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ARTICLE

Combining Technology and Geometric Morphometrics: Expanding the Definition of the Garivaldinense in Southern Brazil

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Abstract
Research published in the last decade, which has provided data from both technological and morphometrical analyses of lithic points from southeastern and southern Brazil and Uruguay, suggests that there is much more cultural diversity among hunter-gatherers during the Early to Mid-Holocene than previously suggested by the Umbu Tradition model. Some of these studies have suggested new archaeological cultures and new definitions of lithic industries. In this article we present new data on another lithic assemblage that we associate with the Garivaldinense lithic industry and is found at the Pedro Fridolino Schmitz site. We also present, for the first time, the definition of two new types of lithic bifacial stemmed points. Our data suggest a low-density occupation of the site from the Middle to Late Holocene (8000–1000 BP) and some variability within the Garivaldinense industry throughout time and space.

Resumo
Pesquisas publicadas na última década, as quais forneceram dados de análises tecnológicas e morfométricas de pontas líticas do Sudeste e Sul do Brasil e do Uruguai, sugerem que a diversidade cultural entre caçadores-coletores durante o Holoceno Inicial e Médio é muito maior do que se sugeria a partir do modelo conhecido como 'Tradição Umbu'. Alguns destes estudos têm sugerido novas definições de culturas arqueológicas e indústrias líticas. Aqui nós apresentamos novos dados sobre mais uma coleção lítica que foi associada à Indústria Lítica Garivaldinense: O sítio arqueológico Pedro Fridolino Schmitz (ou sítio PFS). Também apresentamos, pela primeira vez, a definição de dois novos tipos de pontas bifaciais pedunculadas. Nossos dados sugerem uma baixa densidade de ocupação do sítio durante o Holoceno Médio e o Holoceno tardio (8000–1000 aP), assim como certa variabilidade dentro da Indústria Garivaldinense através do tempo e do espaço.

Keywords: lithic technology; geometric morphometrics; Middle and Late Holocene; hunter-gatherers

Palavras chave: tecnologia lítica; morfometria geométrica; Holoceno Médio e Tardio; caçadores-coletores

Many studies in the last decade have discussed the hunter-gatherer occupation of southern Brazil and Uruguay, suggesting that what was once associated with the Umbu Tradition should instead be associated with other lithic industries and archaeological cultures (Moreno and Okumura 2018, 2020; Suárez et al. 2018). This reassessment is based not only on lithic studies on technology (Araujo and Okumura 2021; Moreno and Garcia 2022; Moreno and Okumura 2020; Suárez 2015) but also on faunal remains and bone artifact studies (Mingatos and Okumura 2020).

One of these lithic industries is the Garivaldinense industry, which seems to be present in the central and eastern Brazilian state of Rio Grande do Sul. The Garivaldinense industry definition was first proposed by Moreno (2019a, 2020) and Moreno and Okumura (2020) after a systematic analysis of the Garivaldino archaeological site and comparison of its data to other previously Umbu Tradition–associated assemblages. More recently, Moreno and Garcia (2022) identified a Late Holocene hunter-gatherer mound location, known as Pororó site, in central Rio Grande do Sul state, radiocarbon dated to 2450 ± 30 BP (2699–2346 cal BP). This site presented some of the same point types associated with the Garivaldinense industry, as well as a new type of point, the Pororó type, which is considered to be a product of regional and chronological variability within that culture. Brochier-type points were absent. The Garivaldinense and the Montenegro types were found to be the most common types in all Garivaldinense industry-associated sites so far, even though the Brochier type can also be found.

The Garivaldinense points, in morphological terms, have been described as presenting a triangular-shaped body with irregular or straight edges and a straight bifurcate or convex stem. They are usually between 25 and 45 mm long, 15 and 25 mm wide, with a width thickness proportion between 2.1/1 and 3.1/1 (Moreno and Okumura 2020), which can be considered as thick. These points were made using one of three technologies: (1) bifacial reduction by selective trespassed percussion, followed by retouch using pressure flaking; (2) bifacial reduction by convergent untrespassed percussion, followed by retouch using pressure flaking; and (3) pressure flaking retouch of flakes that have the standard width/thickness proportion, without any need for bifacial reduction (Moreno and Okumura 2020). The percussion technique could not be identified by those authors. However, an experimental replication by Moreno (2019b) revealed that soft percussion was a possible technique.

Montenegro points, from the same archaeological contexts, have a triangular-blade-shaped body with straight serrated edges and a bifurcated stem. They are usually between 20 and 36 mm long, 10 and 16 mm wide, and with a width thickness proportion between 2.1/1 and 2.5/1 (Moreno and Okumura 2020), which can be also considered a thick proportion. The Montenegro type is bifacially reduced by parallel pressure flaking forming a median ridge and serrations in the edge; however, small unmodified parts of the blank usually remain in the final artifact (Moreno and Okumura 2020). Retouch by pressure flaking is only observed in the stem.

The Pororó type is quite similar to the Garivaldinense type in shape, size, and proportions but differs significantly in technology. The bifacial reduction is made by parallel pressure flaking, forming a median ridge in the artifact (Moreno and Garcia 2022). It has been interpreted as a Late Holocene variation of the Garivaldinense type, originally produced during the Early Holocene. Its identification is a good example of why lithic analysis cannot be reduced to morphological features.

The Brochier type has only been identified in one site so far, and it differs significantly from the other points: it is made only from thin flakes or fragments of agate and is simply made by retouching the distal part into a pointed-shaped tip (Moreno and Okumura 2020). In addition, the other types of points are made from a variety of raw materials that are accessible and good for flaking, such as silicified sandstone, dacite, agate, and, more rarely, flint. The Brochier type seems to be the only one made from one specific type of rock: agate.

The Pedro Fridolino Schmitz (PFS) site is in the eastern portion of Rio Grande do Sul State in Brazil; it is within the Bom Princípio municipality in the lower Jacuí basin of the Caí River Valley (Figure 1). Small streams from nearby springs can be found close to the site. It is outside the area that floods during the rainy seasons but is still close to a year-round source of water. It is located on the low slopes in the margins of the Rio Grande do Sul Plateau in which mild slopes (less than 10° of inclination) and low altitudes (20–150 m asl) predominate. The Middle Holocene (8000–4000 BP) in southern Brazil, the period in which the site was first occupied (Table 1), has been characterized as a period of low humidity and higher temperatures (Araujo 2014; Cheliz et al. 2020; Cruz et al. 2005; Leal and Lorscheitter 2007).

The site is a small sandstone rockshelter, measuring 10 m in width, 4 m in depth, and 4 m tall (considering the dropping line; see Figure 2). This sandstone is associated with the Mesozoic Botucatu Formation. On top of the sandstone, 27 m high, is the Jurassic-Cretaceous Serra Geral Formation,

