDA2 are ubiquitous in the study area and are present both in the northern and southern sections (Tables 1 and 2). In contrast, PDA3 only appears in the southern section (#20 and #40; Table 2).

Two grey obsidian samples (#47 and #49) from the Meseta del Lago Buenos Aires sites stand out because they present a distinctive chemistry. This is different from the black PDA obsidian and also from other known obsidian sources in southern Patagonia (Tables 3 and 4). These MLBA samples are highly alkaline obsidians with high Y, Zr, Nb and Hf concentrations compared to the PDA obsidian (Fig. 2; Table 4).

6. Discussion

Pampa del Asador was the obsidian source most recurrently used in central-south Patagonia, as was demonstrated in the investigations of many different areas in this region as well as in the area studied here (e.g., Stern, 1999, 2004a; García-Herbst et al., 2007). This pattern could be result of the high quality of PDA obsidian, the large area of this source and accessibility in some points relatively far from this source where nodules were transported by fluvial processes (e.g., Belardi et al., 2006).

The broad group of samples analyzed here, many from long-dated sequences, makes it possible to say that PDA also was the most exploited obsidian source in the study area. It was used in both the northern and southern sections of the study area, along all

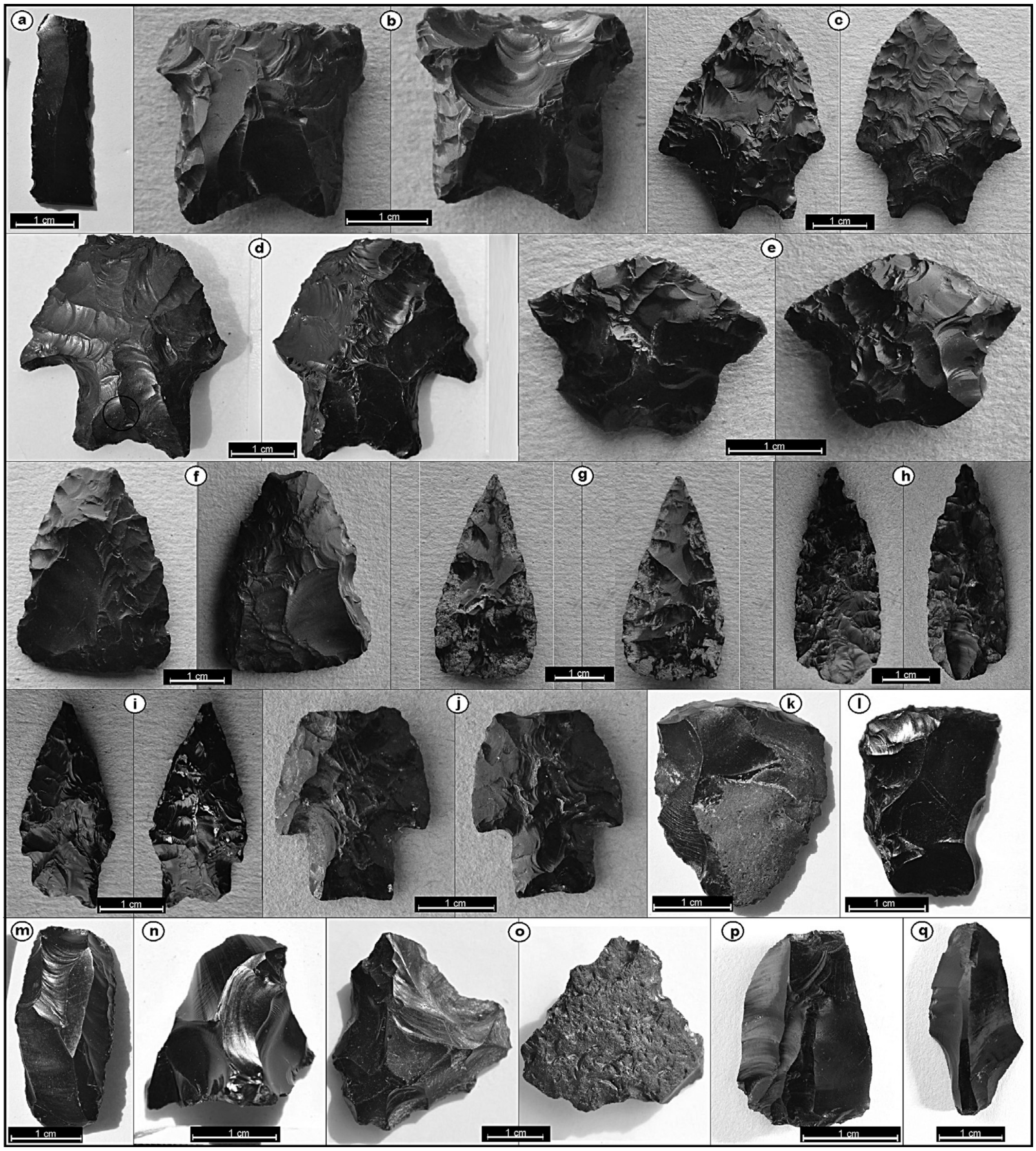

Fig. 4. a) knife from Los Manantiales I surface open air site in northern section; b) projectile point from Cerro Bayo surface open air site in southern section; c) projectile point from La Misteriosa surface open air site in southern section; d) projectile point from Lago Columna II surface open air site in southern section; e) projectile point from Los Manantiales I surface open air site in northern section; f) projectile point from Los Cóndores I surface open air site in southern section; g) projectile point from SM1 Layer 8 (3) stratigraphic rockshelter site in southern section; h) projectile point from SM1 Layer 5; i) projectile point from SM1 Layer 3 (1) stratigraphic rockshelter site in southern section; j) projectile point from SM1 Layer 3 (1); k) end-scraper from Los Cóndores I surface open air site in southern section; l) end-scraper from Los Manantiales I surface open air site in northern section; m) sidescraper from Los Cóndores I surface open air site in southern section; n) exhausted core from Los Manantiales I surface open air site in northern section; o) exhausted core from Lago Columna II surface open air site in southern section; p) exhausted core from SM1 Layer 5; q) bipolar core from SM1 Layer 4.

river and lake basins and in both the steppe and forest-steppe ecotones. On a temporal scale, this obsidian was selected from the beginning of the occupation in the study area (6120 BP). Its use persists until historic times when obsidian was found in the same contexts with materials such as man-made glass and metals.

