

Breaking Metals

Quantification and Interpretation of Bronze Fragmentation in Bronze Age Italy and Europe

ABSTRACT

This article explores the phenomenon of bronze fragmentation in Bronze Age Italy and Europe, focusing on the quantification and interpretation of metal breakage practices. The intentional fragmentation of bronze objects from the Middle Bronze Age onwards has been interpreted through ritual, utilitarian, and economic lenses. This paper reviews existing classifications of fragmentation methods and their interpretive implications, proposing an alternative proxy to assess the purpose of fragmentation: weight analysis as a null hypothesis. By applying quantitative methods, such as metrological analysis and statistical evaluation, this study offers a comprehensive understanding of fragmentation processes and their socio-economic implications. Drawing on data from hoards across Europe, the article argues that bronze fragments, often shaped to specific weight standards, may have functioned as money, aligning with the development of weighing technologies.

KEYWORDS

Bronze Age hoards | fragmentation | scrap hoards | Bronze Age money | economics

Hoarding and Fragmentation Studies: A Brief Overview

The practice of depositing metal objects, particularly copper-alloyed, emerged prominently in Europe during the late 3rd millennium BCE and continued into the 2nd millennium BCE (Peroni 1994; Bradley 2013). The hoards contain objects intentionally buried together, and their interpretation has been the subject of extensive debate, with scholars' views primarily divided between ritual and utilitarian explanations (Bradley 1990; 2005). The phenomenon of hoarding is made even more enigmatic by the appearance, around the middle of the 2nd millennium BCE, of the practice of fragmenting deposited objects (Brandherm 2018; Hansen 2016; Huth 1997; Nebelsick 2000).

The systematic study of metal fragmentation across Europe reveals regional variations and temporal shifts. For instance, in Central and Southern

Europe, fragmentation practices became widespread during the Middle/Late Bronze Age (Hansen 2016; Lago 2020). Starting from the mid-2nd millennium BCE, single-class hoards became increasingly rare (Neumann 2015; Lago 2020), making it harder to find coherence in the mixture of different objects collected together (Wiseman 2018). Only rarely does this operation appear convincing, while in larger hoards, there often seems to be a heterogeneous collection of objects with varying degrees of fragmentation. The increased fragmentation and changing patterns of hoard compositions – moving from complete objects to fragments and from single-class to multi-class hoards (Neumann 2015) – may suggest shifts in metal circulation, possibly tied to evolving trade practices (Primas 1997), changes in ritual practices (Brück 2006), increasing consumption of met-

al with related metal recycling (Wiseman 2018) and several other possible explanations.

While trying not to oversimplify such a complex topic, we can attempt to group the various interpretations given over almost 150 years of study into three main hypotheses to explain the phenomenon of fragmentation and, in some way, the phenomenon of hoarding itself.

The Ritual Hypothesis: This theory suggests that the intentional fragmentation of objects was part of a ritual to erase their functional value and transform them into offerings for deities. The manipulation of bronze items – such as bending, twisting, or burning – could be seen as an act of »killing« the object. This approach posits that the objects' destruction was a symbolic gesture, marking a transition or serving as a sacrifice, and thus, objects were not meant to be retrieved once deposited.

The Recycling Hypothesis: This perspective views the hoards as temporary metal stores intended for recycling by metalworkers. Broken objects or

metal scraps found in hoards could indicate these were »founders' hoards« – collections meant for future melting and reuse. This theory also contemplates the practical aspects of transporting and recycling bronze, suggesting that objects might have been fragmented to fit transportation needs or to prepare them for melting processes.

The Money Hypothesis: Some scholars propose that fragmented metal objects served as a form of currency. According to this view, objects were broken down into pieces of specific weights to facilitate trade, reflecting a widely accepted economic value.

Some authors – and I agree with this contention – believe that these explanations are not mutually exclusive (Bradley 2005; Brandherm 2018). Hoards could simultaneously serve ritualistic, utilitarian, and economic purposes. For example, bronze fragments might circulate as money but could also be deposited in a ritual context or melted down to produce new objects, indicating that the functional and symbolic uses of metal were often embedded.

Breaking, Fragmenting, Damaging, Portioning: Towards a Shared Methodology to Classify Fragments

In recent years, interest in the study of fragmentation practices has intensified, as evidenced by the conference held in Mainz in 2023. The increase in studies has inevitably led to the need to more clearly define what is meant by fragmentation, breaking, damaging and all other terms that were more or less used interchangeably in the literature of the last century.

There are several proposed classifications of fragments. Among the most influential studies on the subject are probably those by Ch. Sommerfeld (1994), B. Rezi (2011), and M. G. Knight (2021). All these authors agree that it is important to distinguish between deliberate fragmentation and non-deliberate fragmentation, where non-deliberate fragmentation refers to that caused by the use of the objects.

