# Creating frames of reference for chert exploitation during the Late Pleistocene in Southwesternmost Iberia.

# 1 Introduction

Southwestern Iberia has often been considered a key area to understand techno-cultural transitions from the Middle Paleolithic to the end of the Upper Paleolithic. As a territory located at the tip of the European continent and with a generally stable climate even during the coldest periods punctuating the Late Pleistocene, it has been regarded as one of the most significant glacial refugia in Europe (Hewitt, 2000; Gómez and Lunt, 2007; González-Sampériz et al. 2010; Carvalho et al., 2022). For this reason, Southern Iberia has frequently been at the center of some of the most debated topics regarding Late Pleistocene human adaptations.

A particularly good example is the role that the region might have played in being one of the last territories to be occupied by Neanderthal populations right before their complete disappearance (Finlayson et al., 2006; Zilhão et al., 2017). Neanderthals occupied the European continent for more than 300 000 years and are thought to have disappeared as modern humans arrived on the territory (Jennings et al., 2011; Tzedakis et al., 2007). The last territory (and possibly the latest) where Neanderthal populations seemed to exist was Southern Iberia, around c. 37 thousand years ago, or perhaps even earlier, as it has been considered a climatic refugium during the harshest climatic conditions (Finlayson et al., 2006; Tzedakis et al., 2007; Carvalho et al., 2022). This region is key to understanding how the Neanderthals survived until such a later chronology, what contact they may have had with modern humans (Finlayson et al., 2006; Zilhão et al., 2017), and how and why they eventually went extinct (Dalén et al., 2012; Melchionna, 2018).

Another example is the importance the region possibly had during the Heinrich Event 2 (HE 2) and the Last Glacial Maximum (LGM), and the Upper Paleolithic (UP) cultural transitions taking place during this time. The HE 2 and the LGM are characterized by abrupt and drastic climatic changes that impacted modern human behavior all across Europe (Gamble et al., 2004; Sanchez-Goñi and Harrison, 2010). During this period, south Iberia and particularly, central and south Portugal, also functioned as a climatic refugium (Bicho et al., 2017), which allowed its continuous occupation by human communities. However, these occupations are still marked by evident changes to their population dynamics, culture and technology (Gamble et al., 2004; Bradtmöller et al., 2012; Bicho et al., 2017; Cascalheira, 2019).

It is clear that Upper Paleolithic occupations in south Iberia have been key to understanding human behavior and adaptations, and their study has advanced the current known paradigms for the Late Pleistocene. This is well illustrated in the archaeological site of Vale Boi, located in southwesternmost Iberia (Algarve, Portugal). This shelter and open-air site comprises one of the most complete Upper Paleolithic chronocultural sequences of Iberia (Bicho et al., 2012). As such, Vale Boi offers the opportunity to understand the movements of the first groups of Humans to reach the territory, their cultural changes throughout the Upper Paleolithic, as well as the impact of abrupt climatic change in culture. In fact, a great amount of studies has originated from the archaeological site of Vale Boi, and have aided in understanding the aforementioned topics, as well as the several technocomplexes and the transitions between them (i.e., Bicho et al., 2012, 2017; Manne et al., 2012; Pereira et al., 2016). A large portion of these studies has focused on lithic technology (i.e., Cascalheira, 2010; Marreiros et al., 2015; Belmiro et al., 2020). Unlike what happens in other areas of Portugal (i.e., Aubry et al., 2012, 2022; Pereira et al., 2016a), archaeological studies focusing on raw materials, and especially chert, have been more scarce.