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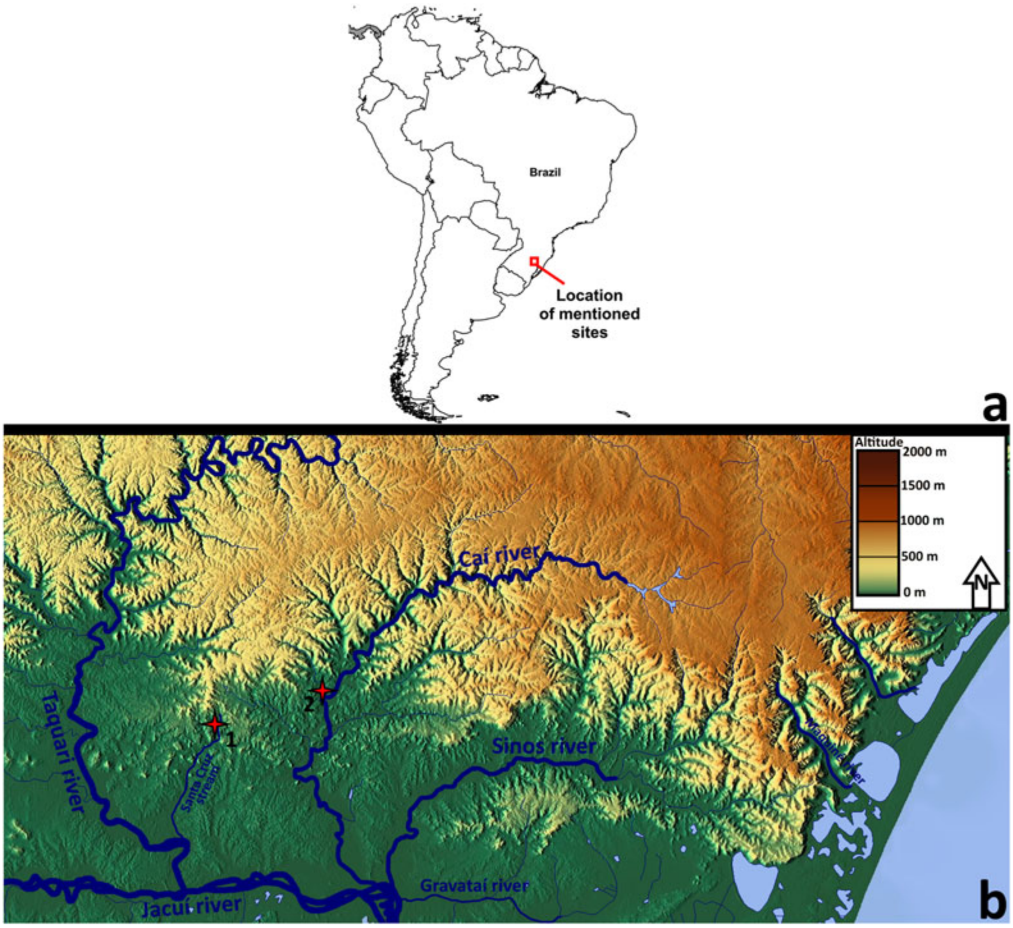

Figure 1. (a) Location of the studied area in southern Brazil in relation to South America; (b) location of the Garivaldino and Pedro Fridolino Schmitz (PFS) sites and the main rivers. (Color online)

made of basal rocks and eventual geodes that may have large and good-flaking quality agate and quartz. The famed "Brazilian agate" used by many modern knappers comes from this region of Brazil.

Although the vegetation landscape has been modified in the postcolonial period, the site is located in an Atlantic Subtropical Forest area that has abundant dietary resources: terrestrial fauna, such as capybara, hogs, deer, armadillos, monkeys, big lizards, and snakes; birds, such as black-fronted piping guans, penelopes, solitary tinamous, and red-winged tinamous; fish, such as Loricariidae, *Synbranchus* sp., *Hoplias* sp., and catfish; and plants, especially fruits (*Garcinia gardneriana*, *Vitex megapotamica*, *Saxifraga granulata*, *Myrcianthes pungens*, and many types of coconuts and figs; Schmitz 2010) that are still found today in the region. However, none of these organic materials have been preserved on the

Table 1. Radiocarbon and Calibrated Dates from Pedro Fridolino Schmitz Site.

Sample Number	Level (cm)	Excavation Unit	^{14}C Date (BP)	SHCal20 Calibration (95.4% Probability)	Original Reference
BETA-211727	30–40	D1	1400 ± 40	1345–1177	Schmitz 2010
BETA-204345	50–60	C2	7800 ± 50	8639–8418	Schmitz 2010

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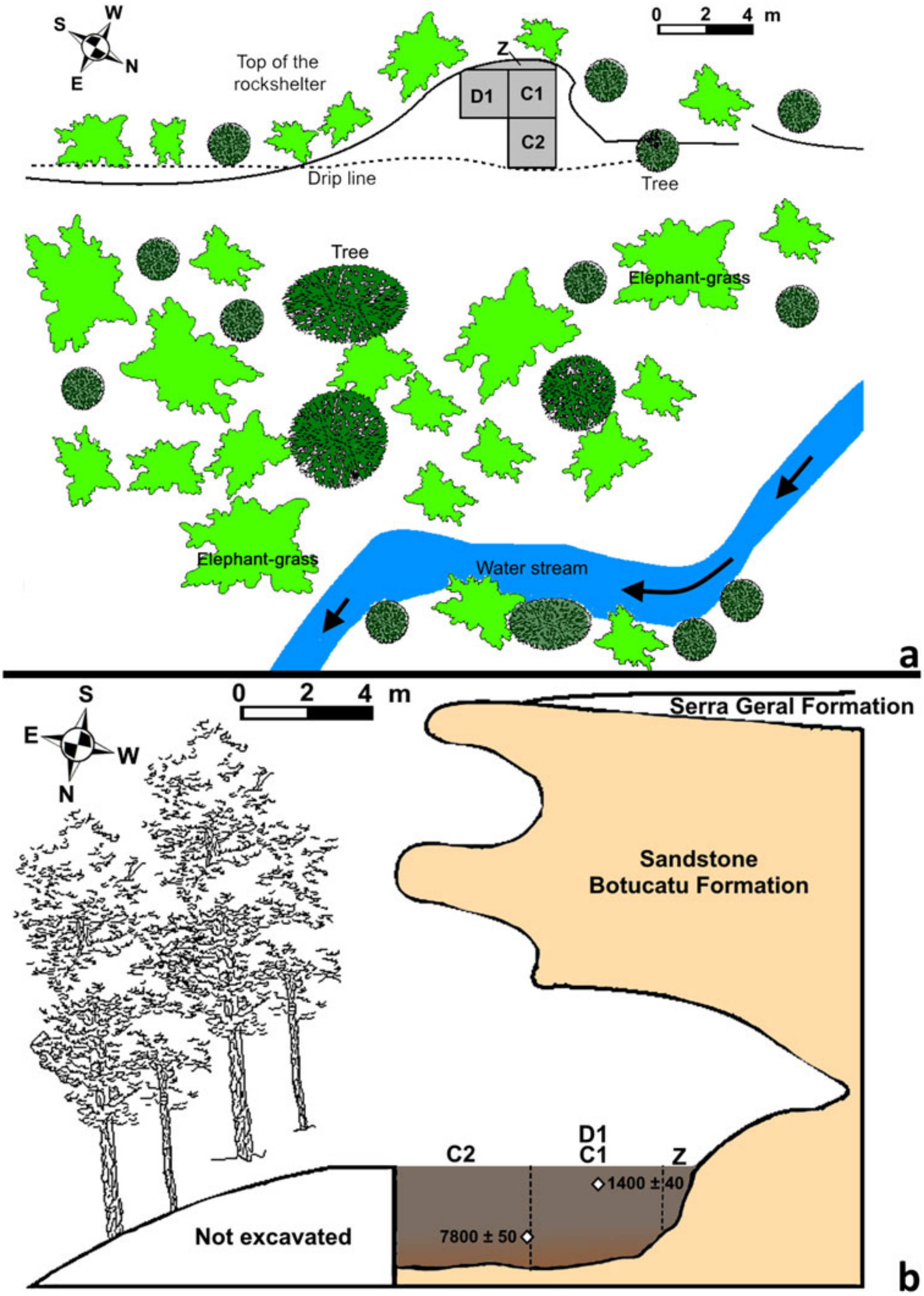

Figure 2. (a) Map of the 1970s excavation (modified from the original by Fúlvio Arnt; Schmitz 2010); (b) east–west cut section of Pedro Fridolino Schmitz site, including stratigraphy and the position of dated samples (modified from the original by Fúlvio Arnt; Schmitz 2010).

site. The only organic materials found were the two small pieces of charcoal that allowed the dating of two stratigraphic layers.

The site was found and recorded by Brazilian archaeologist Pedro Augusto Mentz Ribeiro in 1966 within the property of Pedro Fridolino Schmitz, after which it is named. It was then excavated in 1970

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by a research team from the Instituto Anchietano de Pesquisas, including Brazilian archaeologist Pedro Ignácio Schmitz (son of Pedro Fridolino Schmitz), Danilo Lazzarotto, and Irene Basile Becker (Schmitz 2010). Four 2 × 2 m excavation units—C1, D1, C2, and Z (defined as the space between the sandstone wall and the D1 and C1 unit; Figure 2)—were opened. Almost 27,000 pieces of lithic material were found during the excavation.