The criteria used to establish this, however, are slightly different and require varying levels of observation. According to the classification by Sommerfeld (1994, 32), one must distinguish between unintentional fragmentation due to the use of objects (*funktioneller Bruch*); ritual fragmentation, which includes items shattered, destroyed, broken, and with traces of prolonged exposure to fire (*ideeller Bruch*), where the objects are partially or completely reconstructible, with the aim of preventing the profanation of metals once deposited; and material fragmentation, which includes items broken, cut with chisels, bent, or shattered (*materieller Bruch*), where the objects are no longer reconstructible and the goal is to reach specific weight standards.

The classification by Rezi (2011) is more focused on the intensity of fragmentation, which to some ex-

tent would also explain the function of the fragmentation itself. The lowest intensity of fragmentation is found in damaged objects. These are not necessarily broken but have been subject to twists or blows that cannot be explained by normal use and are therefore intentional. The categories of broken and destroyed objects are distinguished by the intensity of fragmentation. While some broken objects could result from the object's use, destroyed objects have always been intentionally fragmented. The latter, in fact, are often broken into multiple pieces and do not allow for the reconstruction of the original object.

The most recent classification proposal is the one suggested by Knight in various articles (e.g. Knight 2021 and this volume). The author has created a well-structured classification grid for fragments (Damage Ranking System) that, through observation of the fragments, allows for categorizing them into one of the proposed categories and hypothesizing the nature of the fragmentation. It is a very detailed grid, and therefore, reference is made to the original articles. In an attempt to simplify, I propose a summary of what the author suggests: bending, twisting, notching, and breaking can always result from either voluntary or involuntary actions. To determine the intentionality or randomness of these events, careful observation of the objects is required. Break-

age due to use can be suggested by wear traces and the characteristics of the break itself (e. g. at points of structural weakness, production flaws, bending not associated with other signs of damage); definite intentional breakage is indicated when extreme bending is associated with damage, notches inconsistent with the object's use, or twisting on objects not usually subjected to such treatment. Between these categories, there is a broad overlap that includes objects likely broken intentionally, where the intensity of twisting and bending, as well as the depth of notches, suggests deliberate actions.

Although these are different classifications, the intensity of fragmentation seems to be a common and important parameter for determining the intentionality of the action, and the shared idea is that deliberate fragmentation can serve both ritual and utilitarian purposes. While the proposed classifications may be quite accurate in determining the intentionality of fragmentation, it must be said that they provide little insight into the purpose of the fragmentation itself. Therefore, while we can consider that the search for proxies to indicate intentionality or non-intentionality has reached a good degree of reliability, the same cannot be said for the search for proxies that indicate whether the fragmentation was ritual or utilitarian.

Breaking Marks are Unreliable Proxies for Determining the Purpose of Fragmentation

The information derived from the types of fragmentation is, in my opinion, sometimes biased. In my presentation at the conference held in Mainz in November 2023, I did not include slides on the experimental archaeology of bronze fragmentation. However, during the interesting discussion slots, the importance of insights gained from metal fragmentation experiments was repeatedly emphasized. For this reason, before resuming the discussion on fragment classification, I shall briefly touch on some observations I made while fragmenting the objects.

In June 2021, I carried out an archaeological experiment with some colleagues that included:

- The experimental production of 20 bronze sickles.
- The production of equal-arm balances and balance weights consistent with those attested in the Bronze Age.
- The breaking of the sickles using chisels, axes, and hammers after heating them in a fire, with the goal of obtaining fragments of the same weight as the balance weights.
- Weighing on equal-arm balances while noting the perception of weight equality/inequality.

The results of the experiment and the data have been published, and reference is made to the orig-

inal article (Lago et al. 2023). However, many other unexpected results emerged. My colleagues and I found that – just as correctly highlighted in other studies (Knight 2017; 2019) – breaking bronze without properly heating it first is very difficult, even for thin objects like sickles. Handling red-hot objects and striking them with the intent of breaking them can generate a number of other unexpected fragments caused by the impact. Additionally, it often happened that we damaged the object without successfully breaking it on the first attempt. The marks from these failed breaks remained clearly visible once the bronze had cooled. Even though we assume that the skill and experience in handling metal that people in the Bronze Age had is incomparable to that of myself and my colleagues, it is impossible not to notice a certain similarity between the results of our mistakes and some of the archaeological artefacts found in hoards (e.g. Stein 1979; Sommerfeld 1994; Gabillot 2000; Toune 2014; Nowak et al. 2019).

