A NON-DESTRUCTIVE TECHNICAL AND STYLISTIC COMPARATIVE ANALYSIS OF SELECTED METAL ARTEFACTS FROM THE DITSONG NATIONAL MUSEUM OF CULTURAL HISTORY

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I declare that the above thesis is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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ABSTRACT

The destructive nature of conventional analytical techniques, coupled with the finite nature of ancient/historical artefacts, has long restricted technical examinations of museum collections, mainly due to ethical constraints. However, over the past few decades, the application of Non-Destructive Evaluation (NDE) techniques has become increasingly popular within the fields of archaeology and cultural heritage diagnostics. The application of such techniques has facilitated the examination of objects that have long remained uninvestigated. However, this positive development also held a slight drawback, in that researchers tend to now focus on technical analyses alone, while excluding more traditional means of analyses, such as comparative stylistic analysis and surface investigation. By employing a combination of stylistic analysis, visual surface investigation (by means of SLR photography and digital microscopy) and nuclear imaging (by means of Microfocus X-Ray Computed Tomography), the thesis sets out to justify the application of mixed methodologies as part of a more holistic integrated authentication approach. Thus stated, the thesis presents a mixed-methodological approach towards the analysis of selected metal objects from the Ditsong National Museum of Cultural History in Pretoria, South Africa. The objects under investigation include a small collection of ancient Egyptian bronze statuettes, a Samurai helmet (*kabuto*) and mask (*menpó*), a European gauntlet, and an Arabian dagger (*jambiya/khanjar*). While all the objects are curated as part of the museum's archaeology and military history collections, the exact production dates, manufacturing techniques and areas of origin remain a mystery. By using a combination of techniques, the thesis aims to identify diagnostic features that can be used to shed light on their relative age, culturo-chronological framework and, by extension, their authenticity.

Keywords: Ancient Egyptian bronzes; integrated authentication; *jambiya, kabuto, khanjar*, *menpó*, Microfocus X-Ray Computed Tomography; mixed method approach; Non-Destructive Evaluation

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ABBREVIATIONS AND ACRONYMS

ANE	Ancient Near East
BP	Before Present
BCE	Before Common Era (formerly BC)
CE	Common Era (formerly AD)
DNMCH	Ditsong National Museum of Cultural History
MXCT	Microfocus X-ray Computed Tomography
NDE	Non-Destructive Evaluation
NECSA	Nuclear Energy Corporation of South African
ND	Neutron Diffraction
NT	Neutron Tomography
ToL	Tower of London

KEY TERMS

Attenuation	The gradual loss of flux intensity through a medium
Artefact	An archaeological/historical object
Artifact	A visual anomaly caused by beam hardening (nuclear imaging)
Beam scattering	The deviation of radiation (beams) from a straight trajectory
Jambiya	Arabian dagger, with the sub-type known as *khanjar*
Kabuto	Samurai helmet
Menpó	Samurai mask
Provenance	The history of the artefact's/object's use and ownership, both ancient and modern
Provenience	An artefact's location, position, and context within the archaeological record
Radiopauqe	Attenuated passage of radiation through a medium (opaque)
Radiotransparent	Un-attenuated passage of radiation through a medium (transparent)

TABLE OF CONTENTS

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 6

CHAPTER 8

LIST OF IMAGES

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

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[1] The Digital Media Project. http://www.dmlp.org/legal-guide/fair-use [Accessed on 28/06/2018].

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

For many decades, the technical analyses of artefacts relied on the acquisition of physical samples, which often resulted in irreparable damage to the object. Since a significant proportion of museum objects represent finite, irreplaceable examples of material culture, the destructive nature of most materials science techniques meant that many artefacts remained unanalysed. Conservation ethics therefore prevented the destruction of cultural heritage for the sake of science, irrespective of how valuable the scientific findings may prove to be.

Fortunately, over the past few decades, the development of Non-Destructive Evaluation (NDE) has grown exponentially, with the primary focus on the provision of industrial solutions within the automotive, aerospace and life science sectors. In terms of research, the valuable applications of NDE within the realms of biology and geology were soon realised, followed by applications in the fields of palaeontology and archaeology. With the heritage sector keen on taking advantage of technological developments, museums and other holding institutes commenced with research endeavours that remained stagnant for many decades due to ethical restrictions.

Although the South African heritage and archaeology sectors have been taking advantage of NDE for many years, the full potential of this niche area of materials science remains unrealised. Many collections remain unexplored – their stories untold. In addition, where NDE does take place, the majority of researchers tend to focus on the application of a single (or perhaps two) techniques at a time. They also tend to draw a definite line between the human science approach (i.e. stylistic analysis and historical research) and the materials science approach (i.e. nuclear imaging, chemical analyses, and microstructural examination). This human vs hard science approach does not recognise the potential of multi-disciplinary research.

On order to address the latter and most pertinent point, the thesis will combine analytical approaches (traditional stylistic surface analysis and image-based humanities computing) within the greater context of an integrated authentication methodology. In order to showcase the value of using a combination of analytical techniques on a small, non-randomised sample group, artefacts from

- **different cultures** (Egyptian, European, Japanese, Arabian),
- **time periods** (Ancient, Medieval, Imperial, Modern), and
- **varying/composite material compositions** (bronze, iron, steel, silver, leather, cotton, etc.)

will be subjected to the same analytical techniques:

- **historical contextualisation**,
- **stylistic analysis** (visual comparative analysis),
- **surface investigation** (digital microscopy), and
- **nuclear imaging** (Microfocus X-Ray Computed Tomography)

By using different analytical techniques, the thesis aims to gather complementary data on diagnostic features that can in turn shed light on the objects' relative age, culturo-chronological framework and, by extension, their authenticity. The sample group includes a small collection of ancient Egyptian bronzes, a Samurai helmet and mask, a European gauntlet, as well as an Arabian dagger. The objects are housed by the Ditsong National Museum of Cultural History, located in Pretoria, South Africa.

1.1.1 The Question of Authenticity

Museums and other holding institutes are often faced with the dilemma of object authenticity. Since these institutions often receive cultural objects as donations from the public, or are intrusted with the estates of deceased antiquities collectors, objects without known provenience make their way into museum collections. While some artefacts are placed on display, others are catalogued and placed within the museum's research collections. In many instances, objects come without certificates of authenticity, especially when dealing with private collections that were compiled long before any regulations were in place to govern such ownership. While a selected number of objects boast informal documentation, these records in most instances merely postulate the place and/or period of origin with no real scientific or historical backing. In worst-case scenarios, objects are brought to museums without any documentation, contextual data or means to validate their authenticity.

To briefly revert to the basics, we have to ask the question: "what exactly does the term *authentic* mean?" According to the Oxford Advanced Learner's Dictionary (2017, 82), the word *authentic* translates as "known to be real and genuine and not a copy", with the verb *authenticate* meaning "to prove that something is genuine, real or true". Although these definitions make both the concept of authenticity and the act of authentication appear simple, neither is. In contrast to identification, which merely states or indicates the nature or identity of an object, authentication sets out to legitimise that identity through a series of validation processes. Fortunately, authentication does not necessarily rely on the validation of all aspects of identity, as the validation of a solitary, yet historically significant aspect may prove sufficient in terms of legitimacy[2]. Within the context of this thesis, we will attempt to identify as many significant aspects of identity as possible, with the mixed methods approach facilitating the collection of complementary datasets.

Since objects cannot be left in a state of uncertainty, it becomes the responsibility of museum curators, with the help of subject specialists and technical experts, to authenticate objects. Unfortunately, even among reasonably well-staffed international museums, only a selected number of individuals possess the required expertise to perform the task. To add to the challenge, conflicting views (held by different experts) and personal biases (either towards the donor, the holding institution, or the object itself) often hamper the process. In addition, individual/departmental research interests, improper job coordination or a lack of funding may prevent certain authentication projects from commencing. In short, authentication is by no means a stereotypical process, whereby a spectacled, lab-coat-wearing curator chubs a stamp of authenticity on an object after merely staring at it attentively for 10 minutes.

The situation is indeed quite serious. According to the International Council of Museum's (ICOM) International Observatory on Illicit Traffic in Cultural Goods, inauthentic or fake objects often infiltrate museum collections. This continues to happen in spite of serious efforts that are being made to identify forgeries *before* accepting donations or purchasing cultural objects[3]. The reality is therefore that objects of unknown authenticity still end up in our museums, and we have to find a means of countering the negative consequences.

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[2] https://en.wikipedia.org/wiki/Authentication [Accessed 02/02/2018].

[3] https://www.obs-traffic.museum/authentication [Accessed 12/08/2018].

All things considered, authentication must still occur within an environment which holds the object's longevity at heart – even though the object in question may turn out to be a forgery. In all instances, we have to give objects "the benefit of the doubt" and treat them as though they are genuine. From a global perspective, fakes and forgeries might be prolific, but originals are few and far between, often one-of-a-kind. In short, this is where Non-Destructive Evaluation (NDE) can play a significant role.

1.1.2 Non-Destructive Evaluation (NDE)

a) *Infinite vs Finite Resources*

In contrast to the natural sciences, were samples are often infinite, research materials within the cultural heritage sector are finite and irreplaceable. In most instances, cultural heritage resources are rare, one-of-a-kind examples of material culture. In extreme cases, type specimens are worth more their weight in potential knowledge, than gold. Their worth lies within the variety of cultural elements they embody, those beyond the physical – artisan skill, cultural diffusion, resource utilisation, artistic expression, personal defence, religious beliefs, social status, etc. These objects hold the potential to reveal insights into the lives and life-ways of their ancient creators. They are objects with hidden histories, with stories to tell, and we as researchers are their modern interpreters. We observe physical phenomena and "transcribe" (for lack of a better word) the ancient messages embedded within each artefact. To this extent, the application of nuclear imaging techniques in artefact analysis has been described by de Beer (2016 pers. comm) as the process of "revealing the hidden with the unseen"[4].

b) *The Role, Development and Future of NDE*

Over the course of many decades of materials research into ancient artefacts, the destructive nature of conventional analytical techniques has limited the in-depth technical investigation of museum collections. Ethical considerations, directly linked to the rarity and/or sensitivity of cultural objects, prevented destructive investigations from being performed. This restriction had a two-fold result, although the limitations protected artefacts (positive), the lack of materials research stifled significant developments towards our understanding of ancient production technologies (negative). However, over the past few decades, the application of

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[4] In the context of de Beer's work, within the field of nuclear imaging the "hidden" refers to physical phenomena that have remained concealed, while the "unseen" refers to a variety of radiation emissions, such as X-ray and neutron radiation.

NDE techniques has become increasingly popular within the fields of art, archaeology and cultural heritage diagnostics.

In terms of image-based NDE, the creation of three-dimensional (3D) models has led to the virtual replication of historical objects. In simple terms, “3D scanning produces a high-precision digital reference document that records condition, provides a virtual model for replication, and makes possible easy mass distribution of digital data” (Wachowiak & Karas 2009, 142). This versatile application has allowed researchers to digitally/virtually interact with material culture without the object being physically handled – a great advantage, especially when dealing with fragile objects. As Katz and Tokovinine (2017, 1) explain,

> Digital replicas enable remote analysis by allowing scholars to inspect and measure the objects from all possible angles, enhance the visibility of the surface topography, produce technical drawings, and even automate searches for matching measurements across multiple objects. The analysis of fragile artifacts is now only made possible through their digitization

Wachowiak and Karas (2009, 142) provide a brief synopses of the main uses and applications of 3D modelling:

> These systems provide a high quality, high-resolution 3D archive of an object’s surface topography with measurement accuracy to the sub-millimetre level. In addition, 3D scanning allows measurement of the surface geometry, texture (which, in the jargon of 3D surface imaging, includes colour), and volume of most objects, without contacting an object’s surface. As in two-dimensional photography, a graphic representation of the surface is created. The 3D data provide an extremely accurate record of an object’s physical structure, unlike flat photographic representations of objects or virtual reality displays of objects created by compiling 2D photographic images. Like photography, 3D scanning does not provide information about structure below an object’s surface. 3D data, however, can be used in conjunction with x-radiography and CT scanning as a complement to these analytical tools to reveal structure and spatial relationships with very high resolution.

Both image-based and chemical NDE techniques are mostly applied in aid of artefact conservation, restoration and authentication, but have also been used extensively to gain insight into ancient materials, technological advancement, production, artisan skills and trade.

Artioli (2013, 55) aptly defines the complementary relationship between archaeometry[5] and conservation science:

> Archaeometry and conservation science deal with materials that have been transformed through human activity. Their main task is to understand the materials and the objects as inserted into a time-line, that is to interpret the evolution of the material in time from the raw materials, through the man-made production and transformation processes, their use, diffusion and composition until their disposal, degradation, or perhaps their conservation in cultural collections.

With the latter being stated, NDE has also been used to diagnose processes of deterioration in artefacts, thus providing museum conservationists with much needed technical insights into when to commence restorative measures. For example, in most instances, dimensional changes in artefacts remain hidden until internal displacements cause external visual indications of deterioration (Tornari et al. 2008, 8401). Thus said, investigative methods that deliver invaluable data pertaining to the artefact's overall condition (both interior and exterior) should ideally be performed prior to the application of conservation efforts (Rant et al. 2006, 7).

In addition, by revealing previously undetectable phenomena, NDE has the potential to place technological developments within more well-defined historical contexts (Young 2012, 1). By understanding ancient styles, materials and production techniques, we gain insights into their evolution across time and space, thereby increasing the possibility of allocating each individual object within its (now quantified and historically contextualised) cultural chronology.

With the availability of advanced methods to help identify these phenomena, Rant *et al.* (2005, 81) propose that advanced imaging techniques and chemical analyses should become routine practice in the modern-day study, conservation and authentication of artefacts and museum objects. In addition, it is essential that imaging techniques be combined with chemical analysis (where possible) in order to confirm the absence or presence of certain phenomena and/or material properties. For example, in her archaeometallurgical study of

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[5] Archaeometry is broadly described as the "The application of techniques and procedures from the hard sciences (physics, chemistry, biology, etc.) and engineering to archaeological questions and problems". https://www.oxfordreference.com/view/10.1093/oi/authority.20110810104359844 [Accessed 03/11/2019]. Also see Darvill (2009: 13).

Early Medieval knife-making technologies, Blakelock (2010, 83) notes that “even though features seen in x-radiographs can be essential to the analysis of the assemblage of a whole, metallographic analysis is still required to confirm features”.

1.1.3 Non-Destructive Evaluation Approaches

An absolute multiplicity of non-destructive evaluation techniques are at the disposal of modern researchers. A complete list, accompanied by brief description of each technique and its potential applications, could probably fill an entire research paper on its own, but luckily this is not the purpose of the following section. Within the context of this thesis, NDE will follow two analytical strategies: (a) traditional surface analyses (executed primarily through stylistic analysis), and (b) image-based humanities computing (executed through digital microscopy and Microfocus X-Ray Computed Tomography (MXCT)).

a) *Traditional Stylistic and Surface Analyses*

Although highly-advanced imaging techniques are now available to researchers, traditional methodologies of object authentication should not be discarded. In fact, preliminary investigations of this nature can identify visual/surface phenomena that can be validated through the application of more advanced techniques. This methodology is based upon the identification of signs and signals that can help to establish the authenticity of an object. The International Observatory on Illicit Traffic in Cultural Goods[6] lists the following key basic elements that guide visual examinations:

- Style
- Dimensions and proportion
- Materials (type, age, oxidation, etc.)
- Workmanship, construction details and techniques
- Condition
- Signature (media, dimensions, location, mode)
- Inscriptions and markings
- Price[7]

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[6] https://www.obs-traffic.museum/authentication [Accessed 12/08/2018].

[7] Price will not be used as an element of examination, as no monetary value has been assigned to the objects earmarked for this study.

b) *Image-Based Humanities Computing*

The application of NDE in cultural heritage is included in Nowviskie’s (2002) definition of image-based humanities computing. The latter term is broadly used to refer to data visualisation and graphic analysis techniques within the arts (archaeology, ancient history and museum conservation). For example, techniques such as MXCT and Neutron Tomography (NT) deliver 3-dimensional models of objects, allowing the researcher to interact with the object virtually. In addition, NDE also includes techniques such as Neutron Diffraction (ND), which allows researchers to investigate the microstructure of a material. Whichever the case, whether 3-dimensional or microstructural, for a technique to be classified as truly non-destructive, analysis should exclude the procurement of physical samples and should leave the item unscathed or in the same condition it was prior to the examination (Adriaens 2004, 583).

c) *NDE Strategy: Integrated Authenticity*

Within the context of this thesis, we will combine the two analytic strategies mentioned above. Combining traditional surface analysis with image-based humanities computing will allow us to gather data using two different yet complementary strategies, with the end-goal being dual validation: two sets of data are compared, with both confirming the existence of the same phenomena. Such an endeavour falls within an integrated authenticity methodology, which is defined by Siano et al. (2009, 673) as “a practicable multi-disciplinary authentication study including non-destructive and micro-analytical material characterisations along with archaeological, historical and technical examinations”.

d) *How Complementary Techniques Facilitate Dual Validation*

This thesis therefore arose from the need for an integrated authentication study, that uses a combination of (a) stylistic analysis, (b) surface investigation, and (c) advanced non-destructive imaging techniques, to contextualise and authenticate artefacts from various cultural and historical backgrounds that share one basic similarity: material type. The true value of a mixed method or integrated authentication approach lies not in the creation of large volumes of data itself, but rather with the prospect of one technique providing complementary, supportive evidence that can be used to confirm the results obtained by others. This approach holds great value, as it is only through the application of complementary techniques that we can obtain the maximum amount of data (Rant et al. 2006, 8) to facilitate dual validation. The aim of the study is therefore to use complementary data sets in order to identify ancient manufacturing techniques and authenticate artefacts through the observation of diagnostic stylistics and physical features, alongside the provision of historical contextualisation.

1.2 THE RESEARCH FACILITIES

1.2.1 The Nuclear Energy Corporation of South Africa

The Nuclear Energy Corporation of South Africa (NECSA) is a state-owned entity regulated by the South Africa Nuclear Energy Act of 1999. Apart from its functions as a commercial group, NECSA's primary mandate is to facilitate and support research into nuclear energy, radiation sciences and related technological fields. In addition to its direct focus on the development of nuclear instruments and technologies, NECSA is also dedicated to the application of radiation techniques within fields not directly related to nuclear physics. For example; the company actively promotes research from the fields of entomology, human anatomy, palaeontology, and museums studies, among others. This initiative to promote a wide variety of research foci is driven, in part, by the National Research Foundation's (NRF) requirement that equipment funded by the organisation be made available to registered post-graduate students (at little or no direct cost to either the student or the institution). The agreement has proved highly fruitful, as the research outputs delivered through joint publications between NECSA and its student researchers has grown over the years.

In light of this ease-of-access to advanced imaging technologies, and with the continued willingness of holding institutes like the Ditsong National Museum of Cultural History (DNMCH) to collaborate on such projects, it was decided to make full use of the opportunity.

1.2.2 The Ditsong National Museum of Cultural History

The DNMCH in Pretoria, South Africa, plays host to millions of artefacts, many of which have never undergone in-depth analysis. The archaeology collection features a wide variety of local and international cultural objects, while the weapons collection houses objects of military interest from around the world. Selected items from both collections have been analysed by local researchers over the past decade, including a number of bronze statuettes from the Egyptian collection – a falcon (De Beer et al. 2009), child Horus (De Beer et al. 2009; Smith et al. 2011), corroded Osiris (Gravette 2011; Masiteng et al. 2010), Osiris, seated Osiris, Isis and Apis (Masiteng et al. 2010) – and a suite of Samurai armour (Teichert, Smith & Collopy 2012).

The NDE techniques employed in the above-mentioned studies included Neutron Tomography (NT), X-ray Diffraction (XRD), X-ray Fluorescence (XRF) and energy X-ray Dispersive Spectroscopy (EDS). However, none of the studies employed MXCT, despite its availability (through NECSA) and the imaging technique's potential to reveal datasets complementary to those already captured.

In addition, despite the significant work done by these researchers, none of the studies managed to employ an integrated, three-tiered approach which combines stylistic, basic visual and advanced computational analysis.

1.3 THE SAMPLE GROUP

When this study was initially proposed, the intended focus fell exclusively on the analysis of ancient Egyptian bronzes using a variety of non-destructive techniques. However, since two of the proposed technologies (neutron tomography and neutron diffraction) became unavailable due to system upgrades, the focus had to be shifted. Instead of analysing a few objects using multiple techniques, multiple objects were going to be analysed using fewer techniques. Therefore, additional objects of interest, including a Samurai helmet and mask, a European gauntlet and an Arabian dagger, were included as research objects.

The collection of ancient Egyptian bronzes has been dated to the late Middle and New Kingdom by the DNMCH. The statuettes, in varying sizes, are all believed to be votive[8] figurines used in households and smaller local temples. Thanks to their small size, these statuettes were highly portable and often featured as part of festivals or ritual processions[9] (Robins 2005). Cast in bronze, the 14 statuettes range between 3 cm and 20 cm in height and are all in a fairly well preserved condition. Apart from the common solid casts, there is one exception in terms of casting method, namely the hollow-cast figure of the lion-headed goddess Sekhmet (often also referred to as Wadjet-Bast). Due to its unique nature, and

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[8] The term "votive" refers to "an object offered in fulfilment of a vow, such as a candle used as a vigil light" (http://www.dictionary.com/browse/votive). Since most temples were not congregational in nature, and since access to the inner shrines – where the statues of the god were kept – was restricted, most private citizens owned small representations of the gods in household shrines (MET 2004). The faithful could also purchase statuettes and 'donate' them to the temple with the hopes of receiving blessing from the divine (Ambers et al. 2008, 2).

[9] Larger votive bronzes were often affixed as standards atop wooden poles and carried during festivals and processions as representatives of their respective deities/cults. One example can be found among the inscriptions and reliefs of the Festival Gateway of Osorkon II in the Great Temple at Bubastis, where an individual is seen carrying a Standard of Bastet (Bakr & Brandl 2010, 165).

satisfying performance during radiographic examination, the Sekhmet statuette will receive greater attention through this thesis compared to the other bronzes.

A near-complete set of Samurai armour, believed to date from the mid-Edo Period, is also housed by the museum and has received some research attention in the past. The helmet was previously scanned using nuclear imaging, but it was decided that a second round of investigation could deliver complementary data. It was also decided that the accompanying mask should also undergo scanning.

Another near-complete set of armour takes the shape of an undated suit of European armour on permanent loan from the Tower of London Museum in the United Kingdom. Since the existing nuclear techniques on offer hold certain limitations in terms of scanable object size and thickness, it was decided that the gauntlet (forearm armour) should be scanned. In both the Samurai and European armours' case, the remaining objects from the near-complete suits were not be examined directly (individually), but served as additional stylistic points of reference when placing the examined objects within their broader socio-cultural frameworks.

Lastly, an Arabian dagger of unknown origin and age was also selected to form part of the study. Since the object has been in the museum's public display for a number of years, the condition of the steel blade within its scabbard is unknown. The object thus provided the researcher with a unique opportunity to examine an object without removing it from its scabbard.

The following sub-sections provide basic visual descriptions of the objects that will be assessed as part of this study. More detailed sections in Chapter 3 will provide the reader with historical contextualisation in terms of resource acquisition, period-specific technological developments, as well as socio-cultural contexts.

1.3.1 Sekhmet/Wadjet-Bast

The seated Sekhmet/Wadjet-Bast[10] is approximately 12.5 cm high, 3 cm wide and made of bronze. It features a hollow core, making it unique within the museum's statuette collection. It wears a tight fitting dress with a modest traditional head-dress and her hands rest on her lap.

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[10] The interchangeable use of Sekhmet and Wadjet-Bast within the context of Chapters 1 to 4 become apparent in Chapter 5's stylistic comparison between traditional images of Sekhmet and that of Wadjet-Bast.

The now empty eye-sockets would have featured eyes made of clay, faience or semi-precious stones, while the ear holes would have been adorned by earrings.

The item is in a fairly good condition, despite being broken along the lap area. The front tip of the left foot as well as the *uraeus* (hooded cobra) on its head has also broken off. Fortunately, the remaining cobra head which formed the *uraeus* is kept in storage, as it broke off during modern times.

Figure 1.1: Sekhmet/Wadjet-Bast, as viewed from the right (A), front (B) and close-up (C).

At first, the five Egyptian bronzes were to receive equal attention in terms of analysis, but Sekhmet (Wadjet-Bast) soon became the prominent figure within this investigation, not only due to its unique hollow casting, but also due to its breakages, corrosion and patina[11].

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[11] For the purpose of this thesis, and to avoid confusion between the terms patina and corrosion, we shall follow Scott's (2002, 11) definition of terms. 'Strictly speaking patina and corrosion are different words for the same surface alteration… the term patina will be used to describe a smooth, continuous layer that preserves details and shape, while the term corrosion will be used to describe mineral deposits that do not form a continuous and smooth layer. Corrosion may be termed as the process of chemical attack of an environment on a material, while patina could be defined as the accumulation of corrosion products and other materials from the environment'.

1.3.2 Bastet/Cat

The sitting Bastet is 5.5 cm high and roughly 2 cm at its widest section. Along its profile, from tail to nose tip, it measures less than 4 cm. The item is quite heavy, considering its size, which suggests a solid-cast bronze nature. The item is in a very good condition and, apart from some patination, the surface carries a smooth, polished sheen. The cat is cast in unison with a platform that features a single tang, suggesting that it was placed upon a similar wooden base as Sekhmet (Wadjet-Bast).

Figure 1.2: Bastet/Cat, as viewed from the right (A), front (B).

1.3.3 Ibis

The broken ibis is a small statuette with a length of 6.5 cm from beak to tail, standing approximately 6cm tall. Considering its size to weight ratio, the artefact is definitely solid cast. It once stood on a rectangular pedestal, with which it was cast in unison. Unfortunately, given the angle at which the legs join the feet, the item broke along this inherent line of structural weakness. The ibis itself is free from any patination, yet the underside of the pedestal exhibits a patination typical of bronze. What makes the object interesting is the appearance of the left leg. The leg depicts a clear separation between a shiny silver-coloured inner metal surface, featuring copper-coloured inclusions, and a more naturally coloured bronze outer layer.

Figure 1.3: The Ibis, as viewed from the right (A), and the broken-off feet, as viewed from the top (B).

1.3.4 Dog/Jackal /Wepwawet

The museum records are quite vague about this item, and do not specify whether it is a dog or a jackal. This statuette is the smallest within the collection and stands less than 4cm tall. The canine resembles a typical pharaoh hound, a breed known for their slender bodies, long legs and pointy ears. The animal stands on a sled and features a collar around its neck, with the latter transforming into a loop.

As with the ibis, the size to weight ratio is indicative of a solid cast nature. In addition, the small size of the item would have made it impractical – and also near impossible – to facilitate hollow or clay-core casting.

Figure 1.4: The dog/jackal, as viewed from the left.

1.3.5 Samurai Helmet (*Kabuto*)

A semi-complete set of Japanese samurai armour (*katchu*) was first investigated by Teichert, Smith and Collopy (2012) in preparation for the “Objects with stories” exhibition. It was concluded – based on basic technical and stylistic analyses – that the armour was made following the *Tósei-Gusoku* (“modern armour”) style and dates from the mid-Edo Period. The helmet (*kabuto*) was the only component of the suit of armour to be subjected to NDE as part Teichert, Smith and Collopy’s (2012) investigation.

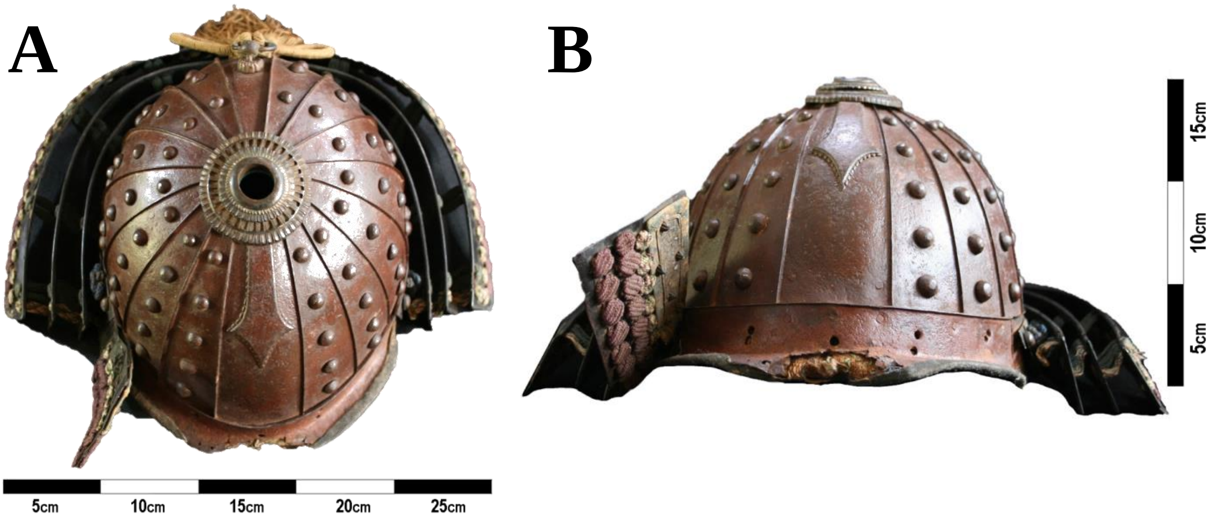

Figure 1.5: The *kabut*o as viewed from the top (A) and front (B).

1.3.6 Samurai Half-Mask (*Menpó*)

A samurai half mask (*menpó*) forms part of the above-mentioned suite of armour. While the *kabuto* was investigated in greater detail, the *menpó* was not. Since the helmet did not present the previous researchers with a maker’s mark during x-ray and cold neutron radiography (see Teichert, Smith and Collopy 2012), it was agreed that a similar attempt at identification should be made using a complementary technique such as MXCT. Apart from its flaking lacquer coating, the object is a fairly good condition following its recent restoration.

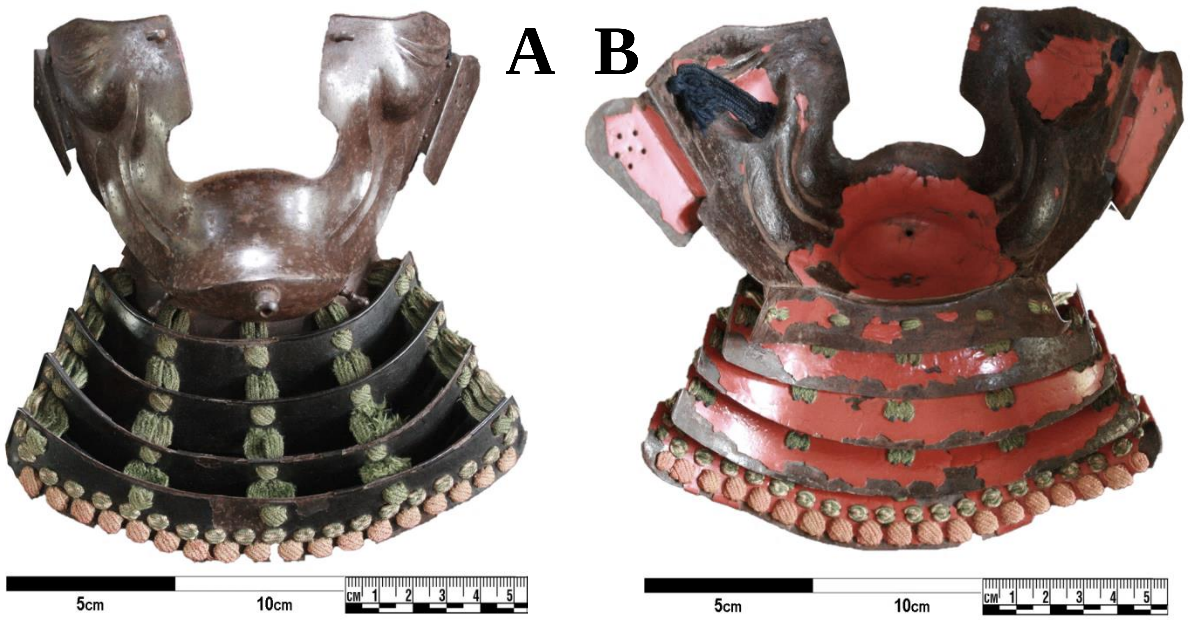

Figure 1.6: The *menpó* as viewed from the front (A) and inside (B). Kindly note that the angle at which image B was taken creates the illusion that the mask is wider than it actually is.

1.3.7 Tower of London Gauntlet

The Tower of London gauntlet forms part of a collection of medieval armour on semi-permanent loan from the Tower of London Museum in London, England. The DNMCH has no official documentation on the collection pertaining to its date of manufacture or historical context. Only one of the suit's components (the left-hand gauntlet) still contains an internal organic (fabric and leather) lining. The latter point made the gauntlet an ideal candidate for non-destructive study, as MXCT would be able to see beyond/underneath the lining, allowing us to examine the condition of the underlying metal surface and identify any hidden manufacturing components.

Figure 1.7: The Tower of London gauntlet.

1.3.8 Arabian Dagger (*Khanjar*)

The Arabian dagger (referred to interchangeably as a *jambiya* or *khanjar*) is on permanent display in the DNMCH's "Objects with Stories" exhibition. Unfortunately, not much is known about the dagger, apart from it being Arabian. Since the dagger has been sheathed for quite some time, the condition of the blade itself was unknown at the commencement of this study. Although it was unlikely that the blade would have corroded significantly over the years[12], the situation provided us with a unique opportunity to examine the blade three dimensionally without having to remove it from its scabbard.

Figure 1.8: The Arabian dagger.

1.4 AIMS AND OBJECTIVES

1.4.1 Research Aims and Objectives

The aim of the study is to use a combination of different analytical techniques (stylistic analysis, digital microscopy and MXCT) in order to gather complementary data on (a) period-specific styles, (b) material composition, (c) ancient manufacturing techniques, and (d) object integrity. The objective is to authenticate the research collection by critically analysing the complementary data collected and comparing the results with known/curated examples of identical/similar objects.

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[12] Good quality steel, which is a trade-mark of antique *khanjars*, never rusts. Although other components of a *khanjar*, such as the scabbard and handle, could degrade over time, blades were often reused over many generations. https://timesofoman.com/extra/OmaniDress/ [Accessed 02/03/2018].

1.4.2 Research Questions

In applying the thesis' experimental methodology (as outlined in Chapter 2), the goal is to better understand these individual objects in light of their various components/elements outlined by Artioli (2010, 108) as nature, state, material components, physical reality, function and behaviour. To foster this understanding, one must ask, and try to answer, a specific set of critical questions, for example:

1. Can we identify any *stylistic attributes* in terms of external features (shape, size, decoration, colour)?
2. Are these stylistic attributes comparable to known/curated stylistic attributes through a process of *comparative analysis*?
3. Can we identify any characteristics or phenomena in the physical structure and material composition of the sample group, which can be considered as *diagnostic features*?
4. Is the occurrence of these physical phenomena (a) amply recurrent and frequent; to be classified as the result of intended actions and/or production methods, or (b) nonrecurring and infrequent; to be classified as the result of unintended/accidental actions and therefore not the result of specific methods?
5. Is it possible to correlate physical diagnostic features with stylistic attributes in order to compile more comprehensive *culturo-chronological timeframes* (relative dating)?

These questions are posed within the framework of quantitative research, which means that they can be tested through experimentation.

1.4.3 Hypothesis

A *mixed method approach***,** that utilizes complementary techniques (stylistics analysis, digital microscopy and MXCT), can be employed to gather complementary data ((a) period-specific styles, (b) material composition, (c) ancient manufacturing techniques, and (d) object integrity), which can in turn be used to compile more comprehensive culturo-chronological frameworks – in turn facilitating *integrated authentication*.

1.5 THESIS OVERVIEW

This thesis comprises eight chapters followed by a Reference List. All images have been placed within the body of text (as opposed to listing them in a colour plate appendix) to facilitate ease of reference.

Chapter 2 (Methodology) presents the research design (experimental methodology and theoretical framework), instrumentation and test parameters (of digital microscopy and MXCT), as well as the fundamentals of stylistic analysis. This chapter will also list the scope and limitations of the study.

Chapter 3 (Literature Review) provides brief synopses of the most relevant works in the field of heritage diagnostics that can be used to identify period-and culture-specific variables in production. Instead of merely summarising the current knowledge (including substantive findings, theoretical frameworks and methodological contributions) and identifying possible gaps in existing research, the chapter will provide a practicable body of knowledge (presented as case studies) to which cross-references are made throughout the thesis. In additional, since the overall nature of this thesis is highly visual, relevant images from the articles under review will be included in the body of the text and will serve as points of reference for the visual analyses conducted in Chapters 5 through 7.

Chapter 4 (Historical Contextualisation) will outline the historical contexts of each object class (Egyptian bronzes, Japanese Samurai armour, European armour, and Arabian daggers) by discussing their period and culture-specific settings, material properties, broad stylistic attributes and possible manufacturing techniques. In doing so, the chapter aims to lay a foundation upon which more detailed technical and stylistic analysis can be structured in Chapters 5 through 7.

Chapter 5 (Stylistic Analysis) will discuss each object by providing a detailed synopses of external visual features, followed by an in-depth comparative analysis. This chapter's primary goal is to provide further historical contextualisation by focusing on the unique stylistic attributes of each artefact type (i.e. Samurai armour) followed by possible categories (i.e. *Tósei-Gusoko*) and sub-categories (i.e. *Okegawa Dou*). While relying primarily on published literature, the chapter will also employ comparative visual analyses through an investigation of online collections from museum archives, auction houses, private collections and online interest websites.

Chapter 6 (Surface Investigation) will exhibit and discuss surface visual phenomena identified by means of digital microscopy. The chapter aims to identify phenomena that can be discussed on an individual level, but also those which can be considered as “points of departure” for the more in-depth three-dimensional investigations to be presented in Chapter 7. With the latter aim in mind, this chapter can be considered as a preliminary technical analysis, forming a basis upon which more advanced nuclear imaging can be based.

Chapter 7 (Three-Dimensional Nuclear Imaging) will present the results obtained through Micro-Focus X-Ray Computed Tomography. As mentioned above, the chapter will provide greater detail on the preliminary visual phenomena identified in Chapter 6, but will also feature new phenomena not previously identified by basic visual analyses.

Chapter 8 (Discussion and Conclusion) will collate the information presented in Chapters 4 through 7 and discuss how these complementary datasets (stylistic, microscopic and nuclear) can be used to authenticate the objects under investigation. Based upon the results obtained, the chapter will also provide recommendations for further research. The concluding section will provide a concise review of the thesis and highlight its primary findings.

The Reference List follows the Chicago Manual of Style’s (2017) Author-Date system.

CHAPTER 2
METHODOLOGY

2.1 INTRODUCTION

This chapter presents the research design, experimental methodology, theoretical framework, methods, instrumentation, test parameters and technical considerations, along with a general overview of radiation imaging techniques.

2.2 RESEARCH DESIGN

2.2.1 Empirical Research and the Quasi-Experiment

The research design of this thesis is mainly structured around the principles of empirical research and quasi-experimentation. Empirical research obtains data and generates knowledge through direct and/or indirect observations and experience of phenomena, rather than from theory (Stern Cahoy 2015). In general, a quasi-experiment is "empirical interventional study used to estimate the causal impact of an intervention on target population without random assignment"[13].

Quasi-experimental research resembles traditional experimental design, with the main difference being the lack of randomisation pertaining to the assignment of both interventions and target populations. Defined criteria are used for the selection of interventions and target populations, rather than random assignment[14]. Within the context of this thesis, the selected interventions are represented by our analytical approaches (stylistic, microscopic and nuclear), while the target population takes the form of selected (non-randomised) metal artefacts.

Although quasi-experimentation has been criticised because of its lack of randomization, the model has definite advantages when randomisation is not practical or reasonable. In the context of this thesis, randomization cannot form part of the research design, as the sample group is extremely limited in quantity. Also, because object size and thickness influence the

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[13] This definition of quasi-experiment comes from the filed of engineering (Sidhu 2009, 153), with the author adding that "Quasi-experiments are subject to concerns regarding internal validity, because the treatment and control groups may not be comparable at baseline."

[14] https://en.wikipedia.org/wiki/Empirical_research [Accessed 02 June 2018]. Also refer to Harris et al (2006, 16) and Handley et al (2018, 5).

penetrative depth of the beams and subsequent clarity of images (when dealing with radiation imaging), the random selection of objects from the sample group would serve no practical function.

The value of the quasi-experimental model is that it facilitates *pre-post testing*, allowing preliminary tests to be done prior to the main phase of data collection. This enables the researcher to determine if there are any expected tendencies within the target population and to predict any possible outcomes (dependent variables) that are directly related to known variables[15].

In the context of this thesis, stylistic analyses and surface investigations by means of macro-photography and digital microscopy represent the preliminary (*pre*) phase of investigation, while the advanced nuclear radiography represents the main (*post*) phase. Datasets derived from both phases are then compared and analysed quantitatively.

2.2.2 Experimental Methodology

According to Rabbiola and Porter (2006, 1), “the authentication of ancient metals still remains an important scientific challenge that requires both strict methodology and pertinent criteria”. However, in terms of the methodologies that would facilitate authentication, Rabbiola and Portier (2006, 1) also point out that

> despite the recent development of analytical techniques since these last decades and the new performances to elucidate the origin of objects or to identify corrosion products, no clear and precise methodology is applied for authenticating metals.

In *lieu* of an existing formal methodology, Robbiola and Portier (2006, 1) propose two main approaches when scrutinising cultural materials. The first is a “historical and artistic” approach, which focuses on the identification of style and typology, as well as the temporal origin and history of the artefact. The second approach is known as the “materials science” approach, which focuses on the identification of physical characteristics such as composition, fabrication techniques, alterations and patinas/corrosion. Although, in their schematic representation of the authentication process, Rabbiola and Portier (2006, 2) exclude the “historical and artistic” approach from their study, the duel application of both “historical and

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[15] https://en.wikipedia.org/wiki/Quasi-experiment [Accessed 12/03/2017].

artistic” and “materials science” falls soundly within the mixed-methodological approach of this thesis’s integrated authenticity methodology, as illustrated by Fig. 2.1.

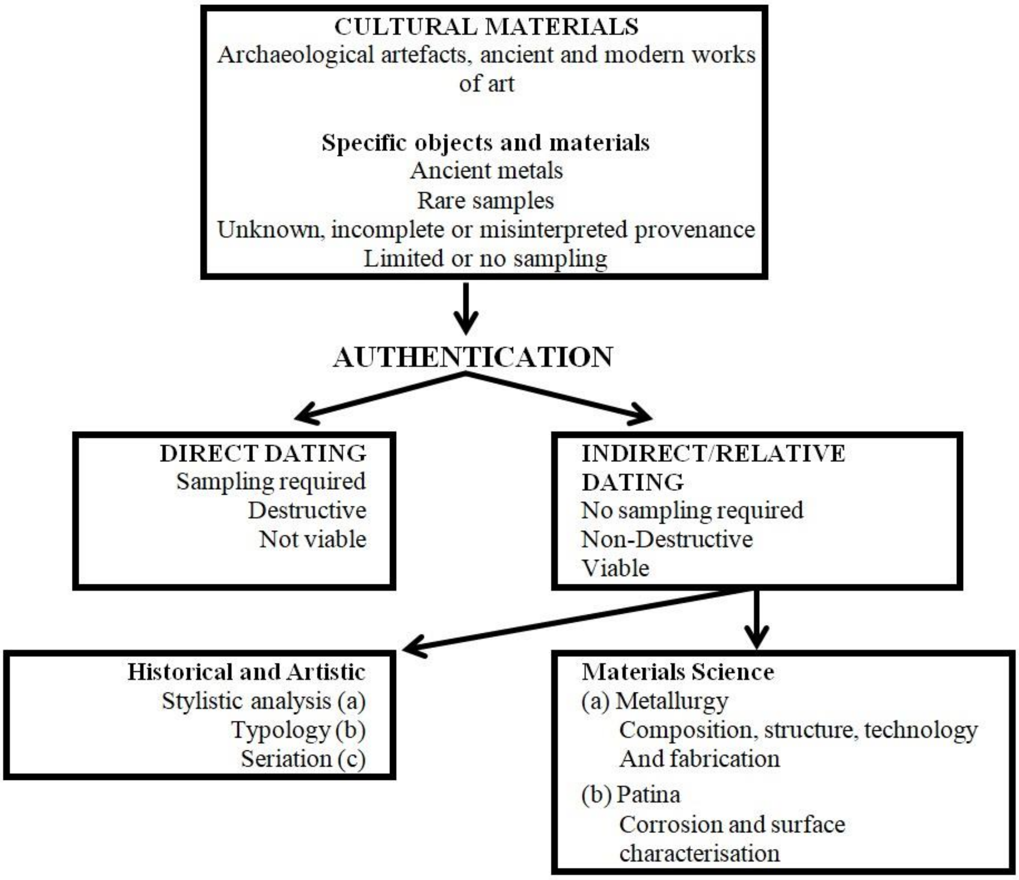

Figure 2.1: A diagrammatic representation of the authentication process.
Adapted from Rabbiola and Portier (20016, 2) to include the historical and artistic approach.