The stratigraphy is very homogeneous. The sediment is loose and gray, made up mainly of ashes mixed with sand. The quantity of ashes decreased only in the bottom of the excavation where it had a more red-brown color (Schmitz 2010; Figure 2). The site was very well preserved, without any observable perturbation in the stratigraphy.

Because of the lack of preserved organic materials, only two radiocarbon samples could be dated. They were originally presented by Schmitz (2010): a burnt seed of *Syagrus romanzoffiana* found around 3 cm deep in the D1 unit and charcoal found around 60 cm deep in the C2 unit (Table 1). We attempted to date small pieces of charcoal found in the deeper levels, but the samples were considered unfit to be dated by the laboratory.

The Lithic Assemblage

A total of 26,826 lithic vestiges distributed in eight levels were recovered from the excavation (Figure 3). Around 83% of the raw material is silicified sandstone, and 10% is agate. Rhyolite only appears in 3% of the assemblage, and other materials comprise less than 1%.

There were 34 lithic points identified (including one recycled as a stemmed scraper); 20 of these were found between 50 and 70 cm deep (Figure 3), as well as a point fragment that could not be refitted to any other fragmented point. No other artifacts (with retouched active edges) were identified in the assemblage, except for a small, retouched agate flake, identified as a scraper. There were also 68 bifacial preforms (unfinished points) in the assemblages, of which 47 were found between 50 and 80 cm deep (Figure 3). One core was also identified in the 70–80 cm level. A total of 16,123 pieces were identified as flakes, most of which seem related to lithic point production. The other 10,599 lithic vestiges are unidentified fragments (detritus).

To better understand the diversity of lithic materials from the PFS site, we applied a technological analysis to all tools and cores and a geometric morphometric analysis to all the points. No other lithic analyses were carried out on the assemblage. The late development of lithic technology and geometric morphometrics analyses in Brazilian archaeology, which were first used only about 10 years ago, has contributed the delays in the systematic analysis of this and other assemblages. Because of difficulties in dating the materials and the small size of the samples, we were not able to verify changes throughout time.

Technology

Conducting technological analyses has been the main approach for the study of artifact industries, especially for understanding methods and techniques of lithic production, since the mid-twentieth century (e.g., Balfet 1975; Bordes 1947; Collectif 1980; Deforge 1985; Lemonnier 1986, 1993; Schiffer and Skibbo 1987; Swanson 1975; Tixier 2012). As menionted, in southern Brazil, lithic technology has only been used by a few researchers in the past two decades (e.g., Galhardo 2016; Hoeltz 2005; Hoeltz et al. 2015; Moreno 2017, 2019a; Moreno and Guimarães 2016), with most lithic studies using other approaches such as lithic points morphology (Okumura and Araujo 2014, 2016), lithic points style, and shape classification (Dias 2003, 2007, 2012).

A technological analysis is still the most powerful, if not the only, approach for understanding the stages of production of these classes of artifacts, also known as *chaîne opératoire* (Balfet 1991; Cresswell 1976; Leroi-Gourhan 1964, 1965; Tixier 2012). The application of "true" technological studies to Brazilian lithic points, which aim to understand the methods and techniques of production by observing their related features (including but not restricted to size and shape), has been implemented since 2015, along with an experimental archaeology application, in a research project aiming to understand the evolution and diversity of cultural traits in hunter-gatherers from southern Brazil (Correa et al. 2023; Moreno 2019b, 2020, 2023; Moreno and Garcia 2022; Moreno and Okumura 2020; Moreno et al. 2023).

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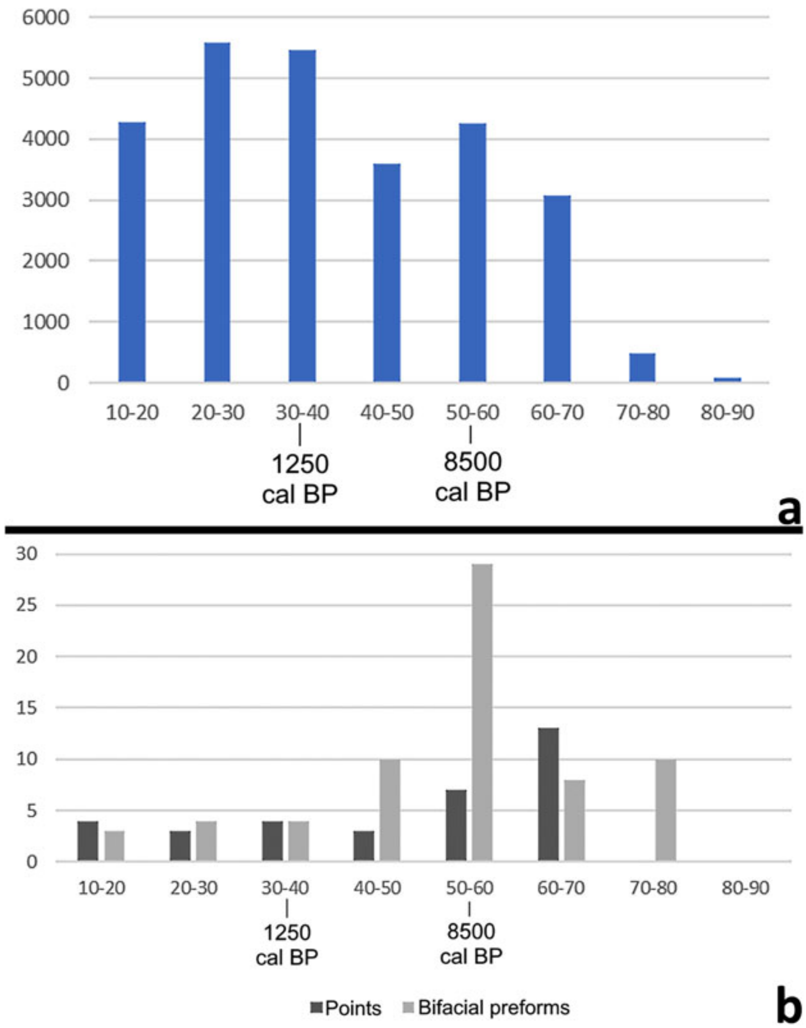

Figure 3. (a) Distribution of lithic material by archaeological level (10 cm each); (b) distribution of points and preforms by archaeological level (10 cm each).

Materials and Methods

The technological analysis focused on finished products (artifacts) and cores. We analyzed all 34 points, 68 bifacial preforms, both scrapers, and the one single core, but no flakes. The procedures for the study, which are based on the Moreno and Okumura (2020) proposed protocol, guide the observation and measurement of metric, morphological, and technical attributes (see Table 2 for a complete list of attributes), as well as the classification of artifacts and cores into types. This protocol also considers (1) the diachrony of the negatives to understand the order of each negative removal and (2) identification of which production stage each negative is related to (blank/debitage, reduction, retouch, etc.).

We classified the lithic points into six types that we mainly defined by observing the standards on shape, dimensions, and, especially, technology, following Moreno and Okumura's (2020) method. Four types seem to fit with those previously defined by Chmyz (1981), Moreno (2019a, 2020), and Moreno and Okumura (2020), and the other two types are new. The points were divided into the Garivaldinense type ($n = 12$; Figure 4), the Brochier type ($n = 10$; Figure 5), the Montenegro type ($n = 3$; Figure 6), the Bituruna type ($n = 1$; Figure 6), and two types that have never been defined before: PFS type 1 ($n = 5$; Figure 6) and PFS type 2 ($n = 3$; Figure 7).

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Table 2. Common Raw Material, Metric, Morphological, and Technological Attributes of Garivaldinense-Type Points from the PFS and Garivaldino Sites.

