Beyond the coastal periphery: chert use and procurement patterns in the Upper Paleolithic of Southwesternmost Portugal

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Text of abstract

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Highlights:

# 1. Introduction

Knappable raw materials play a crucial role in understanding the lifeways of past hunter-gatherers across time, given the ubiquitous presence of lithics throughout prehistory. More than mere stones with which stone tools are produced, these resources are intimately connected to a group’s technological, social, and cultural organization, potentially influencing the group’s overall survivability (Oestmo, 2017). Several key topics to the study of hunter-gatherer behavior and organization have been explored through raw material analysis, such as modalities of procurement and mobility strategies (Ambrose and Lorenz, 1990; Binford, 1979; Binford and Stone, 1985; Gould and Saggers, 1985, 1985; Kuhn, 1991; McCall, 2007), occupation types and their duration, (Kuhn, 2004; Surovell, 2009) to the establishment and dimension of social networks (Whallon, 2006) as well as exchanges between groups or individuals (Gamble, 1999; Wurz, 1999). This has frequently been done through the systematic characterization of geological and archaeological raw materials, the identification of corresponding sources for a clear differentiation between local and long-distance raw materials, and the study of their proportions within a site, often throughout different occupations and chronologies. These approaches and concepts have also been extensively applied to the study of lithic assemblages from prehistoric archaeological sites in the Iberian Peninsula (++). Frequently coupled with technological analyses, the study of raw materials, especially chert, through a wide range of methods such as macroscopic, petrographic, and geochemical, have recurrently aided in answering key questions to Iberian archaeology. One such question is the disappearance of Neanderthals and consequent replacement by Modern Humans (Aubry et al., 2022). Raw material studies have also contributed to understanding how different groups organized their technology, managed time, and risk (through the embedded/direct procurement approach) and chose resources during different chronological periods (Matias, 2016; H. A. M. Matias, 2012; Pereira et al., 2021; Pereira et al., 2016a). Furthermore, these studies frequently highlight long-distance procurement, even if in low proportions at times. In fact, raw material studies and the distinction between local/regional and exotic have also been successfully applied to identify long-distance contacts (>150 km) during the Upper Paleolithic (UP) in the Côa Valley, interpreted as the result of reciprocal exchange (Aubry et al., 2016, 2004). Although commonly known and identified during late prehistory (Costa et al., 2022; Nocete et al., 2005; Rodríguez et al., 2011), the identification of these contacts has expanded our understanding of often large-scale social networks and contacts during the UP in central Portugal, painting a picture of a wide interconnected territory. However, unlike other regions of the Iberian Peninsula such as central Portugal, and despite the potential of raw material studies to provide key data on the lifeways and organization of Paleolithic hunter-gatherers through time, as well as the mobility range and existence of social networks, the behaviors of management and procurement of raw materials are still in a preliminary phase in southern Portugal, especially in the Algarve region. Although much is known about the technological organization of Paleolithic hunter-gatherer groups in southwestern Portugal, especially due to the archaeological site of Vale Boi (Bicho et al., 2013; see Cascalheira et al., 2013; Marreiros et al., 2015), raw material studies have been scarce. Previous studies applied macroscopic methods to characterize the cherts from Vale Boi. Preliminary results showed the presence of a large component of local cherts from the Jurassic limestone formations, along with a less abundant and variable allochthonous chert component throughout the several UP occupations of the site (Bicho et al., 2013; Pereira et al., 2016b; Verissimo, 2004). Pereira et al. (2016b) suggest that the exogenous group may have been the result of embedded procurement within a 16 km radius, while the allochthonous group may have been the result of transportation during trips to other areas of the Algarve, Alentejo, or even south Spain. The presence of chert from the Cretaceous formations of central Portugal has also been suggested (Bicho et al., 2013). Furthermore, previous studies aiming to characterize the local and regional chert sources in the Algarve region have established a comparative macroscopic and petrographic database (Belmiro et al., 2023; Pereira et al., 2016c), a key element in raw material studies, especially to distinguish between local and non-local raw materials and understanding changes in the archaeological record (Pop, 2015; Surovell, 2009). These preliminary results, coupled with the existence of regional reference collections, show the potential for a systematic raw material study at the site, using different methods and approaches and applied to the lithic assemblages throughout the several Upper Paleolithic occupations, to understand how these hunter-gatherer groups behaved through time: how they explored their landscape and lithic resources, where they moved across a territory nestled between water and land, and with whom did they establish social networks. To address these questions, we aim to characterize the raw material procurement and mobility patterns of hunter-gatherers throughout the Upper Paleolithic of southern Portugal. By studying the chalcedony and chert artifacts of the UP levels of Vale Boi we aim to characterize these raw materials macroscopically and petrographically, to identify different chert groups and their souces.

## 1.1 Site description

Vale Boi is located on the western coast of the Algarve region in southern Portugal, within small valley that connects south to the Atlantic current coast at around 2 km. It is bordered by a limestone hill, characterized by limestone exposures that form rocks shelters facing west and southwest (Cascalheira, 2010). The site extends for more than 10,000 sq m along the slope of the valley, through which three main occupation areas have been identified: Slope, Shelter and Terrace. The excavation methodology included the recording of all artifacts with dimensions superior to 2 cm or complete small artifacts (i.e., bladelets) with a total station, and was applied to all main areas. Several occupations have been identified in both the Terrace and the Shelter area. The Terrace includes occupations from the Holocene to the Upper Paleolithic, resulting in the identification of eight main lithostratigraphic units where several UP occupations were identified, from the Gravettian, Proto-Solutrean and Solutrean. The Shelter area shows four main lithostratigraphic units, with Magdalenian, Solutrean and Gravettian occupations. From these, the Solutrean levels show the largest occupation, with three, well-preserved archaeological horizons (Cascalheira et al., 2013).