In particular, during the attempt to break some sickles that were not sufficiently heated, the blows caused the object to bend but not to break (**fig. 1**). In other cases, the attempt at fragmentation resulted in notching of the object, leaving clearly visible blow marks (**fig. 2**). Some of these marks are attested in Bronze Age objects from hoards and are often interpreted as evidence of ritual activity, with the argument that, having no apparent practical function, this type of fragmentation or damage can only be ritual (Nebelsick 2000; Gabillot/Lagarde 2008; Rezi 2011; Bietti Sestieri et al. 2013; Dietrich 2014; Tarbay 2022).

While not denying that they can also actually result from fragmentation occurring in a ritual con-

text, I would like to point out that such outcomes can also be accidentally achieved. Consequently, the observation of similar traces on objects cannot be considered definitive proof, but rather circumstantial evidence.

Since the treatment of objects is not a reliable proxy for distinguishing between utilitarian and ritual fragmentation, researchers mainly rely on qualitative observations such as:

- The context of the deposition (when available).
- The type of objects contained in the hoard.
- The observation of specific traces on the objects that are believed to indicate the reason for the fragmentation (e.g. supposed ritual traces such as fire marks presumably linked to ritual activities; extreme degree of twisting and fragmentation; blocked socketed axes, etc.).

This inevitably leads to speculative and sometimes contradictory arguments. For example, while one might assume the »cultic« nature of certain sites (mountain peaks, river courses, sanctuaries), it is rather difficult to establish the »non-cultic« nature of all other locations. Indeed, many reasons – beyond our understanding – could have contributed to making a place »sacred« in the past, just as they do today. Likewise, a scrap hoard from a settlement should not necessarily be considered a foundry stock (Bernabò Brea/Cavalier 1980; Borgna 2021). Additionally, a large part of the hoard dataset unfortunately comes from old and unsystematic excavations, or even from the antiquities market or museum collections, making it impossible to obtain reliable information on the find contexts.

From Qualitative to Quantitative Analyses: In Search of New Proxies

The proposed classifications for fragmentation are useful for the autoptic study of materials and can certainly provide valuable insights in a context-by-context approach. However, to study fragmentation using the vast bibliography of already

published hoards, it is necessary to use an even simpler classification, applicable to all or a significant portion of the published material.

In order to quantify fragmentation across various periods and regions of Europe, we limited our

Fig. 1 Experimental bronze sickle replica made as part of an archaeological experiment. – **A** Sickle replica as cast. – **B** Failed attempt at fragmentation after heating and striking with a wooden hammer. – **C** Fragment obtained after reheating and striking with a chisel. – **D** Remaining fragment of the sickle. – (After Lago et al. 2023; photo to M. Cianfoni). – Scale 1:3.

