Raw materials and functional designs of Fishtail projectile points from southern Brazil

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Abstract:

This study analyses the lithic landscape and the selection of rocks used to manufacture Fishtail points (FP) in southern Brazil, their designs, and some functional aspects. In order to identify the offer of lithic resources, we carried out several surveys throughout 15 months in 47 counties in the Southern Brazil covered by the Botucatú - Serra Geral Vulcano Sedimentary Complex. The lithic composition of numerous hill slopes, fallen rocks, and accumulations of pebbles and boulders in the riversides was evaluated. The results show that basalts (including a small proportion of andesites and rhyodacites-rhyolites), and silicified sandstones, are ubiquitous in the landscape. Conversely, non-translucent cherts are scarce, so their acquisition would have been time-consuming. However, these local cherts were the rocks mostly used to manufacture these points, being another example of the selectivity for high quality rocks by Paleoamerican hunter-gatherers. The same cherts selected in southern Brazil to produce the FP were used to manufacture other point-types by local hunter-gatherers of the early and middle Holocene grouped in the so-called "Umbú Tradition". Not a single FP of the entire collection analyzed here was made from silicified limestones, which is one of the most common raw materials among the Uruguayan FPs, nor were they made from quartzites as were most of the FPs of the Pampean plains.

Regarding to the designs of these projectiles, some morphotypes appear to have been designed to produce multiple injuries through successive thrusts and withdrawals in the bodies of the prey, while in others, the design seems to have favoured penetration and fixation on the prey, suggesting in this case, a single shot technique for each projectile. As the maintenance process unfolded, especially for points below ~ 80 mm in length, they show features that negatively impacted their efficiency, including distinct asymmetries, somewhat open front angles, a decrease in the cutting perimeter and cross-sectional area, an increase in the bevel angle of the blade edges, and a tendency to a conical cross-section. Behaviours intended to counteract these problems were maximizing the length of the leading edge, maintaining the symmetry and the triangular blade resting on straight shoulders, and maintaining the aerodynamic properties as much as it were possible, in order to improve their lethality and the fixation capacity.

Beyond these rejuvenation processes, three different morphotypes of points appear to be included within the sample. The first includes points over 120 mm and ~ 80 g in weight, with triangular or slightly lanceolate limbs, which mostly present straight shoulders, but there are also examples of rounded shoulders. The second design corresponds to projectiles between 110 and 87 mm and ~30 g in

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weight, with triangular or slightly lanceolate blades and straight shoulders. The third design presents the classic shape of these projectiles, with a fish silhouette, with maximum lengths below 90 mm, with a more robust and conceptually different design, where the angles of the edges of the blades and of the shoulders are equal, perhaps with the intention to facilitate the spear withdrawal to produce multiple injuries.

Keywords: Fell 1 projectile points; Fishtail; Paleoamericans; South America; Brazil

1. Introduction

Junius Bird's excavations in Fell's cave in southern Chile in 1936-1937 (Bird 1969) allowed the identification of a particular morphotype of projectile point in South America, dated to the Pleistocene-Holocene boundary. After more than 80 years since Bird's pioneering work, subsequent researches have shown the subcontinental coverage of these points, confirming their chronology (Nami 2020a; Waters *et al*. 2015).

Fell 1 projectile points, Fell points, or just Fishtail points (FP hereafter) are stemmed bifaces whose design includes a lanceolate or triangular blade, mostly slightly concave on both sides and base of stem, with small divergent ears, which are eventually thinned by fluting on one or both sides. Most of them are made on thin flakes with final shaping by short pressure retouches, limiting them to a relatively marginal extent from the edge of the blade; in some pieces these final retouches were done after careful bifacial flaking. This general design shows subcontinental variations, especially in the shoulders and blade shape, as well as differences in the sizes. However, beyond this variability, both the general bauplan and production technique reveal the existence of a shared technological and stylistic knowledge throughout Central and South America between ~ 12,900 and 11,500 years BP (Bird 1969; Briceño Rosario 2010: 262; Dillehay 2000: 109-187; Grosjean *et al*. 2005; Hermo *et al*. 2015; Mayer-Oakes 1986a; 1986b; Meneghin 2004; 2006; Miotti & Terranova 2015: 182; Nami 2007; 2014a: 282-290; 2014b: 184-187; 2019; 2020a; Waters *et al*. 2015; Weitzel *et al*. 2018; among others). This very narrow distribution over time suggests a rapid expansion, typical of hunter-gatherers of the Late Pleistocene in relatively empty spaces (Surovell 2000; Web & Rindos 1993).

This study has precisely two main objectives related to this variability. First, we focus on the structure of the lithic landscape, selection of the raw material used to produce the FPs in southern Brazil (Figure 1), and the related behaviours on rock acquisition. The second, to explore the design and some functional aspects. It is not the intention of this paper to compare these points with others from South America, an objective that completely exceeds this contribution; we will make some brief comparisons only in those opportunities where this could improve the understanding of the results obtained here.

2. The record of FPs in south Brazil

Most of the Brazilian FPs were recovered in the southern states of this country, along ~1300 km from the State of São Paulo to the borders of Argentina and Uruguay. However, this record is one of the least studied local techno-complexes in the local archaeology. The reason probably lies in the wide dispersion of the collections, the scarcity of excavated sites of the Pleistocene-Holocene boundary, and to a large extent, because most of these bifaces were mainly found in unpublished cultural resource management projects (CRM) and surveys. Another bias is the expectation to find FPs in each site of this techno-complex, which certainly does not happen, which prevents the correct identification of some of these contexts (Nami 2014a: 282; 2020a).

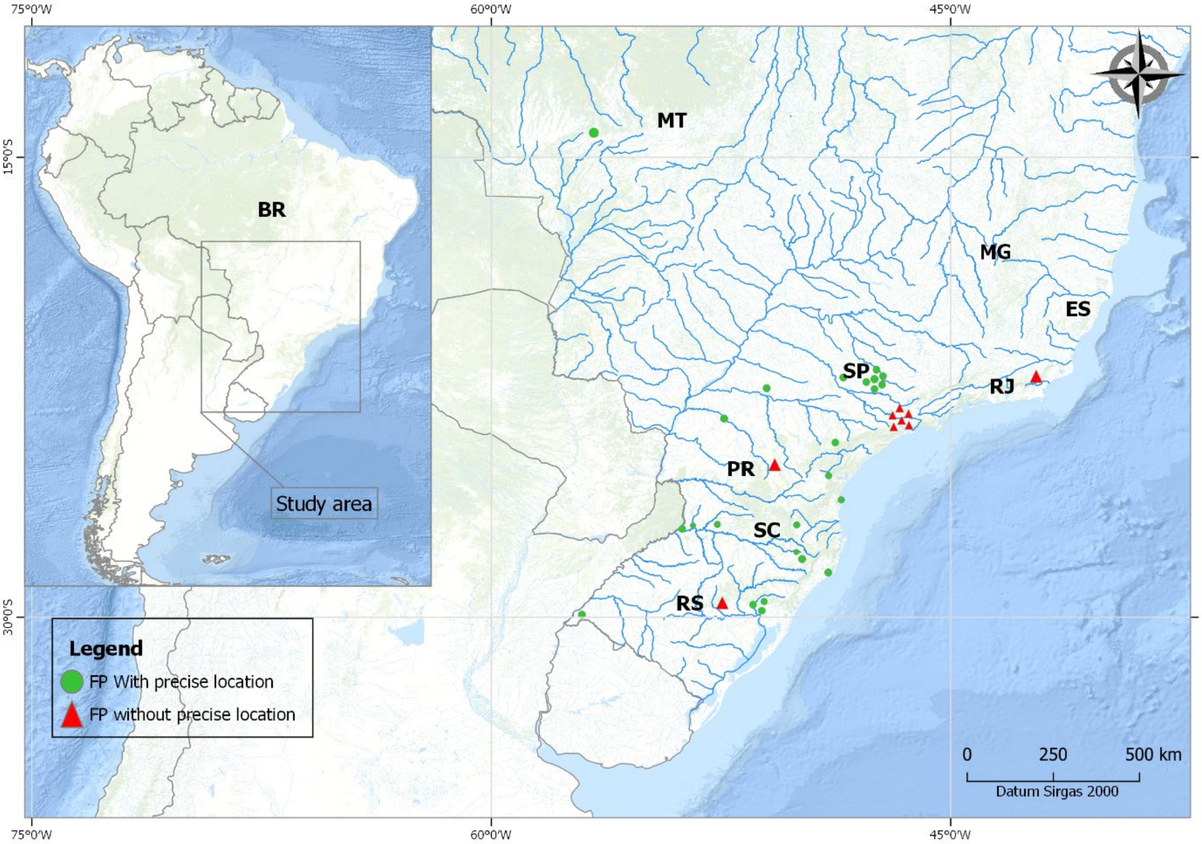

Figure 1. Study area with localization of the findings of FPs included in this study. Green circles: FP with precise location. Red triangles: FP without precise location. BR: Brazil. RS: Rio Grande do Sul State. SC: Santa Catarina State. PR: Paraná State. SP: São Paulo State. RJ: Rio de Janeiro State. ES: Espírito Santo State. MG: Minas Gerais State. MT: Mato Grosso State.

Several researchers have previously recognized the presence of FPs in Brazil (Becker 1966; Beltrão 1974; Collet 1987; Meggers 2007: 137; Nami 2016a; Silva Lopez & Nami 2011; Prous 1992: 76; Prous & Fogaça 1999; Rohr 1966; Schobinger 1974; among others), including some findings, or potential findings in stratigraphy. However, the number of FPs identified until a few years ago was relatively small. Perhaps for this reason, they have been interpreted as a product of exchange with southern groups (*e.g.*, Dias 2012). In this interpretation, the FPs were manufactured in the adjacent plains of Uruguay and perhaps in Argentina, but not in southern Brazil, which certainly was intriguing since the Uruguayan plain and most of southern Brazil constituted of the same biome during the end of the Pleistocene (and even today in some areas), with the same or similar faunal resources, and without significant topographic distortions (Adams & Faure 1997; Cione *et al*. 2009: 128; Gallo *et al*. 2009; Loponte & Carbonera 2017; Vivo & Carmignotto 2004). In fact, the southern states of Brazil, Uruguay and Northeast Argentina present a continuous distribution of other points (early and middle Holocene) from the so-called Umbú Tradition (Nami 2020a; Okumura & Araujo 2014; Prous 1992: 148-149; Rodríguez 2005). On the other hand, even in the presence of environmental differences, the subcontinental coverage of FPs (Nami 2020a) indicates a high degree of adaptive plasticity for the colonization of different environments of these early hunter-gatherers. In that vision that supports the presence of FP by exchange, these artefacts not only did enter Rio Grande do Sul, bordering with Uruguay, but they also reached Santa Catarina, Paraná and São Paulo states (the latter about ~ 1300 km from northern Uruguay), Bahia State (> 2000 km) (Nami 2010), and also Piauí State (2800 km) (Boëda *et al*. 2021). It also draws attention to the fact that these points were not made from silicified limestones from the Puerto Yeruá-Mercedes Formation, which is one of the most common raw materials among the Uruguayan FPs (Castiñeira *et al*. 2011; Gascue *et al*. 2013; Nami 2010; 2013; Suárez 2011b: 173, see below), banded chalcedony ("Uruguayan type") that outcrops in the north of Uruguay (Suárez 2011a), nor were they made from quarzites as were most of the FPs of the Pampean plains (Flegenheimer & Weitzel 2017). In fact, most of them are made of non-translucent cherts, which are rare in the Uruguayan FPs, and certainly absent in the assemblages recovered at the Argentinean Pampas. FPs were also recognized in the provinces of Corrientes, Entre Ríos and Misiones in northeast Argentina (Loponte & Carbonera 2017), in Venezuela and Guiana (Nami 2016a), surrounding Brazil from north to south. Following the explanation that considers the FPs of Brazil as a product of exchange, they should be considered as one of the most significant exchange events in American prehistory (see also a FP in the upper Río Negro River, Amazon basin in Meggers 2007: 137).

The other explanation, more parsimonious, is that the findings of FPs of Brazil represent a typical local hunter-gatherer record of the Pleistocene-Holocene boundary. Therefore, their presence on the Atlantic slope of this country is in accordance with the subcontinental model of diffusion, with a general direction from north to south (Miotti 2006; Nami 2020a). The analysis of some museum and private collections in the southern states of Brazil has made it possible to identify a growing number of FPs in different stages of use and maintenance, made from local cherts and other local raw materials (Becker 1966; Beltrão 1974; Boëda *et al*. 2021; Loponte *et al*. 2015; 2016; Nami 2010; Prous & Fogaça 1999; this study).

Findings of FPs in southern Brazil are concentrated on the surface, similar to what has happened in other regions regarding early occupations, such as the Alaskan fluted points discovered in the 1940s, but identified in stratigraphy 40 years later (Smith & DeWitt 2017); or in the Argentine Pampa, where until the 1980s they were practically only recognized by surface findings, and as still happens in the plain of Uruguay. Here, they had been recognized in a few sites in stratigraphy such as Urupez, Minas de Callorda, Navarro, perhaps in Cerro de los Burros (Gascue *et al*. 2013; Meneghin 2004; 2006; Nami 2007; 2020b), and a fragment that has been proposed as FP at the Tigre site (Suárez & Cardillo 2019). Certainly, the identification of reliable early sites with good resolution is still extremely rare as is the case in many other South American regions (Nami 2019), and it will take time to discover local sites of the Pleistocene-Holocene boundary with adequate records in South Brazil. In Uruguay around 200 FPs were recovered, most of them on the surface, after several decades of work done by archaeologists and private collectors (Baeza & Femenías 2005: 5; Gascue *et al*. 2013; López Mazz *et al*. 2003-2004; Nami 2010; among others). In Brazil, the systematic recognition of these points began only a few years ago, but it has already allowed for the identification of around 50 pieces (Loponte *et al*. 2015; 2016). However, the real dimension of the FP collected in South Brazil in still unknown, since the analysis of unpublished collections (including public ones), often makes it possible to identify unknown FPs, as has happened during a recent CRM project in the counties of Lages and Painel (Santa Catarina State, south Brazil) (Carbonera & Loponte 2020), where within two small collections (one public), new specimens were identified (Figure 2).

The initial recognition of a record like this, based on surface collections, is one of the most common ways to analyse spatial distributions, being the first approach in understanding the variability of the regional record, which serves to develop subsequent studies of greater complexity (*i.e.* VanPool *et al*. 2008: 86; Wandsnider & Camilli 1992). On the other hand, it is expected that the FPs have a low representativeness in the archaeological surface assemblages compared with the record of Holocene points ("Umbú Tradition"), since the former are more deeply buried, and they have had a substantially lower quantity of replicators throughout the archaeological time. The latter, with notable technological and morphometric differences from the former, were manufactured over several millennia during the Holocene.

And as we have pointed out above, not all Fell sites have points (Nami 2014a: 282), which makes it difficult to identify other findings of this techno-complex only by these bifaces.