By integrating contributions from human sciences (the historical and artistic approach) and technological fields (the material science approach), the study aims to achieve the maximum degree of multi-disciplinarily, as specified by Siano et al. (2009, 672).

The true value of a mixed method or integrated authentication approach lies not in the creation of large volumes of data itself, but rather with the prospect of one technique providing supportive evidence that can in turn be used to test results obtained by others. Simply put, the more methods that support the presence of a certain phenomenon, the more likely it is for its existence to be real. Therefore, the ideal is to facilitate “a synthesis of artistic criteria, scientific evidence, and personal judgement based on experience” (Goffer 1980, 349). In short, the relevance of mixed methods within cultural heritage diagnostics is explained by Goffer (1980, 347):

> A positive approach to authentication should employ both artistic and scientific criteria, one complimenting the other. Chemical and physical evidence should be used to reinforce stylistic and aesthetic considerations; scientific finding ought to be interpreted in the light of aesthetic standards.

To be more specific, Siano et al. (2009, 674) divide authentication studies into three steps:

1. Archaeological attribution and archival information
2. Interpretation of crafting procedures through optical examinations (naked-eye and microscopy) and radiographic images
3. Material analysis of bulk and alteration levels using TOF-ND and LIPS[16].

Within the context of this thesis, Siano et al.'s (2009) three steps will be represented by:

1. Chapter 3: Literature Review
   Chapter 4: Historical Contextualisation
2. Chapter 5: Stylistic Analysis
   Chapter 6: Surface Investigation
3. Chapter 7: Three-Dimensional Nuclear Imaging (MXCT).

The application of such a three-step process holds the potential to produce data that can be merged and assessed in order to reach multi-disciplinary conclusions (Siano et al. 2009, 674). Therefore, within the framework of an integrated authentication approach, the main focus should fall on material analysis, while typological, historical[17], archaeological[18] and stylistic data should be used to contextualise the results obtained through materials analysis (Siano et al. 2009, 675). Refer to Fig. 2.2 for a diagrammatic representation of this framework.

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[16] Time-of-Flight Neutron Diffraction (TOF-ND) and Laser-Induced Plasma Spectroscopy (LIPS); not to be used within the context of this thesis.

[17] Historical research can provide information on the find site (geographical location) and possible time period (relative chronology), while art historical studies are useful to some extent in interpreting iconography as well as regional stylistic features of objects (Gravette 2011, iii).

[18] In archaeological terms, artefacts represent the material remains of a past society and by studying it, information is supplied about the culture which produced it (Renfrew & Bahn 2004, 9; 61).

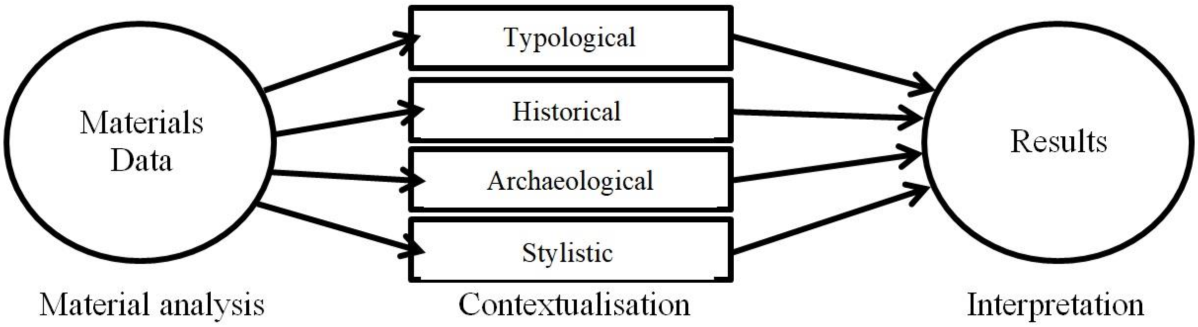

Figure 2.2: A diagrammatic representation of the integrated authentication approach. ***Source:*** The author.

The advantages of using mixed-methodological or integrated authentication approach will be illustrated in greater detail in Chapter 3, when the reader will be introduced to a selection of relevant case studies. Within the context of our comparative study, the above-mentioned section will also provide cross-referable material (both visual and theoretical) for the chapters to follow.

2.2.3 Diagnostic Feature Identification

The identification of physical phenomena is crucial to our understanding and contextualisation of material culture. Schorsch (2007, 189) explains the concept as follows:

> Evident in the archaeological record are *signs* of how meticulously produced works have been altered intentionally, by chance, or systematically as a result of environmental conditions. These insights compliment and sometimes contextualise observations and judgements concerning style, date, iconography, and function [emphasis added].

In addition to an increased understanding of ancient materials and technologies, physical phenomena or *signs* also aid with the authentication process. As Goffer (1980, 349) explains,

> The composition of materials, consistency and structure of decay products, techniques of manufacture, and internal structure of objects are all capable of providing objective criteria for the acceptance or rejection of archaeological objects.

In addition, it is not only the presence of individual *signs* that lead us towards establishing authenticity, but also the relationship between them. For example, the presence of a physical feature may relate to the preservation condition in which the object finds itself. When discussing the relationship between core holes and mineralised support rods, Schorsch and Frantz (1998, 22) note that "we often find that the relationship between such small structural features and their condition provides the most compelling indication of an object's authenticity". This notion goes hand-in-hand with an earlier statement by Schorsch and Frantz (1998, 19) reminding researchers that we "rarely find that a single attribute of an object is sufficient to determine authenticity".

In light of this, the experimental methodology of this study is designed around our observation of physical phenomena (*signs*) that can be classified as diagnostic. These phenomena exist as a result of dynamic processes including (a) ancient manufacturing techniques, (b) ancient use-wear, (c) long-term ageing, and/or (d) contemporary events. It is expected that most of the artefacts under investigation will display a mixture of diagnostic features resulting from a combination of dynamic processes, both ancient and modern. In an ideal scenario, these diagnostic features will also display relationships between one another, thus serving as complementary evidence.

In order to identify diagnostic features, we will use complementary analytical techniques (a) and interpret the results through comparative analysis (b):

a) *Analytical Techniques*

The techniques will be performed in chronological order, as listed:

1. Stylistic analysis. This process will rely heavily on a comparative visual analysis between the DNMCH collection and online catalogues (from museum registries, auction sites, etc.).
2. Preliminary surface investigation by means of macro photography (Canon EOS 550D) and digital microscopy (Celestron high-powered, 600x digital microscope).
3. Radiography and 3D modelling by means of MXCT, located at the Mixed Radiation (MIXRAD) facility, Nuclear Energy Corporation of South Africa (NECSA).

b) *Comparative Analysis*

After the diagnostic features have been identified, each object will be compared (in terms of identified features) to curated examples. As no formal databases exist for a comparative study of these and other artefacts in South African museums, we have to rely on a number of internationally housed artefacts for comparison. Examples will be assessed from online museum catalogues, holding institutes, antiquities dealers and other sites of interest. These objects need to be of a similar age and place of origin in order for us to establish possible cultural links between them and our own collection. A side-by-side comparative analysis will focus on identified similarities in terms of:

Traditional surface analysis: (a) style, (b) decorations. (c) size, dimensions and proportions, (d) workmanship, construction details and techniques, (e) signature, and (f) inscriptions and markings.

Materials science: (a) materials, (b) surface colour, (c) surface texture, (d) surface anomalies, (e) external layer thickness, (f) internal composition, (g) porosity, (h) internal anomalies, and (i) condition.

2.2.4 Theoretical Framework

a) *Establishing Relative Culturo-Chronological Frameworks*

The establishment of relative culturo-chronological frameworks for the objects under investigation represents the cornerstone or theoretical underpinning of this thesis. Chronological sequencing is based on the simple premise that technologies and styles change over time. The concept that one technology/style is either older or younger than its counterpart is the basis of relative dating (Renfrew & Bahn 2004, 121).

To create a relative chronology, we rely on the principles of relative dating, which is further defined by Renfrew and Bahn (2004, 585) as "the determination of chronological sequence *without recourse to a fixed time scale*; e.g. the arrangement of artefacts in a typological sequence, or seriation". This method stands in direct contrast to absolute dating, which is defined by Renfrew and Bahn (2004, 579) as 'the determination of age with reference to *a specific time scale*, such as a fixed calendrical system; also referred to as chronometric dating" [emphasis added].

In absolute dating, advanced methods and techniques provide us with more specific and unambiguous dates. However, these methods (such as radiocarbon-, potassium-argon-, and thermo luminescence-dating, to name but a few) are often destructive in that they require the procurement of physical samples[19]. In contrast, methods of relative dating (such as seriation, sequence dating, morphology and typology) are non-destructive in that they exclude the need

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[19] In addition, Robbiola and Porter (2006, 1) point out that "since metals do not possess physical properties that can be expressed as a function of time, ancient metallic artefacts cannot be directly dated".

for physical samples by relying predominantly on the identification of visual phenomena or characteristics (*signs*) that can be used to categorise objects into sequences, styles and types.

Since this thesis focuses on NDE, it relies heavily on the latter point, namely *type*, which in methodological terms refers to “the systematic organisation of artefacts into types on the basis of shared attributes” (Renfrew and Bahn 2004, 287). Consequently, in order to test the thesis hypothesis, we must work from the scientific supposition that regular patterns present themselves in all natural and man-made phenomena (*signs*[20]), and that the researcher is able to observe and describe the nature and extent of these phenomena, record them and categorise them into *types*.

b) *Illustrating Relationships between Phenomena/Diagnostic Features*

It is also crucial to recognize and illustrate probable relationships between these phenomena in order to better understand their occurrence (Watson et al. 1984, 3–4). In turn, in order to understand their occurrence, it must be kept in mind that the production conditions (independent variables), under which these phenomena (dependent variables) arise, are subject to differentiation and may vary across both time and space. In addition, differences also occur both *between* and *within* the culture(s) that create them. It is also crucial to recognise that as the independent variables change, they will undoubtedly influence both the nature and scale of the dependent variables, all within a temporal framework of “cause-and-effect”.

Independent variables are those that influence the outcomes or effects, while dependent variables are the results or outcomes of independent variables (Creswell 2008, 49–50). Within the context of this thesis, independent variables include manufacturing techniques (i.e. forging, smithing, casting, bending, hammering and sanding), while dependent variables will include phenomena that occur as a result of manufacturing or use-wear (i.e. internal phenomena such as core materials, porosity, and cracks, as well as external phenomena such as decorative lines, polishing striations and rounded edges). By considering these variables (both dependent and independent), and by systematically grouping, classifying and analysing the resulting phenomena by means of comparative analysis, we should be able to arrange the objects within their relative culturo-chronological frameworks (Ciliberto 2000, 2; Scudieri et al. 2001).

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[20] From here on forward, *signs* will be referred to using the more technically correct term *diagnostic feature(s).*

2.3 METHODS, INSTRUMENTATION AND TEST PARAMETERS

2.3.1 Stylistic Analysis

According to Renfrew and Bahn (2004, 427), "style is any distinctive and therefore recognisable way in which an act is performed or an artefact made". To be more precise, objects made during a certain period, at a specific location, by a particular group of people, typically reflect individualistic, recognisable style (Renfrew & Bahn 2004, 124). In addition, artefact variability within a specific artefact category is explained by Heinze (2015, 94) as follows:

> Artifactual variability within a given category, e.g. the different forms and styles of a dagger, is a result of this relationship between form (including material possibilities) and cultural conceptualizations of what daggers looks like (style) and what one can do with it (function). Style and function are, however, not two different dimensions of an object that coexist next to each other, with style adding an aesthetic dimension to the basic form of an object defined by its functional dimension. Rather, style is to be considered a function in itself as it allows for the sending of messages, is communicative and part of one's symbolic capital, with cultural concepts at the heart of every judgment on what is beautiful, desirable, valuable, and allowed.

Thus stated, stylistic analysis goes above and beyond the mere determination of style for artistic or aesthetic value. It is a qualitative endeavour in its own right, which holds the possibility of elucidating information about the object's chronology or typological sequence, and therefore authenticity. In the words of Renfrew and Bahn (2004, 126), "different types of artefact change in style (decoration and shape) at different rates, and therefore vary in the chronological distinctions that they indicate". Therefore, if an object's stylistic attributes can be assigned (with relative certainty) to a specific time period, we can confirm its authenticity with a fair amount of certainty.

Since stylistic analysis is highly comparative, in the sense that unknown objects have to be compared to objects that have been positively curated, the analysis performed within the context of this thesis will rely heavily on existing published works, as well as online archival sources, museum databases and auction catalogues (as mentioned before). Because of the visual nature of this type of analysis, the thesis will provide a comprehensive series of in-text colour images, with the exception of a few grey scale images obtained from publications. The provision of colour images is of utmost importance, as colour profiles, variations and similarities form part of the datasets of this thesis. In addition, certain textural phenomena, shading patterns and other physical visual phenomena are often lost when converted into grey scale.

2.3.2 Surface Investigation: SLR Photography and Digital Microscopy

High resolution photographs were taken using a Canon EOS 400D digital SLR Camera, which offers 10MP at a maximum resolution of 3888 x 2592 DPI. The camera features an EFS 18–55 mm wide-angle lens with a 0.25 mm close-focusing distance, with the latter specifications ideal for object photography. Although the camera comes with a built-in flash, basic guidelines for museum collections photography stipulate that flash photography should be avoided. Thus stated, objects were placed within a home-made light-box that utilises three individual, moveable light sources that ensure uniform illumination (ambient light). To avoid the unwanted formation of shadows, the moveable light sources could be adjusted to accommodate individual objects and the unique shadows they cast.

Digital microscopy was performed using a handheld Celestron Digital Microscope Pro. The 5 MP CMOS digital camera captures high resolution images through a 5-Element IR cut high-quality glass lens. The microscope has a 20x–200x power capability and connects to any computer using a USB port[21]. An adjustable LED light source offers the user the opportunity to regulate the direct light intensity to either reduce glare or highlight certain features.

Digital image manipulation, of images produced by both microscopy and photography, were kept to a minimum to ensure that colour variations and textures were faithfully represented. Image resizing (with aspect ratios maintained), the removal of unwanted backgrounds and the addition of digital photo scales represent the limit of image manipulation.

2.3.3 3D Visual Analysis: Microfocus X-ray Computed Tomography

Through the generous cooperation of the DNMCH, three-dimensional radiography was performed at NECSA's mixed radiation (Microfocus X-ray Radiography and Tomography) facility (MIXRAD). The Nikon XTH 225/320 LC[22] dual source industrial system has a voltage setting of between 30 and 225kV, with beam currents ranging from 0 to 1mA and a maximum power output of 30W (Hoffman & de Beer 2012, 2).

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[21] System specifications can be found at http://www.celestron.com/browse-shop/microscopes/digital-microscopes/handheld-digital-microscope-pro [accessed on 29 August 2015].

[22] Product information can be found at https://www.nikonmetrology.com/en-gb/product/xt-h-225 [Accessed 09/09/2018].

Although the process of 3D nuclear imaging is quite complex, what follows is a brief explanation, from a layman's perspective, of how MXCT works (Fig. 2.3). A radiation source (A) emits a microfocus, stable X-ray beam (225kV with a 3µm focal spot size) (B) directed at a target/object (C). While the beam source (A) and detector (E) remain stationary, the object (C) is placed on a rotating base to ensure that tomograms are captured along a 360-degree rotation. X-rays are then attenuated (a reduction in flux intensity through a medium) based upon the object's material composition, with different materials exhibiting variable attenuation rates based upon their thickness, density and chemical composition[23]. These attenuated beams (D) exit the object and are captured by an x-ray sensitive detector (E) that captures the raw data and transfers it to a data capturing and processing computer (F).

Figure 2.3: Example of a MXCT beam-line setup. A radiation source (A), microfocus x-ray beam (B), object (C), attenuated x-ray beams (D), x-ray sensitive detector (E), computer (F).

Since hundreds of individual tomograms are captured as the object rotates, any form of movement must be avoided during the 30-minute X-ray session. To ensure stability, objects are placed on pedestals made of polystyrene or florist foam, which appear invisible (radiotransparent) on tomograms due to their almost non-existent attenuation values. Using specialised image rendering software (VG-Studio Max), a three-dimensional model of the object is compiled from hundreds of individual tomograms. Once the digital reconstruction is complete, the composition is saved as a "project", and the end-user is able to view objects

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[23] See https://en.wikipedia.org/wiki/Attenuation [Accessed 09/09/2018] and Escudier and Atkins (2019, 12). It is also noted that the absorption of radiation by a target material follows an exponential decay function. Exponenetial decay is where one observes a "decrease in a quantity at a rate that is proportional to its value" (Schaschke 2014: 204). Thus said, for some materials (depending on the thickness), it will not help to increase the x-ray intensity, as no amount of energy will be able to pass through the material. This fact should be kept in mind during the examination of the Egyptian bronze collection, as it explains why x-rays are limited to providing lower resolution images compared to neutron tomography.

using a simplified version of the compilation software, known as myVGL[24]. The user is then able to rotate the model and pan through the object from any direction, allowing for virtual interaction and non-destructive evaluation.

The material composition and sample size of the objects being scanned dictate the parameters entered into the system. Depending on the individual material's attenuation, the kV settings of the system have to be adjusted in order to ensure satisfactory beam penetration. For example, as bronze is known for its high attenuation of X-rays, the voltage was set at 205kV when examining the collection of Egyptian bronzes. As high density materials such as copper and lead (the main components of bronze alloy) offer high levels of resistance to the penetration of X-rays (De Beer 2005), copper filters (which act as monochromating agents by filtering out lower energy x-ray photons) were placed at the beam source in order to reduce possible beam scattering and possible post-reconstruction beam hardening. These measures were unnecessary when it came to the processing of the other objects (helmet, mask, gauntlet and dagger), as their compositions – mainly iron, steel and silver – presented less challenging attenuation conditions.

Beam scattering is an unwanted – yet often unavoidable – occurrence in nuclear imaging. Along broad scientific terms, scattering is defined as,

> …a general physical process where some forms of radiation, such as light, sound, or moving particles, are forced to deviate from a straight trajectory by one or more paths due to localized non-uniformities in the medium through which they pass. In conventional use, this also includes deviation of reflected radiation from the angle predicted by the law of reflection[25].

Beam scattering may in some cases lead to a ghost-like haze surrounding an object that makes it difficult to define the exact borders of an object or distinguish transitional zones between materials types within the same object. In addition, beam hardening may also result in unwanted visual anomalies. Brooks and Di Chiro (1976, 391) explain that if x-ray pass through matter:

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[24] myVGL is a free-to use software package developed by Volume Graphics and is available to researchers at https://www.volumegraphics.com/en/download-viewer.html [Accessed on 07/09/2018].

[25] https://en.wikipedia.org/wiki/Scattering [Accessed on 09/09/2018]. Also refer to the following page for an illustration of electromagnetic scattering: https://cso.kmi.open.ac.uk/topics/electromagnetic%20scattering [Accessed 01/11/2018].

> Low energy photons are preferentially absorbed, and the (logarithmic) attenuation is no longer a linear function of absorber thickness. This leads to various artifacts in reconstructive tomography, [but fortunately] artifacts can be remedied by the additional prefiltering of the beam and by applying a linearization correction to the detector outputs.

With these factors considered, it is of utmost importance that researchers who are new to nuclear imaging consult with trained professionals in the field who are able to distinguish between visual anomalies and active diagnostic features. In all instances, the MIXRAD team assisted the researcher with basic visual interpretations during project compilation.

2.4 LIMITATIONS OF THE STUDY

Throughout the proceeding sections, the relevance of chemical composition has been noted on a few occasions, and will also be referred throughout the remainder of the thesis. Therefore, a seemingly glaring omission from this thesis is the application of non-destructive chemical analysis. The question may arise: “if so important, why not include it in this research?” Unfortunately, time restrictions, limited access to facilities, and the researcher’s personal lack of experience in this field, prompted the exclusion of chemical analysis. However, since chemical analysis can form part of future endeavours (as stipulated on the final chapter’s recommendations for future research), a brief synopsis of its value is included below.

2.4.1 Possibilities for Future Research

Future research into microstructure, chemical composition and corrosion materials can be conducted using a range of techniques. Options include X-ray Diffraction, Inductively Coupled Plasma-Mass Spectrometry, Scanning Electron Microscopy, Electronic Microprobe Analysis, Fourier Transform Infrared Spectroscopy, X-Ray Fluorescence Spectroscopy, and Optical Metallography, as well as Polarised-Light Microscopy. Examples of the applications of these works within the realms of cultural heritage diagnostics are provided in Chapter 3. While Section 2.4.1 summarises the application and value of chemical analysis in the broader sense, Section 8.3.2 will provide detailed recommendations based upon the conclusions drawn from this thesis.

2.4.2 The Application and Value of Chemical Analysis

The analytical study of metals within the field of archaeology is performed within the scope of archaeometallurgy. During the 20th century, researchers set out to identify the possible geological origins of archaeological metals, relying primarily on trace element analysis. However, without the addition of lead isotope analyses, which was only introduced during the 1960s, reliable provenance studies were hard to come by prior to this point (Ben-Yosef 2018, 208). Following its introduction, isotope analyses have focused on determining precise amounts of trace elements and lead isotopes (Siano et al. 2009, 672), which is considerably helpful when quantifying the lead isotope compositions of ancient bronzes, for example. Along with the main elements of bronze (copper and tin), various concentrations and distributions of trace elements (i.e. iron, cobalt, nickel, arsenic, zinc, lead, antimony, selenium, tellurium, gold, bismuth) provide metal alloys with unique elemental profiles. Decades of research has revealed much about ancient metal sources, divulging insights into acquisition strategies (such as mining), local and international trade, manufacturing technologies, ancient social structures and even cultural synchronizations between different cultures (such as Egypt and the Levant) (Ben-Yosef 2018, 209).

One of the most successful approaches to authentication is the chemical analysis of alloy composition and corrosion. The latter, as a product of natural chemical reactions, can be analysed to shed more light on the original alloy from which it developed. This is because "the morphology of the [corrosion] surfaces and the elemental composition of the corrosion products depend strongly on the chemical composition of the alloys" (Constantinides *et al.* 2002, 100). Trace element analyses have therefore proved useful in the authentication of copper alloy artefacts.

This knowledge is of great value, as data on the quantitative elemental composition of artefacts can aid in the allocation of relative dates, as alloy compositions and metallurgical additives were often period-specific, thereby serving as chronological markers (Fortes et al. 2005, 136; Robbiola & Portier 2006, 2). The identification of elemental composition not only allows us to better understand the physical and chemical processes that occurred throughout the artefact's lifetime, but can also aid researchers in identifying production time and region. This is because compositional variations within artefacts are directly linked to the raw materials from which they are made (Scott 1994, 4), with raw material acquisition (mining and trade) and utilisation changing across the Metal Ages (Fortes et al. 2005, 136).

The physio-chemical and trace element compositions of both raw materials and manufactured objects, along with the thermal conditions of production (identified through microstructural techniques, such as ND), can illuminate multiple factors of ancient production. It can help identify the possible origins of raw materials, provide insights on manufacturing techniques and production conditions, as well as identify local and international trade routes. The latter point is made possible through the application of raw material source data, the observance of specialised localised (geographical) production techniques, as well as archaeological object provenance – all while considering the greater socio-cultural context and history of the originating culture.

It is therefore important that we identify the elemental composition of artefacts in order to place them within more accurate culturo-chronological contexts. To do so, a multi-disciplinary approach to chemistry and archaeometallurgy is required (Alberghina et al. 2011: 129), which in itself encourages researchers to employ multiple techniques to obtain complementary data. However, even though elemental analysis can provide us with a wealth of information, Schorsch and Frantz (1998, 23) remind us that chemical analysis is by no means the "be all and end all" of authentication research:

> We are frequently asked to what degree the materials used to make a particular object provide information about its origins. During the fifty years [by this stage, seventy] extensive efforts by many researchers have been made to answer this question with respect to both major-element and trace-element composition of a wide variety of works of art. Despite the successes achieved in certain areas, there are no immediate answers for many types of archaeological objects, and especially for those made of metal.

2.5 CONCLUSION

This chapter commenced with a brief introduction to the principles of empirical research and quasi-experiment – around which the thesis's research design is structured. It was outlined that the research design would focus on the implementation of *complementary analytical approaches* (traditional surface analysis, image-based humanities computing) and *integrated authenticity* towards the authentication of the sample group (metal artefacts). Since the sample group is small, and the analytical techniques limited, the practice of randomised sampling was therefore excluded. In addition, pre-post testing was identified as a strategy, with stylistic analysis, and surface investigation (by means of macro-photography and digital microscopy) representing the *preliminary* ("pre") phase of investigation, and with advanced nuclear radiography (MXCT) representing the *main* ("post") phase. The research design allows datasets derived from both phases to be compared and analysed quantitatively within the framework of an integrated authenticity methodology.

When considering the experimental methodology, the focus once again returned to the application of two complementary approaches: a) the historical and artistic approach (which focuses on the identification of style and typology, as well as the temporal origin and history of the artefact), and b) the materials science approach (which focuses on the identification of physical characteristics such as composition, fabrication techniques, alterations and patinas/corrosion).

The identification of *diagnostic features* was identified as essential to our understanding of material culture and, by extension, the authentication thereof. However, it was made clear that the identification of diagnostic features would only become meaningful if we are able to establish possible relationships between these features.

The establishment of *relative culturo-chronological frameworks* for the objects under investigation was identified as a significant part of the thesis' theoretical framework. In addition, and of equal importance, was the recognition of suspected relationships between phenomena/diagnostic features, and what these occurrences might mean.

The methods, instrumentation and test parameters were also outlined. Stylistic analysis (through comparative visual analysis), surface investigation (through SLT photography and digital microscopy) and 3D nuclear imaging (through MXCT) were discussed in greater detail. The exclusion of chemical analysis was discussed as a limitation of the study, yet its relevance for future research was also made clear.

CHAPTER 3
LITERATURE REVIEW

3.1 INTRODUCTION

While traditional literature reviews offer an overview of existing literature on a specific topic, coupled with an evaluation of each source's strengths and weaknesses, this literature review follows a two-part structure:

- Sections 3.2 and 3.3 will follow a more traditional approach by consulting multiple sources to provide an overview of NDE within cultural heritage, reflect on technical considerations with regards to composite artefacts, as well as identify gaps in the existing body of research.
- Sections 3.4 and 3.5 will focus on the summary and presentation of key research articles[26], in order for them to serve as points of reference (case studies) throughout the remainder of the thesis.

Instead of merely summarising the current knowledge (including substantive findings, theoretical frameworks and methodological contributions) and identifying possible gaps in research, this dual strategy will provide a practicable body of knowledge that can be cross-referred to in the core chapters (5 through 7). Although it is uncommon for a thesis to arrange a literature review literature in this fashion, the presentation of case studies in §3.5 aims to provide up-close, in-depth, and detailed synopses of relevant works, which will be used as a contextual basis for the analysis presented in Chapters 5 through 7. In addition, since the overall nature of this thesis is highly visual, relevant images from the articles under review will be included in the body of the text and will serve as points of reference for the visual analyses conducted throughout the thesis.

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[26] In order to be more efficient in terms of space within the text, sections 3.4 and 3.5 will use the et al. convention to present content authored by multiple contributors. Full author details will be provided in the Reference List at the end of the thesis. In the case of online sources, lengthy URLs will also be omitted from the in-text reference but will be available within the Reference List.

3.2 NDE WITHIN CULTURAL HERITAGE

In the not too distant past, the main technique upon which curators relied to authenticate objects, and establish culturo-chronological contexts, was stylistic analysis. Based mainly on an assessment of form, function and decorative features, stylistic analysis became, and still remains, a valuable technique in establishing the authenticity and relative age of artefacts. However, as both style and material appearance can be replicated by skilled forgers, modern technology provides us with a means of adding additional layers of information about the objects in question. This “marriage” of the human and physical sciences holds many advantages for archaeology and ancient history alike.

According to Robbiola and Portier (2006, 1), modern authentication relies on two main approaches;

> The first one is the “historical and artistic” approach, which is conducted in order to identify the style, the typology, the temporal origin and history of the artefact. The second approach, here called the “materials approach”, is based on the characterisation of the materials (structure and composition, fabrication and finishing techniques, alteration or patinas) in order to verify the original features of the object.

NDE has played a critical role in revealing the internal morphological and physical characteristics of artefacts that eluded researchers for many decades. These characteristics remained hidden, as the undesirable effects of destructive sampling prevented their analysis due to ethical concerns (i.e. the damage/destructive of culturally/historically significant objects). Fortunately, the applications of various types of high resolution nuclear imaging techniques and non-invasive chemical analyses have aided researchers in discovering both physical and chemical features that are indicative of specific manufacturing techniques. As a mixed-method approach holds the potential to produce complementary data, the predominant trend in material science today is the consecutive application of two or more NDE techniques. In fact, Robbiola and Portier (2006, 1) believe that “metal authentication requires an inter-disciplinary investigation involving several scientific methods”.

Section 3.2.1 provides the reader with a general overview of radiation imaging techniques and is followed by an introduction to the uses and applications of MCXT (§3.2.2) and NT(§3.2.2) within the field of cultural heritage diagnostics.

3.2.1 A General Overview of Radiation Imaging Techniques

In contrast to the natural sciences, where samples are often infinite, cultural heritage objects are limited and often represent unique examples. Ancient artefacts cannot be replaced if damaged and must be treated with extreme care. Therefore, the researcher should aim to acquire the maximum amount of data using the bare minimum invasive procedures (Adriaens 2005, 1504). For this reason, NDE techniques have become increasingly popular in the cultural heritage sector, as they seldom require physical samples and usually cause little to no physical damage to the object.

In addition, 3D models facilitate a multiplicity of virtual interactions with the object that produce stunning visual data. For example, clipping features allow researchers to "dissect" object volumes to view internal structures. Segmentation tools facilitate thin-section examination that was previously reserved to the realms of thin-section microscopy (a highly destructive technique). Exceptionally accurate measurements can be made using digital measuring tools with a capacity to measure tenths of a millimetre. Materials that share similar densities can also be selected and colour-coded in order to visually stand out from dissimilar densities within the volume dataset. Animations can also aid visual presentations by creating "fly-through" videos that take the viewer on a virtual flight through the object.

Various tomographic systems have been developed, varying in terms of their radiation sources and detector types. When identifying the most appropriate tomographic system, it is essential that the physical characteristics (density and size) of the objects be taken into consideration. For the purpose of our study, two technologies were initially identified, but due to system upgrades to the NT facility, only MXCT was available. What follows is a brief synopsis of both technologies, as well as a sub-section on their complementary use. The justification behind discussing a technology that will not be used within this study lies with the fact that it still holds potential for future research (post-Doctoral research). The thesis also cross-refers to examples taken from existing NT studies on cultural objects, so it is imperative that the readers of this thesis posess a basic understanding of the similarities and differences between X-ray and neutron radiation and what each technique can reveal.

3.2.2 Microfocus X-ray Computed Tomography

One of the most valuable NDE techniques for the full-volume inspection of artefacts is MXCT. X-ray tomography (CT), in simple terms, is "the process of taking a series of two-dimensional X-ray image ‘slices’ through a body” (Lehoux 2013, 111). While traditional X-rays show contrast variations, but fail to illuminate finer interior details (van Langh *et al.* 2011, 951), X-ray tomography is capable of revealing internal anomalies in much greater detail. The method provides data on the composition, structure, texture and phase contrast of an object along various depths and scales (Ryzewski et al. 2013, 344), while achieving one thousand times the contrast perception of traditional radiography (Giuliani, Komlev & Rustichelli 2010, 123).

The ability of X-rays to penetrate an object is directly influenced by the atomic mass number of the material. The attenuation, or gradual loss of X-ray intensity, is relative to the atomic mass number of the material. The greater the mass number (the heavier the atom is), the greater the interaction with the x-rays, leading to the loss of X-ray intensity (Deschler-Erb et al. 2004; Lehmann et al. 2005). In simple terms, X-rays are proficient at highlighting density variations (Rant et al. 2006, 8).

For neutrons, the progression is not that straightforward, being determined by the interaction of neutrons with the nucleus of the target element. In tomography, X-rays are utilised to generate images of phases proceeding from their attenuation coefficient (Giuliani, Komlev & Rustichelli 2010, 123). For a more simplified explanation, we turn to Schorsch and Frantz’s (1998, 22) description of the relationship between darkness, lightness, thickness, porosity and mass:

> For the reader unfamiliar with the interpretation of radiographs, we should note that the darkness or lightness observed in a particular area is a function of both the thickness of material and its atomic mass relative to surrounding areas. In order to interpret the radiographs, one must keep in mind that the whiter regions correspond to the more radiopaque[27] portions of the object that are relatively greater in atomic mass – for example, containing a higher percentage of lead – or that are physically thicker than adjacent areas.

By using the appropriate mathematical algorithms, a “topographical map” of attenuation is compiled along the rotational position of the object (Bouzakis et al. 2008, 635) in a process

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[27] Radiopaque is a term used to denote objects/areas that appear opaque (non-transparent) to radiation. Such areas attenuate radiation and appear whiter/lighter than radiotransparent areas. As the name suggests, the term radiotransparent refers to an object/area that allows radiation to pass through (without attenuation) and appear black/dark.
https://www.medicinenet.com/script/main/art.asp?articlekey=12057 [Accessed 02/04/2018].

known as spatial mapping (Bertrand 2007, 105). The full volume data is then compiled into a 3-dimensional image using computational software packages, such as VG-Studio Max. The researcher is then able to pan through virtual sectional slices of the object from any direction. The technique provides data on the morphological features and physical appearance of internal structures, while preserving the integrity of the artefact (Morigi et al. 2010, 653; Vontobel et al. 2006, 475).

3.2.3 Neutron Tomography

Neutron radiography is a valuable technique for assessing composite artefacts, such as bronze figurines containing clay cores[28]. This is because the different neutron attenuation coefficients of internal materials produce different contrast levels or grey values, allowing non-destructive visualisation (Kiss et al. 2015, 685). Neutrons are also able to penetrate through thick layers of both metal and corrosion deposits[29], making them ideal for visualising objects which cannot be sampled (Kockelmann et al. 2006; Kockelmann & Kirfel 2004), or those that are simply too thick to scan using x-ray tomography. Neutrons owe their penetrative power to the fact that they are only minimally absorbed by the material they pass through, compared with the high absorption rate of photons, protons and electrons in the case of X-rays (Kockelmann et al. 2006; Kockelmann & Kirfel 2004).

In addition, while X-rays interact with the electron cloud surrounding each atom, neutrons are electrically neutral and interact directly with the nucleus of the atom (Giuliani, Komlev & Rustichelli 2010, 156; Ryzewski et al. 2013). While most neutrons pass through material without any interaction, others are either captured or scattered by the material through which they pass (Kockelmann et al. 2006; Kockelmann & Kirfel 2004; ISIS 2015).

3.2.4 The Complementary use of X-rays and Neutrons

Although van Langh et al. (2011) state that “X-radiography only reveals partial information about the production technique of a sculpture”, in fairness, no technique is capable of providing complete or all-inclusive data. This is why it is essential to apply a mixed-methods approach. In this light, Kockelmann et al. (2011, 175) mention that “neutron analysis is both unique and complementary to X-ray techniques”, making it the ideal partner technique. By

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[28] Thermo luminescence is a type of direct dating that can be used to determine whether or not a clay core is ancient or not (Rabbiola & Portier 2006, 1).

[29] Seeing “through” corrosion deposits is a valuable research tools, especially in the investigation of corroded ancient bronzes. This stems from the fact that the surfaces of ancient bronzes are found within the corrosion layers. In order to reveal these surfaces, one would have to employ either chemical or mechanical processes of cleaning, neither of which are truly desirable, as both can cause unexpected damage (Born 1989, 182).

employing both techniques, alternative yet complementary data is obtained based upon the variable interaction between X-rays and neutrons upon the transmission medium (the object), which effectively results in the provision of diverse contrast information between techniques (Deschler-Erb et al. 2004, 648; Lehman et al. 2004, 4). In this way, complementary data is acquired that can be combined and superimposed. This provides the researcher with exceptional quantitative and qualitative analytical tools for artefact examination (Koleini et al. 2012, 252).

In general, the penetration of X-rays through certain metals is limited (Lehmann et al. 2005, 69), compared with the penetrating capacity of neutrons, with the latter being much greater (Giuliani, Komlev & Rustichelli 2010, 156). While certain metals such as gold, silver and lead appear almost radiopaque (high contrast) to X-rays (Rant et al. 2006, 8) neutrons allow most metal objects to appear more radiotransparent (Adriaens 2005; Lehmann et al. 2005)[30]. This is particularly true for metals like copper, tin, iron, bronze and lead (Lehmann *et al.* 2010, 272; Rant et al. 2006, 8; van Langh et al. 2011, 951) or alloys containing lead, bismuth or uranium, which usually appear black in X-rays (Giuliani, Komlev & Rustichelli 2010, 156; Rzewski et al. 2013, 344). Because of this, neutrons provide much better contrast when compared with X-rays (De Beer at al. 2009, 167).

Neutrons can also pass through bronze (as a transmission medium) with greater ease than X-rays. Therefore, varying attenuation, caused by fluctuating energy levels and material thickness, will not cause image distortion as a result of beam hardening, even among smaller samples (van Langh et al. 2011, 951). This makes NT the preferred technique when dealing with bronze items, especially smaller samples. However, NT cannot serve as the only analytical method, as certain anomalies identified by this method can only be identified in full by applying complementary data obtained from methods like ND and XRF (van Langh et al. 2011, 955). For example, while differences in neutron attenuation can identify the presence of different bronze alloys (van Langh et al. 2011, 955), it cannot identify the elemental composition directly. In addition, since radiography also does not provide direct information on crystals or phase microstructure (Kockelmann et al. 2006, 178), it is important to employ a complementary non-destructive techniques such as ND.

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[30] Lehman et al.'s (2004) article represents an excellent example of how the same objects boast different radiopaque or radiotransparent features based upon the type (x-ray vs neutron) of radiation employed.

In support of conventional X-rays, the results of Jacobsen, de Beer and Nshimirimana's (2011, 240–243) confirmed that X-rays are more suitable for scanning ceramics than neutrons, which should be kept in mind when scanning bronze objects with clay cores. Also, because organic materials are less transparent to neutrons (Lehmann, Hartman & Speidel 2010, 416), neutron radiation provides better contrast in organic objects such as wood and fabric (Lehmann et al. 2005, 69), revealing more detailed structural characteristics (Deschler-Erb et al. 2004, 653). Because neutrons can penetrate metals with relative ease, the underlying wooden structures can be seen "through" the metal casings. For this reason, composite items made of wooden cores enclosed by metal plates or castings, are best investigated by means of neutron imaging (Lehmann, Hartman & Speidel 2010, 416).

While X-radiation is attenuated by materials with a high atomic number, neutrons are attenuated by hydrogen (Bettuzi et al. 2015, 1162) or hydrogenous materials (such as organic materials, water and water-logged materials, tar and resin) (Rant et al. 2006, 8). X-rays interact weakly with hydrogen, while neutrons interact strongly with hydrogen. In objects containing hydrogen, or those that have been treated with substances containing high levels of hydrogen (such as stabilizing resins and adhesives), the attenuation for thermal neutrons (neutrons with energy between 0.01 eV and 0.1 eV) is greater. This effect is known as neutron scattering (Giuliani, Komlev & Rustichelli 2010, 156). The interaction between neutrons and hydrogen often results in a bubble or cloud effect in neutron images, as hydrogen has a scattering effect on neutrons. For this reason, neutron imaging is best performed prior to the application of such substances (Deschler-Erb et al. 2004, 653), but can therefore also help to identify past treatments. Along with hydrogen, neutron radiation is also attenuated by calcium and nitrogen, which allows for the detection of organic components[31].

While neutrons provide us with a greatly enhanced probability to visualise hydrogenised materials inside metal artefacts, x-rays provide us with visualisations reflecting the object's physical integrity. X-rays also have the added advantage of seeing through organic materials to detect internal metal parts (Rant et al. 2006, 8).

For a three-dimensional object to be created, whether it is via conventional X-rays or neutron imaging, it is essential that the following conditions be fulfilled: (a) the radiation must be able to pass through the entire object, and in doing so, (b) the radiation must interact with the

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[31] This was demonstrated when several Egyptian bronze falcon statuettes, from the Walters Art Gallery in Baltimore, Maryland, were found to contain bird mummies (see Agresti et al. 2016).

material in such a way that it creates suitable contrast for visualisation. This means that the item should not be solid or impenetrable to radiation, but should also not be completely transparent to it (Koleini et al. 2012, 247).

The ways in which radiation interacts with objects, depends on the nature and composition of the object, along with the type of radiation wave being employed. Since the objects under investigation in this study are of a composite nature – consisting of various components made from different materials – the following section will discuss a number of technical considerations that should be kept in mind.

3.3 COMPOSITE ARTEFACTS: TECHNICAL CONSIDERATIONS

When analysing artefacts, a rather simple notion should be kept in mind in terms of material composition; the larger the object, the more likely it becomes that the object consists out of multiple parts. The converse holds true for smaller objects; the smaller the object, the more likely it is that the object is made from a single component. The complexity of the object also plays a role in the variety of materials and components that are employed. For example, it would be nonsensical to create a small (4 cm x 3 cm) bronze statuette from individual components if the technology exists to cast it as a single unit. On the other hand, it would be pointless to waste a huge amount of metal to cast a larger (30 cm x 40 cm) bronze statue from solid bronze, if individual components, such as the torso, could be filled with cheaper material (such as a clay or wooden core).

3.3.1 Material Type and Conservation

As the name infers, composite artefacts consist of a number of different components, which in most instances differ in material type (i.e. metals, organic elements, fired clay, etc.). These components all react differently to environmental conditions; undergoing individual processes of deterioration and deformation, in different ways and at different rates. Although these processes are highly individualised, the resulting products of deterioration can have adverse effects on the preservation of surrounding materials (Dalewicz-Kitto et al. 2013: 35).

In addition, deteriorating materials may become so fragile over time that their neighbouring components pose a threat to their longevity. For example, textile components may become so fragile over time, that contact with their adjacent rigid or abrasive metal components may cause damage (Breeze 2008, 1). Another example would be the deterioration of organic components; in which case the absorption of environmental moisture would pose a direct threat to surrounding metals or alloys.

A further example comes from the research conducted by Tornari et al. (2008) on the holographic inspection of dimensionally responsive artwork materials. In artefacts containing hygroscopic materials – such as wood, bone, adhesives, varnish and lacquer – changes in humidity and temperature may lead to dimensional changes. These dimensional changes create strains that adversely affect mechanical integrities, such as the adhesion strength between constituent layers. Because composite artefacts consist of diverse materials with differential porosity, hygroscopicity and elasticity, the resulting stresses usually appear heterogenic or non-uniform (Tornari et al. 2008, 8402).

3.3.2 Material Type and Non-Destructive Evaluation

Researchers must also be cognisant of the fact that, while examinations are conducted within the framework of NDE, certain materials are vulnerable to radiation exposure. This holds true, not only for organic materials included in the original design of the artefact, but also organic compounds applied during restoration. For example, what may be non-destructive towards the metal alloy, clay core or faience inserts, may not necessarily be non-destructive towards the organic polymer adhesive used in restoration efforts. One specific example of such an instance presented itself in this research, but details will be provided in Chapter 7.

3.3.3 Implications for Interpretation

Certain mechanical and chemical processes cause physical anomalies that can be linked to long term aging and/or the object’s contemporary exposure to unfavourable environmental conditions, rather than ancient production methods or use-wear. For example, certain processes, such as the flaking of gold leaf, could be interpreted as the result of decaying adhesives (due to rising humidity), rather than the lack of heat treatment during ancient manufacturing. In addition, one should also consider the effects that certain antique restoration efforts had on objects. In the early years of museum conservation and restoration, chemical treatments were often performed without the long-term effects of such treatments being known. At first, these applications might appear beneficial, but over many decades, the treatments themselves begin to fade or flake. This may cause an object to have an outward appearance that may result in an erroneous determination of age.

3.3.4 Period-and Culture-Specific Variables in Production

Ancient artefacts often contain “hidden treasures” that take the form of previously unknown or unidentified components and materials, which may elucidate information on manufacturing processes, object use and period of origin (Lehmann et al. 2005:68). For example, in the case of ancient metal artefacts, these objects represent unique compositions that were made long before the age of industrial standardisation (Zhang et al. 2009, 80). Through physical characterisation and identification of diagnostic features, we are able to “reverse engineer” certain ancient fabrication processes (Artioli 2007, 899; Rant et al. 2005). In the process, we foster a greater appreciation of ancient technologies and craftsmanship within their respective periods and cultures (Adriaens 2005, 1504).

