

Discussion

GST Multi-scale Analysis, Challenges and Potential

As highlighted several times throughout this paper, GST are an important key to explore many aspects related to the daily routines of past human populations. Through the study of this type of artifact, it is possible to characterize aspects related to diet, technology, and symbolic behavior. During this research three distinct GST assemblages from three different archaeological sites were analyzed. In all case studies, it was possible to present a significant contribution to the technological characterization of the past groups that occupied these sites during the Middle Palaeolithic.

To efficiently explore the high potential of GST, it was fundamental to consider two major complementary approaches: a) a detailed analysis that interrelates different scales of observation, combined with the implementation of qualitative and quantitative methods of data acquisition, and b) the linking of the archaeological observations with data from experimental reference collections.

For the analyses of the archaeological materials, it is important to start from the general characterization, including the technology and morphometry, and gradually progress to the characterization of the micro use-wear. It is essential that the different scales of observation are complementary to each other to contribute to the complete picture of the materials. In order to include quantitative data in the characterization of the tools at the macro scale, this project explored the use of 3D models of the tools to provide a detailed characterization of their surfaces, in terms of the distribution of the slope angles and their surface complexity by computing the Terrain Ruggedness Index (TRI). By applying these computations to the entire surface of the tools, it was possible to characterize the different typologies at a macro scale and have a general overview on the complexity of the assemblages. However, due to the heterogeneity and variation of the natural morphologies of the tools, this approach becomes very challenging in characterizing smaller scale variation, particularly different types of anthropogenic damage. To overcome the »noise« of the natural morphology of the tools, a small area, restricted to the active areas of the tools,

was sampled to run the same computations, making it possible to characterize and quantify more precisely the active areas of the different typologies.

The 3D models, and the resulting digital elevation models of the surfaces, are valuable tools to quantify the macro alterations of the tool surfaces, but they are not suitable for characterizing the use-wear of the tools as the only method because of limitations in the characterization of the micro alterations, such as polish formation. This reinforces the importance of combining different scales of surface analysis, where the combination of 3D scanning and microscopic imaging becomes a powerful analytical combination to understand archaeological tools.

In the study of Palaeolithic GST, one of the first challenges is to distinguish which alterations on the materials surfaces are caused by human use and which result from natural post-depositional processes. In many cases, this sorting is difficult and is based on qualitative criteria, that in turn are based on singular experiments or empirical observations. Such procedures have been criticized due to the high level of subjectivity and the lack of a solid experimental background.

Therefore, methods have been developed in use-wear analysis during the last decades to help on this crucial task. The location of the use-wear marks on the surface of the tool is very important, showing patterns for the concentration and distribution of the use-wear traces in contrast to the natural wear marks (e.g., post-depositional), that have been assumed to appear in arbitrary locations on the surface of the tool.

Besides location, it is also crucial to explore the combination of macro and micro diagnostic features of use-wear that can be related to and diagnosed with some type of material, and/or different types of actions. Based on the archaeological evidence from the case studies explored in this project, an experimental program to test percussive and grinding motions was developed, including different contact materials. Since high levels of bone fragmentation and flint debitage are documented in considerable frequencies at all archaeological case

studies, the percussive experiments included two different processed materials, flint and bone (Centi/Zaidner 2020; Crater Gershtein et al. 2022; Gilead/Grigson 1984; Goder-Goldberger et al. 2020; Malinsky-Buller et al. 2014; Prévost/Zaidner 2020; Zaidner et al. 2014).

Due to the complexity of polish types identified in the Nesher GST assemblage, a set of experiments dedicated to grinding activities on vegetal matter were developed, where acorns were used in both a dry and moist state in order to explore different conditions. During the analysis of the archaeological materials tools with a specific polish (type C) were identified, with characteristics that seem to have been developed by contact with some product with oily features and some plasticity, which promoted the development of a micro polish which is very penetrative on the low micro topography. Therefore, based on the type of polish identified in previous experiments involving this material, acorns were selected for this experiment. In this sense, these were selected as proxy to explore this hypothesis and understand how this type of product develops use-wear on limestone.

All experimental results were analyzed in a multi-scale approach that helped to explore with a high level of detail the different features that characterize the various types of use-wear traces diagnostic of a particular type of use. Based on the research questions that arose from the variability observed in the archaeological record, the experimental program followed a mechanical design based on two main objectives: 1) differentiating GST from unused items, and 2) in the case of GST, understanding their main functions.