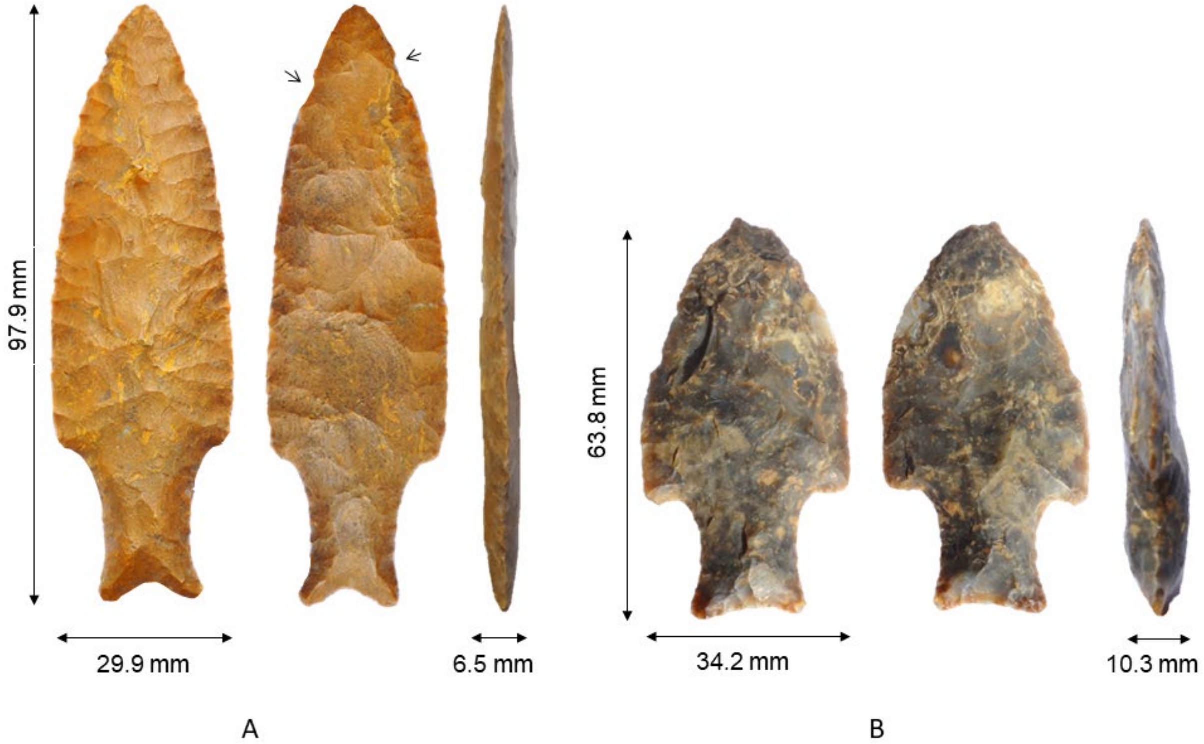

Figure 2. Piece A: FP recovered on the surface at Urupema County, and currently curated at the Museu Histórico Thiago de Castro, Lages, Santa Catarina. B: FP collected on the surface at Painel County, Santa Catarina. Private collection.

Most of the FPs in South Brazil were collected by landowners during agricultural work as well as by workers during infrastructure construction, who preferably collect complete pieces, easy to recognize on the surface; therefore, they usually ignore fractured pieces. However, fragmented and recycled pieces such as scrapers were identified (Loponte *et al*. 2015; 2016; Miller 1969; 1987; Nami 2013; Dias 2012). These pieces, manufactured from unusable points, seem to be quite common (Nami 2015a) (see also Supplementary file 1).

In this study we have selected 31 FPs from southern Brazil reproduced in Figure 3 and listed in Table 1. Except points 8 and 17, all of them were previously published (Loponte *et al*. 2015; 2016). The selection of these pieces is based mainly on the availability of their measures and completeness. A few complete points have not been included either due to the lack of some metric data, adequate photographs or descriptions (see these other pieces in Loponte *et al*. 2015; 2016, and the references cited there. See also Supplementary file 1).

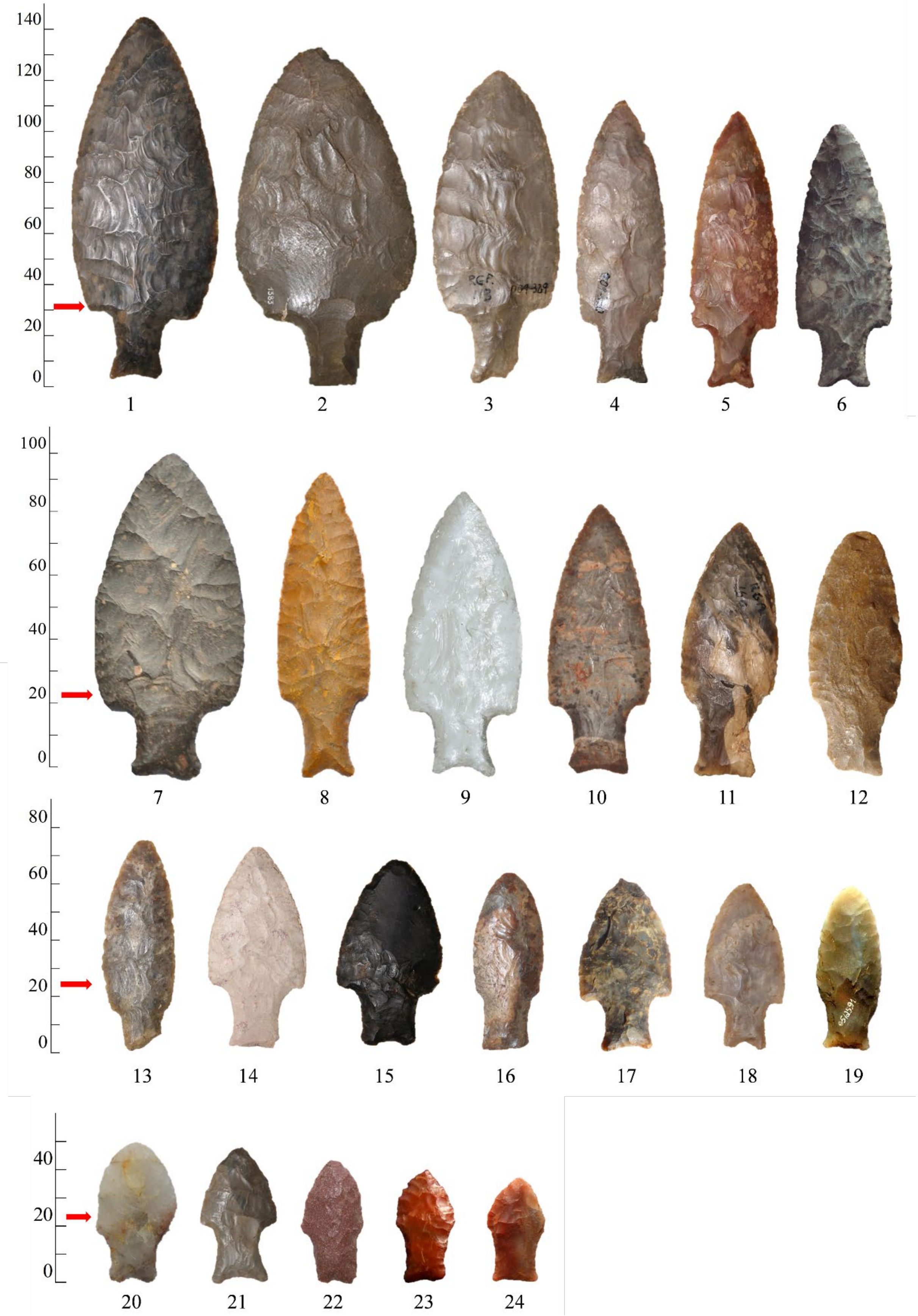

Figure 3. FPs included in this study. The red arrow indicates the average length of the stems.

Table 1. Raw materials, weight, linear dimensions (regular font) and elaborated metric values (in bold) of the FPs included in this study. The map of the measurements can be seen in Supplementary file 2. ML: maximum length (or total length). BW: Blade width. Th: Thickness. BL: Blade length. SL: stem length. SW: stem width. SL/SW: ratio. MSW: Minimum stem width. BC: Basal concavity. *With chalcedony or opal inclusions. The width of the blades of pieces 1 and 3 are corrected from Loponte *et al*. (2016). In the piece #13 the maximum length and the stem measurements are estimated due to an oblique fracture. The cross-section area (1) and perimeters (2) (3) are based on Sisk & Shea (2011) formulae. The perimeters were calculated for both triangle cross-section (2), and rhomboid cross-section (3).

Piece #	State	Site/ Location	Raw material	ML	BW	Th	BL	SL	SW	SL/ SW	MSW	BC	Weight	Area (1)	Per. (3)	Per. (2)	Pred. angle	BW/ Th
1	SP	-	Chert	141.0	59.5	7.6	115.0	26.0	24.6	1.1	16.5	2.0	76.0	226.1	119.5	120.0	14.6	7.8
2	MT	Norterlândia	Chert	133.9	68.8	8.6	108.6	25.3	26.9	0.9	18.0		84.5	295.8	138.1	138.7	14.3	8.0
3	SP	-	Chert	121.2	52.0	7.3	94.2	27.0	24.7	1.1	18.0	2.5		189.8	104.5	105.0	16.0	7.1
4	SP	-	Chert	110.6	31.9	6.6	85.6	25.0	19.0	1.3	16.5	3.0	28.5	105.3	64.5	65.2	23.4	4.8
5	SP	-	Chert	108.7	32.5	7.0	85.7	23.0	19.2	1.2	14.0	2.0	27.5	113.6	65.6	66.4	24.4	4.6
6	SP	-	Chert	104.0	38.0	7.0	83.4	20.6	20.4	1.0	17.3			133.0	76.6	77.3	20.9	5.4
7	SC	Mondaí	Acid rock	101.1	46.2		79.3	21.8	23.1	0.9	18.8	2.1						
8	SC	Urupema	Chert	97.9	29.9	6.5	72.8	25.1	16.9	1.5	14.1	2.5		97.2	60.5	61.2	24.5	4.6
9	RJ	-	Quartz	92.5	36.6	8.6	73.2	19.3	20.9	0.9	17.1	3.0	31.6	157.4	74.2	75.2	26.5	4.3
10	SP	Iepê	Chert	87.5	33.1		65.5	22.0	19.8	1.1	17.5	2.5						
11	SP	-	Chert	81.2	31.0	6.8	58.1	23.1	19.3	1.2	16.2	1.0	18.2	105.4	62.7	63.5	24.8	4.6
12	SC	Jaguaruna 11	Quartzite	79.9	30.1		56.8	22.1	18.4	1.2	18.1							
13	PR	Paraná state	Chert*	76.2	25.9	6.6	62.9	13.3	16.6	0.8			15.5	85.5	52.6	53.5	28.6	3.9
14	PR	Piraquara	Chert	74.9	35.9	6.6	51.3	23.6	23.4	1.0	17.1	1.0	19.8	118.5	72.4	73.0	20.9	5.4
15	SP	Jau	Chert	68.1	36.1	8.0	47.3	20.8	21.7	1.0	18.3	1.5	18.4	144.4	73.1	74.0	25.0	4.5
16	SP	Rio Claro	Chert*	65.0	24.0	8.0	44.5	20.4	19.0	1.1	16.2		14.9	96.0	49.3	50.6	36.9	3.0
17	SC	Painel	Chert*	63.8	34.2	10.3	44.7	19.1	18.4	1.0	16.4	1.8		176.1	69.9	71.4	33.5	3.3
18	SC	Taió	Chert	60.7	27.3	6.5	42.3	15.1	15.7	1.0	14.5		11.5	88.7	55.4	56.1	26.8	4.2
19	RS	Montenegro	Chert	60.6	23.2	7.0	43.6	17.0	18.0	0.9	16.5			81.2	47.4	48.5	35.3	3.3
20	SC	Orleans	Quartz	49.2	28.2	8.3	31.3	17.9	17.3	1.0	15.6			117.0	57.6	58.8	32.9	3.4
21	SP	Rio Claro	Chert	48.0	28.5	4.9	28.7	18.5	21.0	0.9	15.4	2.0	8.2	69.8	57.4	57.8	19.5	5.8
22	RS	RS-I-47	Sil. Sandstone	46.7	25.4		29.5	17.2	18.5	0.9								
23	PR	Jusante	Chert	40.8	21.0	6.3	19.8	21.0	19.3	1.1	14.2			66.2	42.9	43.8	33.4	3.3
24	SC	Irani River	Chalcedony	38.4	20.9	6.9	17.5	20.9	16.5	1.3	14.5			72.1	42.9	44.0	36.7	3.0
25	RS	RS-I-69	Quartz															
26	SP	Apiaí	Chert	131.0	58.0	6.0	109.7	21.3	20.2	1.1			85.0	174.0	116.3	116.6	12.0	9.7
27	SC	SC-U-23	Chert	55.0	27.0	8.6	35.7	19.3	19	1.0				116.1	55.3	56.7	34.4	3.1
28	RS	RS	Quartz	46.0	22.0	7.0	27.8	18.2	15.3	1.2				77.0	45.1	46.2	35.4	3.1
29	SP	Rio Claro	Chert	50.0	26.0	8.0	30.0	20.0	20.0	1.0				104.0	53.2	54.4	34.2	3.3

Piece #	**State**	**Site/ Location**	**Raw material**	**ML**	**BW**	**Th**	**BL**	**SL**	**SW**	**SL/ SW**	**MSW**	**BC**	**Weight**	**Area (1)**	**Per. (3)**	**Per. (2)**	**Pred. angle**	**BW/ Th**
30	SP	Rio Claro	Chert	53.5	44.0	5.0	38.0	15.5	22.0	0.7				110.0	88.3	88.6	13.0	8.8
31	SP	Rio Claro	Chert	38.0	23.0	5.0	29.0	9.0	12.0	0.8				57.5	46.5	47.1	24.5	4.6

2.1. Raw materials

The acquisition of raw materials is a critical step that conditions the entire subsequent manufacturing sequence and the effectiveness of the lithic artefacts (Ahler & Geib 2000; Andrefsky 1994a; 1994b; 2009; Bettinger & Eerkens 1999; Ericson 1984: 1; Whittaker 1994: 14). The criteria to select rocks by hunter-gatherers include their availability in the landscape, accessibility, package, quality and adequacy for the design, intended function, and the final performance of the tools (Ahler & Geib 2000; Ataman & Drews 1992: 201; Elston 1992; Gould & Saggers 1985; Kuhn 1991; Mackay & Marwick 2011; Torrence 1983; among many others). Each of these properties may gravitate in a non-homogeneous way throughout the archaeological time, generating rankings of rocks which may change along time and space. Thus, lithic assemblages often include a limited variety of raw materials with differential distributions according to the landscapes, artefacts typo and archaeological units. While there may also be symbolic or aesthetic aspects influencing the selection of rocks, they must achieve certain quality thresholds to be selected, especially for projectile points, where the effectiveness is a central concern of hunters (*e.g.*, Ahler & Geib 2000; Brantingham *et al*. 2000; Friis-Hansen 1990; Hughes 1998; Whittaker 1994:14).

Some previous studies linked local raw material to FPs in south Brazil (Boëda *et al*. 2021; Nami 2019; Collet 1987). So far, there is no general analysis of the raw materials used to make these bifaces in the area. In Table 1 and Figure 4 the frequencies of rocks among the points included in this study are listed, which reflect the predilection for non-translucent and homogeneous cherts (massive, microcrystalline quartz, with waxy lustre), although some of them have a breccia appearance (*e.g.*, pieces 5, 6 and 10 of Figure 3), with occasional small inclusions of translucent chalcedony, opal or both. Some FPs are made of xenomorphic (piece 9, Figure 3) and hyaline quartz (Supplementary file 7). The former was considered sub-optimal compared to hyaline quartz (automorphic) and to some types of cherts (Nami 2015b). Some authors pointed out that quartz perhaps was selected by symbolic or aesthetic reasons (Flegenheimer & Weitzel 2017; Nami 2015b). Other rocks were sparsely used. Piece 22 is made from a low-quality intertrap sandstone; piece 7 from an undetermined acid rock (piece 7), that may be rhyolite or basaltic andesite. Piece 24 is made of chalcedony, and piece 12 of quartzite. The latter has grain size, colour and general appearance similar to that of the crystalline basement that outcrops in the east of Santa Catarina, from where this piece comes. Quartzite of identical appearance was used in that region to make other artefact-types (Figure 5). Quartz and chalcedony are ubiquitous in south Brazil, as well as non-translucent cherts, although the latter appear to be much rarer (see next section). In the Rio Claro area, the FPs are made of a peculiar grey-brown chert that was widely used there to produce other point-types (Beltrão 1974; see also Figure 5, group G of this study).