Several lithic technology studies from Vale Boi have approached raw materials, although solely through a macroscopic methodology, often related to the location of the settlement (i.e., [@bicho\_o\_2003]; Pereira et al 2016) or the description of the collection (i.e., [@cascalheira\_tecnologia\_2010], [@marreiros\_lithic\_2015]). The work of Veríssimo (2005), albeit focusing on the occurrence of chert in western Algarve which provided the initial basis for comparative studies with the assemblages from Vale Boi, also maintained a macroscopic component. Finally, the creation of LusoLit, a lithotheque currently hosted at the University of Algarve (Telmo et al. 2016), and the collection of samples from several outcrops in the region provided a new leap in the study of chert in the region. However, the samples from the Algarve are still in need of an exhaustive analysis and interpretation. A few geological studies have also contributed to understand the availability and characteristics of chert in south Portugal (i.e., Rocha, 1976; Ribeiro, 2005). Nevertheless these studies are often unpublished or comprehend answers to geological questions, which hamper the comparative use of the data with archaeological assemblages. Furthermore, a large portion of chert-bearing outcrops in south Portugal still remains unstudied, both by archaeologists and geologists.

Given the presence of several chert-bearing outcrops in South Portugal, most of which remain unstudied, and the opportunity to conduct raw material studies in key sites from the UP such as Vale Boi, which demand a complete knowledge of the geology of the territory, the Algarve stands as a region full of potential for an exhaustive, geoarchaeological study of chert. This includes the development of a complete lithotheque which may serve for comparative studies within the Algarve and outside, where chert may have been transported and traded.

As such, this paper aims to locate and characterize the nature of chert sources in southern Portugal (Algarve) and their availability. Furthermore, it aims to test the potential of different methodological approaches to characterize the regional cherts and develop a methodological approach adapted to this study area.

## 2. Geological setting and chert outcrops

### 2.1. Geological setting

The Algarve is the southernmost region of Portugal, framed north by the Alentejo region and east by Spain. To the west and south, it is bordered by the Atlantic ocean. It extends for ~130 km E-W and ~50 km N-S and is characterized by a variety of geomorphic sub-regions and geological units, that make this region a complex territory. On the north sector of the Algarve, the Serra Algarvia is characterized by a mountainous range with a dense hydrographic network, which separates the Algarve from Alentejo. On the south sector, the Litoral is characterized by a flatter, long strip of land, that extends through all of the coastal strip of the Algarve. The Barrocal is nested between the other sub-regions and has a more moderate relief, characterized by carbonated Jurassic formations and an important sub-terranean water circulation (Gago, 2007).

Geologically, the Algarve is composed of two main geological units: the South Portuguese Zone (SPZ) and the Algarve basin. The SPZ is located in the north sector of the Algarve, extending up to Alentejo (Fernandes, 2012). It main lithologies are schist, greywacke and quartzite (Fernandes, 2012; Pereira, 2016). The SPZ is overlain unconformably by the Mesozoic sedimentary rocks of the Algarve basin [@fernandes\_new\_2012]. The basin corresponds to the Mesozoic-Cenozoic sediments that outcrop south of Algarve, from the westernmost to the easternmost point of the region, and it is associated with the opening of the central Atlantic ocean and with the eventual oceanic crust formation in the western part of the Tethys sea, between the Algarve and North Africa (Terrinha et al., 2013). Paleozoic sedimentation of the basin started in the Triassic and continued thereon. In the Lower Jurassic (Lower Pliensbachian, also regionally known as Carixian) the basin was divided into two sub-basins – western and oriental sub-basin (Rocha, 1976; Terrinha et al., 2013). The existence of the two sub-basins and the expansion and retraction of the seas created a variety of sedimentation environments, such as external and internal platform, continental, hemipelagic and deep marine (Terrinha et al., 2013), as well as moments of sedimentation hiatus. This variability in deposition environments created a variety of Paleozoic sedimentary facies, with moments of more or less homogeneity throughout this period. For example, during the Lower Pliensbachian, in the Lower Jurassic, the sediments in the western sub-basin can be described as marine of external platform, while the sediments of the eastern sub-basin can be described as marine of internal platform. During the Upper Jurassic however, the basin is marked by a moment of prominent lithofacies variation, followed by a moment of uniformity in both sub-basins (Terrinha et al., 2013).