Point Attributes	PFS Site ($n = 12$)	Garivaldino Site ($n = 222$)
Raw material	Silicified sandstone (41%) Agate (33%)	Silicified sandstone (63%) Agate (28%)
Mass	**2.7–13.5 g**	**1.9–6.9 g**
Total length	**28–64 mm**	**26–44 mm**
Maximum width	**18–26 mm**	**14–24 mm**
Maximum thickness	5–9 mm	5–9 mm
Width/thickness proportion	**2.4–3.6 / 1**	**2.1–3.1 / 1**
Body length	18–50 mm	15–31 mm
Stem length	9–15 mm	9–15 mm
Active edges length	23–51 mm	16–32 mm
Shoulders width	**18–26 mm**	**14–24 mm**
Neck width	**11–17 mm**	**9–15 mm**
Stem width	12–18 mm	10–16 mm
Body thickness	5–9 mm	4–8 mm
Neck thickness	4–8 mm	6–8 mm
Stem thickness	5–7 mm	4–6 mm
Active edges angle	55°–65°	50°–70°
Body shape	Triangle (67%)	Triangle (75%)
Active edges lineation	Irregular (58%)	Irregular (39%) Straight (29%)
Shoulder shape	**Straight (75%)** **Expanded (25%)**	**Straight (97%)**
Neck lineation	Obtuse (87%)	Obtuse (87%)
Stem shape	**Bifurcate (50%)** **Straight (25%)**	**Straight (38%)** **Bifurcate (27%)** **Convex (23%)**
Body section shape	Elliptical (50%)	Elliptical (43%) Plan-convex (31%)
Stem section shape	Elliptical (83%)	Elliptical (64%) Plan-convex (21%)
Blank type	**Flake (33%)** **Undefined (67%)**	**Flake (65%)** **Undefined (35%)**
Reduction method	**Bifacial (75%)**	**Bifacial (54%)** **Absent (29%)**
Reduction technique	Percussion only (58%)	Percussion only (32%) Absent (28%) Pressure only (24%)
Retouch method	Bifacial (83%)	Bifacial (59%)
Retouch technique	Pressure only (83%)	Pressure only (82%)
Body negatives organization	Selective trespassed (28%)	Not reduced (30%) Selective trespassed (28%) Convergent (25%)
Stem negatives organization	**Selective trespassed (28%)**	**Not reduced (67%)**

Notes: Results from the PFS site were from our descriptive and frequency analysis, and those from the Garivaldino Site were according to Moreno and Okumura (2020). Only frequencies higher than 20% are presented for qualitative attributes. The range of quantitative attributes corresponds to the mean plus and minus the standard deviation. **Bold** attributes are those with significant differences according to bivariate tests.

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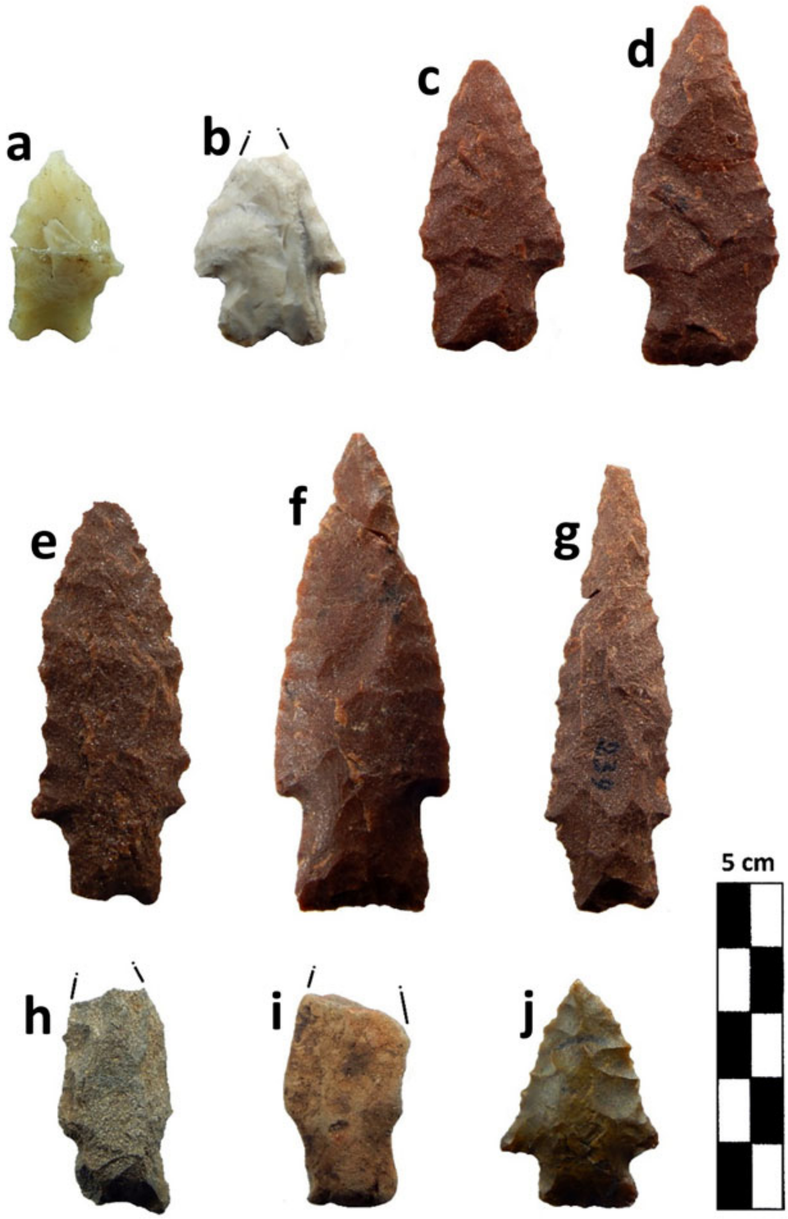

Figure 4. Examples of Garivaldinense-type points from the PFS site: (a–b) agate; (c–g) silicified sandstone; (h–i) rhyolite, each one presenting a different degree of natural corrosive/erosive alteration; and (j) flint. (Color online)

The only two identified scrapers were a Garivaldinense-type scraper and a lesmina-type scraper (Figure 7). The Garivaldinense-type scraper consists of Garivaldinense points modified into a stemmed scraper by reduction, retouching, or both of the distal part of the body (Moreno and Okumura 2020). Lesminas are small scrapers (less than 7 cm long) produced by unifacial retouching of bladelets or blade fragments (Moreno and Okumura 2020). Both artifacts are unique in the studied site, so it was not possible to carry out descriptive statistics on them.

The only identified core has a pyramidal debitage method structure (Figure 8) that produces flat blanks (flakes), with thick and flat platforms and parallel negatives. Blades (or bladelets) might be occasionally produced by this debitage method (Tixier 2012). This type of core is also found in sites from Early Holocene in the mid-Uruguay valley (Moreno 2017).

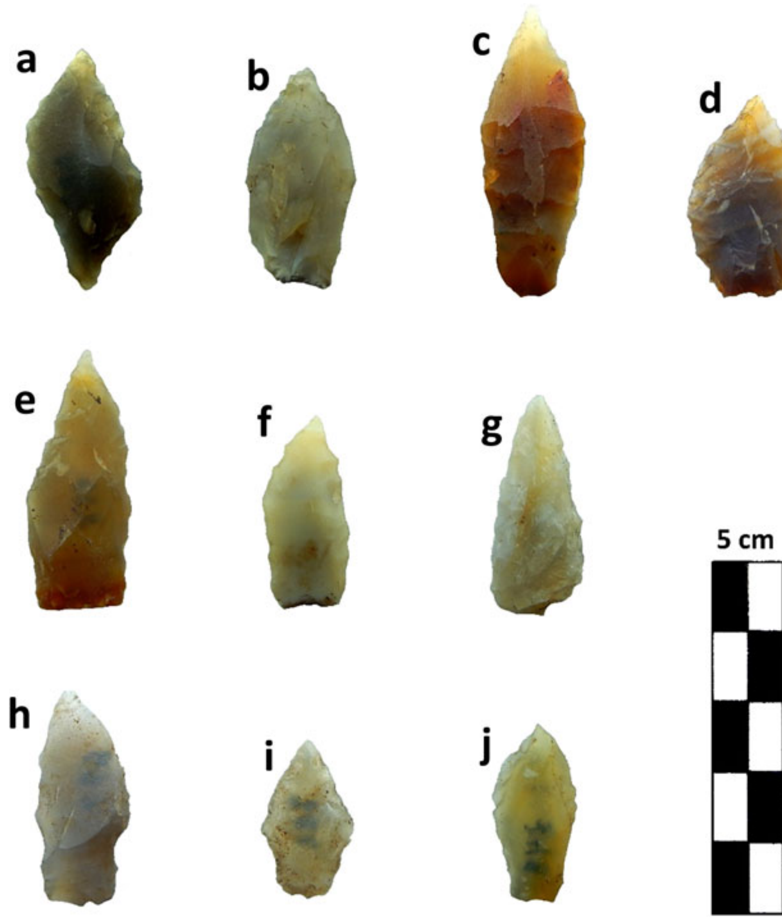

Figure 5. Examples of Brochier points from the PFS site, all made on agate. (Color online)

Results for the Lithic Points

The only point types on which descriptive statistics could be carried out were the Garivaldinense- and the Brochier-type points because they were the only ones present in a minimum number (10) for a good sample. We used bivariate statistical analysis (chi-square, Dunn-Bonferroni) to compare these points to the data provided by Moreno and Okumura (2020; for the complete analysis see Supplemental Table 1; original data in Brazilian Portuguese). Table 2 presents the values for each attribute observed in the technological analysis of the Garivaldinense-type points, and Table 3 presents that data on the Brochier-type points; both types were compared to the Moreno and Okumura's findings (2020) for the Garivaldino site.