Although there is a notable predominance of non-translucent cherts, the fraction of points made from quartz and the other few specimens made from other rocks, makes the diversity of raw materials intermediate ($D_s = 0.43$).

The preference of cherts to produce the local FPs follows the same trend observed for other South American assemblages, where microcrystalline and amorphous raw materials are common (Briceño Rosario 2010: 262; Hermo *et al*. 2015; Miotti & Terranova 2015: 185; Nami 2013) to the detriment of basalts and quarzitic rocks, with the exception of the Argentinean Pampas, where the highest proportion are made of sedimentary quartzites (see Figure 6). Chert is probably the rock with the highest quality in the region to make points (see below), and in fact, cherts of the same qualities and appearance were used to produce other point-types by Holocene local hunter-gatherers grouped in the “Umbú Tradition” (Figure 5), although they also incorporated other rocks in major proportions (Beltrão 1974; Bond *et al*. 2018; Collet 1987; Costa 2016: 92; Okumura & Araujo 2014). Non-translucent cherts were also recovered in the survey area in stratigraphy at early sites ACH-LP-07 and Otto Aigner 1 as cores, flakes, other projectile point-types, and other retouched artefacts (Loponte & Carbonera 2018; Lourdeau *et al*. 2016; Supplementary file 6 of this study; see also Carbonera *et al*. 2016 for other assemblages with local cherts in the region).

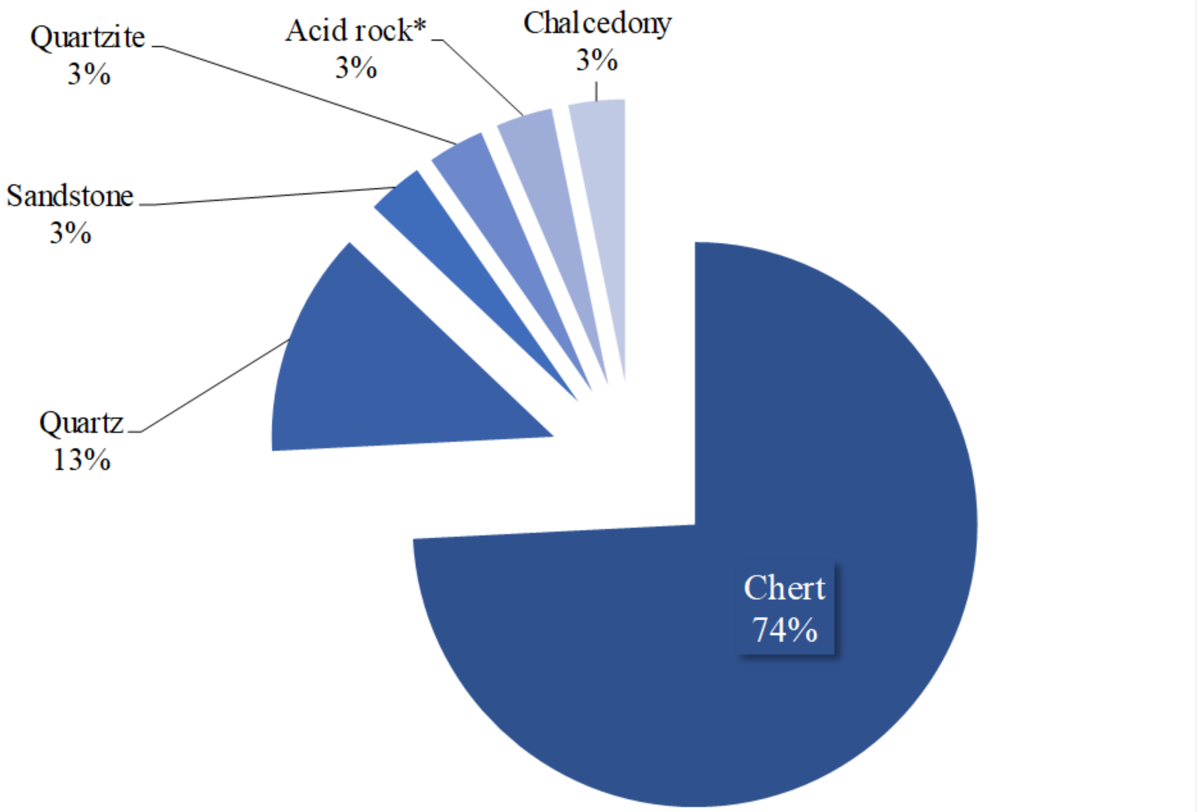

Figure 4. Raw materials recognized among FPs in south Brazil (based on Table 1). *Rhyolite, rhyodacite or basaltic- andesite. "Sandstone" refers to silicified sandstone.

Around the world, it is usual to find high quality exotic rocks incorporated in small quantities among hunter-gatherer´s assemblages, especially in artefacts with a high symbolic meaning, or in those that are expected to have a high performance, like projectile points. These rocks could have been directly acquired at distant locations by special trips to procure raw materials, or by exchange with other groups with related lineages (Gould 1980: 155-156), or alliances (Sahlins 1965). These behaviours have been well identified many decades ago in ethnographic studies (Binford 1979; Goodyear 1979: 9; Gould & Saggers 1985; Kelly & Todd 1988). For now, among the FPs included in this analysis, and collected in the area covered by the Botucatú - Serra Geral Vulcano Sedimentary Complex (see next section), there are no rocks that *a priori* could be considered as non-local. It must also be pointed out that there are no quartzites from the Argentine pampas, nor silicified limestones that constitute the most common rock among the FPs of Uruguay (Figure 6; see Batalla 2016 for availability of this and other rocks in northern Uruguay, and Flegenheimer & Weitzel 2017 for silicified sandstones within the Pampean assemblages). Silicified limestones, which although are cherts, they have a different origin with distinctive inclusions and typical macroscopic characteristics (Apolinaire *et al*. 2019; Loponte *et al*. 2011: 134-137; Martínez *et al*. 2015).

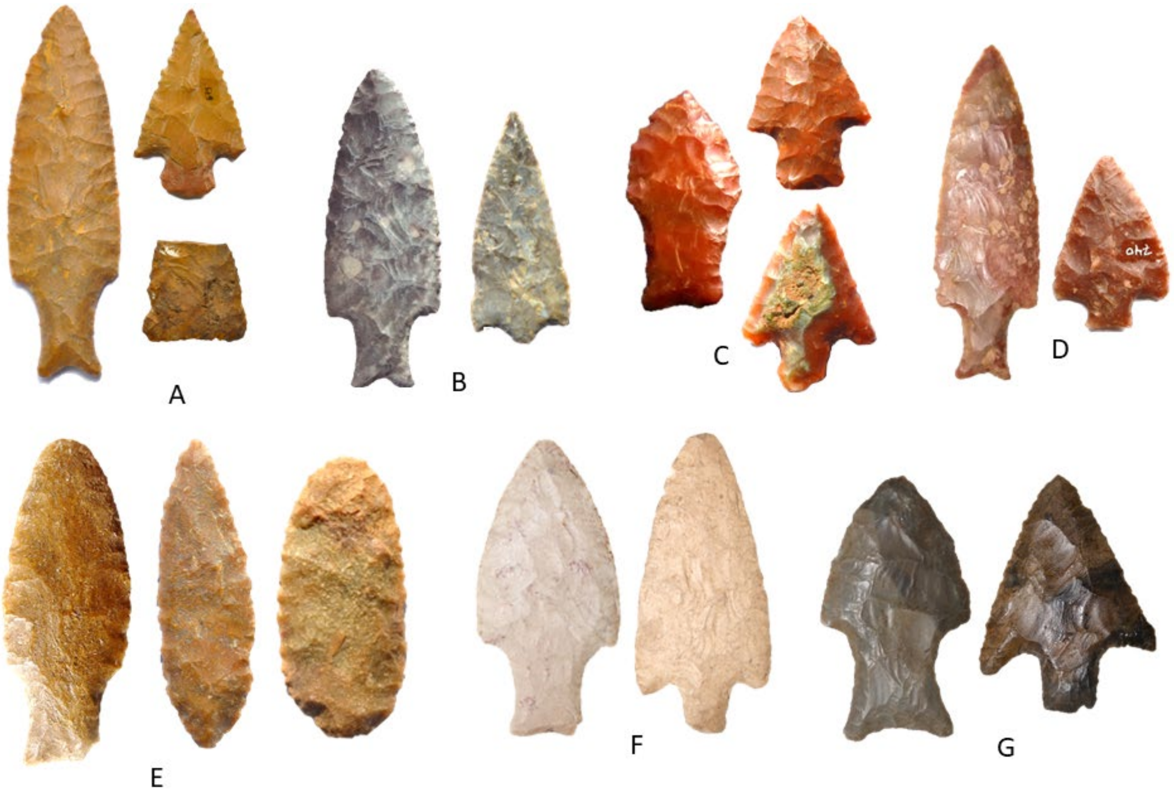

Figure 5. Fell points (left of each group) and Holocene bifaces from southern Brazil. The non-FPs artefacts grouped in A, B, D, and E are curated at Museu ao Ar Livre Princesa Isabel de Orleans, State of Santa Catarina. Group C: the two red cherts points ("Umbú" type) were recovered at the Chapecó county and curated at the Centro de Memória do Oeste de Santa Catarina (CEOM/Unochapecó). One of them preserves the cortex of the tabular node from which it was manufactured (CEOM/Unochapecó collection, Santa Catarina State). F and G: National Museum collection, Universidad Federal do Rio de Janeiro (courtesy of Mercedes Okumura). The groups of pieces are not to scale.

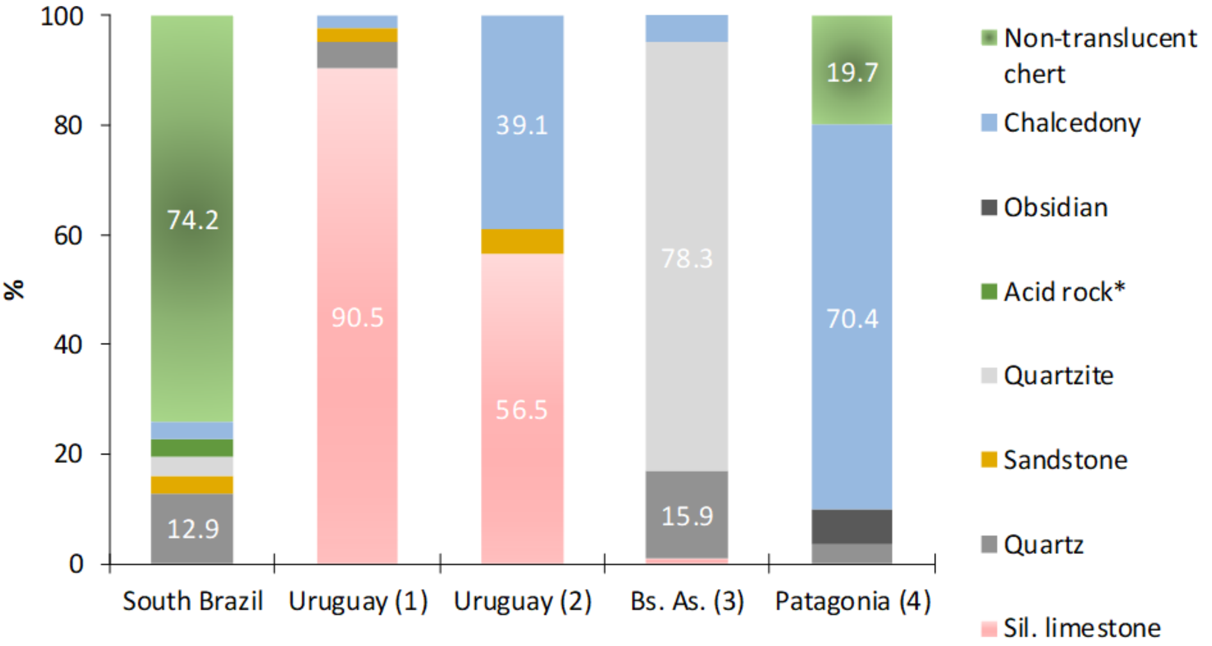

Figure 6. Raw materials in different collections of FPs. South Brazil is based on Table 1 of this study; Uruguay (1) based on Nami (2013: table 1); Uruguay (2) based on Castiñeira *et al.* (2011: table 1); Bs. As. (3) based on Flegenheimer & Weitzel (2017: table 3). (4) based on Somuncurá collection reported by Hermo *et al.* (2015: 105). The collections from Uruguay are assumed to have random selection criteria, but it cannot be assured.

2.2. The lithic landscape

In order to identify the offer of lithic resources in the landscapes of Southern Brazil covered by the Botucatú - Serra Geral Vulcano Sedimentary Complex (BSGC hereafter) (see Supplementary file 3), we carried out several surveys in different counties of Santa Catarina State (Supplementary file 4), associated with a large scale CRM project (Carbonera & Loponte 2020). The BSGC includes the sandstones of the Botucatú Formation (Jurassic - Cretaceous aeolian sandstones), originated under an arid desert climate, on which the lavas of the Serra Geral Formation flowed, as a consequence of the Atlantic Ocean opening, and which covered most of the surface of the southern States of Brazil. They are formed mainly by tholeitic basalts (90%), andesites (7%) and rhyodacites-rhyolites (3%) (Piccirillo & Melfi 1988: 123; Benites *et al*. 2020), where different facies were recognized (Wildner *et al*. 2006: 17, 2007). These basalts form the hills and the bedrock (~ 500 m thick on average, up to several km) below the topsoils, except in the coastal area and the surroundings, where other geological formations emerge, and the more complex geology of the Paraná basin is exposed (see Supplementary file 3). The BSGC also includes intertrap silicified sandstones, composed by quartz (~ 90%), feldspar (~ 5%) and opaque minerals (~ 5%), cemented with chalcedony (Pinto *et al*. 2015), interpreted as an injectite complex formed mostly from the sands of the Botucatú Formation (Pinto *et al*. 2015; Hartmann *et al*. 2012). They are interspersed between the basalts as small mantles, ranging from a few centimetres to a few meters thick (Martins *et al*. 2011; Milani *et al*. 2007; Wildner *et al*. 2006: 32).

During the surveys, carried out throughout 15 months in 47 counties, the lithic composition of numerous hill slopes, fallen rocks, and riversides was evaluated, including a systematic sampling of rocks available in local rivers and streams. The results show that basalts (including a small proportion of andesites and rhyodacites-rhyolites), and silicified sandstones, are ubiquitous in the landscape covered by the BSGC, both easy to be identified and extracted from the local hills, canyons, and in all the rivers and streams widely distributed in the region, which furrow the surface of the landscape. In the rivers and streams, basalts and silicified sandstones are present as boulders, cobbles and loose pebbles as well as in conglomerates in the river-banks, which facilitates the identification, selection and handling (Sillitoe & Hardy 2003 for ethnographic examples of selection of pebbles handling and selection) (Figures 7, 8 and 9).

Four facies of basalts at least were recognized during the surveys (Figure 10). Each one of them has a different composition and properties, with distinct quality for knapping. Basalts were subjected to direct knapping with a hammerstone. Flakes were extracted from cores by direct percussion to evaluate the quality of the natural edges, and then they were retouched by direct percussion and pressure to assess its workability. The results show that the effusive facies Campo Erê and Capanema (*sensu* Wildner *et al*. 2006: 20, 28) have no or very little quality for knapping, although low quality cutting edges are obtained with the second. The Campos Novos facies presents a somewhat better quality, and Cordilheira Alta facies shows the best conchoid fracture of all the basalts observed, reaching medium quality to medium-high quality in the case of silicic dacites – rhyolites. Silicified sandstones were also tested. The quality of this rock for knapping varies according to the degree of silicification and the grain size they have (see thin sections in Supplementary file 5). As an average, they are of medium to medium-high quality.