Understanding the Algarve basin is key for raw material studies in the Algarve, especially when studying chert, since it is in the basin, more specifically in the Paleozoic sediments, where chert primarily outcrops in the region.

### 2.2. Chert outcrops

The presence of chert is commonly associated with carbonates in limestone and dolomite formations. This is explained by characteristics (such as the presence of water or specific temperatures and pH) which are ideal for both the formation of limestone and the precipitation of silica (Luedtke, 1992). The pelagic and marine environments of the Algarve basin during the Paleozoic gathered those such ideal characteristics, allowing the sedimentation and precipitation of limestone and silica, creating limestone layers with chert nodules. The existence of two basins with different sedimentation environments also shows potential for the precipitation of different types of chert throughout the basin and their differentiation. For example, during sedimentation, skeletal grains of fossils may be preserved. Many of these fossils are restricted to specific sedimentation environments and time intervals (Flugel, 2010), which may allow the identification of chert outcrops through the fossil content. The basin and sub-basins thus show potential for the existence of different geological formation with different chert type, and their study.

Previous works, both geological and archaeological, confirm that chert is present in the Algarve in the Jurassic limestone or dolomitic limestone layers of the Algarve basin. This means that chert outcrops can be identified on the central/south sector of the region, from west to east. Variability in chert availability as well as chert types is expected, considering that during the sedimentation process, the Algarve basin was already sub-divided and in constant environmental change. Due to this, several formations with chert nodules can be identified in the Algarve, corresponding to different sub-periods of the Jurassic.

In the western sector of the Algarve, chert can be found in the Lower Jurassic limestone or dolomitic limestone layers (from the regional Carixian), often visible in areas where the layers are exposed, such as beach-generated cliffs and associated deposits. This includes outcrops such as Cabo de S. Vicente (CSV) and Praia do Belixe (PBLX). These sediments and chert nodules are also available inland, albeit more scarcely, as is the case of the small outcrop named Ferrel, 3 km from the current coastline. Lower Jurassic chert-bearing outcrops are barely unexistant in the center/east sector of the Algarve, with one single formation with micro-nodules identified in geological works [@oliveira\_carta\_1992].

Middle Jurassic geological layers with chert nodules are only found in the center/east sector of the Algarve in a geological formation called the Malhão Formation. The formation can be described as carbonated, from a marine sedimentation environment.

Finally, Upper Jurassic sediments with chert nodules have also been mostly identified in the center/east sector of the Algarve, attributed to the Jordana Formation. This formation is characterized by dark-gray limestones, with frequent secondary silicifications with abundant fossil fragments. One single outcrop from the Upper Jurassic has been identified in the western sector of the Algarve basin, located at Praia da Mareta.

# 3 Materials and methods

To locate and characterize chert outcrops in southern Portugal and understand the chert’s characteristics, a macroscopic and petrographic approach was applied to the study of geological samples which were collected through fieldwork.

A combination of methods in a multilayered approach is an important tool to reconstruct the geological and geographical origin of raw materials especially since different methods have their inherent limitations. By combining these two different methodologies the goal was to create several layers of analysis, to which new layers may be added if necessary (Brandl, 2016). Several other similar methodologies and approaches have been applied in other regions (REFS). However, the chosen analysis techniques should be adapted to the specific geographic context, the research questions, problematics, and the characteristics of the types of cherts in question. Since only preliminary studies of raw materials were applied in the western portion of southern Portugal, and petrographic data has been shown to provide good results for the characterization of cherts in this region (Ribeiro, 2005), the two methodologies were chosen for the study.