Within the context of this thesis, the analysis of composite artefacts will allow the researcher to collect and compare data on several different material types within a single object. The kind of diagnostic information that is obtained will depend on the type of material (metal, clay, leather, etc.) under investigation (Adriaens 2005, 1508). For example, in the analysis of metal objects, physical anomalies may divulge information on the type of metal alloy used, as well as the manufacturing techniques (casting, hammering, bending, etc.) that were employed. Complementary information can help us to understand ancient trade and sourcing of raw materials, production methods, technological evolution and even regional skills development. These elements can then be used as diagnostic features in the assessment and subsequent authentication of artefacts.

Although we would like to readily identify period-and culture-specific variables in production by comparing our results with similar objects from same cultures and/time periods, this is not always possible. In fact, diagnostic features identified among similar objects from different cultures, time periods and geographical regions can be used in comparative analyses, as physical anomalies are often related more directly to material properties than cultural influences on production. In simpler terms, we should not limit ourselves to the study of ancient Egyptian bronze statuettes when, for example, we are investigating a specific anomaly (chaplets and casting holes). As similar production techniques were employed in bronze casting throughout much of the Ancient Near East (ANE), we may identify similar anomalies from objects that originate from other cultures. We should therefore look further afield and compare technological similarities across different cultures. In defence of this approach Scott (1991, 74), in his study of Pre-Hispanic gold wire from South America, argues that,

> The use of the same, or similar, technologies for the manufacture of wire in the New World as compared to the Old need not be problematic. The careful observation and manipulation of gold by ancient craftsmen could explain why technological processes are often the same, without postulating the transmission of knowledge by diffusion.

Along similar lines, James's (1972, 41) statement on the continuation of production methods and techniques for gold beating, provide additional support for this argument:

> Modern gold-beaters have declared that the attitudes adopted by the beaters, and the nature of the anvil and hammer used, suggest that the ancient beating technique was very similar to that used in Europe since at least mediaeval times.

With both statements considered, we must keep the following point in mind during comparative analysis. Similar objects may share similar production materials and methods – and by extension, physical phenomena – even though they were made by ancient cultures that existed worlds apart. The same holds true for objects that exist within the same culture but are separated by decades or even centuries.

In addition, it is not only well-curated, authentic objects that can serve a purpose within comparative analyses. Surprisingly, we can (to a certain extent) consider modern forgeries as period-specific variables in production. Although these objects mimic their ancient counterparts stylistically, the methods employed in their production will differ vastly, thereby serving as chronological markers in their own right. With specific reference to the usefulness of modern forgeries, Schorsch (1988, 41) provides us with basic guidelines for comparative analyses that are not always considered – our consultation of forgery styles, methods and techniques as chronological indicators and authentication markers:

> If it can be established that a piece is a forgery, and that almost invariably it is an assemblage of features that must be examined and judged, this recognition may be useful in defining the limits of what one can expect to observe on ancient examples.

In short, the identification of forgeries may be controversial (in that they expose our own limitations in terms of curation), and may urge some traditionalists to denounce the worth of forgeries all together, but these objects still hold value – if only in their potential to help identify other forgeries.

3.4 IMAGING METHODS AND TECHNIQUES

This section provides an overview of the most essential literature in the field, comparing global trends in mixed-methods NDE with those applied within the South African context. The section aims to highlight the uses and applications of complementary technologies, rather than provide comparative examples through case studies (which is the aim of §3.5).

Festa, G., et al. 2013. "Simultaneous and Integrated Neutron-based Techniques for Material Analysis of a Metallic Ancient Flute." ***Measurement Science and Technology*** **24: 1-9.**

The research highlights the value of a mixed-method approach, as the application of ND, neutron relative capture analysis and neutron radiography delivered complementary data on a 19th century metallic flute. It was found that the mouth piece and body of the flute consists of different metallic components; lead for the mouth piece and zinc for the body (2013, 6). While the body can be traced to the Frenchman, Charles Mathieu (a 19th century flute maker), not enough data is available to validate the mouth piece as an original part of the flute (2013, 8). However, the re-soldering of the mouthpiece, along with its differential composition to the body, clearly suggests that it was replaced at a later stage. In short, although only one object was analysed, the research highlights the possibilities of using multiple and integrated NDE techniques in the assessment and authentication of composite artefacts, with the strengths and weaknesses of each technique directly related to the material composition (lead and zinc) of each component.

Jacobson, L., et al. R. 2011. "Tomography Imaging of South African Archaeological and Heritage Stone and Pottery Objects." ***Nuclear Instruments and Methods in Physics Research A*** **651: 240-423.**

In this locally (South African) conducted research, the focus falls on the analysis of a tempered ceramic sherd and alleged "engravings" on rock slabs. Although the findings do not bear direct relevance to our investigation of metal artefacts, the study highlights the potential value of applying a mixed method approach, in which MXCT and NT provide comparative data. While neutrons resulted in lower contrast images, X-rays produced images of a higher resolution and displayed better contrast between the matrix and inclusions. It was found that dark spots (radiotransparent) represent voids, lighter areas (radiopaque) represent quartz and grit inclusions, while grey and dark grey parts represent the clay matrix (2011, 241). This information is important to keep in mind when dealing with Egyptian bronze figurines that could potentially feature in-tact clay cores, or even remnants thereof.

Enguita, O., et al. 2002. "Characterization of Metal Threads using Differential PIXE Analysis." ***Nuclear Instruments and Methods in Physics Research B*** **189: 328-333.**

This study employed the Proton Induced X-ray Emission (PIXE) technique to characterise the structure of selected ancient gold and silver threads that were wrapped around silk and cotton cores. The technique provided insight into the homogenous nature of the alloys used to make the threads and also determined the presence, or absence, of certain archaeological trace elements, including lead (Pb) and Mercury (Hg). The research focused on objects belonging to the textile collection of La Alhambra (19th century) and the textile collection of the National Archaeological Museum of Spain.

The study also suggests that the thickness of metal alloy threads can be used as chronological markers (2002, 328) when authenticating artefacts and identifying forgeries. This type of information can prove of great value when analysing the silver threads encountered on the Arabian dagger in this thesis.

Goffer, Z. 1980. "Archaeological Chemistry: A Sourcebook on the Application of Chemistry to Archaeology." ***Chemical Analysis: A Series of Monographs on Analytical Chemistry and its Applications*** **(vol. 55). New York: John Wiley.**

The article provides a review of the work done on a bronze statuette of a horse, which is credited as being an authentic example of ancient Greek bronze work, housed by the Metropolitan Museum of Art. During previous research (conducted in 1967), magnetic surveys suggested the presence of iron while visual inspection revealed what appeared to be a casting fin (1980, 359–360). X-rays also exposed the use of iron wires (armature) in the internal cavity of the statuette, leading researchers to brand the item as a modern forgery. However, doubts among the academic community prompted later researchers to perform more detailed studies on Roman bronzes. The 1969 study of Blumel (in Goffer 1980) revealed that iron armatures were indeed used in ancient Greek statuary. The composition of the metal, its structure and levels of corrosion were also seen as indicative of authenticity. Further research, which incorporated thermoluminescence dating of the core material, proved that the item was indeed ancient, with an estimated age of 2000-3500 years.

Bettuzzi, M., et al 2015. "Computed Tomography of a Medium Sized Roman Bronze Statue of Cupid." ***Applied Physics A: Materials Science & Processing*** **118: 1161-1169.**

In their investigation of a 1st century C.E. bronze statue of Cupid from the J. Paul Getty Museum, the authors included endoscopy, cross-sectional microscopy, X-ray fluorescence (XRF) and X-ray diffraction as part of their preliminary examinations. Through these preliminary investigations, the researchers were able to identify chemical compounds within the patina, measure wall thickness and record casting features such as joints, chaplet holes, casting flaws, air bubbles and minor repairs. Although the introductory information focused on a mixed-method approach, the article's main focus was the showcase how X-ray computed tomography revealed ancient casting and construction techniques.

Most importantly, CT scans revealed that the figure was cast in several parts using the lost wax method, with components being joined at a later stage using either wax-to-wax or metallurgical joins. Lead and iron corrosion deposits on the body also suggest that the item once featured additional attachments (possibly wings) (2015, 1163).

It was noted that metal sheet or wall thickness could also be considered diagnostic when dealing with bronze statuettes, as the methods and techniques of artisans developed over time, thus providing us with chronological markers. According to tomographic examinations, Roman statuettes boast much thinner walls compared to their Renaissance counterparts (2015, 1161). Wall thickness across the entire object may also be used as a diagnostic feature, as thickness variability and consistency represent different production processes. While variable thickness suggests direct work, the consistent tracking of inner and outer contours suggests indirect wax application to the mould (2015, 1166). In the past, researchers relied mainly on ultrasonic measurements to determine wall thickness, but these can now be measured using CT-derived cross-sections.

Lehman, E.H. et al., 2010. "Investigation of the Content of Ancient Tibetan Metallic Buddha Statues by Means of Neutron Imaging Methods." ***Archaeometry*** **52(3): 416-428.**

In this study of ancient metallic Buddha statues from Tibet, neutron imaging revealed that material homogeneity indicates the use of similar metals for different components. Organic glue, wax or lacquer was used to secure decorations imitating gemstones on various positions on the statues, especially the eyes. Interestingly, some statues contained wooden sticks (*tsog-*

sin) rolled in textile. Some statues contain flowers in the lower parts of the figure, while others contained ceramic residues that were particularly noticeable along the internal surfaces.

Kockelmann, W., et al. 2006. "Applications of TOF Neutron Diffraction in Archaeometry." ***Applied Physics A: Materials Science & Processing*** **83: 175-182.**

Microstructural analyses conducted by means of Time-of-Flight Neutron Diffraction (TOF-ND)[32] revealed microstructural evidence of production methods among a selection of synthetic samples (bronze). Texture maps revealed that certain specimens showed signs of working strength and working direction, while the hammered specimens were associated with the alignment of poles in relation to the specimen surface. The results hold relevance in establishing links between texture strength and hardening range (2006, 179). The purpose of using a synthetic collection was to establish as many behavioural patterns (of different alloys compositions) as possible for comparison with ancient counterparts (2006, 179). In their analysis of 16th century silver Taler coins, it was also affirmed that grain orientation can be used to distinguish between minted originals and cast copies (2006, 179), as irregular grain distributions are usually associated with forgeries (2006, 181).

3.5 CASE STUDIES

The following section presents summaries of the most relevant case studies relating to NDE within the realms of cultural heritage diagnostics. Most importantly, the details drawn from various case studies will be used to identify diagnostic features (both stylistic and technical) that may also present themselves during our own analyses. By comparing the diagnostic features from case studies – which have been assigned with relative/absolute dates – with our own newly-identified diagnostic features, the latter will in effect serve as chronological markers themselves. These diagnostic features (as chronological markers) will be used to place artefacts within more accurate culturo-chronological timeframes, thereby allowing us to assess their authenticity.

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[32] Time-of-flight neutron diffraction measures the velocity of scattered neutrons (Gorini & Kamermans 2009, 217).

Lehman, E.H., et al. 2004. "Non-destructive Investigations of Swiss Museum Objects with Neutron and X-ray Imaging Methods." ***Available online*****.**

In this study, the authors highlight how a combination of two related NDE techniques, namely X-radiography and neutron tomography, can provide complementary evidence about sample properties and applied conservation treatments. The study aimed at revealing previously undocumented inner structures, as well as defects and clues relating to ancient manufacturing techniques. A group of Celtic and Roman Era objects from museums in Switzerland were investigated, including a copper alloy finger ring from Kaiseraugst, a coin assembly known as the "Zurich lump", a spearhead from Guibiasco, items from the 3rd century CE Roman bronze collection, as well as an imitation Roman helmet. Although the investigation did not attempt to provide in-depth analyses of the visual data obtained, it did provide side-by-side examples of how X-ray and neutron imaging differ in terms of attenuation values and their related differences in contrast. For example, while the high iron content of the spearhead produced high contrast levels under X-ray transmission, the metal appeared relatively transparent under neutron investigation. While the neutron transmission did not reveal finer detail, NT data proved interesting when considering the object as a whole (Fig. 3.1).

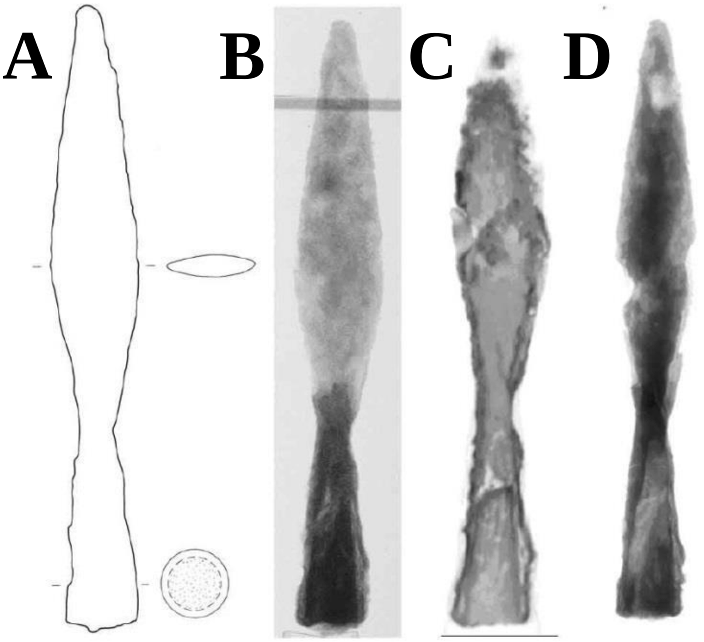

Figure 3.1: The spearhead represented through a line drawing (A), neutron transmission image (B), NT slice (C) and X-ray transmission image (D).
Source: Lehman et al. (2004, 5).

The Roman statue, known as “Merkur from Aster”, has a relatively thick bronze structure and high lead content. Both factors made it difficult to obtain sufficient levels of X-ray transmission through the object – a necessity for providing clear and/or detailed images – even at voltage levels of 150 kV. On the other hand, neutron transmission, which penetrated several centimetres, provided much greater detail of internal features and structural details (Fig. 3.2).

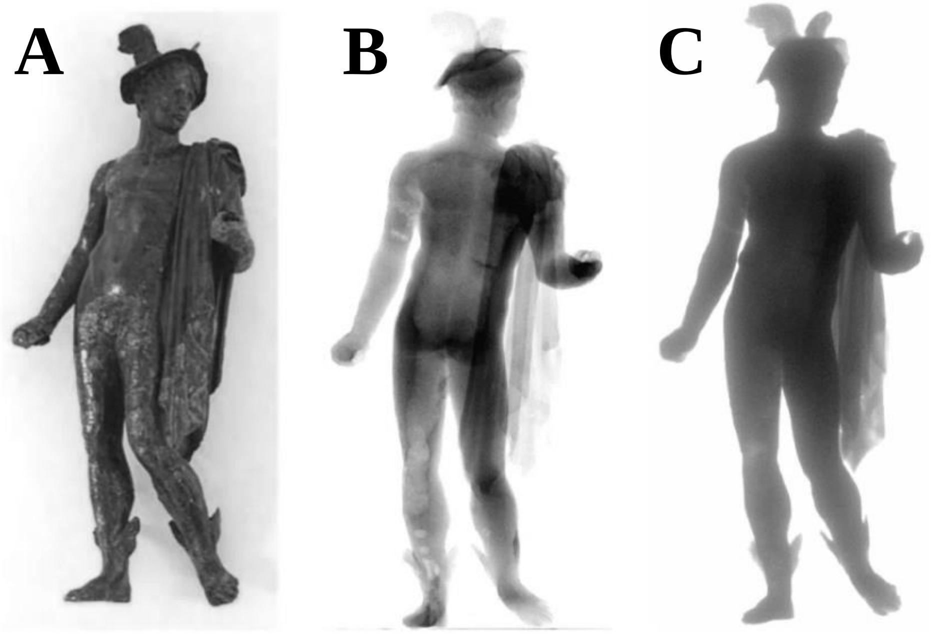

Figure 3.2: The bronze “Merkur from Aster” (A), thermal neutrons (B) and X-ray transmission at 150 kV (C). ***Source:*** Lehman et al. (2004: 5).

What was thought to be the remnants of a Roman helmet[33], and reconstructed as such, was later identified as the metal constituents of a basket or bucket. Nonetheless, what made this object’s investigation interesting, irrespective of its authenticity, was the way in which X-rays delivered better results than neutrons. While the hydrogen atoms within the wood caused high attenuation levels of the neutron beams, resulting in almost no transparency, X-rays passed through the hydrogen atoms undisturbed, providing greater transparency and clearer images (Fig. 3.3).

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[33] It appears as though the original object, thought to be a bucket, was remodelled into a helmet during the early 20th century. The reconstructed object does not resemble typical helmets from the time period in question (Late Iron Age to Early Roman Period). The aim of the study was thus to separate the ancient and modern materials. A major modern element was the use of multiple hidden nails, identified by X-ray.

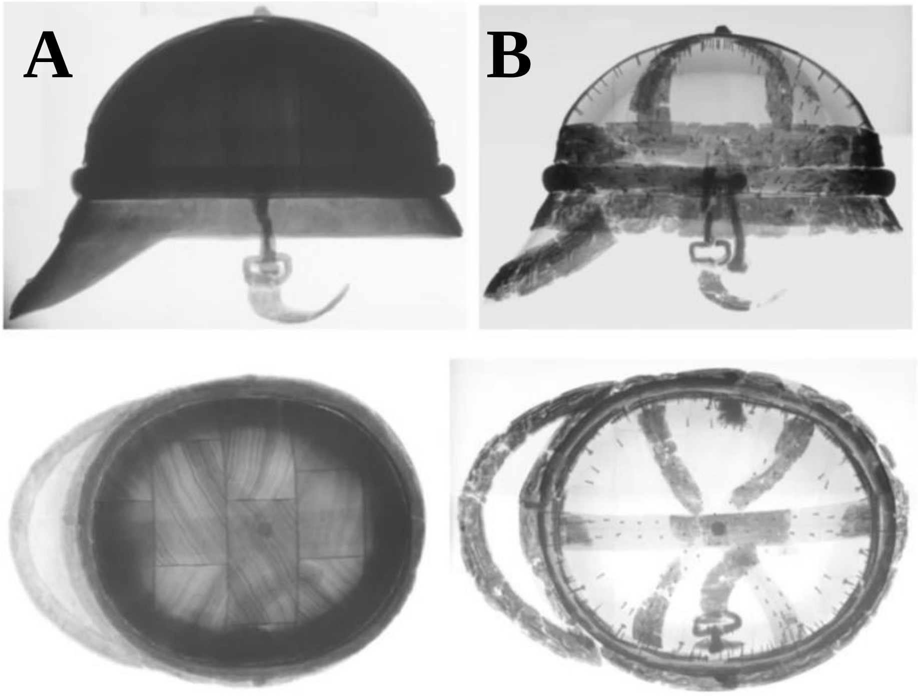

Figure 3.3: A Roman helmet/bucket as observed through neutrons (A) and X-rays (B).
Source: Lehman et al. (2004: 6).

Deschler-Erb, E,. et al. 2004. „The Complementary Use of Neutrons and X-rays for the Non-Destructive Investigation of Archaeological Objects from Swiss Collections.” *Archaeometry* 46(4): 647-661.

The paper highlights the potentials offered by the complementary use of X-ray and neutron beams when investigating metallic artefacts. Iron Age buckets and spearheads were investigated alongside a dagger, gladius (sword) and finger ring of Roman origin.

Under X-ray investigation, the metal gladius (Fig. 3.4) is visible within a scabbard made of layered lime wood. Plating and metal connections are clearly visible, and the differential attenuation levels of brass, bronze and steel provide a clear distinction between these metal and alloy types. Under neutron investigation, the longitudinal lines of the scabbard’s wooden structure were identified. Adhesives and resins used during the conservation process were also identified due to their high hydrogen content (which causes high attenuation of neutron beams) (2004, 650-653)

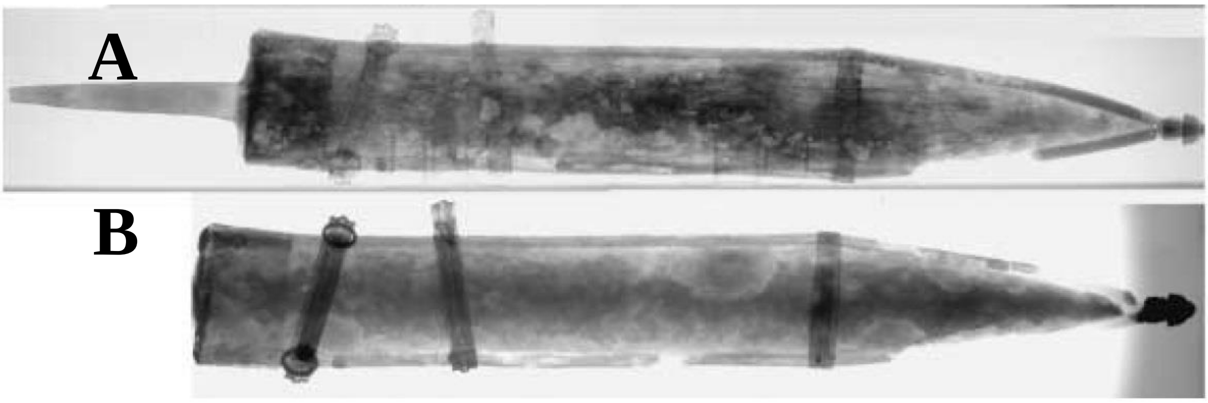

Figure 3.4: The gladius as observed though neutron (A) and X-ray imaging (B).
Source: Deschler-Erb et al. (2004: 652).

Under X-ray investigation, the Roman dagger (Fig. 3.5) from Basel-Münsterhügel features longitudinal tapes from the forged structure of the blade, indicating that the blade could have been damascened. Rivet holes and heads on the hilt do not enter the hilt bar, indicating that they were merely decorative, while two sections of iron cladding on the hilt is joined by means of fixing rivets. Neutrons revealed folding structures, positioned between the dagger and scabbard, were identified as the residual remains of either wool or leather. This indicates that the dagger was wrapped before being placed in the scabbard. Organic filling elements were identified on the hilt, which helped to secure the iron cladding to the iron core. A minimally invasive investigation by microscope identified these fillings as bone (2004, 653-656)

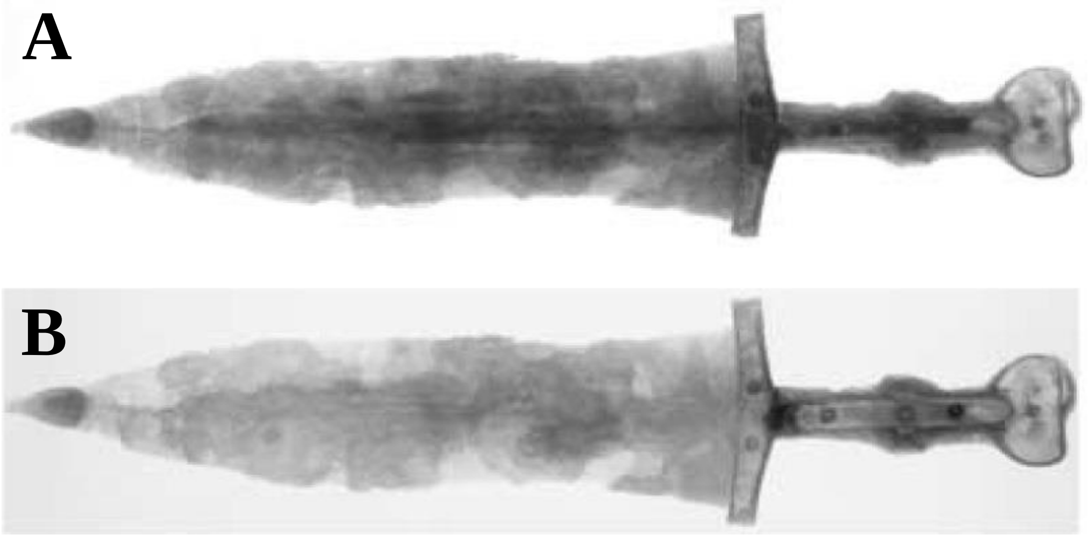

Figure 3.5: The Roman dagger as observed though neutron (A) and X-ray imaging (B).
Source: Deschler-Erb et al. (2004, 654).

Lehmann, E.H. et al. 2005. “Non-invasive Studies of Objects from Cultural Heritage.” *Nuclear Instruments and Methods in Physics Research* A 542: 68–75.

The study notes the importance of performing non-destructive analyses on objects of cultural significance. Also, by using a combination of techniques, the authors were able to demonstrate the value of superpositioning the derived data. The objects used for this research article originate mostly from Roman and Celtic collections in Swiss museums.

The Roman dagger, from the Vindonissa Museum in Switzerland, was in a heavily corroded condition when examined, and it is believed that a few metallic parts were missing (Fig. 3.6A). Under X-ray examination, the high attenuation levels of the metal allowed the researchers to identify areas within the dagger’s internal structure that still consisted of un-corroded metal. The X-rays also highlighted cracks on the blade itself. As these phenomena are ‘hollow’ and therefore do not absorb any radiation, they appear white in contrast to the dark, highly attenuated metal superstructure (Fig. 3.6C). Interestingly, under neutron examination, the adhesive resin that was used to repair the cracks were readily identified by their darker appearance, as the hydrogen found within organic compounds display high attenuation levels. The neutrons also revealed possible decorations along the edge of the blade (2005, 70) (Fig. 3.6B).

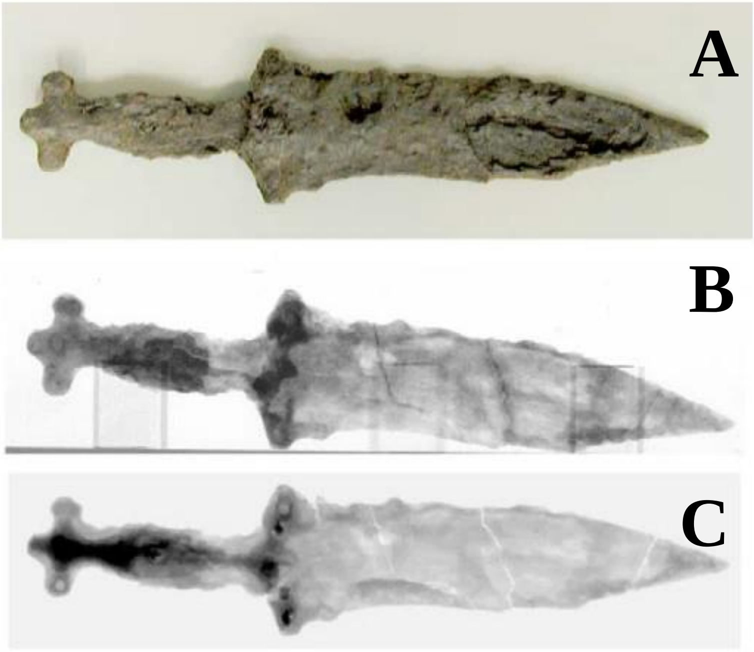

Figure 3.6: The heavily corroded Roman dagger (A) as observed through neutron transmission (B) and X-ray transmission (C). ***Source:*** Lehmann et al. (2005: 70).

The bronze belt buckle, which features decorative millefiori inlays, performed much better under neutron than X-ray transmission. Reconstructed sections of the buckle are visible under neutrons (Fig. 3.7A) but appear completely invisible under X-ray (Fig. 3.7B).

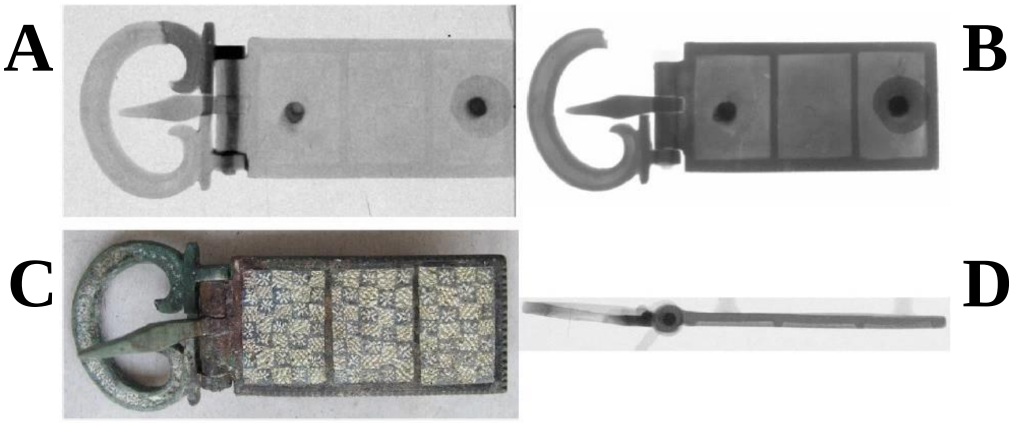

Figure 3.7: The inlaid belt buckle (C) as observed through neutron transmission (A), and X-ray transmission (B & D). ***Source:*** Lehmann et al. (2005, 71).

Postma, H., et al. 2010. "Non-destructive Bulk Analysis of the Buggenum Sword by Neutron Resonance Capture Analysis and Neutron Diffraction." ***Journal of Radioanalytical and Nuclear Chemistry*** **283: 641-652.**

While the study focuses primarily on the microstructural characterisation of the "Buggenum sword", the article includes a brief discussion on radiographic results. X-ray images (Fig.3.8A) show that the hilt is thin-walled and hollow, featuring rib-like ridges. The tang of the blade extends well into the handle, reaching up to the second ring (as counted from the pommel), while the top edge of the blade is attached to the hilt by two rivets. A line drawing (Fig.3.8B) helps to illustrate the construction, as the radiographs do not clearly indicate the edges of the blade itself.

With the complementary data obtained using neutron resonance capture analysis and ND, the team was able to determine that the hilt and the blade are different cast types. The tin content of the blade was high enough to homogenise and harden the edges by means of hammering and annealing. However, the segregation of tin along the centre of the blade, coupled with the presence of a delta phase, indicated that the blade is an "as-cast" object, meaning that it was not subjected to homogenising treatments post-cast (2010, 650). Although a lack of surface use-wear indicates that the sword was used for ceremonial purposes only, the techniques employed in its manufacture suggest that it was a potentially functional weapon (2010, 652).

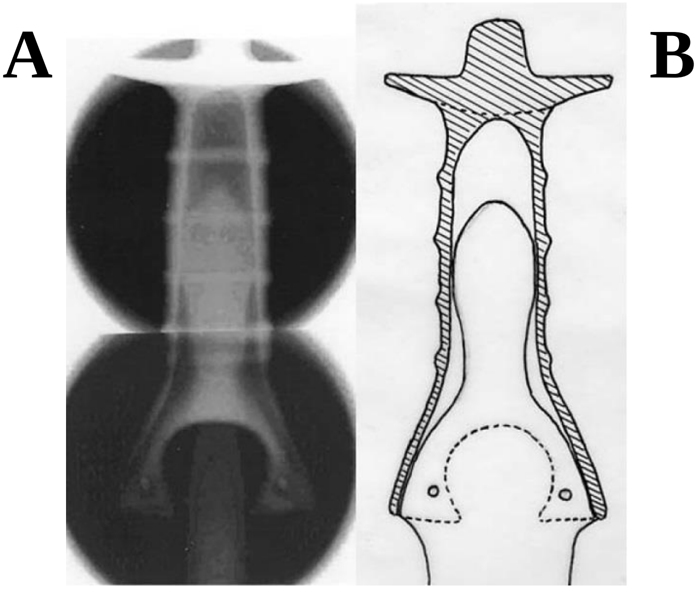

Figure 3.8: The “Buggenum sword” as seen through X-rays (A) and as a line drawing (B).
Source: Postma et al. (2010: 644).

Unfortunately, the article does not provide any information on the internal hollow of the sword handle. It is possible that the void could have been filled with glue, but since organic resins and glues are usually radiotransparent, the presence of such substances can usually only be confirmed by means of direct visual inspection.

Blakelock, E.S. 2010. “The Early Medieval Cutting Edge of Technology: An Archaeometallurgical, Technological and Social Study of the Manufacture and use of Anglo-Saxon and Viking Iron Knives, and Their Contribution to the Early Medieval Iron Economy.” PhD thesis, University of Bradford.

The thesis was undertaken following a review of archaeometallurgical research (conducted during the 1980s and 1990s) on Early Medieval Period (410–11000 CE) iron knives excavated from English, Scottish and Irish sites. Although the original analyses revealed changing manufacturing techniques and varying technological patterns across time and between sites, a re-analyses of the artefacts using more advanced methods was required. For the purpose of this reanalysis, both non-destructive (X-radiographs) and destructive (reflected light microscopy and Scanning Electron Microscope with Energy Dispersive X-ray Analysis, both of which require physical sampling) methods were employed to identify diagnostic features that may elucidate information on the standardisation of production techniques and the differences in quality between urban and rural knives. Most relevant for our own study, was the radiographic investigation of blade condition and use-wear.

X-radiographs were able to identify weld lines and spotted (radiotransparent) regions that are indicative of heat-treated steel along the cutting edge (Fig. 3.9A), while corresponding metallographic sections confirmed the phenomena (Fig. 3.9B–E). Weld lines are particularly radiotransparent due to a lack of slag inclusions and/or a lack of slag penetration (2012, 82).

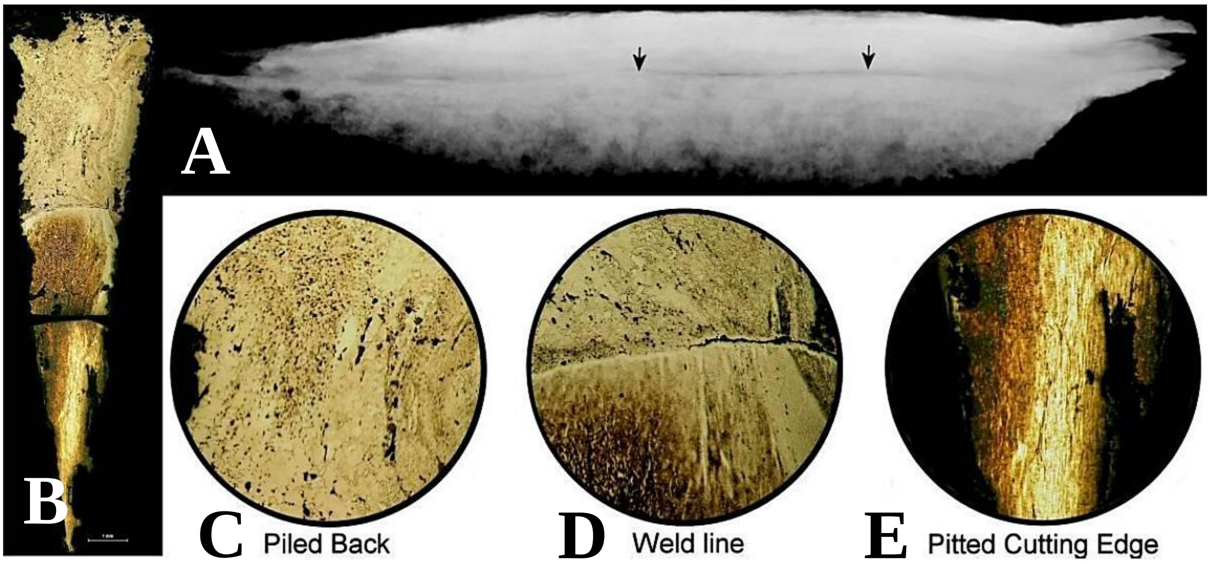

Figure 3.9 X-radiograph (A) and corresponding metallographic sections (B–E).
Source: Blakelock (2012, 82).

X-radiographs were also able to detect use-wear patterns that were directly related to the manufacturing type[34]. For example, Type-1 sandwich-welded knives typically display elongated s-shaped wear along edges (Fig. 3.10A). Traverse notches and straight grooves can also be identified using X-rays (Fig. 3.10B), as these features are quite often masked by thick layers of corrosion. Decorative inlays, created using non-ferrous metals, are often identified through their distinctively bright (radiopaque) appearance (Fig. 3.10C). Non-ferrous metals were also used for specific components, such as the tang to blade interface (Fig. 3.10D). Pattern welding is also observable through the many stations that appear as patterned radiotransparent lines (Fig. 3.10E). Throughout the study, it was also found that the identification of different alloys was based upon their respective densities[35] (2012, 84).

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[34] It does not fall within the scope of this thesis to go into too much detail surrounding the types of Early Medieval sandwich-welded knives.

[35] It must be kept in mind that density itself cannot be used to identify the type (in chemical terms) of alloy used. Differential density and/or porosity between comparative samples can only verify that different alloys were used, but not what these alloys are.

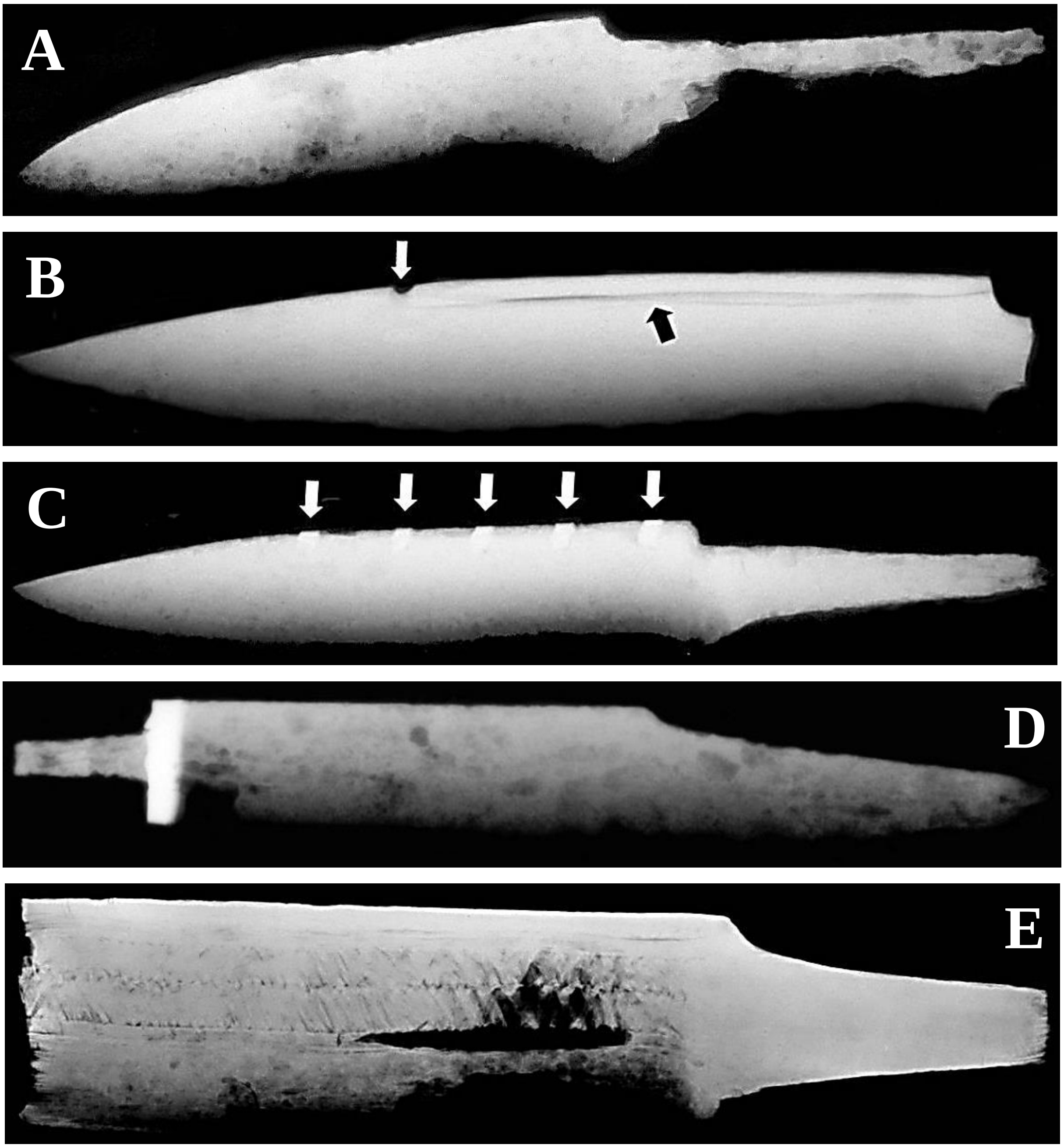

Figure 3.10: Elongates s-shaped edge wear (A), traverse notches and straight grooves (B), non-ferrous inlays (C) and components (D), and pattern welding striations (E).
Source: Blakelock (2012, 83, 158).

The sample group also included a fragmented blade that features remnants of a copper alloy sheet (Fig.3.11). The latter component most likely decorated the knife's scabbard and was reattached to the sample using resin[36] after it became detached during sampling. The object stands as an example of how radiographic techniques can penetrate through layers of different materials and alloys, with the attenuation of each material type resulting in different levels or intensities of radiopacity.

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[36] The radiotransparent nature of organic resin allows these substances to go virtually undetected during x-radiography. Therefore, the presence of organic resin does not influence the visual analysis of metal objects.

Figure 3.11: The copper sheet boasts a characteristic green patina (A), while the x-radiograph is able to see “through” to outer copper sheet (B). ***Source***: Blakelock (2012b, 96).

Deschler-Erb E., et al. 2010. Neutron Tomography as a Valuable Tool for the Non-Destructive Analysis of Historical Bronze Sculptures. *Archaeometry* 52(2): 272-285.

In their non-destructive investigation of a 3rd century CE bronze Roman bust known as the “Mars from Oberweningen”, the authors demonstrate how NT is superior to conventional X-ray tomography, especially when dealing with objects that contain high attenuation metals such as copper, tin and lead. Even with a high voltage (320kV) and the addition of a 2 mm copper filter, the X-rays could not produce images of a nature similar to those obtained through thermal neutrons (Fig. 3.12).

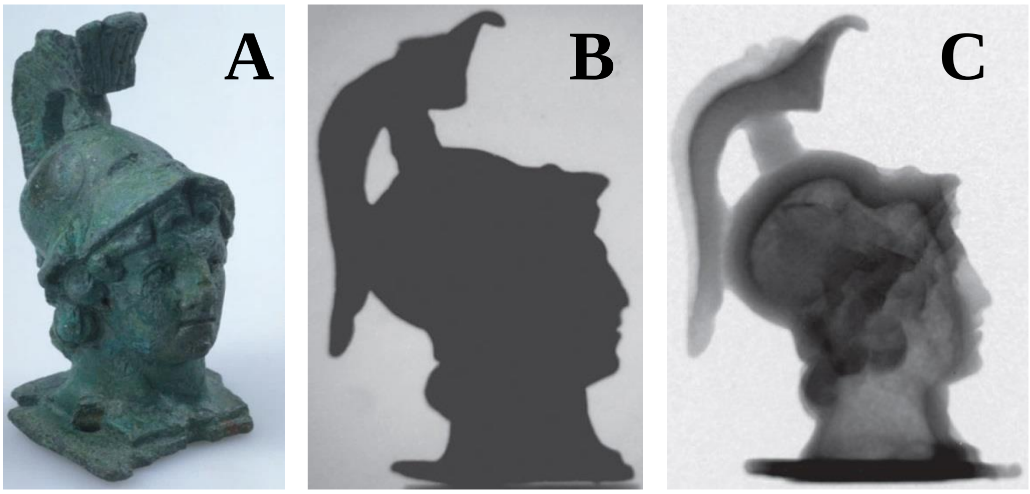

Figure 3.12: The bronze Mars from Oberweningen (A), X-rays (B) and thermal neutrons (C). ***Source:*** Deschler-Erb et al. 2010, 278, 275, 275).

Tomographic slices along two vertical positions show a clear distinction between the bronze cast and the internal fill material (Fig. 3.13). The researchers note that the smooth inner surface of the metal casting, compared with the porous, foam-like outer surface of their internal fillings, suggests that fill materials were applied during secondary phases of production (2010, 279).