The results corroborate the classification of the sampled points into the Garivaldinense and Brochier types. Most of the significant differences were related to the size of the points, especially their length and width; there was no difference in their thickness. Other significant differences were mostly caused by differences in the frequency of certain features of the points, but the same standard features were all still present.

The diachronic analysis of the points, which aims to verify the order of each flake removal from the points, revealed that none of the points were resharpened after any type of fracture. Indeed, an impact fracture is still present in at least one of the stemmed points (Figure 6).

Results for the Bifacial Preforms

We identified a total of 68 bifacial preforms in the PFS site, from which 56 were made on silicified sandstone, 11 on agate, and one on rhyolite. Supplemental Table 2 presents the metric pattern revealed

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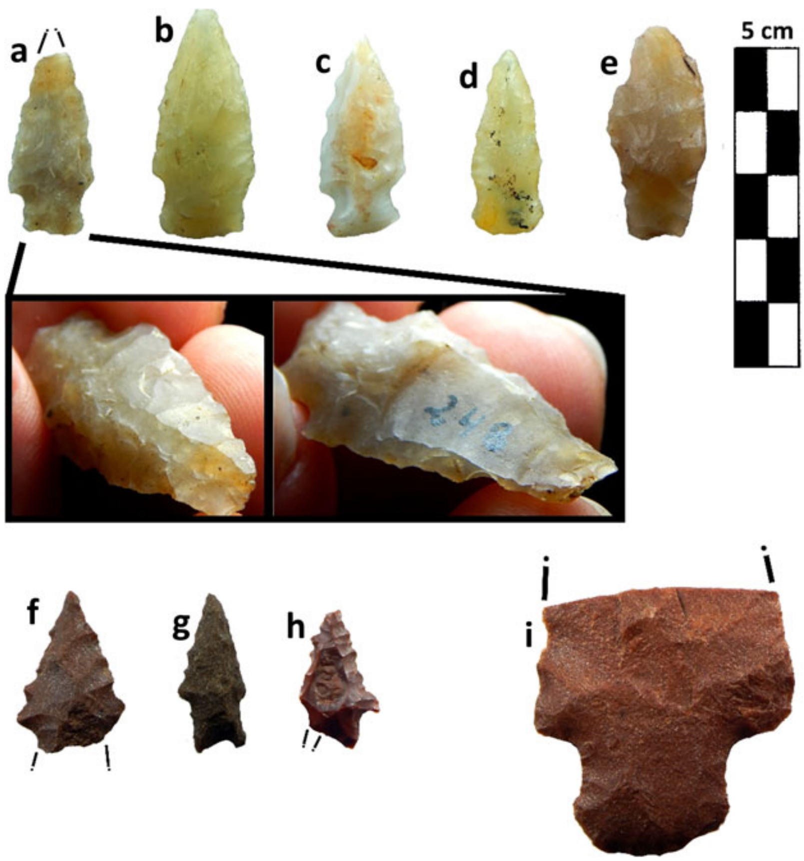

Figure 6. (a–e) Examples of PFS type 1 points (Schmitz type), all made on agate: (a) presents signs of use in both faces (flaking by projectile impact); (e) could be considered a preform, because it was unfinished due to production errors in the final stages of reduction; (f–h) examples of Montenegro-type points from the PFS site; (f) and (g) silicified sandstone; (h) flint; (i) Bituruna-type point from the PFS site, made on silicified sandstone. (Color online)

by the descriptive analysis of unbroken and broken preforms compared to each other and the finished Garivaldinense points.

The unbroken preforms have a similar length to the finished points, but they are a little wider and thicker. This supports one of our hypotheses. We speculated that the unbroken ones would be bigger (especially wider) and proportionally thinner (in relation to length) than broken preforms during the stage they were abandoned, so that they could be finished using local methods and techniques, and they would present with cultural metric patterns of the points.

Geometric Morphometrics

Geometric morphometrics is a quantitative method that originated in biology and is used to describe and compare shapes (Zelditch et al. 2012:1) and quantify their variation using geometric coordinates. In simple terms, morphometrics is the "study of shape variation and its covariation with other variables" (Adams et al. 2004:5). Although approaches using linear measurements are often applied to obtain information on the shape and size of formal artifacts, it is well known that a set of measurements of length, width, and thickness are, in many cases, insufficient to capture all the properties of the geometry of interest from the object (Adams et al. 2004; Zelditch et al. 2012:6). The visualization of results using linear measurements is often through tables and scatterplots, which are not very intuitive tools (Benítez and Püschel 2014). In contrast, geometric morphometric methods (GMMs) allow the preservation of all the geometric information of form (constituted of shape and size) throughout the analyses.

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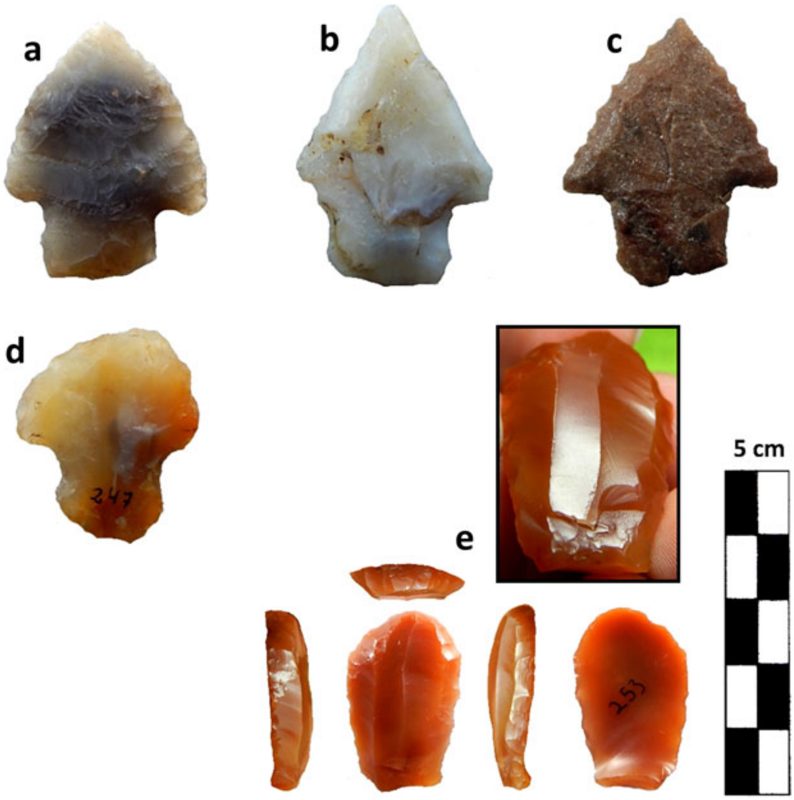

Figure 7. (a-c) Examples of PFS type 2 points (Caí type): (a–b) agate, (c) silicified sandstone; (d) Garivaldinense scraper from the PFS site made on agate; (e) lesmina-type scraper from the PFS site made on agate. Detail of the bladelet negatives on the upper face of the artifact, pointing to the presence of bladelet technology in the PFS site. (Color online)

Figure 8. Pyramidal core from the PFS site made on silicified sandstone. (Color online)

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Notes: Results from the PFS site were from our descriptive and frequency analysis, and those from the Garivaldino Site were according to Moreno and Okumura (2020). Only frequencies higher than 20% are presented for qualitative attributes. The range of quantitative attributes corresponds to the mean plus and minus the standard deviation. **Bold** attributes are those with significant differences according to bivariate tests.