TABLE: Table with short layer description, attributed technocomplex, and radiocarbon dates. Will need complete field layer description and the dates we currently have for VB from JC.

MAP: With geological context, location of VB, Iberian Peninsula small map.

## 1.2 Geological context

The Algarve region is a complex territory, marked by several geomorphic sub-regions and geological units that provide different lithological resources used throughout prehistory. Two main geological units characterize the region: the South Portuguese Zone (SPZ) in the north sector of Algarve and the Algarve basin to the south. The SPZ is characterized by schists, greywacke and quartzites, while the Algarve basin features limestones, dolomites, and marls. It is within these limestones and dolomitized limestones from the Triassic to the Upper Jurassic where chalcedony and chert nodules and beds can be found. Chalcedony is located approximately 10 km from Vale Boi, in the marl-carbonated Triassic formations as lenses or nodules and was formed through hydrothermal processes (Bicho et al., 2013). The cherts can be found in several Jurassic formations throughout the Algarve, but are frequently known for the Lower Jurassic beds and small nodules in the limestone cliffs at ~20 km from the site, which have been previously studied and characterized (Belmiro et al., 2023; Ribeiro, 2005). Chert is also available in the less known Upper Jurassic limestone formation in western Algarve (++ km from the site), and in the center and eastern portion of the Algarve, in Middle and Upper Jurassic formations with chert nodules (Belmiro et al., 2023).

QUESTION: Should I include a short description of the cherts in the text, or do this through an image or table?

# 2. Materials and methods

To characterize the siliceous raw materials in the Upper Paleolithic occupations of Vale Boi and identify their geological sources, we applied a macroscopic and petrographic approach to the study of the chalcedony and chert archaeological materials from the Terrace and Shelter area. We applied two different methods to obtain a more complete characterization of the materials and compensate for the inherent caveats of each methods (Luedtke, 1992). Macroscopic analysis, for example, shows several caveats related to the lack of quantitative variables (Bustillo et al., 2009). However, given the large sample size of chalcedony and chert lithics at the archaeological site, a macroscopic approach presents a non-destructive, easy and less costly of characterizing all the materials. As such, we apply a first step of macroscopic analysis, followed by a petrographic study to reduce the subjectivity of the analysis (Bustillo et al., 2009) and complete the characterization with petrographic data. Similarly, the combination of these two methods was previously applied successfully in the characterization of the cherts from the Algarve region as the result of recent prospection works (Belmiro et al., 2023), and as such, a comprehensive macroscopic and petrographic comparative collection is available for the comparison with archaeological materials when using the same methods.

This reference collection is located at the Lusolit lithotheque (hosted at ICArEHB, University of Algarve), and aided in the characterization and source attribution of cherts. Hand samples were used throughout the macroscopic characterization for comparison with the archaeological materials, and the archaeological thin sections were compared with the previously studied geological chert thin sections. The geological samples at the lithotheque also included cherts collected from previous prospections from other areas of Portugal (such as central Portugal) and chalcedony, of which 4 thin sections were produced for this study (3 of chert from the Estremadura and ++ of chalcedony from the Algarve). The lithotheque from the Unit of Geoarchaeology and Archaeometry Applied to Historic Artistic and Monumental Heritage from the University of Cadiz (hereon UCA) was also visited, to understand the macroscopic variability of the Cadiz local and regional cherts, to aid in the source attribution of cherts not congruent with local sources and identify possible long-distance chert-use.

As aforementioned, the study started with a macroscopic analysis of archaeological materials. The samples chosen for this study consist of the chert and chalcedony lithic artifacts with individual IDs (excluding buckets) from the Upper Paleolithic levels of the Terrace and Shelter areas of Vale Boi.This means that the smaller fraction of artifacts (lithics smaller than 2 cm) was not considered, and thus we may be missing patterns of differential raw material use and miniaturization. However, similar methodologies were applied to studies using formal models for raw material and mobility studies applied to archaeology, where only artifacts above 2 cm were considered to improve comparative studies between assemblages (Surovell, 2009).

The sample from the Terrace area (VB-T) consists of 3600 lithic artifacts from levels 4 to 7/8 (excluding levels with a small sample such as level 4B), while the sample from the Shelter area (VBS) consists of ++ lithic artifacts from levels C to A. These two areas were chosen since both have detailed spatial information (as mentioned in section *IN*), several radiocarbon dates through different levels, and previous studies providing lithic technology, faunal, and geoarchaeological data. The archaeological materials are currently located at ICArEHB’s laboratories (University of Algarve) and no permits were necessary for their study. The macroscopic analysis was divided into two steps. The first step included a preliminary characterization using a hand lens of 10x magnification. This step allowed us to create groups and subgroups based on similar macroscopic characteristics which have been used in previous studies to describe and discern between different types of chert; these include characteristics such as color, translucency, and feel (Luedtke, 1992); a data dictionary for the recorded variables can be found in the Supplementary Materials (++). In the second step, we used a Nikon SMZ25 stereomicroscope to observe each sample in further detail, which allowed us to better characterize the artifacts (especially regarding inclusions and alterations), and the previously established groups. The data dictionary used for the individual samples can also be found in Supplementary Materials (\*\*). Given the inherent macroscopic variability of the geological samples and archaeological specimens, as well as the number of samples, the database used for the individual analysis is simplified and focused on collecting data related to weight, cortex, and alterations. A caveat of using this methodology of analysis is the inability to unequivocally characterize and group artifacts which have surface alterations such as patinas, pits or fire-related alterations. Whenever artifacts displayed extensive alterations and could not be unequivocally characterized ([Figure 1](#fig-terrace-alterations)), they were analysed using the individual sample dataset, and instead grouped in a category of indeterminate cherts (INDET).