Figure 7. A: exposed basalts in a typical hillside in Urubici County (Santa Catarina State). B: basalt bedrock under the topsoil of the forest (~ 30 cm thick), exposed by mechanical excavation (Bom Retiro County, Santa Catarina State). C: fallen rocks (basalts) (Lava Tudo river, Urubici County, Santa Catarina State).

Figure 8. Left: pebbles and cobbles in the Upper Uruguay River (Caxambú do Sul County; Santa Catarina). Right: exposed walls, fallen rocks, cobbles and pebbles in Santa Bárbara stream (Bom Jardim da Serra County, Santa Catarina).

Figure 9. Silicified sandstones marked with white arrows. A: boulder (fractured) emerging in Taquarussú River (Chapecó County). B: pebble fractured during the sampling in Taquarussú River (Cordilheira Alta County). C: pebble in Uruguay River (Palmitos County, Santa Catarina). D: fractured pebbles in Ariranha River (Arvoredo County, Santa Catarina).

Despite the medium to medium-high quality of some basalts and the silicified sandstones, and the wide availability of both rocks in the landscape, we have already seen that they were rarely selected to manufacture FPs (see Figure 4). The reason probably lies in the fact that cherts are easier to knap and to resharpen than macro and mesocrystalline materials such as basalt and silicified sandstones (Wilson 2007). While the appreciation of quality is often subjective (Callahan 1979), the edges and the conchoidal fracture of the basalts, even in the Cordilheira Alta facies, seem to be of a lower quality compared with the chert. The latter also has higher compression strength than basalt (Luedtke 1992: 72), which makes it less susceptible to impact fractures (Bergman & Newcomer 1983; but see Loendorf *et al*. 2018), although its elasticity is somewhat lower. On the other hand, the silicified sandstones are more friable and brittle than chert.

Chalcedony is another rock included in the BSGC, although its availability is substantially much lower than basalt and silicified sandstone. It occurs in small outcrops included in the basalts (Figure 11), although these tabular nodules seem to be rare. In fact, they are practically undescribed in the BSGC geology. We found just one outcrop identified during the surveys in Alto Bela Vista County. However, fragments of tabular nodules and pebbles of high quality of translucent and banded chalcedony were observed in local museums, collected in the surroundings of each town (Supplementary file 8). The most abundant source of chalcedony observed in the surveys are geodes and amygdales included in the vesicular mantles of the basalts (Wildner *et al*. 2007), which once eroded, mostly by fluvial action, are accumulated in banks and along the rivers and streams, easy to identify and handle (see next section). This rock was poorly represented among the points included in the collection (see Figure 4), although it was widely used in Patagonia (Hermo *et al*. 2015 and to a lesser extent, in Uruguay; see Figure 6). Probably, its exclusion to manufacture FPs in the area is due to the scarcity of outcrops and the small sizes of the chalcedony pebbles, often smaller than 7 cm (see next section). However, a higher frequency in larger samples cannot be ruled out.

Figure 10. Basalt facies of the BSGC. A: Campo Erê facies. B: Cordilheira Alta facies (Painel County). C: Capanema facies. D: Campos Novos facies (Anita Garibaldi County). Photos A and C correspond to the province of Misiones (adjacent to the survey area) and have been selected because they better illustrate these two facies (both images are courtesy of Marcela Remesal and Silvia Chavez).

We have already seen that a few quantities of FPs were made from quartz (Figure 3, Table 1; see also Miller 1987: 57 & fig. 13a). Also, a preform of FP made from tabular xenomorphic quartz was recovered in Orleans County (Santa Catarina), and other is curated at the Instituto Anchietano de Pesquisas, Rio Grande do Sul State (Supplementary file 7). This rock is also included in the BSGC, often as small geodes and amygdales in the vesicular basalts (Fernandes *et al*. 2010; Reis *et al*. 2014; Wildner *et al*. 2006: 15) (see Figure 12). Small and loose fragments of quartz were also recognized within the topsoils. No tabular outcrops nor pebbles longer than 6 cm were identified during the surveys.

Figure 11. Chalcedony outcrop included in the basalt (Alto Bela Vista County, Santa Catarina State).

Finally, only one small tabular outcrop of non-translucent chert was identified. These siliceous fillers are also not well documented in regional geology. It was detected included in the basalts of the bed of the Santa Bárbara Stream, in Bom Jardim da Serra County (Figure 12). We also observed a chert nodule collected by a resident of Abdon Batista County on the bank of the Uruguay River (Supplementary file 8), and some non-translucent chert pebbles on other riversides (see next section). Given these results, their occurrence in the landscape appears to be quite rare.

2.2.1. Pebbles and cobbles in river banks

We have mentioned that rivers and streams erode the BSGC, acting as natural samplers of the landscape lithologies, and forming linear lithic sources composed by loose pebbles and cobbles, as well as fluvial conglomerates exposed in the riverbanks. This facilitates the identification, testing, selection and handling of rocks along the landscape. To recognize their lithological composition, eleven sampling units (1 m^2 each one) were analysed in Uruguay, Ariranha and Taquarassú riversides (see Figure 13 and Supplementary file 4 for geographic location). In total, we tested 265 cobbles and pebbles larger than 6 cm, identifying the lithologies by fracturing them with a hammerstone.

Figure 12. A: amygdales of quartz included in the basalts (Abdon Batista County, Santa Catarina). B: non-translucent tabular nodule of chert (white) included in the bed of the Santa Bárbara stream (Bom Jardim da Serra County). The scale has painted segments, each one of 10 cm length.

Figure 13. A: Sampled area in the Uruguay River (Palmitos County). B: Detail of the pebbles on the same riverside. C: Detail of pebbles and cobbles in Ariranha River (Arvoredo County). D: Sampled area in the Ariranha River. E: Sampled area in the Taquarussú River (Cordilheira Alta County).

The results of the sampling (Figure 14), show that among pebbles and cobbles, the basalts (all facies added) predominates (81% – 92%; average 85.7%), followed by silicified sandstone (19% – 8%; averaging 13.8%). This sampling also reveals the scarcity of chalcedony, quartz and non-translucent cherts in cobbles and pebbles larger than 6 cm. To broaden the sampling, an extended and selective search was done to look for non-translucent cherts on the overall surface of the riverbanks of the three sampling areas, encompassing in total 15,500 m^2 covered by pebbles and cobbles. Boulders were also tested. As a result, besides some chalcedony small pebbles (< 6 cm), four potential cores of non-translucent cherts greater than 6 cm long were identified (Figure 15), reinforcing the results previously obtained in the surveys regarding the scarcity of the offer of these cherts.

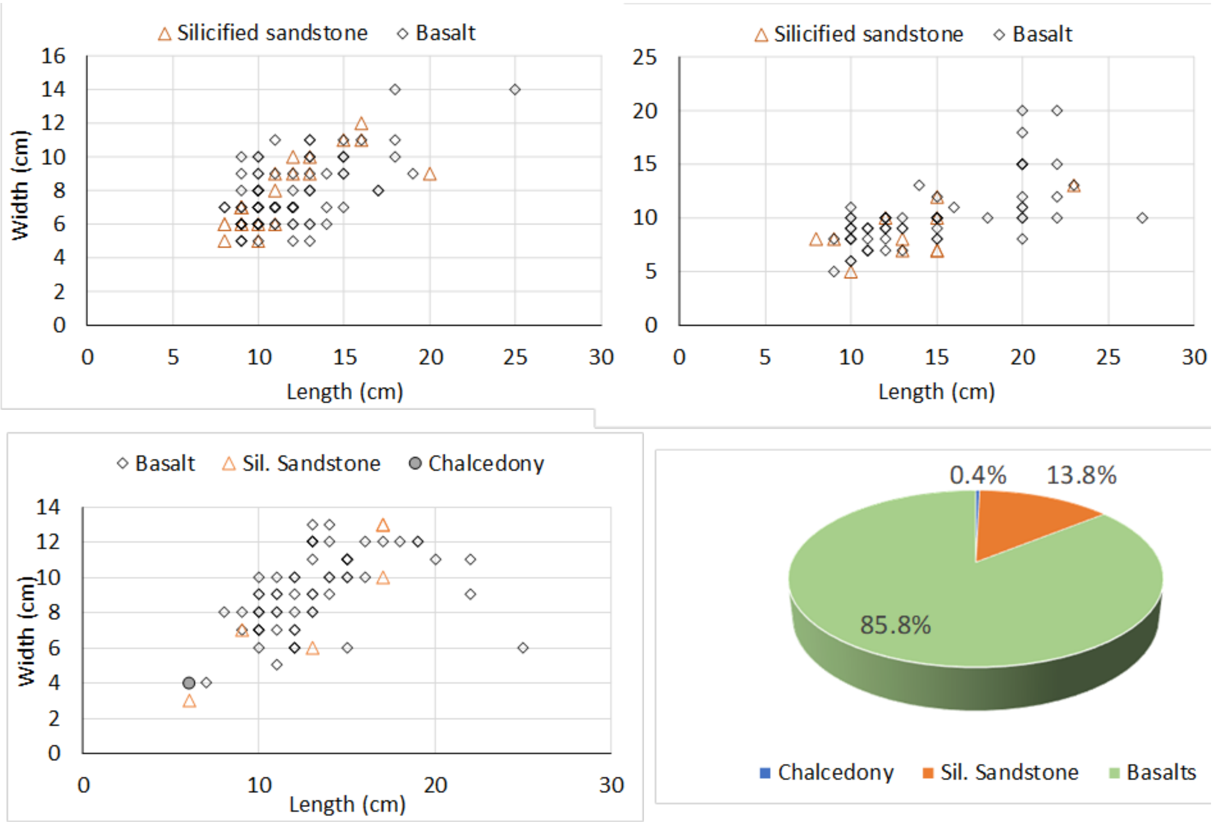

Figure 14. Lithologies and sizes (rounded) of the pebbles and cobbles analysed in the sampling units located at the Uruguay, Ariranha and Taquarussú rivers (Santa Catarina State). The basalts may include a small fraction of andesites, rhyodacites and rhyolites. The pie chart includes all the samples of the three rivers.

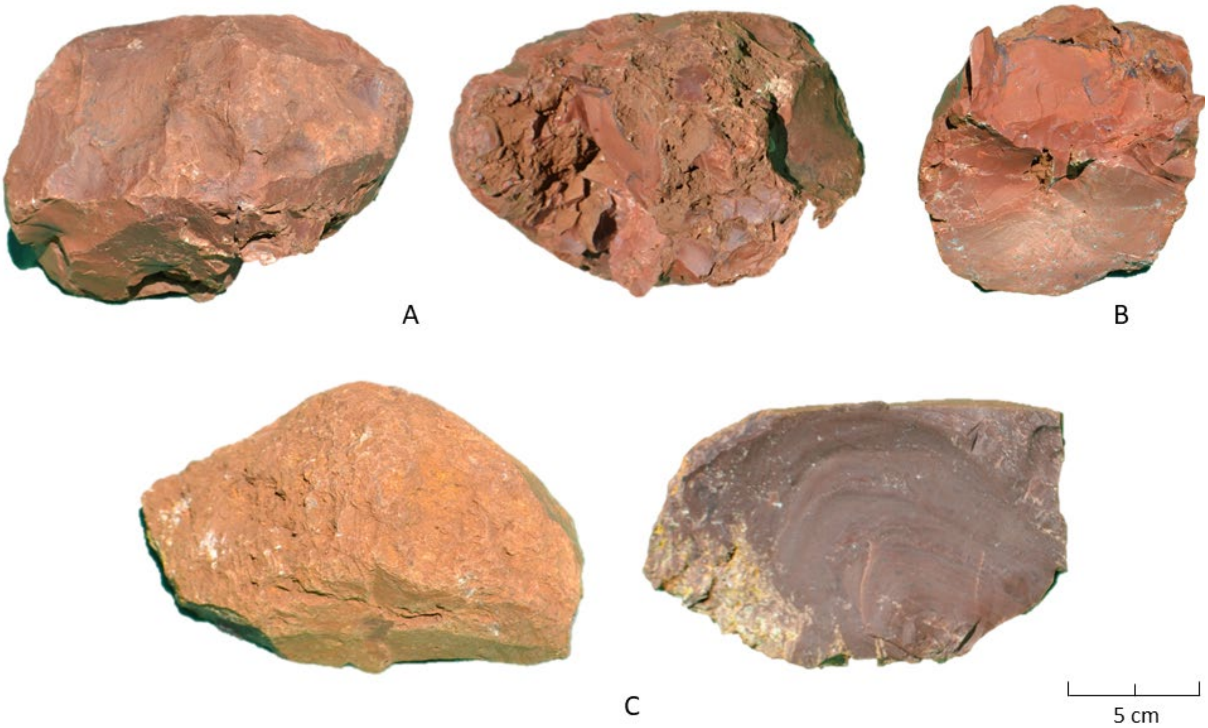

Figure 15. Non-translucent cherts recovered from the riversides during the survey. Upper line: pebble (probably from tabular clast) of reddish chert. A: external views. B: fractured by percussion. C: pebble of brownish-reddish chert. Left: external view; right: fractured by percussion.

On the riversides, non-translucent pebbles of cherts could be recognized with the naked eye. However, we cannot rule out an underrepresentation in our sampling. In fact, their external identification is sometimes doubtful and therefore must be broken for evaluation of lithology and also its quality. Likewise, it is very feasible that in the past, this testing procedure was common in the area, leaving a record of broken pebbles on the riversides (*e.g.*, pebbles with one or few extractions, "choppers" and "chopping tools"). The searching and testing process carried out, indeed proved to be a very time-consuming process.

2.3. Acquisition

Two main mechanisms have been proposed for the direct acquisition of the main lithic raw materials used by hunter-gatherers: opportunistic supply embedded in subsistence activities, or exclusive trips, although the latter is described as rare (Binford 1979: 259; but see Burton 1984 -among others- for horticulture societies). The most usual techniques suggested for direct provisioning (excluding catches) are unexpected encounters, planned surface collection or planned quarry extraction (Ataman *et al*. 1992; Elston 1992; Elston *et al*. 1992; Wilson 2007).

For the surveyed area, the acquisition of basalts and silicified sandstone can be embedded in other activities, since they are ubiquitously distributed. Conversely, non-translucent cherts are scarce in the landscape, so their acquisition would have been time-consuming. For primary sources (tabular clasts), special travels should be considered, and planned surface collection for secondary sources.

During the Pleistocene-Holocene boundary, the vegetation of the Campos predominated in the Brazilian Plateau (Behling 1995; 2002; Behling & Oliveira 2018; Eidt *et al*. 2021; Lima 2010: 227; Lima *et al*. 2016), which undoubtedly left large areas of the BSGC uncovered, and then, random encounters with small outcrops of non-translucent cherts would have been somewhat more frequent than today. However, chert outcrops are substantially less frequent in the landscape than pebble accumulations. Given that the analysed points have no traces of cortex, we cannot make any progress in identifying whether they come from pebbles or tabular nodules, but due to the environmental scarcity of these cherts, both forms may have been used, and they must have been a highly valued raw material, subjected to conservation strategies.