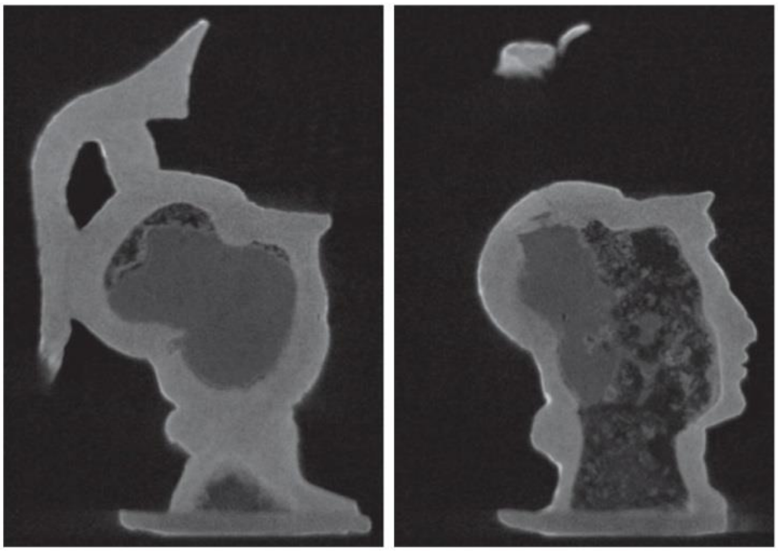

Figure 3.13: Two vertical neutron slices through the Mars from Oberweningen.
Source: Deschler-Erb et al. 2010, 280).

In addition, NT also revealed additional manufacturing clues: nails were used to secure the bronze bust to the internal core, the inner surface of the bronze was relatively smooth, a partial clay core is situated within the inner hollow, lead was used the fill the internal cavities, and an outlet was used to withdraw the core and subsequently used to apply the filling. In the primary state, a clay-core, lost-wax method was used to cast the bust. During the secondary state, the emptied internal hollow was partially filled with lead. Lastly, the bust was attached to a base plate with nails forced through the plate metal to secure it to the lead filling (2010, 281-284).

Van Langh, R., et al. 2011. "New Insights into Alloy Compositions: Studying Renaissance Bronze Statuettes by Combined Neutron Imaging and Neutron Diffraction Techniques.''*Journal of Analytical Atomic Spectrometry* 26: 949-958.

Research into a Renaissance-period bronze, known as the "Striding Nobleman", revealed a number of internal features, which could only be detected using nuclear imaging techniques. The object, housed by the Rijksmuseum, was investigated at an earlier stage using X-rays, which revealed a bar-like structure inside the back of the figure (Fig. 3.14). Although the X-rays provided contrast variations, not enough detail on internal features could be observed (2011, 951). This prompted the use of complementary techniques, including XRF ND and NT. The latter technique (NT) revealed that the statuette was hollow cast, with solid cast arms and legs attached using brass rods and brazing techniques (2011, 954).

These joining methods were rounded off with such skill that they were unobservable with the naked eye. Only through the differential attenuation of neutrons could the researches establish which parts were soldered. On the other hand, the difference in attenuation values between different copper alloys and iron was not great enough to allow researchers to identify and distinguish between these alloys. As a result, NT could not, for example, identify the presence of iron chaplets (2011, 955).

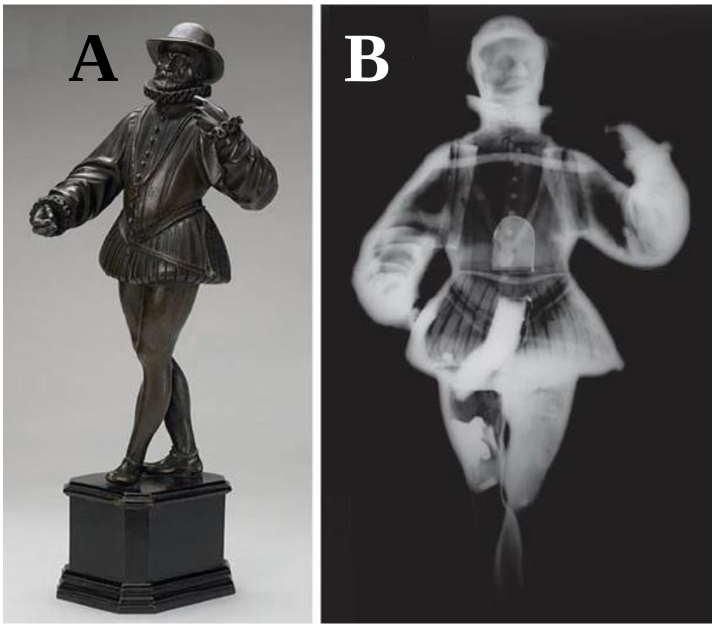

Figure 3.14: The “Striding Nobleman” (A) as observed through X-ray radiography.
Source: Langh et al. (2011, 951).

X-ray fluorescence results revealed that the surface of the statuette was homogenous, which supports the theory that heat treatments influenced surface composition. The alloy composition (including major, minor and trace elements) revealed that the ratio between copper, zinc, lead, iron, nickel and arsenic was typical of Renaissance-period bronze (2011, 955). ND was able to identify three different alloy compositions based upon the lattice parameters of the copper-type phases (2011, 955).

Van Langh, et al. 2009. "The Study of Bronze Statuettes with the Help of Neutron-Imaging Techniques.'' *Analytical and Bioanalytical Chemistry* 395: 1949–1959.

The authors note that, up until the recent past, analyses of Renaissances bronzes were performed through naked eye analysis, microscopy and X-radiography, and that the field could benefit greatly from the application of complementary X-radiography and neutron imaging. For their study, the authors examined a bronze statuette known as the "Hercules Pomarius".

With neutron radiography, variations in the grey scale (caused by differential attenuation) were interpreted as indicative of varying metal thickness between the torso and legs of the statuette. Distinctions could also be drawn between the core material (appearing much darker) and the bronze (appearing in shades of white). It was also noted that while the lower arms, lower legs and head contained core material, the remaining internal cavity was free from such material (2009, 1957) (Fig. 3.15).

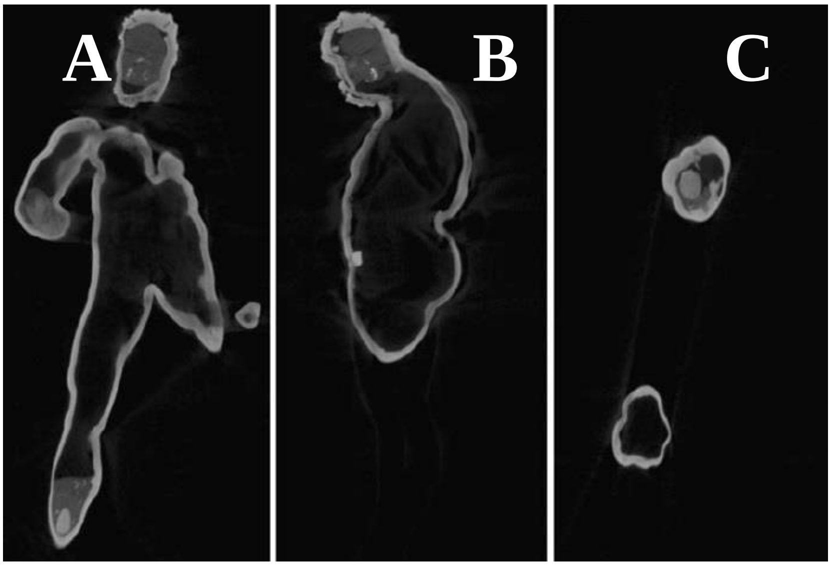

Figure 3.15: Neutron radiography of the "Hercules Pomarius", along two vertical (A, B) and one horizontal (C) cross-section slices. ***Source:*** Van Langh et al. (2009, 1952).

A comparison between X-ray and neutron transmission also highlighted the superior nature of the latter in revealing greater internal detail. This holds especially true when dealing with materials and alloys that are not easily penetrated by X-rays (2009, 1958). To illustrate this point, in Fig. 3.16B, the internal core material is much more visible under neutron investigation than that of X-rays, Fig. 3.16C.

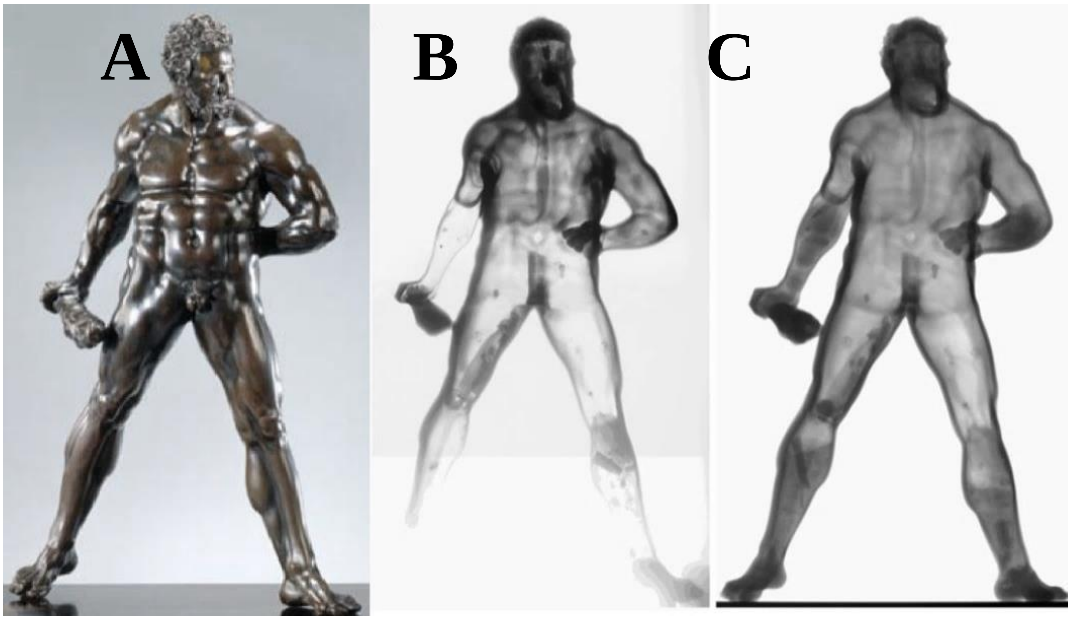

Figure 3.16: The bronze “Hercules Pomarius” (A) as observed through X-rays (B) and neutrons (C). ***Source:*** Van Langh et al. (2009, 1952).

Schorsch, D. 1988. “Technical Examination of Ancient Egyptian Theriomorphic Hollow Cast Bronzes – Some Case Studies.” In: *Conservation of Ancient Egyptian Materials.* Watkins, S.C., C.E. Brown (eds). London: UKIC Archaeology Section. Pp 41–50.

In her analysis of hollow cast ibis-shaped bronzes, Schorsch makes a number of significant technical observations that should be kept in mind when assessing ancient Egyptian bronzes. Perhaps the most important of these, is that no two Egyptian bronzes are exactly alike even though they may share similar stylistic nuances. In fact, one tell-tale sign of forgery is the existence of exact duplicates[37] (1988, 42).

Schorsch also notes that no matter how small, hollow cast statuettes were often assembled from several individual pieces; such as hollow bodies accompanied by solid legs, necks and heads. In some instances, the head may be hollow-cast along with the rest of the body, but in others, it may be cast in solid metal from the neck up. In selected examples, particularly with ibis figures, the legs may be cast as separate entities, only to be joined to the body at a later stage through the use of tangs and socket holes. Ancient tangs are usually rectangular, tapered and cast from solid metal, and double or hollow tangs are usually seen as a good indication of forgery (Fig. 3.17A) (1988, 43).

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[37] This stems from the fact that Egyptian bronzes were not mass produced in reusable moulds but rather that each object’s features were individually carved into the wax model and surrounded by a clay investment material, both of which would be lost at the end of production.

Core supports, used to keep the internal core material in place during last wax casting, where kept to a minimum in ancient bronzes, with the presence of multiple supports generally seen as indicative of forgery (Fig. 3.17B). In addition, the removal and plugging (with lead) of these supports is a practice that was only introduced during the Renaissance, with no examples being observed (yet) in ancient bronzes (1988, 43). Since ancient core supports were hammered, and usually made of more ferrous metals, such as iron, most have been replaced by corrosion material, leaving radiotransparent holes as location markers. Since ancient core pins were all square or rectangular, the presence of round holes suggest modern origins. Ancient sand cores also leave behind more rounded edges along inner cavities, compared with abrupt rectangular edges of modern examples (1988, 44).

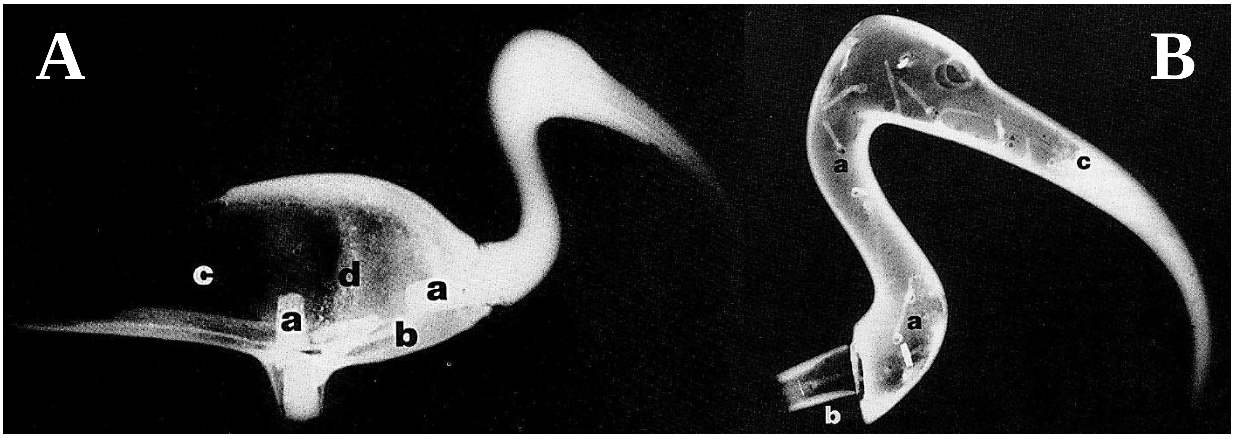

Figure 3.17: Hollow cast ibis with tang (a), sand core (b), radiostransparent wood (c) and lead spotting (d) clearly visible (A). An ibis, believed to be of modern origins boasting multiple cope supports (a), hollow tang (b) and edges of core activity (c) (B). Alphebetical annotations are those of the original author. ***Source:*** Schorsch (1988, 43, 45).

In terms of wall thickness, ancient objects of the same size often show great variation. While modern casts tend to have thicker, more uniform walls, this alone cannot be used as a criterion to recognise forgeries. In fact, even walls are often the result of superior craftsmanship, especially when it came to the meticulous layering and sculpting of the wax. Similarly, irregular thickness may simply be the result of uneven layering by an impatient crafter (1988, 45).

In terms of the radiographic examination of bronzes, Schorsch warns that the positioning of objects during scanning, coupled with beam scattering (and other visual anomalies), may obscure our observation of wall thickness. In addition, the presence of lead (identified as scattered opaque spots), the texture of the core and the presence of corrosion add to the challenge (1988, 45).

Surviving core material often appears in radiographs as a fine grained material with homogeneous radiopacity (1988, 46). Since casting cores were not removed from bronzes, unless the object was specifically intended for use as an animal mummy sarcophagus, the presence of hollow cores on closed cavity bronzes, or the appearance of small holes that have been plugged, are indicative of possible forgeries (1988, 47).

Schorsch D., Frantz, J.H. 1998. "A Tale of Two Kitties." ***Metropolitan Museum of Art Bulletin*** **55(3): 16-29.**

This 1998 article by Schorsch and Frantz provides one of the cornerstones of comparative data within the context of this thesis. In their article, the authors discuss two examples of ancient Egyptian cat bronzes (simply referred to by the authors as the "small" and "large" cat) within the greater context of feline-related mythology and burial practices. Alongside mummified felines, small metal figures of Bastet (either in her form as a cat-headed goddess or as a domestic cat) proved popular in Egypt from the Late through Ptolemaic Periods (1998, 17). In their discussion on the use of cat bronzes as animal sarcophagi, the authors note that they cannot confirm whether or not the two cat bronzes under discussion were used for this purpose or not (1998, 19).

During X-ray investigations, radiographs revealed a number of casting features that share similarities with first millennium BCE hollow statuary. A low porosity cast, well-defined core remnants and vestiges of rectangular core supports (as identified through radiotransparent spots) are clearly discernable on the small cat (Fig. 3.18A). Slight variations in the wall thickness of the small cat are also indicative of the use of refractory cores, a process in which the cores for the head, body and legs were made separately and joined together with wax when the model was shaped. These transitional areas are clearly visible along near the top of the front legs (Fig. 3.18B). The tail, front paws, ears and tip of the nose were most likely created separately, entirely from wax, and joined to the near-complete wax model (1998, 20–22)..

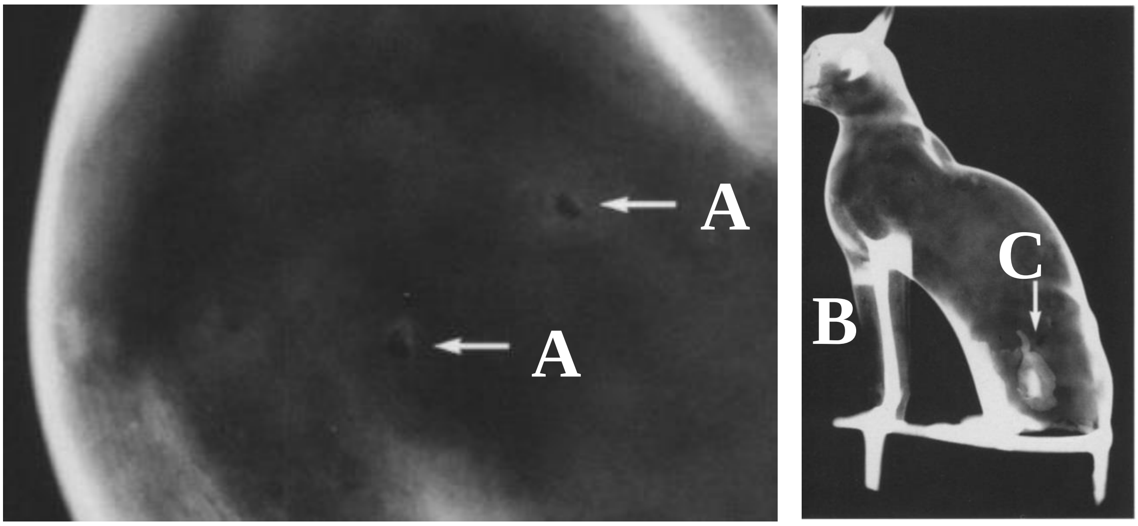

Figure 3.18: Radiotransparent spots mark the locations of where original core pins were located (A) transitional zones (B) and repair work (C). ***Source:*** Schorsch and Frantz 1998, 22).

Two radiopaque zones are also indicative of ancient repair work that was meant to cover up imperfections in the original cast. The ancient nature of the repair work is further supported by the fact that these areas have been completely reworked and smoothed on the surface of the object, so much so that it is completely indiscernible through surface investigations (1998, 23).

X-ray spectrometry confirmed that the bulk composition of the small cat fits well within the range of bronze alloys used during the first millennium BCE (1998, 24), while inter-granular corrosion (microstructural) falls in line with what is expected from most archaeological bronzes (1998, 25).

Ambers, J. et al. 2008. "A New Look at an Old Cat: A Technical Investigation of the Gayer-Anderson Cat." ***The British Museum Technical Research Bulletin*** **2: 1-13.**

In their re-investigation of one of the "Gayer-Anderson Cat" (Fig. 3.19A-B), Ambers *et al.*, (2008) applied a mixed-method approach that combined stylistic analysis, surface investigation (conventional microscopy), internal visualisation (radiography) and elemental analysis (X-ray fluorescence spectroscopy, X-ray diffraction, Raman spectroscopy, gas chromatography-mass spectrometry, and Fourier transform infrared spectroscopy). The surface and sub-surface investigations revealed insights into the object's ancient production and subsequent modern restorations.

X-radiographs (Fig. 3.19C) revealed remnants of a clay core, but otherwise hollow-cast statuette with solid front legs and tail, the latter having been modelled entirely from solid wax during the ancient manufacturing process (2008, 4).

The object had sustained a number of breaks throughout its history, most of which had been repaired in modern times. What is particularly interesting to note is that a group of cracks, which are clearly visible on real-time X-ray footage, emanate from a central point on the cat's head, suggesting that the object received a direct impact at some stage. The damage that was sustained was repaired during modern times by an elaborate "scaffold-type" internal structure (2008, 6) (Fig. 3.19C).

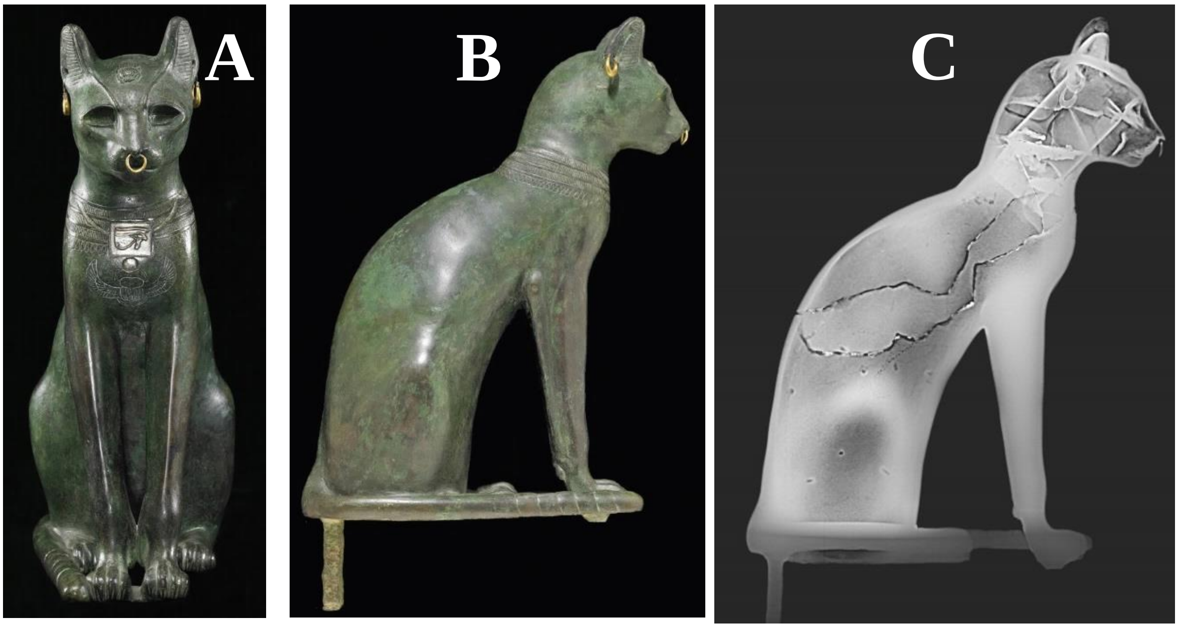

Figure 3.19: The "Gayer-Anderson cat" from the front (A) and side (B). The side-view radiograph shows both ancient and modern elements (C). ***Source:*** Ambers et al. (2008, 2, 4).

The presence of square-sectioned core pins is validated, not only through surface microscopy (Fig. 3.20A), but also through radiography (Fig. 3.20B). The pins share a remarkable resemblance to those identified in the work of Schorsch and Frantz (1998) discussed above.

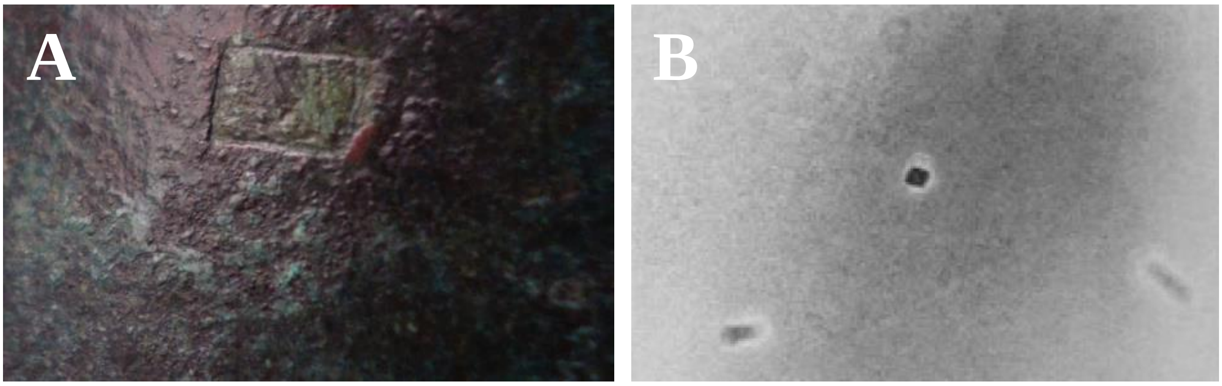

Figure 3.20: Images of square-sectioned core pins as observed through microscopy (A) and radiography (B). Source: Ambers et al. (2008, 6, 5).

The statuette also features an incised collar around the neck which resembles the rectangular-beaded necklaces that were popular in ancient times (Fig. 3.21A). Visual examinations suggest that these multiple incisions were produced through chasing[38] rather than engraving (2008, 6).

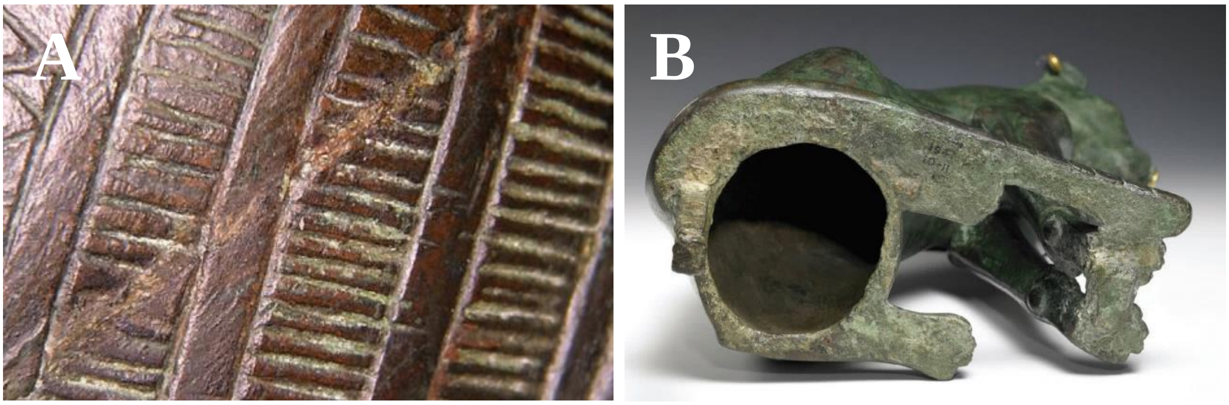

Figure 3.21: The incised collar (featuring a major crack) (A) and the statuette as viewed from below, with the casting hole made obvious (B). ***Source:*** Ambers et al. (2008, 6, 5).

Agresti, J., et al. 2016. "Non-Invasive Archaeometallurgical Approach to the Investigations of Bronze Figurines Using Neutron, Laser, and X-ray Techniques." ***Microchemical Journal*** **124: 765-774.**

The study investigated three ancient Egyptian bronze figurines – a falcon, Neith and Isis – housed by the Egyptian Museum of Florence. The team applied a mixed-method approach to identifying technological features related to ancient production methods by using a

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[38] Chasing is a metalworking technique in which the front of the object is skilfully hammered with tools in order to push the metal aside to create either raised or depressed features. During the process, no metal is actually removed, as would be the case with engraving (https://www.britannica.com/art/chasing). The reverse technique of chasing, known as *repoussé*, is similar but focuses on working the inside/back surface to create a raised surface on the front (https://en.wikipedia.org/wiki/Repouss%C3%A9_and_chasing).

combination of X-ray Fluorescence (XRF), X-ray Diffraction, Raman Spectroscopy, Laser-Induced Plasma Spectroscopy, TOF-ND and high resolution NT.

High-resolution NT revealed the remnants of a clay core and core pins, the latter which had transformed almost entirely into rust (Fig. 3.22). Interestingly, these pins were also identifiable from the surface, which allowed XRF measurements to be taken 'on target'. The results suggested that the now heavily corroded pins were once solid iron – something that was already suggested by the high attenuation levels experienced during NT (2016, 769).

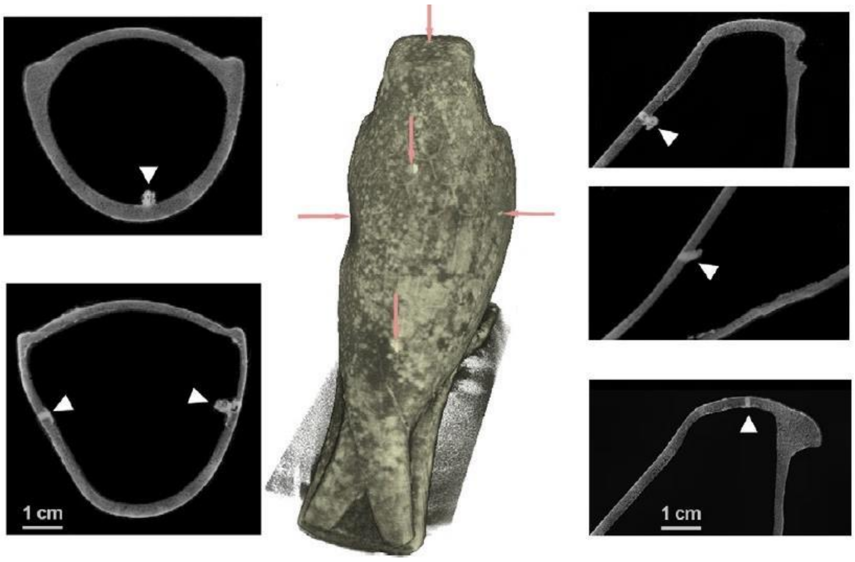

Figure 3.22: The bronze falcon as observed through NT. The arrows point towards the position of corroded iron pins. ***Source:*** Agresti et al. 2016, 767.

Tomographic analysis also revealed the presence of internal material within the empty cavity of the statuette (Fig. 3.23). What is interesting to note is that the core material is readily identifiable though its inhomogeneity, while the surrounding internal alloy surface appears significantly more homogenous by comparison. While the surrounding metal alloy appears smooth, the core material appears fibrous, laminar and elongated – a factor which should indicate the presence of small bones, textiles or other organic materials (2016, 769).

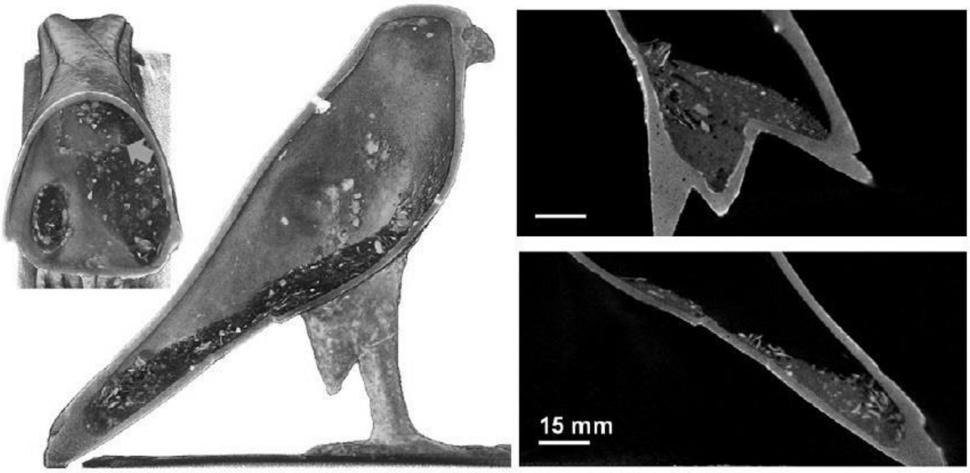

Figure 3.23: NT reveals the remnants of inner core material within the internal hallow of the falcon. ***Source:*** Agresti et al. 2016, 767.

Tomographic analysis of both the Neith (Fig. 3.24A) and Isis (Fig. 3.24B) statuettes provided additional evidence, not only of the use of casting pins, but of the appearance of corroded casting pins (indicated by arrows) within a bronze superstructure.

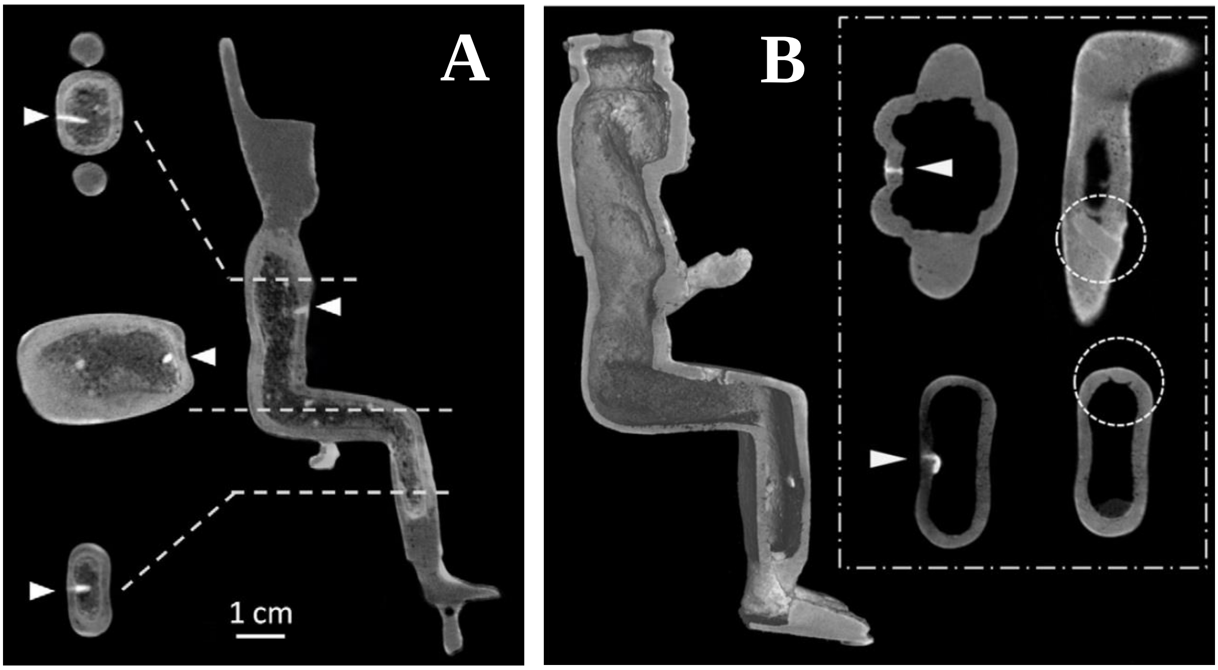

Figure 3.24: NT reveals casting pins within the Neith (A) and Isis (B) statuettes. ***Source:*** Agresti et al. 2016, 771.

In contrast to the hollow falcon, the Neith statuette boasted an in-tact and sealed casting core. The core itself is very rough in shape, with the head and arms moulded directly out of wax, and numerous rusted iron core pins (chaplets) can be observed (2016, 770). The final statuette, Isis Lactans, is a hollow cast figure with solid arms and feet. The figure has three core pins (on the chest, leg and lower back), a repair patch (probably used to cover a casting defect) and only minor remnants of the casting core. A uniform[39] black, alternating to dark red, patina covers the entire surface and is believed to be the result of intentional patination. Certain areas were then gilded with fine gold leaf secured using animal glue (2016, 772).

De Beer, et al. 2009. "Archaeology Benefits from Neutron Tomography Investigations in South Africa." ***Nuclear Instruments and Methods in Physics Research A*** **605: 167-170.**

In their analysis of an ancient Egyptian bronze falcon (Fig. 3.25A) and Child Horus[40] statuette (Fig. 3.25B) from the DNMCH, the authors identified a number of internal phenomena that were deemed as indicative of ancient production methods and materials. A clay core and chaplets, identified by means of NT, were identified and presented as evidence of the lost-wax method (2009, 168-170), without specifically mentioning whether it fell under the direct or indirect method.

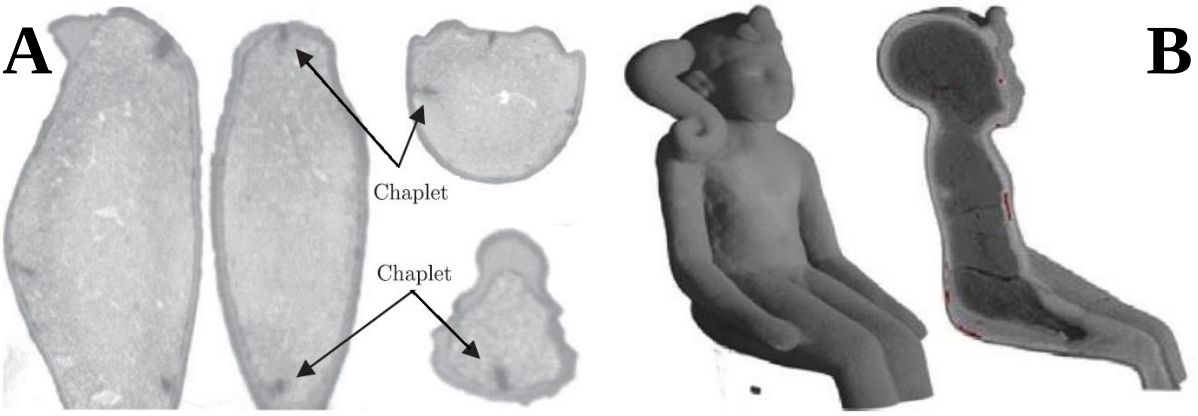

Figure 3.25: Frontal, sagittal and axial slices of the bronze falcon reveal core material and chaplets (A). 3D Neutron tomogram (left) and 3D slice (right) of the Child Horus reveal core material and chaplets (B). ***Source:*** De Beer et al. (2009, 169, 170).

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[39] Corrosion is rarely uniform over the entire surface of an artefact (Savage 1968, 24). In this regard, it is important to note that while exceptionally uniform patinas may be indicative of intentional patination, Bernard and Joiret (2009, 52) remind us that that patina thickness is not dependent on the artefact's age. In other words, while un-uniformity is possibly indicative of authenticity, thickness does not necessarily equate antiquity.

[40] The Child Horus, is typically identified as a child form of the god due to the presence of a pronounced side lock; a hairstyle which characterised male youths during ancient times. Moulded in a seated position, the legs and feet point slightly forward, while the arms are positioned against the body with the palms facing downward. He wears the royal uraeus and boasts a curled side lock of youth. His heart-shaped face and slender smile is reminiscent of the Ramesside Period (18th to 19th Dynasties) (Gravette 2011, 11), while the smile itself beckons towards the 26th Dynasty 'Saite smile' described by Tiradritti (1999, 247; 359).

Smith, A. et al. 2011. "The Examination, Analysis and Conservation of a Bronze Egyptian Horus Statuette." *Nuclear Instruments and Methods in Physics Research* A 651: 221-228.

During further analysis of the Child Horus investigated by De Beer *et al*. (2009), it was highlighted that the indirect lost-wax (clay core) method was used (Smith et al. 2011, 222, 228). X-ray diffraction (XRD) and X-ray fluorescence (XRF) was also used to gather elemental data on the exposed clay core. It was also found that the figure had been cleaned of external corrosion elements, removing vital information in the process (Smith et al. 2011, 223).

A minute tang appears beneath a small base plate, which forms part of the feet. Because of the seated position of the statuette, coupled with the relatively small dimensions of the tang, the tang itself probably prevented the statuette from sliding off its miniature throne, rather than keeping the item in a strong upright position. According to museum records, the statuette suffered a clean break at the lap and front arms during the fitment of new display stands. The break revealed a core consisting of sand, clay and some corrosion materials from the surrounding metal (Smith et al. 2008, 75-76).

Masiteng, I., et al. 2010. "X-ray Tomography, Neutron Tomography and Energy Dispersive X-ray Spectroscopy Investigations of Selected Ancient Egyptian Artefacts." *National Cultural History Museum Journal* 5: 1-18.

The study also made use of combined nuclear radiography techniques (MXCT and NT), but included a third technique which focuses on chemical analysis, namely Scanning Electron Microscopy with Energy Dispersive X-Ray Spectroscopy (SEM-EDS). NT identified internal features of five Egyptian bronze figures, including chaplets, clay cores, solid casts, metal porosity, corrosion and physical damage. One of the bronzes was subjected to SEM-EDS, which provided quantitative data on the elemental composition of the bronze alloy. A small wooden figure (priestly doll) was subjected to MXCT, highlighting previous restoration attempts, cracks, voids, wood grain, penetration depths of paint and physical damage, while NT identified the hollow nature of the platform/pedestal.

Although the study moved towards a mixed methods approach, it failed to subject each object to all three techniques, missing out on the opportunity to gain both comparative and complementary data. Although certain techniques have their limitations, it is still worthwhile to conduct experiments in order to define exactly what these limitations are and how complementary techniques can be used to supplement data.

Gravette, V.F. 2011. “A Critical Analyses of Selected Egyptian Bronze Artefacts in the National Cultural History Museum (NCHM).” MA thesis, University of South Africa.

While this dissertation focused mainly on stylistic and historical analyses of selected Egyptian bronzes (with the goal of authentication), the study produced a number of interesting findings based upon internal investigations by means of NT. The investigation of a heavily corroded Osiris figure (Fig. 3.26A) revealed a clay core encased in layers consisting of ‘copper alloy, textile, gold foil and plaster of Paris’ (2011, 107). Similar scans of a seated Isis figure (Fig. 3.26B) revealed that it was a solid cast. Interestingly, the gas bubbles that had formed during casting were still visible (2011, 8).

Figure 3.26: Seated Osiris figure (left) and neutron radiography (right) showing chaplets (A). Nursing Isis (left) and neutron radiography showing solid casting (B).
Source: Gravette (2011, 4, 5).

Scans also revealed at least three internal chaplets that indicate that the Osiris statuette was made using the clay core lost wax technique (2011, 108). Two of the three chaplets appear as thin, clearly distinguishable grey shapes that extend through the surrounding bronze and into the core material (Fig. 3.27A). The third chaplet appears to be heavily corroded, as the corrosion material has already become partially absorbed by the surrounding core material (Fig. 3.27B). A three-dimensional reconstruction reveals the internal structure of the statuette, with the clay core digitally removed (Fig. 3.27C).

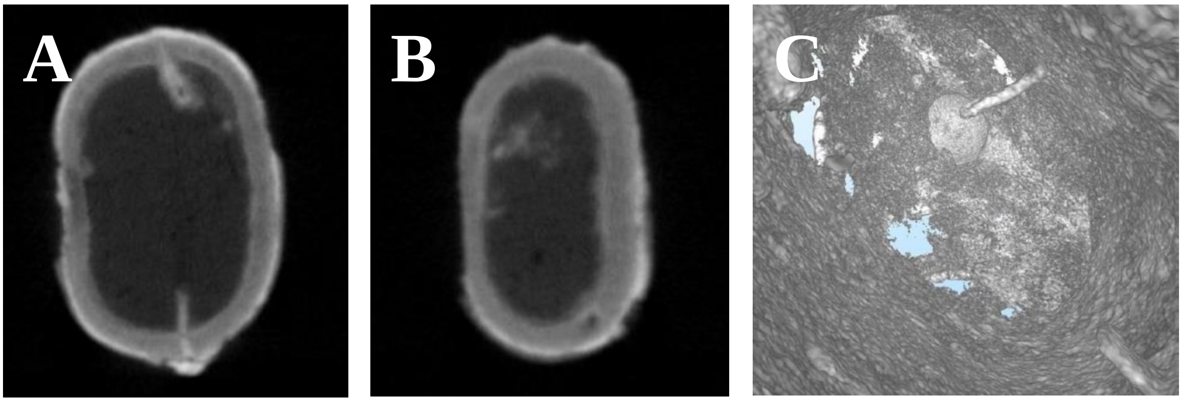

Figure 3.27: 2D tomograms reveal two intact chaplets (A) and one heavily corroded one (B), while 3D reconstruction reveals internal features (C).
Source: Gravette (2011, 108, 109).

Perea, A. et al. 2013. "Pre-Hispanic Goldwork Technology, the Quimbaya Treasure, Colombia." ***Journal of Archaeological Science*** **40: 2326–2334.**

Due to a general lack of archaeological context, attempts to arrange pre-Hispanic gold production along culturo-chronological timeframes have resulted in few conclusions, especially when relying solely on stylistic comparisons. Therefore, the gathering of archaeometric data is essential when determining the technological, metallurgical and chronological frame of the so-called Quimbaya Treasure (which consists of more than one hundred objects). In this study, a wide variety of techniques were utilised, including OM, SEM-EDS, XRF, PIXE, RBS, AMS and X-ray imaging.