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| Figure 1: Photo and close-up of samples with extensive alterations which impossibilitate the identification of chert type. a) artifact with cracks, white patina and reddening covering 100% of the surface; b) artifact with surface alterations, displaying a portion with patina (brown) and a portion without patina (gray), cleaned with HCL. |

To better characterize the different chert groups identified in the macroscopic analysis, 22 thin sections were prepared at Thin Section Lab (Toul, France) and analyzed at the ICArEHB laboratory. The samples chosen for this analysis include at least one sample from each group present throughout the stratigraphy of the Terrace area, from different archaeological levels ([Table 1](#tbl-TS-list)). For groups that showed macroscopic variability, several thin sections were analyzed to ensure the collection of petrographic data that reflected this variability. Petrographic thin sections were analyzed by polarized light microscopy (Nikon LV100ND) to determine the mineral composition, textural characteristics, allochems, and bioclasts, as well as any alterations.

Table 1: A table with a thin section list.

| Type | Sample ID | Level | TS # |
| --- | --- | --- | --- |
| Type 1 | I19-1615 | 4D | 8 |
| Type 2 | I19-2835 | 5 | 17 |
| Type 2 (altered) | H18-1938 | 4D | 20 |
| Type 2 (multi) | H21-3095 | 4C | 6 |
| Type 2 (multi) | H21-4234 | 5 | 7 |
| Type 2 (reddening) | H19-2426 | 4D | 3 |
| Type 2 (rmu\_17) | I19-2226 | 4E | 18 |
| Type 3 | I20-3160 | 5 | 10 |
| Type 4 | H20-2441 | 4E | 19 |
| Type 5 | I21-3252 | 4E | 14 |
| Type 5 (banded) | H18-2708 | 5 | 2 |
| Type 6 (CPT) | I19-3350 | 6 | 9 |
| Type 6 (CPT) | I20-3689 | 6 | 16 |
| Type 6 (CPT) | J18-778 | 5 | 13 |
| Type 6 (LLB) | I20-3951 | 6 | 11 |
| Type 6 (6E) | H19-4074 | 6 | 4 |
| Type 7 (01b; 01a) | L19-64 | 5 | 12 |
| Type 7 (04) | J18-1264 | 8 | 22 |
| Type 8 | H19-2924 | 4E | 1 |
| Type 9 | I21-2966 | 4C | 15 |
| Type 10 | H19-4216 | 6 | 5 |
| White patinated | H20-4166 | 6 | 21 |

The petrographic analysis PDF files for all thin sections studied in this paper (including macroscopic and microscopic figures) can be found in our GitHub page (++) as well as the OSF repository (++). The geological thin sections can also be consulted in the LusoLit online database at https://lusolit.icarehb.com/. A detailed macroscopic and petrographic description and figures for each type and sub-type of chert and chalcedony can be found in the SOM (++), as well as the datadictionary used for the petrographic analysis. The entirety of the R code used for the analysis and visual representations contained in this paper can be accessed through our online research compendium (++). We use the rrtools package by Ben Marwick to create a research compendium and write a reproducible journal article; rrtools is a free and open-source RStudio package accessible at <https://github.com/benmarwick/rrtools>. To produce these files, we followed the procedures outlined by Marwick (2017) for constructing research compendiums, aiming to enhance the reproducibility of our research. The provided files include the complete set of raw data used in the analysis, along with a custom R project (Wickham, 2015) containing the code required to generate all tables and figures. To enable maximum reuse, the code is made available under the MIT license, data under CC‐0, and figures under CC‐BY (additional details can be found in Marwick, 2017).

# 3. Results

The three main used raw materials at the archaeological site of Vale Boi are quartz, greywacke, and chert. Other raw materials such as chalcedony, dolerite and schists have also been identified. Using the field database with all individually coordinated lithic artifacts, we compared the incidence of chert and chalcedony in opposition to the remaining lithics of other raw materials. [Figure 2](#fig-rm-comparison) shows that for the selected levels, chert represents only ~20-15% of the lithic assemblage. Based on previous lithic studies in the terrace area, the remaining 80% of other raw materials are mostly composed of quartz and greywacke. Although no systematic raw material research has been applied to the latter raw materials, they have been interpreted as local and readily available in the proximity of the site (Pereira et al., 2016b). Frequently, the quartz and greywacke assemblages include large amounts of shattered and/or unknapped chunks or slabs. Previous studies from the terrace area have also shown that when removing shatter and chunks, the percentages of chert become much more representative when compared to greywacke and quartz (Belmiro et al., 2021; Belmiro, 2020). Based on this, despite the low amounts of individually plotted chert artifacts in the field database, chert continues to be one of the main raw materials to produce lithic stone tools, with complete knapping sequences and formal toolkits. The importance of chalcedony has also been shown in its use to produce formal tool kits during specific technocomplexes at the site (Belmiro et al., 2021).

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| Figure 2: Comparison of chert, chalcedony and other raw materials coordinate in the terrace area of the archaeological site of Vale Boi. |

As previously mentioned, whenever too altered to confidently attribute a group, the artifacts were instead classified as indeterminable (INDET). As seen in [Table 2](#tbl-indet-freq), level 4 shows the higher percentages of indeterminate artifacts, corresponding to 40% of the total sample (n=1027). This is due to the frequent alterations of the sample, especially related to patinas and alteration rinds, pits and fire/heat alterations. For all other levels in the Terrace, indeterminate represents in mean ~28% of the chert artifacts, while in the Shelter the frequency of indetermiates is slightly lower (~20-25%).