3. Designs and technological features

Lithic raw material properties, abundance and distribution impact the organization of the technology, and to some extent, the typology (Andrefsky 1994a; 1994b; Archer & Brown 2010; Brantingham *et al*. 2000; Eren *et al*. 2014), which is closely related to the functionality of the artefacts. At the same time, their features are related to cultural transmission of the kappers (Eerkens & Lipo 2005). In order to explore the designs related to the functionality of the points, a frame of reference is essential, including the original designs supported by morphometric and technological criteria; replications of the manufacturing process, and a collection of points showing the most common behaviours of resharperning and rejuvenation (see Hayden 1987 and Towner and Warburton 1990 for the differentiation of both terms). We use here the general term rejuvenation as any modification of the piece, leaving it different from its original design, which is generally applied due to the damage received during its us processes, and keeping the analysis in three dimensions, which in projectile points is crucial (*e.g.* Bradley & Stanford 1987; Flenniken & Raymond 1986; Frison & Zeimans 1980; Hughes 1988; Iovită 2011; Nami 1990; 2014b: 183; Sholts *et al*. 2017; Shott & Ballenger 2007, among many others). Fortunately, several studies and ideas about design, manufacture and maintenance sequence of FPs are available to be applied or compared to our sample (Ardila Calderón 1991; Flegenheimer & Weitzel 2017; Hermo *et al*. 2015; Mayer-Oakes 1986a; 1986b; Nami 2003; 2007; 2010; 2013; 2014a: 285; 2014b: 183; Suárez 2011b: 169). Thus, as part of the second objective of this study, in the next sections we will discuss briefly some of the design and functional aspects of the collection included in this study.

3.1. Stems and thickness

Regardless of the rejuvenation process, the stems of the FPs in southern Brazil show a robust design, with a stem length/width ratio close to 1 (Table 1). This robust design is also evident in the stem width/maxim thickness ratio (SW/Th), averaging 2.8 ± 1.2, and reaching an extreme robustness in piece 17 (ratio 1.8; see Figure 16). Due to this shape, the bevel angles of the stems are substantially greater than those of the blades. For instance, in Figure 16, the angles of the blades are 29° and 34°, but their stems are ~ 40° and 54° respectively. This robust shape contributes to keeping the stem unmodified during the rejuvenation process. Indeed, the coefficient of variation of the stem length in points listed in Table 1 is 19.3%, and 15.8% in the width. Both are substantially smaller than the CV of the maximum length (39.3%) and the blade width (35.7%), both subjected to regular rejuvenation processes, although some variation in the last two dimensions are related to different original designs (see next sections). The small dimensional variability of the stems through the rejuvenation process are mainly related to the fracture of the ears, which protruded laterally from the shaft, leaving them exposed and prone to impacts when the projectile hit the prey (Flenniken & Wilke 1989). The rejuvenation of the ears also modified, to some extent, the profile of the basal concavity of the stem. Thus, the ears of the rejuvenated points tend not to be prominent, and the basal concavity may be softened (Figure 16), or disappear. This, of course, does not happen in all the rejuvenated pieces, since in some of them the ears and the basal concavity may be reshaped.

Due to these small modifications in the stems, the maximum length and width do not show strong allometric relationships with other measures of these points (Loponte *et al.*, 2015; 2016). The fact that stem sizes are barely modified during the rejuvenation is well known in literature, and therefore, their measures are usually used as an indicator of the initial sizes of the points (Buchanan *et al*. 2015; Hoffman 1985; Nami 1990; 2000; Shott 1993; Shott & Balanguer 2007).

Besides the small variation in maximum length and width of the stems, their lateral biconcavity (measure MSW, see Supplementary file 2) varies even less ($\bar{x}_{22} = 16.4 \pm 1.5$ mm; CV = 9.1%) probably because of their passive function. Although there is a moderate relationship with the maximum length of the points ($r = 0.41$; $p = 0.06$), in absolute terms showing a variation of ~ 4 mm between the largest and smallest points included in this study (Figure 17, left graph). However, it is certainly true that points which are close to the "saturated resharpened" stage (Nami 2013) present the smallest SMW of the entire collection (Figure 17, left graph), probably due to the rejuvenation of the ears that forces a slight modification of the stem biconcavity, which happened towards the end of the life-cycle of the points. But on the other hand, in some large points, the SMW are even smaller than some of these highly resharpened pieces (Figure 17, left graph), showing the low or null impact of the rejuvenation process on the stem's sides.

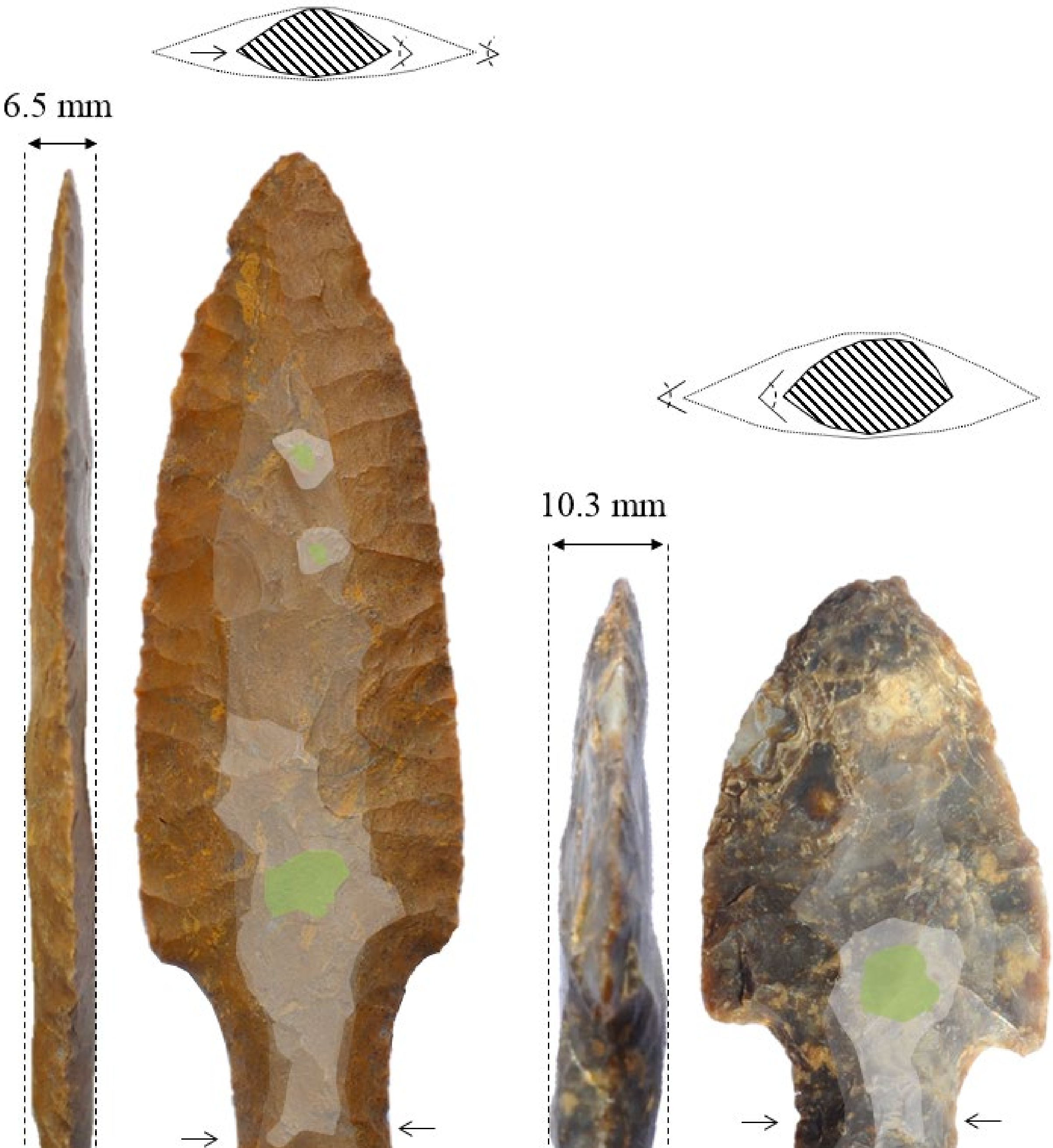

Figure 16. Topographic model (dorsal view) of a large triangular (slightly lanceolate) FP (piece A), and a reshaped triangular one (piece B). In grey, the greater thickness area; in green, the maximum thickness spots. The cross-section view compares blade and stem angle, area and perimeter. At the bottom, potential changes in the basal concavity (white lines) and ears (red lines) through the rejuvenation process. See the abrupt change in the thickness along the distal stem and blade base, and its mid sector in the rejuvenated point B.

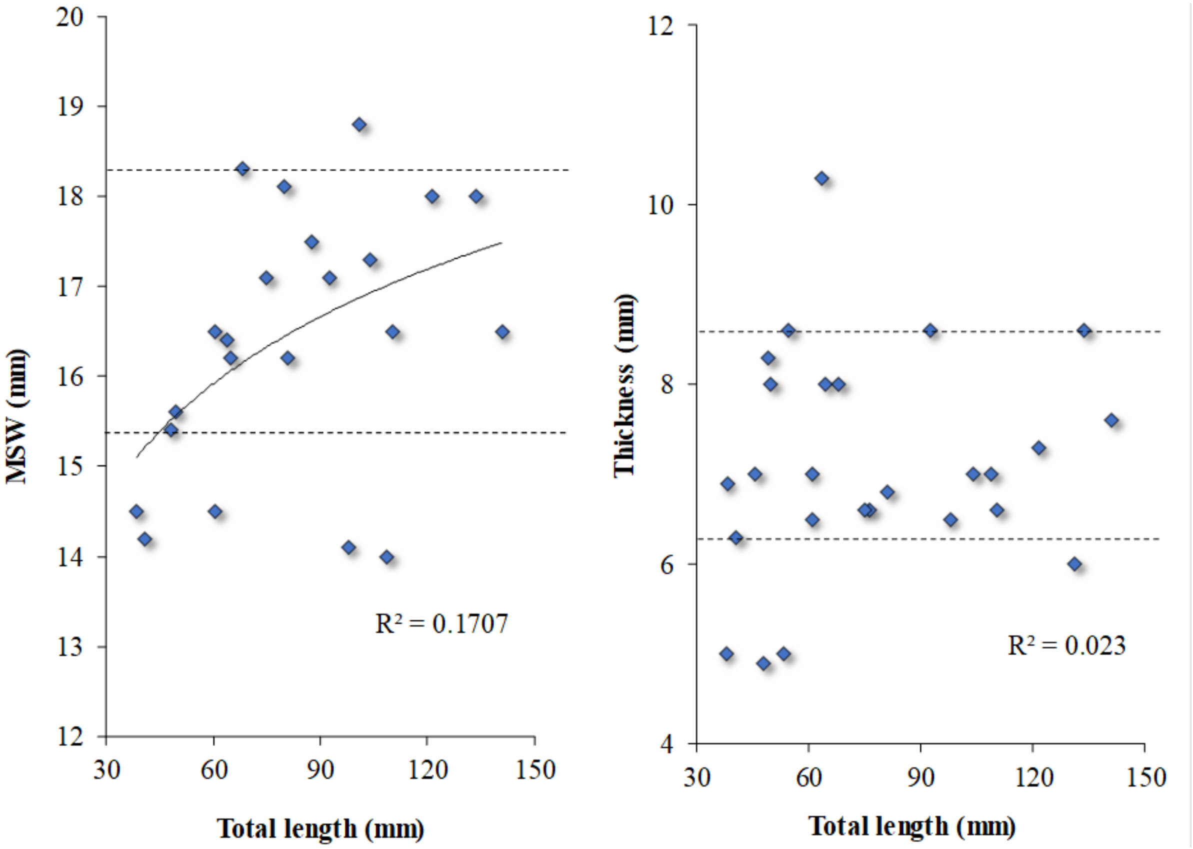

Figure 17. Left: biplot between the maximum length of the points and the minimum width of the stem (MSW). The dotted lines between 15.4 - 18.3 mm comprise 72% of MSW distribution (Q1 – Q3: 15.4 – 17.5 mm). Right: maximum length and maximum thickness of the points. The dotted line (2 mm) encompasses ~ 80% of the thickness, between 6.3 - 8.6 mm (Q1 – Q3: 6.5 – 8 mm).

The other key dimension of the stem is the thickness, which shows no variation at all during the entire rejuvenation process. This dimension is probably the most critical in a stemmed point, because a fracture in the midsection or distal area of the stem often implies its uselessness as a weapon, or a significant rejuvenation process (see discussion about the basal thickness and hafting fractures in Hughes 1998). The maximum thickness of the stems in the FPs in the collection analysed here is similar to the maximum thickness of each point, forming with the base of the blade, the thickest area of these bifaces (Figure 16). However, in some pieces of other regions, the fluting surpasses the blade-stem junction (Meggers 2007: 137; Nami 2016a), leaving more fragile this area. Different studies report a significant proportion of fractures precisely in the middle and distal area of the stems, and in the adjoining area with the blade of the FPs (Briceño Rosario 2010: 258-259; Flegenheimer & Weitzel 2017; Hermo *et al*. 2015; Nami 2001; 2014b: 187; 2016a). These fractures are also observed in pieces used in replicative attempts of manual launches (Flegenheimer *et al*. 2010: 225), although quartzite instead of cherts were used, which certainly have different mechanical properties.

Similar to stems, the maximum thickness of the blades shows practically no variation. No significant correlation was observed between the thicknesses and the length of the points selected in this study (r = 0.15, p = 0.45) (Figure 17, right graph), nor with other significant measurements. The thickness invariance is also well known in morphometric studies of projectile points (Bettinger & Eerkens 1999; Flenniken & Raymond 1986; Nami 1990; 2000; Shott *et al*. 2007; Towner & Warburton 1990). We have already seen that the greatest thickness is located at the base of the blade, near where it joins the stem. This happens for both large and small points, including those with numerous and typical variables resulting from the rejuvenation (see below). This centre of gravity shifted towards the basal sector could be designed to cope with the stress of leverage, and to dissipate the tensional stress behind the compressional forces during the impact, deriving the fracture towards the distal end of the blade, allowing a controlled rejuvenation process (see Hughes 1998). Fractures above this gravity spot, probably as a result of the impact, can be seen in FPs published by Miller (1969, fig. 4, point n), and in other South American regions that also used cherts to produce FPs (see images and discussions of these fractures in Bird 1969; Briceño Rosario 2010: 258-260; Hermo *et al*. 2015; Nami 2014b: 187-203).

3.2. Blades and shoulders

Based on size, weight, morphology and technological evidence of rejuvenation, we grouped the points into three subsets. Those above 120 mm of maximum length (pieces 1, 2, 3 and 26, Table 1) are included in the first cohort, which are probably original designs (see below). These large and heavy points (~ 80 gr, see Table 1) present lanceolate blades, preferably with straight shoulders. The point 7 (Figure 3), which is somewhat smaller (101.1 mm), shows this same design. Below the threshold of 120 mm, the blades show a simple and similar reduction process, or follow a similar design pattern in most of the points, which keeps an allometric relationship with the maximum length ($r = 0.82$; $p. <0.001$), until the width of the blade is substantially reduced, approaching the width of the stem, and concurrently with a progressive decrease in the ratio blade width/blade thickness, turning the points towards a conical shape, decreasing its penetration capacity (Figure 18 and see below figures).

The second subset comprises pieces between ~ 110 and 87 mm long, and ~ 30 gr of weight (pieces 4 to 10, Table 1). Whether they are the product of a rejuvenation process or probably original designs (see Section 4), they have predominantly triangular or slightly lanceolate blades (like point 4, Figure 3). The trailing edge practically disappears or is minimally developed, maximizing the length of the leading edge which rests on mostly straight shoulders (Figure 3, points 4 to 10; see also Figure 19).

