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COMPREHENSIVE MULTI-PROXY LITHIC ANALYSIS FROM PEDRA FURADA 1, NORTHEASTERN BRAZIL, 60-30 KA BP
Investigating he Complexities in Identifying Anthropogenic Features in Pebble Objects

ANÁLISE MULTI-PROXY DETALHADA DE ARTEFATOS LÍTICOS DE PEDRA FURADA 1, NO NORDESTE DO BRASIL, DATADOS DE 60-30 KA BP
Explorando as Complexidades na Determinação de Características Antropogênicas em Objetos sobre Seixo

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ABSTRACT
In this study, we introduce a new preliminary multi-proxy evaluation of four lithic artifacts from the most ancient phase of the Toca do Boqueirão da Pedra Furada site in northeastern Brazil, which are dated between 60 000 and 30 000 BP. Excavated in 1988 by Fabio Parenti and Nière Guidon during the *Mission française du Piauí*, these artifacts underwent a detailed electron microscopic examination by Robson Bonnichsen in 2004. Our updated assessment delves deeply into a 3D taphonomic, morphological, technological, structural and indirect use-wear exploration of the artifacts' manufacturing characteristics. Additionally, we conduct a comprehensive examination of both macro and micro traces found on the artifacts' surfaces and edges. This provides enriched insights into their potential origins and usage, and also offers new perspectives on the intersection of taphonomy and technology in pebble-based objects. Our findings offer a renewed perspective on the importance of these artifacts in understanding the early human presence of northeastern Brazil, and foster a complete revisit of Pedra Furada lithic assemblage.

Keywords: Toca do Boqueirão da Pedra Furada; Lithic Taphonomy; Traceology; 3D Lithic technology; Early peopling of the Americas.

RESUMO
Neste estudo, apresentamos uma nova avaliação preliminar multi-proxy de quatro artefatos líticos da fase mais antiga do sítio Toca do Boqueirão da Pedra Furada, no nordeste do Brasil, datados entre 60.000 e 30.000 a.C. Escavados em 1988 por Fabio Parenti e Niède Guidon durante a Missão Francesa do Piauí, esses artefatos foram submetidos a um exame detalhado de microscopia eletrônica por Robson Bonnichsen em 2004. Nossa avaliação atualizada aprofunda-se em uma exploração tafonômica, morfológica, tecnológica, estrutural e indireta do desgaste de uso dos artefatos, em 3D. Além disso, realizamos um exame abrangente de macro e micro traços encontrados nas superfícies dos artefatos. Estes dados proporcionam inferências sobre suas origens e usos potenciais, e também oferece novas perspectivas sobre a interseção da tafonomia e tecnologia em objetos sobre seixo. Nossos resultados oferecem uma perspectiva renovada sobre a importância desses artefatos na compreensão da presença humana mais antiga no Nordeste do Brasil e promovem uma revisão completa do conjunto lítico da Pedra Furada.

Palavras-chave: Toca do Boqueirão da Pedra Furada; Tafonomia Lítica; Traceologia; Tecnologia Lítica em 3D; Primeiros Povoamentos das Américas.

1. RESEARCH CONTEXT

The study of lithic artifacts is pivotal in unraveling techno-behaviors associated to early human presence in the Americas. These remnants of Paleoamerican life offer valuable insights into technology (Lourdeau, 2015; Weitzel et al., 2022), daily life (Parenti, 2023), migration patterns (Davis et al., 2022; Pérez-Balarezo et al., 2023), social interaction (Kitchel, 2023), and environmental adaptations (Barlow & Miller, 2022; Prates et al., 2022) of early inhabitants. Toca do Boqueirão da Pedra Furada (from here on TBPF) in northeastern Brazil, discovered in the 1970s, has emerged as a key site in this exploration. It presents a wealth of lithic objects (Parenti, 2001, 2023), rock art, and combustion structures (Guidon & Delibrias, 1985, 1986), some dating over 60 000 BP (Santos et al., 2003), challenging traditional theories and models of human arrival in the New World (Lourdeau & Bueno, 2022).

While TBPF has already reshaped our understanding of the temporal depth of human presence in the Americas, and has been accepted by some researchers as one of the oldest sites in the Americas (Bahn, 1993; Butzer, 1988; Dennell & Hurcombe, 1995; Pérez-Balarezo et al., 2023; Pérez-Balarezo & Ramos, 2021), it continues to generate debate and controversy. Other researchers (Agnolín & Agnolín, 2023; Fiedel, 2022; Gómez Coutouly, 2021; Meltzer et al., 1994) suggest that the anthropic nature of many of TBPF's Pleistocene features has not been adequately demonstrated. Instead of disregarding this debate, we believe it presents an opportunity for self-criticism and continuous theoretical,

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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methodological, and instrumental improvement. In this light, TBPF, like any other site, demands a reassessment with the advent of new methodological tools. In this study, we employ cutting-edge technologies such as 3D modeling and refined analytical approaches to re-examine lithic collections from the site's earliest phase: Pedra Furada 1. Our focus is on a detailed exploration of the taphonomic, technological, and traceological characteristics of four lithic artifacts from this phase, which were analyzed by Robson Bonnichsen in 2004. This analysis employs a multi-proxy approach within the framework of *chaîne opératoire* and traceology.

Central to our study is the hypothesis that the lithic objects from Pedra Furada 1, dated between 60 000 and 30 000 BP, were modified by humans and are not the result of natural processes. This premise guides our examination, aiming to discern whether the observed characteristics of these artifacts are indeed indicative of human activity or simply the product of natural geological and geomorphological processes. This work is part of a comprehensive reassessment of Pedra Furada 1, and it also aims to test the potential and limitations of the multi-proxy approach conceived for its analysis.

The confirmation or refutation of this hypothesis has significant implications for understanding the early human presence in northeastern Brazil and the broader narrative of the early peopling of the Americas. By integrating data from 3D modeling, taphonomic, technological, and traceological data we aim to offer a comprehensive glimpse into the prehistoric technicity and alterity of these objects, thus contributing to the dynamic and ever-evolving field of archaeological research in the Americas.

2. GEOGRAPHIC, GEOMORPHOLOGICAL AND GEOLOGICAL CONTEXT OF PEDRA FURADA

Geographically, Pedra Furada is located within the Piauí-Parnaíba basin, part of the larger Serra Grande group (particularly, the Ipu Formation). Its position at the southern edge of the Serra da Capivara National Park (SCNP) marks a pivotal ecological boundary, transitioning from a northward-dipping arid plateau to a more humid Plio-Pleistocene pediment (Figure 1). The geomorphological features of the site are distinguished by a prominent cuesta, indicative of the region's dynamic geological evolution. This steep hillside is interspersed with pre-Cambrian limestone outcrops, or serrotes, such as Antonião, Sansão, and Garrincho, adding to the site's geomorphological diversity. Overlooking the valley of Boqueirão, Pedra Furada's location is not only visually commanding but also plays a significant role in the acoustic landscape, factors that likely influenced its historical use.

From a geological perspective, Pedra Furada is primarily a sandstone rock-shelter, carved into Devonian sandstone of the Serra Grande group. The shelter is approximately 70 meters wide and 12 meters deep, facing south and holding a prominent position in the landscape. Notable geological elements include a visible whitish conglomerate and a deep incision in the sandstone wall, the result of an active waterfall. The presence of a thin siltite layer at the base of this incision is key to understanding the shelter's formation and preservation.

The vegetation surrounding Pedra Furada predominantly consists of the Caatinga biome, distinctive of this region and encompassing approximately one million square kilometers of the inner Brazilian Northeast. This biome, typified by xeric (dry) shrubland and thorny forests, has evolved to thrive in the region's arid and semi-arid climates. While the Caatinga is the prevalent vegetation type, pockets of more humid and arboreal vegetation persist, particularly in the shaded, narrow boqueirões near the majority of the area's rock shelters (Emperaire, 1989). The site's archaeological context is enhanced by its proximity to other significant sites, such as Toca do Sítio do Meio, which are rich in late Pleistocene deposits.

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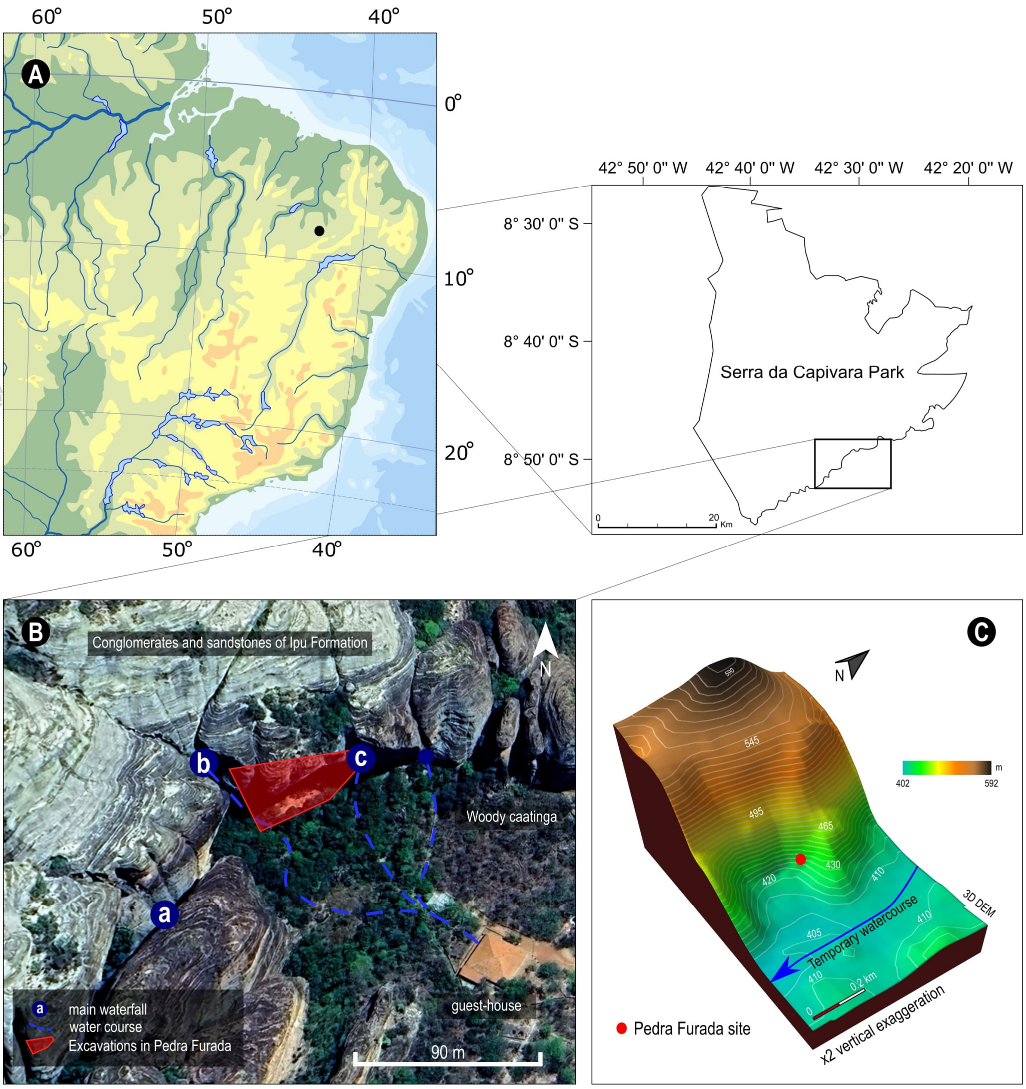

Figure 1. Geographic location of the study area in northeastern Brazil and Serra da Capivara National Park (A). Location of the Pedra Furada site in Conglomerates/sandstones and woody caatinga (B) context. 3D Digital Elevation Model of Pedra Furada's surroundings. Illustration B follows the topographic study carried out by Parenti (1992, 2001, 2023).

3. PREVIOUS WORKS IN PEDRA FURADA: CHRONOSTRATIGRAPHY ACCORDING TO N. GUIDON AND F. PARENTI

The total excavated area at TBPF encompassed approximately 700 m², with a sediment volume of 2050 m³ (Parenti, 2001, 2023). The site underwent eight distinct excavation campaigns from 1978 to 1988, initially focusing on the Western sector (1978–1987) and later expanding to the Eastern sector (1987–1988). The remaining unexcavated and preserved areas accounted for approximately 10% of the site (Parenti, 2023).

A significant methodological shift occurred in 1982 with the abandonment of the 1x1 meter grid in favor of a planigraphic technique. This change, necessitated by challenging site conditions, notably enhanced the spatial understanding of the site. In 1984, the excavated area reached about 100 m² with a depth of 3 meters, revealing complex strata double dipping East-West and North-South. The discovery of a massive pile of collapsed blocks at the bottom of the sequence in 1985 and 1987 was pivotal in understanding sediment retention between the blocks and the wall.

Radiocarbon dating played a crucial role in the site's chronological study, with charcoal fragments collected primarily for this purpose. The introduction of anthracological analysis in 2013 furthered the understanding of the site's Holocene units.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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The Western sector, under the direction of Niède Guidon, saw a comprehensive collection of all fragmented cobbles and pebbles, while charcoal fragments were sampled for radiocarbon dating. In contrast, the Eastern sector, led from 1987 to 1988, employed a selective approach, choosing pieces based on specific characteristics derived from comparative analyses. This shift in methodology, although limiting a robust statistical evaluation of the lithic assemblage, provided nuanced insights into the site's occupation.

The focus of excavation in the Eastern sector from July 1987 to July 1988 led to reaching bedrock at a depth of 2.5 meters over an 8 m² area, with no artifacts or structures found. The Western sector, collectively referred to as "Escavação Central," encompassed the deepest units, significantly contributing to the overall understanding of the site's stratigraphy and human occupation patterns.

The TBPF site's sediment deposit, as described in Parenti (2001), exhibits a tripartite origin. The largest sediment source is medium to coarse sand and sandstone slabs from the Silurian Serra Grande formation, forming the lowermost part of the wall. Additionally, heterometric quartzitic cobbles and pebbles from the uppermost part of the cuesta front contribute to the site's geology. The third component is exogenous sediment, comprising transported stones and organic materials. The absence of bone remains in Pleistocene units is attributed to low pH levels, which led to the degradation of organic components.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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Central to the shelter, along reference section 3, lies a stratigraphic sequence extending from sandstone bedrock to archaeological layers dating between 60–7 cal BP. All strata dip approximately 10° East to West, mirroring the underlying sandstone substratum. This inclination, combined with a low sedimentary rate (average 10 cm/ky), accounts for the dispersal of fine combustion remains, such as small charcoals and ashes, downstream, including in the Vale da Pedra Furada site area.

A detailed sedimentological analysis in 1996 by Evelyne Débard focused on the preserved baulk of sector 5, integrating the results into the broader understanding of the site's geology. Chronology at BPF has been primarily established through radiocarbon dating of abundant charcoal remains, following the original subdivision proposed by N. Guidon and expanded upon with deeper excavations. Thermoluminescence (TL) dating of quartz cobbles and sandstone slabs, initiated in 1988 in the Eastern sector, suggested an extended chronology for the lowest layers, predating the radiocarbon dates. However, this paper emphasizes a preference for a robust and coherent radiocarbon sequence, treating the TL dates as a hypothesis needing further testing.

Parenti (2001) proposed a chronostratigraphy divided into three phases and seven layers, named Pedra Furada for the Pleistocene and Serra Talhada and Agreste for the Holocene. This division, initially based on uncalibrated dates, has been updated by Parenti (2023) using the Intcal20 calibration curve. Notably, three main gaps in the radiocarbon sequence are identified: between 40 and 37.5 cal BP, 29 and 26 cal BP, and 17 and 12.5 cal BP. The third gap is particularly significant, marking a clear lapse in human presence at the site towards the end of the Pleistocene and before the dense peopling of the lower Holocene, coinciding with Heinrich Stadials 1 and 2.

In conclusion, as Parenti (2023) repeats the cultural layers at TBPF are not direct paleosurfaces but represent the best integration of archaeological stratigraphy and geochronology.

4. PREVIOUS FUNCTIONAL STUDIES

The functional studies on the lithic assemblage of TBPF, as conducted by Fabio Parenti and Niède Guidon, focus on the analysis and interpretation of stone tools. Their studies, although preliminary, encompass a range of methods and perspectives. It was Douglas Gibson, who conducted the microscopic analysis of the lithic pieces. Gibson (1989) examined a 12 quartz specimens from the Pedra Furada 1 and 2 phases, employing scanning electron microscopy to identify micro-traces of usage. This analysis revealed deep irregular striations and pitting on the tools, suggesting a scraping use (Table 1).

ET	/	SECT	NIV	PL	CLASSIFICATION Fabio Parenti (1992)	Result Analyses by D. Gibson (1989)
3282	4	EC4	PF 1-2		-	Perpendicular striations to the edge
4416	1	EC4	PF 1-2		-	Perpendicular striations to the edge
4425		EC4	PF 1-2		-	Perpendicular striations to the edge
4477		EC4	PF 1-2		-	Perpendicular striations to the edge
4497	1	EC4	PF 2		Flake	Perpendicular striations to the edge
4624	5				-	Perpendicular striations to the edge
4646	5	EC4	PF 2		-	Perpendicular striations to the edge
4668	8	EC4	PF 2		Bifacially flaked pebble	Perpendicular striations to the edge
4670	2	EC4	PF 2		24	Perpendicular striations to the edge
16437		EL	PF 2		Unifacially flaked pebble	Not examined
16478		EL	PF 2		Flake	Not examined
17086		EL	PF 2		Flake	Striations parallel to the right edge
18300		EL	PF 1	24	Flake	Not examined, problem with the equipment
18371		EL	PF 1	22	Naturally used fragment	Not examined
18492		ELT	PF 1	24	Awl on natural blank	Rounded on the left notch: for pushing, not piercing
18579		EC7	PF 1	24	Naturally used fragment	Not examined
18650		EC7	PF 1	23	Naturally used fragment	Not examined
18661		ELT	PF 1	24	Naturally used fragment	Not examined
18662		EC7	PF 1	24	Naturally used fragment	Not examined
18664		EC7	PF 1	22	Naturally used fragment	Parallel striations to the proximal part

Table 1. Analyzes of micro-traces using M.E.B carried out by D. Gibson (1989) and reported by Parenti (1992, Annex 13).