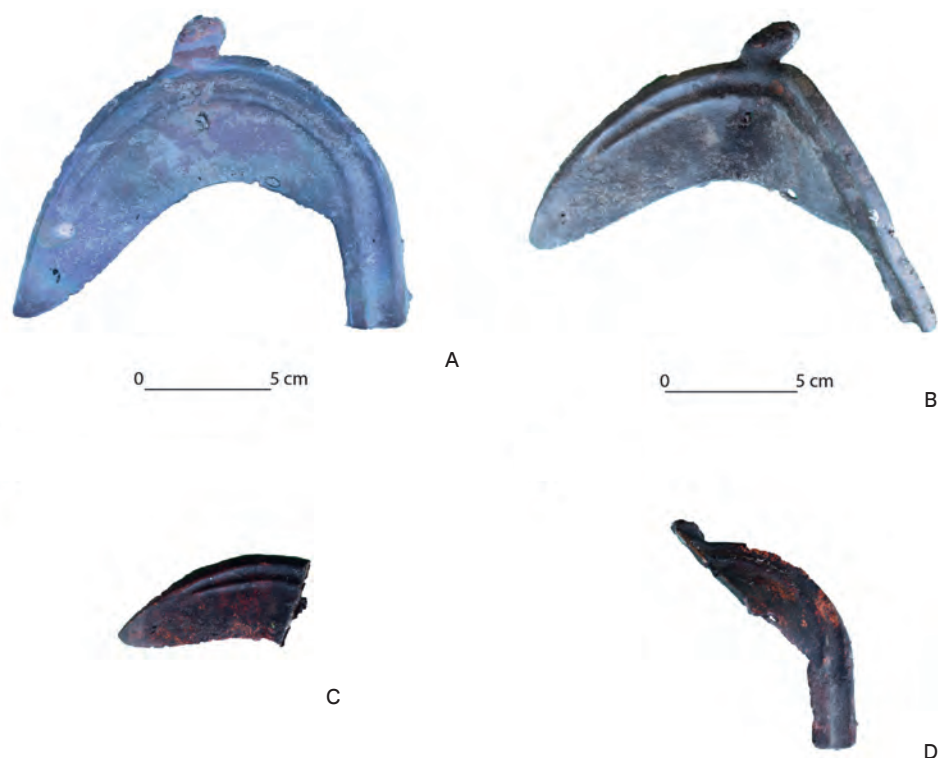
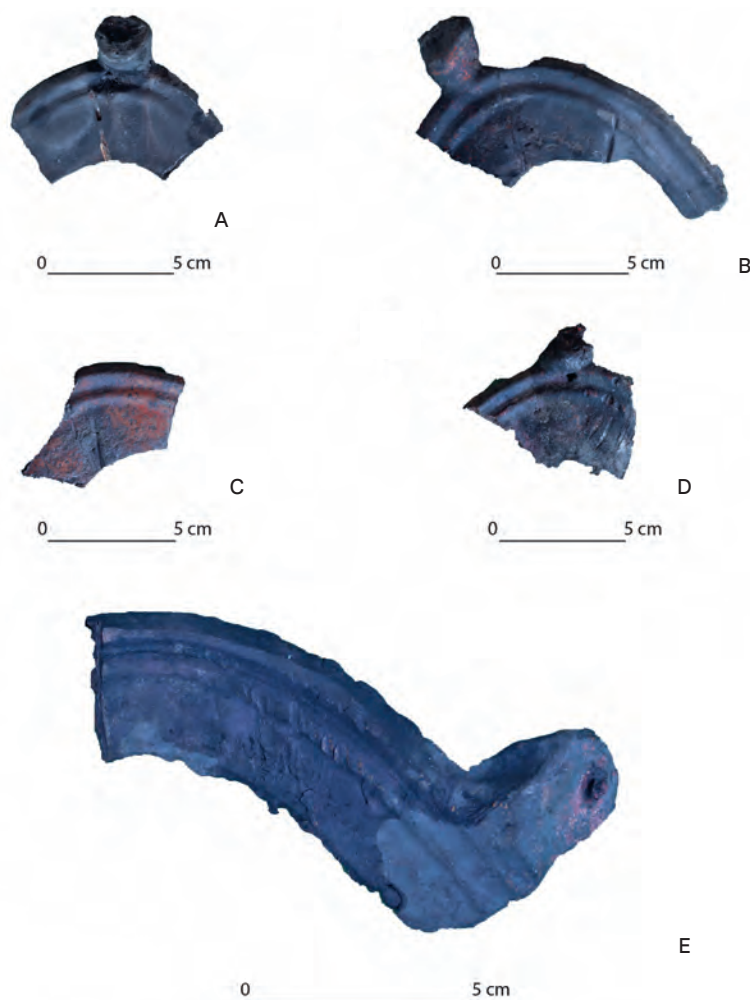


Fig. 2 Blow marks and notches accidentally produced during experimental attempts to obtain weight-regulated fragments from sickles. – (After Lago et al. 2023; photo M. Cianfoni). – A–D scale 1:3; E scale 3:5.



analysis to count whole objects, fragments, and matching fragments. This allowed us to gather a large amount of data to trace the spread of object fragmentation as a social and economic phenomenon during the Bronze Age (Lago 2020; Ialongo/Lago 2021; 2024).

The disadvantage of this approach is quite evident when it comes to characterizing the possible biographies of objects, losing any detail in terms of observations on use-wear and, especially, on the intentionality of the fragmentation itself. On the other hand, the advantages should not be underestimated, particularly in terms of the ability to collect significant amounts of data and perform statistical analyses using replicable methodologies.

From quantitative analyses made on several European countries (Lago 2022), we can now affirm that:

1. Fragmentation became relevant in the European Bronze Age at least by the Middle Bronze Age (fig. 3).
2. The fragmentation phenomenon appears to have similar characteristics in Central Europe and Italy.
3. No class of material is spared from the phenomenon of fragmentation (fig. 4).

4. When quantified, certain treatments – such as bending, twisting, or torsion of objects, signs of exposure to fire, folding (all classified as »damaging«) – as well as the presence of matching fragments, are very rare, generally below 5 % (Lago 2020; 2022, 202 figs 4–5).

These results can be considered descriptive and open to various and opposing interpretations. For example, can the pan-European spread of fragmentation be seen as evidence of shared cultic behaviour or as proof of the shared use of fragments as a medium of exchange in Middle and Late Bronze Age Europe? Could the apparent lack of selection in the collection and deposition of objects be interpreted as a deliberate choice somehow linked to the increasing rate of metal recycling, or is it evidence of the participation of different social groups in the rituals of fragmentation and deposition of hoards? Could the low rate of particular and seemingly non-functional »damaging« practices be related to a distinction between ritual scrap hoards and founders' hoards?

