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Extraction of archaeological information from metallic artefacts—A neutron diffraction study on Viking swords

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ABSTRACT

Vikings (800–1050 CE) are famous for being fearsome seafarers and their weapons represented an indispensable tool in their plundering raids. Sword from the Viking age often showed pattern-welding, made by welding together thin strips of iron and steel that were twisted and forged in various ways, producing a decorative pattern on the surface. In this work we present a neutron diffraction study of three swords from the Viking age belonging to the National Museum of Denmark. This non-invasive approach was used to allow us to characterise the blades in terms of composition and manufacturing processes involved. The study shows how the effects of past conservation treatments can either help or obstruct the extraction of archaeological information.

1. Introduction

Scientific investigations and archaeometric studies, such as for dating and provenance attribution, have played a major role in the field of archaeology, especially with regard to materials transformed through human activity. Archaeometallurgy, in particular, represents a crucial tool for understanding all the processes that were able to convert raw materials, like iron ore, into 'cutting edge' artefacts of iron and steel technology, such as swords, where the best materials available and expertise were often applied. Scientific investigations can not only shed light on the manufacturing processes involved (e.g. smelting, refining, and smithing) and on their use and degradation over time, they can also, on a broader scale, help in understanding the economy of an archaeological site and its technological evolution. In fact, in human history, it is often the case that the more contacts a population had, the stronger its technology and culture became.

More than two thousands swords from the Viking Age (800–1050 CE) have survived until today, buried in graves of the period, or deposited or lost in rivers, often developing thick corrosion layers both during burial and after excavation. Swords have been investigated following mainly two approaches: either using invasive techniques like metallography and Scanning Electron Microscopy (SEM) (Williams, 2009; Lorange, 1889; Müller-Wille, 1970; Williams, 1977), or through visual investigation mainly based on hilts, favouring style classification over technological classification (Petersen, 1919; Mortimer Wheeler, 1927). Since swords were very costly to make and were considered as possessing individual authority of their own, good blades were often bequeathed from father to son, possibly acquiring new hilts in the process in order to follow the fashion of the time. For this reason, some Viking Age blades might be much older than their hilt or their burial site.

In the past, large samples were required to be taken from the artefact to perform a representative analysis, however, recent methods allow dense material to be characterised non-invasively (Lang et al., 2011; Fedrigo et al., 2013). Diffraction techniques are fundamental tools for the characterisation and understanding of crystalline materials (as is the case of metals), especially with regard to phase identification and quantification, texture studies and microstructural properties like crystallite size, texture, and accumulated strain, from both manufacture and use.

Among diffraction techniques, X-ray diffraction (XRD) is useful for small powder samples and surface analysis, while neutrons represent

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an ideal probe when much greater penetration is required. In fact, thanks to the limited interaction of thermal neutrons with other nuclei, it is possible to probe metals through a thickness of several centimetres (Squires, 1996), even in the case of thick layers of rust (Strobl et al., 2009; Triolo et al., 2009). Neutron diffraction (ND) therefore represents one of the most suitable techniques to characterise, in a non-invasive way, the bulk of metallic artefacts. From a diffraction pattern it might be possible to retrieve the history of the object: retrieving information on the smelting process, on the likely thermal treatments and working techniques applied, and, last but not least, the current conservation status of the artefact as a whole (Fedrigo et al., 2013; Grazzi et al., 2011).

In this paper we present a neutron diffraction study on three 'pattern-welded' sword-blades from the Viking Age, all pertaining to the National Museum of Denmark (http://natmus.dk/historisk-viden/danmark/oldtid-indtil-aar-1050/vikingetiden-800-1050/vaaben/svaerd, n.d.). The samples, pictured in Fig. 1, are stray finds from Central Jutland, dating 9th–10th century, that were acquired by the Museum between 1880 and 1892. As revealed from a neutron tomography characterisation (Fedrigo et al., 2016), the states of conservation differ widely: the blade fragment C6871 is highly corroded, while, for the other two blades D2335 and C6375, the original surface was removed prior to acquisition through unknown conservation/cleaning treatment.

The analyses aimed for the characterisation of the metallurgical properties of the swords, from defining the composition and microstructure, to the quantification and distribution of residual strains, which are permanent deformations in the metal introduced during manufacturing. Although the study is nothing like a complete picture of Viking-age swords, the results obtained have added greatly to our knowledge of how these pattern-welded blades were made and how their composition may influence the type and extent of future and ongoing deteriorations. They also underline the extent of information that can be elicited through a non-invasive and in particular non-destructive approach enabling an extended number of artefacts to be studied in order to complete the picture in the future.