The geological samples used in the study were obtained during fieldwork, between August of 2021 and June of 2022. The locations prospected were chosen after reviewing previously known research, which included preliminary raw materials studies in the region (Veríssimo, 2004; Pereira et al., 2016b), geological papers and thesis focusing on the Algarve basin and with reference to chert outcrops (Rocha, 1976, 1976; Marques, 1983; Ramalho, 1985; Ribeiro, 2005) and geological maps, which signaled the presence of chert nodules within the outcrops (Rocha et al., 1979, 1983, 1989; Oliveira, 1984, 1992; Manuppela et al., 1987; Manuppella et al., 2007). Unpublished data and coordenates for unprospected locations with potential for chert-bearing outcrops gathered during the organization of the LusoLit lithotheque were also prospected. Whenever coordinates or specific locations for known outcrops were available, these were directly visited and the surrounding area was prospected to understand the extension of the outcrops and possible secondary deposition outcrops nearby. Whenever no specific locations were described (for example, in geological maps) several locations with potential to find chert outcrops within one larger formation were visited and prospected.

Samples were collected whenever possible, focusing on both primary and secondary outcrops. When chert nodules within one single outcrops showed macroscopic differences (such as differences in the color, texture, translucency or cortex), samples of each different nodule were collected, in order cover all chert variability within the outcrop. This variability was also recorded using a database (to distinguish between homogeneous or heterogeneous chert nodules within the outcrop) and through photography. All samples were registered with resource to an android app which allows coordinates to be associated with photos and data stored in a database, regarding the outcrop characteristics and conditions (i.e. abundance, visibility, access, geomorphology, chert morphology and conditions). All data related to the app and dataset for the variables recorded can be found in the supplementary materials. Individual ID tags were associated with each sample, which was washed and labeled in the laboratory.

A two step approach was applied to characterize the geological samples. As a first step, the samples were analyzed macroscopically following a pre-established dataset. The variables were defined based on specialized literature (i.e., Luedtke, 1992; Crandell, 2005; Bressy, 2002), and the dataset with the variables can be found in the Supplementary materials. A small hand-lens of 10x magnification was used for this analysis, followed by a higher magnification analysis with the resource of a Nikon SMZ25 stereomicroscope, focusing primarly on inclusions and fossil content. Despite several caveats, especially related to the subjectivity and lack of quantative variables, a macroscopic approach is currently still frequently used in chert raw material studies, if not as a preliminary approach to a large archaeological assemblage. For a comparative analysis with archaeological artefacts, other methods may be inconvenient or impossible to use, since they may be destructive and often difficult to apply to large assemblages. Macroscopic analyses have the advantage of being less costly and easy to apply. Establishing a reliable macroscopic characterization and understanding the potential of macroscopy to differentiate between cherts, outcrops and formations is essential for comparative studies between geological samples and archaeological assemblages (Bustillo et al 2009).

The second phase of the study focused on the petrographic analysis of the geological samples. Thin-sections were produced from geological samples of all formations, focusing on obtaining petrographic data that reflected the macroscopic variability. In total, 29 thin-sections were produced (thin-section database info), divided in three groups: 1) 19 thin-sections of geological samples from different outcrops within the western section of the Algarve; 2) 9 thin-sections of geological samples from different outcrops from the eastern section of the Algarve; 3) 1 thin-section of a geological sample recovered from previous works (prior to 2021), which was not identified in our survey. Although primary outcrops were prioritized, thin-sections of secondary deposition samples were also produced, in order to characterize the chert from most of the identified outcrops. Information about the thin-sections, including the laboratories in which they were made, are provided as Supplementary materials. To compare with the thin-sections from this study, other thin-sections from previous studies of Jurassic outcrops from western Algarve (Ribeiro, 2005) were also consulted. All thin-sections were analyzed using a Nikon LV100ND or a Leica DM2500 P and following standard petrographic description (full descriptions of the variables considered for the petrographic description can be found in the Supplementary materials).

All descriptions (macroscopic and petrographic) and accompanying photographs will be available online on a database, and downloadable as PDF files. The paper was written with resource to R and R Studio and can be found open-source at the **link**.

# 4 Results

Eighteen outcrops (primary and secondary) were revisited or newly identified in the Algarve region. Nine are located in the westernmost territory and nine to the east (between Loulé and Tavira). From these, 70 samples were recovered and analyzed. Some of these samples were recovered as isolated finds or in secondary settings.