Table 2: N and percentage of grouped and indeterminate artifacts by level.

| Group | 4 | 4C | 4D | 4E | 4E/5 | 5 | 6 | 7 | A | B | C |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Grouped | 615 (59.88%) | 286 (71.68%) | 287 (66.74%) | 330 (73.33%) | 155 (73.11%) | 209 (70.85%) | 430 (73.13%) | 146 (72.28%) | 318 (77.56%) | 1,049 (75.85%) | 455 (79.41%) |
| Indeterminate | 412 (40.12%) | 113 (28.32%) | 143 (33.26%) | 120 (26.67%) | 57 (26.89%) | 86 (29.15%) | 158 (26.87%) | 56 (27.72%) | 92 (22.44%) | 334 (24.15%) | 118 (20.59%) |
| Total | 1,027 (100.00%) | 399 (100.00%) | 430 (100.00%) | 450 (100.00%) | 212 (100.00%) | 295 (100.00%) | 588 (100.00%) | 202 (100.00%) | 410 (100.00%) | 1,383 (100.00%) | 573 (100.00%) |

## 3.1 Characterization and source attribution

### 3.1.1 Cherts congruent with local sources

Through the macroscopic and petrographic analysis, we identified 10 main chert/chalcedony groups, present throughout the stratigraphy in the Terrace and Shelter area (TABLE with groups). A single different group was identified in the Shelter area, with limited presence in the Terrace (n=2), and 14 varieties of chert and 2 chalcedony composed of one to three samples were identified in several levels of the Terrace and Shelter. The latter varieties were collapsed into a category named TL (Trace lithotypes). Through the comparison with the reference collections, we identified cherts congruent with the local sources and cherts which are not local.

TABLE WITH SHORT GROUP DESCRIPTION.

The raw materials which are congruent with local sources are the chalcedony and massive, micro-cryptocrystalline cherts (local\_grid). The chalcedony (Type 1; A1) is a massive, fibrous chalcedony without allochems. It is characterized by a colorless and translucent appearance, often partially or completely white patinated. It is characterized by frequent large crystallizations, irregularities and fractures which impact the knapping. It is macroscopically and petrographically congruent with the hydrothermal chalcedony found in lenses in Triassic formations, also frequently characterized by irregularities and fractures. NEED chalcedony data from previous works from X.T.

The cherts are massive micro-cryptocrystalline quartzes from a marine environment. Macroscopically, these groups show variability which resulted in their separation in four different macroscopic groups (Group 2 to 5). In general, these are opaque to sub-translucent cherts, with colors varying brown, yellow, pale red and grey, with the frequent presence of spicules and iron oxides. The differences are in their colors, nodule morphology, frequency, and variety of bioclasts (Group 2 including triaxon sponge spicules and echinoderm spines), something already identified in the geological samples (Belmiro et al., 2023). Petrographically, however, these cherts are homogeneous, except for a small number of artifacts with a banded variety within group 5. The macroscopic separation was maintained for its possible usefulness in identifying preferred types of nodules or macroscopic varieties through time and for future correlation with technological data. These cherts are characterized by wackestone textures, with accessory amounts of macrocrystalline quartz and fibrous chalcedony, frequently found replacing fossils and occasionally dolomite. Type 5 shows higher percentages of micrite/sparite. In all samples, fossils range from common to very frequent, albeit frequently unidentifiable. When identifiable in thin-section, they are sponge spicules (B2, C2, H2), with the rare occurrence of possible foraminifera (Type 2 and Type 5) and ostracod (H3) in a sample from type 5. Porosity varies between 10% and 1%, of vug type. Based on the previously described macroscopic and petrographic characteristics of the Lower Jurassic cherts of the Algarve (Belmiro et al., 2023), we interpret Groups 2, 3, 4 and 5 to be local, as they are congruent with the described characteristics. Groups 2 and 3 are congruent with the frequently available brown/yellow and red nodules and beds, ranging from uncommon to very frequent fossils. The macroscopic similarities of Groups 4 and 5 are more limited, as they show similarities to specific nodules, rarely found in the known outcrops, and mostly located in the Ferrel area. As such, we interpret these cherts as local, but from nodules and outcrops that are no longer frequently available or visible in the landscape. This is especially relevant, since the Ferrel outcrops are mostly destroyed and can be found in poor preservation conditions, and with small, broken nodules in the surface, frequently altered (Belmiro et al., 2023).

FIGURE: local\_grid, variability of local chert macroscopic and petrographic characteristics

### 3.1.2 Cherts not congruent with local sources

We identified several chert types with macroscopic and petrographic characteristics that are not congruent with the chert available in known outcrops in western Algarve (nonlocal\_grid).

Group 6 (A1, B1, A2, B2) corresponds to a massive cryptocrystalline quartz with a mudstone texture, from a marine environment. This chert is translucent and shows a variety of colors, ranging from brown, red, and gray, which seem to vary in function of the artifact’s thickness. In unaltered samples, visible bioclasts are rare. The cortex is rounded, and rarely pebble-like, ranging from thin to medium thickness. Two sub-groups were individualized based on macroscopic characteristics such as color, translucency variation, and patterns, although they may simply reflect the use of specific nodules from within Type 6’s variability. Five thin sections were produced to better characterize the macroscopic variability of this group and sub-groups. The petrographic analysis shows the samples are characterized by a mudstone texture and massive microstructure. It is mainly composed of cryptocrystalline quartz (between 95-97% in the samples), with accessory fibrous chalcedony found replacing fossils or filling fractures, and in some samples macrocrystalline quartz, microcrystalline quartz, and micrite/sparite. Allochems are opaques, iron oxides, and bioclasts. Bioclasts are unidentifiable and poorly preserved, with rare identifiable fossils such as sponge spicules, replaced by fibrous chalcedony and rarely by microcrystalline quartz. Porosity is present between <1-1%, of vug-type when identifiable.

FIGURE: nonlocal\_grid, variability of non-local chert macroscopic and petrographic characteristics.