None of the proposed quantifications provides a definitive answer to these questions. However, there is one kind of data that may help us: the weight of the fragments.

Testing Theories: Metrological Analyses to Test the Null Hypothesis

So far, we have discussed the difference between ritual and utilitarian purposes. Two possible and alternative utilitarian purposes for fragmenting are those related to metal recycling (i. e. fragmentation carried out during the recycling process, or in anticipation of it to facilitate the collection and transport of fragments) and those related to breaking metal to fit certain weight standards. The latter function, which we could define as economic rather than purely utilitarian, does not explain the reasons for hoard burial, which could be either temporary or ritual (on this topic, see also de Marinis 2019). However, it has the significant advantage of being testable using statistical methods.

Ritual fragmentation and utilitarian fragmentation aimed at recycling, along with the intentionality of fragmentation, share the common assumption that the size and weight of the resulting fragments are unpredictable (Wiseman 2018). In the case of ritual fragmentation, one would expect to find completely random fragments. Given the »aimless violence« to which the objects are subjected (Nebelsick 2000), it is unreasonable to expect any dimensional or weight pattern. In the case of fragmentation aimed at recycling, we might expect fragments no larger than the size of the crucible, or perhaps we might think that the fragments actually recycled are those broken off from the object found in the hoard.

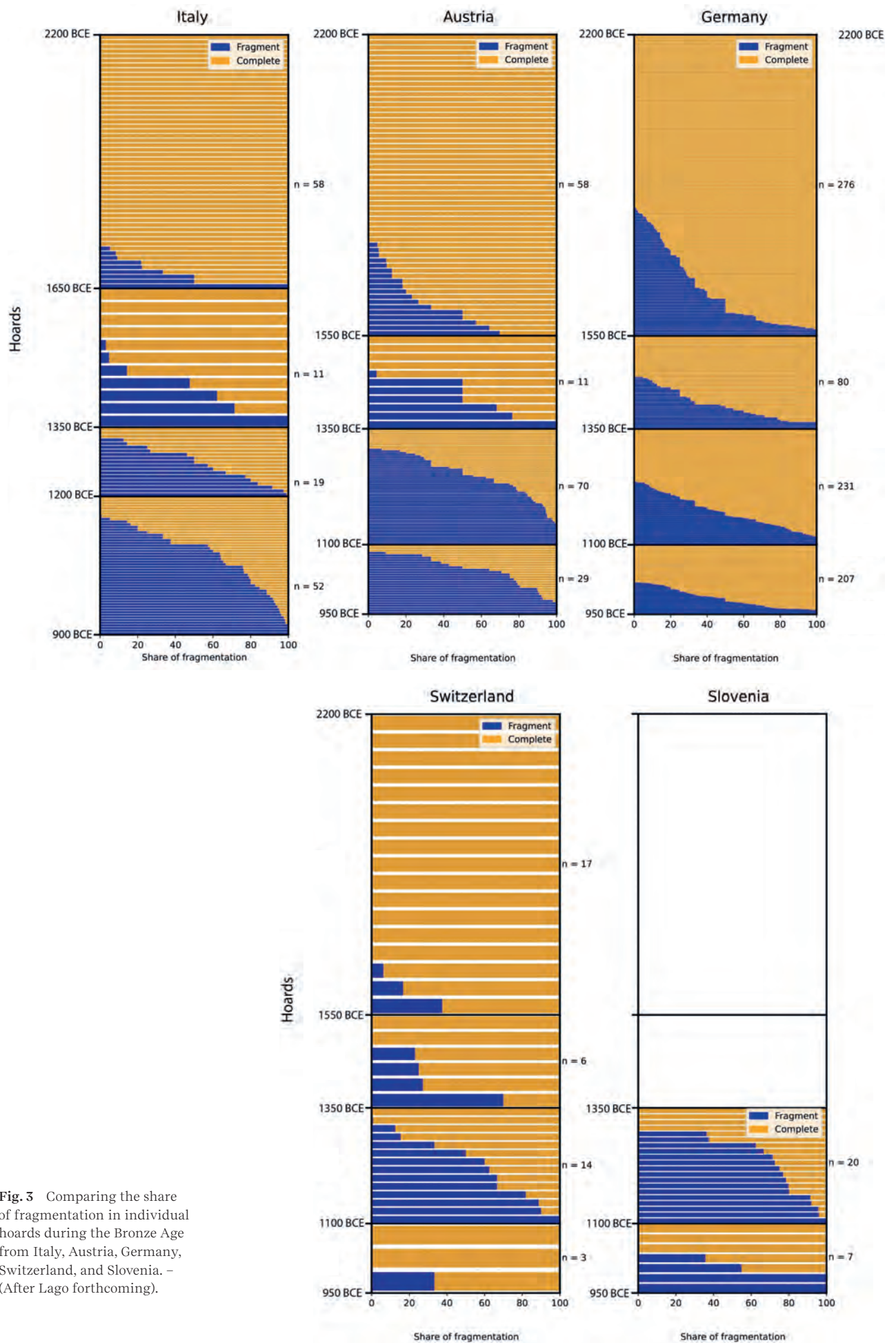


Fig. 3 Comparing the share of fragmentation in individual hoards during the Bronze Age from Italy, Austria, Germany, Switzerland, and Slovenia. – (After Lago forthcoming).

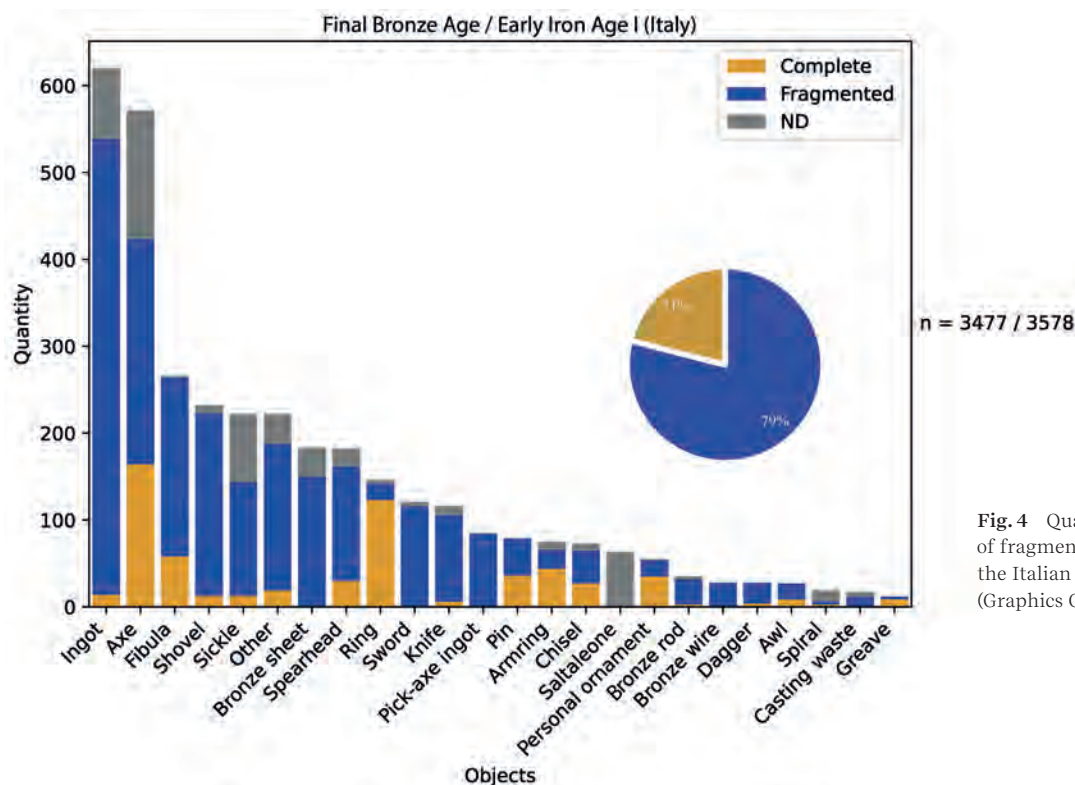
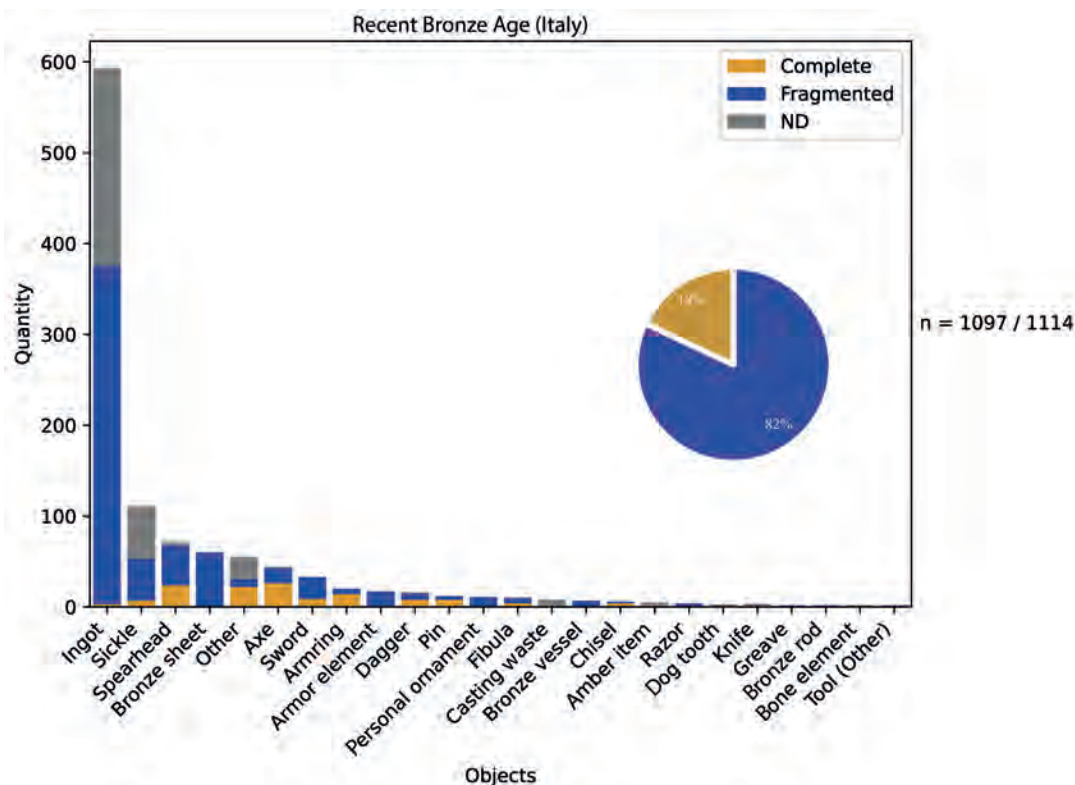