On the westernmost part of the Algarve, there are mainly cherts from two different formations: Lower Jurassic and Upper Jurassic. The latter can be found in a single known outcrop - Praia da Mareta. Lower Jurassic outcrops are more common and have been better studied (**ribeiro\_evolucao\_2005**). These outcrops are heterogeneous, showing different characteristics and chert colors.

The Lower Jurassic cherts can be grouped in three main macroscopic types: yellow and/or red type; grey/brown type; yellow and red with fossils type. These macroscopic types not only show differences in color, but also in the fossil content, visible at naked eye and stereomicroscope. The first two types are present in all outcrops. They are mainly characterized by dull to medium luster and opaque translucency, although some samples were sub-translucent. The feel ranges between the smooth and semi-smooth, although many of the Belixe cherts have a rough feel. In the Yellow/Red cherts, fossil content is present but visible only as white, red or yellow speckling. The Grey/Brown cherts show little fossil content, barely visible with the stereomicroscope. The Yellow/Red with fossils cherts show a large quantity of big fossils, which are easily seen at naked eye and can be identified under the stereomicroscope.

According to the microscopic approach, the Lower Jurassic cherts of Western Algarve are composed mainly by microcrystalline quartz, with textures that range mostly from the wackestone to the packstone. In more than 50% of the samples, no fossil can be identified, as all fossils, albeit common to very frequent, are poorly preserved, filled with chalcedony or quartz, and without any identifiable morphology. Whenever identifiable, fossils present in the sample are: Echinoderms, Radiolarians, Sponge spicules and a Bivalve shell.

Despite the similar characteristics between these cherts, independent of color or location, the outcrops are heterogeneous and show varying characteristics, which may be of importance to distinguish between chert sources within the Lower Jurassic formation. These outcrops have been divided in four groups, following the available literature: Cabo de S. Vicente (including Cabo de S. Vicente and Aspa); Foz dos Fornos; Ponta dos Altos; Praia do Belixe (which includes Belixe Sul); and Ferrel.

The Cabo de S. Vicente (CSV) and Aspa (ASP) chert is characterized by abundant nodules in the natural rock banks of the cliffs, appearing as horizontal layers within the parent rock. The banks seem to be mainly dolomite or dolomitic limestones. The process of dolomitization seems to have affected the chert nodules, as they often present different levels of silicification from the edges of the nodule to the interior (which is more silicified), which also affects the knapping quality. The nodules vary in size, ranging from small 4 cm in diameter circular nodules to bed-like groups of nodules of ~20 cm width. At the Aspa outcrops, the nodules are less frequent and smaller. Due to the proximity to the cliffs, the visibility of the chert nodules is good, and in present times, small chunks of chert (without cortex or with small amounts of parent rock attached) accumulate in secondary deposition nearby.

Foz dos Fornos (FZF) and Ponta dos Altos (PdA) show similarities to the CSV outcrops. The nodules are visible in several banks of dolomite, dolomitic limestone and limestone, partially covered by soil. The nodules can be circular, around 5 cm diameter, or wide with nearly 20 cm of width. Despite their size, these cherts are frequently filled with fractures which fragment the larger nodules into smaller volumes of raw material. Alike CSV, FZF and PdA also shows cherts with differing degrees of dolomitization, although in apparent smaller quantities than CSV. Besides the abundant presence of primary outcrops, there are also abundant chert nodule fragments in secondary deposition, down the slope of the cliff (in the case of FzF) or at the top of the cliff, on a sand path (in the case of PdA). These are small, between 1-4 cm of width, but of easy access. Between the FZF chert and the PdA, the main differences seem to be the cortex and parent rock, which show differing reactions to hydrocloric acid, the first being a dolomite or dolomitic limestone, and the second being mostly a limestone, with some degree of dolomitization in certain areas.