Parenti emphasizes the potential of experimental approaches in lithic analysis, acknowledging the limitations of small sample sizes and the need for dynamic use of data. He highlights the contributions of African studies in methodological advancements in lithic technology analysis, referencing the work of researchers like G. Isaac, H. Roche, and N. Toth in developing balanced methodologies between experimentation and historical analysis.

The interpretations by Fabio Parenti, grounded in the methodologies and findings of Nicholas Toth, focus on understanding lithic tools, particularly in terms of their usage and efficacy for various tasks. Toth is renowned for his experimental and detailed approach to the study of stone tools, and Parenti has incorporated aspects of this approach in his work. Specifically, Parenti utilized Toth's schema to assess the efficacy of different types of lithic tools for specific tasks. This involved examining how the physical characteristics of the tools influenced their ability to perform certain functions.

In his detailed analysis of activities represented by the lithic assemblage over time, particularly at the site of Pedra Furada, Parenti identified three distinct patterns of activities represented by the lithic tools from the Pleistocene to the Holocene. Certain activities, such as bone breaking and heavy woodwork, were prominently represented during the Pleistocene and diminished in the Holocene. In contrast, activities like leather cutting, light butchery, and vegetable cutting saw a significant increase in the Holocene. Additionally, activities that remained relatively stable over time, including heavy butchery, light woodwork, and leather scraping, were identified. This suggests a continuity in certain techniques and practices across periods.

The application of functional categories, a prominent approach in Toth's work, enabled Parenti to classify tools according to their probable use. This entailed considering both the morphology of the tools and the observed wear patterns. Parenti emphasizes that these interpretations are hypothetical and derive not only from specific studies but also from a conjectural approach that proposes a different perspective on the technical changes in lithic tools over time.

Guidon's excerpt addresses a controversy regarding the nature of the lithic samples from Pedra Furada, with some colleagues suggesting they resulted from natural processes rather than human activity. To address these concerns, Professor Robson Bonnichsen conducted analyses using an electronic microscope, providing a report with photographs and conclusions in 2004. Guidon (2008) also mentions a planned excavation by Bonnichsen in an untouched sector of Pedra Furada, aimed at providing new data, which was unfortunately canceled due to his passing away in 2005.

Overall, these studies by Parenti and Guidon at Pedra Furada underlines the complexity and multidisciplinary nature of studying early human tool use and technological development in Pedra Furada site.

5. MATERIALS

According to our ongoing new analysis, the Pedra Furada 1 phase includes 178 pieces. The majority of these pieces are classified as "used fragments" (n=74; 41.6%) according to Parenti's typology (1992, 2001). The remaining artifacts are categorized, following the same typology, as "retouched flakes" (n=25, 14.0%), "monofacially flaked pebbles" (n=23, 12.9%), "cores" (n=18, 10.1%), "bifacially flaked pebbles" (n=17; 9.6%), "flakes" (n=14, 7.9%), and to a lesser extent "simple scrapers" (n=4, 2.2%), "scrapers-awls-beaks" (n=3, 1.7%).

In terms of raw materials, the Pedra Furada 1 phase is predominantly composed of quartz (n=115; 64.6%). This is in addition to quartzite (n=33; 18.5%) and milky quartz (n=30; 16.9%).

The present study encompasses four artifacts, constituting 2% of the total from this phase. Three of these artifacts are made of quartz and one of quartzite. These artifacts were classified differently by Parenti in 1992 and 2001. Table 2 outlines these classifications, along with the traceological observations made by R. Bonnichsen, under electronic microscope, as reported in Guidon (2008). Regarding the context of these artifacts, Parenti (2023) recently detailed their spatial distribution (Figure 2), demonstrating that the drip line had no influence in this context, which further supports their anthropic nature. Figures 3 and 4 present new drawings created by one of us, M. de Almeida. Only artifact 23-18352 was previously drawn by Parenti (1992, plate 19) (Figure 5).

CODE	SECT	U	F	DATE	L*	W*	T*	M*	RAW MATERIAL	TYPE (Parenti 1992)	TYPE (Parenti 2001)	BONNICHSEN'S OBSERVATIONS (Guidon, 2008)
23-17359	Est-sud	32	-	10/05/1988	63	54	35	135	Quartzite	Core	Without description	Lacquer-like polish from the lateral cortical edge. Reformed silica adhering to the edge possibly deposited on the edge from tool use.
23-18326	Est	12	2	16/06/1988	84	63	47	256	Quartz	Used fragment	Without description	Fine striae ("linear indicators" on non-cortical surface suggests tool movement in two directions. Abrasive polish, indicating tool use smoothed the texture of the rock surface.
23-18352	Est	12	3	17/06/1988	53	45	19	54	Quartz	Classified as "Flake" in Annex 21, and as "side-scraper on quartz cortical flake (entame)" in Planche 19.	Side-scraper on quartz cortical flake (entame)	Polished and abraded surfaces with linear indicators from ventral face of the cutting edge. Linear tracks of plastically reformed silica indicating tool movement in two directions. Silica build-up from implement use along the arris. Repeated tool use has resulted in deep coarse scratches overlaying and oblique to the finer ones. Material is clearly being gouged from a previously smoothed surface
23-18547	Est total	14	2	28/06/1988	44	31	10	12	Quartz	Used fragment	Without description	Rounded and polished edge Directional indicators which indicate tool movement direction, are generally oblique to the edge. Smoothed and "lacquered" by silica gels deposited during tool use.

*L: length (mm), W: width (mm), T: thickness (mm), M: mass (g).

Table 2. Composition of the lithic sample analyzed by R. Bonnichsen.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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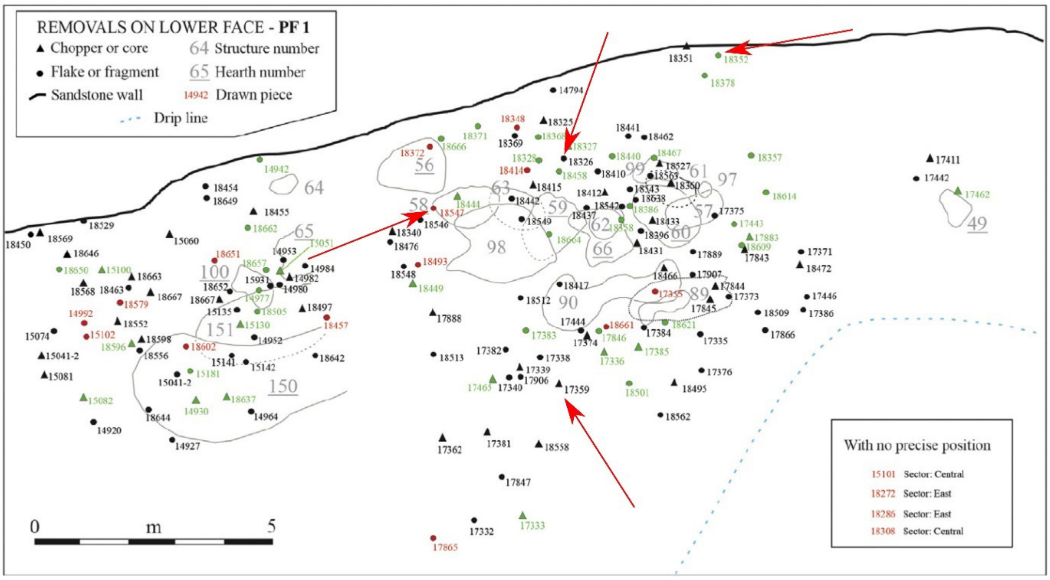

Figure 2. Location of the artifacts subject to the current study from the PF1 phase (modified from Parenti, 2023, p. 40, fig. 36). The red arrows mark the positions of the artifacts from the Bonnichsen collection.

Figure 3. Photographs of pieces 23-18326 and 23-17359 from the Bonnichsen collection.

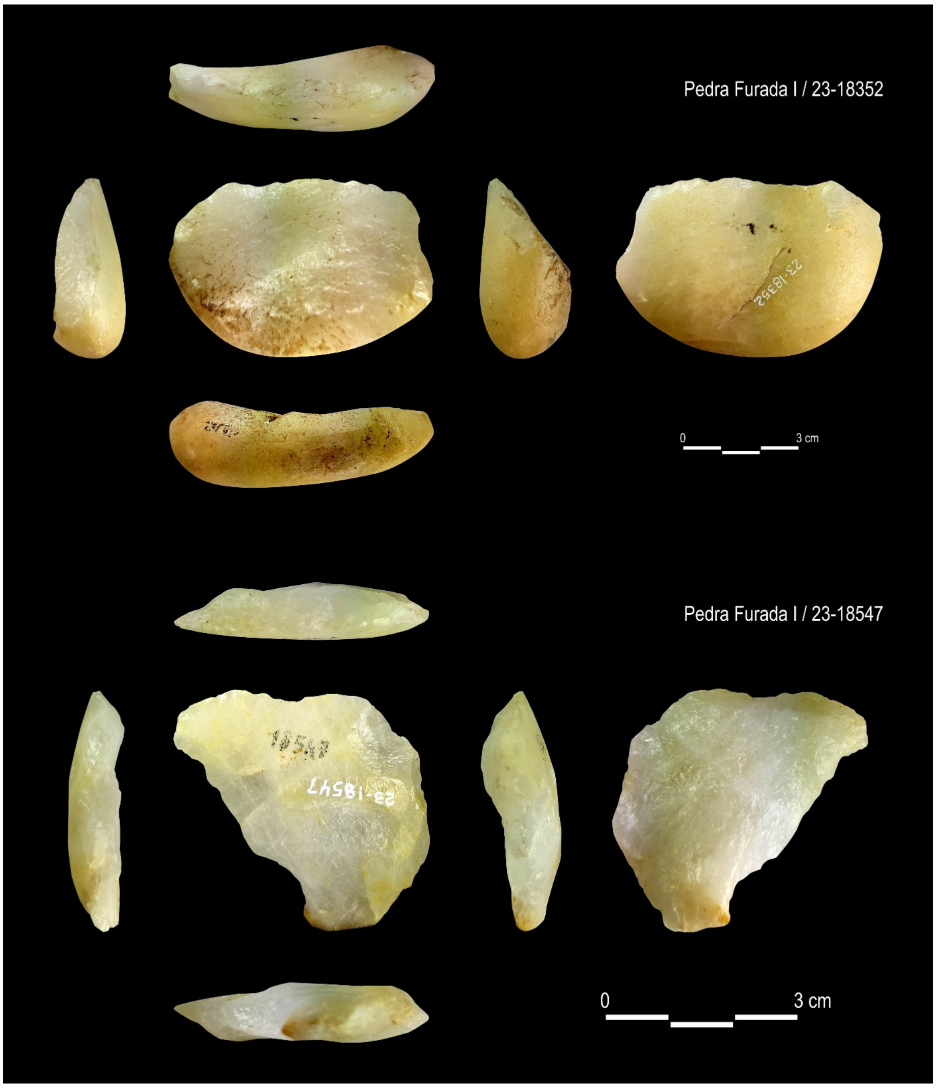

Figure 4. Photographs of pieces 23-18352 and 23-18547 from the Bonnichsen collection.

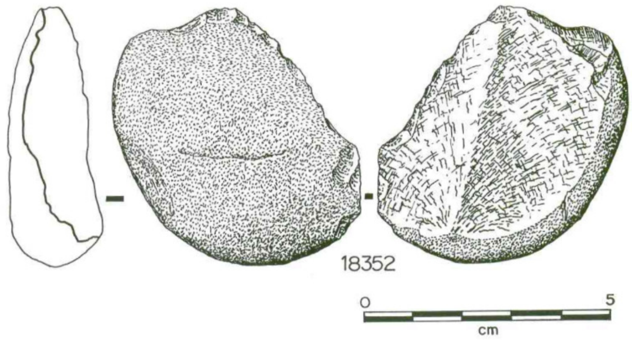

Figure 5. Technical drawing of piece 23-18352, made by F. Parenti (Modified from Parenti, 1992, Vol. II, pl. 19, pp. 51). The "23-" was later added by FUMDHAM codification. On page 50 of the same work, the author describes the piece as "scraper on quartz entame. The propagation of the fracture front caused a dihedral bulb, a very frequent phenomenon in quartz" (Parenti, 1992, 50. Our translation).

6. METHODS

6.1. Study approach

In this study, we understand traceology as the discipline that examines all traces associated with the processes of manufacture, use, maintenance, taphonomic alterations, and transport of tools. The aim is to reconstruct the technological and social processes that originated these artifacts (Clemente-Conte, 1997, 2017; Clemente-Conte et al., 2019). Based on the theoretical framework proposed by Clemente (1997) and Clemente et al. (2019), our analyses enable us to categorize lithic remains into categories such as tools, waste, or discarded products (Briz et al., 2005; Clemente-Conte, 1997). We consider any archaeological remnant that shows evidence of having been used in some productive process (e.g., butchery, carpentry, plant harvesting) as a tool, whether it be a flake, a blade, or any other unmodified base, as well as retouched products used in productive activities.

Analyzing how populations interact with the environment through labor and how they exploit resources provides us with fundamental data to understand how, with what tools, and in what manner the necessary goods for human subsistence and reproduction were obtained (Clemente-Conte, 2017) (Figure 6).

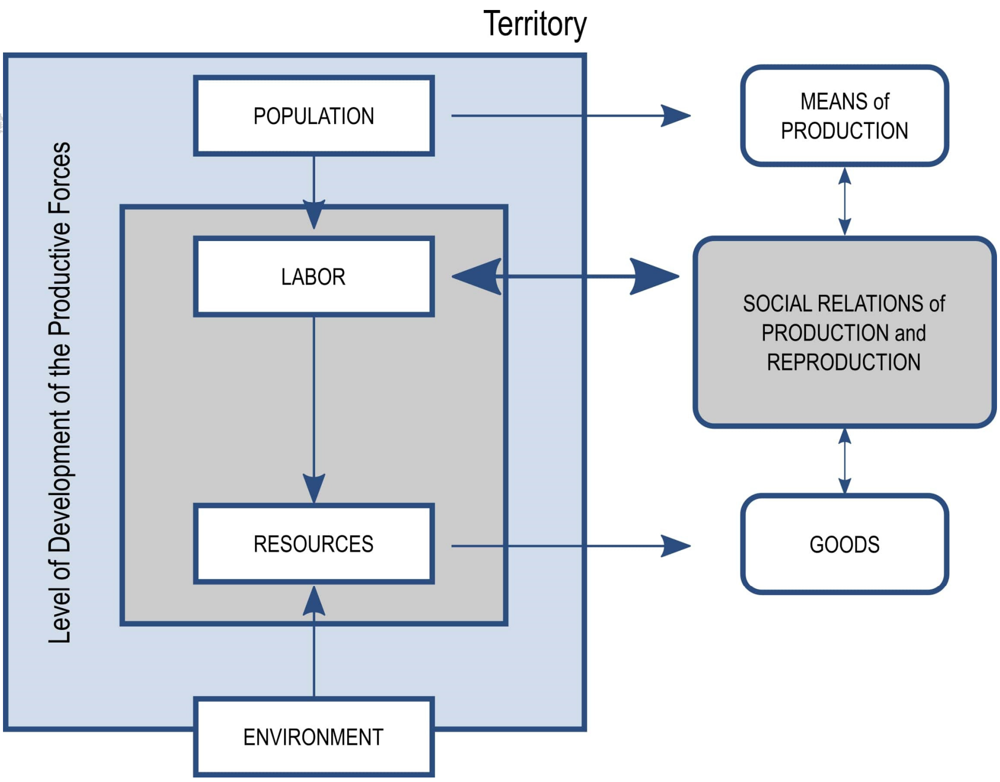

Figure 6. Schematization of the role of labor as a means of production for the acquisition of consumer goods (Modified from Terradas 2001 and Clemente et al. 2019).

Based on our prior experiences at the SCNP and other sites across various continents, we acknowledge R. Bonnichsen's contributions, including the provision of four artifacts from Pedra Furada. These artifacts offer a modest yet notable advancement in our comprehension of consumer goods acquisition and, thereby, the nature of past social production relationships. In reports sent to N. Guidon by R. Bonnichsen, we have observed detailed macro and microphotographic records. Based on all this, and other previous works in SCNP, Table 3 below describes the various natural and geological factors that could modify the pebble and cobble surfaces of Pedra Furada site. We thus rely on this inventory to better characterize these surfaces.

Factors/Attributes	**Water**	**Chemical Alterations**	**Animals**	**Other Geological Processes**
Environments	Waterfalls, Creeks	Rock Surfaces, Soils	Habitats of Primates	Erosion Zones
Phenomena	Hydraulic Transport	Weathering, Oxidation	Tool Usage, Movement	Landslides, Fractures
Macroscopic Stigmata	Smoothed Surfaces	Discoloration	Wear Patterns	Breakage, Displacement
Microscopic Stigmata	Micro-erosion Patterns	Mineralogical Changes	Micro-scratches	Micro-fractures

Table 3. Natural and geological factors that could modify the pebble and cobble surfaces of Pedra Furada site.

It is important to note that, despite ongoing discussions about the anthropic origin of these tools, previous research has already demonstrated that certain types of tools described could not have been created naturally (see Parenti, 1992, 2001, 2018, 2023). Unfortunately, a lack of dialogue between different disciplines and approaches investigating the same phenomena has diminished the possibilities of understanding them in an integrated, systematic, and thoroughly documented manner. This has made the "quartz (and quartzite) problem" (Spry et al., 2022) in lithic studies of the late Pleistocene in Piauí a conundrum.