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GMMs quantify and test differences in shape through the use of landmarks (Bookstein 1991). Landmarks are sets of discrete points in which all the elements of a given dataset are related (63). The type of correspondence (anatomical, topographical, developmental, functional, etc.) depends on the scientific questions being asked, and the landmark configuration on a particular structure must be determined by the hypothesis being tested (Oxnard and O'Higgins 2009; Viscosi and Cardini 2011).

In geometric morphometrics, the concept of size—the measure of scale that expresses the magnitude of an object—is defined in terms of the centroid of the configuration. Centroid size is a quantity that depends on the distance between the centroid and each landmark of the shape. One of the main reasons for choosing such a measure of size is that centroid size is geometrically and statistically independent of shape (Bookstein 1991; Zelditch et al. 2012). This desired attribute of a size measure makes it possible to treat shape features independently of variation in scale (Zelditch et al. 2012:60), thereby obtaining the "pure" shape. Centroid size is determined by calculating the square root of the summed squared distances of each landmark from the centroid.

Applications of geometric morphometrics to archaeology have increased greatly in the last few decades. As a method developed mainly by evolutionary biologists, the application of its concepts and techniques to material culture studies has been mostly in the field of evolutionary archaeology (Okumura and Araujo 2019). GMMs have gained particular prominence in the field of lithic studies because it enables archaeologists to address questions regarding artifact variation in time and space (e.g., Buchanan et al. 2014; Cardillo and Charlin 2018; Cardillo et al. 2016; Garcia-Medrano et al. 2020; Lycett 2009). Their application to Brazilian stone tools has been carried out since 2010 in a research project embedded in a cultural evolutionary framework (Okumura and Araujo 2010). It uses GMM analysis of bifacial projectile points of hunter-gatherer groups from southern and southeastern Brazil to better describe the variability of such points and, ultimately, better understand the past cultural diversity and evolution observed in this region (Araujo and Okumura 2017, 2021; Okumura and Araujo 2013, 2014, 2015, 2016, 2017).

Materials and Methods

The geometric morphometric analysis was applied to 14 bifacial points. It used a landmark-based procedure, meaning the use of points of reference (Bookstein 1991), followed by two fundamental analyses in GMM: the generalized Procrustes analysis (GPA), which captures only information on shape from each specimen, removing all differences that are not shape differences, such as size, position, and orientation (Mitteroecker et al. 2013; Zelditch et al. 2012:73)—and the principal component analysis (PCA), which constructs new independent variables from the original ones for simplifying the description of shape variation among individuals (Zelditch et al. 2012:135).

The standard Procrustes superimposition technique to separate shape from size, translation, and rotation is generalized Procrustes analysis (Zelditch et al. 2012). It removes the three "nonshape" components of variation and extracts the shape coordinates from the data in three steps (Figure 9):

(1) Move the configurations of landmarks to a common position. In this step, the centers of gravity (centroids) of the landmark configurations are all shifted to the origin of the coordinate system, the point (0.0). This result is obtained by subtracting the averages of the x and y coordinates of all landmarks from the coordinates of each landmark of the configuration.
(2) Scale the landmark configuration to unit centroid size (centroid size of 1.0) by dividing each landmark coordinate by the centroid size of the whole configuration of landmarks.
(3) Choose one configuration of landmarks as a reference and then rotate the other configurations to an overall best fit to minimize the sum of squared distances between corresponding landmarks (for a detailed description and formulas, see Dryden and Mardia 2016; Rohlf and Slice 1990).

In this study, we used 2D GMM in the analysis of the morphology of bifacial points, using the proposed point types to track changes in shape. GMMs can be particularly useful when combined with the technological analysis of formal artifacts. These two approaches are complementary in material

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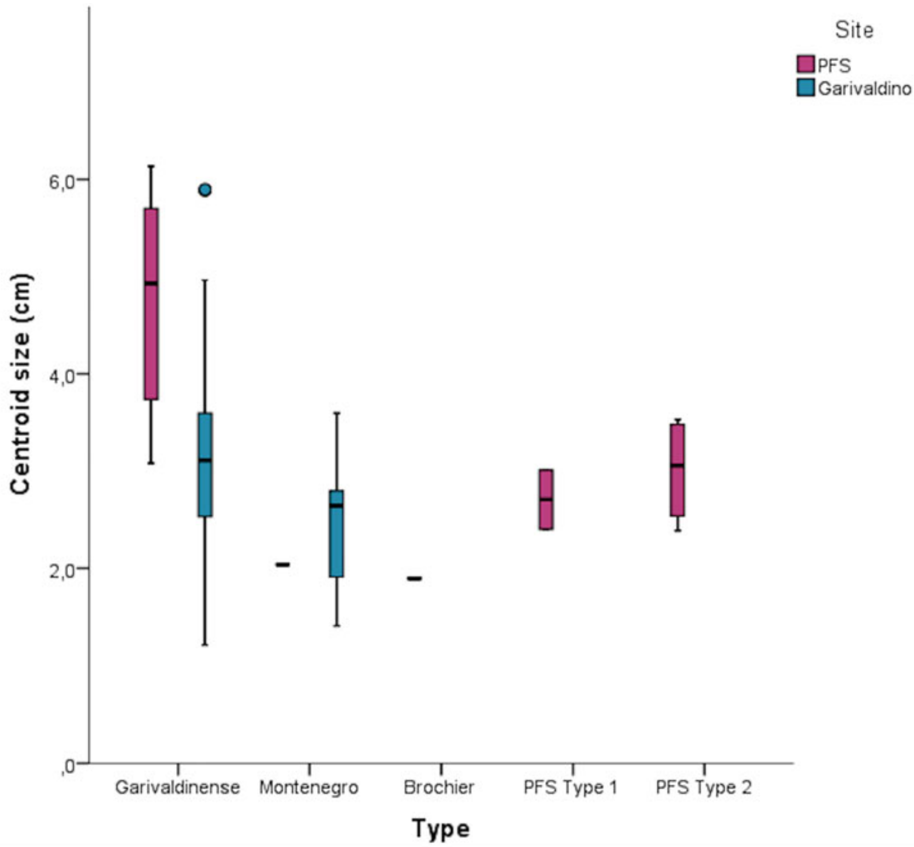

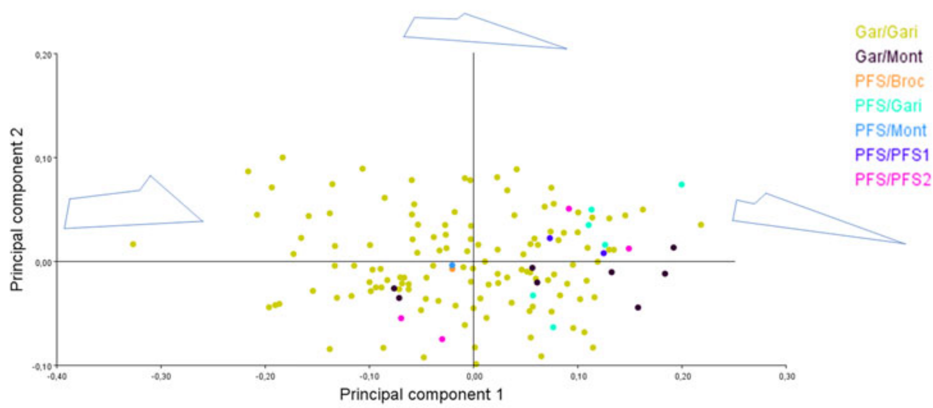

Figure 9. (a) Boxplots of centroid sizes of each point type, divided by site; (b) PCA graph of shape coordinates. The extreme shapes of each axis are presented. Point types and sites were paired, and the legend and colors can be read as follows: Garivaldino site/Garivaldinense type (mustard green); Garivaldino site/Montenegro type (brown); PFS site/Brochier type (orange); PFS site/Garivaldinense type (turquoise); PFS site/Montenegro type (blue); PFS site/PFS type 1 (purple); PFS site/PFS type 2 (pink). (Color online)

culture studies, because GMMs offer a detailed study of the form (shape and size) using shape variables that are not considered in technological analyses: for example, the use of landmarks and semi-landmarks to describe the outline shape of an object provides morphological information that may not be properly obtained using linear variables, such as measurements of length, width, and thickness. In this sense, GMMs may corroborate the results of technological analyses by providing a robust

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quantitative approach applied exclusively to the shape and size of archaeological objects. Thus, they are relevant to this study, which prioritizes technology for expanding the description and definition of previously and newly defined point types.