2. Sword production during the Viking Age (800–1050 CE)

Scandinavians from the Viking Age are notorious for being fearsome sea-raiders and their weapons represented an indispensable tool for war. Different kinds of weapons were used depending on the social status, ranging from affordable axes, spears, and lances, to costly swords, usually possessed by the elite. But the impressive success of the Vikings was not only piratical, it was also rooted in their role as highly skilled traders and explorers, with trade connections established and spread more widely than any European prior to the colonisation processes that followed the discoveries of Columbus (Foote and Wilson, 1970). As a result of these journeys, new raw materials and technologies were introduced into Scandinavia; as in the case of crucible steel (*wootz*), which was likely imported from Central Asia exploiting the trade route from the Baltic to Persia via the Volga River, active during the 9th and 10th centuries (Mitchiner, 1987; Stalsberg, 1982; Williams, 2012). Crucible steel was used to produce the famous 'Ulfberht' sword, a blade made of a single homogenous piece of hypereutectoid high carbon-steel (Williams, 2007) that appeared probably around 800 CE (Stalsberg, 2008). As soon as the 'Ulfberht' swords became renowned, swordsmiths of the time started replicating them, producing a broad range of counterfeits using varying amounts of bloomery steel (Williams, 2009).

During the Early Middle Ages in Europe, iron was still produced by heating iron ores with charcoal in small furnaces (bloomeries, therefore the name 'bloomery iron'), and reduced to metallic iron undergoing a transformation in the solid state, as the temperature never reached the melting point (1538 °C). The lump of iron produced was rich in slag inclusions and needed refinement and further treatments to be used for the final object. Moreover, with this method a variable and inhomogeneous amount of carbon might be contained in the bloom (anywhere between 0% and 0.8%, but generally $<$0.2 wt% of C), compared to crucible steel, where a high carbon homogenous material was produced ($\approx$1.0–1.6 wt% of C).

Most of the Viking era artefacts were smelted from bog iron, a phosphorous rich ore which represented the local source of iron. Bloomery steel ($\approx$0.2–0.8 wt% of C) might also be produced by extending the reduction time in the furnace, but the process was not understood and therefore difficult to control.

European swords of the time were usually double-edged, up to 1 m long, and often showed pattern-welding. Such blades were made by welding together rods of iron and steel, which were then folded, twisted and forged in various ways to produce, after polishing and etching, a herring-bone—or more complicated— pattern on the surface (Lorange, 1889). Because of the slight difference in colour of phosphoric iron, low P % and high P % iron were also largely used in pattern welded swords.

Forging together small pieces of carburised and uncarburised iron was a way of producing a large billet of steel-like material whose mechanical properties were more or less controlled. In addition, this technique produced a much sought after decorative effect that might have been thought to resemble the watered-silk pattern of Damascus steel. Most sword blades from before the Viking Age were made by this technique (Lorange, 1889; Müller-Wille, 1970; Williams, 1977) but its use had become essentially decorative by the Viking Age.

Using steels of increased carburisation levels is only one way of producing a harder material, the crystalline microstructure of a metal is the factor that mainly determines its mechanical properties: work-hardening, precipitation of martensite through quenching, formation of grain

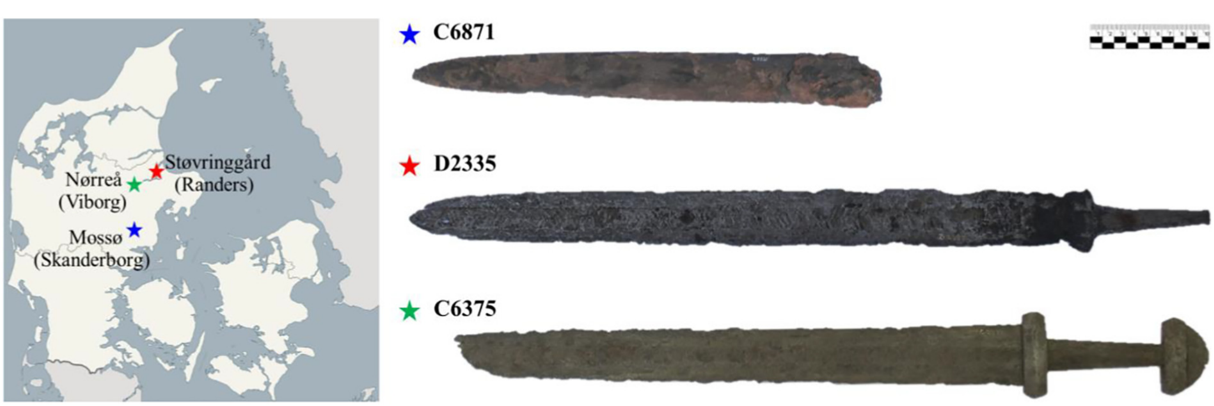

Fig. 1. (Left) Map of Denmark with place of the finds, where the swords were most probably deposited in water-logged areas. (Right) Double-edged sword-blades from the Early (9th c.) and Middle (10th c.) Viking Age. All three blades are 'pattern-welded' with a long central fuller.