In this context, our new analysis of the Pleistocene lithic assemblage from TBPF site adopts a broad methodological approach which includes taphonomic, morphological, technological, structural, and use-wear secondary analyses, assisted by scanning and 3D modeling, following the "3D MODAL" protocol developed by Pérez-Balarezo & González-Varas (in press). This protocol encompasses four major stages: data acquisition, meshing, post-processing, and analysis. The latter stage involves a taphonomic analysis, relief analysis, cross-sections analysis, measurement of cross-section angles, thickness analysis, and center of mass determination. This protocol globally incorporates various variables and criteria developed from diverse studies in 3D analysis of technology, morphometrics, and surfaces (Benito-Calvo, Arroyo, et al., 2018; Benito-Calvo, Crittenden, et al., 2018; Pop, 2019; Viallet, 2019; Weiss et al., 2018; Yezzi-Woodley et al., 2021). The models from the Bonnichsen collection were created using a Shining 3D Scanner – EinScan SP V2, which boasts a precision of ≤0.05 mm. We employed the AUTO SCAN mode (with turntable) and the 'Non-Texture Scan' mode. The 3D models were generated using EinScan software, followed by post-processing and analysis in Meshlab 2022.02 (Cignoni et al., 2008).

These 3D models allowed us to qualitatively address variables previously tested in similar contexts in South America, such as the cases of Parenti (2001), Parenti et al. (2018), Carranza (2015), Carranza et al. (2020), Borrazzo (2006, 2010, 2020), among others, and established the following workflow for our study:

- Evaluation of the geoarchaeological context to identify taphonomic agents that influenced the formation of the lithic assemblage.
- Analysis of the natural and cultural pieces to explore intermediate attributes
- Evaluation and systematization of taphonomic and technological attributes:
- Taphonomic attributes: abrasion, crushing, differential weathering, among others.
- Technological attributes: number of removals from all knapped edges; angle of the knapped area; delineation of edges; facial extension; continuity, overlap, and alignment of negatives.
- Tapho-technological attributes: proportion of the knapping edge area, thickness of the edge, natural edge angle, recurrence of knapping logic, among others.
- Evaluation of potential techno-structural features: backs, edges, and reliefs.
- Indirect use-wear analysis using the microphotos provided by R. Bonnichsen.
- Interpretation of the anthropic nature of the pieces.
- Interpreting the edge functions, whether knapped or not, of each piece.
- The direct taphonomic and technological analysis of the pieces also used a binocular magnifying loupe (BAUSCH & LOMB Optical Company, Rochester – N. Y., United States of America, model DD2646).

6.2. Analytical procedures

The Bonnichsen collection comprises two objects on pebble and two on flake. Thus, in terms of the orientation of the tools on pebble, we have merged the proposals of Aschero (1983) and Roche (1980): we first determine a face A and B, with face A being the most worked and/or the most convex. Eventually, an AB face (left profile) and a BA face (right profile) are also determined. Subsequently, we prioritize the carved part of the pebbles. This carved part determines a supposedly active extremity called the “knapping edge”, delimited by two extreme points that can be joined, thus forming the “string of the carved edge” (kech) which is placed in a horizontal position. We refer to this type of orientation as morpho-functional orientation. As for the objects on flake, face A will always be the dorsal (or upper) surface, and face B the ventral (or lower) surface. Once this is done, the technological axis of flaking is used as a reference to orient them, corresponding to the traditional technological orientation. However, one of the flake objects in the Bonnichsen collection has a well-recognizable, supposedly active edge, which has led us to prefer a morpho-functional orientation (Figure 7). Up to this point, we essentially follow the proposal of Roche (1980).

Once the pieces were oriented, we proceeded to create a "locational grid" (*sensu* Aschero, 1983), utilizing 3D models. In the case of the objects on pebble and the piece on flake with a supposed recognizable active edge, the string of the carved edge was thus parallel to the top and bottom sides of the locational grid. Subsequently, we segmented the piece into 6 equal-sized sub-grids. These sub-

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
https://doi.org/10.51359/261425

grids generate 10 sectors which are designated according to the modification made by Hocsman (2006) with numbers from 0 to 9, with the upper left lateral sector being number 1 and the front proximal right sector number 0 (Figure 7).

The subsequent step involved taking measurements, either on the 3D model or on the actual piece. Thus, following the proposals of Aschero (1983) and Roche (1980), we considered the following measurements (Figure 7):

- Extension in mm of the knapped edge chord (kech);
- Morpho-functional Length (mfL), parallel to the vertical axis of the locational grid;
- Morpho-functional Width (mfW), parallel to the horizontal axis of the locational grid;
- Morpho-functional Thickness (mfT), parallel to the horizontal axis of the AB face;
- Morphological Length (mL), equivalent to the general morphological axis of the pebble or flake;
- Technological Length (tL), equivalent to the technological axis of flaking in flakes;
- Maximum Length (xL), equivalent to the axis of maximum elongation of the pebble, which often coincides with mL;
- Angle of morphological symmetry (alpha), the angle formed by the central vertical axis of the locational grid and the mL;
- Angle of technological symmetry (beta), the angle formed between the mL and the tL;
- Angle of maximum symmetry (gamma), the angle formed by the central vertical axis of the locational grid and the xL.

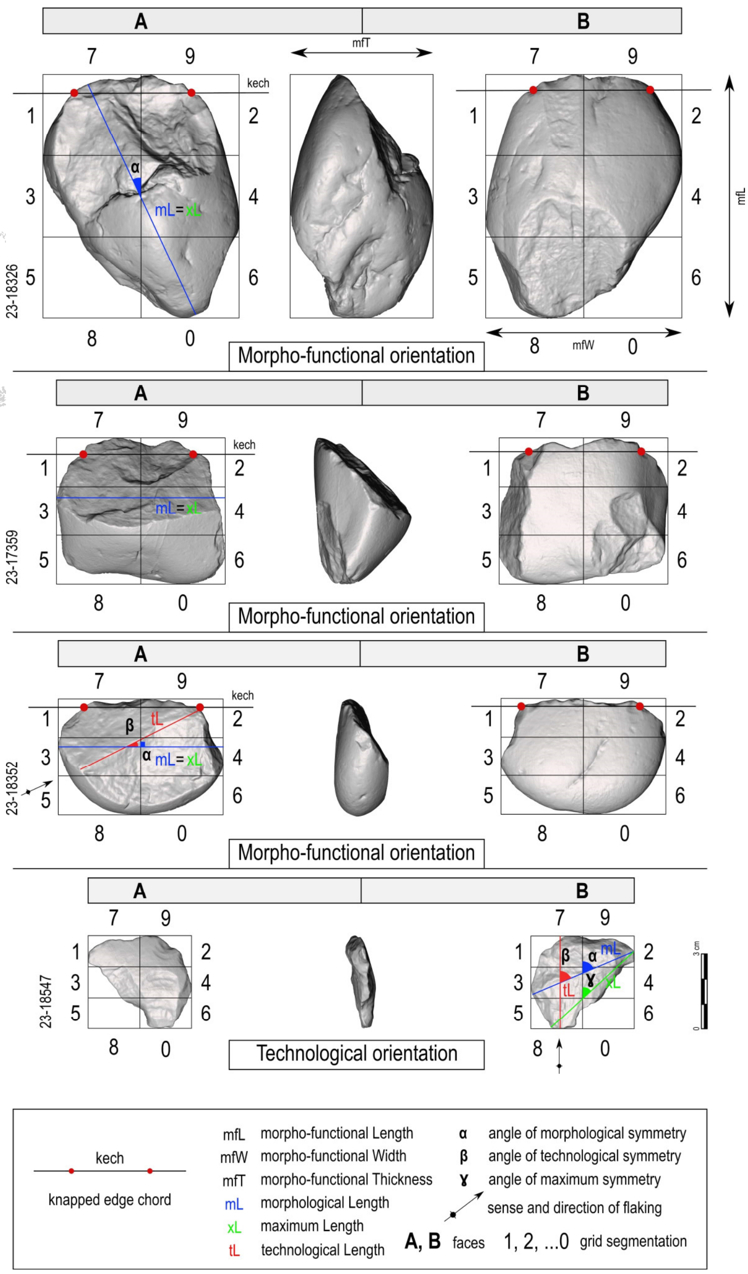

Figure 7. Morpho-functional and technological orientation criteria of the Bonnichsen Collection, Pedra Furada 1.

The subsequent procedure involved describing each of the edges that constitute the pieces, both by edge and by face (always in a clockwise direction), drawing inspiration from Hocsman's (2006) "sub-secuencias de formatización", but without following the exact same procedure. This approach establishes the ordered succession of steps through which the artifact underwent and its morphological and structural consequences (Bonilauri & Lourdeau, 2023; Pérez-Balarezo, 2022). Wherever possible, we used the same locational grid for the taphonomic, technological, structural, and use-wear descriptions. All of this allows us to reach an interpretation of the potential function of each edge and of each tapho-technological and use-wear process that established them, which we illustrate with the aid of a structural syntax, as has been done by other authors in different contexts (e.g. Frick et al., 2017). At the illustrative level, the four pieces were drawn following traditional standards (Dauvois, 1976), photographed, and modeled in 3D.

7. RESULTS

7.1 Local geology and the origin of fractures in quartz clasts

After Assis et al. (2019) in northeastern Brazil is preserved one of the largest Ordovician-Silurian sedimentary record of western Gondwana, represented by the Serra Grande Group. That unit is composed from the base to the top, by the Ipu, Tianguá and Jaicós formations. The former unit is not subdivided formally in members but in portions. The lowermost portion of the Ipu Formation is characterized by immature conglomerates in a scarp-related alluvial fan system. Upwards, the Ipu Formation grades to a braided river system. Its uppermost portion contains a glacial deposit, discontinuously preserved across the basin. The Ipu Formation overlies the Precambrian metamorphic basement and Cambro-Ordovician sedimentary rocks. An important unconformity is observed between Ipu Formation over the metamorphic and sedimentary basement.

According to Moraes (1933), the basin bedrock belongs to the Proterozoic Eon and it is composed by low-grade metamorphic rocks of the Miaba and Vaza-Barris Groups in the Sergipe sub-basin.

The age of the Ipu Formation has been proposed using ichnofossils in which the time span ranges from the Ordovician to Devonian periods, therefore its age is uncertain. Reworked glacial deposits occur in this formation (Caputo, 1984; Caputo & Lima, 1984), who observed striated and flatiron shaped clasts in basal conglomerates and beds of tillite on the top. For this reason, the Ipu Formation might be correlated to the Late Ordovician glacial sequences of South America and northern Africa interior basins (Assine et al., 1998; Villeneuve, 2005).

At the TBPF site the silicicoclastic facies of the Ipu Formation is better interpreted as well sorted orthoconglomerates composed by quartz and metamorphic rocks clasts, angular, rounded, and well-rounded with platy to elongate forms. There are also intercalations of well sorted white sandstones, with trough cross stratification. The sequence resembles the *Alluvial fans facies association* (FA1) from Assis et al. (2019).
In the Ipu Formation at the Piauí region, well-rounded quartz clasts are recognized in an orthoconglomerate. These rocks could have been formed by fluvial or fluvioglacial processes. However, it is necessary to understand that such a degree of textural and

mineralogical maturity cannot be achieved in one sedimentary cycle, but in two, or usually three. Long transport distances and aggressive climates that favor weathering are also required. Fig. 1 shows a geological map of the region surrounding Sao Raimundo Nonanto (Assis et al., 2019). It is observed at the scale of the map that the Cenozoic cover dominates in this area, with no development of the Ipu Formation observed. However, these conglomerates are not continuous throughout the basin. They are very localized, and they are also not continuous throughout the basin. This would be because the quartz conglomerates of TBPF were not deposited on a flat terrain (A. Assine, personal communication, November 2023).

The sedimentary unit Jaibaras Group (Cambrian – Ordovician) cannot be the origin of the quartz conglomerates because it is not possible, as mentioned above, to obtain well rounded quartz-rich rocks in one cycle of erosion transport and deposition. Neither can be the Late Neoproterozoic Ubajara Group because it is too far to the north. Thus, only two units can be considered as source of de quartz orthoconglomerates: the Neoproterozoic and the Paleoproterozoic / Arquean Basament (Figure 8), both south of Sao Raimundo Nonanto.

Due to the size of the quartz clasts (up to 20 cm), this mineral should come from veins within metamorphic basement rocks. This quartz underwent high-energy transport in glacial and fluvial environments for several hundred million years. For this reason, the primary fractures originated by both tectonic and ice action must have disappeared. Thus, the quartz clasts of the orthoconglomerate in TBPF should not present primary fractures that would favor their breakage by non-anthropogenic causes.

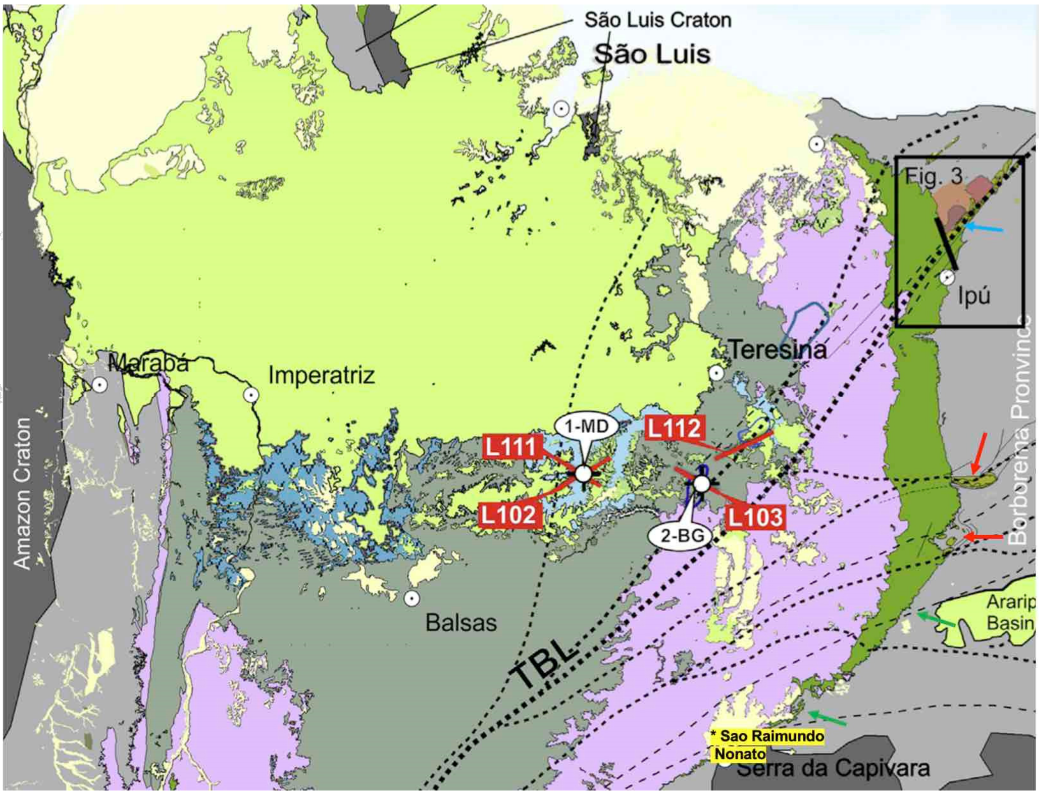

Figure 8. Geologic map of the NE of Brasil. At the scale of this map, the small outcrops of the lower member of the Ipu Formation (green colour arrows) in TBPF are not visible. The only rocks that could be the source of the quartz clasts of the conglomerates in TBPF are those older: the sedimentary Cambrian - Ordovician Jaibaras Group (red colour arrows); the Late Neoproterozoic Ubajara Group (light blue colour arrow); the well-developed Neoproterozoic Basement (light gray colour) and the Paleoproterozoic / Arqean Basament (dark grey colour). Modified from Assine et al. (2019).

7.2 Raw material and macro taphonomic traces characteristics

Three of the pieces from the Bonnichsen collection (23-18326, 23-18352, and 23-18547) correspond to xenomorphic quartz, while the piece 23-17359 is made of medium-fine grain quartzite. However, the piece 23-18547 exhibits characteristics intermediate between xenomorphic and automorphic quartz. In all the quartz specimens, the neocortex presents a light yellowish color (5Y 9/6), while the parts without neocortex show a whitish color (5Y 9/2). On the other hand, the quartzite piece exhibits a cream neocortex (5Y 5/4), cleavage planes of a more grayish hue (5Y 6/2), and removals with a slightly lighter tone (5Y 7/2).

<u>Piece 23-18326</u>: Object on pebble. This pebble presents a 3D geometry corresponding to a triaxial ellipsoid. The piece is complete. The raw material is fine-grained xenomorphic quartz. The neocortical part exhibits a slight degree of abrasion, whereas the parts with negatives of removals show a heterogeneous degree of abrasion: the knapped surface of face A (located in sub-grids 3 to 4) exhibits moderate abrasion at A37, and light abrasion at A94. The knapped surface at B43 shows a moderate degree of abrasion. In general, this piece does not display signs of crushing. It has a well-developed patina on the surfaces of A94. A minor zone with crushing marks is found in the central portion of the BA face. It presents two large incipient Hertzian cones in the central portion of face B. This type of stigma manifests as a subtle semi-circular fracture at the point of impact, distinguished by a texture that is slightly rougher and a tone marginally more opaque compared to the rest of the smooth surface of the pebble. The central

point of impact, although small, is clearly visible as a darker concentric mark. Unlike well-developed Hertzian cones, which are products of stone-on-stone (SoS) percussion (Arroyo et al., 2021), no fine radial fracture lines emanate from the epicenter, nor are there small craters and splinters, known as hackles, observable neither in pieces (Figure 9 B) directly nor in 3D curvature analysis (Figure 9 B’). These features typically serve as indicators of the energy released during the impact (Byous, 2013).