Then, after this second cohort, all FPs below ~ 80 mm of maximum length, show distinct techno-morphological evidences of rejuvenation, keeping preferentially the triangular blade form (Figures 19 and 20) (except for those medium-sized points with rounded shoulders and lanceolate blades which we will discuss below). These smaller and triangular points show the classic compression of the silhouette with a more obtuse front angle than the second subset, generating wider blades associated with more or less straight shoulders. Again, this reduction scheme preserves the maximum cutting edge, maximizes the size of the wound and the bleeding area as much as possible, increasing the possibility of reaching central arteries and vital organs. The straight shoulder probably seeks a projectile to be fixed into the body of the prey, holding the bleeding and not to withdraw the projectile to deliver new thrusts. This maximum lethality design to be made in a single thrust, is maintained even in smaller FPs as piece 21 (Figures 3 and 19). Note that at least one of the shoulders is still sought to be held straight even in the smaller pieces of the collection, such as points 20, 22 and 23 (Figure 3). These pieces are points so heavily modified that their maximum blade widths reached dimensions close to the maximum width of the stems, such as point 24 of the Figure 3 (see also Figure 18, left graph).

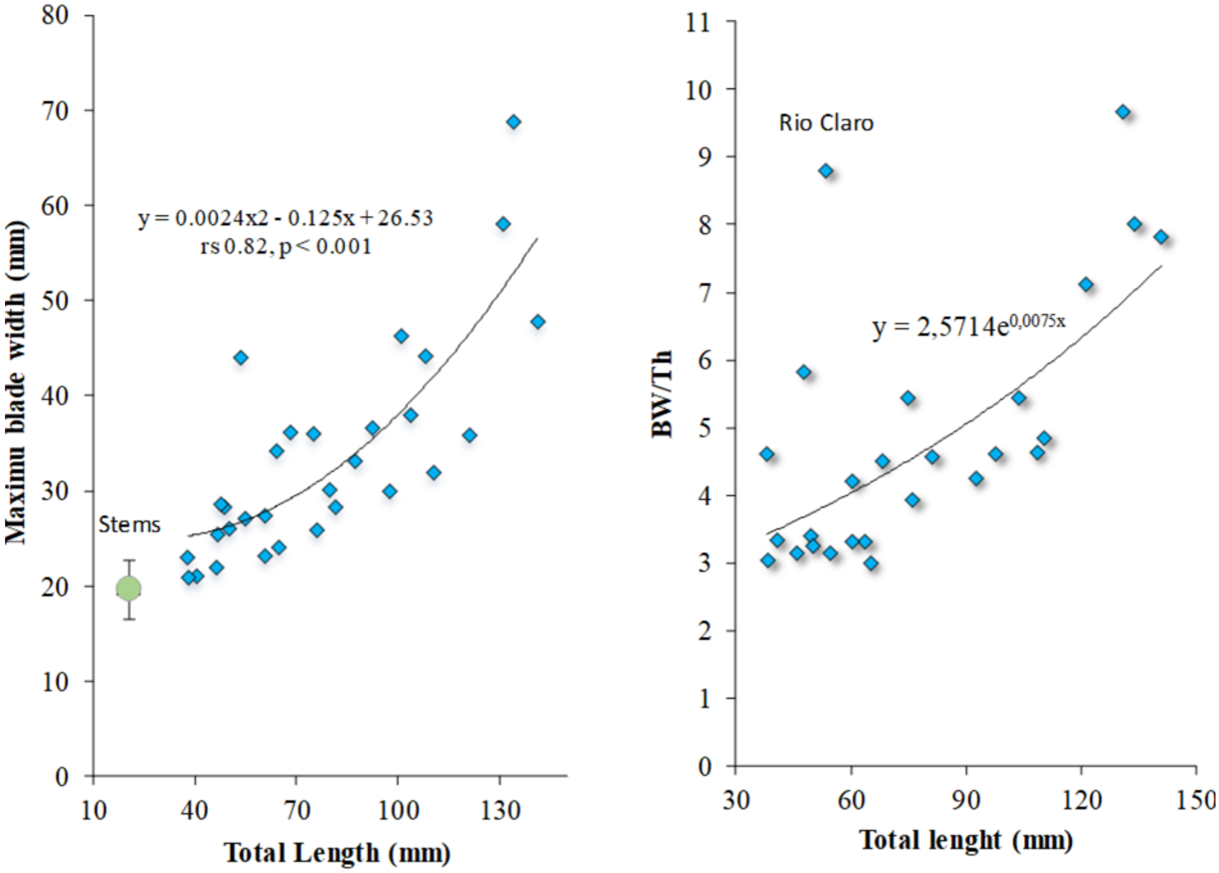

Figure 18. Left: biplot of the maximum length of the FPs and the maximum width of the blade. The green spot represents the stem sizes (± 1 σ). Right: biplot of the maximum length and the ratio blade and thickness.

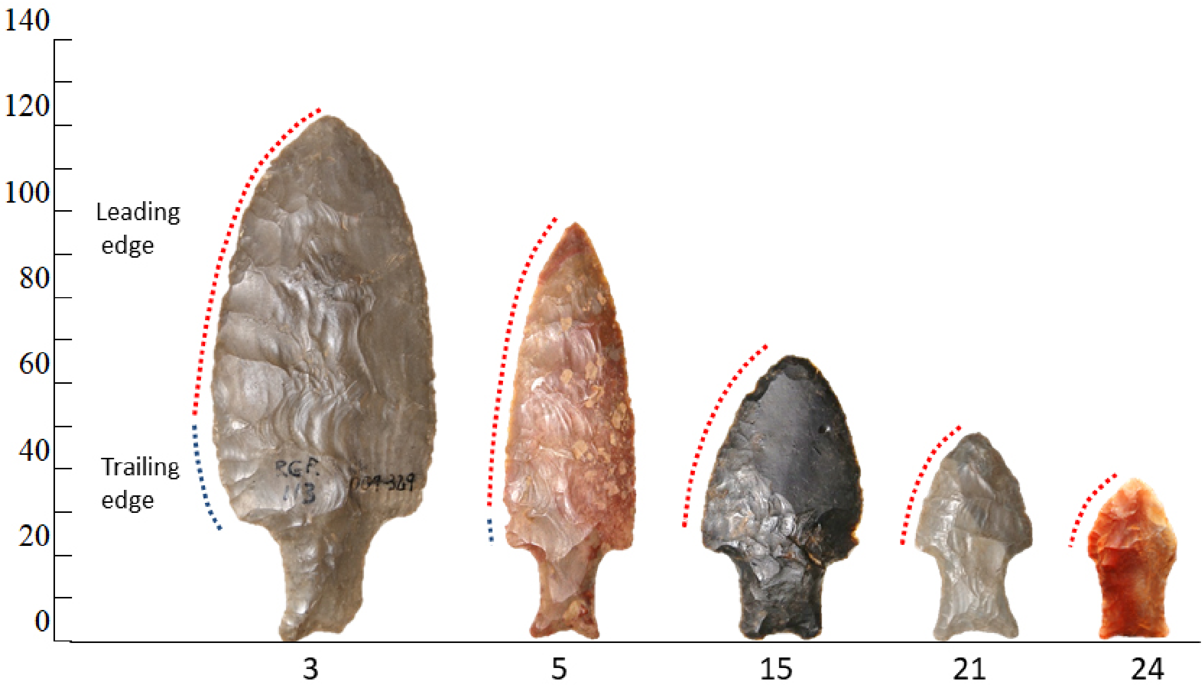

Figure 19. Changes in the relative length of the leading edges, keeping triangular blades and straight shoulders (except in the smaller point #24) throughout the rejuvenation process (or different and smaller designs; see text).

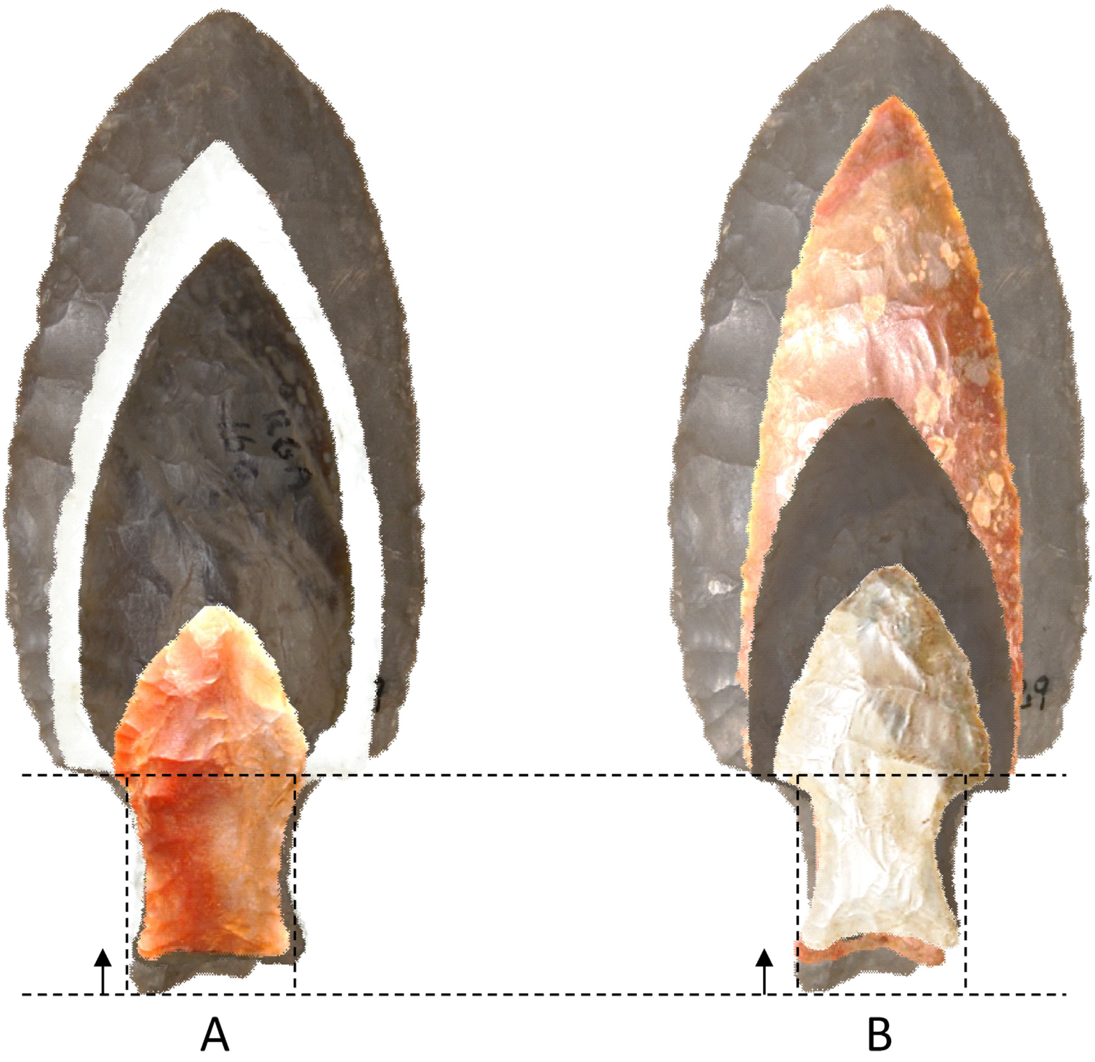

Figure 20. Schematic overlay of some of the points included in this study, featuring different original designs and simple rejuvenation process of blade and the stem (see text). Note that the quadrangular shape of the stem, and their low size variation, focused on the ears. The Example B shows the straight shoulder from larger to smaller points. The figures are slightly coloured.

The overlay of projectile point silhouettes is a resource widely used in studies on morphological variability in relation to rejuvenation processes, used by several authors since some decades ago (*e.g.*, Bradley *et al*. 2010: 185; Flenniken & Raymond 1986; Nami 1990), and recently through digital images, with a different explanatory capacity depending on the examples used, and how this methodology is applied. In the FPs, drawings of overlay silhouettes of several points were used by Suárez (2003: 33), whose main conclusions are that the blade is reduced during the maintenance process, as well as shoulders becoming rounded, since the larger pieces would present straight shoulders, and points below ~ 7 cm (according to the scale of the scheme), rounded ones (see also Suárez 2011b: 181-182). The latter idea was also suggested by Iriarte a few years before (1995: 144). In fact, the modification of the shoulders as the points are used has also been pointed out for other projectile points (*i.e*. Flenniken & Wilke 1989). Likewise, according to the scheme presented by Suárez (2003: 33), the larger pieces have triangular blades, and those that would have been rejuvenated, show lanceolate blades. Regarding this, Nami (2014b: 189) pointed out that differences in shoulder morphology may be due to what we could classify as random replicative variations. Certainly, the largest points of the subset 1 and 2 included in this study, in general terms, have straight shoulders, but large FPs with rounded shoulders were also published (Nami 2013: fig. 4, pieces g and l; Collet 1987: 102-103 which is included in Table 1 of this study as point 26. See also piece 2 of this study, but it is probably unfinished). On the other hand, we have seen several small points below 7 cm that keep the triangular blades, and the straight shoulders as long as they can (Figure 3, pieces 15, 17, 18, and 21, and one straight shoulder in pieces 20 and 22), which could be related to functional requirements. Thus, within the analyzed sample, the original designs and the rejuvenation process seem to be somewhat more complex, and the reduction processes do not necessarily produce rounded shoulders, except in highly resharpened and “saturated” points (Nami 2013).

3.3. Front and edge angles

Lithic studies have been measuring the angles of the points for decades, since the front angle is linked to the penetration capacity (Ahler & Geib 2000; Crabtree 1966; Frison & Zeimans 1980; Friis-Hansen 1990; Hughes 1998; Thomas 1978; Sisk & Shea 2011). Given that most of the tips are eroded, the angles should be measured according to the inclination of the tip sides. We measured the front angles of the points with a manual angle meter, or with the free access GeoGebra program once the points were digitalized.

The first subset of points has front angles that vary between ~ 70° and 90° (except for point 2 which is ~110°, but it is probably not finished), getting sharper in the second dimensional subset, which regularly exhibits ~ 60° (points 4 to 10 of Figure 3, except piece 7, which has an angle of ~ 85°, similar to the first cohort; see also section 3.2). Therefore, a wider front angle is not observed in this second cohort as is expected as a general trend in reworked points, reinforcing the idea that the second dimensional subset may respond to original designs.

In the third dimensional cohort, which includes the points below the 80 mm of maximum length, the front angles are similar to the first subset, ranging from ~ 70° to 80°, and ~ 90° in piece 20 (Figure 3). Finally, it should be noted that in the medium-sized lanceolate points with rounded shoulders (pieces 11, 12, 13, 16 and 19 from Figure 3), the front angles oscillate around 70° - 90°. While we will not include a discussion of the propulsion system here, the observed range of the front angles are wider than those proposed for points used with complex propulsion devices (Friis-Hansen 1990; Sahle & Brooks 2019), but similar to other points used by Paleoamericans where complex systems are alleged (*i.e.*, Ahler & Geib 2000). The option for open angles such as those observed in the FPs included here in both the bigger and smaller subsets, has been related to behaviours that favour the conservation of the points to the detriment of a better quality of penetration (Ahler & Geib 2000; Crabtree 1966; Hughes 1998; Sahle & Brooks 2019). For subset 2, the angle of attack is certainly sharper, favouring the penetration capacity. In Uruguay, a set of FPs shows front angles ranging from 60° to 120° (groups A and B; Suárez 2011b: 181).