The similarities between chert artifacts at the UP occupations of Vale Boi and the chert from the Rio Maior region (Estremadura Portuguesa) have been previously suggested although without systematic studies to ascertain the attribution. These Cretaceous cherts, found in secondary deposition settings, are described as frequently translucent, with geodes, with colors ranging from yellow to red or grey, and mineralogically homogeneous between them. Petrographic studies from the Estremadura area highlight the presence of iron oxide accumulations and rare fossil ghosts or frequently difficult to see in thin section (Matias, 2016). When identified, sponge spicules and possible rare foraminifera have been identified (H. Matias, 2012). Studies of Upper Cretaceous cherts from the Torres Vedras, Sintra and Lisbon area describe cherts with similar macroscopic characteristics, with micro-cryptocrystalline quartz mudstones with bioclasts such as sponge spicules or bivalve fragments, or wackestone/packstone textures with abundant bioclasts, including ostracods and different types of foraminifers (Jordão and Pimentel, 2022). These cherts have also been reported as found in highly variable cobble morphologies and macroscopic traits, which is also observable through the reference samples from central Portugal hosted at LusoLit. Alike the archaeological thin sections from Type 6 and congruent with other studies (Jordão and Pimentel, 2022; Matias, 2016), the thin sections produced from the Cretaceous cherts hosted at Lusolit show a massive, cryptocrystalline mudstone structure, with uncommon fossils (ghosts), commonly barely visible, iron oxides and low porosity (<1%). From these cherts, only the dark grey nodules (RT231) showed identifiable fossils which were rare ostracods. Based on the macroscopic and petrographic similarities to the geological references from Central Portugal and congruence with previous studies from this area, we interpreted Group 6 (and sub-types) as belonging to the macroscopically variable Cretaceous cherts from the Estremadura and Lisbon region in central Portugal.

Group 7 (C1, C2, D1, D2) is a massive micro-cryptocrystalline, peloidal/oolitic packstone, from a marine environment and possibly a high-energy, shallow depositional environment, due to the type, sorting, and preservation conditions of the ooids. It is characterized by white and grey colors. The cortex is from an outcrop, rounded, and varying between medium thickness to thick. This group shows several facies, with different types and concentrations of allochems and bioclasts, of which identifiable are peloids, ooids, and sponge spicules. A detailed scheme of the facies can be found in the SOM (++). The petrography results show this chert has a massive microstructure and packstone texture. It is composed mainly of micro-cryptocrystalline quartz (80%), fibrous chalcedony (10%), and micrite (10%). Allochems are opaques, iron oxides, ooids and peloids. The ooids are poorly preserved and only uncommonly show concentric lamellae in plane polarized light. Unlike macroscopical observations, bioclasts under the thin section are all unidentifiable, although rare fossils may be bivalve shells. Porosity is variable (<1-10%). The consultation of the lithotheque hosted at UCA allowed us to identify a sub-set of cherts with similarities to those from Type 7 from the Middle Subbetic region (south Spain). These cherts are massive, sub-translucent, peloidal/oolitic packstones. Allochems include very frequent peloids and ooids. The peloids are densely arranged in the samples, more or less visible depending on the alterations to the surface or the thickness. The ooids are poorly sorted, with oval or round shapes and replaced by quartz. Uncommonly the ooids show a preserved nucleus. The presence of bioclasts varies between samples, ranging between common to rare, and when present/identifiable include sponge spicules (common), foraminifera (rare to uncommon) and echinoderm spines (rare). Similar cherts have been identified and described in previous works, describing grey cherts with peloidal and oolitic facies and occasional foraminifera (Rodríguez et al., 2011). Despite the nonexistence of thin sections for comparison, the macroscopic similarities between the cherts allows us to interpret Type 7 as coming from the Upper Jurassic formations of the Betic Systems, extending from Cadiz to Alicante.

Group 8 (E, F1, F2, F3) corresponds to a massive micro-cryptocrystalline quartz from a marine environment and shelf/platform depositional environment. Identified and well-preserved fossils are foraminifera from the Pfenderenidae family, which are larger benthic foraminifera from marine environments. The association of these foraminifera indicates this chert formed from sediments deposited possibly between the Jurassic to the Cretaceous. Macroscopically, this group is characterized by gray and white colors. The translucency ranges from sub-translucent to opaque. Whenever present, the cortex is rounded and thin. Petrographically, this group is a packstone (mudstone texture close to the edges) with a massive microstructure. It is composed of 97% micro-cryptocrystalline quartz, macrocrystalline quartz, and fibrous chalcedony, found mostly replacing fossils. Other minerals include uncommon iron oxides and the porosity is of vug type (3%). Fossil content is very frequent, albeit mostly unidentifiable and poorly preserved. Identified fossils are rare sponge spicules , rare ostracods with some degree of preservation, common small, unidentified foraminifera (100 μm) of differing preservation degrees, and as aformentioned foraminifera from the Pfenderenidae family (500 μm). Despite the macroscopic similarities between type 8 and cherts from the Middle Subbetic region chert formations, the geological reference samples showed no macroscopically visible foraminifera. However, our results indicate that despite no foraminifera being visible macroscopically, they are present in thin section. The fact that no foraminifera were identified in the small number of analyzed samples from the Cadiz lithotheque may simply be a result of their uncommon visibility. Another possible source may be the Upper Cretaceous wackestone/packstone cherts with foraminifers from the Lisbon region (Jordão and Pimentel, 2022). However, these studies do not specify the existence of Pfenderenidae foraminifers. Given the lack of this specific fossil in the reference samples from Andaluzian chert and the central Portugal cherts, the probable source of Type 8 remains unknown.

Type 9 (G1, G2) corresponds to a banded micro-cryptocrystalline quartz/micrite peloidal packstone. It is opaque and has a heterogeneous structure and is characterized by a variable color distribution: it shows a horizontal laminated and finely laminated pattern, with gray dark gray bands intercalated with light gray bands. Whenever present, the cortex is rounded (from an outcrop source) and is generally thin. In specific samples, the cortex is present on two parallel planes of the sample (parallel to the laminations), which indicates the chert was originally available in bedded layers. Petrographically this chert is a banded packstone (banding of sedimentary origin), composed mostly of micro-cryptocrystalline quartz (48%), micrite (40%), dolomite (10%), and accessory fibrous chalcedony and mica (muscovite). The allochems are peloids, unidentifiable bioclasts, iron oxides, and opaque minerals. Porosity is low (1%). Although its origin is unknown, when visiting the Cadiz lithotheque, we identified a small group of banded black cherts without noticeable fossils or inclusions. Despite the lack of comparative petrographic data, the macroscopic resemblances raise the possibility that Type 9 belongs to Andalusian chert formations in southern Spain.