The experiments were designed with standardized and reproducible settings (in terms of effect), with results showing that the use-wear formed on limestone samples used to strike flint is characterized by deeper alterations at a macro scale level compared with use-wear on samples used on impact bone experiments, on which no significant damage was identified. In terms of macro scale perspective, our results show that flint produces much deeper alterations in terms of surface topography, even when used less intensively.

Micro level analysis revealed that while all the materials explored can produce polished areas, the characteristics of the different micro surface features show polish patterns which are considerably different. The bone impact experiments tend to develop polished areas that are more penetrating in

the lower micro topography, with domed cross sections, fluid texture, and more diffuse contours. The flint contact experiments tend to produce polished areas more restricted to the high micro topography, with flat cross sections, rough texture, and sharp contours. The formation of deep abrasive tracks is also very frequent.

During the qualitative analysis at micro scale, we identify overlap in some features of polish formed by the contact with flint and dry acorns, namely in terms of the cross sections, polish contours, and patterns of striations. However, when combining and comparing macro and micro traces, it was possible to clearly distinguish the use-wear formed by those two activities, since flint contact produces high level of macro surface alterations (e. g., fatigue, mineral crushing, and some level of shipping, flaking), while acorns produce almost no macro surface changes. The application of confocal analysis to the micro polish also supports the distinction between these two types of polish, and it was possible to verify that there is no overlap in most of the parameters used for micro surface analysis. This practical case demonstrates once again the importance of combining different scales of analysis and exploring the quantitative tools available to complement the qualitative analyses.

Nevertheless, the experiments reveal that the contact material can be differentiated in terms of use-wear, even when the same type of motion is performed. Being aware of the limitations of the reference collection, since only a few products were tested, it is important to keep in mind that these results should be used as a baseline to help use-wear analysts in the identification of a type of contact material and not a specific material in terms of species, type of bone, or specific rock. In this sense, the experiments on flint were intended to support the identification of traces produced by the contact with a very hard mineral. In the same way, our results of the dry acorn experiment should help in the identification of traces generated by contact with a hard seed, because at this stage we do not know if contact with another seed with similar physical properties would lead to similar results.

These experimental conclusions should be seen as a contribution for the field of use-wear analysis that, along with other reference collections developed by other researchers, should help to equip use-wear archaeologists with methodological »tools« of great importance for the functional interpretation of materials handled by humans of the past.

New Data about Palaeolithic GST in the Levant

The different scales of analysis made it possible to extract different sets of complementary data, that, when combined, allowed a comprehensive characterization of the assemblages studied. In terms of morphometry and typology, the three analyzed assemblages reveal clear differences. Nevertheless, when doing such a comparison it is important to keep in mind the very first and notorious distinguishing feature, which is the size of the assemblages in relation to the frequencies of the tools. Concerning this aspect, Neshet Ramla presents a number of artifacts that is by far the largest amount of artifacts included in this study. Although Far'ah II is a comparatively small assemblage by comparison with Neshet Ramla, the collection of Far'ah II GST is generally not a small assemblage within the MP context. Regarding the frequency of finds, it is important to remember that the assemblage of Ein Qashish is very small by comparison with the other previously mentioned sites. With these differences in mind, it is possible to start comparing the data itself resulting from the different analytical approaches.

The first significant element of similarity between the case studies is the presence of limestone as the predominant raw material within the GST assemblages. However, there are some variations in the type of limestone, where Neshet Ramla and Far'ah II have a harder limestone and the limestone of Ein Qashish tends to be softer, as indicated by the level of surface erosion on most of the tools analyzed. This can be a possible explanation for the higher level of general surface erosion observed on the tools from Ein Qashish compared with the other sites. However, the limestone tends to be generally homogeneous within each assemblage.