Within the collection, the angles of the edges of the blades vary with the total width, since the thickness remains quite constant, thus, this angle is closely related to the maintenance process (Figure 21). The resharpening creates a more obtuse angle, decreasing the penetration capacity of the point if the kinetic energy of the hit remains constant. These angles could be calculated using the cotangent function considering the trigonometric reduction of the hemisection of the blade, based on the relationship between its width and its thickness, which is a geometrically consistent way of measuring (Ahler & Geib 2000). The resulting predicted distribution observed in Figure 22 is a flat cross-section of the larger pieces (subset 1) maximizing their lateral cut capacity and wound width. On the other hand, points below 80 mm length (third subset) present a substantially open cutting angle which decreases their effectiveness and the wound size by reducing its cross-section area and perimeter, also tending to form conical cross-sections, which also decreases, to some extent, the efficiency of penetration. This subset often shows asymmetric and unbalancing blades (Figure 21)

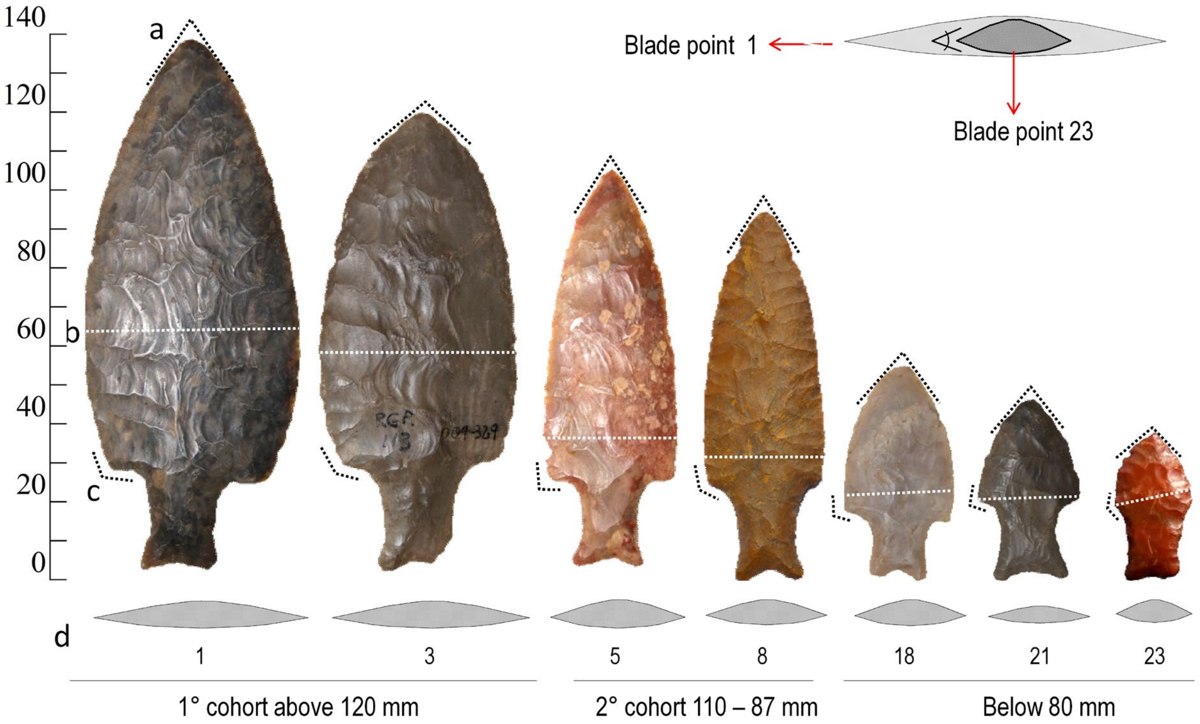

Figure 21. Some morphological features of the points discussed in the text. a: front angles. b: Symmetry of the leading edges; c: shoulders; d: cross-section area and perimeter; e: superimposed images of the sections of pieces 1 and 23. Note the taper tendency of the cross-section of the blades as the pieces became smaller (except piece 21). The dotted lines of the front angles are placed for the purpose of illustration.

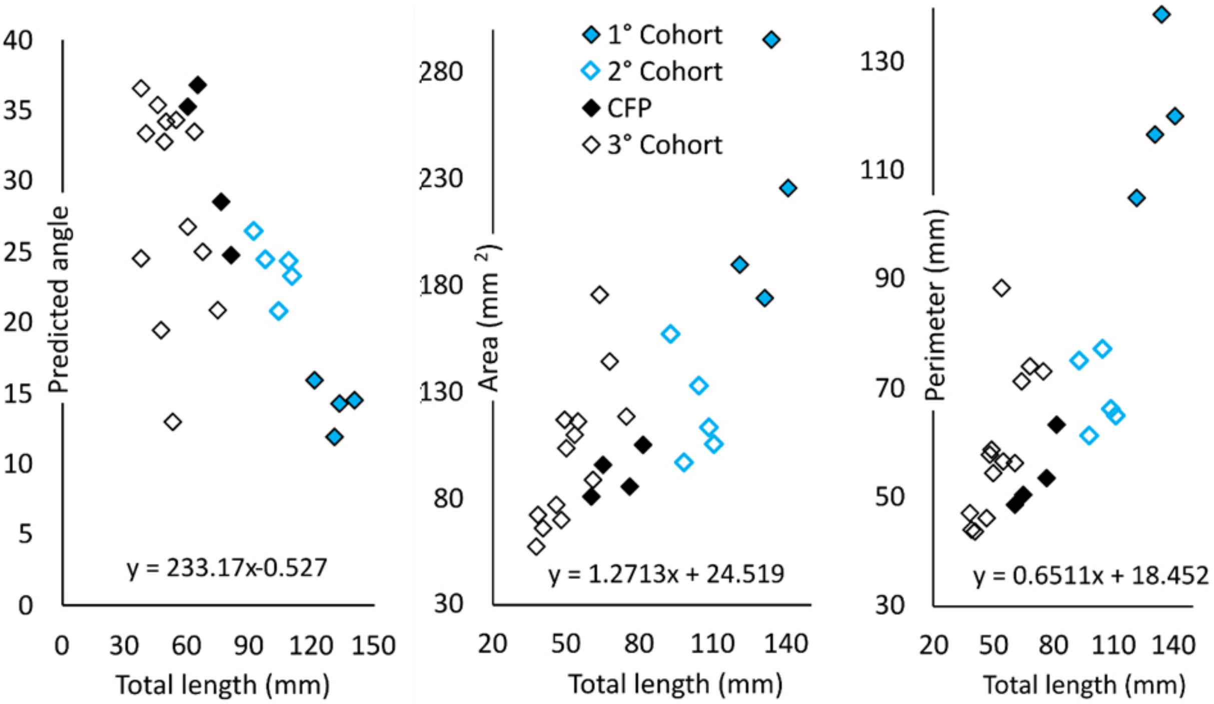

Figure 22. Left: Predicted angle of the edges of the blades. Centre: cross-sectional area of the blades. Right: perimeter of the blades. Area and perimeter are based on Hughes (1998), modified by Sisk & Shea (2011). CFP: included the classic Fishtail projectile points, pieces 11, 13, 16 and 19 from Figure 3 (piece 12 lacks thickness).

We have already seen that the shoulders have been mostly kept straight (or close to it), during the rejuvenation process, perhaps related to assuring the projectile stuck in the prey. In these straight shoulders, the angles of their edges were maintained with values similar to those of the stems, and eventually even more abrupt, ranging between 80° and 90°, even in small points of 40 mm in length. These abrupt angles were obtained both by well-organized short and narrow retouches (Figure 23), and by notches with equally abrupt angles (Figures 23b and 23c). This design is not selected for cutting, but probably to improve the fixation into the wound, concurrently with the straight shoulders. As a disadvantage, they reduce the ability to withdraw the spear to deliver new thrusts, especially when they enter the thoracic cavity increasing the probability of becoming stuck between the ribs or ligaments (Flenniken & Wilke 1989; Hughes 1998). The concurrence of straight shoulders and abrupt angles of their edges suggests neither interest nor opportunity to carry out successive thrusts. On the contrary, those medium-sized points with rounded shoulders and lanceolate blades (classic FPs; pieces 11, 12, 13, 16 and 19, Figure 3) have a different concept. Here the angles of the edges on the shoulders show the same angle as the blade to which they are integrated (Figure 24), facilitating the spear withdrawal to produce multiple injuries (see discussion about this feature in Friis-Hansen 1990; Hughes 1998, among others).

4. Original Designs

Most of the complete FPs recovered in South America correspond to highly rejuvenated forms, which do not facilitate the identification of the original designs (Nami 2013; 2014a: 285; 2014b: 185-186). Those points close to the original design are those that were lost by the hunters, remaining stuck in animals that were not finally hunted, or pieces fractured during the final stage of manufacture.

Maximum length clearly emerges as one of the most important criteria to identify the original designs (Hughes 1998). The dimensional subset above 120 mm suggests they are indeed points in the initial phase of use of life, or close to it. For several technological reasons that we will not deal with here, we do not agree with the idea that these supposed “oversized” points could have been used designed as knives, as it was suggested elsewhere (see a summary of this idea in Pearson 2017); not at least with points with such complex stem, shoulder designs, mass balance and axis symmetry. In addition to the maximum length to discuss original designs, the points included in the first subset show regular retouches from the edges to the centre in a continuous way, without overlapping. The symmetry of the limbs is very precise, with the same leading-edge extension. The shoulders are symmetrically designed, as well as the basal concavity of the stem, which is located in the axis of axial symmetry of the blades. The ears of the stem are generally prominent, with a divergent and well-marked profile. This cohort shows notable similarities in size and shape to the largest FPs identified in Uruguay illustrated by Nami (2013: fig. 4, pieces g and l), and somewhat larger, but with the same design, compared to those from Ecuador (Nami 2014b: fig. 16a) and Guiana (Nami 2016a: fig. 2 & piece f), which were also considered original designs. In fact, piece 7 of Figure 3 of this study shows this same design, slightly smaller, and thus, closer to those illustrated by Nami from Ecuador and Guiana.

Within these large-sized points, there may be some variations in the shape of the shoulders as we mentioned before, which are rounded such as the Apiaí point illustrated by Collet (1987) (piece 26 of the Table 1 of this study), as well as the points from Uruguay published by Nami (2013), and others with straight shoulders (Figure 3, pieces 1 and 3).

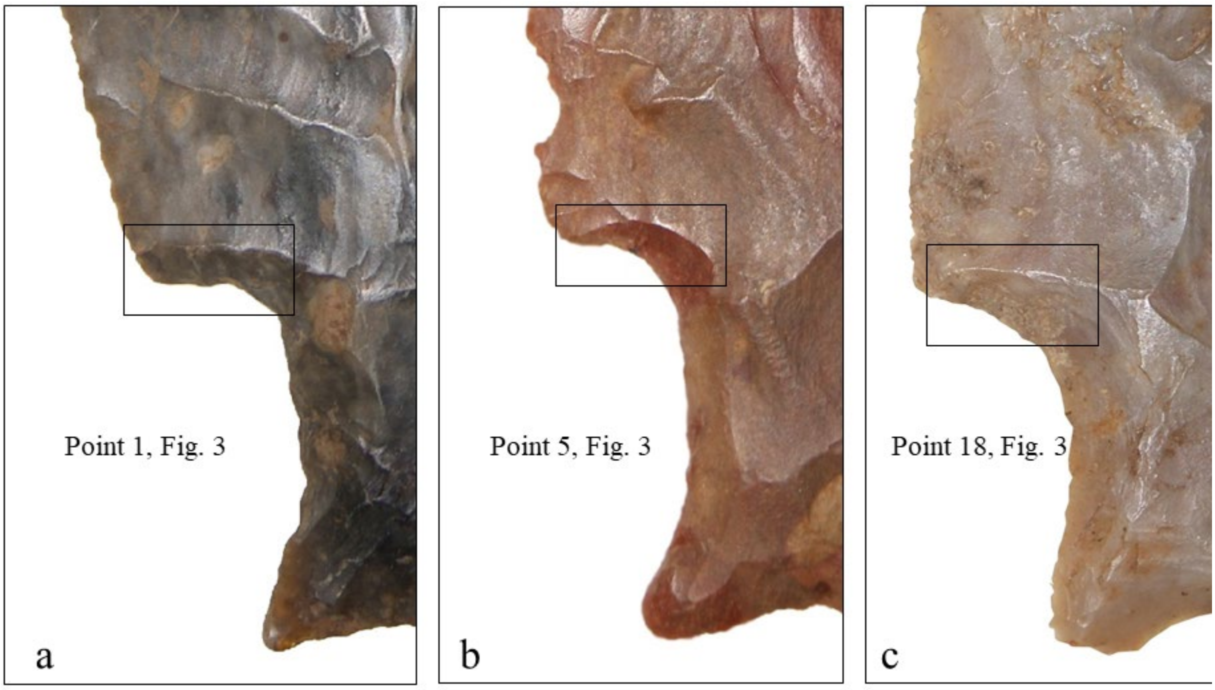

Figure 23. Straight shoulders with bevel angles near 90°.

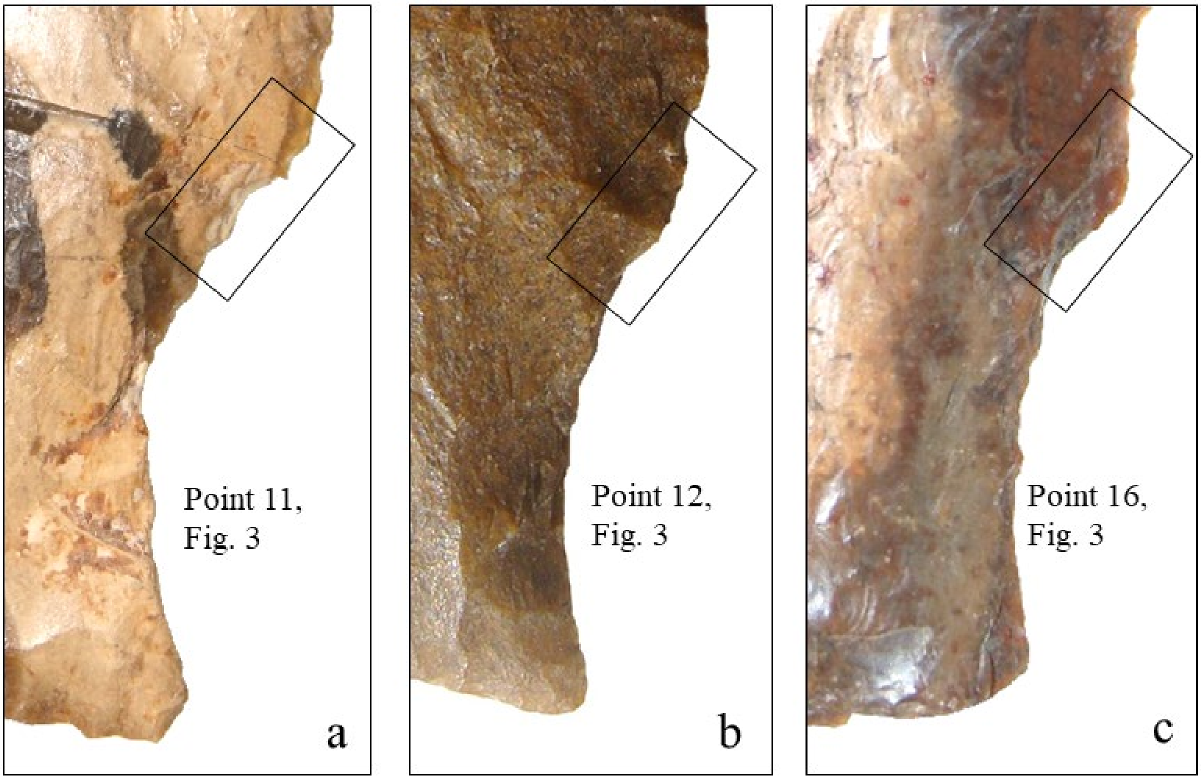

Figure 24. Rounded shoulders with similar edge angles integrated to the edges of the blades in classic FPs.

