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Unsupervised model-based clustering for typological classification of Middle Bronze Age flanged axes

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ABSTRACT

The classification of Western European flanged axes dating to the Middle Bronze Age (1650–1350 BC) is very complex. Many types of axe have been identified, some of which have numerous variant forms. In the current French terminology, all axes are divided into two generic groups: namely "Atlantic" (*Atlantique*) and "Eastern" (*Orientale*). Each of these generic groups, however, is highly polymorphic, so that it is often very difficult for the operator to classify individual axes with absolute confidence and certainty. In order to overcome such problems, a new shape classification is proposed, using morphometric analysis (Elliptic Fourier Analysis) followed by unsupervised model-based clustering and discriminant analysis, both based on Gaussian mixture modelling. Together, these methods produce a clearer pattern, which is independently validated by the spatial distribution of the findings, and multinomial scan statistics. This approach is fast, reproducible, and operator-independent, allowing artefacts of unknown membership to be classified rapidly. The method is designed to be amendable by the introduction of new artefacts, in the light of future discoveries. This method can be adapted to suit many other archaeological artefacts, providing information about the material, social and cultural relations of ancient populations.

1. Introduction

Many types of flanged axes produced in Western Europe during the Middle Bronze Age (1650–1350 BC) have been recognised by archaeologists (e.g. Abels, 1972; Briard and Verron, 1976; Gomez de Soto, 1980; Kibbert, 1980; David-Elbiali, 2000; Gabillot, 2003; Michler, 2013). Most types have numerous variants, so that fine typological classification on the sole basis of their shape is generally problematic. The situation is even more complex because typologies generally combine several criteria, such as edge height, the possible presence of ornaments, and the total size of the object, but do not always take all of them into account. These descriptive criteria are not always given the same weight in type definition. Briard and Verron (1976) merged axe types into two generic groups: namely "Atlantic" (*Atlantique*) and "Eastern" (*Orientale*), broadly following the location of the find: closer to the Atlantic coast, or closer to the Alps. Nevertheless, this distinction no longer seems completely adequate to differentiate rapidly between axes of each generic group. For instance, the shapes of concave-blade flanged axes (Atlantic group) and those of the Neyruz type (Eastern group), which each have several variant forms, are at first glance very similar (Fig. 1a:2, 4). Since the 1970s, specific studies on axes, and regional syntheses (Butler, 1995/1996; David-Elbiali, 2000; Gabillot, 2003; Michler, 2013) on metallic artefacts dating from the Bronze Age have refined the previous classification presented by Briard and Verron (1976), but they have not really called into question this early work. Without a precise location for the find, it is impossible to attribute a flanged axe to a group, except for some specific types, such as Roseaux-Morges, Möhlin, or the large cutting blade type (Fig. 1b:12–14; Abels, 1972; Briard and Verron, 1976). In any case, a typological system based on the location of the find, which may seem convenient, would not be appropriate to tackle archaeological questions relating to the quality of exchanges or potential stylistic and technological influences between cultural entities.

During the Middle Bronze Age, in addition to flanged axes, another category of object, the so-called axe-ingots, was also produced (Fig. 1c). Their shape is quite similar to common flanged axes, but they are almost exclusively composed of copper (e.g. Rychner and Kläntschi, 1995), and do not seem to have been used after casting (e.g. Nicolardot and Verger, 1998). The casting cone and burrs on the edges are still present on axe-ingots, unlike functional axes. Two main hypotheses concerning their function have been formulated: they could have been designed as copper ingots for future casting operations, or they

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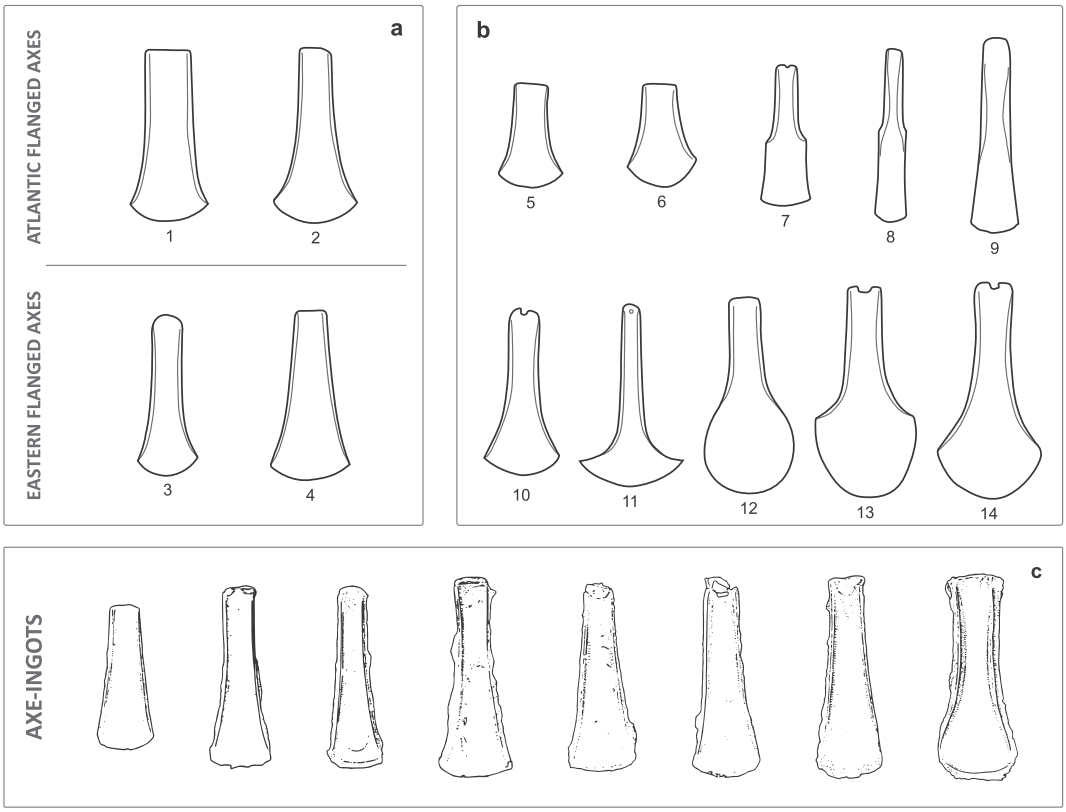