There is a clear difference in the morphometric patterns of the tool supports, where Neshet Ramla presents a considerably more homogeneous pattern than the other two sites, where the assemblages are much more heterogeneous in terms of size and shape of the tools. These general differences are confirmed by the data from the 3D analyses. When moving to a finer scale of observation using microscopy, it is possible to verify that the assemblage of Neshet Ramla is very complex in terms of the different types of wear associated with anthropogenic actions. All of the assemblages present a very high percentage of tools with evidence of having been used, where in the case of Ein Qashish and Far'ah II the percentages are higher than 80 %. In the case of Neshet Ramla, this number drops to 53 % due to the higher num-

ber of identified manuports ($n = 224$). Neshet Ramla presents the larger diversity of both impact marks and development of micro polish, where different types of micro wear were associated with different activities and contact materials. Specifically, in terms of the micro scale, it is possible to see that Neshet Ramla presents several tools with the development of the micro polish, while micro polish is rare in Far'ah II and absent in Ein Qashish. The higher diversity identified in Neshet Ramla in terms of use-wear is also reflected in a wider range of typologies, although the distribution of use-wear traces is not uniform across the typologies, as in the case of hammerstones, where it is possible to identify a greater variety of impact marks and polish types. Again, however, the differences in frequency should be considered before proceeding to further explanation of this scenario. Another important aspect to consider when comparing the presence of micro polish between sites, is the degree of preservation of the tools, with this consideration being particularly important in the case of Ein Qashish, where the tools exhibit a significantly higher degree of surface erosion compared to the other assemblages. In other words, it is possible to say that if there are use-wear marks on the tool, these marks can be interpreted and associated with past human actions, but if a tool has a surface without marks, in many cases it is not possible to be sure that this represents an absence of past use: absence of use-wear is not evidence of absence of use. Other possibilities should also be taken in consideration in the debate, such as the possibility of erosion of the marks by natural elements, or a limitation in current observation methods.

This study provides a solid combination of data that has brought to light two levels of new data. First, it clearly identified a large number of tools with solid evidence of past human use, and second, it characterized these tools at different scales, allowing the identification of different types of use. The development of a dedicated experimental program supports an important part of the use-wear characterization and helps to test the interpretations of mineral contact and bone contact. Based on the experimental result, it is now possible to present these interpretations with solid support. The experimental program also included the grinding of acorn seeds in order to learn about the use-wear formation associated with this type of product on limestone. This series of experiments represents the first attempt to find an explanation for one type of polish identified at

Nesher Ramla, which is clearly different from those associated with bone and flint. But the experimental results in this case are inconclusive. This emphasizes the importance of continued experimentation to test more products and increase the experimental sample size.

The Nesher Ramla site presented an exceptionally high amount of GST, which is different from that registered for most MP contexts. From these GST different types of traces were documented. In the MP of the Levant and beyond, these tool types normally appear in low frequencies and almost exclusively in open-air sites. This raises the question of the relationship between GST technology, site function and settlement pattern. To answer this question, it is fundamental to understand the activities in which the GST were involved.

The multi-scale approach applied here allows the characterization of surface alterations at different scales. This approach is based on the principle that different levels of magnification must be included in a complementary workflow to fully understand the tools (Marreiros et al. 2020a). Analysis of the entire surface of the tool was crucial to identifying the artifacts which presented a high potential for micro use-wear preservation. Nevertheless, it should be taken into account that some activities can leave traces which are not detectable at all scales of observation. Some activities produce different types of polished areas that can only be observed at a microscopic scale (so-called high-power approach).

This study shows that pebbles and cobbles of different sizes were used as tools without any preparation, performing the activities directly on their cortical surface. The preparation of an irregular »edge« with low level of symmetry was also observed on some tool types (i. e., chopper-like tools), apparently intended to perform some tasks related to percussive activities on bone, according to the interpretation of use-wear.

The identification of macro and micro traces allowed a detailed characterization of the assemblage. Nevertheless, it is important to stress that macro traces were identified much more frequently than micro traces in all the assemblages analyzed. The overlap between macro traces (e. g., impacts) and micro traces (e. g., polish) rarely occurs in this assemblage. Most of the tools where micro polish has been identified do not show any conspicuous macro alteration. This feature is of particular interest because it may indicate variability in individual tool use not only in terms of materials processed but also in terms of types of actions/motions.

From use-wear studies, macro and micro wear traces are known to vary with both kinematics and the processed material (Adams 2014). Macro traces are influenced not only by contact material, but also by the way the tool is used (e. g., striking vs grinding or cutting vs scraping). On the other hand, in addition to the kinematics and the raw material of the tool, micro wear traces are largely affected by the contact material (e. g., flint vs bone).