Type 10 (H1, H2) is an oolitic packstone, massive micro-cryptocrystalline micrite/quartz from a marine environment and possibly a high-energy, shallow depositional environment, due to the type, sorting, and preservation conditions of the ooids. Its heterogeneous structure has two types of fabrics with different macroscopic characteristics: brown (opaque) and black (sub-translucent) fabric. Petrographically this chert is a packstone with a massive microstructure. The chosen sample for the thin section is composed of 35% micro-cryptocrystalline quartz, 53% micrite, 9% macrocrystalline quartz, and accessory fibrous chalcedony (filling fractures) and mica; the percentages of quartz and micrite might be related to the fabrics present in the artifacts. Allochems are common iron oxides and very frequent ooids. Bioclasts are rare, poorly preserved, and replaced by quartz. The porosity is intraparticle and vug (10%). The ooids are distributed homogeneously across the sample (although clearly macroscopically visible in the brown fabric) and are highly abundant and concentrated. They are poorly sorted, varying between 500 and 20 μm. They show round-to-elliptical shapes, and their preservation is variable: some ooids show a poorly preserved micritic structure, while others show concentric laminae structures around a round nucleus (Flügel, 2010), pp. 144]. This chert shows no similarities to any consulted reference material. Despite the existence of oolitic limestones in the Algarve region, no chert nodules are mentioned (++) and the visit of outcrops mentioned in the geological cartography did not allow their identification; however, the trade of oolitic cherts in recent prehistory may indicate that these types of cherts are available in the landscape in long-distance (Nocete et al., 2005), and their presence in Vale Boi may simply reflect similar mobility patterns.

Just realized I need to add Type 11 here. –

Finally, the TL groups are characterized by several samples with differing characteristics from the previously established groups, and with without correspondence to the local cherts and chalcedony from the Algarve region. These are composed of blanks or retouched tools, rarely with cortex, and rarely the same TL group is found in different archaeological layers. A detailed description of these types can be found in the SOM (++).

Apart from the groups common throughout the stratigraphy of the Terrace and Shelter, Type 11 and samples from the TL group also show no identifiable source. The exceptions are TL01, TL10-11 and TL15-16. Jasper is known in the SPZ area (Missing a ref here), from the Alentejo region to Spain, above the Algarve suggesting that the source of TL01 may be from the Évora/Beja region. Similarly, despite different from the frequent Cretaceous nodules, the macroscopic similarities between TL10 and TL11 and specific nodules from Central Portugal in the Lusolit lithotheque may indicate these cherts are from the Estremadura/Lisbon area. This difference in appearance may be due to the already mentioned variability of the nodule’s macroscopic characteristics. Finally, TL15 and TL16 show macroscopic similarities to radiolarite reference samples located at the Cadiz lithotheque, which may indicate the source of these cherts is from Middle Subbetic region (Domínguez Bella, 2010; Domínguez-Bella, 2006).

DOUBT: Should I include here the figure with the smaller groups, or simply leave it in the SOM?

## 3.2 Stratigraphical distribution

Chert groups are present across the stratigraphy (except for Type 11 which appears only in level 4 and in a small number of artifacts; n=2). Different chert types were consistently used in the Terrace area throughout time, with different intensities of use. [Figure 3](#fig-type-per-level) A shows the percentage of chalcedony and chert types used throughout the stratigraphy in the Terrace area of Vale Boi, while [Figure 3](#fig-type-per-level) B shows the percentages of weight sum of these raw material types per level; this data excludes the unidentifiable and altered samples, categorized in a group named INDET. In the Solutrean and Proto-solutrean levels, local cherts make up more than ~70% of the chert (n) and 80% when considered the weight. Despite this homogeneous pattern, the use of Type 2 and Type 4 marks significant differences between the Solutrean occupations (levels 4, 4C, and 4D) and the Proto-Solutrean occupations (4E and 4E/5); in the first group the yellow/brown cherts (Type 2) represent ~30% of local chert use, while in the second group, the use of Type 2 diminishes drastically (~10-15%). In contrast, Type 4 becomes the most used chert with percentages above 35% in level 4E and ~20% in the top of level 5. For both occupations, chert non-congruent with the known local sources represent percentages lower than 30%. This pattern seems to shift in the bottom of 5 and throughout the Gravettian occupation; the use of chert local cherts drops to 45-60%, while the percentages of specific non-local chert types increase significantly, such as Type 6 and Type 7. However, when considering the sum of the weight, the percentages of Type 6 diminish, instead representing around 20% of the chert use, and bringing for level 6 the use of local chert to 50% in comparison to chert types of non-local source. Other non-local cherts such as Type 10 and TL categories also show smaller increases in the Gravettian occupation. Chalcedony (Type 1) seems to be present but always in small frequencies. Despite this, there is a small increase in the use of chalcedony in level 5 (both top and bottom), from lower than 5% in level 4E to 13.5% in top of 5, with a tendency to decrease in the older levels.

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| Figure 3: Chalcedony and chert types per level, without unidentifiable samples. Only percentages superior to the 5% threshold are presented in the figure. |

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| Figure 4: Boxplot of weights. |

When plotting the weight, it is apparent that most of the samples are located under the 0.3 kg mark, with median and bottom quartiles often falling under the 0.5 kg line. Local types, such as Type 2, Type 4 and Type 5, although mostly represented by artifacts with a small mass (~0.3 kg), show the heaviest and highest number of heavy artifacts. In comparison, other types, although showing some variation in the weight of artifacts, show lighter numbers of artifacts, and their means and medians are frequently closer to the bottom quartile. As seen in [Figure 3](#fig-type-per-level) B, non-local types show larger masses from level 5 to level 7.