Within the second subset pieces 4 to 10 (Figure 3) are included, ranging between ~ 110 - 87 mm in maximum length. Although smaller than the previous ones, they are still of a considerable size, and present all the same properties of symmetry as the first subset. Finishing retouches are parallel, without abrupt overlaps or changes in their orientations. In addition, the front angles are notably sharper (except in piece 7, see above and previous sections) than all the other points included in this study. In the case of piece 8, that we have been able to analyse in more detail, the retouches are extremely flat and regular on the dorsal side, while on the ventral face they are shorter but regular, usually without interruptions, developed on the thinning extractions that eventually exceed the axis of symmetry. The bevel angles of these pieces along the blades show no changes, and the thickness features a smooth decline towards the tip. All these characteristics are expected in points that are slightly or not at all rejuvenated, suggesting also original designs. The differences with the bigger points could be linked to different weapon systems, hunting techniques, types of prey, or space-time evolutionary drifts. The significant difference in weight between the points of the first subset (~ 80 gr) and those of the second (~ 30 gr) should also be noted.

The rest of the points below 80 mm in maximum length show a bigger variability, some of them probably linked to different designs, but also with the rejuvenation processes. Among the latter, most of these points show a concurrent set of variables that are not observed in the previous ones, such as asymmetries in the limbs or an unequal length of the leading edges (or both); abrupt changes in the bevel angles in the blades and in the thickness of the basal blade with respect to their distal ends; a compressed blade and a taper shape of the blades; ears with different orientation or size (or both); asymmetry in the basal biconcavity of the stem, or even absence of this biconcavity. Different overlapping retouches are also observed in these points, especially the retouches of the stems are different in quality, suggesting that blade retouches were made when the points were hafted. In general, two or more of these associated features are present in these pieces, and conversely, none (or rarely) are seen in the first and second subsets. To all this, we could add that all the stems of the smaller points, below 80 mm of maximum length, have practically equivalent dimensions in absolute terms to the larger pieces, with differences basically concentrated in the length, form and orientation of the ears, although this similarity in size could be also related to highly standardized shafts. In addition, the total thicknesses in the smaller points are practically the same as the larger ones (except point 21, but this piece also presents other evidences of rejuvenation), suggesting that the small pieces (or mostly of them) are derived forms from bigger points (not necessarily from the biggest ones).

Having said that, there are some interesting exceptions. The Point 14 (Figure 3, maximum length 74.9 mm), although it shows a somewhat unbalanced axis, the retouches in the blade are regular, without overlapping. The stem and the blade show a relatively symmetric shape. The breakage of the ear (which may be post-depositional) did not modify its balanced design. Its ratio BL/Th is 5.4, and the predicted angle is ~ 20° (see Table 1), both values are included in the range of the first and second subset. This piece certainly could correspond to a medium-size original design with triangular blade and sharp shoulders. Piece 15 (Figure 3, maximum length 68.1 mm) has the same design as piece 14, but it has clear signs of having been rejuvenated because of its unbalanced blade, and the shape of one of the shoulders. However, it shows a large amount of cortex in one face, shaped mainly with short retouches along the edges, as many other FPs in South America (Bird 1969; Nami 2007; Patané Aráoz 2011). Although it may have been a large point marginally retouched on its edges, it cannot be ruled out that it was originally designed as a medium size point subjected to some rejuvenation process.

Included in the points below 87 mm, a subgroup clearly emerges with the classic shape of FP (pieces 11, 12, 13, 16 and 19 of Figure 3). They present some evidences of rejuvenation, but in general terms, they are still quite balanced. All are medium-sized, ranging ~80 – 60 mm, well-shaped with a smooth transition between blade and stem, including the same bevel angle as we saw before; the tips tend to be somewhat rounded (besides post-depositional process) and the basal concavity of the stems tend to be smoothed (see also Nami 2013). Due to the open front angles, the more circular cross sections (BW/Th average 3.7), and the smooth transition between the stem and the blade, it outlines them as certainly more robust points (see also the cross-section area and perimeter in Figure 22). All these differences perhaps reflect a distinct weapon system, and it was pointed out as a part of the variability of the original designs (Nami 2013; 2014b185-186; 2020a; Suárez 2015). The identification of possible preforms for this design should also be mentioned (Loponte *et al*. 2015; Nami 2013; see also the Supplementary file 7), and new findings will be shortly integrated within this topic.

Finally, within the smaller points there are highly resharpened pieces (below 50 mm long). The pieces 20 and 22 (see Figure 3) have one straight shoulder and the other rounded, suggesting, because the design of the blade, that the original design was straight, and the rounded one is a form derived from fractures and rejuvenation (see also Beltrão 1974: 215, piece 11). In piece 23, it seems that one shoulder stayed straight until practically the end of the life-cycle of the piece. In point 24, which is close to the “saturated resharpened” stage, the rounded shoulder could be an original design or the result of the rejuvenation process. In piece 21, which is certainly a small (~ 40 mm) and very rejuvenated point, the shoulders are kept quite straight.

5. Conclusions

The FPs in southern Brazil are mostly made of chert, constituting another example of the selectivity for high quality rocks by Paleoamerican hunter-gatherers (Ellis 2011; Goodyear 1979: 1; Hermo *et al*. 2015; Hester & Grady 1977; Nami 2016b, 2020a; Kelly & Todd 1988). As the sample size increases in southern Brazil, it will be observed if this trend is consistent. Particularly interesting for this discussion are the points recovered in those states with greater complexity in their geology such as Paraná, Minas Gerais and São Paulo States, as well as southern Rio Grande do Sul due to its proximity to silicified limestone outcrops.

The selection of cherts allowed the manufacture of large points (subsets 1 and 2) useful for a long and planned rejuvenation process, reducing the time and energy in manufacturing and re-hafting new points (Flennniken & Raymond 1986; Nami 2013; Shackley 1996), and avoiding the risk of not having hafted projectiles after eventual fractures (Amick 2013). Thus, they were subjected to a simple rejuvenation process, maintaining as far as possible their lethality even in the smallest points, probably being integrated into the personal hunting equipment of each hunter, with various types of projectiles, which are still poorly known (see Nami, 2014a: 285; 2020a for an overview). As the maintenance process unfolded, especially for points below ~ 80 mm in length, they exhibit features that negatively impacted their efficiency, including distinct asymmetries, somewhat open front angles, a decrease in the cutting perimeter and cross-sectional area, an increase in the bevel angle of the blade edges and a tendency to a conical cross-section. Behaviours intended to counteract these problems were maximizing the length of the leading edge, maintaining the symmetry and the triangular blade resting on straight shoulders, and maintaining the aerodynamic properties as much as it were possible.

Although we have not discussed here the propulsion system of these points, some differences in the designs could be related, as one possibility, to the weapon system. Larger points of the first subset clearly have all the properties of thrusting spears, with a potential concurrent use as a throwing spear of short range (both are different than flighting weaponry; Hughes 1998). The second subset has a greater aerodynamic design and reduced weight compared to the first, whose blade seems to favour even more the penetration and aerodynamic features rather than durability. The persistence of straight shoulders with abrupt bevel angles in most of the pieces below 80 mm in length, suggests the selection and maintenance of a design intended to improve the fixation on the prey, and therefore, a one-shot hunting technique for each projectile during each hunting event. The rounded shoulders (usually one of them) in these smaller pieces seems to be a consequence of the rejuvenation process as others authors suggested (see Section 4), but this process seems to be mostly independent of the generation of the classic forms of FPs. Conversely, these medium-sized points with symmetrical and balanced designs, rounded shoulders with sharp bevel angles similar to those of the blades, could be indeed a different original design from the previous ones as other studies remarked for other regions (see Section 4).

The small collection analysed here is far from having exhausted the spatio-temporal variability of the FPs from southern Brazil, a record which is expanded every year, and that will allow us in the short term, to incorporate new and old unpublished findings, as well as different perspectives to improve the knowledge of this techno-complex in southern Brazil.

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Data accessibility statement

The data use here are from the ownership of the authors, and the others are cited.

List of supplementary files

Supplementary file 1
"CARBONERA_LOPONTE - supplementary file 1 - Supplementary file 1.tif"
A and B: possible FPs recycled as scrapers (both cherts). C, D, H: possible FPs highly-saturated resharped (basalt, chert and quartz). E, F: broken stems of FPs (chert). G: possible broken FP (Silicified sandstone).

Supplementary file 2
"CARBONERA_LOPONTE - supplementary file 2 - Supplementary file 2.tif"
Measure map.

Supplementary file 3
"CARBONERA_LOPONTE - supplementary file 3 - Supplementary file 3.tif"
Left: Covered area by the Paraná Basin Geotectonic Unit Distribution. Right: distribution of the Botucatú - Serra Geral Vulcano-Sedimentary Complex (Gondwana III) (maps taken and modified from Werlem *et al.* 2018). The survey area in this study is marked in white (Santa Catarina State).

Supplementary file 4
"CARBONERA_LOPONTE - supplementary file 4 - Supplementary file 4.tif"
Counties included in the survey. 1: Sampling of pebbles in Uruguay River, Palmitos County. 2: Sampling of gravels in Taquarussú River, Cordilheira Alta County. 3: Sampling of gravels in Ariranha River, Arvoredo County.

Supplementary file 5
"CARBONERA_LOPONTE - supplementary file 5 - Supplementary file 5.tif"
Holocene artefacts made from silicified sandstones from pebbles. A-D thin section of silicified sandstones of the BSGC with different degree of silicification (taken and modified from Loponte & Carbonera 2018).

Supplementary file 6
"CARBONERA_LOPONTE - supplementary file 6 - Supplementary file 6.tif"
Non-translucent cherts recovered at Holocene sites in the survey area. A: flake from a pebble river recovered at ACH-LP-07 (Águas de Chapecó County, Santa Catarina State.). B and C: cores recovered at Otto Aigner 1 (Itá County, Santa Catarina State). D: biface - probably a knife - (Otto Aigner 1). E: projectile point ("Umbú" type) (Otto Aigner 1). The drawn scales are approximate.

Supplementary file 7
"CARBONERA_LOPONTE - supplementary file 7 - Supplementary file 7.tif"
A: FP made from hyaline quartz (curated at Instituto Anchietano de Pesquisas, UNISINOS). B: Possible FP preform made from tabular and xenomorphic quartz (Museu ao Ar Livre Princesa Isabel, Febave, Orleans County. The scale is approximate.

Supplementary file 8
"CARBONERA_LOPONTE - supplementary file 8 - Supplementary file 8.tif"
A and B pebble of banded chalcedony (Uruguay River). C: tabular nodule of chalcedony (Orleans County). D: White chert recovered at Uruguay River (Abdon Batista County)

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Materias primas y funcionalidad de los diseños de las puntas de proyectil cola de pescado del sur de Brasil

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Resumen:

Este estudio analiza la oferta de materias primas líticas aptas para la talla y la selección de rocas utilizadas para la manufactura de puntas de proyectil Fell, también conocidas como Fell 1 o cola de pescado (PCP) en el sur de Brasil, sus diseños y algunos aspectos funcionales de los mismos. Para identificar la oferta de recursos líticos, se realizaron numerosas prospecciones a lo largo de 15 meses en 47 municipios del Sur de Brasil, cuya geología superficial se expresa mediante la exposición del Complejo Vulcano-Sedimentario Botucatú - Serra Geral. Se evaluó la composición lítica de numerosos afloramientos rocosos y de acumulaciones de rocas caídas en las laderas y en los piedemontes, y se efectuaron muestreos sistemáticos y selectivos de las acumulaciones de guijarros y bloques existentes en las riberas de tres cursos fluviales de la región. Los resultados demostraron que los basaltos (incluyendo una pequeña proporción de andesitas y riodacitas-riolitas) y las areniscas silicificadas son omnipresentes en el paisaje. Por el contrario, los cherts no translúcidos de buena calidad para la talla son muy escasos, por lo que su adquisición requiere una inversión de tiempo significativa de búsqueda y testeo. A pesar de su escasez, estos cherts fueron seleccionados para la fabricación de las PCP en el sur de Brasil, constituyendo otro ejemplo de la selectividad por las rocas de alta calidad por parte de los grupos de cazadores-recolectores tempranos de América. Estos mismos cherts también fueron seleccionados por los grupos cazadores-recolectores más tardíos de la región bajo estudio, agrupados bajo el nombre genérico de la llamada “Tradición Umbú”. Debe notarse que ninguna de todas las puntas analizadas del sur de Brasil está confeccionada con caliza silicificada proveniente de la Formación Puerto Yeruá-Mercedes, que es la materia prima por excelencia con la cual están confeccionadas las PCP de Uruguay. De la misma manera, tampoco hay una sola pieza manufacturada con ortocuarcita de la región pampeana de Argentina, que es la roca más abundante entre las PCP de aquella región. Por otro lado, ni la ftanita pampeana ni la calcedonia bandeada del norte de Uruguay, han sido identificadas entre las materias primas utilizadas en el sur de Brasil. Sumando evidencias concurrentes tales como la ausencia de materias primas exóticas entre las PCP de Brasil, la gran cantidad de proyectiles que se están identificado en este país, incluyendo zonas tan alejadas de la frontera con Uruguay y Argentina como Bahia y Piauí (2800 km de la frontera con Uruguay), se considera que la idea del intercambio de estas puntas desde estos países hacia el actual territorio de Brasil es la hipótesis menos probable. Por el contrario, las PCP que se recuperan a lo largo de la vertiente atlántica de Brasil parecen reflejar la ocupación por parte de grupos que manufacturaban estos cabezales, de acuerdo con los modelos generales subcontinentales de dispersión de estas puntas.

En cuanto a los diseños, algunos morfotipos parecen haber sido diseñados para producir múltiples lesiones a través de sucesivos ingresos y retiros de los proyectiles en los cuerpos de las presas, mientras que otros, la morfología favoreció la penetración y fijación de las puntas en las heridas, probablemente con el objeto de generar un canal permanente de sangrado, sugiriendo en este caso, una técnica de un disparo único para cada proyectil. A medida que se desarrolló el proceso de mantenimiento, se observa en las puntas diferentes características que impactaron negativamente en su eficiencia, especialmente en aquellas que exhiben longitudes menores de 80 mm, tales como asimetrías, ángulos frontales más abiertos, una disminución en el perímetro de corte y del área de la sección transversal, un aumento en el ángulo de bisel de los filos de los limbos y una tendencia general hacia una sección transversal cónica. Todo ello redunda en una menor capacidad de penetración. Las conductas destinadas para contrarrestar esta disminución en la letalidad de los cabezales fueron la maximización de la longitud del borde de ataque, el mantenimiento de las simetrías de los limbos a través de su reducción y el mantenimiento de los hombros rectos tanto como esto fue posible, probablemente con la intención de seguir manteniendo su capacidad de fijación en el cuerpo de las presas.

Más allá de estos procesos de mantenimiento, en la muestra parecen estas incluidos tres morfotipos diferentes de cabezales. El primer diseño incluye puntas con umbrales mínimos de alrededor 120 mm de longitud y ~ 80 g de peso, con limbos triangulares o ligeramente lanceolados, que en su mayoría presentan hombros rectos, pero también hay piezas con hombros redondeados. El segundo diseño corresponde a proyectiles entre 110 y 87 mm de longitud y unos 30 g de peso aproximadamente, con limbos triangulares o ligeramente lanceolados y hombros rectos. Los hombros están diseñados con ángulos de bisel abruptos, generalmente obtenidos por retoques cortos y anchos o muescas de retoque, que producen un cambio inmediato del ángulo del bisel entre los filos del limbo y de los hombros. El tercer diseño presenta la forma clásica de estos proyectiles, con silueta de pez, con longitudes totales inferiores a 90 mm. Su diseño es conceptualmente diferente, siendo piezas más robustas, con hombros redondeados cuyos ángulos de bisel son semejantes a los ángulos de los filos de los limbos, quizás con la intención de facilitar el retiro de los proyectiles para producir múltiples y sucesivas heridas.

Keywords: Puntas de proyectil Fell 1; Cola de Pescado; Paleo-americanos; Sudamérica; Brazil