Hammerstones and anvils are the most common type of artifact that was identified and characterized in the assemblages analyzed in this study. The anvils tend to be smaller at Far'ah II, in contrast to Ein Qashish where the largest was documented. Nesher Ramla shows a considerable variation in terms of the metrics for this artifact category. However, it is important to keep in mind, the large difference in the frequency of this type of artifact, when comparing Nesher Ramla with Far'ah II and Ein Qashish, which is an obstacle to presenting comparative conclusions based on metrical patterns (fig. 105).

Regarding hammerstones, the metric variation is not significantly different between the tools found at Nesher Ramla and Far'ah II. The single hammerstone from Ein Qashish is larger than the majority of the tools in this category from the other two sites, but once again, since it is a single occurrence, no further comparisons are possible (fig. 106).

Processing of Organic Materials and Their Implication on Subsistence

Microscopic analysis at low and high magnification shows that at Nesher Ramla many stone materials were used for different types of actions, mainly for activities involving impact and abrasion motions. Use-wear traces identified on hammerstones and choppers reveal actions involving bone contact, which may represent bone breaking. Bone breaking for marrow extraction can be explained by its nu-

tritional importance, since marrow has a high level of calories, fat, protein and vitamins, namely B12, E and A (Hassan et al. 2012). Different types of tools were identified with use-wear related to bone processing. This observation confirms the archeozoological analyses of the other units at the site (Crater Gershtein et al. 2022). The tool morphological variability at Nesher Ramla may indicate two different types