The piece has some isolated areas with pits in the central part of face A and, to a lesser extent, in the left lateral-central part of face B (Figure 9 B, B’). Additionally, the piece displays 2 large internal fissure lines oriented obliquely to the morphological long axis of the pebble (Figure 9A). In the center of edge B79, the piece has a fissure approximately 18 mm long, oriented perpendicular to the edge (Figure 9 B, B’). The same edge B79 also exhibits signs of light splintering and radial fissures (Figure 9 C, C’). The piece has between 50 to 75% neocortex. The AB face has a partially extended negative, face A two large partially extended, continuous, overlapping, and aligned negatives; face BA has no negatives and face B two large negatives that are also partially extended but not continuous, overlapping, or aligned. On A79 and B79, the distal edge has at least 7 negatives with a length of less than 7 mm of marginal extension, aligned, discontinuous, and partially overlapping. Excluding these micro-negatives, the piece in total has 3 counter-bulbs: 2 very visible on A3 and B80, and 1 partially trimmed on the AB face. The edge A79/B79 presents observed angles between 60 and 90° (Figure 9B), with an average of 80°, an estimated average angle of 60°, and a natural angle of 45°. The edge at B80 has an observed angle of 82°, while the edge on AB has an observed angle of 124°. Regarding the abrasion state of the edges, the edge A79/B79 is slightly rounded, while the edges B80 and AB present crushed and rounded edges.

Piece 23-17359: Object on Pebble. This pebble exhibits a 3D geometry corresponding to an orthorhombic shape. The piece is complete. The raw material is a medium-fine grained quartzite. On face A, the neocortical part shows a degree of abrasion ranging from none to slight, the area corresponding to the cleavage plane exhibits slight abrasion, and the part with negatives of removals also shows a slight degree of abrasion. On face B, the neocortical part is similar to face A, but at B40, it shows moderate abrasion of scars along with signs of edge battering and patina (Figure 9 G, G'). Moreover, this artifact does not generally exhibit signs of crushing. There is a slight orange-hued patina in the central area of face B (Figure 9F), with no signs of crushing. It displays at least 6 incipient Hertzian cones in the lower left portion of face B (Figure 9 H, H'). The piece has subsurface and parallel fissures at the ends of edge B79 (Figure 9D). Additionally, it shows at least two lines of fissures extending across the entirety of the pebble, oriented perpendicular to the morphological length (Figure 9E). The artifact has between 50 to 75% neocortex. Face AB features a large negative extending across its entire surface. Face A has a partially extended major negative measuring 22 mm in length and 38 mm in maximum width. It also presents two small negatives (less than 5 mm long and less than 10 mm wide) continuous and overlapping the major negative. Face BA is entirely neocortical, though it has at least 2 small negatives less than 3 mm long and less than 7 mm wide. Face B features at B40 at least 3 partially extended and overlapping negatives, although these are likely the result of a single taphonomic and/or technological event. The piece totals 1 clearly visible counterbulb in the central portion of edge A79. The chipped edge A79/B79 shows angles observed between 50 and 60°, averaging 50°. The same edge presents a natural angle (cleavage plane) estimated at an average of 55° and another more open natural angle (neocortical plane), impossible to determine. The edge A26 shows angles observed between 85 and 90°, with an average of 90°. Finally, the edge at B0 shows an observed angle of 92°. Regarding the state of abrasion of the edges, the edges A79/B79 and A26 are slightly rounded, while the edge B0 shows a ground and rounded edge.

Piece 23-18352: Object on Pebble. This pebble exhibits a 3D geometry corresponding to a triaxial ellipsoid. The piece is complete. The raw material is fine-grained xenomorphic quartz. On face A, the neocortical part shows no abrasion, and similarly, the part with negatives of removals, including both surfaces and ridges, also shows no abrasion. On face B, the neocortical part is similar to face A, without any abrasion. Additionally, this piece does not generally display signs of crushing or differential patination. It presents at least 2 incipient Hertzian cones in the lower left portion of face B. The artifact has between 25 to 50% neocortex. Face AB features a large partially extended negative. Face A presents a non-cortical surface belonging to the positive of an extraction, which is divided into two planes. In fact, as noted by Parenti (1992, p. 50, Planche 19), the propagation of the fracture front led to a "dihedral" bulb, a fairly common phenomenon in quartzes. Face A also has at least 5 small negatives (less than 5 mm long and less than 10 mm wide) discontinuous, unaligned, and partially overlapping. Face BA is entirely neocortical, although it has at least 1 small marginal negative less than 4 mm long and less than 8 mm wide. Face B features at B79 at least 5 small (< 5 mm in length and width) marginal, discontinuous, and partially overlapping negatives. The piece totals 1 clearly visible counterbulb in the negative of face AB. The edge A79/B79 shows observed angles between 85 and 135°, averaging 102°. The same edge presents an estimated average angle of 55° and another more open natural angle, impossible to determine. The edge A26 has an average observed angle of 110°. Regarding the state of abrasion of the edges, the edges A79/B79 and A26 are moderately rounded, although the edge A26 also shows slight grinding.

<u>Piece 23-18547</u>: Object on Pebble Flake. This pebble flake has an irregular sub-trapezoidal silhouette. The piece is complete. The raw material is fine-grained xenomorphic quartz. On face A, the neocortical part shows no abrasion, and likewise, the part with negatives of removals, both surfaces and ridges, also exhibits no abrasion. On face B, which lacks neocortex, is similar to face A, with no abrasion present. Furthermore, this piece generally does not display signs of crushing or differential patination. It does not present any incipient Hertzian cones

on any of its faces. The artifact has between 0 to 25% neocortex. Face A features at least 4 large partially extended negatives. Face B presents a non-cortical surface belonging to the positive of the extraction. Face A also has at least 2 small removals (<3 mm long and < 7 mm wide) that are marginal, discontinuous, unaligned, and not overlapping. Face B also has at least 1 small marginal negative less than 4 mm long and 7 mm wide. The piece has 1 clearly visible counterbulb on the small negative of B9, and another counterbulb on A05. The edge A79/B79 exhibits an average observed angle of 90°. The chipped edge A10 has an average observed angle of 45°. Finally, the edge A26 has an average observed angle of 65°. Regarding the state of abrasion of the edges, the edges A10 and A26 are moderately rounded, while the edge A79/B79 shows either no or slight abrasion.

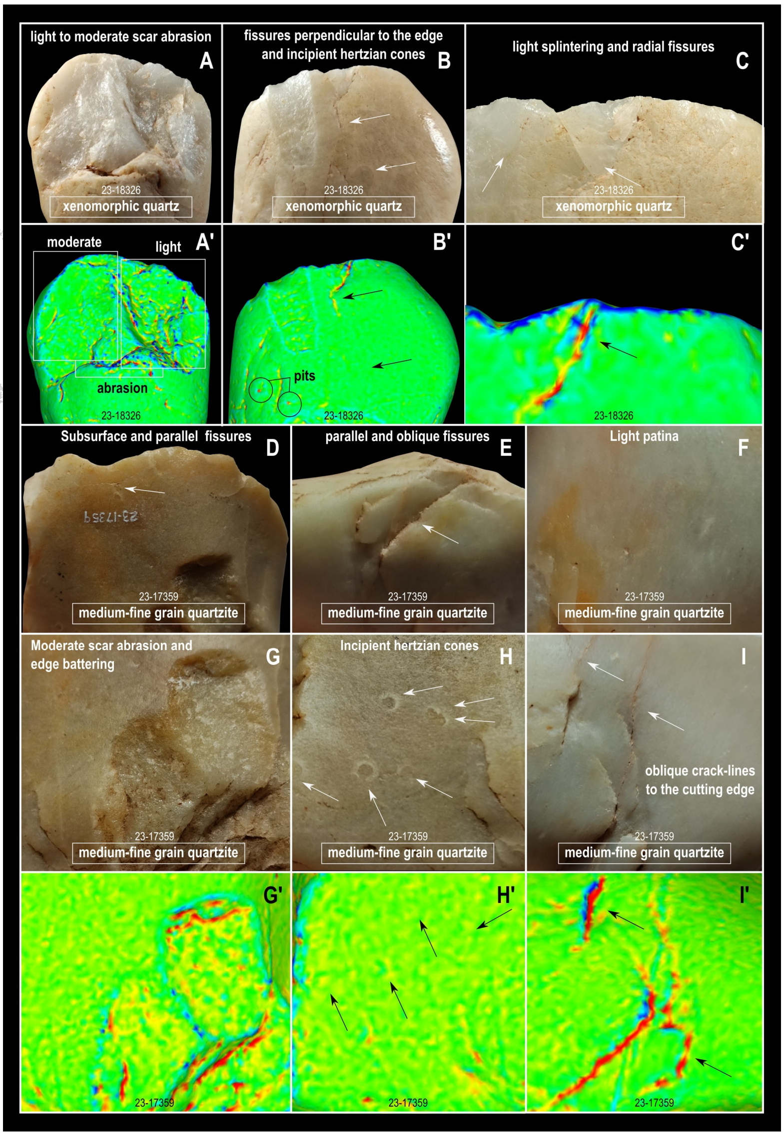

Figure 9. Raw materials and taphonomic characteristics of the Bonnichsen collection, Pedra Furada 1. The pieces are not scaled. A', B', C', G', H', I': curvature analysis in Meshlab with MLS – Filter scale of 2.

7.3 Morpho-metrical characteristics

Figure 10 illustrates the morphometric characteristics of the Bonnichsen collection within the broader context of the entire assemblage of artifacts from the Pedra Furada 1 phase. Examining the relative values of all indices collectively, it is observed that piece 23-18326 predominantly shares dimensions with bifacially and monofacially flaked pebbles, as well as cores. Conversely, piece 23-17359 tends to align with the typical dimensions of used fragments and retouched flakes. piece 23-18352 also shares dimensions primarily with used fragments, flakes, retouched flakes, and simple scrapers. Finally, piece 23-18547 falls within the typical value range of used fragments and retouched flakes. The masses in the Bonnichsen collection vary between 12 and 256 grams, with an average of 114.25 g.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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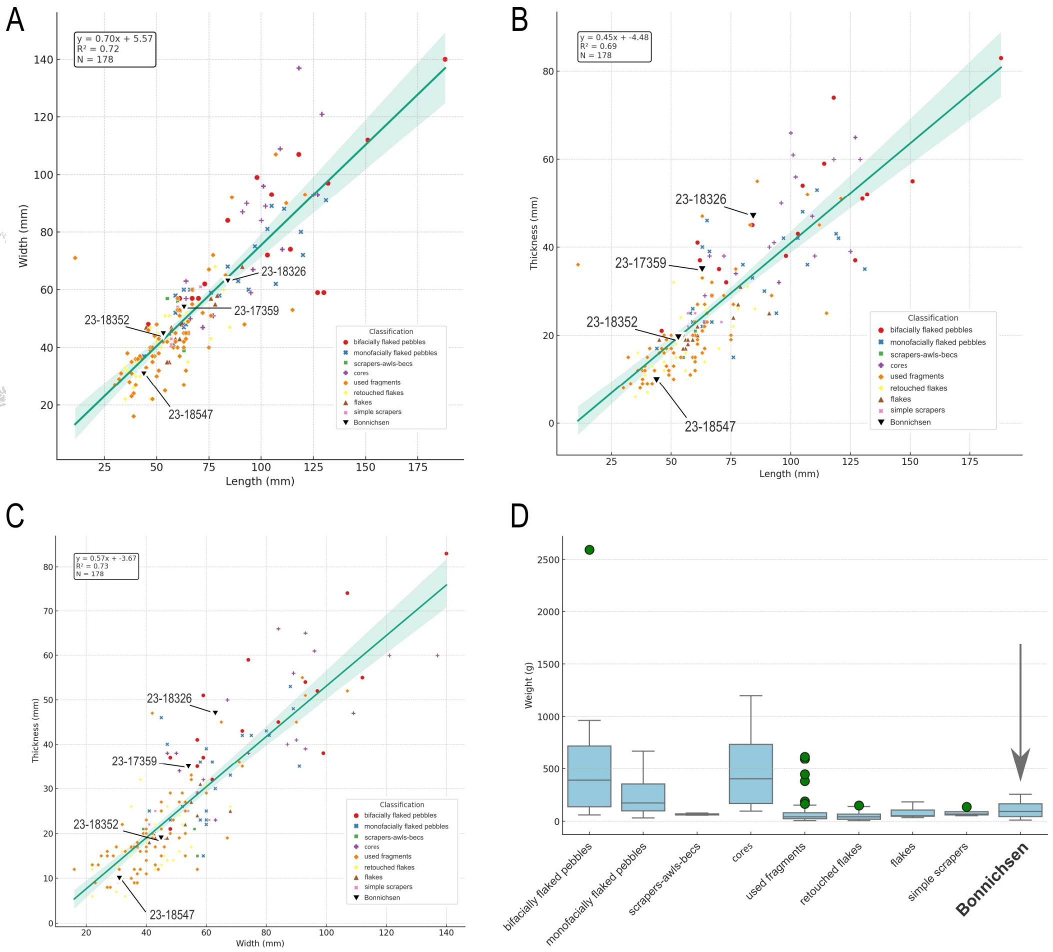

Figure 10. Morpho-metric characteristics of the Bonnichsen collection in the context of the total pieces of the Pedra Furada 1 phase: (A) elongation index, (B) fineness index 1, (C) fineness index 2, weight distribution. In A, B and C: Linear regression between morphological length (L), morphological width (W), and morphological Thickness (T).

7.4 Techno-structural characteristics

Based on the taphonomic and morphometric characteristics previously presented, we provide here a description of the techno-structural features of each piece.

Piece 23-18326: The blank is a quartz pebble with three natural fracture removals, two of which are contiguous and located in the basal portion (Figure 11). Both natural and anthropic fractures have substantially altered the object such that the views displaying the most cortex are the bottom view and the left side of the piece. The cortical band is rounded and regular, except on the left flank where it exhibits fissures and ancient depressions. As illustrated in the Figure 12, cross sections reveal that: a) the apical portion has a semicircular shape (2 and 3) from a thinner morphology (1); b) the medial portion has a circular shape (4 and 5); and the basal one has a rectangular morphology (7), with a pentagonal transition from the circular medial shape (6). Longitudinal sections indicate a recurrent teardrop shape (B, D, and E), with triangular (A) and diamond-shaped (C) variations. The mesio-basal portion, despite its irregular characteristics and conical volume with the longitudinal axis displaced to the right (Figure 12C), was used without transformation probably in a prehensive function.

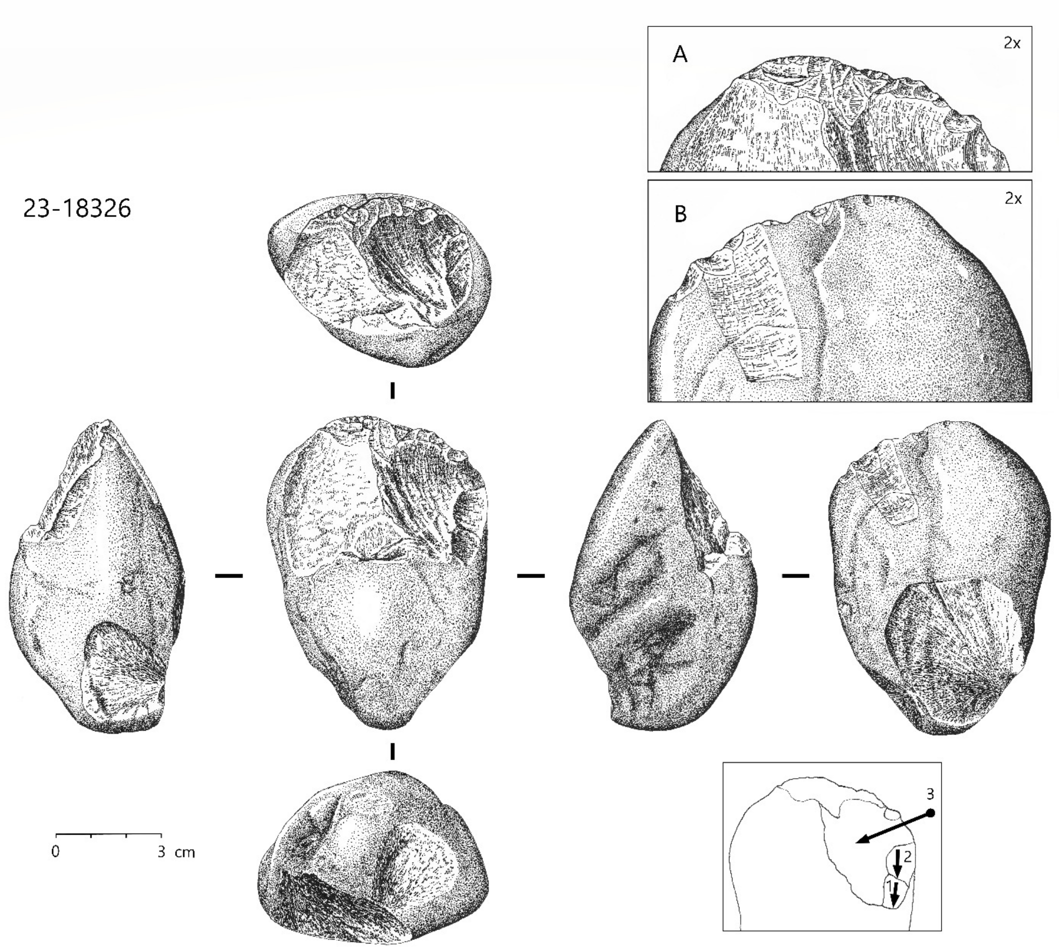

Figure 11. Technical drawing of the orthogonal views of the piece 23-18326. (A) Detail of the apical end of the upper face; and (B) detail of the apical end of the lower face. In the lower part, the diacritical scheme of the anthropic removals (without scale). Drawing by M. de Almeida.