X-ray imaging (gathered by means of portable equipment) revealed the skilled formation of internal cores and the artful modelling of homogeneous, thin wax layers. The homogeneous porosity is clearly visible as fine, evenly dispersed dark (radiotransparent) spots on a phytomorphic vessel (Fig. 3.28A). Another phytomorphic vessel includes clearly defined chaplets (bright circular holes) used to keep the core material in place during casting (Fig. 3.28B). A seated figure of a woman (Fig. 3.28C) features repaired voids that are clearly identifiable as bright (radiopaque) blotches on the abdomen.

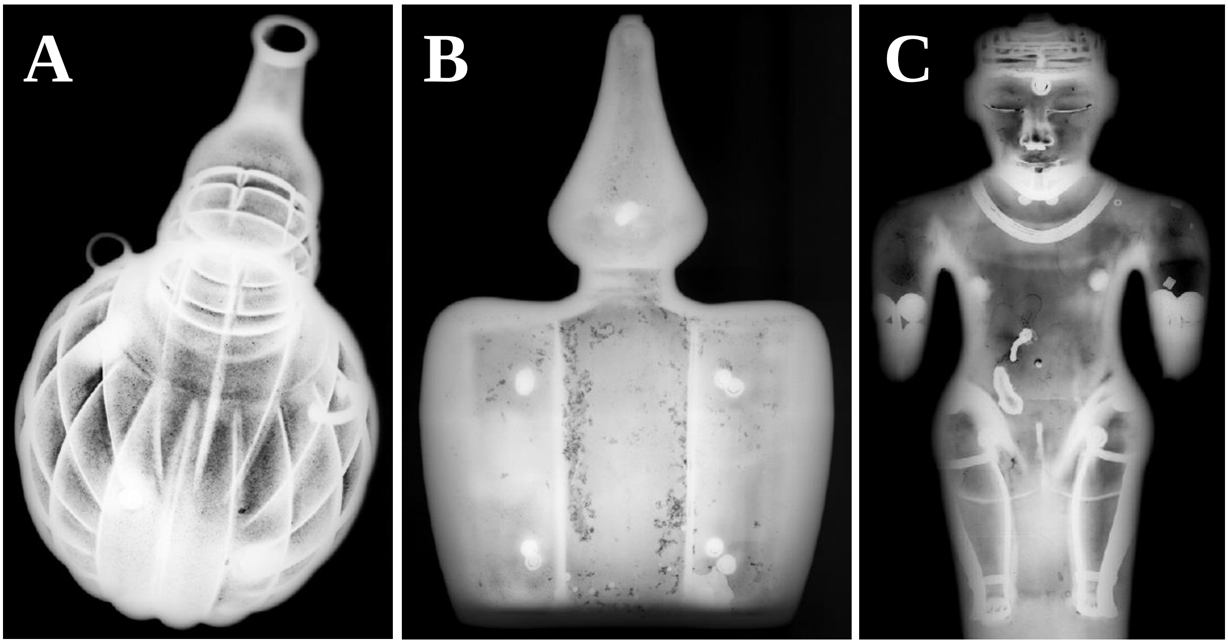

Figure 3.28: X-ray images of phytomorphic vessels (A and B) and an anthropomorphic vessel representing a seated woman. ***Source:*** Perea et al. (2013, 2332–2333).

The performed chemical analyses, coupled with the identified visual diagnostic features, indicate that the objects date from the Classical Quimbaya Period (500 BCE–600 AD) and can be deemed characteristic of a specific phase of gold work production in the area (2013, 2334).

Dalewicz-Kitto, et al. 2013. "Japanese Armour and the Conservation of a Sakakibara Family Armour at the Royal Armouries." ***Journal of the Institute of Conservation*** **36(1): 35-52.**

The research paper details the construction of Samurai armour and discusses the various components. It also presents an account of extensive restoration work performed on a 16th century suit of armour that once belonged to the Sakakibara family. The study confirmed the existence of an interesting practice (known as *kiritsuke kozane*), where certain components (such as shoulder guards) were made using a combination of rawhide and metal lamellae. The material composition of these components can be identified through the use of X-rays (Fig.3.29), as metal parts appear white (radiopaque) while leather appear dark (but not completely radiotransparent due to their lacquer coatings).

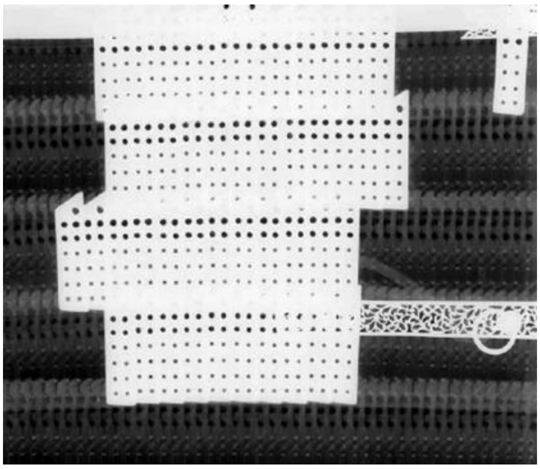

Figure 3.29: X-rays of a shoulder guard reveal metal (white) and rawhide (dark) components.
Source: Dalewicz-Kitto et al. (2013, 37).

Interestingly, these interspersed metal plates can be identified by much simpler, non-technological means, by wrapping a magnet in soft material and passing it over the armour. The magnet will naturally be attracted to the underlying armour and not to the rawhide.

Horn, C. 2017. "Combat and ritual – Wear Analysis on Metal Halberds from the Danish Isles and the Cimbrian Peninsula." ***Journal of Archaeological Science: Reports*** **14: 515–529.**

This study focused on the use-wear analysis of selected copper alloy halberds (axe-like weapons) originating from the Danish Isles and Cimbrian Peninsula. The objects under investigation date from around 2500 to 1800 BCE and were investigated both macro- and microscopically[41]. The results helped to create a sense of scale and intensity in terms of the battles these weapons were involved in.

Diagnostic features (Fig. 3.30) include discolouration, repair work, displaced material (in a wave pattern), blow marks, post-recovery striations, rounded blow marks, displaced tips, as well as flattened and indented material. Other identified use-wear indicators include fractures, ancient grinding striations, steep angled marks, rivet holes, traces of hafting, twisting, upturned hafting plates, flattened tips and flattened midribs (2017, 519–522).

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[41] Following macroscopic investigation, the blades were further subjected to microscopic investigation at 300 times magnification using a microscopic camera (Horn 2017, 516). The XLoupe G20® microscopic camera used in Horn's study is less powerful (in terms of magnification) than the Celestron digital microscopy used in this thesis.

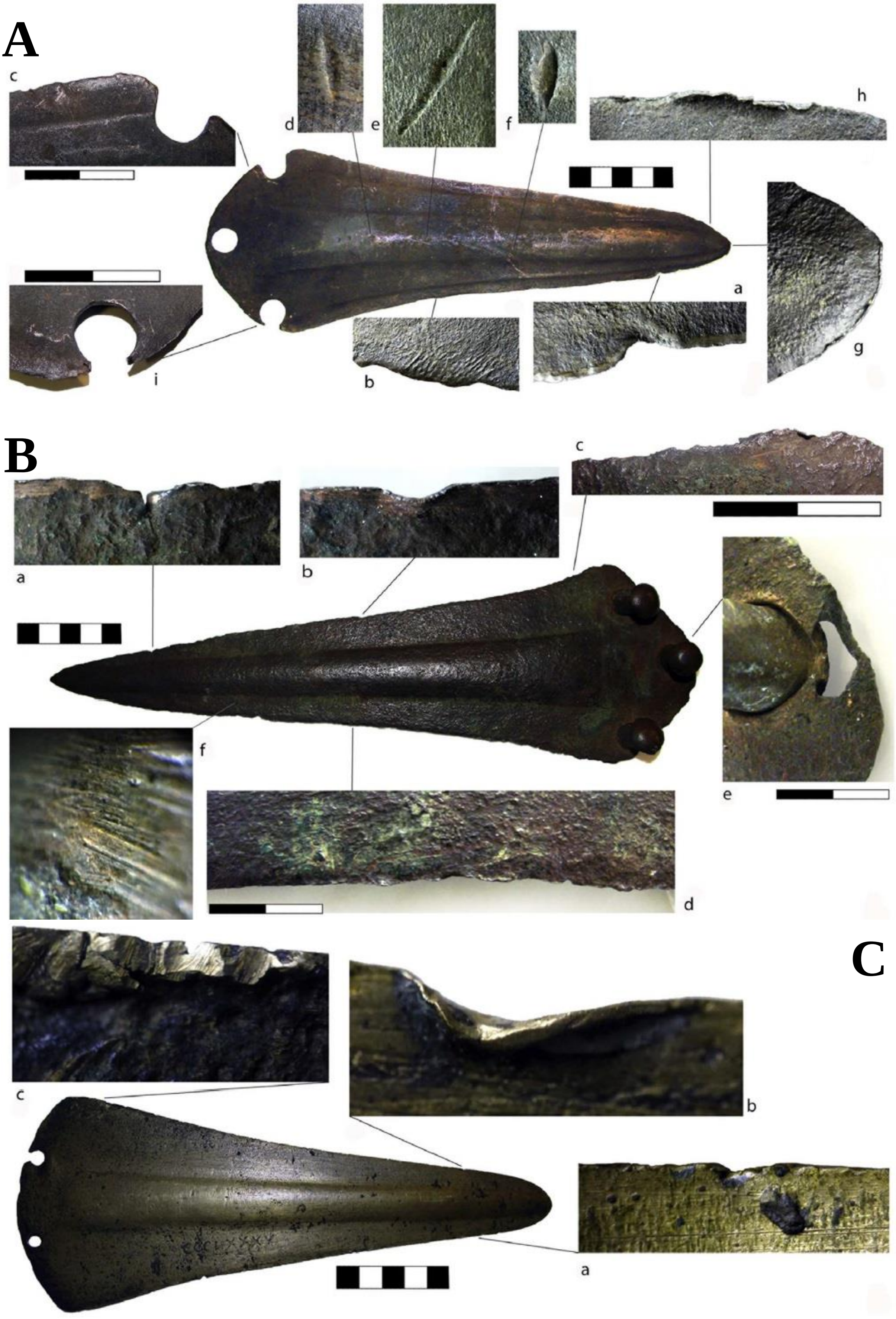

Figure 3.30: Halberds with numerous diagnostic features indicative of battle.
Source: Horn (2017, 521–522).

From these results, the researchers determined that the halberds represent different chronologies, dissimilar typological parallels within the European material, as well as varying geographical distributions. Certain physical phenomena, such as notches, are indicative of combat, as markings obtained through butchering practices do not leave steep angled marks (2017, 526). Although ritualistic in nature, use-wear indicates prior use in combat with a transition to ritualistic use, as opposed to a purely ritualistic, non-utilitarian use (2017, 529)[42].

Dupras, N. 2012. "Armourers and their Workshops: The Tools and Techniques of Late Medieval Armour Production." PhD thesis, University of Leeds.

In his multidisciplinary study of medieval armour, Dupras identifies the techniques used by armourers to manufacture items by investigating tools marks left behind. This relatively new methodology within collections-based analysis focuses on the use of the objects themselves as the primary source of information. The work is also highly comparative, as museum inventories and works of art were compared to the items under study. Experimental work, which sought to recreate tool marks, hammering patterns, demonstrated the relation between tools, processes and the physical phenomena they leave behind. According to Dupras, this type of research could be used to link unmarked armours to their armourers by noting diagnostic similarities between objects. Forgery identification is mentioned as a possible outcome of such research, but did not form an integral part of the study.

Dupras notes that the bulk of technological investigations into medieval armours have focused on metallurgical analyses, most of which rely on photomicrographs to provide information on the crystalline structure of the metal. These datasets can elucidate information on casting or heat treatments during production, but do not provide detailed information on fabrication techniques or the tools that might have been used to create armour (2012, 8). While some studies, such as those conducted by other researchers have focused on tool marks, Dupras notes a number of gaps in the research. Firstly, studies often focus on decorative elements and the tools used to create them, without focusing on the production of the objects themselves. Secondly, even when tool marks are discussed in relation to production methods, they are discussed superficially or are even, in some instances, completely misinterpreted (2012, 9).

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[42] Other relevant works on use-wear analyses include Dolfini (2011), Dolfini and Crellin (2016), Crellin (2018), Higgins (2010), Horn (2013) and Horn and Holstein (2017).

For the context of this thesis, it is therefore important to note that the work of Dupras represents one of the few (if not the only) bodies of research that is dedicated to the identification of production methods based on diagnostic features.

3.6 CONCLUSION

The section on imaging methods and techniques summarised a selection of technical articles dealing with the application of nuclear and other advanced imaging techniques within the field of cultural heritage diagnostics. The value of mixed-method approaches in the collection of comparative data was illustrated by the work of Festa et al. (2013), Jacobson et al. (2011), Enguita et al. (2002) and Goffer (1980). In Bettuzzi et al.'s (2015), the mixed-methods approach was fully exploited through the application of five different yet complementary techniques. The articles not only discussed the value of using complementary imaging techniques, but also showcased how chemical and microstructural analysis could add value to visual data. In addition, Kockelmann et al.'s (2006) article demonstrated how microstructural analysis, by means of TOF-ND, could provide researchers with information on texture, grain orientation and their associated production processes.

In Lehman et al.'s (2004; 2005) studies, a selection of metal and composite objects were analysed using both neutron and traditional X-ray imaging techniques. In this paper, it was made clear how different yet similar techniques can provide complementary evidence, thereby providing dual validation. The work of Deschler-Erb et al. (2014) also highlighted the benefits of using both traditional and neutron X-rays. Most importantly, the articles provide us with examples of how helmets, daggers and belt buckled will perform when subjected to these screenings. While the work of Postma et al. (2010) focused on microstructural analysis, their inclusion of basic radiographic data provides us with additional information on the appearance of sword hilts and blade tangs.

The case studies section examined a number of detailed research papers that deal with the non-destructive evaluation of specific objects (specific in terms of class, type and material) using a variety of specialised techniques. The research article of Deschler-Erb *et al*. (2010) showcased how thermal NT, when compared to regular X-rays, can serve as a superior tool in the analysis of historical bronze sculptures. Along similar trends, Van Langh *et al*. (2011) provided new insights into physical structures and alloy composition using a combination of neutron imaging and ND. Both articles showcased how the material composition of an object can influence the attenuation of radiation sources, with particular reference to the appearance of statuary.

The remainder of the case studies focused on the examination of ancient Egyptian bronzes. Schorsch (1988) performed a technical examination of hollow cast bronzes, with a focus on identifying diagnostic features by means of X-ray analysis. Phenomena such as core pins, solid and hollow cast features, core remnants and wall thickness were discussed as possible clues of authenticity. In Schorsch and Frantz (1998), the authors sought to identify similar diagnostic features, providing us with one of the cornerstones of comparative analysis for ancient Egyptian bronzes. While the paper focused on visual analysis, the authors concluded their paper with a section on X-ray spectrometry, which confirmed one object's chemical composition as contemporary with well-curated objects dating from the first millennium BCE. The latter point highlights the potential of NDE to place objects within relative culturo-chronological timeframes.

In Ambers et al.'s (2008) reinvestigation of the "Gayer-Anderson cat", the author applied a mixed-method approach that included no less than seven techniques. Not only did the techniques reveal clues on ancient production, they also provided information on modern restoration work. What is most important to our own study is the identification of square-sectioned core pins that resemble those mentioned earlier in the work of Schorsch and Frantz (1998).

The work of Agresti et al. (2016) focused on the application of six different NDE techniques, but it was the results obtained through high resolution NT that proved to be of the greatest value to our own research. Tomographic analysis revealed various diagnostic features that could be used in comparative analyses with our collection of bronzes.

The final three researches by De Beer et al. (2009), Smith et al. (2011), Masiteng et al. (2010) and Gravette (2011) presented us with examples of local (South African) research performed on objects from the DNMCH. Focus fell on the analyses of an Egyptian bronze falcon, Child Horus and a heavily corroded gilded Osiris figure. While the first three publications focus on materials analysis, Gravette's (2011) thesis was the only body of work that included in-depth historical contextualisation and stylistic analysis.

Although the articles provide a vast amount of information regarding materials science studies, the majority focus on technical analysis and have not included comprehensive stylistic analyses. If there is any gap to be identified within the literature, it is the application of integrated authenticity methodologies within the realm of cultural heritage diagnostics. Although some researchers are applying this method, its seems as though the majority are still torn between purely stylistic or purely materials-science approaches.

CHAPTER 4
HISTORICAL CONTEXTUALISATION

4.1 INTRODUCTION

Before we can attempt any form of technical or stylistic analysis, we must keep in mind that "the classifications and labelling of objects as well as their artifactual variability are shaped by the society in which these objects are manufactured, utilized and consumed" (Heinz 2015, 80). Put slightly different, Gener (2011, 117) explains that "like a natural object is the product of a natural environment, a manufactured object is product of a human and social environment, and that this environment leaves a fingerprint on the object." To this point, Matthews (2005) adds that:

> "a fingerprint that is not only traceable, as a consequence of its use, but also technological, as a consequence of the use that was allegedly intended for it, and of the subsequent technical decisions that have been taken, in each case, in its process of manufacture."

The main goal of Chapter 4 is therefore to outline the historical contexts of each object class (Egyptian bronzes, Japanese Samurai armour, European armour, and Arabian daggers) before we set out to identify *fingerprints* in Chapters 5 through 7. Since the nature, cultural context and historical period of each object class differs significantly, the sections dedicated to the discussion of each will therefore differ in terms of their individual focal points. Although the aim was to create a level of consistency between sections, there are a few key differences in terms of research structure.

For example, the section on Ancient Egyptian Bronzes commences with an introduction to the general stylistic trends that were popular from Predynastic times until the Third Intermediate Period. Thereafter, the focus shifts to an historical overview of technologies (introduction of copper, utilisation of bronze, trade, elemental additives, corrosion and microstructure), and ends with a discussion on casting methods, joining techniques and surface refinement.

In the succeeding sections on Samurai and European armour, the emphasis falls mainly on the culturo-historical contexts of the respective cultures, and how societal changes and martial needs lead to technological innovations. This overview is facilitated by the fact that historical sources are more detailed from the periods under discussion (within the CE range), when compared to that of ancient bronzes (BCE). In the section on Samurai armour, the historical context of the Samurai as a warrior class (from the Late Nara to Meiji Periods) is discussed followed by an overview of major technological developments (from the Classical to Edo Periods). The section on European armour follows the same research structure by commencing with an overview of European knights, soldiers and armies (from the Middle Ages to the Renaissance), and concluding with an historical overview of technologies and styles from the same periods.

The section on Arabian daggers is focused on cultural significance and regional styles, rather than mythological or martial importance. This approach was taken since *jambiya* represent social status and manhood within Arabian traditional attire, and are generally valued more for their cultural symbolism than their functionality as weapons. Also, unlike ancient Egyptian bronzes and traditional armours, *jambiya* are still actively used within modern-day society and continue to reflect regional group identities. The focus of this section therefore falls on the identification of different regional *jambiya* styles.

Before commencing with the discussions outlined above, the chapter starts with a brief overview of the differences between object provenance and provenience; two concepts that should be kept in mind when dealing not only with the ancient historical contexts (production, use and ownership) of objects, but also their subsequent modern contexts (as museum objects and collection items).

4.2 OBJECT PROVENANCE AND PROVENIENCE

Two factors, which should be kept in mind considering the historical context of objects, are provenance and provenience. On the one hand, provenance[43] refers to the history of the artefact's/object's use and ownership, both ancient and modern. On the other hand, provenience[44] refers to an artefact's location, position, and context within the archaeological record.

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[43] https://en.wikipedia.org/wiki/Provenance, also refer to the Oxford Advenced Learner's Dictionary's definition of the term, with the example reading: "There's no proof about the provenance of the painting (whether it is genuine or not)".

[44] "The term provenience in archaeology/archaeology has largely replaced provenance because provenience is restricted to in situ location at the date of archaeological discovery rather than the 'origin-to-present' chain of custody. Details of proper provenance as is customarily used by historians, museums, and commercial

When an object is separated from its archaeological provenience (in situ location), it loses much of its initial value to the scholar. This is due to the fact that location, position, and context within the archaeological record convey a great deal of information about an object's origins and historical use. In addition, detailed information on provenience also makes object authentication a much easier task. However, an artefact's provenience may not always be a good indicator of relative age. Since provenience deals with the object's three-dimensional position within the archaeological record, the circumstances surrounding the object's deposition should always be considered. As many objects were originally discovered by archaeologists in large caches (as is often the case with Egyptian bronzes), similar objects from the same cache may in fact originate from several different periods (Ghoniem 2014, 42). This mainly results from the practice of reusing votive objects, like temple statuettes[45], across many generations. Thus said, although objects may share the same three-dimensional location within the archaeological record, a shared or common age should not be assumed without further stylistic and technical analysis.

In addition, one must take into consideration that some regions experienced extensive looting, not only during modern times, but also during ancient history. These potential troves of information are severely disrupted, leaving little behind in terms of original deposition, stratigraphy and context. In addition, many controlled excavations (especially those conducted before regulatory standards and ethical guidelines were enforced within archaeology) overlooked smaller, seemingly "insignificant" finds in favour of larger or more impressive treasures. In their discussion on ancient bronze feline statuettes, Schorsch and Frantz (1998, 18) note the following:

> ...despite the many extant bronze cats, only a few have been recovered from controlled excavations. When Edward Naville excavated Bubastis in the 1880s, for example, the site had already been largely destroyed by looters, while at other ancient sites, the excavators concentrated on treasures dating to earlier dynasties. These circumstances, together with the fact that such objects are seldom inscribed, explain why few cat sarcophagi with secure date or provenance are known.

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entities." https://en.wiktionary.org/wiki/provenience. However, it should be noted that within southern African archaeology, the meaning are reversed.

[45] With particular reference to the collection of ancient Egyptian bronzes.

Luckily, apart from the ancient Egyptian bronze collection[46], none of the objects in this study were removed (excavated) from the archaeological record. Therefore, within the context of this thesis, the focus is on provenance (the object's history) rather than provenience (archaeological record). However, even with the focus falling on provenance, the DNMCH objects in general do not possess clear collection records or detailed information about where they came from. In general, the lack of provenance (details on the object's history) can also be problematic, but a lack thereof simply makes the researcher's task more challenging, but not completely impossible.

Because provenance deals with the chronology of an object's ownership, custody and location, it must be taken into account that these variables are often influenced by a number of factors including ancient hereditary use, ancient/modern looting, modern excavation/discovery, informal/private collection and formal accessioning. In many instances, the details surrounding the discovery of an object and its provenience are lost, or were never recorded due to unprofessional practices. In addition, objects are often donated to museums from private collections without information pertaining to their origins. The contextual or circumstantial evidence for the object's original production or discovery is therefore lost and creates complications for authenticity. However, when discussing ancient *khanjar* without proven geographical provenance, Al Busaidi (2015, 85) makes the following statement:

> Some ancient *khanjars* are privately owned and have been inherited from parents and grandparents, while others are located in museums. With or without a defined geographical provenance they still contribute to the typology of the *khanjar*.

Although the loss of provenience and provenance may appear like major obstacles in the path of authentication, they can be circumnavigated. In this regard, Goffer (1980, 347) notes that the authentication of isolated (of lost provenience and provenance) objects relies on the fact that antiquities carry with themselves evidence (*fingerprints*) of the time and place of their manufacture. Through a combination of stylistic and technical analyses, we are able to identify the evidence that forms an inherent part of each and every object. However, before one can attempt any form of stylistic or technical analysis, it is critical that we possess background information on the cultures and time periods from which they originate. The

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[46] The museum possesses so little information about the bronze collection, we cannot be sure whether they were excavated from temple deposits or whether they were found in tombs.

remainder of this chapter will therefore focus on providing contextual information for each artefact/object.

4.3 ANCIENT EGYPTIAN BRONZE STATUETTE

4.3.1 Ancient Egyptian Bronze: Historical Overview of Styles

a) Prehistory and Early Dynastic Period

During Egypt's prehistory (pre-3150 BCE), artists were making statuettes from a wide variety of materials (i.e. clay, bone, wood, ivory) long before the introduction of metals. Once metalworking became standardised during the Early Dynastic Period (1st to 2nd Dynasty: 3150–2686 BCE), small copper statuettes and gold amulets became popular funerary items or grave goods. According to Bianci (1989, 62), the first inscription documenting the production of a royal copper statue dates from the 2nd Dynasty.

At first, statuette designs were informal, as prescribed artistic styles were only introduced during unification (3000 BCE). During the Early Dynastic Period, formal styles became the norm, and artists were depicting kings and gods/goddesses wearing royal regalia or icons of divinity. Both statuettes and their monumental counterparts share a number of characteristics: they are commonly depicted with the right foot ahead of the left, robes wrapped tightly around the body, and a forward thrusting head. Figures face straight ahead, looking into eternity, and are positioned in a vertical, rigid pose (Bianci 1989, 62).

b) *Old through Middle Kingdoms*

During the Old Kingdom (3rd to 6th Dynasty: 3686–2181 BCE) sculptures were naturalistic, with some human forms appearing thickset or muscular, perhaps in an attempt to represent a more "realistic" image of the individual. Facial expressions reflect a peaceful nation enjoying a relaxed way of life. The style was commonly referred to as the Memphis style. This naturalism stands in stark contrast to the highly idealised rigid and slender figures that became popular during later years (Bianci 1989, 63).

Bianci (1989, 63) notes that bronzes from the Middle Kingdom already possessed characteristics that would set them stylistically apart from their ANE counterparts. This expression of identity through material culture proves that the Egyptians were fully aware of the alloy's creative potential during early periods. However, Bianci (1989, 64) provides another important note regarding the relationship between evolving metalworking technologies and rigorous stylistic rules:

> The technology of casting bronze in the lost-wax method was shackled and pressed into service for the creation of typical Egyptian statuary types. Tradition is maintained at the expense of any innovation inherent either in this newly adopted technology or the material, bronze. The statuette of an official parallels types known in stone, and the exquisite tripartite modelling of the torso of the figure identified as Amenemhet III recalls the finest torso modelling of the period. These masterful bronzes are completely and thoroughly Egyptian in both their conception and style. Their appearance forces one to consider subsequent development of bronze casting in ancient Egypt, for these Middle Kingdom bronzes establish the first link in the chain that ultimately extends to the Third Intermediate Period.

In simple terms, the ancient Egyptians were so bound by stylistic rules and traditions, that the introduction and development of new methods and techniques – which could ultimately have led to new styles, given their improvements to casting conditions and the range of physical forms that could be created – did not encourage the development of revolutionarily new stylistic trends. This element alone makes it incredibly difficult to establish a clear-cut chronological development (dynasty by dynasty) of ancient Egyptian statuary based solely on evolving styles.

Sculptures from the Middle through New Kingdoms are divided into the Theban (11th to 15th Dynasties) and Hyksos (15th to 18th Dynasties) Period styles. In general, both periods were merely a continuation of the Memphis style, but with some notable changes. For example, bodily forms adopted slimmer torsos, arms and legs, while art in general became less individualistic and more formal. The artistic revival of the 12th to 13th Dynasties was interrupted during the 14th to 15th Dynasties, which saw the country fall to Hyksos rule and, by extension, Hyksos cultural and artistic influences. For example, Semitic influences introduced the Turanian facial type, featuring shallow eyes, high cheek bones, heavy hair, aquiline noses, strong mouths, short facial hair and beards[47]. The influx of foreign nationals also saw the arrival of skilled artisans and new techniques. When the country returned to Egyptian rule, a period of revivalism ensued.

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[47] http://www.visual-arts-cork.com/ancient-art/egyptian-sculpture.htm#statues [Accessed on 10/08/2018].

Both the Old and Middle Kingdoms witnessed an increase in the popularity of statuettes as grave goods, as statuettes could take the place of the deceased's body in the afterlife, in case of the latter's destruction after burial. Even if a statuette was of poor quality, the owner's inscribed name was of paramount importance. During this technological overlap between the Middle and Old Kingdom, bronze also became increasingly popular as a medium for creating statuettes, although it was already in use during earlier periods (Bianci 1989, 63).

c) *New Kingdom*

During the New Kingdom (18th to 20th Dynasties: 1550–1069 BCE), Egypt threw off the yoke of Hyksos rule and instated a period of cultural renewal and artistic vigour. Many artisans looked to Old and Middle Kingdom styles for inspiration, but added New Kingdom flairs to designs. For example, while the slender figures of the 12th and 13th Dynasties were re-used and developed, the minimalism of earlier garments was replaced by more intricate designs. In general, the subject matter of art (i.e. gods, goddesses, royalty) remained unchanged. In addition, the growing middle-class (state officials and lucrative merchants) could also afford to have their likenesses immortalised in bronze[48].

During the New Kingdom, the production of votive statuettes grew exponentially. Temples produced statuettes as part of their workshop activities and generated income through sales. Worshippers could buy statuettes and either donate them as offerings, use them in small household shrines, or include them as part of a deceased's funerary items. The ability to produce objects at this commercial scale is largely attributed to the relative ease at which workshops could acquire raw materials; a result of Egypt's integration into the international trade networks of the late Bronze Age (Bianci 1989, 64).

d) *Third Intermediate Period*

The Third Intermediate Period (21st to 25th Dynasty: 1070–664 BCE), was characterised by fracturing local kingships and foreign rule by the Libyans, Nubians and Assyrians. It was believed that, under these unpredictable circumstances, artists struggled in terms of creativity, and therefore relied on styles from bygone eras. However, researchers like Bianchi (1989) believe that it was actually a period of intense creativity, since the reuse and adaptation of classic styles represented revivalism and was not simply creative lacklustre. For example, in a phenomenon known as archaizing, the Libyans and Nubians transformed and manipulated art in such a way as to hide their own foreign identities. By visually portraying themselves in

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[48] http://www.visual-arts-cork.com/ancient-art/egyptian-sculpture.htm#statues [Accessed on 10/08/2018].

Egyptian styles, art was used to officiate their naturalisation as Egyptian. In addition, capital cities remained centres of power, which allowed them to retain their cultural identities and material culture. The latter uniformity in material culture and homogeneity of style meant that Egyptian art did not experience any negative consequences as a result of foreign rule (Bianchi 1989, 62). However, it must be noted that, although the Third Intermediate Period inspired creativity and revivalism, the period's art is generally characterised by its effeminate and refined style, which stands in stark contrast to the sharp and vigorous styles of Egypt's glory days[49].

The Third Intermediate and Late Period (26th to 31st Dynasty: 664–323 BCE) also saw the highest use of votive figures (Ghoniem 2014, 38). Figures of gods/goddesses were usually presented in a sitting pose (to be placed upon a spate throne, usually made of wood) or seated on a throne (Hill 2001). By the Late Period, their growing popularity, coupled with reduced costs in production and ease of mass production, meant that everyday citizens could now afford to own a votive statuette or two as part of their home shrines, as funerary objects, or as offerings to local temples and shrines (Kozloff 2001; Spencer 2007). Statuette clothing[50] from this period was articulated by the addition of inlays, which were hammered into grooves cut into the surface of the bronze. Closer investigation reveals that these grooves were meticulously carved into the wax prior to casting. The popularity of blackened bronzes also grew during this period, but textual references from the 18th Dynasty that refer to "black-bronze" indicate that the practice of darkening bronzes originated in the New Kingdom (Bianci 1989, 68-69).

e) *Style as an Indicator of Relative Chronology*

What is important to note, especially when trying to establish chronological markers of style, is that there is no clear-cut way to trace the exact evolutionary path of Egyptian sculptures. This is due to the fact that Egyptian art changed very gradually over centuries. In addition, no real archaic prototypes exist that can be used as benchmarks for development. In addition, styles did not simply discontinue the moment one dynasty or kingdom was replaced by the next – there were periods of overlap[51]. In addition, periods of revivalism spark a reuse and modification of older styles, as Bianchi (1989, 62) explains

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[49] http://www.visual-arts-cork.com/ancient-art/egyptian-sculpture.htm#statues [Accessed on 10/08/2018].

[50] These decorative costumes were meant to represent the costly embroidered textiles that were created in cities like Alexandria during the Third Intermediate Period.

[51] http://www.visual-arts-cork.com/ancient-art/egyptian-sculpture.htm#statues [Accessed 10/08/2018].

> …the Egyptians were both cognizant of their past and quite capable of recalling it. That demonstrable ability to recall the past and to incorporate aspects of that recollection into cultural patters of subsequent generations explains why ancient Egyptian art is at once so traditional and so long-lived. It is, therefore, always advisable to assess aspects of ancient Egyptian art as a casual, sequential development of all that preceded it. Indeed, Egyptian art is the product of an ever repeating internal cycle by which each succeeding generation selectively draws its inspiration from a common cultural continuum, only to have its oeuvre, once created, intercalated into that very same system. Tradition may be modified, but it is never discarded, and new developments, once adopted, are ever after at the disposal of the Egyptian artisan.

Thus stated, most crucial to any material science research is cognisance of the fact that Egyptian sculpture is primarily marked by its continuity rather than its evolutionary changes. Nonetheless, certain characteristics can help to distinguish between objects from different periods. Most significant in this regard is the use of different materials, technologies and casting types across the ages.

4.3.2 Ancient Egyptian Bronze: Historical Overview of Technologies

Bronze held appeal for millennia, and continues to do so in the modern age. Lucas (1962, 195) notes that bronze was the most popular metal alloy next to electrum, and held great utilitarian and aesthetic value. Its ease of casting, relative longevity and colour variations made bronze an attractive alternative to gold, silver and iron.

a) *Copper as a Precursor to Bronze*

Before the ancients used bronze, they produced wares from copper. The earliest use of copper dates back almost 10 000 years BP (the Neolithic Period) (Scott 2002, xi), with archaeological evidence originating from the sites of Cayonü Tepesi and Catal Hüyük in Turkey (6th millennium BCE) (Scott 2002, 4-5). The ancient Egyptians used copper during the 4th millennium BCE (Bianci 1989, 63), with production dating back to the Badarian and Predynastic Periods (Lucas 1962, 200). The earliest reference to copper statuary comes from the Palermo Stone, which refers to a statue made for King Khasekhem (2782–2755 BCE). The earliest example of copper statuary is an image of King Pepy I (2407–2395 BCE). However, it was only during the Middle Kingdom that the large scale creation of copper statuettes became wide-spread (Bianci 1989, 63).

b) *The Introduction of Bronze*

Although it is difficult to establish who created the first bronze wares in the ANE, Mesopotamia preceded (2400 BCE) Egypt in terms of commercial production (Savage 1968, 12). It is proposed that the Egyptians already knew of bronze during earlier times, but did not exploit its production potential. At some point (between the Old and Middle Kingdoms), the frequency of bronze usage increased, most probably due to the influx of skilled artisans from Syria and Cyprus (Bianci 1989, 63). In general, bronze usage was increasing, by the close of the Old Kingdom (2181 BCE), many utilitarian and decorative objects were being made from this prized alloy (Savage 1968, 36). However, it must be noted that these "first alloys" were actually created by accident, as the smelted ore naturally contained a combination of copper and tin – two of the main components of bronze (Savage 1968, 12). It was only sometime between the 4th and 3rd millennium, that the first "true alloys" (purposefully made) of copper and tin came into existence (Scott 2002, 5). While this deliberate creation of "true bronze" was still scarce during the Middle Kingdom (2055–1650 BCE), alloying had become a standard practice by 1800 BCE (Lucas 1962, 217).

The creation of lead-tin bronze was spurred on by the local availability of natural resources. Although tin was readily available to the Egyptians through the mining of cassiterite deposits in the eastern desert, lead was more readily available, leading to the creation of lead-tin bronze (Bianci 1989, 63). Therefore, objects that were created before international trade blossomed, owed their chemical composition to the principle of localised resource availability.

c) *Trade and Raw Materials*

This overdependence on local resources vanished when international trade opened up during the Second Intermediate Period (1650–1550 BCE). This period is characterised by the Hyksos invasion, which opened up international trade networks. The relative ease of raw material acquisition and increased manufacturing efficiency meant that bronze objects became increasingly popular. After the expulsion of the Hyksos, and the formation of the New Kingdom (1550–1077 BCE), international trade between Egypt and the rest of the ANE expanded even further. Egypt became a large-scale importer of lead, copper and tin (especially from Cyprus) (Savage 1968, 39), facilitating the popular use of bronze during the 18th Dynasty. During the political collapse of the Third Intermediate Period (1096–664 BCE), the size and quality of bronze art diminished (Savage 1968, 41).

d) *Elemental Composition and Relative Dating*

Lucas (1962, 217) notes that the elemental composition of bronzes was significantly variable during ancient times. These period-specific variables in the elemental composition of bronzes can help to establish more tangible production timeframes, with chemical analyses providing a means of relative dating. Analyses of lead isotopes can even be used to trace the geographical origin of lead mines (Goffer 1980, 207, 220), providing us with additional contextual information regarding regional differences in production, trade and economy. As stated before, although chemical analysis falls beyond the scope of this thesis, it is still important to know *when*, and even *where*, metallurgical changes occurred throughout history, if only for the purpose of contextualising associated data.

Ancient metallurgical properties (i.e., the ratio between copper, tin and lead) also influenced (and continue to influence) levels of corrosion, with the latter representing a commonly used measure of authentication within museum studies. Although bronze has many favourable material properties, it also has the tendency to corrode with relative ease. Fortunately, such corrosion is usually limited in its extent, as it rarely penetrates below the surface. A layer of corrosion, also referred to as patina, is often considered as a much-prized quality of ancient and antique bronzes, and is widely regarded as one of the best indicators of authenticity (Savage 1968, 22; Scott 2002, xiii). To illustrate this point even further, Delange's (2005) study on the metal polychromy[52] of ancient Egyptian bronzes highlighted the ancient crafter's intentional use and manipulation of different alloys for the creation of unique colour hues and distinctive patination. As these practices were period- and region-specific, they could be used as culture-chronological markers in determining relative age.

e) *Tin, Lead, Arsenic, Antimony and Zinc*

The creation of "true bronze" (bronzes featuring high levels of tin, also refered to as "tin bronzes") came about following the exploitation of arsenic-rich ores (Abd Allh & Maher 2018, 3); a process which may or may not have been intentional. When added, tin lowers the melting point of copper and improves its overall fluidity, decreasing the likelihood of bubble formation. The alloy is also easier to hammer, with the process of hammering itself actually causing the alloy to harden rather than break (Renfrew & Bahn 2004, 299). The latter development saw the widespread adoption of bronze for weapons production (Sharer & Ashmore 1980, 319). However, despite its advantageous properties, tin dominant bronze only became popular from the Ramesside Period (Ogden 2000, 153).

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[52] However, interesting and insightful as it may be, bronze polychromy falls beyond the scope of this thesis.

By adding lead to “tin bronze”, the temperature at which the alloy could be melted was reduced, increasing the pourability, ease of casting and the bulk of the cast material (Scott 2002, 3). By lowering the melting point, the solidifying alloy is less prone to bubble formation, thereby decreasing overall porosity (Ogden 2000, 154). The addition of lead also increases the alloy’s fusibility[53]. The latter is an essential prerequisite for multi-component bronze sculpting, as independently cast sections were skilfully fused together through the process of reheating contact surfaces (Savage 1968, 14). In addition, as bronze solidifies, it also expands – a mechanical action that forces the alloy into every sculptured crevice of the mould. During cooling, the alloy then contracts, freeing the sculpted bronze from its clay mould (Savage 1968, 14). Considering all these material properties, leaded bronze was far superior to other alloys in terms of casting.

Although lead percentages in Middle Kingdom alloys were quite low, and rarely rose above 2% until the late New Kingdom (1300–664 BCE), high lead levels became characteristic during the Late Period (334–332 BCE), with Ptolemaic (323–30 BCE) objects containing as much as 30% lead (Ogden 2000, 154-155). It must be noted that the intentional addition of lead only gained popularity during the New Kingdom and was only commonly added in the first millennium BCE (Schorsch 1988, 48).

Arsenical copper, being a natural alloy, was produced fortuitously through the smelting of ores that contain both copper and arsenic (Abd Allh & Maher 2018, 3). Whether these ores were specifically selected for their material properties once identified, is still inknown. The presence of arsenic is particularly noticeable from the Old Kingdom and many bronzes from this period onward contained trace amounts (Schorsch 2007, 191). However, from the New Kingdom onward, the percentage of arsenic dropped below 1% (Ogden 2000, 153). One of the key attributes of arsenic-rich copper is the distinctive silver colour the alloy lent to statuary (Gravette 2011, 37). Another trace element, antimony, occasionally occurs in association with arsenic, but Ogden (2000, 153) contends that the intentional inclusion of antimony was common during the New Kingdom, but only sporadic during subsequent periods.

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[53] Fusibility refers to “1. The ease with which materials can be fused together.2. The ease with which a substance can be melted, i.e. the amount of heat required and the temperature to which it must be raised for the metal to fused to another (Escudier & Atkins 2019, 306).

As zinc was never purposefully added to ancient Egyptian bronze, this fact alone gives useful insights in terms of authentication (Schorsch 1988, 48). As very few objects were made from copper-zinc alloys, with some dating from the late Ptolemaic Period, but most originating from the Roman Period (Gravette 2011, 40), experts such as Ogden (2000, 155) believe that zinc levels above 3% are either intrusive (due to corrosion or exposure to certain environmental elements) or indicative of forgeries.

4.3.3 Historical Context of Ancient Egyptian Casting

In order to analyse bronze figurines, one has to gain a basic understanding of the manufacturing techniques employed during ancient times (Gravette 2011, 43). According to Hill (2001, 30), mapping these technological phases could prove useful when identifying distinctions among bronze objects. Thus stated, production techniques and their associated physical distinctions, both of which were period-specific, could be used to place objects within more accurate culturo-chronological frameworks based on the principles of relative dating.

The ancient history of casting and manufacturing was one of trial and error. Ancient smiths realised that pure copper did not cast well, as it had a tendency to create bubbles, which would lead to porous, less durable objects (Ogden 2000, 152). The technique of hammering would cause copper to become brittle, while annealing allowed for a softer, more workable metal (Lucas 1962, 152). Both casting and reworking was significantly improved through the practice of alloying, particularly in the case of the purposeful addition of tin and lead.

It is widely recognised that the majority of ancient Egyptian copper alloy objects were made by casting them into their final form (Gravette 2011, 47), as opposed to hammering the malleable bronze into shape. While the practice of casting itself (as a trade) is not a chronological marker, the different types of casting techniques are. While the earliest bronze objects of the third millennium BCE were solid cast, the earliest hollow cast objects appeared during the second millennium BCE (Hunt 1980, 72). More specifically, hollow casting appeared during the late 12th Dynasty or early 13th Dynasty (1840–1750 BCE) (Schorsch and Frantz 1998, 20). However, it must be noted that “lost wax casting of independent figural bronzes was rare in ancient Egypt before the first millennium BC” (Schorsch 1988, 41)(also refer to §7.2.1 to 7.2.3 for detailed discussions on the different casting methods).

The introduction of immigrant craftsmen to the country during the New Kingdom (around 1559 BCE) brought about a rapid evolutionary development of metal crafts (Hunt 1980, 68). However, it still took centuries for Egyptian artisans to develop a lost-wax technique that bestowed recognisable, uniquely Egyptian features upon hollow castings (Schorsch and Frantz 1998, 20). High quality, elaborate hollow-cast figures were being produced during the Third Intermediate period without there being a formalised, active technological tradition among crafters (Schorsch 1988, 41). It was only during the second half of the first millennium, when there was a significant change in production methods, that both solid and hollow-cast figures became common (Schorsch 1988, 41).

In terms of mass production it must be noted that, even with the increased standardisation brought about by a more formalised industry during the apex of ancient Egypt's metal craft production, each bronze cast represented a unique exemplar (Schorsch 1988, 42). Even though moulds have been found (that suggest the practice of direct bronze casting), most scholars still lean towards their interpretation as wax model casts (Hunt 1980, 73), with no evidence supporting the existence of reusable moulds for the large scale production of ancient replicas (Schorcsh 2007, 193). However, is has been suggested that the rough clay-sand cores, around which the wax was moulded, could have been produced through some form of copy process from models (Agresti et al. 2016, 773). This could mean that at least one phase of production: inner core moulding, could have taken place en-masse.

To return to the point of individuality, Schorsch (1988, 42) notes that no two ancient Egyptian bronzes are exactly alike, no matter how formalised the industry became during later periods. This leads us to an interesting means of identifying forgeries – the identification of exact duplicates. For example, in her examination of a small crouching ibis figure (believed to be a modern replica), Schorsch (1988) found an identical example (in both technological and metallurgical terms) from another collection. This led (in part) the objects identification as a possible forgery.