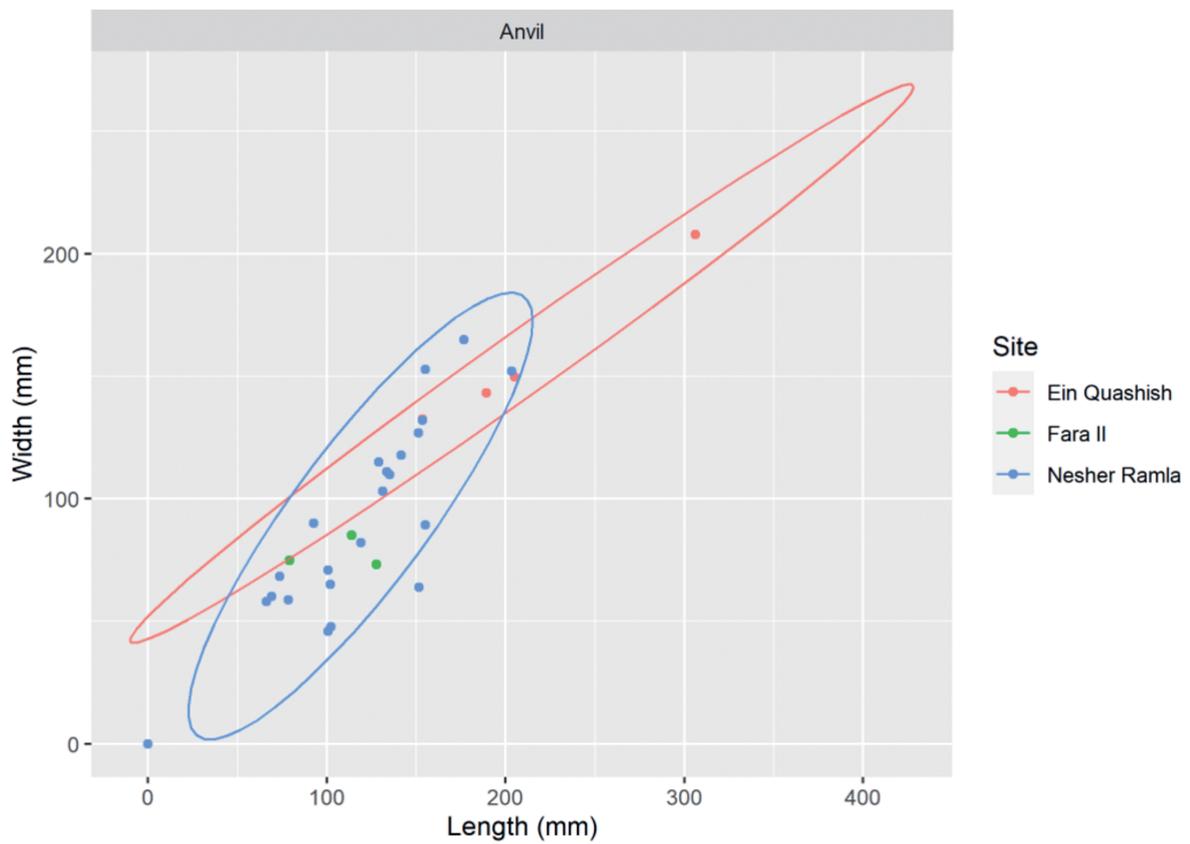


Fig. 105 Scatterplot showing the anvils metric distribution per site. – (Graphic E. Paixão).

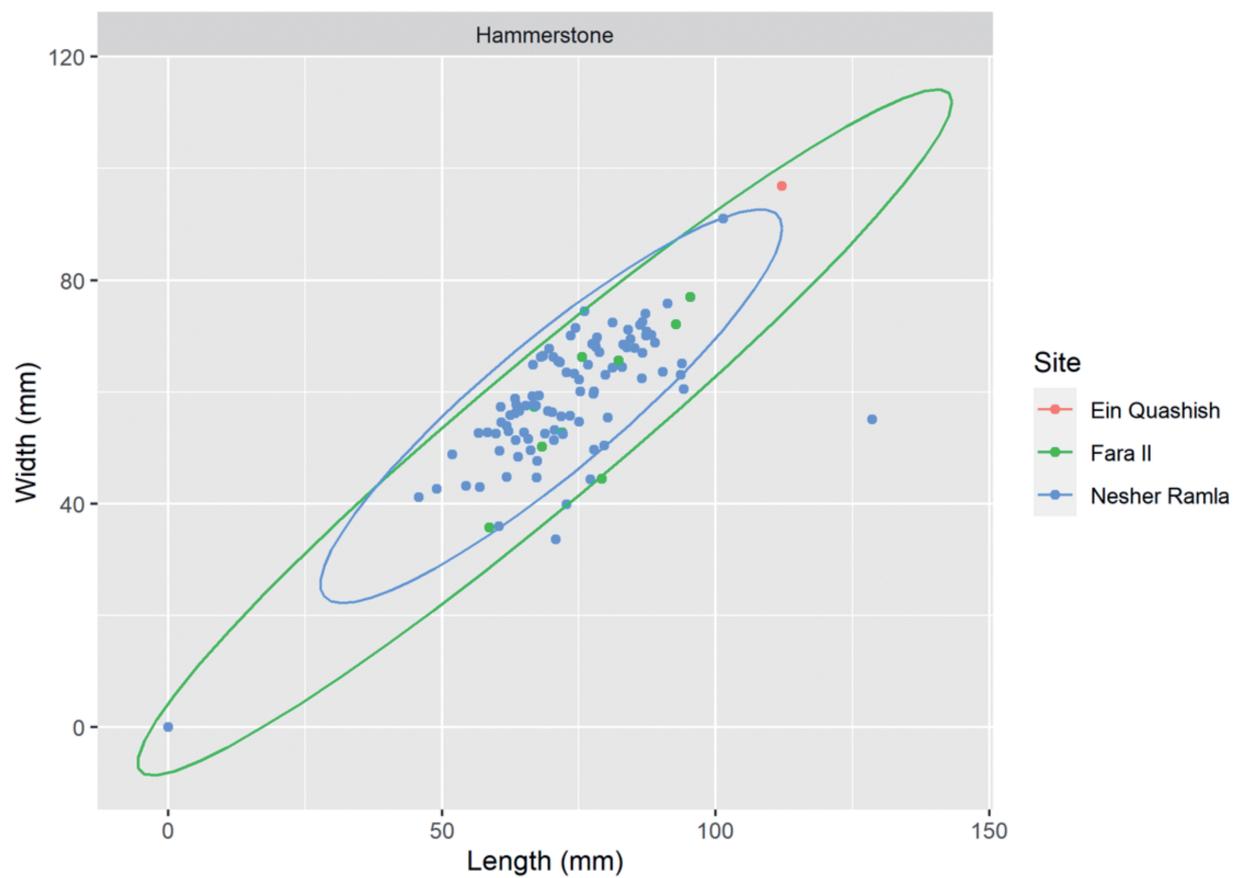


Fig. 106 Scatterplot showing the hammerstones metric distribution per site. – (Graphic E. Paixão).

of activities involving bone processing, or alternatively the processing of different types of bone (e. g., anatomical parts or species). Some tasks required the preparation of an edge, i. e., choppers that show polish associated with bone contact. This polish is also present on unprepared tools such as hammerstones.