Praia do Belixe (PBLX) is characterized by the abundance of chert nodules throughout the dolomite layers of the cliff area. They are visible in certain areas of the cliff and within the rock shelters. The nodules can be small, around 5 cm of diameter, sometimes reaching more than ~30 cm of width, or bedded, as chert layers between the dolomite layers. The cherts show varying degrees of dolomitization, and are mostly characterized by coarse to semi-smooth feel, dull luster and a medium to low knapping quality. Unlike the other outcrops, no chert nodule fragments were found close to the cliffs, and sample could only be recovered directly from the embedded nodules in the cliff walls. Nodules scattered on the floor were only located at Belixe Sul (BLS), a primary outcrop nearly destroyed located on a field, north from the beach area. The chert in this outcrop showed no differences from PBLX, aside from the size of the nodules, which were smaller and often showed signs of post-depositional alterations.

A third location for chert has been previously identified north of BLS. Belixe Norte (BLN) is located on a dirt road and unused agriculture field. Several chert fragments were collected in this location. However, BLN is in proximity to an archaeological site and several collected samples were lithic artefacts. No larger nodules or outcrop were identified in this location. The samples recovered from the location also seem to corroborate that BLN should not be considered an outcrop, as they do not match the local cherts and rather, resemble most the samples recovered from Eastern Algarve.

Ferrel, unlike the other outcrops, is located inland and away from the coast. Due to its location in a homonimous village, the state of the outcrop is poor, and all samples were either recovered as scattered nodules or from larger blocks of rock, from a partially destroyed outcrop. The proximity of an archaeological site nearby also raises questions regarding the nodules found in secondary deposition, as these may be surface finds. Despite these caveats, the recovered samples are similar to those from the other outcrops, albeit with a better quality, being characterized with a shiny to medium luster and smooth to semi-smooth feel. All surface fragments and nodules were small, with around 2 to 3 cm of width which may be explained by the state of the outcrop.

Unlike the outcrops from the Lower Jurassic of western Algarve, this region of the Algarve has only one identified outcrop for Upper Jurassic cherts. These are located at Praia da Mareta (MAR) and abundant, or in secondary deposition at Ponta da Atalaia (PtA). At Praia da Mareta the nodules are only easily accessible in the beach, where large chunks of the cliff (~1 m in diameter) are transported by the waves. Several chert nodules of different sizes can be found in the parent rock washed ashore, ranging between 2 cm to 20 cm in diameter. The quality of the chert also varies, possibly related to different dolomitization stages of the nodules, although this may also be influenced by chemical and physical alterations to the chert. At Ponta da Atalaia the chert can be found atop the cliffs, with rare nodules scattered on the floor. The Upper Jurassic cherts are very similar to the Lower Jurassic, with dull to medium luster and grey/purple colors. The translucency ranges from opaque to areas where the chert is translucent. This translucency may be a significant difference do distinguish between outcrops. Petrographically, the cherts are also similar to the Lower Jurassic ones. The only identifiable difference is the presence of calcispheres. All samples from the Mareta outcrops seen under the petrographic microscope showed the presence of abundant calcispheres, which is not always apparent with the stereomicroscope. Based on the presence of calcispheres, we may also consider the samples recovered at Andorinha (AND) to be Upper Jurassic, which were uncommon and scattered at the top of the cliffs by the beach.

On the eastern part of the Algarve, chert-bearing known formations are from the Middle to Upper Jurassic, known as the Malhão formation and the Jordana formation, respectively.