One last factor that complicates the authentication of ancient bronzes is the lack of production-related inscriptions or maker's marks. Unlike Common Era armours and weapons, that were often engraved with maker's marks, ancient Egyptian bronzes hardly include any inscriptions that may elucidate the place or time of origin (Ghoniem 2014, 39). Where inscriptions do occur, they usually include the name of the donor, which could in turn be used to identify the production time and region. But the latter is only possible if the individual is well-known (through historical accounts) or if the inscription included some reference to the cult centre, town or region (Hill 2001).

e) *Casting Methods, Joinery and Refinement*

Casting methods developed over the centuries and can often be used as chronological markers. However, it must be noted that even with the introduction of new techniques, the old techniques did not fall out of use. These older methods continued to be used, but were used for different applications (mostly depending on the nature and size of the object being cast). Three lost-wax methods were employed: (a) direct lost wax – solid cast, (b) indirect lost-wax – clay core, and (c) indirect lost-wax – hollow core[54].

Solid casting, also known as investment casting (Gravette 2011, 47), represents the most basic forms of casting and was already in use during the Old Kingdom (Schorsch 2007, 192; Spencer 2007, 44), becoming increasingly popular during the Middle Kingdom (Taylor, Craddock & Shearman 1998, 9). The clay core method was mostly used for medium- and larger-sized objects in order to save metal. Although the exact date for the introduction of clay core bronzes is unknown, the most logical conclusion is that it served as a precursor to hollow casting, the latter being introduced during the Middle Kingdom. In both clay core and hollow-cast bronzes, the ancient fabricator used less metal for casting and less resources to stoke longer-lasting fires. He also avoided a number of metallurgical problems[55] that came with casting solid metal objects (Schorsch 1988, 41).

The oldest known examples of hollow statuary date from the Middle Kingdom (11th to 13th Dynasties: 2040–1782 BCE) (Schorsch (2007, 192). A large cache of bronze statuettes was discovered in the Faiyum, which included a number of hollow cast objects, some of which date from the reign of Amenemhet III (1843–1795 BCE). Individual examples boast separately cast arms that were attached to the bodies using mortise-and-tenon joinery. Secondary materials were also used as inlays, particularly in the case of eyes (Bianci 1989, 64).

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[54] Each technique will be discussed in greater detail in Chapter 6, when hollow and solid cast features are discussed within the context of nuclear imaging.

[55] Such as the formation of gaseous bubbles that become trapped within the internal structure of the object (especially during rapid cooling), that subsequently lead to an increase in alloy porosity.

A few examples of hollow-core statues exist where the bronze was cast directly over a clay core, being held in place by metal chaplets. Two of the most well-known examples from the 18th Dynasty include a figure of Thutmosis IV (1395–1386 BCE) and Tutankhamun (1331–1322 BCE), but not many other examples have survived. Even less examples are known from the 19th and 20th Dynasties (1479–1425 BCE). This lack of examples is unfortunate, since the 19th Dynasty initiated hollow-cast metalworking trends that would culminate in a flourishing industry during the Third Intermediate Period. In fact, the astonishing amount of hollow cast figures that appear during this period is widely regarded as the culmination of a process that had already commenced with the 12th Dynasty's introduction of hollow casting (Bianci 1989, 65-66).

Across all three techniques, each figure that was produced using the lost-wax method was unique. Since the wax that was used to sculpt the details of the object was lost before the metal was poured, and the investment that was used to keep the parts together during casting was broken away afterwards, no exact replicas were possible (Schorsch and Frantz 1998, 21).

Larger bronzes were often assembled out of wax models that consisted of various individually moulded parts (arms, legs, torso, head), which were then joined together using hot wax. During joining, the force of pressing these parts together would cause some of the molten wax to squeeze out between the newly joined areas, forming a slight lip or edge (often referred to as a wax drip). Signs of wax compression and inward deformation are also seen. Alternatively, the parts could be assembled post-cast using metallurgical joining. This process usually entailed cutting oval depressions around a joint (*vaschette* method), after which the two sections were merged using molten bronze (Bettuzzi et al. 2015, 1167).

Once a bronze figure emerges from its mould, flaws and defects have to be corrected (even with sophisticated modern casting). While most defects could be repaired post-cast, bronzes often broke as they were freed from their moulds, forcing the ancient crafter to redo the entire process. After removing the statuette from its mould, it was roughly sanded. A variety of rasps, scrapers and files were used to eliminate larger/rougher imperfections, while abrasive materials (such as sandstone) were used for finer smoothing. Once the metal had cooled, the artisan could use a variety of chisels and borers to create decorative incisions, lines and holes (Boucher 1989, 161-162). Inlays would be added once the material had cooled, allowing the artisan to press or lightly hammer these decorations into place (Boucher 1989, 168).

4.4 SAMURAI ARMOUR: HISTORICAL CONTEXT AND TECHNOLOGIES

4.4.1 Historical Context of the Samurai

To understand Samurai armour, one should possess background knowledge of Japan's imperial and feudal systems of government. In essence, the history of the Samurai is that of a growing military class that either gained or lost power, depending on its position within the ever changing geopolitical atmosphere of Japan. The development of armour was directly related to the conflicts in which the samurai were involved, as technological developments in weaponry and combat tactics forced them to adapt their armour. On the other hand, aesthetic characteristics developed from a need to distinguish noblemen and officers of rank from ordinary soldiers. The Samurai were active from the Early Heian Period (794-935) of Classical Japan to the early-modern Meiji Period (1862-1912) (Ogawa 2009, xi) (Table 3.1).

Table 3.1: Periods of Japanese history, with periods linked specifically to the Samurai highlighted in grey

Dates CE	**Main Period**	**Period**	**Sub-Period**
538-710	Classical Japan*	Asuka	
710-794		Nara	
794-935		Early Heian	
935-1155		Middle Heian	
1156-1185		Late Heian	
1185-1333	Medieval (Feudal) Japan	Kamakura**	
1333-1336		Kenmu Restoration*	
1336–1392			Nanbokuchō
1392–1467		Muromachi***	
1467–1573		Sengoku-jidai***	Sengoku
1573–1603		Azuchi–Momoyama	Sengoku
1603–1868	Early Modern Japan	Edo (Tokugawa)****	
1633-1853			Sakoku (closed country)
1854			Convention of Kanagawa
1854-1868			Bakumatsu (end of isolation)
1868–1912	Modern Japan*	Meiji	Pre-war
1912–1926		Taishō	
1926–1945		Shōwa (Prewar)	
1945–1952	Contemporary Japan	Shōwa (Occupied Post-war)	Post-war
1952–1989		Shōwa (Post-occupation)	
1989–present		Heisei	
* Imperial government	**Kamakura Shogunate	***Ashikaga Shogunate ****Tokugawa Shogunate	

Table contents adapted from Ogawa (2009, xi)[56].

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[56] Also refer tohttps://owlcation.com/humanities/Japanese-History-Summary [Accessed 27/0303/11/2019].

a) *Late Nara and Early Heian Periods*

During the late Nara to Early Heian Period (794–934 CE), members of the aristocracy incorporated increasing amounts of agricultural land into their own *shoén* ("private estates"). By the 9th century CE, a number of noblemen had managed to annex some of the emperor's power by strategically acquiring more and more *shoén* across the country. In the absence of their formal owners, who were often nobles who lived in large cities, the *shoén* were managed by *shókan* ("overseers"). In some instances, *shókan* acquired their own *shoén* and came to be known as *kaihatsu ryóshu* ("development proprietors"). These former servants turned land owners were heavily taxed and a bitter rivalry developed between them and the *kokushi* ("provincial government"). As a result, many landowners militarised their estates, hiring warrior-retainers known as *ienok*o or *rótó*, who later became the first samurai[57]. Together, land owners and their *bushi* ("men of arms") transformed into *bushidan* ("militarised bands/crews").

b) *The Heian Period*

Many *bushidan* and *bushi* were the descendants of imperial families and rose to great power, rebelling against the imperial court during the Tohei and Tegyo Wars of the 10th century CE (Ogawa 2009, 13-14). While rebelling *bushi* fought against pro-imperial *bushi*, the imperial court and aristocracy hired the latter to defend the government. These *bushi* roamed the streets as security guards or as body guards for high-ranking officials. From here, the term *samurai* developed from the term *saburau* ("to be armed and to protect high-ranking persons"). By the middle Heian Period, many upper-class *samurai* from *bushi* bands were appointed to guard the interior of the imperial palace (Ogawa 2009, 14-15).

Almost 80 years of peace followed the Tohei and Tegyo Wars, but three uprisings ensued between 1051 and 1087 CE. During this time, major improvements were made in the design of arms and armour. Until then, warfare had been conducted primarily on foot, but as cavalry units became increasingly popular, the specific requirements of mounted combat had to be considered in terms of the design of both arms and armour. To adapt to the shift from employing straight swords to those with curved edges (used primarily during mounted combat), a number of adaptations were introduced to armour styles between the middle 10th and early 11th centuries. Dalewicz-Kitto et al. (2013: 35) note some of the most prominent characteristics:

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[57] According to the translator William Scott Wilson, the term "samurai" first appears in the *Kokin Wakashú* anthology of poems, dated 905-914 CE. http://asaikarate.com/category/archive/page/3/ [Accessed 10/10/2018].

> By the eleventh century Japanese armour was constructed from a wide variety of organic and inorganic materials, including metals (iron, copper alloy), skin products (rawhide, leather, furs), textiles (silk, cotton, hemp), lacquer, wood and *papier-maˆche´*. The type and combination of materials used in the construction of each armour depended on its requirements. In brief, armours changed in use from those specifically designed to be used by cavalry to those of the foot soldier. These adaptations are also reflected in technological advancements driven by the introduction of the firearm into Japan in 1543. Fashion also played a part as armour took on a more ceremonial role during peacetime and its defensive qualities became less important.

Along more specific lines, the most significant development was the combination of *tankó* ("plate armour") with the more flexible *keiko* ("scaled armour") styles of armour. This allowed the making of four-piece *kusazuri* ("skirt") armour that would cover the lower body and upper legs, which was ideal for horseback warfare. The use of handheld shields was replaced through the incorporation of *sode* ("shoulder guards") to the armour. *Kabuto* ("helmets") were made from ten or more trapezoidal iron plates that were riveted together. This new style of armour became known as *yoroi* or *õ-yoroi* (Ogawa 2009, 15).

c) *The Kamakura Period*

Two major anti-imperialist rebellions took place during the 12th century. In 1185, Minamoto no Yoritomo was appointed as *shogun* by the Emperor, marking Japan's first *bakufu* ("feudal military government")[58]. During the Kamakura Period (1185–1333 CE) that followed, the *bushidan* grew in power through their appointment as retainers and stewards. This system of government was akin to that of feudal Europe, in that lords granted income to their vassals in return for services (usually military in nature) (Ogawa 2009, 18-19). During this period, the samurai wore *ó-yoroi* armour while their retainers or attendants donned the *dó-maru* type. In addition to changes in armour, the Samurai now also had to subscribe to the *Jóei-shikimoku* ("code of samurai laws", introduced in 1232 CE). It was also during the 13th century that a robust samurai culture began to flourish throughout Japanese society, fostered in part by the Zen religious sects that promoted disciplined lifestyles, as well as popular military inspired literatures and works of art (Ogawa 2009, 20).

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[58] It must be noted that this new system of government (Kamakura *bakufu*) did not completely replace the imperial government. The shoguns still sought the approval of the emperor on important matters (Ogawa 2009, 18).

During the late 13th century, Mongols had invaded China, conquering the Song Dynasty and establishing the Yuan Dynasty in its stead. After the shogunate refused a demand of tribute from the Yuan, the latter sent armed expeditions to Japan in 1274 and again in 1281, both of which were successfully thwarted by Japanese forces. The invaders brought with them staff weapons, leather armour and even a type of primitive cannon – elements of warfare the samurai had not previously contended with. Also, since the Mongol forces fought as a continental army, the Japanese were forced to move away from mounted warfare and expand their infantry. This change in battle strategy and tactics lead to yet another change in samurai arms and armour (Ogawa 2009, 21).

d) *The Kenmu Restoration*

While the samurai helped to defeat the Mongols, often at great expense, there was no reward system set in place by the Kamakura government. This was interpreted as a sign of apathy, resulting in growing dissatisfaction with the regime. This lead to a brief hiatus in shogunate rule known as the Kenmu Restoration (1333–1336 CE). This temporary restoration of imperial rule under Emperor Go-Diango came to an end in 1336 CE, when Ashikaga Takauji became shogun, thereby establishing the Ashikaga shogunate. The Nanbokuchō Period (1336–1392 CE) that ensued was plagued by civil unrest and war. During these times of armed conflict, most of the battles were fought in mountainous regions – a factor which once again caused adaptations in battle tactics, arms and armour. During this time, the elaborate *ó-yoroi* armour, originally designed for mounted combat, was replaced by the lighter, more practical *haramaki* and *dó-maru* types (Ogawa 2009, 22-23).

e) *The Muromachi, Sengoku-Jidai and Azuchi-Momoyama Periods*

The Muromachi Period (1392–1467 CE) that followed saw infantry fighting at close quarters, with the *yari* ("long bladed spear") becoming a popular weapon. The period also witnessed the growing popularity of *kawari-kabuto* ("exotic helmets"), whose grand, sculpted shapes made their owners stand out amidst crowds of infantry (Ogawa 2009, 23-24).

After the Muromachi Period, Japan fell into nearly a century of turmoil – a period known as the *Sengoku-jidai* ("Age of Wars") (1467–1573 CE). In 1543, with the arrival of guns in Japan, a new era dawned in terms of armour design and materials. Conventional *yoroi* armour, made from articulated iron and leather plates were replaced by cuirasses of sheet iron. While *nanban-dó* ("European armour") was imported as a first resort, the Japanese soon found means to mass produce armour known as *Tósei-Gusoku* ("modern armour"). The exotic *kawari-kabuto* became a rarity, as more utilitarian helmets, such as *zunari-kabuto* ("head shaped helmets") became standard attire. The latter were made of fewer (three to five) iron plates compared to the multi-plate (dozens) *hoshi-kabuto* and *suji-kabuto*. In order to make the functional *zunari-kabuto* stand out, samurai commanders added *maedate* ("plumes" or "crests") to their helmets (Ogawa 2009, 23-24).

The *Sengoku-jidai* came to an end with the toppling of the Ashikaga shogunate, signalling the dawn of the Azuchi-Momoyama Period (1573–1603 CE). The period witnessed the unification of Japan in 1590 CE, which brought an end to centuries of war and bolstered widespread economic growth. The last of the unifiers, Tokugawa Ieyasu, established the Tokugawa shogunate, which endured until 1868. During this time, Japan experienced almost boundless freedom in terms of poetry, art, calligraphy and monumental architecture (Ogawa 2009, 25-26). From a technological point of view, the Momoyama Period saw the introduction of better quality armours that were made from plates of pure ferrite faced with hard steel (Robinson 1959 in Dalewicz-Kitto et al. 2013, 42).

f) *The Edo Period*

The Edo Period (1603–1868 CE) is also referred to broadly as the Tokugawa Era, as the Tokugawa shogunate ruled during the sub-periods that followed (see **Table 3.1**). While the economy grew strongly until 1700 CE, fostering the emergence of an affluent middle class, the Sakoku Period ("closed country") (1633–1853 CE) saw Japanese culture develop unique characteristics that set it aside from growing European-America influences. During the height of cultural development of the Genroku Era (1688–1703 CE), literacy spread among city dwellers and Haikai poetry and Kabuki theatre flourished. During the Banka Bunsei Era (1804–1829 CE), literary culture even developed amongst the lower-class urban populace through novels and poetry. Since the period also saw peace, samurai retained their fighting skills through the practice of *kendo* (swordsmanship) as a martial art. The period also saw a growing interest in antiquities, which lead to the collection of objects of interest by high ranking officials, and even the publication of an 85-volume catalogue of antiquities known as the *Shúko Jusshu* ("Ten Categories of Collected Antiques"). The catalogue was used by many sword smiths and armourers to recreate the styles of the Heian and Kamakura periods under a philosophy known as "restoration sword" (Ogawa 2009, 26–28). This interest in historical objects lead to the preservation of Japan's material culture for future generations. Although the merchant class grew, a strong social hierarchy still existed: headed by the *shogu*n, with the *bushi* occupying the top ranks, followed by the *daimy*o and the various classes of *samurai* (Bottomley 2017, 78–79).

By the mid-18th century, ships from America, England and Russia visited the shores of Japan, hoping to re-establish trade relations. Of these foreigners, the Americans were the most persistent, forcing the *bakufu* into trade through the Convention of Kanagawa (1853). Three years later, the two countries signed the Treaty of Amity and Commerce, and soon afterwards, Japan also signed similar treaties with England, Holland and Russia. Many Japanese citizens were unhappy with the decisions and, coupled with the growing dissatisfaction with the out-dated feudal system of government, which reinforced social hierarchies and stopped upward socio-economic mobility, shogunate rule would soon come to a final end. While the merchant class continued to prosper under the newly-forged trade relations, growing unrest among peasants eventually led to a civil war in 1868. The latter culminated in the return of imperial rule under Emperor Meiji (Ogawa 2009, 26–28).

g) *The Meiji Period*

While the Edo Period was peaceful and sought to preserve ancient traditions, the Meiji Period (1862–1912 CE) was tumultuous and focused on modernisation. The shogunate was officially dissolved and the feudal system of government was replaced by a Westernised constitutional government. One of the most significant events in terms of traditional warfare was the Boshin War, which was waged between the former *bakufu* and the newly-established imperial army. The former *bakafu*, with their outdated flintlock guns and swords, lost to the overpowering might of the imperial army, the latter being equipped with percussion guns and, most notably, a type of Gatling gun. The *bakafu*'s defeat saw an end to the sword as a weapon of combat, reserving its use to loyalists of the new government through the enactment of the *Haitó Rei* edict in 1876 (Ogawa 2009, 29). The last official samurai conflict occurred during the Battle of Shiroyama on 24 September 1877, which brought an end to the Satsuma Rebellion – the last stand of the samurai under Saigō Takamori.

4.4.2 Samurai Armour: Historical Overview of Technologies and Styles

The history of Japanese armour is as colourful as the silk lacings, dyed textiles, lacquered iron and precious metals from which the objects themselves are created. The following section provides more detailed period-specific information about Samurai armour styles. Japanese helmets, or *kabuto*, were constructed in styles that were unique to a specific manufacturing school (Salvemini et al. 2013, 1).

a) *Classical Period Styles*

Two types of armour were in use in Japan before the 8th century CE. The first was known as *tankó* (assembled from iron plates) and the second as *keikó* (leather and iron plates laced together). Two types of *kabuto* ("helmet") also featured prominently the *shókakutsuki kabuto* (featuring a sharp prow-like projection at the front) and the *mabizashi tsuki kabuto* (hemispherical shape with a quarter-moon-shaped brim) (Ogawa 2009, 37; Sesko 2014, 20-). These armour types, with the exclusion of *keikó,* are associated with the pre-samurai military of Japan.

b) *Heian and Kamakura Period Styles*

At the beginning of the Heian Period (794-1185 CE), Japanese armour was designed along the principles of *keikó* (lamellar armour[59]), which came to include the ó*-yoroi*, *dó-maru*, *hara-ate* and *Tósei-Gusoku*[60] styles. The *kabuto* of the Heian Period, which accompanied ó*-yoroi* armours from the 10th century onwards, developed from the earlier *shókakutsuki* styles. The most popular *kabuto,* known as *Hoshi-bachi* ("star bowl helmet"), were constructed in a low-hemispherical bowl fashion and consisted of five to ten trapezoidal iron plates (*tate hagi-no-ita*) that were joined together using conical rivets or *ó-boshi* ("stars") with over-sized *byó-gashira* (rivet heads). As the number of vertical plates increased over time, the amount of surface space upon which these rivets could appear reduced, leading to the creation of smaller rivets called *hoshi,* and eventually narrow rivets known as *ko-boshi* ("little star").

Hashi kabuto, assembled from 60 plates could easily include 1500+ rivets (Absalon & Thatcher 2011, 20–21). The crown of the *kabuto* often featured a hole, known as a *tehen no ana*, through which the owner could pass his hair (Ogawa 2009, 37; Sesko 2014, 62), as well as *fukigaeshi* (turned-back sections of visors meant to deflect attacks from the side). The *o-yoroi* reached the height of its development during the period of mounted warfare towards the latter parts of the Heian and Kamakura Periods (Ogawa 2009, 39).

c) *Medieval (Kamakura to Muromachi Period) Styles*

Throughout the Nanbokuchó and Muromachi Periods, Japanese warfare saw an increase in the use of combat swords and staff weapons. The large and bulky *ó-yoroi* were subsequently replaced by their lightweight *dó-maru* counterparts (Ogawa 2009, 39). *Suji or suji tate-bachi*

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[59] The term 'lamellar' refers to armours consisting out of multiple armour plates that were laced together to form the various components.

[60] Teichert et al. (2012, 54) identified the DNMCH suit of armour as belonging to the *tósei gusoku* style.

kabuto were introduced during this time, featuring flat-headed rivets that appear flush with the surface of the helmet bowl. In order to create this flush appearance, the rivets were countersunk and the surface smoothed out (Absalon & Thatcher 2011, 21).

The term *suji* refers to the ridge/erect flange that runs along the edge of each individual helmet plate at a 90-degree angle (Absalon & Thatcher 2011, 21; Ogawa 2009, 40). In the description given by Salvemini (2013, 6) of a *suji-bachi kabuto*, the authors note that the ridges were designed to absorb energy in the case of a full frontal or diagonal blow to the head. The neck guards often assume the *kaso-jikoro* ("umbrella") styles, which mimics traditional hats (Ogawa 2009, 40).

Apart from the simple *suji kabuto* styles, as depicted above, more decorative examples include those with *kuwugata* (antlers or horns), *maedate* (front crests), as well as various shapes (such as double-edged swords, quarter moon and sun, etc.) (Ogawa 2009, 40).

d) *Medieval (Sengoku-Jidai to Azuchi–Momoyama Period) Styles*

Breeze (2008, 1) and others (Dalewicz-Kitto et al. 2013; Fedrigo et al. 2013; Ogawa 2009) note that Japanese armour underwent significant changes during the 16th century. With the size of military encounters increasing in terms of the sheer number of combatants (Ogawa 2009, 40), and with the introduction of firearms to Japan in 1542, it became necessary for armourers to reconsider the design of protective body armour (Dalewicz-Kitto et al. 2013, 35; Sakakibara in Fedrigo et al. 2013, 908). For example, the need for increased protection led to the development of multiplate (composite) helmets, where several overlapping *tate hagi-no-ita* (vertical plates or lamellae) were held together by a *koshimaki* (circular bottom plate) (Fedrigo et al. 2013, 909).

Kabuto within the *kawari-kabuto* styles were elaborately shaped to resemble animals, shells and even religious symbols. These objects were usually cast from a single piece of forged metal (Fedrigo et al. 2013, 909).

During the first part of the Kamakura Period, riveted helmets known as *Hoshi-kabuto* were exceptionally popular. Apart from their high plate volumes (with some boasting upwards of 50 vertical lamellae in one construction), a characteristic feature of these *kabuto* is the prevalence of star-shaped rivets known as *hoshi* (Ogawa 2009, 87). These helmets were replaced by ridged helmets, *suji kabuto*, at the beginning of the 15th century.

e) *Edo (Tokugawa Period) Styles*

Since the Edo Period (1603–1868 CE) was a relatively peaceful period of cultural development and economic growth (following the establishment of the Tokugawa shogunate), no significant changes to armour technologies were made. Since trade boomed, imported Indian fabrics were being used in armours, and lightweight, foldable armours also became popular for use when travelling (Bottomley 2017, 78–79). As the *daimyo* controlled numerous samurai and retainers, public marches/parades became costly shows of wealth. Because of this, we find many examples of richly decorated suits of armour from the period, some of which are even gold plated (Bottomley 2017, 81–82). Stencilled leathers were reintroduced, and the rounded helmet bowls of ancient times were copied. By the mid-18th century, this nostalgia had led to the re-emergence of the old *do-maru*, *haramaki* and *o-yoroi* styles (Bottomley 2017, 84).

4.5 EUROPEAN ARMOUR

4.5.1 Historical Context of European Knights and Soldiers

Despite the differences in political organisation, international conflict and battle tactics between Japan and Europe, one element remains unchanged: function dictates form. The developments of armour in terms of functionality were intertwined with the conflicts in which European armies were involved, as technological developments in weaponry and adaptations to combat strategies forced armourers to adapt and improve their armour. But, as also observed among the Samurai, aesthetic characteristics developed from a need to distinguish officers of rank from ordinary soldiers, as well as identify noblemen among the ranks of ordinary citizens. The latter part (aesthetics) is influenced by cultural norms and social stratification rather than utilitarian need.

Therefore, to understand European armour, we have to observe a similar approach to the one taken towards Samurai armour. However, in contrast to understanding the geopolitical environment of a single nation (Japan), whose military developments were primarily the result of internal conflicts, we have to consider a much broader, multi-national environment that stretches across most of Europe.

a) *The Middle Ages*

The Middle Ages, also known as the Medieval Period or Dark Ages, lasted from the collapse of the Roman Empire (5th century CE) to the beginning of the Renaissance (15th century CE). During the early Middle Ages, most arms and armours still followed the age-old designs of late Roman types that dominated Europe towards the end of Roman Empire. This uniformity in style existed across much of European, and there were very few culturally distinct features. In fact, during the 12th and early 13th centuries, a soldier would have been hard-pressed to distinguish between the armour of English, French, German and Italian armourers. It was only during the latter part of the 13th century that clear regional differences between these countries and their territories could be detected (Breiding 2004a).

During the first millennium CE, the concept of a highly centralised military force was replaced by a more “individualistic” model of a warrior, with the latter embodied by the medieval knight for centuries to come (Boman, Miller & Sheaffer 2009, 31). With the introduction of feudalism during the Middle Ages, the knight’s role in society was solidified through the establishment of a warrior class (comparable to the Samurai class in Japan). Short-sleeved mail shirts, crafted from interlocking chains of iron, were commonly used, as were scale armours made from overlapping lames of iron or bronze (Norris 2001). The feudal knights had access to a wider variety of arms and armour, thanks to their position within society as a warrior class. The knights wore mail[61] and helmets resembling the *Spangenhelm* (strap helmets), with the latter taking a more conical shape than the helmets of their predecessors.

These warriors were of high social standing and often had the financial resources to afford superior weapons and armours that were unobtainable by ordinary citizens. For example, almost exclusive access to chain mail or plate armour (styles of armour that were quite expensive) ensured that the socially elite had a better chance of survival on the battlefield compared to the common folk, with the latter having no choice but to don padded tunics and boiled leather armour. The differences in armour type and style also helped to distinguish the social elite from the commoners on the battlefield[62]. Knights under the feudal system were

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[61] “Defensive garments composed of interlinking rings should correctly be referred to as “mail” or “mail armor”. The common term “chain mail” is in fact a modern pleonism (a lingual mistake meaning “the use of more words than are necessary to express an idea”: in this instance, both “chain” and “mail” refer to an object made of interlinking rings). In short, the term “chain mail” is saying the same thing twice” (Breiding 2004f).

[62] https://www.encyclopedia.com/history/encyclopedias-almanacs-transcripts-and-maps/knights-and-traditions-chivalry [Accessed 02 June 2018].

responsible for their own combat training, acquiring weapons and maintaining their own armour, but were rewarded (often quite handsomely) with land and other commodities by their feudal lords. This meant that fee men, working as renowned knights for their lords, could themselves climb the social ladder to become aristocrats (Boman, Miller & Sheaffer 2009, 31–32).

b) ***The Renaissance***

The Renaissance (1300–1600 CE) bore witness to a number of significant technological developments across much of Europe. With the introduction of firearms to Western Europe during the 14th century, and with the overall decrease in the price of gunpowder, equipping infantrymen with guns became a popular practice. Since the aristocratic knight could now be killed by a common soldier wielding a firearm, close-range (one on one) combat became a last resort. With this shift in combat style, the ideals of chivalry could no longer be sustained, and the age of the noble knight came to a close (Edge & Paddock 1988, 35). The only place a warrior could now prove his one-on-one fighting prowess, was in the jousting ring. Although tournaments first appeared during the late 11th century, these events became increasingly popular during the 14th century, serving as a platform for knights to show off their skills. Since the nature of tournament sparring differed from battlefield combat, specialised tournament armour was developed (Boman, Miller & Sheaffer 2009, 36). Needless to say, battlefield armours are distinguishable from their tournament counterparts, since the latter is quite heavy, featuring specialised components and decorative elements.

The 14th century in particular bore witness to an “age of experimentation”, in which mail armours were being strengthened with quilted fabrics, metal plates and boiled leather (Breiding 2004b). By the early 15th century, the development of individual armour components culminated in the creation of full plate armour, which enclosed nearly the entire body in a steel “exoskeleton”. Individual components were connected and held in place through articulations such as rivets and leather straps (Breiding 2004c). By the mid-15th century, regional stylistic developments that emerged during the 13th century had become increasingly prominent. Interestingly, the creation of larger components (such as chest plates, greaves and gauntlets) afforded the smith with a greater level of freedom in terms of shaping, decorating and designing custom-made, highly individualistic suits of armour (Breiding 2004c).

In addition to the downfall of chivalry, the increased efficiency of firearms over the centuries also lead to a complete re-evaluation of siege warfare, battlefield tactics and the specialised roles of various military units. The Renaissance's renewed interest in ancient history also led to a rediscovery of ancient Greek and Roman military tactics, the result of which was the formation of massed pikeman squares during the 16th century. These pikemen often carried an *arquebus*[63] in addition to their pikes (Grant 1999, 181). Interestingly, this desire to enable pikemen to use both a medium range weapon (a 5.5 meter-long pike) and firearm (such as an *arquebus*) at the same time led to the creation of the bayonet during the late 17th century (Grant 1999, 182).

The introduction of firearms had another significant effect; the increasing redundancy[64] (in a broader sense) of plate armour. From 1550 onwards, bullet resistant armour began to appear (Grant 1999, 182), with a focus on protecting the essential regions of the body, such as the chest and head. This meant that full plate armour became quite redundant, with its gradual decline becoming most noticeable during the second half of the 17th century (Breiding 2004f). Simply put, the added weight, which resulted from the thickening of plate armour, made soldiers wearing full-body armour slow and prone to fatigue – a disadvantage that outweighed any advantages of wearing bullet resistant armour. Instead, men at arms began to cover only the most vital parts (head, torso, and hands), in order for them to be more agile and fight for longer periods (Breiding 2004e).

During the Middle Ages, most armour was made of iron, as steel was too expensive to allow mass production. Since cast iron (made in bloomery furnaces) was too hard and brittle and therefore useless for making armour, alternative technologies had to be developed. By the late Middle Ages, larger furnaces were in use that could be operated as either a bloomery or a blast furnace. Medieval iron was heterogeneous, containing grains of iron and slag inclusions – the shape of which was determined by the level and extent of hot working. Folding and forging were performed in an attempt to homogenise the metal, while quenching increased the iron's hardness (Norris 2001; Nelle & Jansen 2013).

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[63] An arquebus is A sixteenth-century firearm, the immediate predecessor of the musket (Campbell 2003, 15).

[64] It must be noted that armour never became obsolete on the battlefield, as most modern-day armours still employ the basic designs that proved effective throughout history (Breiding 2004f).

c) *Post-Renaissance*

As the use of firearms in armed conflict increased steadily during the 16th and 17th centuries, the European cavalry had largely abandoned the use of lances and percussive weapons such as the war hammer. A cavalryman's armament now consisted of a sword and firearms (sometimes even multiple pre-loaded pistols), while his armour was reduced to a helmet, cuirass and arm defence. During the time, the formation of pike squares remained a popular tactic amongst infantries across Europe (Grant 1999, 183), but much of Europe also witnessed the introduction of dragoons (horsemen who fought dismounted using carbines) (Grant 1999, 183).

In order to adapt to the ever-increasing firepower, range and efficacy of firearms, armourers had to adapt their trade once again. This was done by increasing the thickness of armour from traditional single-layer plate armour, to double or even triple-layered versions (Leever et al. 2006, 542). This type of armour construction became typical of the *harquebusiers* – a revamped cavalry characterised by their use of the *harquebus*[65] (Grant 1999, 123).

4.5.2 European Armour: Historical Overview of Technologies and Styles

a) *European Body Armour*

During ancient times (up until the founding of Rome in 700 BCE), a general lack of advanced metalworking technologies restricted the scope and variety of armours. Even with the relatively "new" introduction of iron for the manufacture of weapons and armours, ancient smelters were not adept at eliminating impurities or preventing the formation of gaseous pores. Inhomogeneity, which is caused by the latter, represented the main stumbling block in the creation of strong, long-lasting weapons and armour. It was only during Roman times, when the large scale production of quality armours became a priority for the state that metalworking technologies become refined (Boman, Miller & Sheaffer 2009, 5). With the expansion of the Roman empire, metal-working technology spread further across Europe and remained relatively unchanged throughout Early Medieval times (Boman, Miller & Sheaffer 2009, 5). But as always, necessity is the mother of invention and with the introduction of better, more lethal weapons came the need for more affective armours.

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[65] "The invention of the matchlock 'hackenbüsche', or 'arquebus' can not be dated precisely, but evidence points to it having taken place around 1475, probably in Germany. Technically, matchlocks were superceded with the invention of the wheellock in the 16th century, but they continue to employed until the end of the 17th century, largely due to their simplicity' (Royal Armourers 2016, 152). The short barrel made these weapons more manoeuvrable and therefore ideal for mounted troops. https://en.wikipedia.org/wiki/Carbine [Accessed 10/06/2018].

The nature of battles also influenced the type of armour that was in use, and naturally, visa-versa. Since mounted warfare dominated the Middle Ages, armour had to be light enough to not cause undue burden on one's horse, provide manoeuvrability for the mounted knight, while at the same time providing effective protection. On horseback, the cavalry affected a *blitzkrieg*-style attack, being introduced to the battlefield by a foray of arrows from archers and backed-up by infantry (Keen 1999, 187). Where knights dismounted and fought on foot, the bouts of fighting were short and explosive, as moving around in 30 kilograms of armour would have been exhausting. Because of the latter, battles rarely lasted longer than a day (Prestwich 1999, 11).

b) *Tunics and Boiled Leather*

The most basic form of body protection was the padded/quilted tunic, also known as a gambeson. These quilted jackets were ordinary items of clothing that were reinforced by padded layers that absorbed blows from melee attacks. This tactic proved effective against blunt weapons and even deflected some edged weapon attacks. Needless to say, these padded tunics were less effective against sharp edges, weapons or projectiles with a high velocity, yet it remained the choice of poor soldiers for many centuries. The second most affordable type of body protection was boiled leather. By boiling and treating leather with a number of substances, tanners and armourers were able to make items that could withstand more substantial blows. However, general efficiency still depended on the thickness and toughness of the leather, coupled with the skill of the tanner/armourer who made the item. Boiled leather strips could be added to quilted tunics, mail or even plate armour, but could also be shaped into single-piece items that resembled plate armour. Most notable among the latter are the shaped, muscular cuirasses made famous by the Romans.

Because armour was expensive to make, individual components were repaired; often on multiple occasions. Items were also handed down from generation to generation. These combined factors meant that by the 14th century, most infantrymen from England owned mismatched suits of armour made from individual items. Suits of armour therefore consisted of a variety of different materials (Breiding 2000a).

c) *Scale, Lamellar and Mail Armour*

The most basic forms of metal-based armour during the 1st century CE differed little between Europe, the Middle East and Asia. During this time, only a few armour types; scale armour (made from many overlapping plates), lamellar armour (consisting of fewer overlapping plates) and mail (chain and wire mail) were in use.. In contrast to Greek and Roman times, when plate armours made from large sheets of iron or steel were reserved for high-ranking officials, these types of armour became frequently used after the 2nd century CE. Initially worn during the Middle Ages as protective wear in fighting tournaments, solid breastplates made their way onto the battlefield, especially following the introduction of crossbows and firearms. In most cases, iron breastplates were worn over chainmail in order to provide the wearer with an impenetrable (in most cases) outer shell of defence (Norris 2001; Nelle & Jansen 2013).

d) *Riveted, Solid and Chain Mail Armour*

Riveted and solid mails were in use from Roman times until the 13th/14th centuries CE. After the fall of the Roman Empire, and the wars and conflicts that followed during the Middle Ages (invasions by the Germanic peoples, Vikings and Normans, the Crusades, etc.), riveted iron mail became widely used (Norris 2001; Nelle & Jansen 2013), especially among those who could afford it. These items were made from thousands of interlinking metal rings that required hours of laborious dedication, therefore making them expensive and impractical in terms of mass production. However, in terms of its utility, chain mail provided a superior flexibility and manoeuvrability when compared with heavier, less moveable plate armours, making chain mail an item of choice for the centuries leading up to gunpowder warfare. These long, tunic-style mail shirts mainly covered the torso and arms, but often extended into a split skirt, with the latter offering protection to the upper legs. Because of its utilitarian nature, chain mail remained popular until the 14th century (Breiding 2002b).

e) *Plate Armour*

Around 1200 CE, chain mail was being replaced with plate armours, especially in areas such as the shins, knees and elbows (Boman, Miller & Sheaffer 2009, 5), however, reinforced mail was still being produced in Western Europe throughout the remainder of the 13th century. The reinforcing method saw traditional chain mails being strengthened with strips of boiled leather[66] or plate metal in order to protect articulation areas of the body, such as the shoulders, elbows and knees. Over time, these added reinforcements were developed into arm and shin guards, as well as articulated gloves known as gauntlets. By the 13th century, mail for the legs (chausses) and boiled leather or steel components to protect the knees (kneecops) and shoulders (ailettes) came into popular use. Shoulder ailettes, usually displaying heraldic

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[66] The term ‘plate’ refers more directly to the solid shape of the armour, than the use of metal – the latter being a popular misconception when the term ‘plate armour’ is used. As Breiding (2000) notes, plate armour could be made from steel or leather that was boiled in oil or wax (*cuir bouilli*).

devices as decorative elements, represent the first manifestations of “fashion” in European armour, and became especially popular in France. These fashionable ailettes would remain prevalent during the century-long overlap between the 13th and 14th century (Breiding 2004b). With the 14th century came enhancements in crossbow technology and with it the need to protect soldiers against the increased penetrating ability of bolts. Coats resembling ponchos contained rectangular plates that were riveted to the fabric substrate, thereby providing increased protection without limiting movement. To provide additional protection to the extremities, articulated plate armours were developed for the legs, arms and hands (Norris 2001).

f) *Full-bodied Plate Armour*

The development of full plate armour, which covered the entire body, was the next logical step in armour development. Since most individual pieces of armour were already well-developed in terms of form and function, it simply took their conversion from chain or boiled leather into plate armour to develop the full-plate suit of armour. This impressive display of craftsmanship quite literally protected the user from head to toe. By 1420 CE, full suits of steel plate armour were available across much of Europe (Boman, Miller & Sheaffer 2009, 5; Norris 2001) and plate armour quickly became the dominant armour type of the 15th century (Breiding 2002). During this time, armourers would actually test the strength and durability of their wares by firing a crossbow at pieces of armour at point blank range (Edge & Paddock 1988, 34).

During the Renaissance, especially following the introduction of firearms in Western Europe, traditional warfare changed dramatically, and so too did bodily protection. Armour became thicker and heavier, and by extension more costly, which is one of the reasons why full body armour was discarded during the 18th century (Boman, Miller & Sheaffer 2009, 6).

g) *European Helmets*

During the Middle Ages, warfare was still largely based on man-to-man combat, taking place either on horseback or on foot. Apart from ever-present threat of overhead melee attacks, the increasing use of projectile warfare (bows, arrows and spears) meant that head protection gained paramount importance. Interestingly, it was the Romans of the 1st century who first mass-equipped soldiers with metal helmets. While mail and scale armours worked well to protect the body, it proved fairly useless in protecting the head. At the time, one-piece helmets, made from a single piece of sheet metal shaped into a bowl, grew increasingly common. However, since these helmets took too long to make, it never proved feasible for mass production. Therefore, the Roman army returned to the use of bronze, which required less effort and production time. After the fall of the Roman Empire, and the loss of Roman technologies and ingenuity that resulted from it, helmet designs took a backward step. The *Spangenhelm*, a rounded or conical helmet of Middle Eastern origin, which was made from multiple plates, came into use some time around 570 CE. These helmets were made by arranging individual metal plates within a circular frame and riveting the inserts in place in order to maintain a domed shape. The helmets also featured cheek flaps and nasal guards (Norris 2001; Nelle & Jansen 2013).

At the height of the Middle Ages (early 11th to mid-12th century), a typical soldier would possess a sword, lance and shield along with a helmet, long-sleeved mail shirt and hood. Towards the end of the 12th century, the typical conical helmets were replaced by flat-topped exemplars with side plates that hid and protected the face of the soldier. It is believed that the first bascinet (an open-faced helmet with a pointed apex) evolved from the humble skullcap during the early 13th century[67]. During the 14th century, the great helm and wide-brimmed war hat (also known as a *chapel-de-fer*) was joined by a new type of helmet; a close-fitting bascinet featuring a shroud of mail (*aventail*) from the chin to the shoulders. These helmets often included movable visors that were first introduced around 1330 (Norris 2001).

4.6 ARABIAN DAGGERS

4.6.1 Arabian Daggers: Historical Overview of Regional Differences

a) *Regional Linguistic Terminology*

Arabian daggers are generally referred to as *jambiya*, with regional linguistic variations including *jambia*, *jambya*, *janbiya*, or *janbia*. The term is a fairly broad one and is used to describe curved daggers with a double edge and pronounced medial rib (Stone 1999, 310). The name itself is derived from the Arabic word *janb* (side), as the blade was traditionally carried on the wearer's side during earlier times (Atkinson, n.d.). In modern times, however, *janbiya* are mostly worn in front of the lower torso, which (theoretically) allows the user to draw it much quicker when the need arises for close proximity combat (Heinz 2015, 78).

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[67] "The origins of the basinet helmet go back to the metal skull cap worn inside a mail coif and under a great helm. In the case of the basinet, the skull cap extended to protect the side and back of the head" (Royal Armourers 2016, 88).

The term *jambiya* is mostly used in the western parts of Arabia (Yemen and eastern Saudi Arabia), while *khanjar* is used in Eastern Arabia (eastern Saidi Arabia, the Emirates, Oman, Muscat) as well as Syria and Iraq (Elgood 1994 in Heinze 2013, 32). For the time being, both terms will therefore be used interchangeably, as we cannot irrefutably state which term befits the DNMCH dagger until we have performed our stylistic analysis. As Heinze (2015, 76) explains: "*Janbiya* thus not only denotes a specific type of edged weapon, which is part of the wider family of *khanājir*, but also has regional specificity, clearly associating a dagger with a broad, double edged, curved blade with Yemen". In addition, there are various physical characteristics, coupled with the way in which the item is worn, that divides *janbiya* into further subcategories (Heins 2015, 85). While the term *janbiya* technically denotes the blade and hilt of the dagger alone, the scabbards and belts have become almost synonymous with the dagger itself. This stems from the fact that *janbiya* styles are so specific, they require custom-made scabbards (Heinz 2015, 80).

a) *Historical Use and Modern Popularity*

Jambiya have been in use for many centuries, but the oldest evidence of their use comes from a 6th century statue of the Sheban king of the Himyarite Kingdom (110 BCE–520 BCE), who is depicted holding a *jambiya* (Atkinson, n.d.). To this day, the daggers are still worn by men in the Middle East (especially Yemen), and function as a symbol of the manhood, wealth and social status. They are often gifted from father to son at the end of Ramadan to symbolize the latter's coming of age (Al-Zain, 2014).

Although found commonly throughout Yemen and India for centuries, *jambiya* are closely associated with the people of Najran from Saudi Arabia and Yemen, as well as Muslim men from the horn of Africa[68]. Although there are a variety of different types of *jambiya* across the Middle East, the *khanjar* (an Omani styled *jambiya*) tradition is most alive in its homeland of Oman, even to this very day. Of all the Middle Eastern countries to have used *jambiya*, the Omani people are widely credited as the main proponents in the preservation of this aspect of Arabian material culture.

Traditionalists wear their *khanjars* on a daily basis, while the remainder wear them during significant occasions. These include religious festivals, such as Eid Al Fitir and Eid Al Adha, and social occasions, such as weddings, engagements and traditional markets (known as *Al*

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[68] https://en.wikipedia.org/wiki/Janbiya [Accessed 01/04/2018] also see Al Busaidi (2015).

Habtah). They are also worn as an important element of local traditional dress when receiving formal delegations from other cities or countries (Al Busaidi 2015, 38–44).

The cultural significance of the *khanjar* is further illustrated by its appearance on the country's flag and national emblem. Since *khanjar* hold such a revered position within society, these heirlooms are often passed down from father to son, generation after generation (Al Busaidi 2015, 5). In a way, this tradition has transformed living generations into custodians of their own heritage. More examples of early-modern *khanjar* may therefore be in the hands of the original creators/owners' descendants, than in museum collections.