A part of a volume already naturally transformed with a broad reflected removals oriented along the sagittal axis was utilized in a probable transformative function, originating from the bottom face. The surface of this natural fracture is smooth and has a well-developed patina. The anthropic flaking responsible for creating this probable cutting edge started from the right flank, in the most rounded cortical portion between the two faces. During the usage phase of this tool, edge wear was so significant that it caused large fractures on the upper and lower faces of the instrument, the largest of them on the bottom face measuring 2.5 cm in length and 1.2 cm in width (Figure 11A-B). The length of the edge with fracture marks is 4.5 cm. Observing the edge with fractures resulting from use reveals a saw-shaped like edge (*avoyage*) (top view of the piece in Figure 10 and in Figure 12B). (green B).

The piece displayed angles between 80 and 90° (A, B, C, and E, in Figure 12), with the exception of a 60° angle formed between the flaking surfaces of the upper face and the usage fracture on the lower face (Figure 12D). The pronounced wear caused by the task and the transformed material fractured the edge to the point where the fractures on both faces transformed the bevel into a rounded/blunted area.

It is worth mentioning that the morphology and texture of the surfaces of the natural removals are distinct from the anthropic ones, as informed by taphonomy. The three natural removals have more regular, smooth, flat, and shiny surfaces, while the anthropic removals have a brittle, matte, and "crispy" appearance in this type of raw material. The thickest area is in the middle of the upper face (around the center of mass) and the central cortical part of the lower face, extending between cross sections 3 and 5, and between longitudinal sections B and E (Figure 12C). These sections remain relatively stable.

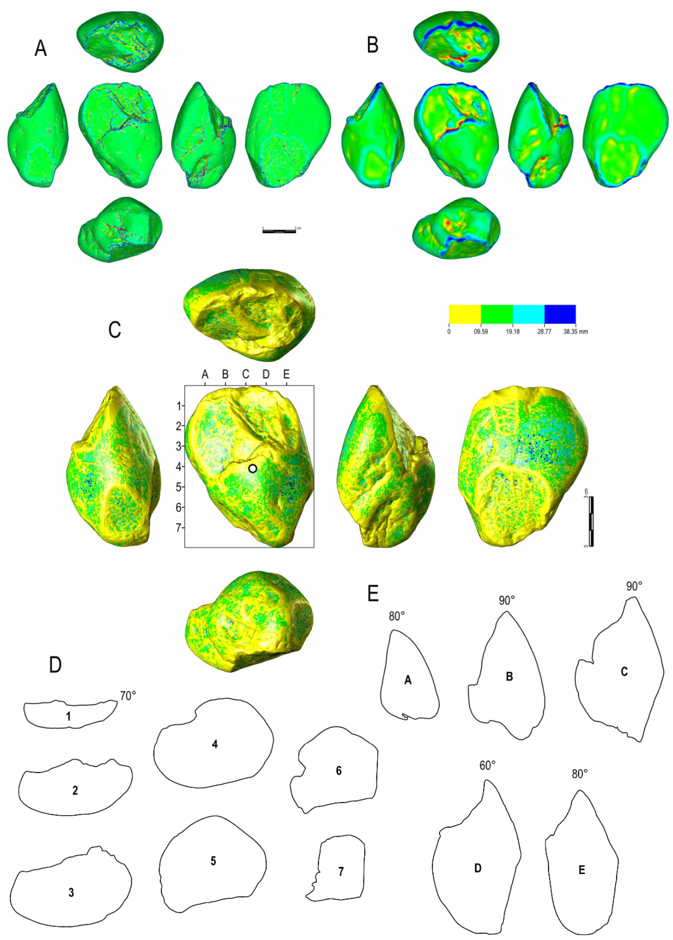

Figure 12. 3D Analysis of piece 23-18326, Bonichsen Collection, Pedra Furada 1: (A) curvature analysis with MLS – Filter scale of 2; (B) curvature analysis with MLS – Filter scale of 15. (C) thickness and center of mass (white circle) analysis and grid of transverse and longitudinal sections taken every 10 mm; (D) transverse sections and angles; (E) longitudinal sections and angles.

Piece 23-17359: This piece was fashioned through a unique modification on a natural quartzite fragment. In other words, the identified transformation indicates that practically the entire structure and all surfaces of the object were already suitable for use, including the relationship between the natural fracture and cortical planes, with only the need for a fresh edge (Figure 13).

The fragment is a slightly angular pebble with well-rounded transitions between cortical surfaces. It also has two natural fractures, with moderately developed patinas and abrasion, located on the right side and the medio-apical part. The natural fracture on the right flank created a face perpendicular to the frontal axis of the piece, while the larger medio-apical fracture has a face with an inclination of 60° or more in relation to the flat cortical surface of the lower face. In general, the longitudinal section planes are triangular and the transverse section planes are trapezoidal. Although not representing a significant structural alteration, the three removals and the crushing (*écrasement*) between the negatives and the cortical surface (striking platform) should be mentioned as anthropic modifications, whose appearance seems contemporary to that responsible for creating a possible cutting edge (underside of the piece, Figure 13). The angular measurements in this sector do not change, remaining at 90° (Figure 14B-C).

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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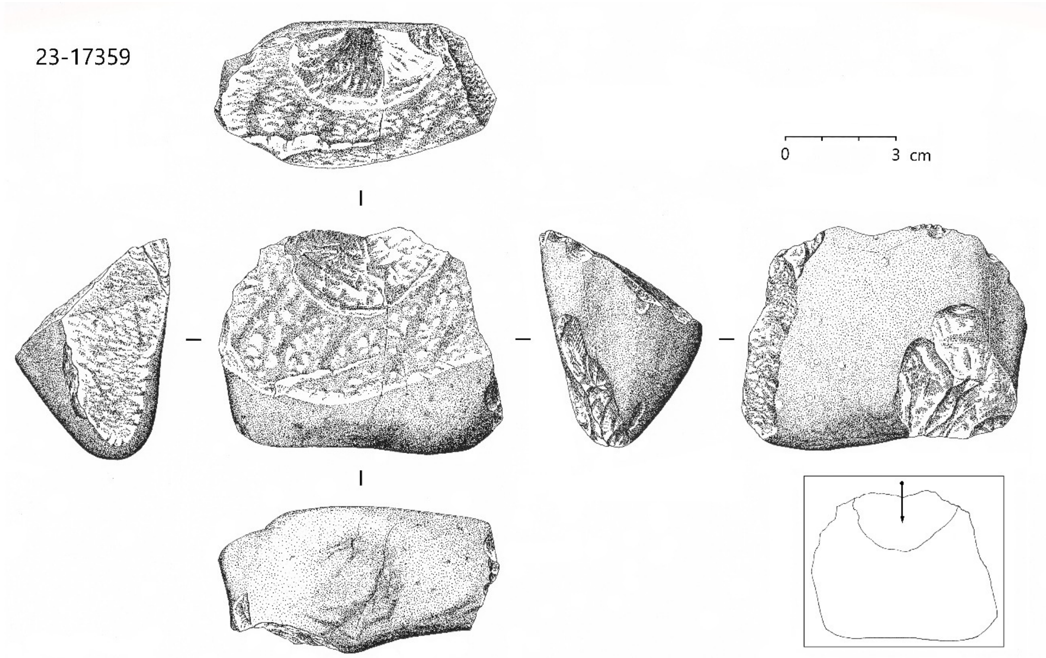

Figure 13. Technical drawing of the orthogonal views of the piece 23-17359. In the lower part, the diacritical scheme of the anthropic removal (without scale). Drawing by M. de Almeida.

At the apical end, the removal is oriented according to the sagittal axis of the piece, extending up to 1/3 of its length. The morpho-structural consequences are the creations of two higher zones B-C and D-E between a lower C-D wave-like in the edge delineation, classified as notching. As the tendency of the transverse morphology is trapezoidal, it is precisely because of it that the edge is limited, not by removals (external retouches) but by the cortical rounding on the left and the topographic rupture caused by the natural fracture on the right (Figure 14D, cross section 1). The angles between the flat lower cortical face and the flat upper face resulting from flaking remain at 50°, as can be seen in the longitudinal section C, D, and x (Figure 14). Except for a subtle change in texture, with the natural fracture surface more rounded, the distinction between the irregularities of both surfaces is notable. As expected, the thickest area is the center of the piece, between the transverse sections 2 to 5 and the longitudinal sections B to E (Figure 14C).

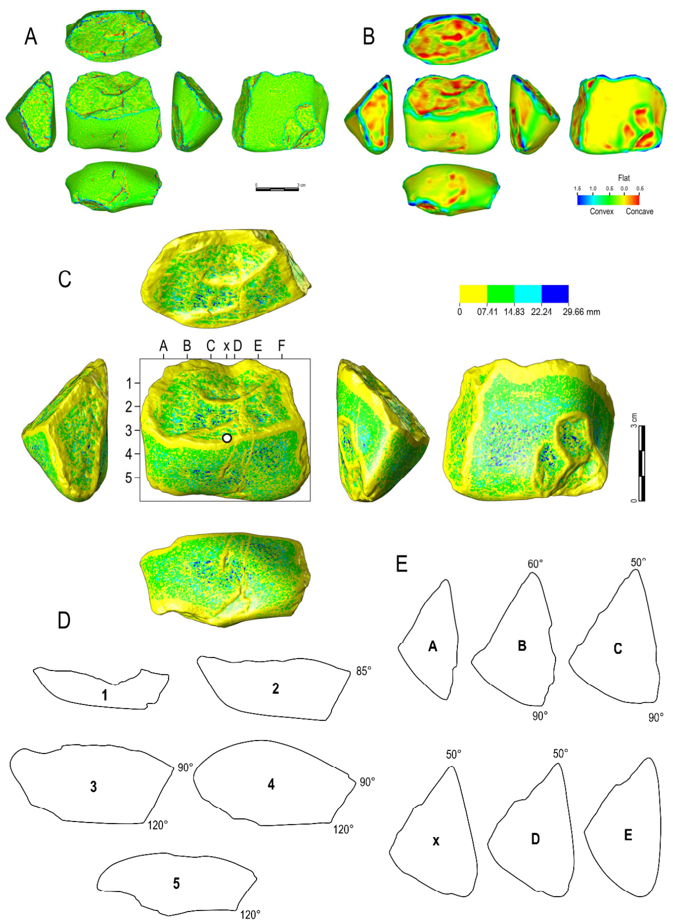

Figure 14. 3D Analysis of piece 23-17359, Bonnichsen Collection, Pedra Furada 1: (A) curvature analysis with MLS – Filter scale of 2; (B) curvature analysis with MLS – Filter scale of 15. (C) thickness and center of mass (white circle) analysis and grid of transverse and longitudinal sections taken every 10 mm; (D) transverse sections and angles; (E) longitudinal sections and angles.

Piece 18352: The piece is a flake *entame* with retouches and usage marks. The target flake-support would have been a less extensive flake, with a teardrop-shaped cross-section, but the result was an extension of the fracture, splitting the pebble diagonally into two parts, if observed from the side profile view (Figure 15). Additionally, the flaking caused a surface formed by two faces, and the axis of flaking approximately follows the edge formed by those faces. The cortical surface is rounded, regular, and smooth, covering almost the entire lower face and the left side, whose longitudinal section planes show a "C" delineation, starting from the basal part of the upper left face and extending to the apical end on the right (Figure 16E).

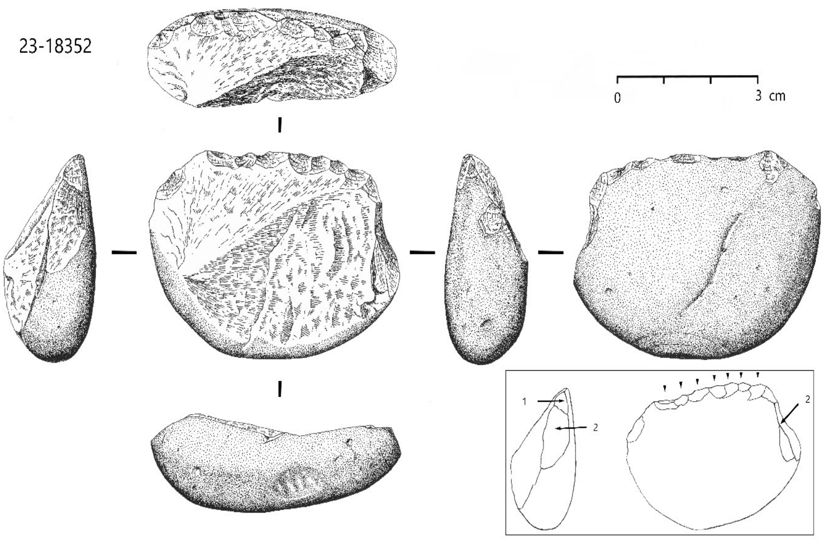

Figure 15. Technical drawing of the orthogonal views of the piece 23-18352. In the lower part, the diacritical scheme of the anthropic removals (without scale), which are distinct, located on the right side of the main view, without the overlapping of fractures along the entire distal edge. Drawing by M. de Almeida.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
https://doi.org/10.51359/261425

A removal was made with significant morphological consequences for both the edge delineation and a possible configuration of prehensive part. This removal started from the surface created by the flaking and limited the probable cutting edge on the right portion of the main face. The angle formed between the two flaking surfaces was greater than 90° (Figure 16D, section 1). On the opposite end, on the left side of the piece, the used edge is well separated and externalized in relation to the cortical surface through an edge created by the flaking (Figure 16C, between A and 1).

Although a fracture caused by use can have significant dimensions, it is likely that this piece underwent three retouches, the largest removals on the upper face, between A, B, and C on Figure 16C, in addition to the direct retouch to externalize the active edge on the right flank. The use of the piece caused fractures on both faces. The consequences of such fractures are the irregular edge delineation, similar to a denticulate, formed by several small notches (teeth of approximately 3 mm), and the edge delineation as saw-like, as seen in the apical view of Image Figure 16B. The thickest area of the piece is displaced to the left relative to the center of the piece, due to the bulb, in this case, unusual. This thickest zone extends between the cross sections 1 and 3 and the longitudinal sections A and C (Figure 16C).

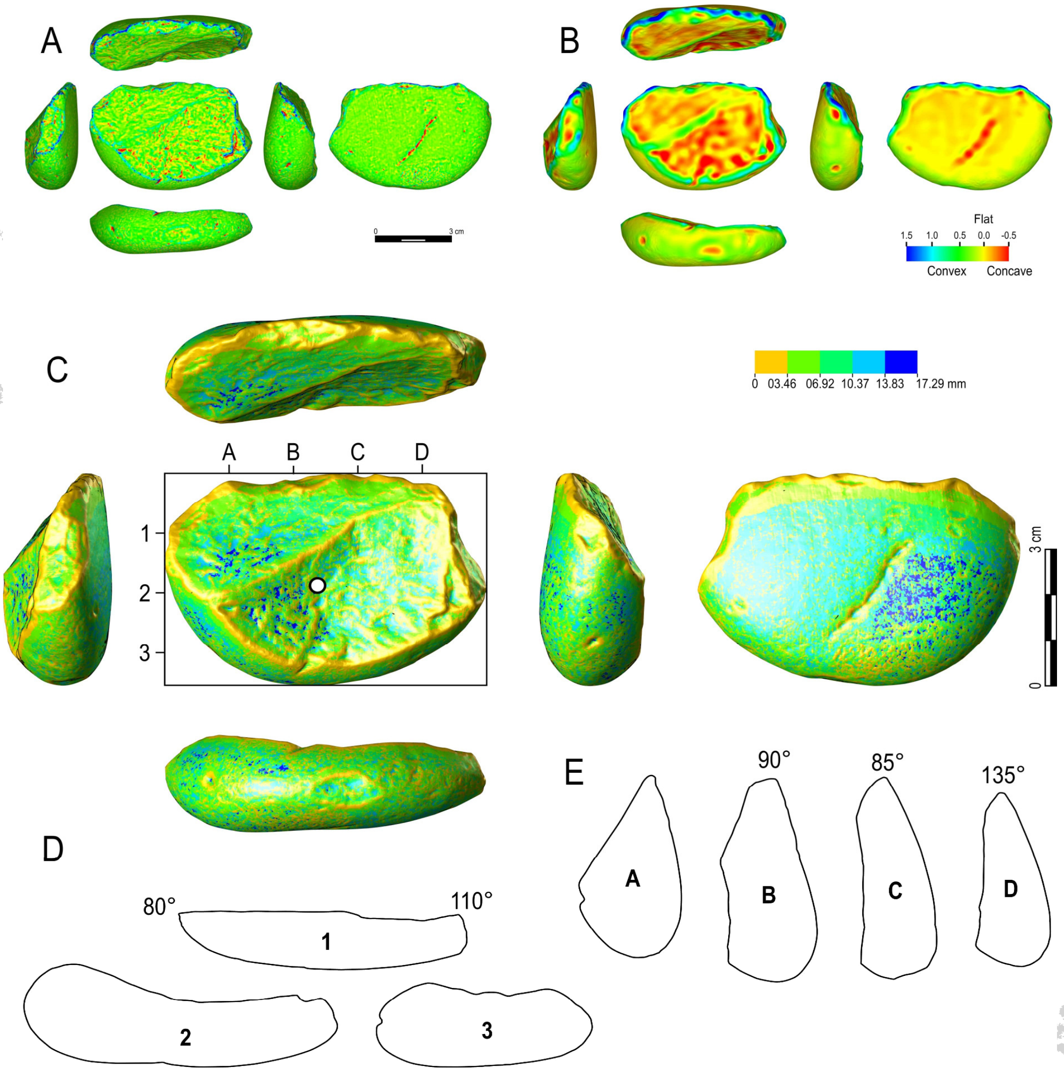

Figure 16. 3D Analysis of piece 23-18352, Bonichsen Collection, Pedra Furada 1: (A) curvature analysis with MLS – Filter scale of 2; (B) curvature analysis with MLS – Filter scale of 15. (C) thickness and center of mass (white circle) analysis and grid of transverse and longitudinal sections taken every 10 mm; (D) transverse sections and angles; (E) longitudinal sections and angles.