Fig. 4 Quantity and type of fragmented objects from the Italian Late Bronze Age. – (Graphics G. Lago).

In both cases, it is highly unlikely that the pieces would exhibit any weight regularity.

Therefore, the consistency of fragments' weight with any metrological pattern is evidence that sig-

nificantly reduces or rules out the possibility that the fragmentation had any objective other than an economic one.

Metrological Analyses on Fragmented Bronze

The hypothesis of fragments as currency is quite old (De Rossi 1884). However, the attempts to collect and analyse data on the weight of hoards have been surprisingly few in the long history of studies on the subject (Peroni 1966; Sommerfeld 1994; König 2004).

In addition to a more appropriate methodology, these analytical attempts required a reference framework that was still lacking at the time, as rightly pointed out by Ch. Pare: »Although the use of weighed metal in the Bronze Age seems plausible, the proposed system can hardly have functioned without standard weights. Suitable weights are, however, not documented in Central Europe until the end of the 2nd millennium BCE. Even then they are so rare that it is difficult to imagine their use in a pan-European system of metal exchange. The use of weighed bronze as commodity-money therefore remains hypothetical, even if the theory is attractive« (Pare 2013, 517).

The gap in knowledge about balance weights has been filled over the last 30 years (e. g. Cardarelli et al. 1997; 2001; 2004; Ialongo 2019; Ialongo/Rahmstorf 2019; 2022; Ialongo et al. 2021), and methodologies such as the Cosine Quantogram Analysis have been used (Kendall 1974), allowing for results whose statistical significance can be tested (Pare 1999; Ialongo et al. 2018; Rahmstorf 2019; Hermann 2022; Poigt 2022).

The Cosine Quantogram Analysis is a statistical method that allows for the discovery of whether one or more basic units exist within a numerical dataset. The results of the analysis are plotted on a graph, making it possible to determine if the dataset has a quantal or random distribution. However, to validate these results, a Monte Carlo simulation is used as a significance test, allowing us to determine the probability that the result is actually random. A Python script has recently been published that enables the Cosine Quantogram Analysis and the Monte Carlo test to be performed in a single environment by uploading an Excel file with the data (Lago et al. 2024).