Interestingly, the cultural phenomenon of the *jambiya* was not restricted to the Middle East. Their use and popularity also spread into the Balkans (Eastern and South-eastern Europe) after the Ottoman Empire's expansion into the region in 1354 CE. During the Empire's period of decline and modernisation (1828–1908 CE), invasions, occupations and alliances with European countries saw an increased interaction between colonial Europe and what remained of the once powerful Ottoman Empire (1299–1922 CE)[69]. Modernisation brought about many social, political and economic reforms, which would have influenced trade and travel into the region. As an increasing number of Europeans travelled to Ottoman territories, *jambiya* would have made their way into Europe as gifts or items of interest (curios). For example, following a number of historical geopolitical events (i.e. Algeria's occupation by France in 1830, Britain's deployment of troops to Egypt in 1882 during the Urabi Revolt, Tunisia's occupation by France in 1881, Labia's occupation by Italy in 1912, and the eventual annexation of Cyprus and Egypt by Britain in 1914[70]), both soldiers and travellers would have been exposed to the material culture of former Ottoman territories. As could be expected, *jambiya* held a particular level of attraction to men in military service as exotic weapons. Interestingly, many expatriates (former soldiers turned explorers), known as "desert-*wallahs*", sent *jambiya* to friends and family across Europe (especially Britain) as mementoes of their travels. As a result, small industries (such as those encountered in Morocco) sprang up to accommodate the growing demand for exotic weaponry (Atkinson n.d., 71).

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[69] https://en.wikipedia.org/wiki/History_of_the_Ottoman_Empire [Accessed 01/04/2018] also see Kerr and Wright (2015: 411).

[70] https://en.wikipedia.org/wiki/History_of_the_Ottoman_Empire [Accessed 01/04/2018] also see Kerr and Wright (2015: 411).

[71] http://atkinson-swords.com/collection-by-region/africa/north-africa/koummiya-morocco.html [Accessed 01/04/2018].

4.6.2 Arabian Daggers: Historical Overview of Technologies

a) *Animal Horns and Ivory*

The hilts of *jambiya* are commonly made of animal horn, wood and metal, but could also be made of elephant or walrus ivory. In rare instances, especially when making blades for wealthier citizens, rhino horn was used. Sheaths are made from wood and covered with cloth and metal, with lavish decorations such as metal ornaments, silver rings, semi-precious stones and leather. Sheathes curve upward to accommodate the curve of the blade, although the curvature is often exaggerated along the tip, representing aesthetic appeal rather than utilitarian need. The tip is often protected by an embossed metal cover, which often serves as an anchoring spot for chains that connect the tip of the scabbard to the belt. Belts are covered in decorative cloth and feature an ornamental buckle. Blades are typically made from iron or steel (Heinz 2015, 113), with a few notable examples made from Damascus or wootz steel (Shackleford 2010).

b) *Damascus Steel*

Damascus is a type of fine-grained, highly ornamental steel, featuring unique patterns of banding and mottling. This sought-after steel is named after the city of Damascus in Syria[72], from where it originated during the early centuries CE[73]. Modern research has shown that Damascus steel was superplastic[74]; a material quality that was well ahead of its time and afforded the metal incomparable sharpness and strength. The wootz steel used to make these blades was imported to the Near East from India and Sri Lanka (Juleff, 1996, 60; Shackleford 2010, 38).

Production of true (historical) Damascus declined over the centuries and eventually ceased around 1750 CE. This lack of active production, coupled with the breakdown of raw material trade routes, meant that the art of Damascus forging became virtually extinct[75]. Although modern metal smiths have come close to reproducing Damascus, chemical differences between ancient and modern raw materials ensure that historical Damascus can never truly be reproduced, at least from a materials science perspective. All things considered, the DNMCH

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[72] https://en.wikipedia.org/wiki/Damascus_steel#cite_note-12 [Accessed 01/04/2018] also see Campbell (2005, 225) and (Shackleford 2010, 38).

[73] Some sources date the advent of Damascus steel to 500 BCE (Shackleford 2010, 38).

[74] Superplasticity refers to 'a state in which solid crystalline material is deformed well beyond its usual breaking point, usually over about 200% during tensile deformation. Such a state is usually achieved at high homologous temperature. Examples of superplastic materials are some fine-grained metals and ceramics' (Escudier and Atkins 2019, 619).

[75] https://en.wikipedia.org/wiki/Damascus_steel#cite_note-12 [Accessed 01/04/2018] also see Campbell (2005, 225).

jambiya was probably not made from Damascus steel, as the estimated date of production falls within the late 19th century CE.

c) *Silver*

Another characteristic of *jambiya* is the popular use of silver for both decorative and functional elements. The use of this metal made the *jambiya* a treasured item, and even in today's monetary terms, the cost of buying one is high due to prevalence of silver components (Al Busaidi 2015, 50).

4.6.3 Arabian Daggers: Historical Overview of Styles

Jambiya designs can be used for stylistic analysis and may be helpful in determining both the relative chronology and regional origin of the object. For example, Arabian Peninsula *jambiya* commonly feature a curved double-edged blade and average at approximately 14 inches (35.5 cm) in overall length, with 19th century CE examples often silver mounted. Those from central north and western parts of Arabia often feature u-shaped scabbards[76] commonly referred to as the Mecca style. *Jambiya* following the Indo-Persian (Iranian) style often boast flat-topped pommels with simple cylindrical handles, especially during the 18th and 19th centuries CE. In addition, exceptional mid-19th century CE Indo-Persian blades feature a "split-tip" design, where the blade divides into five points. *Jambiya* from Iraq often boast narrower blades and a sheath that is significantly less curved (Shackleford 2010, 405–406). In rare instances, dating and subsequent authentication is aided by the presence of maker's marks. Interestingly, after 1920, it became forbidden for Yemeni craftsman to sign jewellery of any kind[77].

a) *Turkish/Persian Jambiya (Turkey)*

Popular during the late 16th to early 17th century CE, Turkish *jambiya* often featured large blades made from Persian wootz steel with no medial ridge (Fig. 4.1). They are characteristically decorated with coral inserts into the blade's upper region (close to the hilt). Wooden scabbards are often covered with black leather and gilded copper, although simple,

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[76] The inner piece of a scabbard is referred to as a *shoft* and is usually carved from wood. Carved as mirrored halves, the two pieces are glued together to form the scabbard's superstructure. While the blade of the knife is curved at 30 degrees, scabbards are often curved to an exaggerated angle of 90 degrees. https://timesofoman.com/extra/OmaniDress/ [Accessed 01/04/2018].

[77] http://www.vikingsword.com/vb/showthread.php?t=20622 [Accessed 01/04/2018].

undecorated ivory handles were also common. The total length of the *jambiya* can reach 12 inches (30.5 cm) [78].

Figure 4.1: An example of a Turkish *jambiya*. ***Source:*** www.oriental-arms.com[79].

b) *Balkan Jambiya (South-eastern Europe, Albania and Turkey)*

These 18th through earlier 20th century *jambiya* feature extended pommel tops and cross guards with hilts made from undecorated walrus ivory (Fig. 4.2). Some examples have large hilts that measure 7.5 x 3 inches (19 x 8 cm) compared to the regular 5 x 2 inches (13 x 5 cm). Blade cores were often forged from pattern welded steel with the outer edges forged from regular unwelded steel. Scabbards are made from wood and decorated with elaborate silver filigree decorations that in most instances cover the entire surface (Shackleford 2010).

Figure 4.2: An example of a Balkan *jambiya*. ***Source:*** www.oriental-arms.com[80]

c) *Mecca Jambiya (Arabia)*

Commonly found during the early to mid-20th century, Meccan *jambiya* are recognisable through their 8-inch (20.3 cm) double-edged blades that feature a prominent medial ridge

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[78] Most scabbards were made from wood, with the preferred type being Calotropis. Since this type of wood does not soak in moisture from the air, scabbards made from Calotropis wood are well-protected from oxidisation (Heinz 2015, 96).

[79] http://oriental-arms.com/item.php?id=2645 [Accessed 10/06/2018].

[80] http://oriental-arms.com/item.php?id=131 [Accessed 10/06/2018].

(Fig. 4.3). Solid rhino horn grips are common, but also ornate silver variants. The scabbards are often made from heavy silver and are curved at an extreme upright, u-shaped angle (Shackleford, 2010).

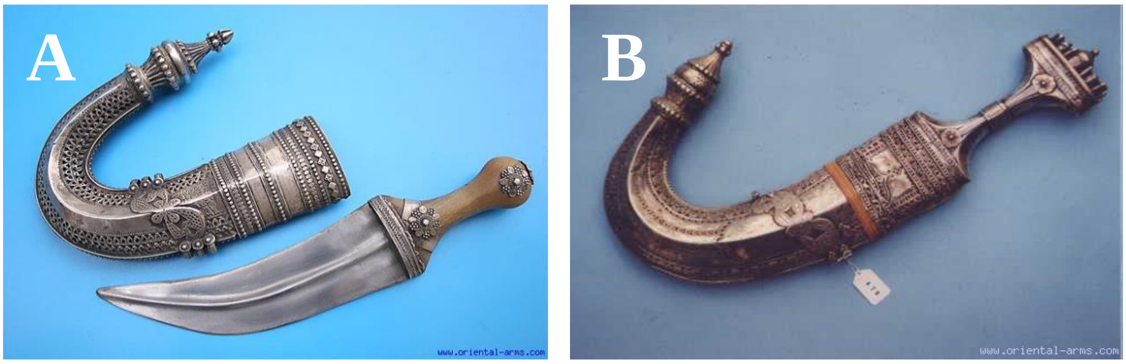

Figure 4.3: Two examples of *Mecca jambiya*. ***Source:*** www.oriental-arms.com[81].

d) ***Thouma (Yemen)***

Thouma jambiya were also popular during the early to mid-20th century, particularly in Yemen. They feature 3-inch (7.62 cm) wide double-edged blades with pronounced medial ridges. Rhino horn handles are often embellished with silver nails and gold coins, while the wooden scabbards are adorned with gilded filigree chapes[82] and niello decorations[83] (Fig. 4.4A). *Thoumah* style scabbards do not feature an exaggerated u-shaped tip (Fig. 4.4B–C). *Jambiya* in this style, which are decorated with exquisite silver plates, are often referred to as *tuza* (Shackleford 2010).

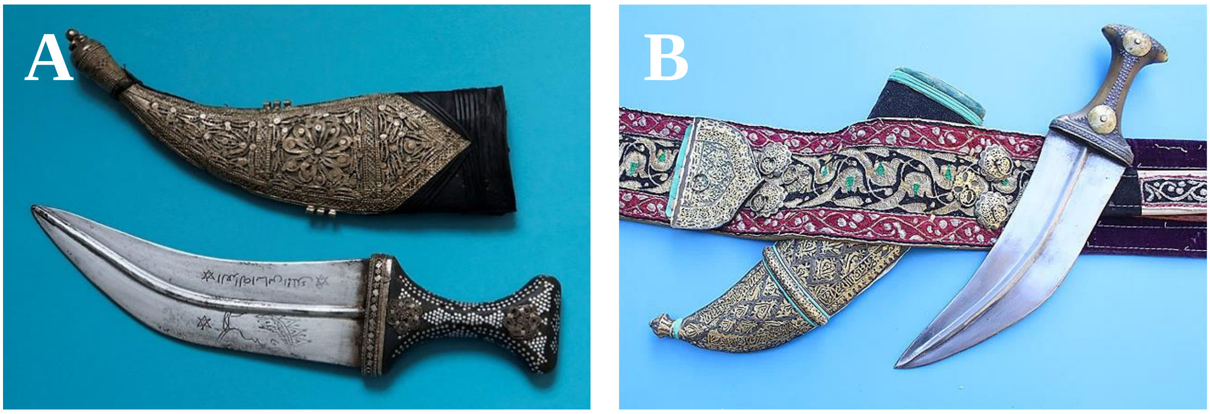

Figure 4.4: Three examples of *Thouma jambiya*. ***Source:*** www.oriental-arms.com[84].

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[81] http://oriental-arms.com/item.php?id=3968 [Accessed 10/06/2018].

[82] A chape is the the “lower terminal of a sword or dagger scabbard which is reinforced to prevent damage to the scabbard” (Darvill 2009, 84).

[83] Niello is an inlay material made by mixing silver, lead and copper with sulphur. The mixture is pressed into engraved lines as a soft paste, where after it is heated or fired until the mixture melts. After cooling, the mixture hardened and was sanded to produce a brilliant sheen (Darvill 2009, 420).

[84] http://oriental-arms.com/item.php?id=7393, http://www.oriental-arms.com/item.php?id=4354 [Accessed 24/07/2018].

e) *Koummiya Jambiya (Morocco)*

These early 20th century *jambiya* are basically Moroccan adaptations of the traditional Arabic *jambiya*. They are characterised by narrower blades, compared with their Middle Eastern counterparts (Fig. 4.5) and also feature a narrow hilt. They boast slim handles with a pommel that seems oversized by comparison. The blades are also straighter and only curve slightly towards the tip, commonly totalling a length 12 inches (30.5 cm) (Shackleford 2010). The scabbard's design can be described is j-shaped.

Figure 4.5: An example of a *Koummiya jambiya*. ***Source:*** www.atkinson-swords.com[85].

4.6.4 Overview of Omani *Khanjar* types

There are six types of *khanjar* that are particular to Oman. Since Al Busaidi's (2015) thesis represents one of the most comprehensive investigations into the stylistic attributes of each type, it will be used as the primary source for the discussion to follow. Where specific stylistic features have not been specified by Al Busaidi, additional visual characteristics are observed from source photos and described.

a) *Al Saidi Khanjar*

This specific type of *khanjar* is most famous for belonging to the Al Busaid royal family, with the name referring to its namesake, Said bin Sultan (the Sultan of Muscat and Oman from 1806 to 1856) (Al Busaidi 2015, 52–55). The most common characteristic is the use of seven rings as part of the scabbard's design[86]. There are three sub-types within the *Al Saidi* type.

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[85] Available at http://atkinson-swords.com/collection-by-region/africa/north-africa/koummiya-morocco.html [Accessed on 08/08/2018].

[86] https://timesofoman.com/extra/OmaniDress/ [24/07/2018].

The first sub-type establishes the primary stylistic features of the type (Fig. 4.6). The handle (also known as a *qarn*) is covered with a rolled silver design, or *al tikasir*, from the ferrule to the pommel. The sides of the handle remain uncovered, allowing the underlying handle material to remain visible. The design on the upper area of the scabbard consists of concentric square geometric designs following Omani and Islamic styles. The belt holder on the scabbard is adorned with seven rings; three on the scabbard itself and four on the belt holder. These rings are attached by means of twisted wires referred to as *sim mahuis* or *um sabea*. The two outer rings on the belt holder are topped by a conical decoration known as a *ter* ("shield") or *amana* ("hat"). The top part, or *al chandah*, of the scabbard is covered with silver or gold thread against a black backdrop, while the bottom half, or *al mekhalah*, is decorated with *al tikasir* designs. The *al mekhalah* is attached to the belt by a silver chain known as a *mirqat* (Al Busaidi 2015, 52–55).

Figure 4.6: An *Al Saidi khanjar*: First sub-type. ***Source:*** Al Busaidi (2015, 52).

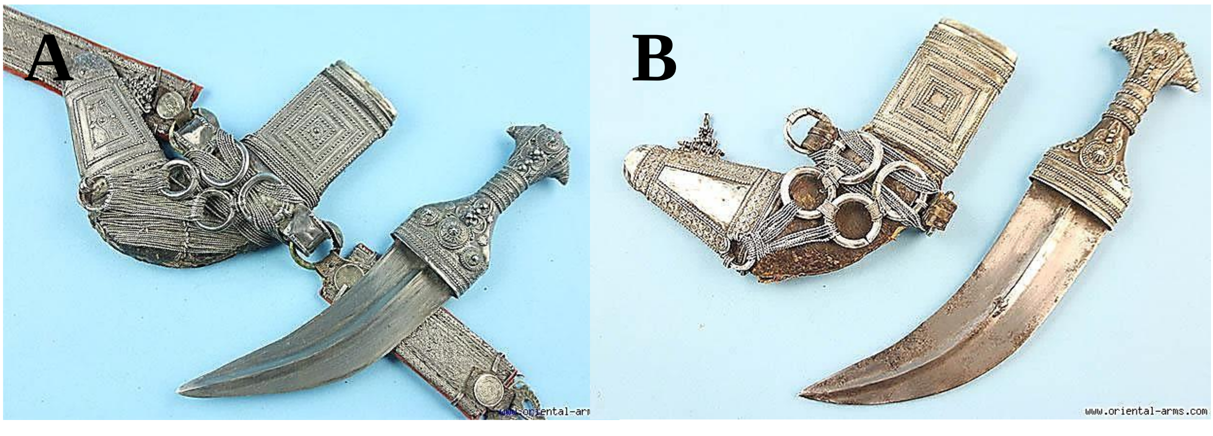

Figure 4.7: Two examples of *Al Saidi khanjars.* First sub-type. The date of the first (A)[87] is not specified, while the second (B)[88] is believed to date from the late 19th century.

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[87] Available at http://www.oriental-arms.co.il/item.php?id=6312 [Accessed on 08/08/2018].

The second sub-type of *Al Saidi khanja*r (Fig. 4.8) shares many similarities with the first, but the following features distinguish it from its predecessor: The handle is completely covered in *al tikasir* and no part of the underlying bone/horn superstructure is visible, while the upper scabbard area is also longer than that of the first type (Al Busaidi 2015, 57-60). An additional feature, not mentioned by Al Busaidi (2015), is that the two outer rings on the belt holder do not feature a conical decorations or *ter*.

Figure 4.8: An *Al Saidi khanjar*: Second sub-type. ***Source:*** Al Busaidi (2015: 57).

The third sub-type of *Al Saidi khanjar* (Fig. 4.9) once again shares core attributes, but with unique features. The handle resembles the second type, in that the underlying bone/horn superstructure is completely covered by al *tikasir*. The upper part of the scabbard is decorated with parallel line decorations, accompanied by additional wavy line or *al qala* designs, and also features four instead of seven rings. The scabbard is covered in silver or gold threads, often accentuated by a dark backdrop, while the *al mekhalah* is free from the typical *al tikasir* design (Al Busaidi 2015, 61–63). Since the *al tikasir* is missing, this sub-type does not boast a *mirqat* to attach it to the belt. Instead, it has a simplified dome-shaped cap or chape covering the edge of the scabbard (Fig. 4.10).

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[88] Available at http://oriental-arms.co.il/item.php?id=6814 [Accessed on 08/08/2018].

Figure 4.9: An *Al Saidi khanjar*: Third sub-type. ***Source:*** Al Busaidi (2015, 61).

Figure 4.10: *Al Saidi khanjars.* Third sub-type. The date of the first (A)[89] is not specified, while the second (B)[90] is believed to date from the late 19th century.

b) ***Al Nizwani Khanjar***

This type of *khanjar* (Fig. 4.11) is named after the Nizwa artisan market in Ad Dakhliah, and is known for its larger size and diagonal position when worn. The handle is carved in the shape of a T, which is accentuated by the accompanying t-shaped silver decoration. In contrast to the fine decorative motives of *al tikasir* designs, the design of *Al Nizwani* handles takes the form of a solid plate known as *shamarikh*. Both sides of the handle are exposed, showcasing a dark bone/horn superstructure. The top of the pommel is decorated with finer silverwork depicting diamond-shaped motifs. The scabbard's upper cover boasts floral designs in the form of roses and leafy branches. The branches follow a neat *el qala* style characterised by helical or spiral designs. The belt holder is slanted in order for the *khanjar* to

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[89] Available at http://www.oriental-arms.co.il/item.php?id=4446 [Accessed on 08/08/2018].

[90] Available at http://www.oriental-arms.com/item.php?id=57 [Accessed on 08/08/2018].

lie diagonally when worn. The scabbard cover is made from sewn silver wire in a design that resembles the more traditional silver plated *al tikasir* designs. The chape covering the edge of the scabbard has a flattened tip, compared to the domed appearance of *Al Saidi* types. *Al Nizwani khanjar* often come equipped with secondary accessories attached to the belt by a small chain, including an additional knife, tweezers and kohl eyeliners (Al Busaidi 2015, 57–60). Most characteristically, these *khanjar* feature only four rings[91].

Figure 4.11: An *Al Nizwani khanjar*. ***Source:*** Al Busaidi (2015, 65).

c) *Al Batini Khanjar*

This type of *khanjar* (Fig. 4.12) gets its name from the Al Batinah governorate, but is also referred to as *Al Saheliah*. While *Al Nizwani khanjar* are typically worn to the front, the smaller *Al Batini khanjar* are worn to the left. The handle can take one of two forms; the first resembles that of the *Al Nizwani* type, while the second features elephant ivory instead of bone or horn. In recent years, the ivory has been replaced by textured marble or even plastic, but still provides a characteristic white appearance that mimics ivory. Decorations take the form of exceptionally thin nails and intricate carvings that are typical of Islamic design. The floral designs on the upper part of the scabbard are more intricate than that of *Al Nizwani khanjar*, and feature rose branches that twist to form three concentric circles. The type also features four circles and sewn designs on the bottom part of the scabbard, while the chape covering the edge of the scabbard is flattened, but with a rounded tip (Al Busaidi 2015: 70-72). These *khanjar* commonly feature four rings[92].

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[91] https://timesofoman.com/extra/OmaniDress/ [Accessed 30/09/2018].

[92] https://timesofoman.com/extra/OmaniDress/ [Accessed 30/09/2018].

Figure 4.12: An *Al Batini khanjar*. ***Source:*** Al Busaidi (2015, 70).

d) *Al Suri Khanjar*

This small and lightweight *khanjar* (Fig. 4.13) is named after the city of Sur in the Ash Sharqiah governorate. The handle can follow two designs; the first is almost identical to that of the *Al Nizwani* and *Al Batini khanjar*, while the second design features a small rectangular plate on the centre of the handle – with some examples being embossed while others remain undecorated. These plates are accompanied by two sun designs known as *shams*; one at the top of the handle and the other at the bottom. The handle design is specifically known as *Al Sifani*, as it is closely associated with the Bani Safi family and the Omani tribes within the Ash Sharqiah governorate. The top of the scabbard is decorated by *al qala* branch designs, often presented in a combination of silver and gold. The belt holder has four rings and is also attached at a slant to allow the *khanjar* to hang diagonally when worn. The scabbard is often decorated with leather featuring sewn decorations in gold or silver. The chape takes a similar shape to that of *Al Batini* types. *Al Suri khanjar* often feature a small pouch or wallet known as al *bakhch*, which is often attached to the shorter part of the belt (Al Busaidi 2015, 74–79). Apart from having four rings, these *khanjar* are also the smallest and most lightweight type[93].

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[93] https://timesofoman.com/extra/OmaniDress/ [Accessed 30/09/2018].

Figure 4.13: An *Al Suri khanjar*. ***Source:*** Al Busaidi (2015, 74).

e) *Al Ganobi Khanjar*

Al Ganobi khanjar (Fig. 4.15) originate from the Dhofar governorate and boast a shape that is more akin to that of a traditional knife than a *jambiya*. Because of its shape and length, it is also known as *Al Qabliah*. Their handles come in two styles; the first style is almost identical to the t-shaped styles of the *Al Nizwani, Al Batini* and *Al Suri khanjar,* while the second follows that of *Al Suri* alone. The entire scabbard is covered in silver and is attached to the belt at a more extreme angle, so that when worn, the *khanjar* is almost horizontal with the belt. The most popular additional accessory is a bullet holder/pouch (Al Busaidi 2015, 80-81).

Figure 4.15: An *Al Ganobi khanjar*. ***Source:*** Al Busaidi (2015, 80).

f) *Al Hanshiah Khanjar*

This *khanjar* (Fig. 4.16) originates from the Ash Sharaqiah governorate and shares many similarities with the *Al Ganobi khanjar*. The scabbard is covered with black leather, which is often left undecorated. The handle is also black and is adorned with gold designs similar to those encountered on *Al Suri* and *Al Ganobi* types. The scabbard is positioned on the belt at the same extreme angle as *Al Ganobi* types and are also often accompanied by a bullet holder/pouch (Al Busaidi 2015, 82-83).

Figure 4.16: An *Al Hanshiah khanjar*. ***Source:*** Al Busaidi (2015, 82).

4.7 CONCLUSION

The information in this chapter has provided us with detailed background information on the cultural-historical context of each object class; when the objects were made, where they were made, the materials and techniques employed during production, as well as the styles unique to each. The following summaries provide condensed overviews of each object class:

4.7.1 Ancient Egyptian Bronzes

Egyptian statuettes, as an object class that existed across millennia, represent a complex area of study with many historical, material and technical considerations. The complex internal shifts in power-dynamics, which led to the rise and fall of three major Kingdoms and their Intermediate Periods, also influenced the availability of raw materials and the dissemination of skills and artisans from across the Ancient Near East.

The availability and quality of raw materials, coupled with metallurgical innovations (i.e. alloying, the purposeful addition of elements) influenced the very nature and behaviour of the metals being used to produce statuary. Technological developments (i.e. new and innovative casting techniques, hammering, joining and polishing) also influenced the way in which statuettes were created, refined and perfected.

4.7.2 Japanese Samurai Armour

The historical context of Japanese Samurai armour is equally rich as that of ancient Egyptian bronzes, but exists primarily within a martial context, rather than a ritualistic/mythological one. As items of personal defence (rather than spiritual, as was the case with votive figures), armours in general are geared towards the practical and utilitarian. Stylistic developments were therefore interlinked with the ever-present need to improve the utilitarian/functional nature of armour, rather than aesthetic whims or “style for the sake of art and iconography”. However, in the case of Japanese Samurai armour, many stylistic attributes, especially when it came to *kabuto* and *menpó* designs, focused on unique styles that reflect social status.

Since much of Japan’s history was one of war and internal political turmoil, the technological and stylistic context of Samurai armour is undeniably linked to the historical period from which they originate, the systems of government that controlled their creators and owners, and the ever-changing state of peace versus warfare. As the saying goes, “necessity is the mother of invention”, and the need to be stronger, better and faster than one’s opponent represented the main driving force behind the evolution of armour. Economic developments, trade relations and economic disparities between civil society, ruling governments and samurai classes also influenced the rise and decline of the use of armours and weapons.

4.7.3 European Armour

The development of European armour moved at a relatively slow pace during the Middle Ages and focused primarily on the individualistic model of the warrior, the chivalrous knight. These knights, who existed within a system of feudalism, had access to arms and armours that were unobtainable by ordinary citizens, making the knightly class a walking, talking, sword-wielding display of social stratification. However, following the introduction of firearms during the Renaissance, this individualism changed dramatically, with the focus of combat redirecting itself from one-on-one combat to ranged assaults. As the age of chivalry lay dying, the age of gunpowder was born.

The Renaissance brought with it not only the introduction of firearms, and the subsequent evolution of armour types, but also fostered the return of ancient battle strategies. The latter came as a result of the period's reinvigorated interest in ancient history. While full-body plate armours become redundant, specialised armours became popular, with specific styles being dedicated to particular roles (i.e. infantry, cavalry, pikemen, etc.). With warfare a constant reality, the high demand for arms and armours led to an increased need for mass-production. This mass production also went hand-in-hand with technological advancement and the development of improved armour designs.

4.7.4 Arabian Daggers

The context of Arabian daggers, or *jambiya*, falls between the strong ritualistic context of votive statuettes and the utilitarian context of arms and armour. As daggers, these objects are primarily classified as weapons, but their symbolic and decorative nature played a larger role in their historical maintenance (continued use within society), than their function as weapons. The *jambiya's* role as a symbol of manhood, wealth and social status meant that the materials and embellishments employed in their design (i.e. rhino horn, ivory, silver, gold), were in themselves symbols of prominence.

Their popularity among travellers and military officers, from influential colonial powers such as Britain and Germany, meant that *jambiya* remained in circulation well into the early 20th century. Their appeal as exotic weapons continues to this day, and the income generated from sales boosts many local economies. The Deutsch Ostafrika Rupie (which will be discussed in greater detail in Chapter 5) presents a unique example of how the juxtaposition of a colonial coin on an item of Middle Eastern origin could provide unexpected details on the provenance of an artefact.

CHAPTER 5
STYLISTIC ANALYSIS

5.1 INTRODUCTION

Now that we have familiarised ourselves with the historical, material and technological contexts of the different objects, we possess the background knowledge required to explore the stylistic attributes of each object in greater detail. In Chapter 4, it was highlighted how specific styles and technologies were popular during certain time periods. This concept allows us to establish relative chronologies based upon stylistic attributes, which is the primary focus of Chapter 5. Each section commences with an introduction that presents a basic recap of existing research, followed by comparative analyses. Within the comparative analyses, we will compare the stylistic attributes of similar (curated and authenticated) objects from research publications and online museum catalogues/archives from across the globe. Where relevant, this chapter will cross-refer to literature and case studies presented in Chapter 3.

Within the chronology of this thesis, Chapter 5 also serves as a stepping-stone towards the more complex and technologically advanced assessments that will be presented in Chapter 6.

5.2 STYLISTIC ANALYSIS WITHIN THE CONTEXT OF THIS THESIS

Before we commence with our stylistic analyses, it must be re-iterated that style within the context of this thesis is not limited to aesthetic or artistic elements alone. The rule that form follows function proposes that an object’s shape (form or style) is primarily based upon its intended purpose (function). Now, since an object’s purpose influences the way it is designed and constructed, and even dictates the types of materials employed in its manufacture, one can propose that technological (non-aesthetic) elements can also be used as stylistic markers. Thus stated, a more perceptive approach to stylistic analysis would encourage holistic methods of determining the relative age of objects.

In support of this methodology, we have to consider the main drawback of stylistic analyses that focus on visual or aesthetic features alone. Throughout history, both ancient and modern, stylistic archaism or revivalism saw the intentional reproduction of aesthetic styles from bygone eras, mostly in an attempt to revive or relive the “glory days”. Revivalism was particularly prominent during the Third Intermediate and Late Periods of ancient Egypt (Hill 2001), with the apex of revivalism taking place during the 25th and 26th Dynasties (Scott et al. 2002, 336). In many instances, valuable items were also transferred from one generation to the next, which meant that objects made in a certain style, and dating from an earlier period, were often in use during later times. However, recreation/reproduction also takes a more sinister form – the creation of fakes and forgeries with the aim of benefiting financially.

Therefore, if one is to apply aesthetic stylistic analysis when dating an object, a match should only be made to a securely dated object sharing similar or identical aesthetic stylistic features (Ghoniem 2014, 42). Although this recommendation is an important one to consider, it oversimplifies the task at hand. When dealing with ancient Egyptian bronzes, for example, most museums offer date ranges that often span across centuries. Since many stylistic changes may have occurred during this time, a “securely dated” reference, such as “Middle Kingdom”, may point us in a general direction, but it does not provide definite answers. To complicate the situation, Schorsch and Frantz (1998, 19) note that one rarely finds a single attribute that is sufficient to determine an object’s authenticity. In simpler terms, multiple stylistic matches should be made before authenticity is considered. Although this is also a valuable point, it complicates the situation even further.

What if the object being analysed only features one “definite” stylistic match? What if it includes other stylistic markers that have simply not been observed and recorded until now? What if it truly is a “one of a kind” example? Do we have to disregard an object’s potential authenticity, just because we can’t find any formally curated example to cross reference? In short, we have to consider the statements by Ghoniem (2014) and Schorsch and Frantz (1998) as guidelines, but at the same time prevent them from setting limitations on our analyses.

Fortunately, within the context of this thesis, we can also turn to certain technological elements as stylistic markers. The incorporation of technological elements into stylistic analysis is supported by the likes of Salvemini (2013) and Ogawa (2009). Most pertinent to this argument, as mentioned above, is the fact that style is often influenced by technological factors, and visa-versa. As Salvemini et al. (2013, 1) explain, “the self-evident differences in style correspond to the technological differences that material scientists can help to understand”. In many ways, particular styles could only be executed thanks to the existence of certain technologies. For example, in Japan, the skills of the Momoyama Period (1568–1603 CE) *papier mache* crafters, coupled with the availability of special lacquers and advanced steel-forging technologies, facilitated the creation of highly stylised, decorative helmets known as *kawari-kabuto* (exotic helmets) (Ogawa 2009; Salvemini et al. 2013, 1). In short, without the existence of these technologies and materials, the highly aesthetic *kawari* styles[94] would never have existed.

5.3 ANCIENT EGYPTIAN BRONZES

As noted before, authenticity, or the confirmation thereof, is a complex field of study in general. It is complicated even further by the very nature and extent of ancient production methods and techniques. For example, if mass production was a simple process during ancient times, modern replication would be equally simple. As Schorsch and Frantz (1998, 19) explain

> It should be noted that ancient Egyptian objects produced in large quantities for ritual purposes were often created in accordance with relatively circumscribed programs of design, and this is certainly true in the case of hollow-cast animal figures. The resulting close similarity among a multiplicity of extant figures, together with the comparative ease with which such objects can be reproduced, has resulted in numerous forgeries. Some of these have revealed themselves readily through their inadvertent incorporation of anachronisms of style, iconography, or technique, while others remain more problematic. For these there is seldom an easy path to a definitive assessment of the authenticity.

It is therefore of utmost importance that authentication studies employ mixed methodologies and avoid the application of a single technique (like stylistic analysis). One local example of a mixed methodological study is Gravette’s (2011) study, in which an insightful revaluation of the DNMCH’s bronze collection is provided by applying both stylistic analysis and NDE.

Gravette (2011, v) notes that most of the items within the collection were dated to the Middle and New kingdoms, but that certain observed stylistic trends and manufacturing techniques

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[94] Examples of kawari-kabuto:
https://en.wikipedia.org/wiki/Kabuto#/media/File:Conch_helmet_-_Higgins_Armory_Museum_-_DSC05525.JPG [Accessed on 30/09/2018].
https://en.wikipedia.org/wiki/Kabuto#/media/File:Helmet_crouching_rabbit_Met_07.48.jpg
http://atomictoasters.com/2012/05/kawari-kabuto/ [Accessed on 30/09/2018].
https://za.pinterest.com/pin/377176537532581834/ [Accessed on 30/09/2018].

were contradictory to those encountered during these periods, and that the objects could be placed within much later dates, possibly even the Late Period. According to certificates of authenticity, the gilded Osiris dates from the 12th Dynasty of the Middle Kingdom[95], while three other bronzes reportedly date from the 18th Dynasty of the New Kingdom (Gravette 2011, 1).

While the nursing Isis figure was dated to the 12th Dynasty, stylistic attributes suggested a relative date that falls within the late New Kingdom or Third Intermediate Period, with the latter representing a more probable timeframe for production (1069–664 BCE). A similar situation applies to the Child Horus statuette, which was dated to the 12th Dynasty but clearly depicts stylistic features that are more reminiscent of art from the 19th and 20th Dynasties (1292–1069 BCE) (Gravette 2011, 6).

Schorsch (1988, 42) focuses our attention on a slightly challenging aspect of technological and stylistic analyses when it comes to ancient Egyptian bronzes:

a) There was a general lack of nation-wide standardisation in the production of bronzes,
b) Each regional centre of production could have slight stylistic variations that deviated from the "prescribed" rules of form, pose and dimensions,
c) Since mass production by means of reusable molds was non-existent, each statuette represents a unique example.

These factors mean there are literally thousands of surviving examples of each type of statuette. In fact, Schorsch and Frantz (1998) even go as far as to suggest that the stylistic attributes attributed to forgeries may in fact represent undocumented examples of authentic Egyptian style. With the latter being stated, the point must once again be reiterated that stylistic analysis alone cannot be used in isolation to determine whether an object is authentic or not.

5.3.1 Comparative Analysis: Sekhmet/Wadjet-Bast

There are a number of prominent feline (lion or cat) goddesses from ancient Egypt, the most noteworthy being Bastet, Sekhmet and Wadjet-Bast. Sekhmet, the lion-headed goddess of

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[95] During Middle Kingdom, especially the 12th Dynasty, a number of technological advances produced prototypes that were in sustained production for many centuries (Grajetzki 2006, 1). The uniform artistic styles that were the norm during the Old Kingdom diminished and were subsequently replaced by regional variants (Grajetzki 2006, 16).

war, strife, fire and heat, was believed to be the manifestation of the enraged eye of Re (Ra) and avenger of the pharaoh. Yet, quite paradoxically, she was also worshiped as the goddess of love and healing. She is characteristically depicted with a solar disk and *uraeus* on its head. In particular, the sun disk identifies her as the daughter of Re (Gahlin, 2010, 44, 192, 197; Watterson 1999, 172).

In some museum collections (such as the Brooklyn Museum of Art), lion-headed goddesses are often referred to as Wadjet, which may cause some confusion to researchers, especially those conducting comparative visual analyses. According to Watterson (1999, 129), Wadjet was traditionally worshiped as a cobra or cobra-headed goddess and seldom depicted in human form. It was only during Egypt's later history that Wadjet became associated with the cat goddess Bast/Bastet, affectively transforming her into the lion-headed Wadjet-Bast. Nefertem, the son of Ptah and Sekhmet, was also depicted as a lion-headed deity. To complicate the genealogy of Nefertem, he was referred to as the son of Bastet by some, while others described him as the son of Wadjet (Gahlin, 2010, 39).

Although the DNMCH feline is identified by the museum as Sekhmet, one major stylistic element (the *uraeus*) could support the theory that she is in fact Wadjet or Wadjet-Bast. While Sekhmet, as the daughter or Re, was religiously depicted with a sun-disk (Gahlin 2010, 44) or a combination of the sun disk and *uraeus*, the DNMCH statuette only has a *uraeus*. This correlates to the description of the Brooklyn female as Wadjet, as it also bears a solitary *uraeus*.

For comparative purposes, if one examines feline figures that have been curated as Sekhmet, almost all feature a sun-disk or a combination of the sun-disk and a *uraeus*. Fig. 5.1A is a representation of the goddess from the temple of Mut in Karnak, and is one of 572 large-scale black basalt statues commissioned by the 18th Dynasty (1550–1292 BCE) Pharaoh Amenhotep III (Kelly Simpson 1971, 160). Fig. 5.1B is granodiorite statue attributed to pharaoh Sheshonq I of the 22nd Dynasty (943-716 BCE). Fig. 5.1C is a bronze figure from the Late Period (716–332 BCE),

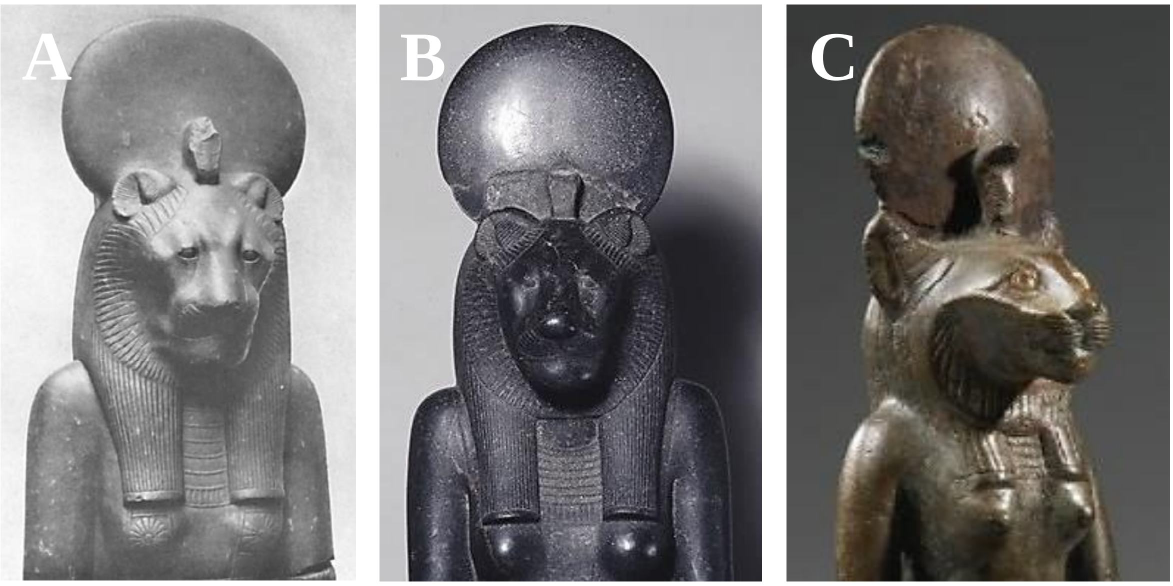

Figure 5.1: Black granite statue from the Metropolitan Museum of Art (A), granodiorite statue from the British Museum (B), and bronze statue from Sothebys (C).
***Sources*:** Lythgoe (1919, 3) (A); British Museum catalogue (B), Sothebys auction catalogue (C).

Depictions of Wadjet-Bast are mostly characterised by the presence of a *uraeu*s cobra on the headdress instead of a sun disk. In quite a few instances, the *uraeus* is broken (as seen in Fig. 5.2A-B). The frequency of this breakage is associated with the object's placement on the top of the figure, coupled with the fact that these decorations are usually slender and therefore prone to breakage.

Figure 5.2: Bronze statue from the Brooklyn Museum (A), bronze statues from Sothebys (B–C).
Sources: Brooklyn Museum catalogue (A), Sothebys auction catalogue (B–C).

With the above visual comparisons drawn, the proposition that Sekhmet[96] is actually Wadjet-Bast is quite compelling. One might counter-argue that the broken *uraeus* might have included a solar disk further up along the cobra's neck, but as is clear from Fig. 5.1A-C, the sun disks are always carved with the bottom edge of the disk connected to the top of the headdress. This design ensured greater stability and might explain why broken Wadjet-Bast cobras are more common than broken Sekhmet sun disks.

5.3.2 Comparative Analysis: Cat/Bast

Domesticated cats were introduced into Egypt around 2100 BCE and, from the Middle Kingdom onward, the benevolent cat-headed goddess Bastet was worshiped throughout much of Egypt (Watterson 1999, 201), especially in cult centres such as Bubastis (Schorsch & Frantz 1998, 17).

According to ancient mythology, Bastet was not always a mild-mannered "kitty-cat", but was once the goddess of war. As legend goes, an enraged lion-headed Sekhmet once left Egypt only to return as the charming cat goddess known as Bastet (Ambers et al. 2008, 3). The goddess's benevolent feline form inspired widespread dedication to cats and the subsequent creation of feline catacombs and cemeteries at Saqqara, Thebes and Beni Hasan (Schorsch & Frantz 1998, 17).

Beloved pet cats were often mummified and interred alongside their owners so that they may spend all of eternity together. A less romantic side of ancient Egypt's obsession with cats saw thousands of cats being bred specifically for ritual purposes; being killed, mummified, sold to worshippers and sacrificed to the gods at cult centres. These mummified cats were often wrapped in linens decorated with painted cat faces, or placed inside simple cat-shaped wooden boxes. Wealthier citizens and royalty could commission hollow bronze statuettes that served as lifelike sarcophagi for their mummified felines. Some of the smallest examples stand little over 11 cm tall, while the largest recorded example stands at 50 cm (Schorsch & Frantz 1998, 18).

Statues of the goddess are often adorned with jewellery or decorated with precious metal inlays (Gahlin, 2010, 18). Our first example is a 28 cm-tall hollow cast bronze cat (Fig. 5.3A-

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[96] From here on forward, the thesis will refer singularly to Sekhmet as Wadjet-Bast, and not Sakhmet (Wadjet-Bast) as has been the convention up until this point.

B) said to date from the 26th Dynasty or later (334–30 BCE) (Schorsch & Frantz 1998, 20). What is interesting to note is the presence of decorations on the figure, which include a broad collar and eye of Ra pendant. Another cat (Fig. 5.3C) wears an incised chain with a pendant that resembles a simplified winged scarab (Schorsch & Frantz 1998, 19).

Figure 5.3: 26th Dynasty (or later) hollow cast bronze cats featuring religious insignia.
Sources: Schorsch and Frantz (1990, 19–20).

Another beautiful example is the Gayer-Anderson cat examined by Ambers et al. (2008) (Fig. 5.4). The cat features a broad collar (typical of those worn by humans during funerary banquets and observed on royal mummies) and square *udjat*-eye pendant. The cat's chest also features a winged scarab below a small sun-disk. The cat's forehead depicts a smaller scarab (which represents the morning sun, creation and birth) while the hairs inside the cat's ears have been cleverly designed to stylistically render the hieroglyphic sign for the goddess Maat (who represents truth, order and righteousness) (Ambers et al. 2008, 2–3). Together, these features indicate that the cat represents a goddess.

Figure 5.4: The Gayer-Anderson cat. ***Source:*** Ambers et al. (2008, 2).