The Malhão formation chert (dating to the Middle Jurassic) was identified in three outcrops, in the Faro parsish and the Tavira parish. Whenever in a primary outcrop, this chert was homogeneous. The secondary deposits were recent waterlines and slope deposits, and the cherts were often characterized by intense post-depositional alterations. In these cases, it was not possible to confirm the outcrop location. In these outcrops, the nodule frequency varied from common to abundant. The nodules are roundish, ranging between 3 to 5 cm of maximum width. In all cases, access to the outcrops was easy. Although the parent rock was hard, several chert nodules could be collected from the surface, accumulating further down in gentle slope deposits. The Malhão cherts show two differing macroscopic characteristics: pink/reddish cherts and grey cherts. In general, they are both characterized by a dull to medium luster, opaque to sub-translucent translucency and smooth to semi-smooth feel. They are easily identifiable through the high amounts of macroscopically visible inclusions, which look like white speckling in plain sight. Under the stereomicroscope, several round fossils and long spicule-like shapes can be identified. The petrographic analysis shows for the Malhão cherts from Casal da Colina (primary and secondary outcrops) high amounts of dolomite within the chert. All of these cherts are characterized by a wackestone texture and high variety of identifiable fossils (although all poorly preserved and replaced by chalcedony or quartz). These fossils are: Sponge spicules, Radiolarians, Ostracods, Tentaculites (also previously identified by –), Echinoderms and Calcispheres.

The Jordana formation chert (Upper Jurassic) was identified in one area in the Algarve, above Moncarapacho in the Olhão parish. Whenever in a primary outcrop, the chert was homogeneous, although alternated with nodules of other lithologies within the parent rock. No chert was identified in any secondary deposits, which might be related to the anthropic alteration of the landscape. Smaller nodules broken from the parent rock were identified near the primary source in a field. Whenever embedded in the parent rock, the nodules varied in size (~1-10 cm) and were abundant, with a high level of difficulty in their removal, due to the hardness of the parent rock. The cherts show little macroscopic variability between nodule and outcrop. They are grey/brown (with visible yellow inclusions). Within nodule however, the cherts are heterogeneous, with dull and shiny or smooth and semi-smooth feel areas. Some of the nodules also show a variability of translucency, with areas which are translucent, with a very fine grain and little presence of visible inclusions. The petrographic analysis shows that the cherts range from a wackestone to packstone texture, which was already seen macroscopically. They are composed mostly of microcrystalline quartz, with the presence of fibrous chalcedony replacing the fossils and negligible percentages of other minerals. Fossils are poorly preserved in general, with a few being identifiable: Calcispheres, Bivalve shell, Sponge spicules, Ostracod, Echinoderms and Gastropod.

Perhaps add a paragraph about the sources which were marked in the geological map but could not be located.

# 5 Discussion

The prospection works and analyses to the collected geological samples show that the south of Portugal has high potential for raw material studies, especially regarding chert. The presence of chert-bearing outcrops in the westernmost part of the Algarve, center and east would provide several possibilities for sourcing and procurement whenever groups moved throughout the territory. This is further important when we consider the geology of this territory.The geology of the Algarve itself may have played an important part in how groups procured their raw materials, specifically, their chert, a task which has been identified as essential for hunter-gatherer groups. To the south, communities would only have access to chert-bearing outcrops up to the coast. To the north, the mountain range would not only have provided no chert nodules, but may have also hampered the movement of populations, forcing groups to move east and west instead of north or south. This movement may have facilitated the gathering of cherts from different formations within the Algarve, posteriorly then brought into the sites. Especially for Middle and Upper Paleolithic occupations, understanding the sources of chert in the Algarve may provide data about where in the territory they were sourcing their raw materials, and how they were using the territory when their movement was constrained by the Peninsula’s natural barriers. This question remains unanswered, but raw material data and comparative studies between archaeological assemblages and geological samples may provide the necessary results to answer it.

However, tracking these movements and procurement patterns is only possible if the cherts from the different formations and outcrops can be traced back to their sources. This presented itself as a first caveat for this type of studies, since for the Algarve, for example, all cherts come from Jurassic formations in pelagic environments. Despite the similar formation environments, in general there seems to be relevant differences between the cherts of different formations and periods. This is further relevant given the fact that they are geographically distant. Within formations, however, there are no discernable differences, both at a macroscopic and petrographic level, as these do not seem to be useful to distinguish between outcrops. That is most obvious on the Lower Jurassic outcrops of west Algarve. The identified chert groups, which varied mostly in color and fossil content, are present in several outcrops. In this region, the variables which may be better used to understand which outcrops were visited may be the quality and size of the nodules. The latter, for example, is an important variable in the Belixe outcrops, which show the largest volumes of rock, even if the knapping quality is worse than some other available, smaller nodules. Size may be used in conjunction with other technological data, to understand whether different nodules were being explored differently based on their size, or their procurement was being preferred in relation to other smaller nodules in possibly closer outcrops in the region.