Digitization of the dataset of points was done using standardized photographs taken with the camera parallel to the projectile point's surface, with the distal end facing to the right; a metric scale was included (see Supplemental Figure 1). Five landmarks satisfactorily covered the geometry of half the point, which is a frequently used technique to reduce the time of data collection in symmetric structures (Viscosi and Cardini 2011); this technique also allows more fragmented specimens to be included in the analysis. These five landmarks are indicated in Supplemental Figure 1. The standardized photographs were previously organized and uploaded for the analyses using TPSUtil (version 1.74; Rohlf 2017a), and the landmarks were digitized on the photographs using TPSDig2 (version 2.30; Rohlf 2017b). MorphoJ (version 1.07a; Klingenberg 2011) was then used to carry out the GPA. We used PCA to reduce dimensions of the shape coordinates and compare the variations in shape among specimens. TPSRelw (version 1.75 64 bits; Rohlf 2021) was used to extract the extreme shapes of the PC axes. Centroid size was also obtained using MorphoJ.

The sample for GMM analysis included the five types of projectile points from the PFS site: Garivaldinense type ($n = 6$), Brochier type ($n = 1$), Montenegro type ($n = 1$), PFS type 1 ($n = 2$), and PFS type 2 ($n = 4$), for a total of 14 specimens. Our sample was limited to these 14 points for two reasons: (1) some points had fractures in landmark locations that prevented their inclusion, given that at least half the point (in longitudinal section) needed to be intact; and (2) from the assemblage of Brochier-type points, only one presented the appropriate features for landmark placement: well-distinguishable shoulders, neck, and stem. Preforms were not included in the GMM analysis.

The PCA of the shape coordinates included 14 points from the PFS site and a sample of 131 points from the Garivaldino site ($n = 131$); the same selection criteria were used for both sites. We used GMMs to perform the same comparison between the two sites as was carried out by the technological analysis. The sample from the Garivaldino site only included Garivaldinense ($n = 123$) and Montenegro ($n = 8$) points, because none of the Brochier points were suitable for the application of GMM.

Results

Figure 9 (top) presents the centroid sizes of the sample divided by type. The first boxplot (pink) corresponding to Garivaldinense points in the PFS site has a higher median centroid size than the boxplot next to it (blue), which corresponds to Garivaldinense points in the Garivaldino site, which present a greater range of variation, including some outliers. The only Montenegro type from the PFS site is smaller than the median observed in the Garivaldino site. The graph also shows that the only Brochier specimen from the PFS site is of fairly similar size to the Montenegro specimens from the Garivaldino site. PFS type 2 points are bigger than PFS type 1 specimens. Given the great variability in size observed in both types (Garivaldinense and Montenegro) from the Garivaldino site, all PFS points are included in such variability regarding centroid size.

Figure 9 (bottom) presents the PCA graph of shape coordinates, in which specimens are distributed according to their shape. The extreme shapes of each axis are shown. On the horizontal axis of the PCA (first PC, 65% of variance), most of the shape variation reflects the *resharpening of the points*, meaning that points located on the left of the graph tend to present a very short body in relation to the stem. The opposite pattern can be observed for specimens located on the right of the graph. The second PC (12% of variance) presents mostly *changes in the shape of the stem*, varying from a convex (upper extreme shape) to a bifurcated or concave base (lower extreme shape). Furthermore, the extreme shapes of this vertical axis show a clear variation in the width of the points: the upper extreme shape is narrower than the lower extreme shape, in both the stem and the body.

The Garivaldinense points from the Garivaldino site present a great diversity of shapes and are distributed in most of the shape space. That means that there is an important overlap between these points and the other point types (from both the Garivaldino and PFS sites). Garivaldinense points from the Garivaldino site include a few points presenting with distinct degrees of resharpening (as

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indicated by technological observations), as well as concave and bifurcated stems. The Garivaldinense points from the PFS site are in the right portion of the graph, showing a tendency for less resharpened points. It is also important to note that the technological analysis revealed no resharpening on the points from the PFS site, except for the recycled point as a stemmed scraper. The other type identified at the Garivaldino site (Montenegro type) can be described as presenting no resharpening or bifurcated stems. The only analyzed (by GMM) Montenegro-type point from the PFS site is very close to the point of intersection between the two axes and thus is similar to the consensus shape (no resharpening and convex stem base). Another important observation is the great similarity in shape between this Montenegro point and the Brochier point from the same site (PFS). It is very difficult to observe any pattern in terms of shape for Brochier, Montenegro, PFS1, and PFS2 types from the PFS site, given the small sample size. The two PFS type 1 specimens from the PFS site are close to each other, indicating a similarity in terms of shape. The distribution of the four PFS type 2 points from the PFS site indicates variation in both body and stem shape, as well as in the general width of the point.

Discussion

The PFS site presents all the lithic features that were originally used to define Garivaldinense lithic culture: Garivaldinense points, Brochier points, Montenegro points (Figure 10e–g), and even the Garivaldinense scraper. These points' changes through time are shown in Supplemental Figure 2. These features allowed us to associate the PFS site with the Garivaldinense lithic industry. However,

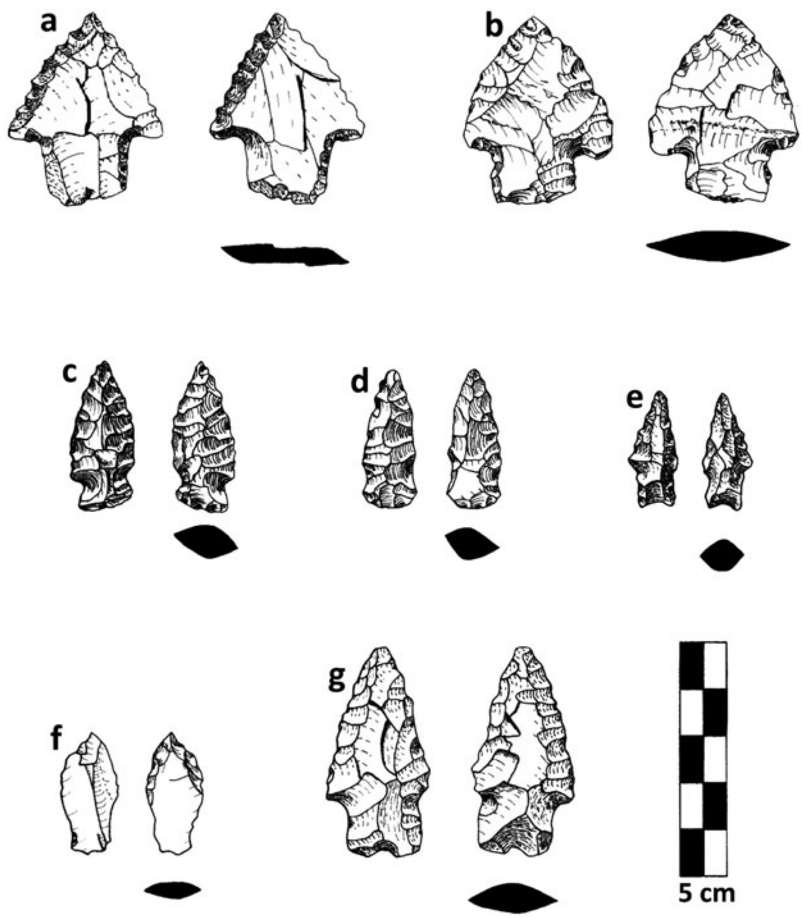

Figure 10. Technical drawing of different types of points associated with the Garivaldinense lithic industry, all from the PFS site: (a) and (b) Caí points; (c) and (d) Schmitz points; (e) Montenegro point; (f) Brochier point; and (g) Garivaldinense point.