In recent years, following intensive data collection campaigns, it has been possible to collect a database of over 30,000 objects from European Bronze Age hoards (Ialongo/Lago 2021; 2024; Lago 2020; **fig. 5**). This impressive amount of data, along with the aforementioned quantitative analyses, has allowed for a metrological analysis of large regions. Through the comparative study of weight systems and metrological patterns in the fragments, it has been confirmed that balance weights and fragmentation spread simultaneously across Europe, approximately from South to North (Ialongo/Lago

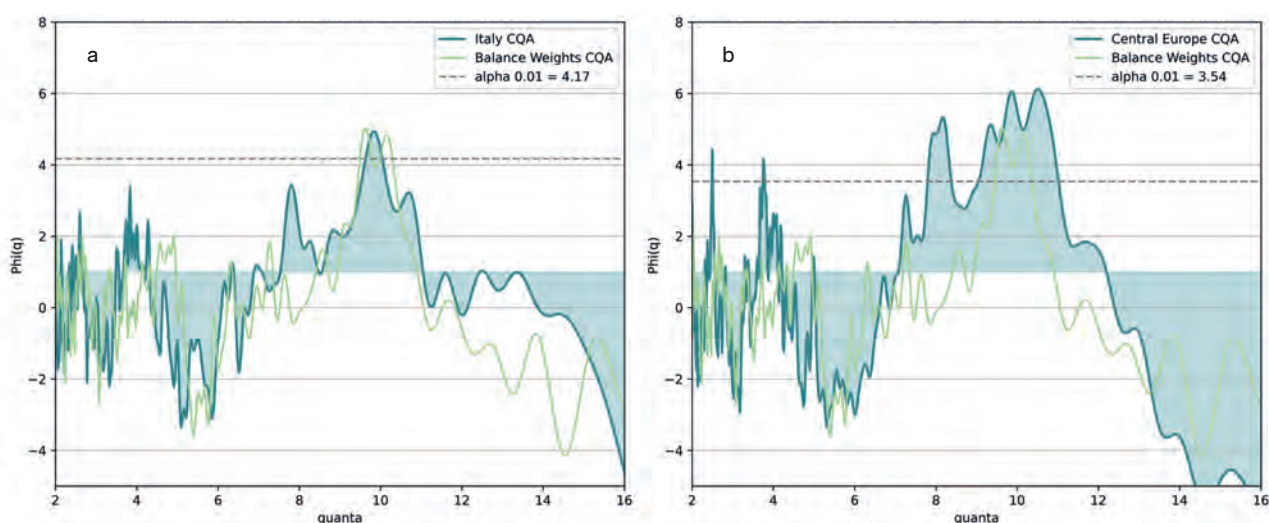


Fig. 5 Cosine Quantogram Analysis (CQA) and Monte Carlo simulations of Italian (a) and Central European (b) fragments from the Middle and Late Bronze Age. Comparison with the results of the Cosine Quantogram Analysis (CQA) of balance weights from the same period. – (After Ialongo et al. 2021, fig. 3; Ialongo/Lago 2024, fig. 4).

2024). From a metrological perspective, the Cosine Quantogram Analysis has allowed us to determine that fragmented bronze shares the same basic unit as balance weights and follows a consistent pattern of values (i. e. multiples of approximately 10 g). This

system appears to be shared between Italy and Central Europe, with small variations in value.

The results achieved strengthen the idea that weight analysis of fragments should serve as the null hypothesis to test against alternative explanations.

Discussion and Final Remarks

The conference held in Mainz once again highlighted how the topic of fragmentation remains compelling, lending itself to various approaches and open to multiple interpretations. Over the past 15 years, there has been renewed interest in this phenomenon, which inevitably contributes to the broader and equally captivating theme of hoarding – one of the most intriguing subjects in Bronze Age studies.

The introduction of methods borrowed from statistical and economic sciences has further fuelled the discussion on how to interpret fragmentation (Wiseman 2018). In this and other works, my colleagues and I have offered our perspective, interpreting the phenomenon of object fragmentation from an economic viewpoint and substantiating our interpretation with data and replicable methodologies (Ialongo/Lago 2021; 2024). It is evident that the weight of objects provides an objective parameter. When collected systematically and analysed using appropriate methodologies, it offers the remarkable potential to approach this issue scientifically. As always, the results leave ample scope for further debate and discussion. While I am convinced that much of the fragmented bronze circulating from the Middle

Bronze Age onwards is the consequence of the simultaneous introduction of weighing technologies, I do not believe we can entirely dismiss the possibility that other forms of fragmentation occurred. For instance, the deposition of de-functionalised weapons (Salzani 1994; 1998; Cupitò/Leonardi 2005) or the rare evidence of fragmented bronze found in smelting contexts (de Marinis 2006) – similar in many ways to those found in many »scrap hoards« (Bellintani et al. 2024; Huth 2024) – suggests a more complex archaeological reality than a single interpretation can explain.

Continued research on the topic will inevitably lead to new discoveries and new data to analyse. The addition of new data could allow quantitative and metrological studies to identify differences where none currently exist and to cover regions where data is currently scarce. It may become possible to reach a more precise characterization of the economic and social practices of Bronze Age communities. At the same time, new methodologies and theories will inevitably be introduced. What we are all presenting today might be just the tip of the iceberg of a much more complex phenomenon within ancient societies.

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