The same raw materials found in the Terrace area are also found in the Solutrean occupation of the Shelter, albeit with some differences. Although with similar percentages to the local cherts, the use of local chert in the Shelter area is heavily dominated by the brown/yellow cherts (Type 2) that frequently characterize the Lower Jurassic outcrops of the Algarve; although other macroscopic types are present, they are not significant. The presence of cherts not congruent with the local sources is, alike level 4, close to 25%, although dominated mostly by Type 6. Type 11 is present in higher numbers than in level 4, however still representing less than 5% of the assemblage. Similarly to the Solutrean occupations of the Terrace, although the artifacts are generally small (lower weights), the local types show a higher variability in mass, with several outliers and heavy samples when compared to the non-local types.

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| Figure 5: Chalcedony and chert types per level, without unidentifiable samples. Only percentages superior to the 5% threshold are presented in the figure. |

# 4. Discussion

The macroscopic and petrographic analysis of chert and chalcedony lithic materials from the UP levels of the Terrace and Shelter areas of Vale Boi have provided crucial insights into the raw material procurement and mobility patterns of hunter-gatherers. These raw materials are useful proxies to identify mobility changes since they show patterns of local and non-local procurement. The prevalence of local raw materials in the Solutrean and Proto-Solutrean assemblages show a preferential use of local resources, although with discrete differences in the used nodules/outcrops. The presence of non-local raw materials throughout the stratigraphy suggests a continuous pattern of long-distance sourcing, which was intense during the Gravettian and slowed down through time.

Despite differences in proportion, there seems to be continuity in the raw materials used throughout the UP, including the allochthonous sources. This may be explained by the tradition of shared knowledge and culture regarding the location of raw materials and other resources in the landscapes (Is there a good ref for this?), or the maintenance of social networks through time. In this sense, raw materials are resilient elements of UP occupations and social/technological organization, and less prone to cultural or technological change. This persistence however, may also be explained by cached raw materials that were accumulated at the site and were intensively used and reused throughout several re-occupations of the site, eventually disappearing and leading to a more intense use of the local sources, either through large nodules or large blanks that remained unused (Binford, 1979; Hofman et al., 2024; Kuhn, 1995; Surovell, 2009).

The local chalcedony and chert show the groups were obtaining a large portion of their raw materials around the 20 km range of the site. The existence of direct procurement of raw materials may be considered since the known sources of chalcedony are located at 7-6 km of distance from Vale Boi, and chert can be found in the inland outcrop of Ferrel, ~8 km from the site. This hypothesis may be strengthened by the existence of UP occupations at Ferrel, which may correspond to quarrying and chert catchment during prehistory (Zambujo, 1998). The procurement of local cherts may have also occurred for larger distances, possibly through embedded activities. The other chert sources (Lower Jurassic and Upper Jurassic) of western Algarve are located by the beach and cliff areas as previously mentioned, between 18-15 km of Vale Boi. Although our current data does not allow us to identify which specific outcrops were visited based on macroscopic and petrographic observations, the presence of marine resources such as shells at the site shows these groups visited the coast, which means they could easily obtain raw materials in the vicinity without necessary detours (Binford, 1979; Surovell, 2009). We may see these patterns of close-distance procurement and possibly caching in the presence of heavy (large mass) nodules and chunks of chert from local types, as well as the considerable amount of outliers (representing larger blocks and chunks) in the weight boxplots throughout the stratigraphy ([Figure 4](#fig-weight)).

MAP/Figure with several elements: map with the several sources cited in the text (local and not local) and cited geological formations, marks exemplifying whether the sources were use or not as for example the eastern outcrops of the Algarve, color codes for type of mobility (close-distance, long-distance), side images for the geological cherts and the archaeological cherts, possibly also using the Quíros Castillo map as a secondary map to exemplify the use of plateaus in the mobility. What do you think?

However, the discussion involving local cherts seems further complicated by the existence of similar outcrops in eastern Algarve. Previous studies showed that macroscopic criteria is not enough to discern whether the used sources are Lower Jurassic (west Algarve within a ~20 km radius of the site) or Middle Jurassic (east Algarve, over 80 km away) since they are similar macroscopically and petrographically, and with similar quality (Belmiro et al., 2023). In this sense, and following other archaeological studies (Surovell, 2009), we cannot discredit that some portion of the local cherts we interpret as being procured within a 20 km radius of Vale Boi, may be the result of long-distance procurement or the result of regional mobility, between ~80-100 km where the Middle Jurassic cherts are located. Given the similar quality of the raw materials and lack of geochemical studies, and following raw material formal and informal models for raw material procurement, we interpret that most of these raw materials are probably from the local (under 20 km sources) while a small quantity may be the result of long distance displacements. Similarly, the Upper Jurassic cherts in proximity to the latter sources, around 90 km from Vale Boi, have not been identified in the assemblages despite having macroscopic characteristics not congruent with the local sources. This may be explained by the medium quality and generally small size of the nodules (frequently between 3-5 cm), or the location of the outcrops, since the known outcrops are located inland, and it may be possible that they were not accessible or visible.