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the PFS site also presents one broken Bituruna point, one pyramidal core, one lesmina, and two other lithic point types (PFS type 1 and PFS type 2) that have not yet been identified in Garivaldino or any other Garivaldinense-associated site.

PFS type 1, in technological terms, consists of points made by bifacial parallel-pressure flaking reduction of the body, with negatives producing a median ridge, followed by retouch by bifacial convergent-pressure flaking of the stem. In morphological terms, these points have triangular bodies with convex edges and a fan-shaped stem. They are usually 30–35 mm long and are relatively thick, with a width thickness proportion from 2.1/1 to 2.6/1. We propose calling this the "Schmitz-type point," in reference to the name of the site where it was first identified (Figure 10c and d).

PFS type 2, in technological terms, consists of points made by bifacial percussion flaking reduction of the blank, with negatives organized in selective and trespassed form, followed by retouch by bifacial pressure flaking of the stem and alternate pressure flaking in the left edge of the body (both faces). In morphological terms, these points have triangular bodies with convex edges and straight stems. They present a precise pattern in length (40–43 mm) and width (30–34 mm), with a thin width/thickness proportion (5/1–6.8/1). We propose calling this the "Caí-type point," in reference to the name of the valley where these points were first identified (Figure 10a and d).

More studies in southern Brazil hunter-gatherer-associated lithic industries are still necessary to understand the presence of these new lithic point patterns (Schmitz and Caí types) in a Garivaldinense-associated site. Perhaps the question we should answer is this: Why were these types not identified in the Garivaldino site? The presence of a lesmina and a Bituruna-type point in the PFS assemblage is also interesting. Bituruna points are bigger than any other type of lithic points ever identified in southern Brazil, except for some of the rare Fell-type (aka fishtail) points found in the country (for more on Brazilian Fell points, see Loponte et al. 2015, 2016). These points, just like the lesminas, were first identified in eastern Paraná State. According to data presented by Chmyz (1981), Bituruna points have triangular bodies (mostly elongated), incurvate (or round) shoulders. and straight or convex stems. Although technological features are not discussed by Chmyz, the published data indicate that these points are usually longer than 7 cm and wider than 4 cm, are relatively thin, and are produced by (1) reduction by bifacial percussion followed by (2) retouch by pressure flaking. These points are usually too big and heavy to be used as darts or arrows but were probably used as spear points or even knives; however, a functional analysis of these points is still necessary.

The presence of a single core indicates that the debitage stage (the stage of blank production) was rarely performed on the site. Most probably the blanks were brought from other places, suggesting that they were produced where the raw materials were located. This rare core indicates one method for blank production of the Garivaldinense industry points. More methods of debitage could be involved, but the only way to determine this is by finding more of this rare type of evidence in the sites or locating the raw material sources where the cores were probably discarded.

Taking into account the small sample of points from the PFS site ($n = 14$) that were fit for the GMM analysis, as well as the fact that almost half were Garivaldinense types ($n = 6$), resulting in the remaining four types being represented by a sample size of only one or two specimens, our results are far from conclusive. Regarding centroid size, the GMM results support the technological analysis, meaning that Garivaldinense specimens in the PFS site are bigger than in the Garivaldino site. PCA of shape coordinates attests to Garivaldinense points from the PFS site having the diversity of shape observed for the same point types from the Garivaldino site. The small sample size of the other types from the PFS site does not enable a pattern in terms of distribution in the shape space to be identified. Although the PCA points to important patterns in terms of resharpening, which can be tentatively attributed as a cultural feature, the technological analysis revealed that none of the points were resharpened, meaning that the present shapes are the original ones, except for the broken ones. A larger sample would be important to verify tendencies in terms of shape.

The fact that the proposed types do not necessarily match the shapes observed in the points should not be a surprise, given that types were originally defined using metric, morphological, and technological attributes. In this case, even the morphological description used to define the types would not necessarily match the shape obtained using GMM, because it depends on landmark placement; for

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example, in our case, there are no landmarks to describe the shapes of the edges of the body of the point as either concave or convex. As is well known, the same artifact shape can be reached using different knapping techniques, and therefore it is not expected that the proposed types and the GMM analysis would match. Thus, artifact classification should be made using different aspects—morphology, technology, raw material, and so on—and should be based on theoretical-driven expectations (Araujo and Okumura 2017, 2021).

Conclusion

The site was in an area with abundant water sources, raw material for lithic artifacts, and a fair amount of vegetation for food hunting and gathering. Therefore, it is logical to conclude that this rockshelter was selected because of these environmental factors that were favorable for occupation. However, it was not intensively occupied, as indicated by the low density of anthropogenic sediment deposition and artifacts in the site. This scenario is observed in several hunter-gatherer sites in central and southern Brazil, which after an intense occupation during the Early Holocene declined in population in the Middle Holocene (Araujo et al. 2006, 2018; Cheliz et al. 2020; Moreno 2020; Okumura and Araujo 2014).

The PFS site is representative of the Garivaldinense culture, as shown by the technological analysis data that indicate the same feature patterns that were previously associated with that lithic industry. It is also supported by the GMM analyses, where the point shape variability of the PFS site is included within the Garivaldino site's diversity. The newly identified and defined point types, Schmitz and Caí, suggest greater technological variability within this archaeological culture that was not always present in other Garivaldinense-associated points. These two new types of points may represent Mid-Holocene innovations in this culture, but new excavations with more absolute dating of the site would be necessary to confirm this hypothesis. Other explanations for the presence of these two new types are regional variation within Garivaldinense culture or even cultural exchange with other cultures, as recently suggested by Moreno and Garcia (2022). This variability of point types might be related to different functions and uses, but we cannot reach any conclusions only by looking at their production technology and shape. We suggest that functional studies, such as a use-wear analysis, be conducted.

The association of the site to the Garivaldinense lithic industry corroborates the idea that this culture was present from the Early to Mid-Holocene throughout central and eastern Rio Grande do Sul state in Brazil, as suggested by Moreno (2020). However, more studies in this region and surrounding areas are necessary to understand the geographical and chronological expansion of Garivaldinense culture.

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Data Availability Statement. All data regarding the technological analysis of the PFS site artifacts are presented as supplementary materials in Brazilian Portuguese. All data regarding the technological analysis of the Garivaldino site points were previously provided by Moreno and Okumura (2020) as supplemental materials (Multimedia component 3 (https://www.sciencedirect.com/science/article/pii/S1040618220304341#appsec1). The analyzed assemblage from the PFS site is currently housed in the Instituto Anchietano de Pesquisa, Universidade do Vale do Rio dos Sinos, in São Leopoldo, Rio Grande do Sul State, Brazil.

Competing Interests. The authors declare none.

Supplemental Material. For supplemental material accompanying this article, visit https://doi.org/10.1017/laq.2024.1.

Supplemental Table 1. Raw Data of the Technological Analysis of PFS Site Lithic Points.

Supplemental Table 2. Comparison of Measurements between the Finished Garivaldinense Points and Preforms on Silicified Sandstone from the PFS Site. The range of quantitative attributes corresponds to the mean plus and minus the standard deviation. The total length of broken preforms was not considered because of the small sample ($n = 2$).

Supplemental Figure 1. (a) Example of 2D digitization of projectile points. The image shows a PFS type 2 (Caí type) point photographed with the camera lens parallel to the specimen, with the distal end facing to the right and the positioning of a scale; (b) schematic drawing showing the landmark configuration used to characterize the different parts of a bifacial point: (A) apex/

tip of the body, (B) most extreme point in the shoulder curve, (C) point where the neck/stem meets the body, (D) meeting of the lateral and basal parts of the stem, and (E) middle point of the stem base in the longitudinal line.

Supplemental Figure 2. Technical drawing mixed with a diachronic color scheme of different types of points associated with the Garivaldinense lithic industry, all from the PFS site. Yellow areas represent unmodified areas from the original blank. Gray negatives represent the reduction stage. White negatives represent the retouch stage in (a) and (b) Caí points; (c) and (d) Schmitz points; (e) Montenegro point; (f) Brochier point; and (g) Garivaldinense point.

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