In previous analysis of lithic artifacts from these same archaeological sites (Fernández, 2013; Fernández and Rocco, 2013; Mengoni Goñalons et al., 2013) we assumed that the obsidian source was PDA. With the results presented here we can now confirm that PDA was the main source. The location of PDA from between 90 km from southern section to 160 km from northern section south of our study area corresponds with previous lithic analysis indicating that the proportion of obsidian in archeological sites decreased from the south to the north (Fernández and Rocco, 2013; Mengoni Goñalons et al., 2013). This pattern can be seen in Tables 1 and 2 (sixth column). In a broad spatial scale, as distance from PDA increased, their frequency decreased and other obsidians sources are also used (e.g., Méndez et al., 2012; Stern et al., 2013).

The prevalence of PDA in the study area is the logical expectation since the source is located within 90–160 km, easily accessible and with an abundance of high quality raw material. Other known sources (e.g., Volcán Chaitén, Cordillera Baguales) are located more than 400 km away from the study area, and this analysis shows they were not used in this area in the past. The presence of potential geographic barriers (the densely forested Cordillera and the Santa Cruz river) that divide various portions of the Patagonia could make obsidian transport across these barriers more difficult (e.g., Morello et al., 2012). Nevertheless, PDA obsidian artifacts have been found as far as 800 km SE from its source, so it is evident that distance barriers alone could be transgressed. The accessibility and abundance of high quality PDA obsidian could also explain the fact that this obsidian was selected even if others were available.

With our results, we can say that the general observation that with increasing distance from the source, the frequency of PDA obsidian decreases, remains true even in a relatively middle scale as that of our study area, compared to the large scale PDA obsidian distribution. So, as was noted (e.g., Civalero and Franco, 2003) the distance to the source seems to play a key-role in the study of obsidian distribution and use.

The almost virtual absence of cores in the northern section and their presence in the southern section could indicate, in general, different procurement strategies and relationship with the source, the southern section being a case of direct procurement of obsidian nodules, supported by the presence of cores and flakes with cortex, while in the northern section obsidian could be procured through transport or exchange of base forms or as finished tools.

All three known types of PDA obsidian were selected for use in the study area. PDA1 was the most extended type both spatially and temporally ($n = 38$; Fig. 3). It is present in both sections, found either in rockshelter stratigraphic sites or in open air surface sites and was used from the earliest to the very latest occupations. PDA2 ($n = 7$; Fig. 3) was only identified in the earliest occupations at SMI, in the south section. In the north section PDA2 is present on the slope of the AMII rockshelter, in a surface context, and in stratigraphic layers dated in 930 BP and 2590 BP, the earliest occupation identified in this section. Finally, PDA3 ($n = 2$; Fig. 3) is present only in the south section in an open air surface site and at CSI, in a layer that has not been dated but was constrained between 3160 and 2209 BP.