Other activities such as the processing of plants, wild grains, or fruits, should not be completely excluded, as suggested by the presence of use-wear traces categorized as type C. This type of wear is observed on tools with no or a limited number of impact marks. However, it shows features such as micro polish and striations, indicating contact with a soft and flexible material, which allows the polish to develop in the lowest micro topography. Some characteristics of the polish, such as the deep penetration into low micro topography, suggest that some wear was caused by contact with oily products (e. g., pistachios, acorns, nuts). Although further experiments should be conducted in the future to test this hypothesis in more detail, it is worth noting that evidence for the use of this type of product has been recovered from sites dated to the Lower Palaeolithic, such as Gesher Benot Ya'akov (Goren-Inbar et al. 2015), as well as from MP contexts (Akazawa 1974; Lev et al. 2005; Madella et al. 2002; Rosen 2003). The preparation of these types of oily products for consumption using GST has been demonstrated in several ethnographic studies around the world (Driver 1961; Hudson 1976; Robitaille 2016).

The hypothesis of plant, wild grain, nut, or fruit processing should be further explored in the future by increasing the range of experiments with different materials and movements. It is important to keep in mind that no matter how detailed, extensive, and controlled experiments are, they can never cover all the possibilities of past activities. However, they are

one of our best tools for understanding past tool use. In this sense, investment in experiments is always crucial in use-wear research.

At the site of Ein Qashish, the possibility of nut cracking activities is strongly suggested by a large passive tool with a circular depression. But due to the lack of micro polish preservation, it is difficult to prove this hypothesis. The assemblage from Ein Qashish also suggests the possibility that bone marrow extraction was part of the routine at the site, where large stones were probably used for breaking bones of large mammals.

At Far'ah II the possibility for bone breaking is not excluded, but no evidence of the use of other organic materials was found during this study.

Specifically regarding bone breaking activities, this study suggests that different types of tools were used for this task, including hammerstones, anvils and choppers. The hammerstones consist of the use of tools with no preparation, while the choppers are tools with a rough angle with some degree of damage on the edge.

This study associates these chopper tools with bone contact activities, mainly due to the fact that at Neshar Ramla choppers were identified with some micro polish formation associated with bone contact, together with macro damage related with impact motions but with topographic characteristics far from those observed during the experiments with mineral materials. This category of tools, although often in low percentages when compared with hammerstones, were present in all the case studies included in this project. This phenomenon suggests that these tools could represent a solution for a common need among the Middle Palaeolithic communities, which can be related with some specificity of the bone breaking process (fig. 107).

Processing of Inorganic Materials – Just Technology or Something Else?

At all the sites studied, materials with traces associated with mineral contact activities were identified. At Neshar Ramla many hammerstones are associated with knapping activities, with some tools probably used for retouching activities. Other mineral contact activities such as ochre processing are not excluded. This specific question should be addressed in further studies, which could combine the use-wear presented in this study with residue analysis. Although ochre processing can be associated with non-functional and symbolic behavior, it can also be related to technological aspects such as hide treat-

ment (Dubreuil/Grosman 2009). The importance of ochre processing among contemporary hunter-gatherer groups has been demonstrated by ethnographic research (Hayes 2015), and should be further explored for the Middle Palaeolithic GST.