The Upper Jurassic nodules of western Algarve also show larger volumes than those from the Lower Jurassic. This, together with the translucency, which is often characterized by sub-translucent fabrics, may be a good macroscopic indicator for the chert’s provenance. However, for a reliable distinction between the Lower Jurassic and the Upper Jurassic cherts, petrographic analyses and the identification of calcispheres may be necessary.

The differences identified between the cherts of the various formations can be seen both at a macroscopic and petrographic level. Given the formation setting, petrographically, all the cherts from the Algarve are fairly homogeneous - marine origin, in limestone or dolomitic limestone rocks, all formed during the Jurassic. The use of fossils for the identification of the cherts is also difficult, since these are often not well preserved enough to allow the identification of species that may connect a group of cherts. The size, frequency and preservation state of the fossils seems to be, then, one of the defining criteria for discerning cherts from different formations, and thus, different geographic areas. These characteristics seem to be observable macroscopically, as well, allowing the cherts from the three different areas and formations - West, Jordana and Malhão - to be differentiated without the need for thin-sections. This is specially important for archaeological collections, specially those which may be small, with small archaeological pieces, or for the study of older collection to which other means of analysis may not be available.

This data seems to confirm the potential of a macroscopic analysis to study the cherts of the Algarve. Albeit applying different methodologies, such as petrographic analyses, to these cherts is a way of completing the petrographic study of a collection, reliably applying mostly a macroscopic analysis to the assemblages coming from southern Portugal helps tackle issues such as the destructiveness, costliness and time consumption of some methods.

The research was able to complete the collection, providing samples of the available cherts which may be compared with archaeological samples. However, there are some caveats to this type of comparative studies. Landscapes have changed through time, specially with the influence of modern societies. House constructions, agricultural fields and roads, for example, have modified the landscape, possibly altering the availability and visibility of raw materials. The existence of chert in specific points in the map may not necessarily mean that they do not exist elsewhere. However, identifying characteristics which are common to most, if not all cherts of a region, may be a good indication that some cherts are not local.

Another caveat regarding chert sources, and specially in a geographic area like the Algarve, is the possibility of some outcrops being submerged. Previous studies have identified the existence of Jurassic outcrops with chert nodules on the west coast, submerged by water. In times where the sea level was similar to the current one, these outcrops would not have been accessible, even during low tide, the only possibility for their procurement in nodules dragged to the shore. However, during periods where the sea level was lower due to water freezing in the polar caps (during the LGM, for example), large portions of the coast would have been accessible. This raises the question whether the chert reference collection is actually representative of all the variability of chert in the region, including the submerged coastal areas. For studies focusing periods like the Proto-solutrean and Solutrean in the Algarve, for example, where nearly 20 km of shore was exposed at the peak of the LGM, there may have been the exploitation of unknown sources or cherts with more variability than that known from the recovered samples. Despite the caveat, this raises the possibility to understand whether this new portion of landmass altered the raw material procurement patterns of these groups, or added new resources which had been previously unavailable. Studies which compare Gravettian and Magdalenian assemblages to Proto-solutrean and Solutrean assemblages, within one single site, may give new insights to this question.

# 5 Conclusion

# 6 Acknowledgements

### 7.0.1 Colophon

This report was generated on 2022-08-31 10:14:24 using the following computational environment and dependencies:

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#> Remote: master @ origin (https://github.com/jbelmiro/article1.git)  
#> Head: [ec61d28] 2022-05-18: - first knit test - Introduction progress