The amount of samples analyzed in this article makes it possible to compare the proportions of PDA1, 2 and 3 with the relative frequencies of these types of obsidians found in a random collection of geologic obsidian nodules from PDA and in a group of samples of black obsidian artifacts previously analyzed from other areas of southern and central Patagonia (Stern, 1999, 2004a; Fig. 3). The first group, 90 geologic obsidian nodules from PDA, shows that PDA1 predominates ($n = 73$), followed by PDA2 ($n = 13$) and PDA3 ($n = 4$; Stern, 1999, 2004a). The second group, 73 obsidian artifacts from other areas of southern and central Patagonia, shows the same pattern (65 PDA1; 7 PDA2; 1 PDA3; Stern, 1999, 2004a; Fig. 3). This would seem to give weight to the idea that the obsidian from which all these 47 study area artifacts were fashioned was collected randomly from the PDA source.

The open air sites from Meseta del Lago Buenos Aires are undated and located in an area that is not directly connected to the Ghío and Jeinemeni river basins. It is also the only place where we found a grey obsidian type visually and chemically different from black PDA obsidian. A small 1 cm in diameter geologic sample of grey obsidian, similar in color to the two samples analyzed in this study, was previously collected by the Chilean geologist Diego Morata (Stern, unpublished data) from the surface of Meseta del Lago Buenos Aires. Although this kind of obsidian could have been transported to the Meseta del Lago Buenos Aires from an as yet unknown source, this independent evidence of its presence supports the fact that it is probably a local occurrence in this restricted area on the plateau. It is noteworthy that this type of obsidian was registered only in the Meseta del Lago Buenos Aires archaeological sites, despite the fact that it is located very close to the study area. If there is an unknown obsidian source in the Meseta, their restricted distribution could be the result of their difficult accessibility (topographical and climatic), as well as their low frequency or the late use of Meseta del Lago Buenos Aires by the inhabitants of the NW Santa Cruz province. Those hypotheses could be resolved with more obsidian analysis and chronological information of Meseta del Lago Buenos Aires sites.

It is important to note that the chemical properties of all the southern Patagonian obsidian sources have not been equally well-established. The Volcán Chaitén and PDA obsidians are widely characterized from both geological and archaeological samples. In contrast, the Seno de Otway and Cordillera Baguales obsidians have relatively few geochemical analyses and these are solely of archeological samples since their geological source contexts are still unknown. In this paper we identified an unexpected new obsidian whose distribution must also be investigate in the future. This is the case for the two archaeological samples (#47 and #49) of grey obsidian discovered on the top of Meseta del Lago Buenos Aires that are chemically different from any other archeological obsidian yet analyzed in southern Patagonia.

While recognizing that the chemical analyses presented here for the majority of the samples are consistent with the geochemically sign of PDA, we need to continue characterizing the already known obsidian sources and further investigate the possible occurrence of new sources in the vast Patagonian territory, as were the case of Meseta del Lago Buenos Aires obsidian samples encountered in this study.

7. Conclusions

The results of the present study suggest that:

- Pampa del Asador was the main obsidian source exploited in the study area of NW Santa Cruz;
- Pampa del Asador obsidian was selected from the beginning of the occupation of the study area, from 6120 BP until historic times;
- Although Pampa del Asador was the most important source, another still unknown source was exploited, probably located on the Meseta del Lago Buenos Aires plateau;
- All three types of Pampa del Asador obsidian were represented in the study area localities;
- The proportions of the three types of Pampa del Asador obsidian in the analyzed samples is similar to their proportions as they appear in the source and in other archaeological areas of Patagonia.

Acknowledgments

Research was carried out with grants from CONICET (2005–6), ANPCYT (2008–11, 2012–15) and UBA (2008–11, 2011–14) for fieldwork. The geochemical analyses were financed with a grant from the Universidad de Buenos Aires (UBACyT 2011–2014 00084). The authors are grateful to Dr. R. Barberena for help in this analysis, to María José Figuerero Torres for her generous guidance and permanent availability, to Daphne Figuerero for English revision and to the Los Antiguos and Paso Roballos community for their hospitality and selfless support in the field at every opportunity. Finally, this work was notably improved thanks the observations of the reviewers. We assumed full responsibility for the observations and conclusions presented in this paper.

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