At Far'ah II the possibility of ochre manipulation/processing is suggested by the presence of a tool with impact marks and crushing evidence in associated with iron oxides concentrations. The natural presence of these oxides should be considered as a possible scenario, that could complicate interpretation. However, this element in correlation with macro and

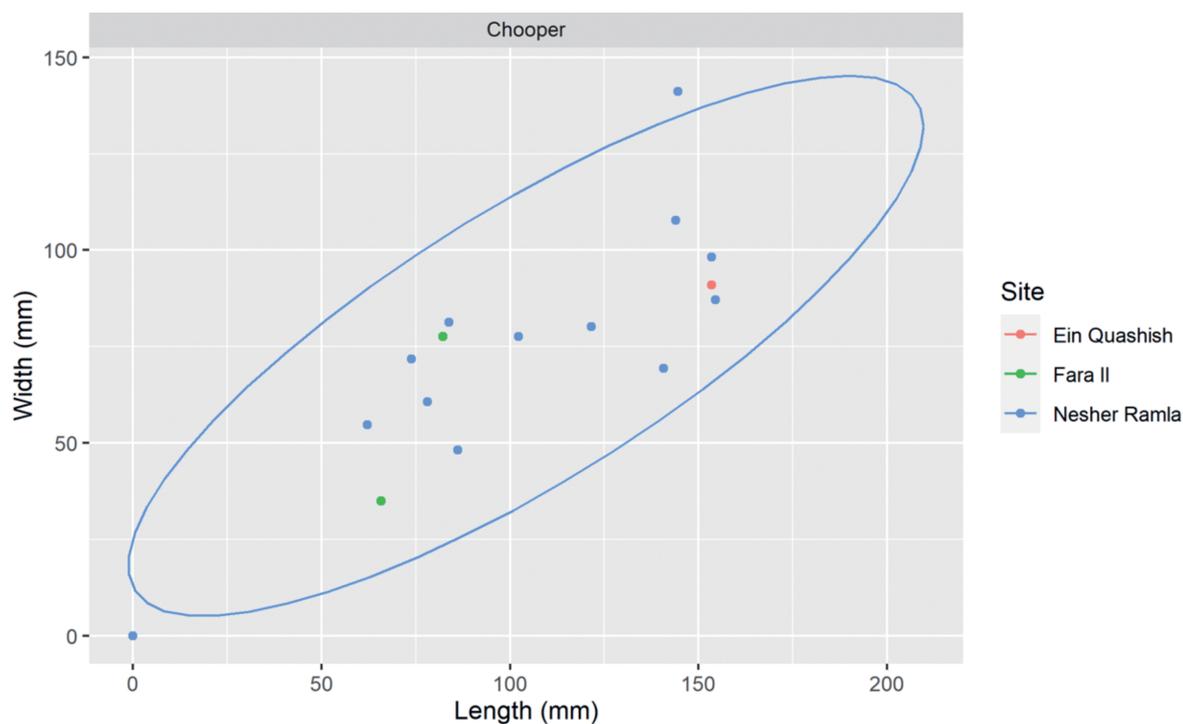


Fig. 107 Scatterplot showing the choppers metric distribution per site. – (Graphic E. Paixão).

micro traces allows the assertion that ochre processing should be considered a very likely possibility. Relating the possibility of ochre processing to some

kind of symbolic behavior is a completely different level of interpretation, and in this case, there is not enough evidence to clearly point in that direction.

Implications for Future Research

Throughout this manuscript, the importance for multi-scale analyses that combines qualitative and quantitative data has been emphasized. This project stands as an example of the importance of taking these different approaches and combining them.

The development of experiments is crucial in use-wear studies, and the research on GST is no exception to that rule. Once again, different approaches to experimentation should be complementary, in this case namely manual and mechanized experimentation. While the manual experiments are important to reproduce activities and to understand the main aspects of the activities, the mechanized experiments represent a possibility to establish a high level of reproducibility and control of the variables involved in a certain action. In this research the main focus was on the functional study of limestone materials. Different actions and contact materials have been studied and presented with objective data, which have been crucial for the interpretations presented and can also support other researchers working in this field.

This project has provided some interpretations for the presence of limestone artifacts in the contexts studied, but it has also raised several questions that may provide important lines of research for future investigations on this topic. One example is the presence of bone contact evidence in tools that are quite different, namely tools without any prior preparation and tools with flake removal prior to their use. The breaking of bones is the main proposal to explain the presence of both categories, but the reason for this techno-typological difference deserves further investigation. This could be achieved by developing further experimental programs that include limestone tools with edges, and by including other activities related to bone processing in the experimental program.

The methods explored here can and should be improved upon in the future, but they represent a solid foundation that contributes to future studies of GST, especially from MP contexts. It is important that more raw materials and activities are explored in the future, to enlarge the reference collection which is always the basis for strong functional analysis.