While the regional Algarve cherts were not identified in the assemblages, the allochthonous cherts with possibly identified sources seem to come from further distances, and from two directions: 1) north, where the Cretaceous cherts from Central Portugal are located, along with the small quantity of jasper (TL01); 2) west, where the peloidal/oolitic chert from south Spain can be found. Despite both these sources being ~300 km away, these cherts may have been obtained at closer distances, through riverbeds with smaller transport distances, without pebble-like cortex. The near nonexistence of pebble cortex does shows they were likely not provisioned at the beach or riverbeds. Despite these high distance travel paths, studies have suggested the existence of low-cost paths to travel through the Iberian Peninsula. In fact, previous formal models designed to explain hunter-gatherer mobility have suggested that variables such as topography are important for the distances traveled by groups or individuals (Brantingham, 2006). For example, Quíros Castillo (2020) describes how Copper age groups reduced subsistence risks by creating exchange networks and practicing regional mobility seen in the exchange of autochthonous raw materials. These exchanges would have come with excessive energy costs and risks. However, the author points out that there are important features about the Iberian Peninsula regarding mobility such as the low cost of moving through the plateaus and the connectivity of the Guadalquivir River valley with the Guadiana and Tagus rivers. In this sense, albeit distant, the existence of the north/east directions of long-distance mobility by hunter-gatherers at Vale Boi may simply reflect the use of these natural highways for hunter-gatherer mobility and explain the high percentages of allochthonous chert use. The identification of the smaller subset of unknown source allochthonous cherts and chalcedonies (TL) may reflect different types of long-distance exchanges of finished products and blanks or with different social networks, possibly even reflecting individual networks and mobility (sensu Gamble, 1999).

A higher percentage of these allochthonous cherts, especially as we see in the Gravettian occupation, may be interpreted then as a high degree of communication and mobility between the groups occupying Vale Boi and an extended social network. This is a significantly different interpretation from that obtained from the Gravettian technology from south Portugal. Using a technological approach to the Gravettian lithic assemblages of Vale Boi, Marreiros et al. (2015) concluded that there are significant differences between the assemblages of central Portugal and southern Portugal. In this sense, studies suggest the presence of Gravettian regional technological facies. These have been interpreted as a different exploitation of territories as well as the reflection of different ecological and ethnographic boundaries between hunter-gatherers (Marreiros et al., 2015). Based on these combined data, it may be possible that the technological aspect of lithics indeed reflects different coexistence boundaries limited to the regional band. The existence of a high frequency of allochtonous raw materials may be the reflection of these contacts and exchanges between different bands, focusing on good quality raw materials in detriment of those found locally. A similar scenario is expressed by Brantingham (2006) when discussing social exchange; that exchange may occur between two bands occupying non-overlapping territories but with established regular meetings between, when they would exchange their raw materials, thus explaining how very long-distance sources might be identified in archaeological sites.

A different interpretation for the high frequencies of non-local cherts during the Gravettian may be used following the “Mean per Capita Occupation Span” model by Surovell (2009). According to this model, short occupations should display high proportions of transported artifacts (in this case, understood by allochthonous raw materials and artifacts produced with these resources), and as the duration of the occupation increases, local artifacts should become dominant. Similarly, the author also suggests long-term occupations may be a product of the environment, as patchy environments and colder temperatures present risks to increased mobility, and the settlement of camp in a locally abundant environment in a scarce regional setting could lead to long-term occupations which would present a less risky option [Surovell (2009)][Kelly 1995]. In this theoretical paradigm, the Gravettian occupations could be the result of high mobility and short-term occupations of Vale Boi, with possible reoccupations (sensu Surovell, 2009), thus showing high amounts of used non-local raw materials. As the climatic conditions begin to change, with the onset of Heinrich Event 2 during the Proto-Solutrean in south Portugal (Belmiro et al., 2021; Cascalheira and Bicho, 2013) and the consequent glacial maximum that characterized the Solutrean (Sanchez Goñi and Harrison, 2010; Schmidt et al., 2012), which caused a dryer, harsher climate with patchy vegetation (Cascalheira and Bicho, 2013; González-Sampériz et al., 2010), the resource abundant characteristics of an ecological niche region such as southwestern Portugal (Cascalheira et al., 2017; Schmidt et al., 2012), could have decreased the mobility of hunter-gatherers. With longer-term occupations to reduce risk, the amount of non-local raw materials from previous expeditions (obtained both through catchment at the source or through trade), would eventually reduce as local raw materials became more dominant.

In general, our results build upon previous preliminary studies, where the majority of the chert used seems to be the local Lower Jurassic cherts within a 20 km range of the archaeological site, while non-local materials composed a small percentage of used chert (Pereira et al., 2016b). Previously suggested long-distance sourcing, such as the Cretaceous cherts from central Portugal are confirmed through visual and petrographic data [Pereira et al. (2016b); ++], as well as the north and east mobility paths that connected the hunter-gatherer groups from the southwest of Portugal to the center of Portugal and the south of Spain (Pereira et al., 2016b). These cherts and chalcedonies with different sources present a picture of hunter-gatherers with complex systems and modes of exploring the landscape, managing resources, and possibly managing risk. Through the identification of allochthonous raw materials, even if in a small percentage in the Proto-Solutrean and Solutrean occupations, the Vale Boi case study shows that hunter-gatherers occupying a peripheric territory in the Iberian Peninsula and Europe, bordered south and west by sea, did not live isolated and instead demonstrate an extensive social network. Alike the results identified in central Portugal (++), in south Portugal we also identify a pattern of interconnection between the Upper Paleolithic hunter-gatherers of the Iberian Peninsula.

The obtained results show potential for a continuous study of these assemblages using different methods and approaches. For future research, we aim to use of a geochemical approach in the studied assemblages and geological reference collection to further expand upon the discussion of mobility through the UP of Vale Boi. Testing with fire and the creation of an altered reference collection may also aid in strengthening the raw material types and group of currently unidentifiable samples as mentioned in previous studies (Pereira et al., 2016b). Finally, we aim to correlate technological data from existing and in-progress datasets to further understand how raw materials (local and non-local) were being used and managed through time and include these in the broader spectrum of the changing environmental conditions occurring throughout the Upper Paleolithic.

# 5. Acknowledgements

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### 6.0.1 Colophon

This report was generated on 2024-01-08 15:09:53.460163 using the following computational environment and dependencies:

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