Piece 23-18547: This is a semi-cortical flake with some retouching along the distal edge. The striking platform is narrow and features fractures that prevent recognition of the original surface of part of the core that served as the striking platform of this flake. Nonetheless, three removals on the dorsal face follow the same direction as the flaking of the support flake in question. The cortical portion is located at the distal part. The retouches referred to are located in the central area of the distal (inverse) edge and at the intersection between the distal and right (direct) edges (Figure 17). However, the modifications made to the blank after its obtention through a unidirectional method were likely for the addition of a prehensive component, given that no signs of use were observed along the distal and right edges.

A small, non-invasive yet broad retouch created a notch-like outline in the proximal portion, on the left edge. This direct retouch apparently served to externalize a cutting edge in the mesial part of the edge. A part with a concave outline on the same left edge in the distal part of the flake may have been formed through flaking to, along with the proximal notch, externalize the cutting edge. However, the stigmas are not very evident in relation to the distal notch. The fact is that the outline of the cutting edge is clearly separated from the ends of the same edge.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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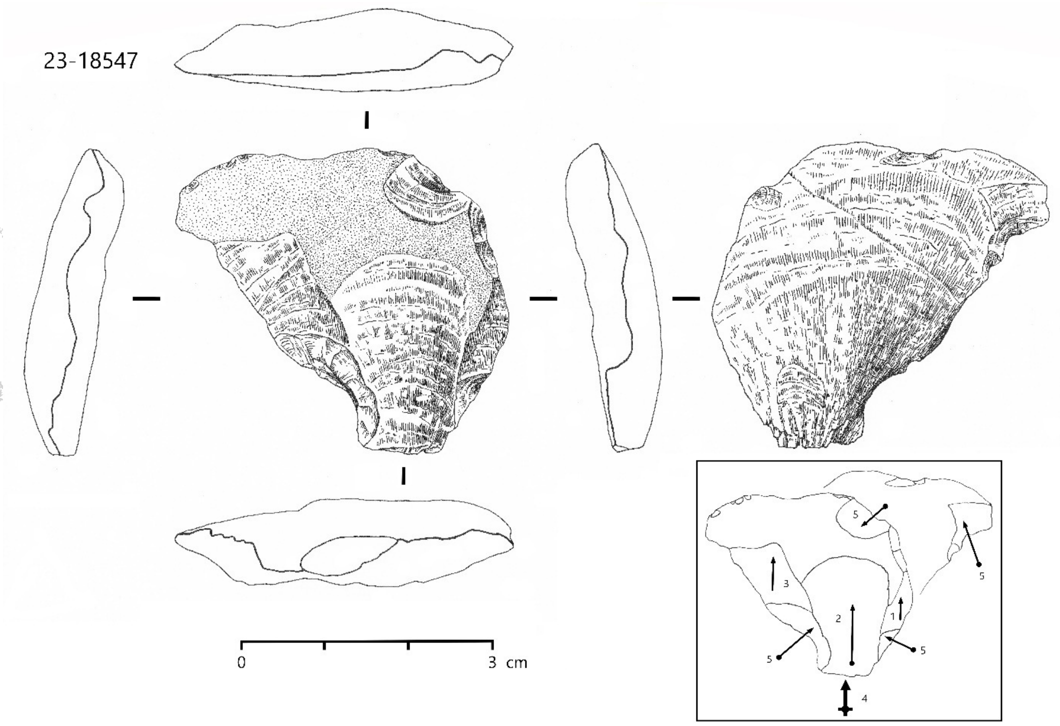

Figure 17. Technical drawing of the orthogonal views of the piece 23-18547. In the lower part, the diacritical scheme of the anthropic removals (without scale). Drawing by M. de Almeida.

The longitudinal section planes are oblong, thin, and irregular (Figure 17, A, B, C, and D). In the transverse section planes, a recognizable hexagonal shape exists with two opposite flat surfaces (top and bottom) close to each other, separated by two dihedrals, one on each side. The angular variations on the sides of this pieces vary slightly (Figure 17, 2 and 3). In the central region of the edge where the usage marks are found, and thus considered the cutting edge, the angle is 50° (Figure 18D, cross section 2). This increase is subtle compared to the ends of the same edge, with identical angles in the proximal and distal portions (Figure 18D, cross section 1 and 3).

The thickest area occupies much of the interior of the dorsal and ventral faces of the flake blank. The internal flaking angle is 100°, while the external flaking angle is 120°.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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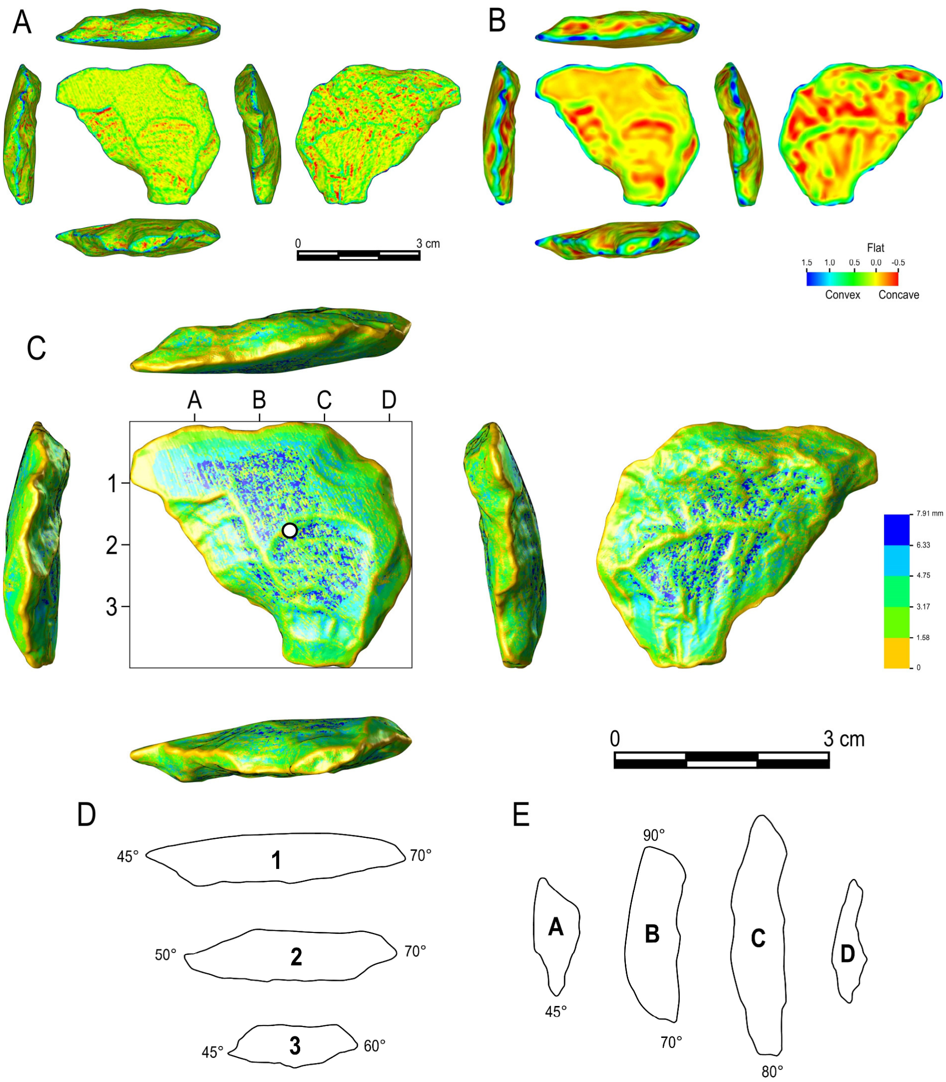

Figure 18. 3D Analysis of piece 23-18547, Bonichsen Collection, Pedra Furada 1: (A) curvature analysis with MLS – Filter scale of 2; (B) curvature analysis with MLS – Filter scale of 15. (C) thickness and center of mass (white circle) analysis and grid of transverse and longitudinal sections taken every 10 mm; (D) transverse sections and angles; (E) longitudinal sections and angles.

Description of taphonomic and use-wear micro-traces

As we saw in Table 2, the general analysis by R. Bonnichsen revealed probable use-wear patterns. These include fine striations indicating bidirectional tool movement, abrasive and lacquer-like polishes, and silica deposits suggesting frequent usage. The objects, for him, show polished and abraded surfaces with linear indicators and deep scratches, indicating extensive tool use and material modification.

It is indeed very difficult to determine taphonomic and use micro traces based solely on photographs. This is partly because microscope photos represent a millimetric part of the edge, and it is necessary to hold the artifacts in hand to see the potential uses of the different edges. Moreover, when enlarging the photos of the different sides of the photos with the scale presented by Bonnichsen in his report, their clarity is lost. Nonetheless, based on our experience analyzing materials from the same TBPF site as well as neighboring sites of Sítio do Meio and Vale da Pedra Furada (Clemente-Conte, Boëda, & Farias-Gluchy, 2017; Clemente-Conte, Boëda, Lahaye, et al., 2017), we will attempt to determine what can be related to a use and what cannot.

None of the microscope photos presented by Bonnichsen can be directly associated with a use in any productive process. In fact, we believe that they are likely taphonomic traces, and there could also be issues related to the cleaning of the artifacts. In our experience with quartz materials from the SCNP, we have found that when attempting to clean the surface for microscopic observation using alcohol or acetone with cotton swabs, oriented adherence marks resembling striations can be left behind. Hence, the importance of properly cleaning surfaces, lithic in this case, to objectively observe and analyze these tools (Figure 19).

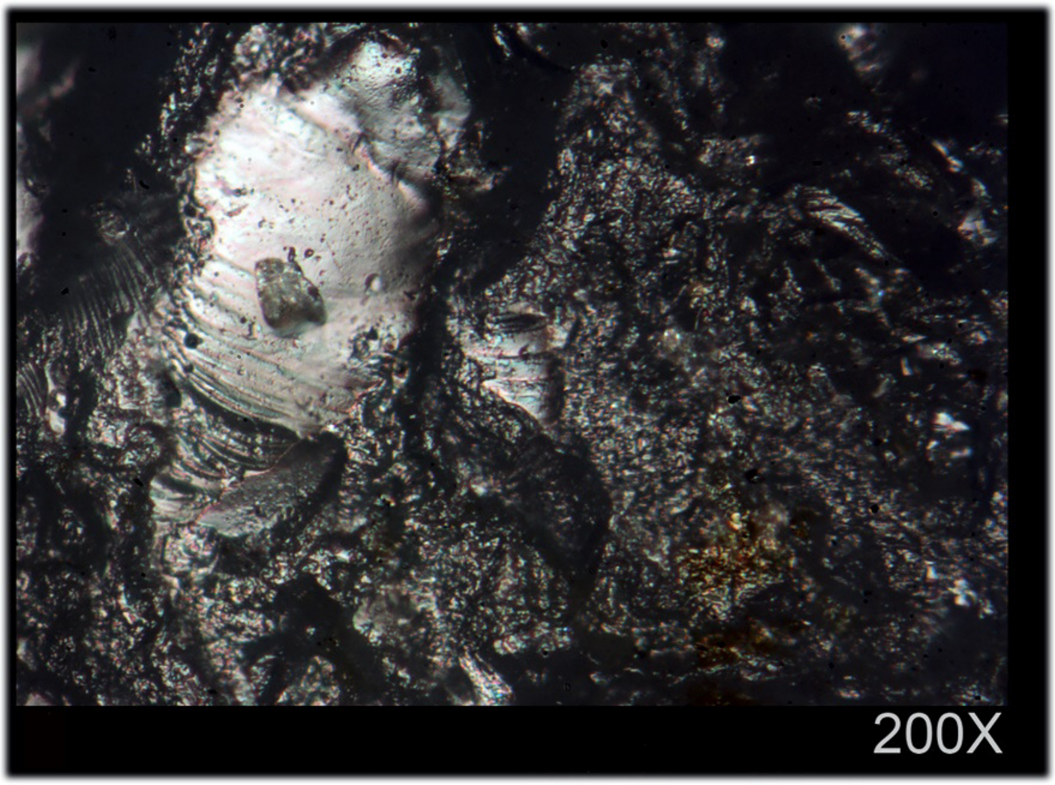

Figure 191. A pristine surface of a quartz tool (both crystal and matrix) from Vale da Pedra Furada. This image highlights the 'continuous breakage' along the crystal's side and small-scale 'pecking' marks on its surface, as described by Clemente-Conte (1997) and Clemente-Conte et al. (2015) . Additionally, the presence of abrasions on the tool suggests a longitudinal cutting motion.

Next, we will present the images obtained by R. Bonnichsen along with all the comments he made for each image. This data might serve as basis for a broader functional and taphonomic considerations in the region.

Piece 23-18326

Pieces similar to this one, morphologically speaking, have been documented in other sites such as Vale da Pedra Furada and Sítio do Meio. Typically, they bear traces of use that exhibit a transversal scraping motion, and they are often used to work with materials of medium and hard density, such as wood or animal hard tissues (Figure 20).

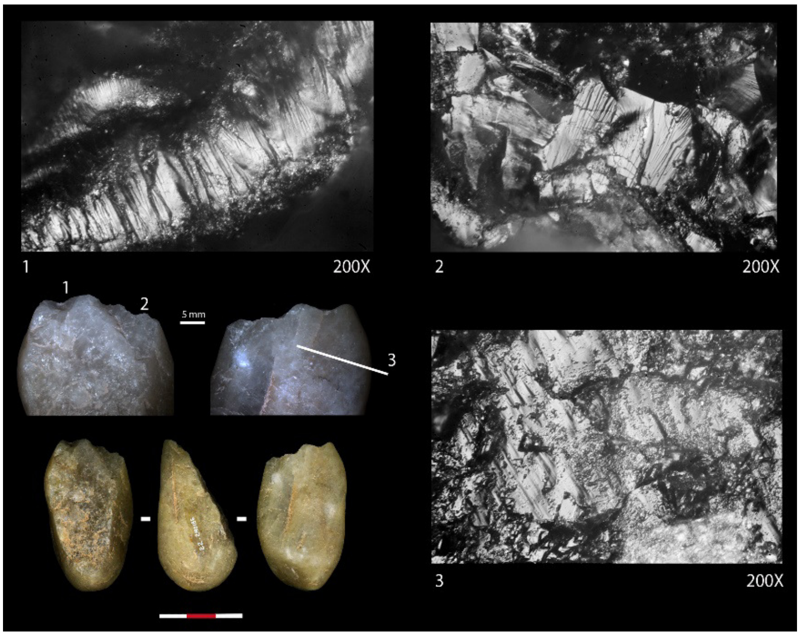

Figure 20. Micro use-wear features in a Sítio do Meio artifact, piece 22-240186 (excavation of E. Boeda team). This tool was specifically used for scraping hard materials, as evidenced by the distinct grooves and striations resulting from a motion transverse to the blade's edge. The crystals on the surface that made contact with the material being worked on are noticeably flattened, showing a pattern of

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
https://doi.org/10.51359/261425

numerous striations and fissures.

However, in the case of the piece 23-18326 from TBPF, the photo corresponding to the red rectangle is taken on a fractured surface. This surface exhibits a patina that differs from both the cortex and the distal external flaking. This surface might correspond to an earlier fracture that has since rounded and developed a differential patina, suggesting it could be a result of taphonomic alteration, where contact with sediment also played a fundamental role. The photo corresponding to the blue rectangle is situated in an area that could be associated with the active edge of this tool (Figure 21A). However, if we only consider this small area of the edge, we might suspect a dual motion - both longitudinal and transversal. But in some cases, we have observed the possibility of crystal fracturing that produces this effect, where the fractures intersect, forming a sort of "checkerboard" pattern. Without knowing precisely how to orient the photo in relation to the edge, we cannot ascertain a specific kinematics of it. Nevertheless, by observing the drawings (Figure 11) and the 3D models (Figure 9 and 12), we can identify a series of notches that could be linked to the probable use of this artifact as a working tool. In Figure 22, we have attempted to show the contact area of the tool with the worked material, which possibly corresponds to a medium/hard material.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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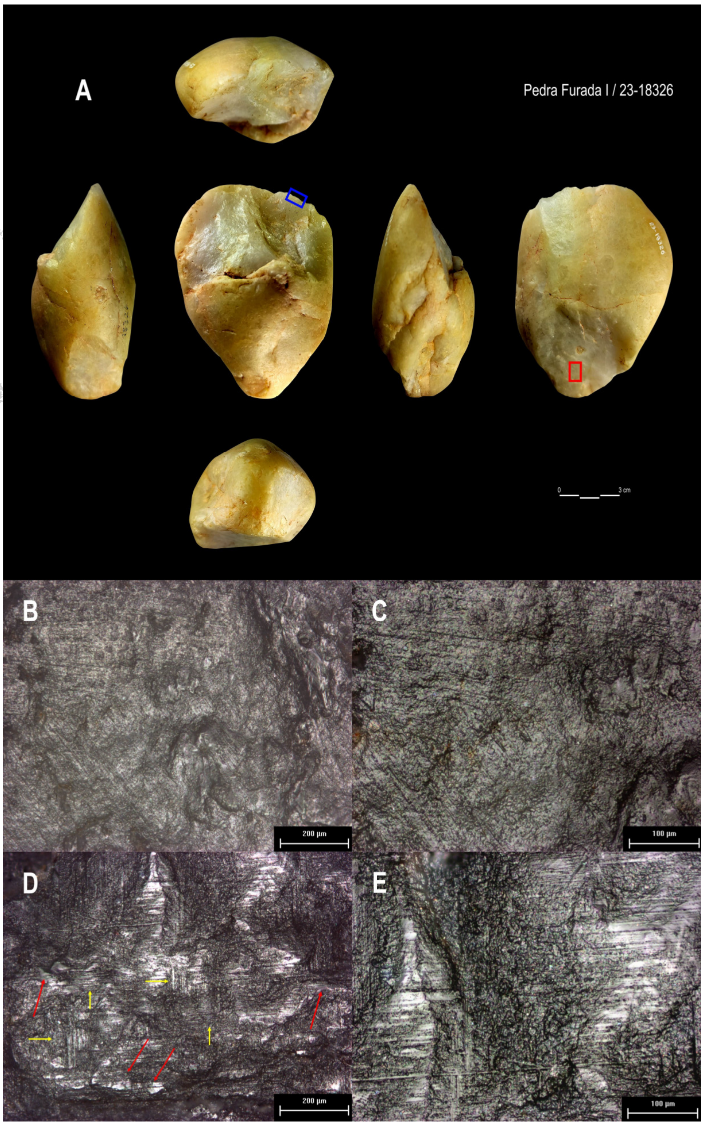

Figure 21. (A) The two areas bounded by blue and red boxes were the chosen places for the microphotographic records. (B) The striations on the surface were considered as use-wear marks, suggesting tool movement in two directions (100x). (C) Detail of the central area of Figure B, illustrated at 200x magnification the alleged multidirectional tool use. (D) This image is from the blue box in Figure A, with 100x magnification showing groups of striations near the edge, indicated by yellow arrows; the red arrows indicate abrasion polish spots. (E) The upper part of this image, with 200x magnification, shows the rounding of the surface caused by the tool use.