Fig. 1. Typological classification of Middle Bronze Age flanged axes, based on Briard and Verron (1976). a) Atlantic and Eastern types integrated into the corpus, b) morphologically specific flanged axe types not included in the corpus, c) examples of axe-ingots found in several eastern French sites. 1) Narrow-blade flanged axes, 2) Concave-blade flanged axes, 3) Salez type, 4) Neyruz type, 5) Low flanged axes, 6) Languedoc types, 7) Shoulder type, 8) Baraque type, 9) Ricardelle type, 10) Porcieu-Amblagnieu type, 11) Large cutting blade type, 12) Roseaux-Morges type, 13) Möhlin type, and 14) Langquaid type.

may have served as a means of exchange. Their potential for use as genuine axes cannot be excluded (Nicolardot and Verger, 1998; Delrieu et al., 2015).

The present study aims at systematising the typological classification of these flanged axes. Our approach is based exclusively on object shapes and their treatment by objective statistical techniques, reproducible in time and space by any operator. Since the 1960s, many morphometric methods have been developed. They are based on linear and angular measurements of objects (e.g. Roe, 1968; Hodson, 1971; Barker, 1975; for Bronze Age axes see Lull, 1983), sometimes simplified by deduced categorical variables (e.g. Hodson et al., 1966; Sackett, 1966; Vaginay and Guichard, 1988), and they have proved their worth in archaeological classification. More recently, morphometrics applied to archaeology has evolved into more complex methods including more information (e.g. Brande and Saragusti, 1996; Gilboa et al., 2004; Lycett, 2009; Karasik and Smilansky, 2008, 2011). These methods are known to allow a better description of the entire shape and a separation of shape and size. They provide a continuous morphospace allowing more complex statistical analyses, including the reconstruction of the mean shape and shape diversity within the group of interest (Adams et al., 2004; Navarro, 2003; Zelditch et al., 2004; Slice, 2005; Wilczek et al., 2014). Two recent studies undertaken on Bronze Age palstaves (Forel et al., 2009; Monna et al., 2013) have already demonstrated that combining geometric morphometrics with spatial analyses can be very effective for the better understanding of artefact production and use.

Our first goal was to apply these techniques to closed contours obtained from a corpus of 247 axes (all available as drawings, either in published literature or in personal collections), in an area circumscribed by the French Atlantic coast, the Rhine valley and Switzerland. A new classification approach, based on shape similarities, unsupervised clustering with Gaussian mixture modelling, and discriminant methods, was then developed. The performance of this model was spatially checked using multinomial scan statistics and compared to classifications currently used in the study area. Finally, 21 axe-ingots were introduced into the typological model, for attribution to one of the newly established groups.

2. Material and methods

2.1. Corpus

The choice of the corpus was guided by several constraints: (*i*) the objects had to be intact and undamaged by use or corrosion, and (*ii*) their silhouette must not have been drastically reworked after they came out of the mould. Axe preservation was estimated visually from available items, or obtained from the literature (Bocquet, 1970; Abels, 1972; Gomez de Soto, 1980; Kibbert, 1980; Gabillot, 1997, 2003; Nicolardot and Verger, 1998; Mélin, 2012; Gabillot et al., 2014; Thevenot, unpublished). Although the above-mentioned constraints considerably reduced the number of individuals available (approximately 50–60% of available items were kept for further analysis), this selection process is expected to produce robust results. The final corpus consists of 247 reasonably contemporaneous flanged axes (126 from the Atlantic group, and 121 from the Eastern group), discovered in 132 sites, located in what is now France, Switzerland and Germany. Other more specific types, visually very different from the corpus of interest (Fig. 1b), or simply very scarce (e.g. type Strasbourg, Herbrechtingen, Luzern, Riquewihr), were not integrated into the present study. Finally, four generic groups of axes (concave and narrow blades for the Atlantic generic group and Salez and Neyruz types for the Eastern generic group) were retained in the study. The spatial distribution of these axes (Fig. 2) is marked by a clear gap between the two groups, possibly due to the relative absence of archaeological