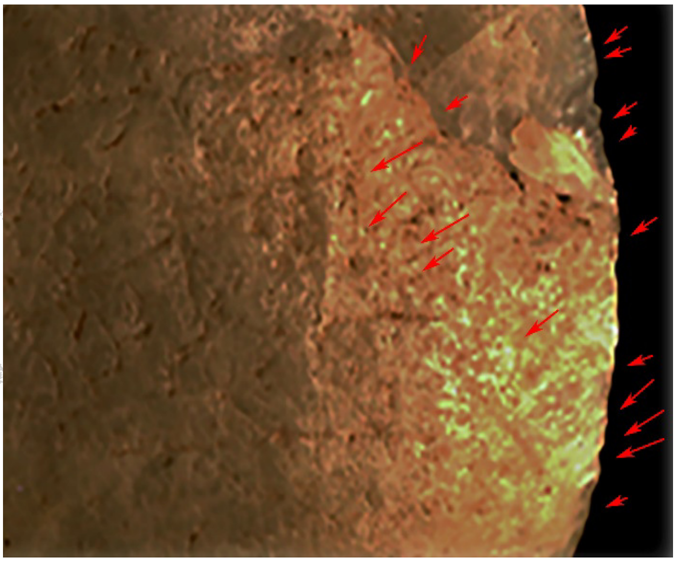

Figure 22. Close-up of the distal right angle on the dorsal face of piece 23-18326, as photographed by Bonnichsen. This image corresponds to the contact face of the tool. Notable features include the rounded edges of the notches and the direction of movement indicated by certain striations. Additionally, the surface displays a smoothing and shine, suggesting the potential development of differential polishing. However, due to the photograph's limited resolution, finer details cannot be discerned with clarity.

Piece 23-17359

This artifact displays a flake, likely the result of a direct blow while it was positioned on an anvil. The resulting edge is somewhat rough and inefficient for cutting tasks. The only potentially useful feature is a small protruding 'tooth', a byproduct of the impact against the anvil. Furthermore, the photographs by Bonnichsen (Figure 23) suggest the presence of greasy residues from handling rather than intrinsic features, due to inadequate cleaning. The whitish deposits (Figure 23: B, C, and D), perhaps from sediment, exhibit no post-depositional changes, as evidenced by the sharp, unrounded edges. This deposit seems to be an extraneous substance, unrelated to the artifact's use, likely removable with proper cleaning. In my assessment, this object is not a tool, though it might be classified as an artifact due to the flaking process undertaken on an anvil.

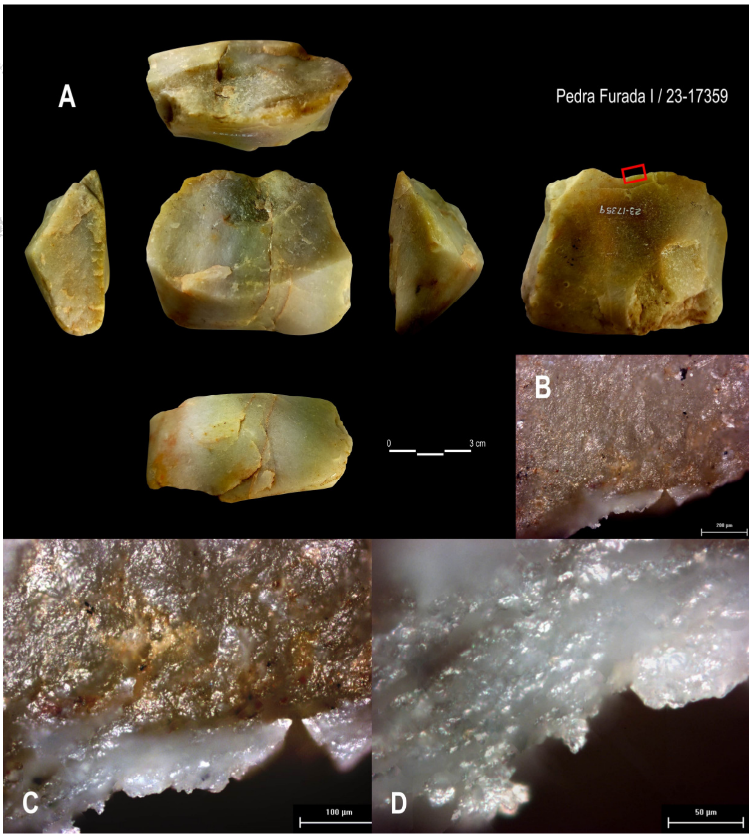

Figure 23. (A) Figure 1. The red box indicates the area where the microphotographs were taken on the dorsal side of the piece. (B) The reformed silica adhered to the edge may have been deposited as a result of use (100x). (C) This image is a 200x magnification of Figure B. (D) This image is the 500x magnification of the reformed silica, present in the previous images.

<u>23-18352</u>

The microscope images presented by Bonnichsen (Figure 24) suggest that the quartz surface of this artifact is coated with a greasy substance. This coating is discernible in all the photographs, with photos D, F, and G of Figure 24 particularly highlighting the substance's adherence. However, only in photos C and D are there indications potentially linked to cutting activities. Photo C shows corrosion on the crystal's lateral edges, possibly due to usage, a phenomenon experimentally observed in cutting both soft animal matter and medium-hard materials like wood. This corrosion, located on the crystal's edge, implies cutting-related use. Additionally, micro-notching on the notch edge in photo D further suggests a cutting application. Extending the analysis to photo G, one might observe linear abrasions, in elongated patterns, on the crystal. These abrasions, grouped and not merely surface-bound, indicate an active undercutting of the quartz. This edge may have been employed in a longitudinal cutting motion on an unspecified material. A detailed cleaning could provide clearer insights into the artifact's potential usage. Notably, the presence of notches on both sides of the edge further supports the hypothesis of its involvement in cutting tasks (Figure 25).

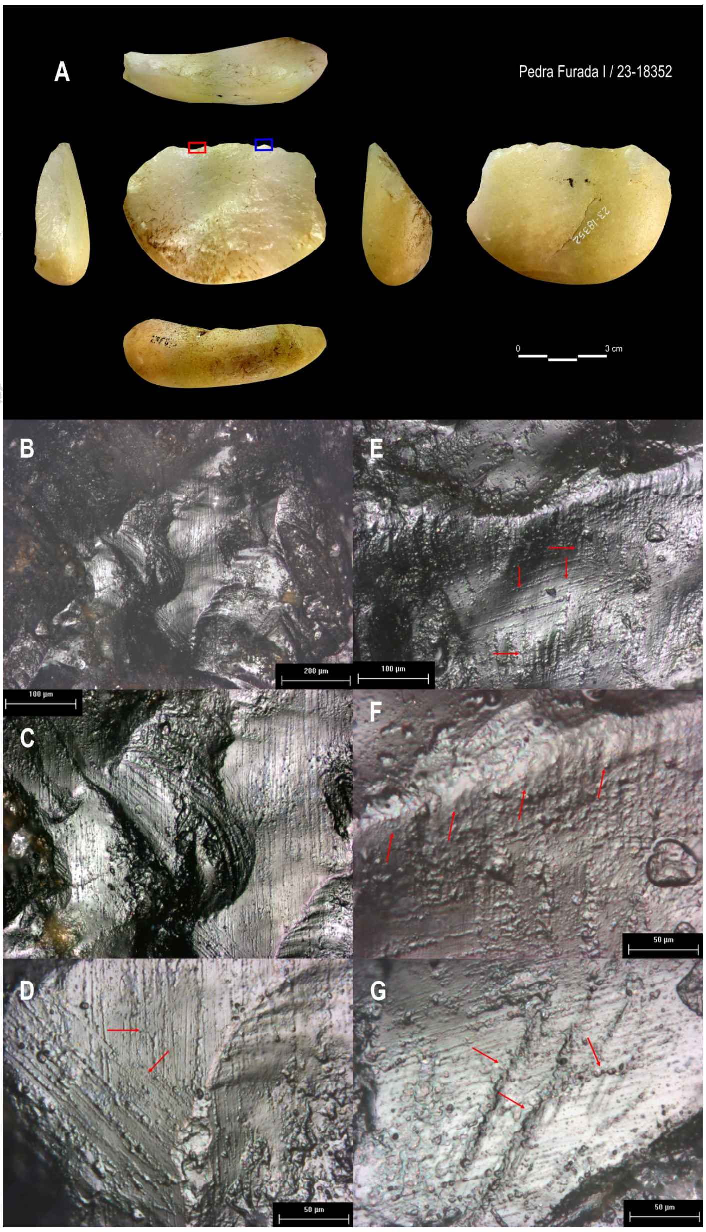

Figure 24. (A) On the ventral side of flaked cobble, there are two colored boxes from which the microscopic images were recorded. (B) Polished and rounded surfaces with striations (100x). (C) Close-up (200x) of the central area of Figure B. (D) The bottom right portion of the Figure C with 500x magnification, where there are striations that are allegedly indicators of tool movement. (E) The red arrows indicate the 'linear tracks' formed during the movement of the tool in two directions (200x). (F) Image obtained from the right central portion of the Figure E at 500x, where the formation of silica is noted, indicated by the red arrows. (G) The image was obtained in the same area as Figure F, but slightly more inward in relation to the tool edge (500x). There is an overlay of thicker, oblique marks in relation to the finer striations. The material is being removed from a surface that was previously smoothed.

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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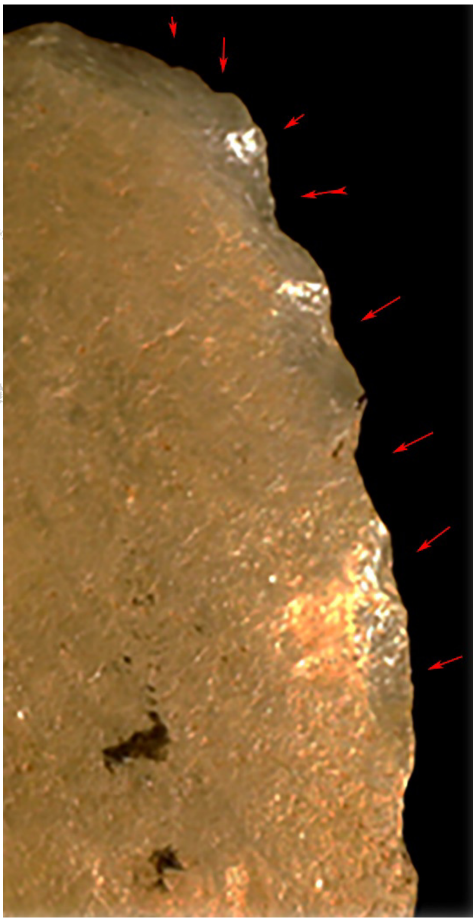


Figure 25. The piece 23-18547 displays notches along its edge, characterized by a distinct patina. These notches are found on both faces of the piece and could indicate use in a cutting activity.

23-18547

Analyzing Bonnichsen's microscope photos, a similar observation to the previous artifacts emerges. It's evident that a more thorough cleaning is required. The presence of greasy substances, likely from handling during excavation and analysis, is apparent, especially in photos C, D, and E of Figure 26. Intriguingly, photo B from the same figure reveals an edge rounding, which might indicate its

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
https://doi.org/10.51359/261425

use in a longitudinal cutting activity. However, for this artifact, we can only tentatively suggest a potential use as a tool.

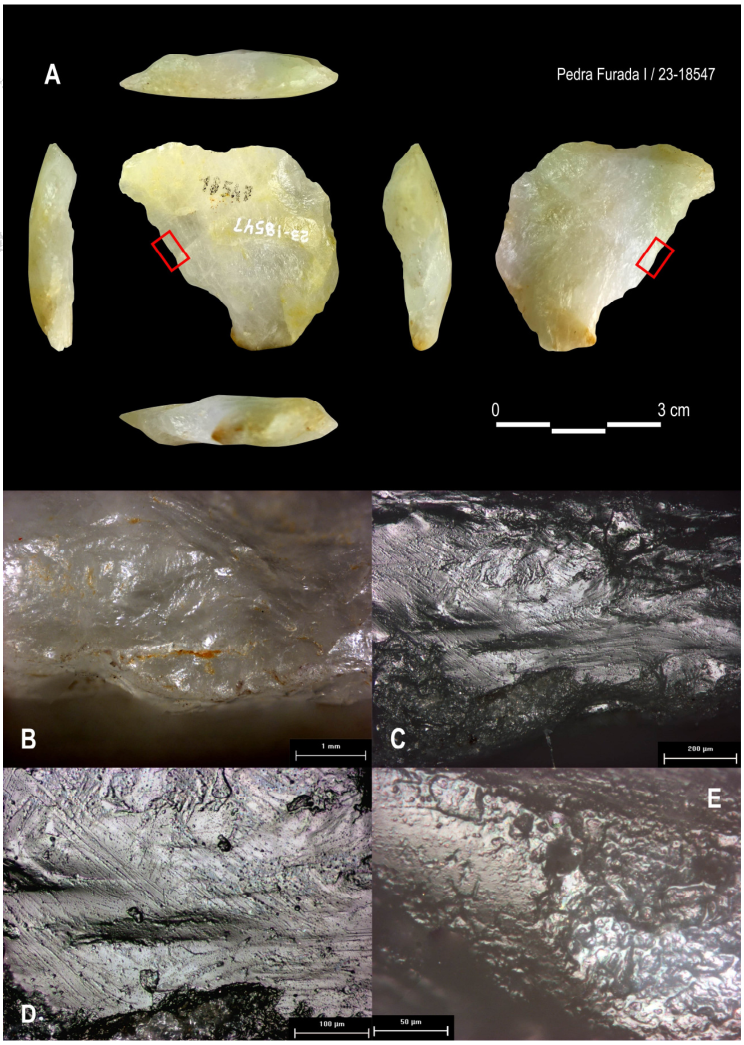


Figure 26. (A) The red boxes in the same zone on both the dorsal and ventral sides indicate the microphotographs origin, where the evidence of use-wear was identified. (B) Rounded and polished edge (40x). (C) The striations indicate the direction of the oblique movement to the edge. Image extracted from the dorsal side at 100x magnification. (D) 200x detail of the upper left quadrant of the Figure C, showing the striations. (E) Image of the ventral side at 500x, showing that it was smoothed and "lacquered" by silica gels.

8. DISCUSSION

8.1 Synthesis of results

The four pieces, 23-18326, 23-17359, 23-18352, and 23-18547, exhibit distinct characteristics, yet also share some similarities (Table 4; Figures 27-28). Each piece shows evidence of human-made removals, indicating deliberate shaping/retouch and use. Pieces 23-18352 and 23-18547 both have at least 10 removals, suggesting more extensive modification. All pieces underwent several structural stages, ranging from selection to use and retouching. Each piece has a main modified edge, which varies in shape and angle. Regarding the differences, 23-18326 and 23-17359 have fewer anthropic removals (3 and 1 respectively), suggesting simpler modification or a different usage compared to 23-18352 and 23-18547.

The edges and bevels of these tools vary significantly. For instance, 23-18326 has an irregular edge and an 80° bevel angle, while 23-17359 has a straight edge and a 45° bevel angle. These variations indicate different cutting capabilities and possibly different functions, although more traceological analysis is necessary to confirm it. There is a variation in the evidence of use-wear and the types of materials processed. 23-18326 and 23-18352 show use-wear, with 23-18352 likely used for cutting soft animal material or medium-hard wood. In contrast, the use and material processed by 23-17359 remain indeterminate.

Piece	Taphonomy	Structural syntax	Center of mass	Main modified edge										
				Front view	Profile view	Bevel	Bevel Angle	Cutting-Edge	Cutting-edge Angle	Length (mm)	Use-Wear	Kinematics	Edge function	Processed material
23-18326	Only 3 anthropic removals	3 stages: selection, shaping and use	mesial part	irregular	irregular	biconvex	80°	irregular	90°	~30	yes	longitudinal/ transversal?	percussion cutting	medium/hard
23-17359	Only 1 anthropic removals	4 stages: selection, retouching (x2) and use	mesio-basal part	concave	straight	biplane	45°	biplane	50°	~20	no	indeterminate	indeterminate	indeterminate
23-18352	At least 10 anthropic removals	5 stages: selection, flaking, retouching 1, use, and retouching 2	mesio-basal part	“denticulate”	saw-like (*avoyé*)	biplane	45°	Plane-convex/ irregular	85°	~35	yes	longitudinal	cutting	soft animal/medium-hard (wood)?
23-18547	At least 10 anthropic removals	4 stages: selection, flaking, retouching, and use?	mesial part	irregular	irregular	biplane	40°	biplane	50°	~15	yes	longitudinal?	cutting	indeterminate

Table 4. Summary table of multi-proxy qualitative and quantitative data for the main edge of the pieces of the Bonnichsen collection.

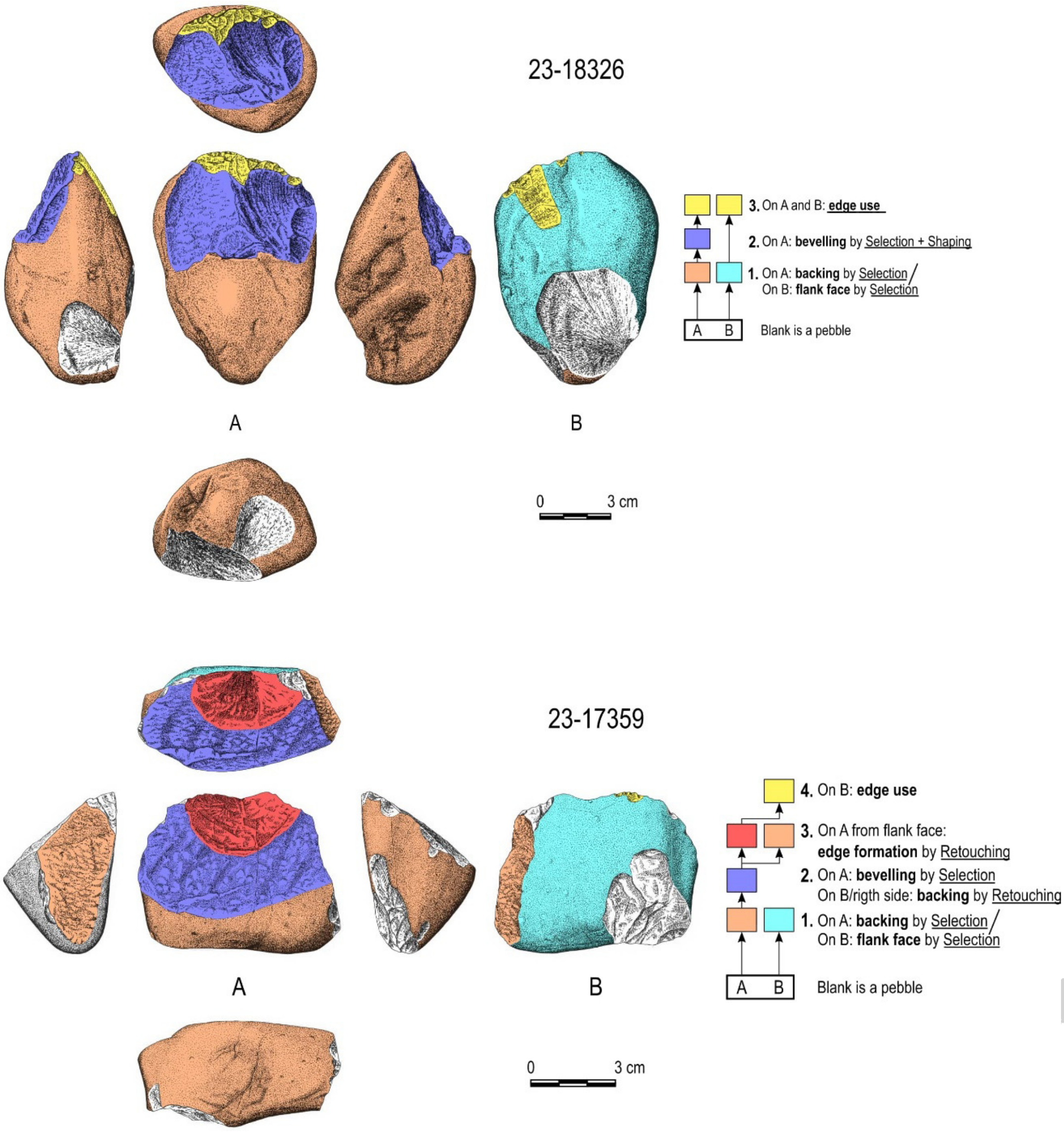


Figure 27. Multiproxy interpretation of pieces 23-18326 and 23-17359 from the Bonnichsen collection.

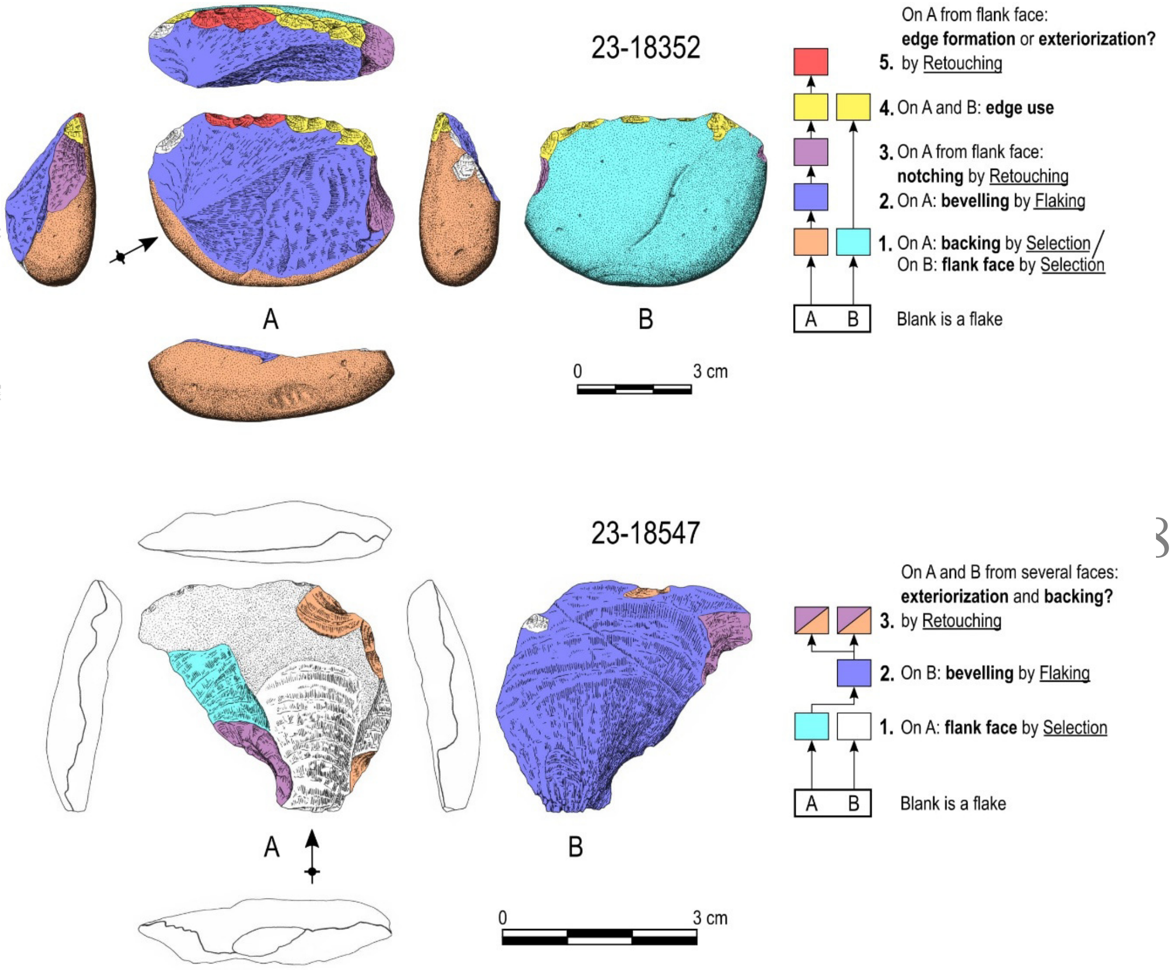


Figure 28. Multiproxy interpretation of pieces 23-18352 and 23-18547 from the Bonnichsen collection.

The tool 23-18547 exhibits clear anthropic flaking. The transformative edge is inferred to be at the distal edge's center, identified by its robustness and simple bevel cross-section. Based on what we already have about this piece, we believe

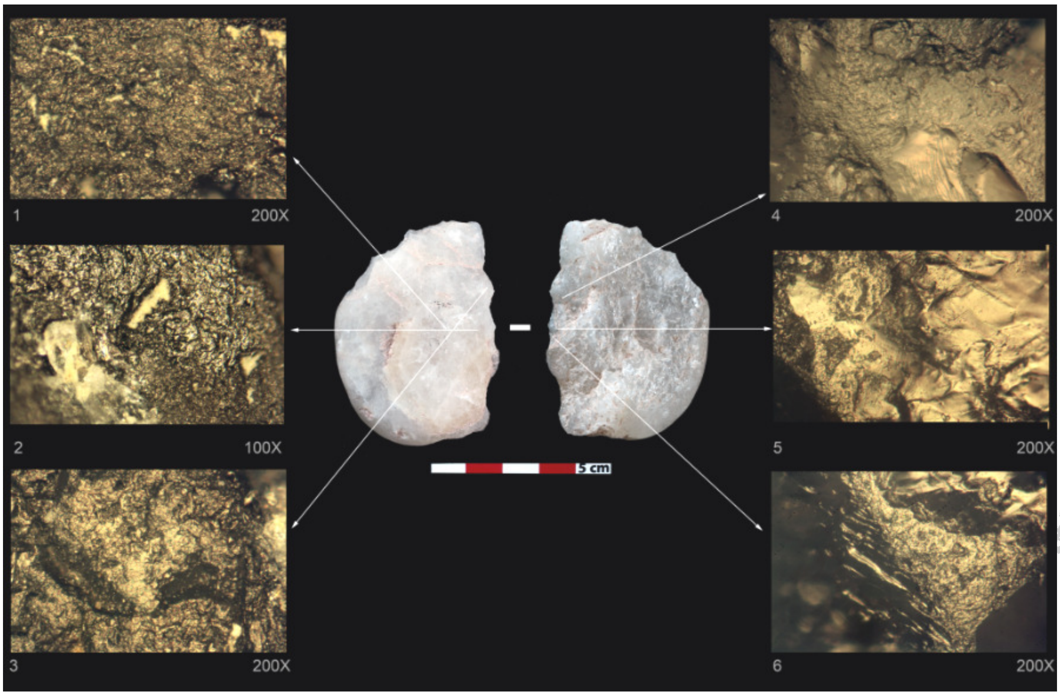
Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
https://doi.org/10.51359/261425

that it is a tool, although direct microscopic observations do not reveal signs of use. However, this was the piece that underwent the most transformation in the stages prior to the flaking of the core, revealing a series of unidirectional flankings without completely removing the cortex, and also for functionalization, with four slightly invasive centripetal removals, one of which is on the ventral face. Tool 23-18326 is unique due to its lack of symmetry. A natural fracture surface was selected and modified resulting in a plano-convex volume. The right apical portion underwent shaping through perpendicular and 45° strikes relative to the longitudinal axis. Tools 23-18326 and 23-17359 both demonstrate the use of singular flaking over natural fracture surfaces to create transformative edges. They also display an energy expenditure in the selection and morphological evaluation of raw materials.

The tools can be categorized into two groups based on the angles of their cutting edges. The first group, with a cutting-edge angle of 50°, includes a retouched flake and fragment. Despite having similar angles, pieces 23-17359 and 23-18547 are distinct in their robustness, gripping methods, and tasks. The second group, comprising 23-18326 and 23-18352, features right and obtuse cutting-edge angles. Tool 23-18352, a retouched flake, shows multiple fractures along its edge, varying between 90 to 135°. Tool 23-18326, with angles primarily between 90 and 80°, exhibits pronounced wear, transforming its bevel into a rounded/blunted area.

Interpretation in the context of previous studies

The observations previously made from Bonnichsen's photographs regarding the cleaning of the pieces, the location of the photographic record, and indications of striations/alterations, can be better clarified thorough the display of surfaces with and without modifications, quartz crystals, and functional interpretations of tools from the same site. Figures 29 and 30 show the differences between natural and altered microscopic surfaces, due to the use of two tools from TBPF (excavations of E. Boeda team). The activities carried out by the pieces were meat and skin cutting (butchery) and wood cutting/carving.



Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
https://doi.org/10.51359/261425

Figure 29. TBPF, T44-C7-238958. Right serrated edge used for butchery involving skin contact. Left photos: 1- View of the 'natural' cortex inside the piece; 2- Half a centimeter from the edge - the upper part with a greasy sheen is the use-polish formed on the cortex, the lower part of the photo shows the 'natural' cortex; 3- Cortex altered by use, with micropolish near the edge. Right photos: Micro-traces on the quartz surface, micropolishes from meat-skin contact, and rounding and orientation of crystals due to longitudinal action. (On the distal edge there are retouches, but no use-traces. More traces from that area show technical features of percussion).

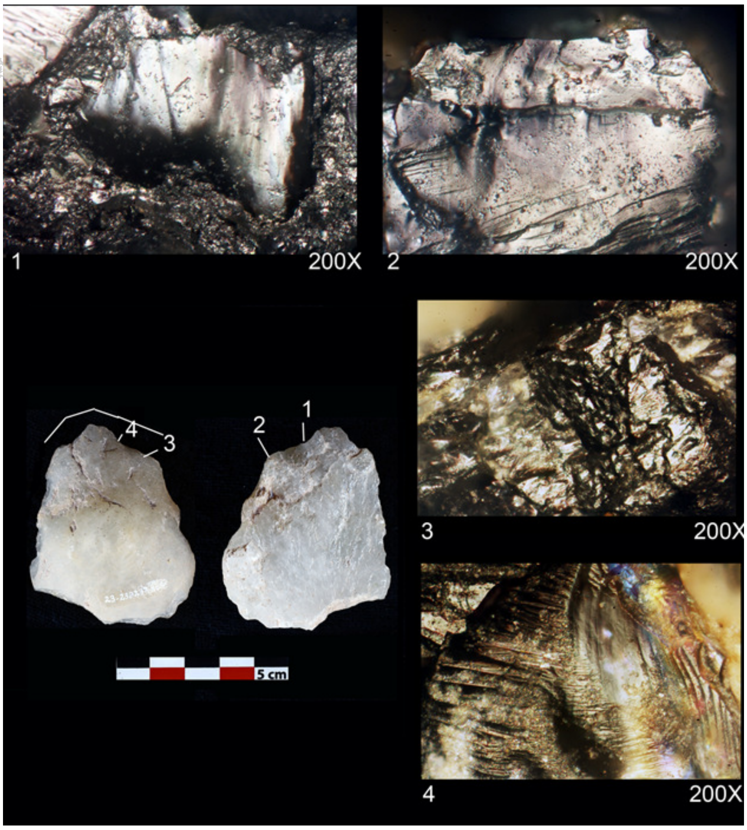


Figure 30. TBPF, T44-C6-238237. This is a rostrum with one extraction on each side. It has been used for cutting/shaping wood. Traces: 1-2 Crystal with polish and corrosion; 3- The edge breaks, forming a micro-stepped surface resembling a file; 4- Striae and orientation indicative of the tool's longitudinal action.

From a technological perspective, the only artifact bearing resemblance to those in the Bonnichsen collection is T44-C7-238958 (Figure 29). This artifact exhibits morphological and volumetric characteristics akin to 23-18352, although it is distinguished by the larger notches that form its transformative edge. While direct functional correlations between the two cannot be definitively established, the process of obtaining the blank, the deliberate modification of the retouched/used area, and the preservation of the area opposite the retouched/used one suggest its potential role as a matrix blank. Functional interpretations, however, can only be substantiated after microscopic analysis of several other artifacts within the broader context of the total lithic population from the Pedra Furada 1 phase, involving a more extensive collection of specimens.

Despite the artisans' preference for specific morphological and structural criteria, which involves either singular striking techniques or the sculpting of one half of a front, there is also an abundant availability of indigenous raw materials. These materials were notably utilized across all three phases of the earliest occupations. This juxtaposition highlights a unique blend of selective craftsmanship and the diverse natural resources at their disposal.

9. CONCLUSION

In this comprehensive multi-proxy lithic analysis of four lithics from Pedra Furada 1, Northeastern Brazil, dating between 60000 and 30000 BP, we have reassessed their geological, taphonomic, technological, structural, and functional

Clio Arqueológica 2023, V38N2, p.17-98, ALMEIDA; PINO; GUIDON; CONTE; DALTRINI; BALAREZO
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aspects within the framework of *chaîne opératoire* and traceology approaches. Originally examined by R. Bonnichsen for use-wear features, these artifacts now present a clearer picture of early human craftsmanship. Our results confirm that these objects were indeed shaped by human hands, exhibiting diverse production techniques ranging from simple flaking to more complex transformative processes that utilized the entirety of the artifacts' volumes and natural surfaces. The indirect analysis of wear patterns has allowed us to unravel layers of interaction encompassing selection, production, use, and discard. This multidimensional approach is crucial not only for enriching our understanding of the technological and functional attributes of these tools but is fundamental in distinguishing the human origins of their formation. This is particularly vital in challenging archaeological contexts like Toca do Boqueirão da Pedra Furada. It is important to note that these four artifacts represent only a fraction (0.6%) of the entire lithic assemblage from Pleistocene phases at this site. Therefore, future investigations of Pleistocene lithic assemblages from this and other sites within the Serra da Capivara National Park must adopt similar multi-proxy methodologies.

The attribution of an anthropogenic origin to Paleoamerican lithic objects is frequently dismissed prematurely in the absence of extensive analytical evaluations. Conversely, hasty anthropogenic attributions are often made without in-depth, fine-grained analysis and proper demonstration. Here we have tried to advance on an intermediate path, with a small sample, but which allows us to test our methodological approach for future analyses. A key direction for future research is the in-depth traceological analysis of both experimental and naturally occurring artifacts. Such detailed studies are indispensable for identifying subtle anthropogenic modifications amidst a plethora of natural fractures and incidental flakings, including those potentially produced by capuchin monkeys. Deciphering the use and functionality of these flaked artifacts, marked by human alteration, poses a significant challenge in studying Pleistocene industries within the SCNP. This endeavor is crucial not only for understanding early human presence in northeastern Brazil but also for shedding light on the broader narrative of human presence in the Americas.

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