However, the exact identity of the cat is uncertain and Ambers et al. (2008, 2) note:

> Which god does the Gayer-Anderson cat represent? Due to the nature of Egyptian religion, it is impossible to say with certainty, as gods could typically manifest in a variety of anthropomorphic, theriomorphic and hybrid forms. However, the best candidate is Bastet. This goddess could be represented as a lioness, as in her principal temple at Bubastis in northern Egypt, reflecting her association with Sekhmet The latter goddess is described in the Destruction of Mankind, an ancient Egyptian mythological text, as attempting to destroy mankind. In another myth, an enraged leonine Sekhmet leaves Egypt but returns as an appeased cat. Thus Bastet as a cat could be interpreted as the benign form of Sekhmet. Votive figurines of Bastet always represent her as a cat, or cat-headed woman, not as a lioness.

In contrast to the examples above, the DNMCH feline does not possess any adornments or insignia that specifically identify it as a goddess or “queen cat”. This may suggest that the statuette depicts a beloved family pet, rather than a goddess. But of course, this theory is hard to prove beyond a doubt.

5.3.3 Comparative Analysis: Ibis

This graceful bird was the sacred animal of the ibis-headed god Thoth. The latter served as a mediator between good and evil, and is often credited as the inventor of hieroglyphs and therefore, scribe to the gods. According to the Metropolitan Museum of Art[97], representations

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[97] https://www.metmuseum.org/art/collection/search/570718 [Accessed 22/09/2018].

of the ibis in copper alloy are some of the most numerous sacred animal statuettes, alongside the cat, falcon, and Apis bull.

Life-size examples of ibises often feature legs, neck and heads made from bronze, with a body carved from wood (such as those mentioned by Schorsch (1988)). These larger birds often feature hidden doors along the underside of the body, which were used to insert mummified birds into the hollow interior. The popularity of the ibis (and its associated animal cults) grew exponentially during the first millennium BCE in general, with thousands of surviving ibis mummies standing as testimony to their sacrificial purpose.

The majority of smaller bronze ibis statuettes were made in the crouching style, with their legs bent (Fig. 5.5 A–C). This is a good example of where practical considerations dictate style, as the high propensity for breakages among straight-legged figures might have encouraged the adoption of a crouched style. Many larger ibis figures still boasted straight legs, but if one considers the ratio between total size and leg thickness, the larger statues would have been more resilient due to their thicker, stronger legs.

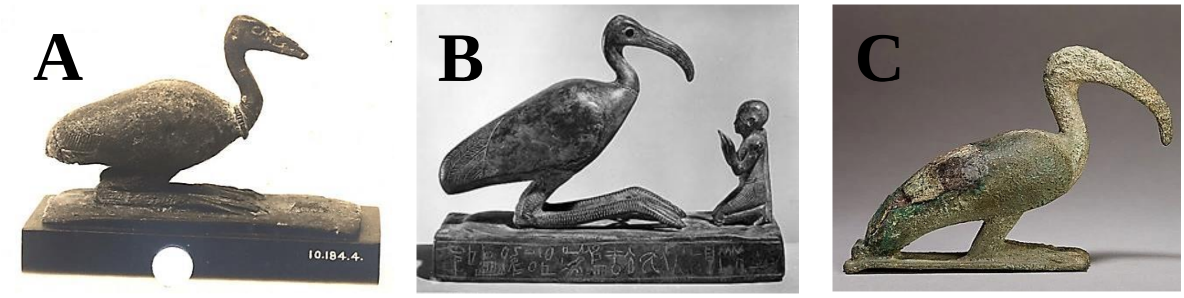

Figure 5.5: Examples of crouching ibis statuettes from the Third Intermediate Period (A), Dynasty 26 (B) and Ptolemaic Period (C). ***Source:*** Metropolitan Museum of Art[98].

In some instances, ibis figures that appear to be stand-alone figures on a base were actually covers/lids for animal coffins (Fig. 5.6). These small rectangular coffins usually housed ibis chicks or smaller bird mummies, and were often solid cast due to their small size.

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[98] https://www.metmuseum.org/art/collection/search/558264 [Accessed 07/07/2018].
https://www.metmuseum.org/art/collection/search/552857 [Accessed 07/07/2018].
https://www.metmuseum.org/art/collection/search/570712 [Accessed 07/07/2018].

Figure 5.6: Oblong bronze cover of an animal mummy coffin, Ptolemaic Period (7 x 7.6 cm).
Source: Brooklyn Museum[99].

Larger, life-sized statues accommodated ibis mummies within the hollow cavity of the bird's body. The Tuna el-Gebel ibis (Fig. 5.7A) is a prime example of the latter case, with X-ray images revealing the in-tact remains of a mummified ibis. Assembled from a combination of gold-leafed wood (body) and silver (head and legs), X-rays revealed joinery methods thanks to the contrast differences between wood and metal (Fig. 5.7B). Theriomorphic coffins intended to house animal mummies are relatively easily identifiable, as they include openings (mummy doors) at the bottom of the figure through which the mummy could be inserted (Fig. 5.7C).

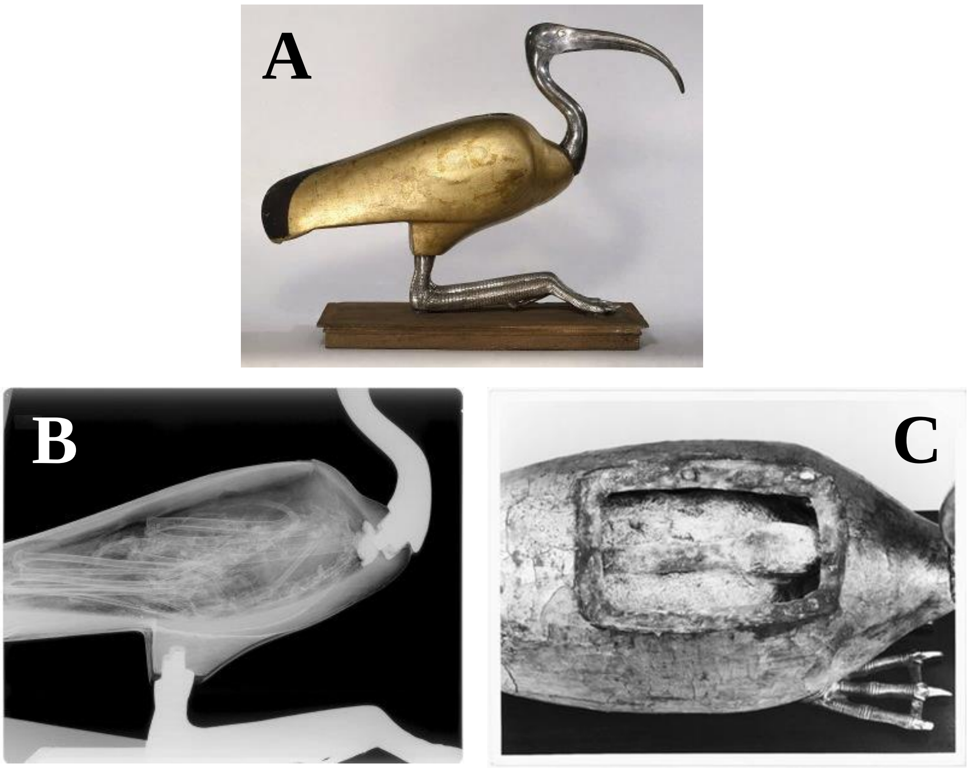

Figure 5.7: The Tuna el-Gebel ibis (42.5 x 20.3 x 55.9 cm) (A), X-ray images revealing a composite structure and intact ibis mummy (B) and a mummy door (C).
Source: Brooklyn Museum[100].

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[99] https://www.brooklynmuseum.org/opencollection/objects/19132 [Accessed 07/07/2018].

[100] https://www.brooklynmuseum.org/opencollection/objects/3532 [Accessed 07/07/2018].

It is difficult to say, without a shadow of a doubt, whether the DNMCH ibis once served as a coffin lid. Based on a side-by-side comparisons between curated examples of coffin lids (such as Fig. 5.6), and the base of the DNMCH ibis, the latter does not feature the characteristic lip or edge that would allow the lid to slot into the underlying coffin structure. However, the latter does boast a square structure inside the rectangular superstructure (Fig. 5.8), which seems to have no obvious practical function.

Figure 5.8: The underside of the DNMCH ibis's base.

The presence of this square feature could indicate that the ibis was placed atop another item (such as a coffin or standard), but no similar examples were encountered within the consulted literature or online image archives.

5.3.4 Comparative Analysis: Dog/Jackal/ Wepwawet

The golden brown, slender hounds of Pharaonic Egypt were revered across all levels of society, not just for their hunting skills, but also for their companionship. Popularly known as the Pharaoh Hound, the general consensus is that the breed originated from the Maltese islands, where they are known as *Kelb Tal-Fenek* (Rice 2006, XIII). While others believe that the modern-day Pharaoh Hound is an original descendant from ancient Egypt, recent DNA studies have shown that the breed does in fact originate from Malta[101].

Because the Pharaoh Hound shares striking similarities with jackals, especially in terms of their upright ears and slender bodies, the two may be confused with one another by the untrained eye. The jackal god Wepwawet, whose name translates as "The Opener of Ways", was believed to guide the deceased along the dangerous paths of the afterlife, leading them

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[101] https://www.akc.org/dog-breeds/pharaoh-hound/ [Accessed 03/11/2019].

towards final judgement at the seat of Osiris. Although Wepwawet is often equated with Anubis, the jackal god had its own identity and even had cult centres at Asyut (known in Greek as Lykopolis, "Wolf-town") and Abydos. The main difference between Anubis and Wepwawet is that the latter is presented in its full animal form, while Anubis is an anthropomorphic figure with a jackal head[102].

As with Wadjet-Bast, the DNMCH's description of the "dog" statuette appears to be incorrect. However, misidentification is understandable, since the ancient Egyptian pantheon of gods and goddesses contained multiple embodiments of the same (or related) deities, most of which bear only the slightest variations in form and style. In fact, in this stylistic battle of dog vs jackal, one must keep in mind that the shape of the Pharaoh Hound closely resembles that of the jackal in ancient art and statuary (as is evident from Fig. 5.9).

Figure 5.9: A typical Pharaoh Hound (A) compared to a Ptolemaic Period bronze jackal/Wepwawet (B).
Source: Pinterest (A), Metropolitan Museum of Art (B)[103].

However, the oft-occurring misidentification of jackal statuettes as dogs does not mean that dog statuettes did not exist at all. In fact, there are many examples of dog statuettes, as the ancient Egyptians loved their canines, not just as hunting dogs but also as pets. In addition, the god Anubis was a canine-headed figure (Fig.5.10A), with the debate still out on whether he represents a Pharaoh Hound, jackal[104] or African Golden Wolf (*Canis anthus*). Whatever the case may be, depictions of the god Anubis in his full canine form can still create some

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[102] https://exhibitions.kelsey.lsa.umich.edu/jackal-gods-ancient-egypt/wepwawet.php [Accessed 23/09/2018].

[103] https://www.metmuseum.org/art/collection/search/570746 [Accessed 10/07/2018].

[104] The term 'jackal' is actually a misnomer, as recent archaeozoological evidence indicates that the Egyptian jackal was actually a type of wolf (Canis anthus lupaster). https://news.mongabay.com/2011/01/egyptian-jackal-is-actually-ancient-wolf/ [Accessed 10/07/2018].

confusion in the minds of curators trying to distinguish between dog and jackal/Wepwawet (Fig.5.10B) figures.

Figure 5.10: An Anubis figure from the Later Period (A)
and a Wepwawet figure from the Third Intermediate Period (B).
Sources: Manchester Museum (A), Metropolitan Museum of Art (B)[105].

Therefore, because it is quite challenging to distinguish between dogs (as domesticated animals) and jackals (as manifestations of gods) based upon the physical features of canines alone, one has to look towards other stylistic features. Most noteworthy among these is the bar of standard. As the gods Anubis and Wepwawet (and jackals in general), were closely associated with death and funerary practices, they were often connected to the cult of Osiris. Canines were often depicted on enigmatic symbols carried as standards in front of the pharaoh during processions. In particular, jackal standards, also referred to as *shedshed*[106], depicted as a balloon- or kite-like object in front of the animal, often accompanied by two curvilinear forms representing *uraeus* cobras (Evans 2011, 103).

As can be observed, the DNMCH jackal (Fig.5.11A) possesses a similar shaped *shedshed* compared to a curated Wepwawet figure (Fig.5.11B) from the Metropolitan Museum of Art. Although our object's shedshed is not as elaborately styled as the latter's, with the typical balloon shape appearing flattened, and the cobras almost unidentifiable as snakes, the stylistic intent behind the design is still quite obvious. Based on this similarity, we can safely say that our figure is indeed a representation of Wepwawet and not simply a wild/domestic canid.

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[105] https://egyptmanchester.wordpress.com/tag/anubis/,
https://www.metmuseum.org/art/collection/search/544913 [Accessed 10/07/2018].

[106] The exact representation or meaning of the *shedshed* remains unclear, but new interpretations, such as those offered by Evans (2011), suggest that the curved shape represents a canid den or burrow, flanked by two cobras for protection.

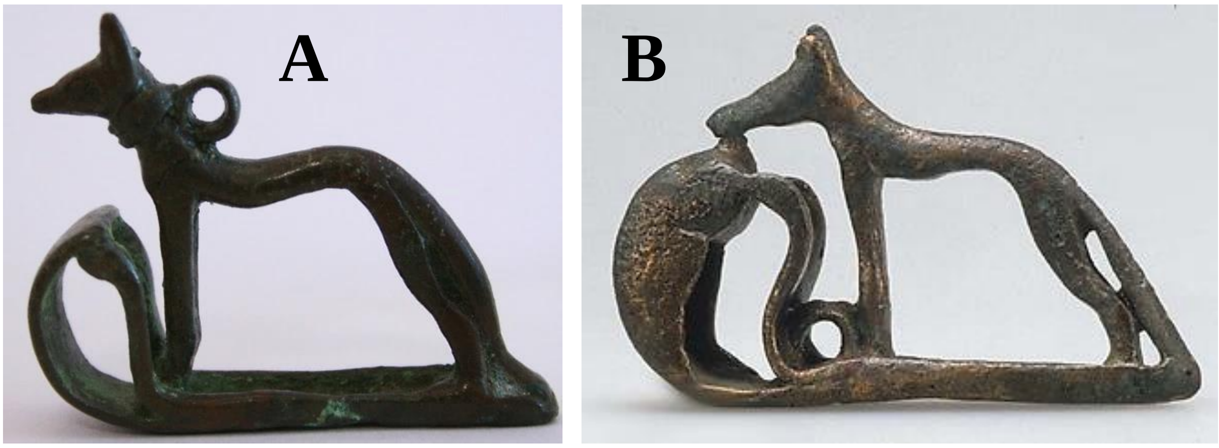

Figure 5.11: The DNMCH Wepwawet (A) compared to one from the MET (B).
Source: Metropolitan Museum of Art (B)[107].

Smaller objects of this nature may have formed part of miniature processional barges that often accompanied the owner into his/her tomb. The loop behind the jackal's neck suggests that it was an amulet, rather than a free-standing statuette. However, this loop could also be another stylistic element not identified from the literature.

5.4 SAMURAI ARMOUR

Based upon the stylistic analysis conducted by Teichert et al. (2012), the samurai armour housed by the DNMCH originates from the mid-Edo Period (17th to 18th centuries) (Teichert et al. 2012, 54). However, to present the "mid-Edo" as a period of history is somewhat vague, as there is no official "mid-Edo" Period classification, as by comparison, we have the Middle Kingdom in ancient Egypt (which is a formal period). In short, to classify an object as "mid-Edo" would result in it falling within the Sakoku Period (1633–1853 CE), also known as the "period of national isolation" or "closed country". Also, during the Edo Period in general, Japan experienced an epoch of relative peace, which meant that the Samurai came to play a lesser role in the military activities of the state, instead taking up roles as courtiers, bureaucrats and administrators. Where confrontation did occur, they occurred between the noble yet impoverished samurai warrior-caste and peasants[108]. Thus said, samurai armour did not develop much during the Edo Period, as the necessity to adapt and evolve alongside changing military tactics and weaponry was almost non-existent. With the latter stated, it would be nice to identify a more exact time frame for the armour, but since stylistic and

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[107] https://www.metmuseum.org/art/collection/search/570343 [Accessed 10/07/2018].

[108] See https://en.wikipedia.org/wiki/Tokugawa_shogunate [Accessed 31/07/2018] and Howland (2001, 355).

technological elements remained largely unchanged throughout this period, a more exact date might not be obtainable unless one resorts to direct dating methods.

It is also mentioned by Teichert et al. (2012, 54) that the composite armour belongs to the *Tósei-Gusoku* style. However, their article does not expand upon the physical attributes of the style, as the article focused on aspects of conservation rather than authentication through stylistic or technological analyses. It is therefore necessary that we look more closely at technological markers alongside that of stylistic attributes in order to place the suite of armour within a more defined relative chronology[109].

5.4.1 Comparative Analysis: *Gusoku* Chest Armours

Before we embark on a comparative analysis of the known stylistic attributes of the *Gusoku* style against that of the DNMCH example, it must be noted that one cannot rely solely on the stylistic analysis of the body armour to classify the helmet. In fact, it is possible that the helmet may either pre- or post-date the rest of the armour, as it was common practice to reuse quality components, especially helmet bowls (Dalewicz-Kitto et al. 2013, 35).

Thus stated, the comparative analysis below will try to establish a clear comparison between the DNMCH body armour and curated examples of the *Tósei-Gusoku* style (and similar *Gusoku* sub-types). The *Tósei-Gusoku* armour style, also referred to as "modern armour", is distinguishable from other styles through its use of *ita-mono* (iron plates), instead of *kozane* (individual scales) to form the *dou or dō* (chest plate). Specific *dou* attributes are then used to further divide *Tósei-Gusoku* into sub-categories according to dominant stylistic features (Table 5.1).

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[109] It must be noted at this stage that it is by no means the intent of the researcher to discredit the work done by the museum's team. In fact, it is quite the opposite: The research aims to provide complimentary data that can be used to validate the conclusions drawn in Teichert et al. (2002).

Table 5.1: *Tósei-Gusoko* sub-categories by dominant stylistic features

Name	Description
Okegawa Dou	Tub-sided: refers to the tub-like shape of the *dou*. Two types: *okegawa dou*: *yokohagi* (horizontal lame110), and *tatehagi* (vertical lames).
Hishinui dou or ***Hishi-toji dou***	Chest armours with rows of prominent cross knots, usually an *okegawa dou.*
Munemenui dou or ***Unamenui dou***	Chest armours with a running stitch that goes horizontally across the surface of the *dou*. This stitch of lacing runs along the surface of the lame looking like a dotted line paralleling the top.
Dangae dou	Meaning "step-changing", a combination of two or more styles.
Hotoke dou	Chest armour which is smooth and shows no signs of lames.
Nio dou	Embossed to resemble the emaciated torso of a starving monk or old man.
Katahada-nugi dou	Embossed to resemble a half-naked torso.
Yukinoshita or ***Sendai dou***	Five plate, four hinge (*go-mai*) chest armour in the *sendai* or *yukinoshita* style.
Hatomune dou	Pigeon-breast chest armour or cuirass: inspired by European peasecod breastplate armour. *Hatomune dou* have a sharp central ridge running vertically down the front.
Uchidashi dou	Embossed or hammered out relief on the front.
Nanban dou gusoku	Armour made on the base of late European armour.
Mōgami dou	Five-plate, four hinge (*go mai*) chest armours with solid lames which are laced with silk braids (*sugake odoshi*) instead of being riveted.

Table contents adapted from Dalewicz-Kitto et al. (2013); Ogawa (2009) and Wikipedia[111]

a) *The Mōgami Tósei-Gusoku piece*

Based on a visual comparison between the DNMCH *dou* (Fig. 5.12A) and online sources, the closest resemblance was encountered on an online discussion forum[112], which simply referred to the object (Fig. 5.12B) as *Mōgami dou* armour. Another example comes from the Ann and Gabriel Barbier-Mueller Museum piece (Fig. 5.12C), which is classified as a *Mōgami Tósei-Gusoku* piece dating from the 17th or 18th century, Edo Period[113]. Another example, referred to as a *Mōgami-do gusoku* style, comes from the Dolphyn Collection of Samurai Art (Cristie's) (Fig. 5.12D). Although the four examples share many similarities in terms of primary style, for example the use of multiple *ita-mono* (iron plates), their slight variations in terms of *ita-*

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[110] A lame is an individual component of composite armours and is usually made from sheet metal. The individual sheets are then joined into a unit by interlacing them with leather straps or silk rope. Together, the interlaced lames form an articulate (having joints or segments that facilitate movement) piece of armour. See https://en.wikipedia.org/wiki/Lame_(armor)

[111] See https://en.wikipedia.org/wiki/Japanese_armour [Accessed 04/11/2018].

[112] Samurai Armor Forum (SAF): http://nihon-no-katchu.proboards.com/thread/520?page=1[Accessed 15/08/2018].

[113] https://commons.wikimedia.org/wiki/File:MAP_Expo_Armure_samourai_05_01_2012_3.jpg [Accessed 15/08/2018].

mono quantities, and lashing pair quantities (per plate), highlight the fact that variations could occur within styles.

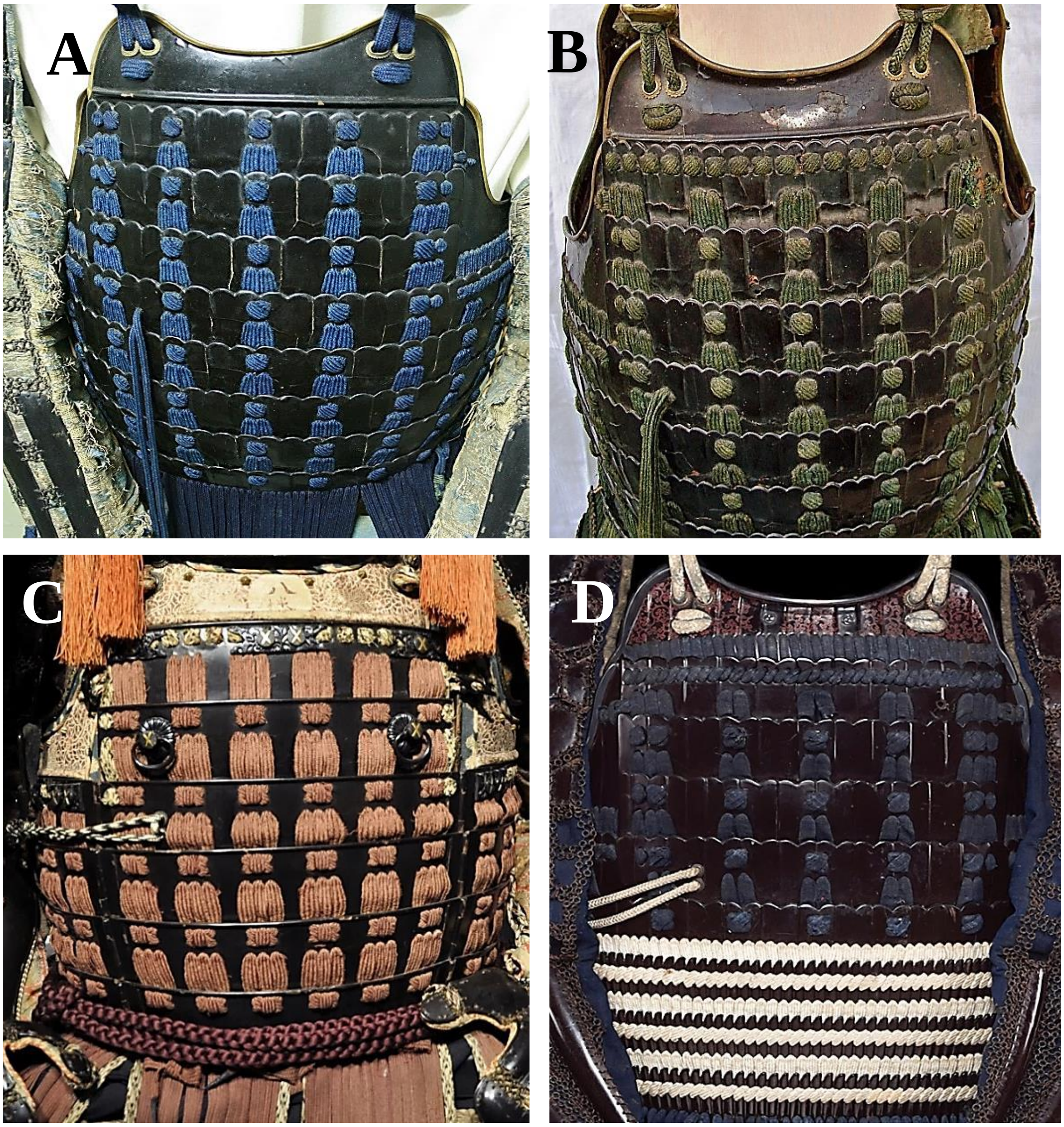

Figure 5.12: The DNMCH *dou* (A), example from SAF (B), the AGBMM piece (C) and an example from the DCSA (D).
Source: The Samurai Armour Forum (B), The Ann and Gabriel Barbier-Mueller Museum (C), The Dolphyn Collection of Samurai Art: Cristie's (D)[114].

The DNMCH *dou* and its three counterparts also boast similarities between individual components:

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[114] http://nihon-no-katchu.proboards.com/thread/520?page=1, https://commons.wikimedia.org/wiki/Category:M%C5%8Dgami_dou_(d%C5%8D)_gusoku#/media/File:MAP_Expo_Armure_samourai_05_01_2012_3.jpg, https://onlineonly.christies.com/s/arts-samurai-dolphyn-collection/mogami-do-gusoku-suit-armour-five-plate-chest-31/51113 [Accessed 15/08/2018].

b) *Shoulder Straps, Tie Downs and Buttons*

The *watagami* (shoulder straps that serve to connect the back of the *dou* with the front, as well as carry the shoulder plates or *sode*) include *aibiki* (tie downs) that are looped around a button (usually oblong and made of wood) attached to the front of the *dou*. The eyelets through which the *aibiki* pass are usually decorated with flower designs. The DNMCH *dou* features oval-shaped eyelets, while the SAF *dou* displays round versions (Fig. 5.13).

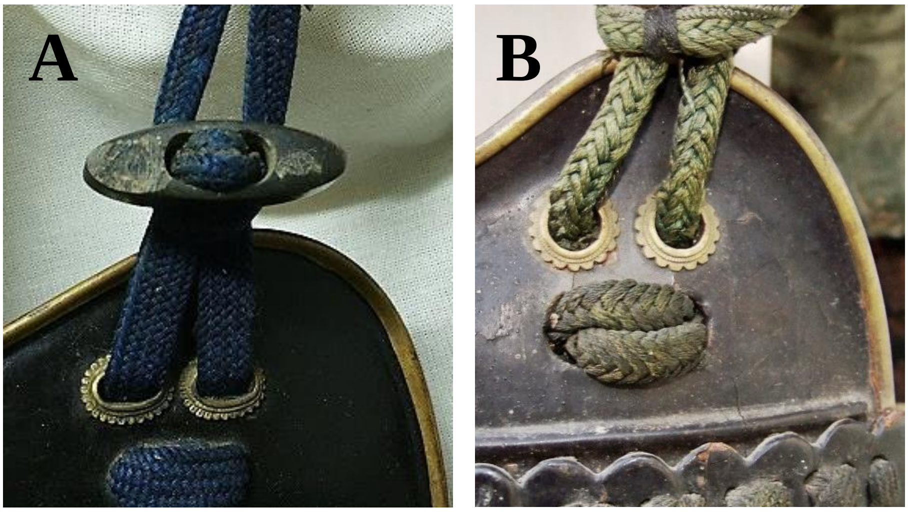

Figure 5.13: *Aibiki* on the DNMCH *dou* (A) and the SAF dou (B).
Sources: Samurai Armor Forum (B)[115].

c) *Amour Plates/Lames*

Another striking similarity lies in the shape of the top edges of the *ita-mono* (armour plates/lames). In both instances the edges display a scalloped appearance, and the *dou*s boast a horizontal ridge positioned just above the topmost *ita-mono* (Fig. 5.14). The general appearance of the lacing that hold the multiple *ita-mono* in place is almost identical, as they feature similar spacing patterns between lace sets. Although these edges on the DCSA piece are similar, they are not as identical to ours as the SAF example.

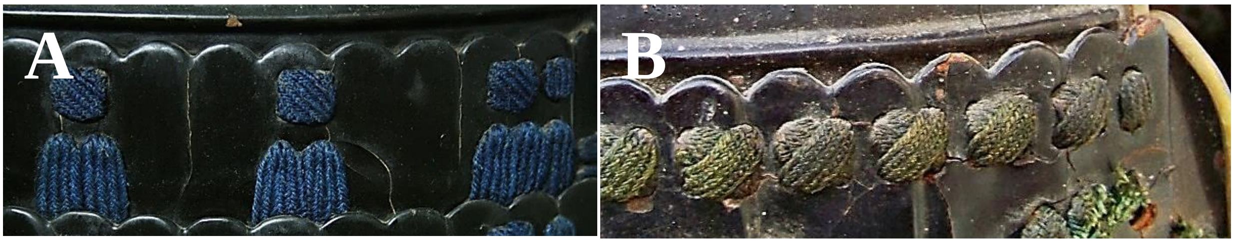

Figure 5.14: Scalloped appearance of *ita-mono on the* DNMCH dou (A) and the SAF dou (B).
Sources: Samurai Armor Forum (B)[116].

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[115] http://nihon-no-katchu.proboards.com/thread/520?page=1 [Accessed 10/10/2018].

[116] http://nihon-no-katchu.proboards.com/thread/520?page=1 [Accessed 10/10/2018].

d) *Chainmail*

A more general feature shared between the DNMCH *dou* and Edo Period armour (Fig. 5.15), is the inclusion of *kusari* (chainmail) on the *kote* (arm-length sleeves that attach to the *watagami* on the shoulders and include a leather glove)[117]. Made from silk, these sleeves are usually covered by metal plates on the upper arms and forearms, and are connected through *kusari*. Presented below are examples from the Dolphyn Collection of Samurai Art (Cristie's), including a *Yokohagi Do Gusoku* armour dating from the 17th century, Edo, and a *Mogami-Do Gusoku* armour dating from the 18th century, Edo.

Figure 5.15. Examples of *kusari* from DNMCH (A), Yokohagi Do Gusoku armour (B) and Mogami-Do Gusoku armour (C).
Source: The Dolphyn Collection of Samurai Art: Cristie's[118].

5.4.2 Comparative Analysis: *Dou, Menpó and Kabuto*

As mentioned before, suits of armour are often displayed with *kabuto* and *menpó* that don't necessarily belong with the rest of the unit (due to ancient practices of re-use). However, we can state with a fair amount of certainty that both the DNMCH *kabuto* and *menpó* belong to each other, as well as to the *dou*. This assumption is based upon the prevalence of decorative elements that correspond between the three objects. The direct relationship between the *menpó* and *kabuto* is relatively easy to establish. While the surface of the *menpó* itself is painted with a red lacquer, the neck guard (Fig. 5.16A) is coated with the same black lacquer that appears on the *kabuto*'s neck guard (Fig. 5.16B). In addition, while the dominant colours of the lashings used differ between the *kabuto* (reddish-brown and green) and the *menpó* (reddish-orange and green), both items feature lashings made from a combination of green, cream and reddish-brown thread (refer to the circled areas).

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[117] Samurai Armor Parts: An Essential Guide to Yoroi Components: http://blog.a-janaika-japan.com/samurai-armor-parts-an-essential-guide-to-yoroi-components/ [Accessed 15/08/2018].

[118] https://onlineonly.christies.com/s/arts-samurai-dolphyn-collection/yokohagi-do-gusoku-suit-armour-horizontal-plate-cuirass-32/51114 [Accessed 15/08/2018].

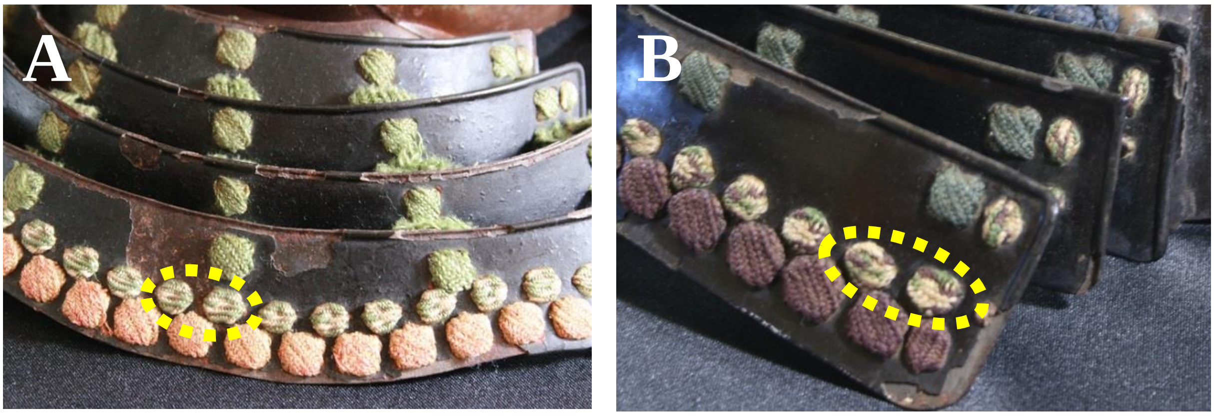

Figure 5.16: Similarities in black lacquer on the *menpó* (A) and *kabuto* (B) neck guards.
Tri-colour lashings have been circled for clarity.

Both the *kabuto* and the *menpó* also feature tie-downs and loops of a similar blue colour. In turn, these blue lashings also correspond to those encountered on the *dō*. However, since colour similarities alone are not enough to confirm a relationship, we have to take a closer look at textural similarities. It is clear to see (Fig. 5.17) that these lashing do indeed share similar weaving patters between the *dō,* the *kabuto* and the *menpó*, although the width and shape (round vs flat) of the threading might differ.

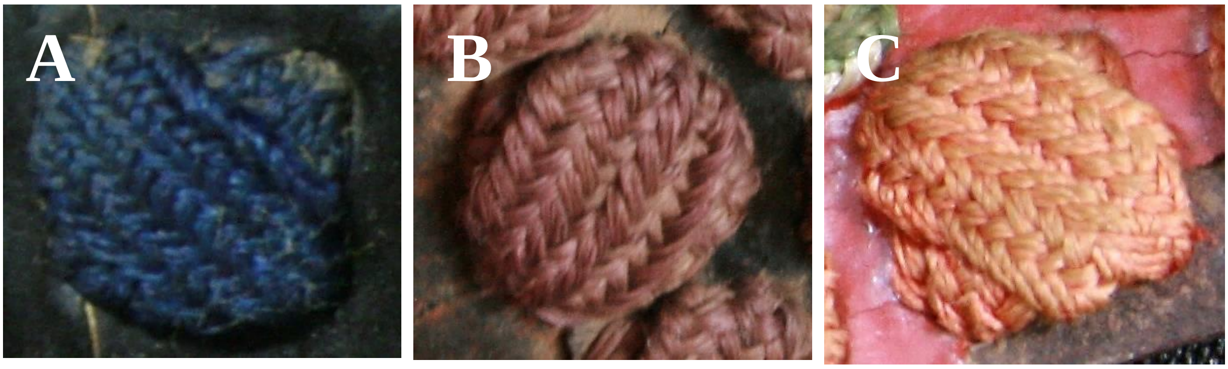

Figure 5.17: Coloured threading as observed on the *dou* (A), the *kabuto* (B) and the *menpó* (C).

In addition to the similarities observed in terms of lacquer colour and texture, the three pieces also share similarities in terms of lacquer cracking and flaking (Fig. 5.18). Thus said, with a positive connection being drawn between the helmet and the body armour, it is likely that the helmet also falls within the 17th to18th century Tósei-Gusoku style.

Figure 5.18: Lacquer flaking patters on the *dou* (A), the *kabuto* (B) and the *menpó* (C).

5.4.3 Comparative Analysis: *Kabuto*:

Before we can analyse the *kabuto*, we should possess a basic knowledge of the various components that make the helmet (Fig. 5.19). This holds particular reference to stylistic analysis, as each of these parts display characteristics that are period-specific.

Figure 5.19: *Kabuto* components include the *hachi* (A), *shinkoro* (B), *fukigaeshi* (C), *mae-zashi* (D), *hari-date* (E), *datemono* (F) and *tehen* (G).
Image adapted from: Wikipedia Commons: *Kabuto* basic parts[119].

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[119] https://en.wikipedia.org/wiki/Kabuto#/media/File:Kabuto_basic_parts.jpg [Accessed 10/10/2018].

a) *Kabuto Shape*

When considering its basic shape, it is clear that the DNMCH *kabuto* falls within the *suji bachi kabuto*, or flange helmet style. In this design, the vertical plates feature raised ridges known as *suji* (Ogawa 2009, 86), that curve upward along the proximal (towards the rear) edge of each plate. In addition, when considering the actual rounded shape of the helmet, our *kabuto* falls within the *Heichozan* (Fig. 5.20) shape-range, of which there are a total of six.

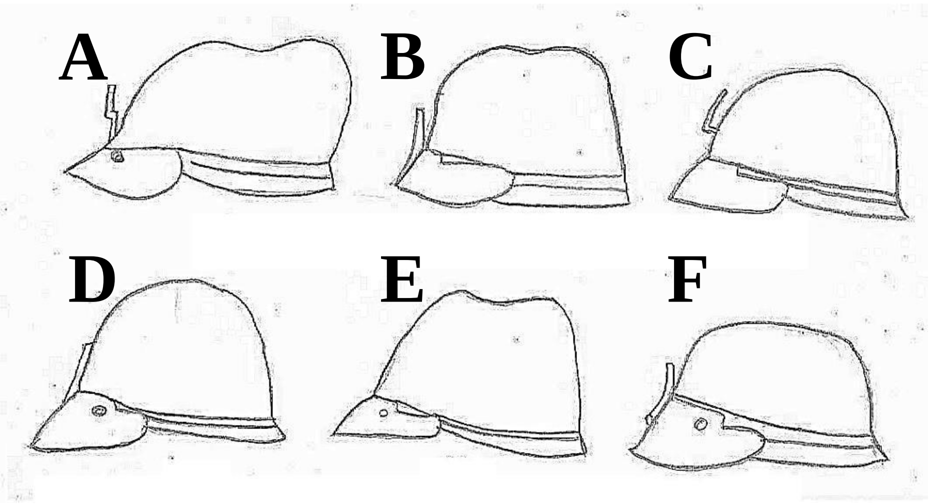

Figure 5.20: Various *hachi kabuto* shapes including *Nari Akoda* (A), *Goshozan* (B), *Heichozan* (C), *Koseizan* (D), *Tenkokuzan* (E) and *Zenshozan* (F).
Image adapted from: Wikipedia: Formen des Hoshi Kabuto[120].

b) *Kabuto Plate Quantity*

In general, dome-shaped composite helmets are known as *hachi*, while the individual plates are referred to as *hagi-no-ita*. While Teichert et al. (2012, 55) state that the *kabuto* consists of 16 plates, closer inspection by means of digital microscopy suggests that only 15 plates were employed in its construction. In this regard, it is quite possible (and understandable) that Plate 2 was counted as two separate entities, as it lies completely beneath Plate 1. However, to justify this statement, we have to take a closer look at the assembly sequence. Within their historical context, 16-plate ribbed *kabuto* known as 16-*ken tsuji* were popular during the late 17th century (Bryant 1994, 42).

c) *Rosetted Grommet: Tehen Kanomono*

The *kabuto* features five rings, of which four are decorated in a rosette (rotational symmetric forms, often meant to imitate flower petals) style (Fig. 5.21). This decorated opening or “grommet” is also known as a *tehen kanomono*[121].

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[120] https://en.wikipedia.org/wiki/Kabuto#/media/File:Formen_des_Hoshi_Kabuto.jpg [Accessed 10/10/2018].

Figure 5.21: The *tehen kanomono* of the DNMCH *kabuto.*

Although these objects could also be used as stylistic markers, no dedicated study of these features could be found. A few examples were identified from popular interest sites such as Pinterest, or the online catalogues of antiquities dealers, but none of these sources discuss the *tehen kanomono* as a separate, stylistic feature. Although *tehen kanomono* designs are almost as individualistic as *maedate* (front crests), the latter are more impressive and have (understandably) received greater attention. What is fortunate is that a number of sites at least discuss the overall style of the *kabuto*, its construction and possible periods of production, which allows us to formulate some idea of what *tehen kanomono* would have looked like during the Edo-Period (Fig.5.22). Striking similarities between these examples and the DNMCH example include the use of 3 to 4 rosettes, a tight formation of dandelion-like petals with a concave appearance, and a fairly smooth, usually undecorated grommet.

Another shared characteristic is the height at which the *tehen kanomono* extends above the topmost surface of the *kabuto*. In the examples above, the device is not too prominent when viewed in profile (Fig. 5.23).

By comparison, an example from a *hagi-no-ita* (wave shaped helmet plates) *hachi kabuto* (production date not specified) (Fig. 5.24) features a *tehen kanomono* that rises much higher above the topmost surface.

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[121] See https://commons.wikimedia.org/wiki/Category:Tehen_kanamono [Accessed 10/10/2018] and Absalon and Thatcher (2011, 279).

Figure 5.22: *Tehen kanomono* on *kabuto* from 1845 (A), 1615-1867 (B) and Mid-Edo.
Sources: Winter Japanese Art (A), Guiseppe Piva (B), Black Samurai (C)[122].

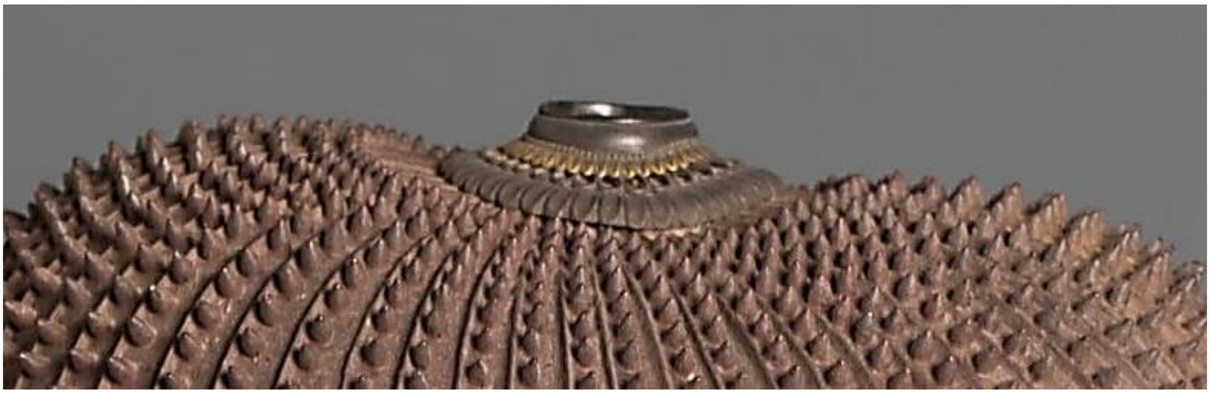

Figure 5.23: A profile view of the *tehen kanomono* depicted in Fig. 5.22B.
Source: Guiseppe Piva[123].

Figure 5.24: A *tehen kanamono* on a *hagi-no-ita* (wave shaped helmet plates) *hachi kabuto*.
Source: Wikipedia Commons[124].

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[122] https://winterjapaneseart.com/archives/galleries/428[Accessed 15/08/0218].
http://piva.powerpad.it/c/118489/21986/koboshi-kabuto.html [Accessed 15/08/0218].
http://www.black-samurai.com/01arch/samurai-armor/item04.htm [Accessed 15/08/0218].

[123] http://piva.powerpad.it/c/118489/21986/koboshi-kabuto.html [Accessed 15/08/0218].

[124] https://en.wikipedia.org/wiki/Kabuto#/media/File:Nami-gata_tate_hagi-no_ita.JPG [Accessed 23/08/2018]

d) *Lacings*

Different types of *odoshi* (lacings) are referred to by different names, depending on their appearance and colour. These lacings (the silk braids used to articulate the lamellae of armour plates) can also be used as stylistic markers and according to Breeze (2008, 2):

> The production of lacings was a specialized industry. The 18th-century Japanese author Sakaki Kōzan states "the *odoshi* colors should be carefully selected in accordance with the divinatory laws of *sōshō* (sympathy) and *sōkuku* (antipathy) else it will bode ill for the wearer".

Interestingly, with specific reference the tri-colour lashings on both the *menpó* and *kabuto*, a similar example was observed on a *Nimai-do Gusoku* two-piece cuirass armour from the Dolphyn Collection of Samurai Art (Fig. 5.25). The complete suit is dated to the 18th century, placing it well within the Edo Period.

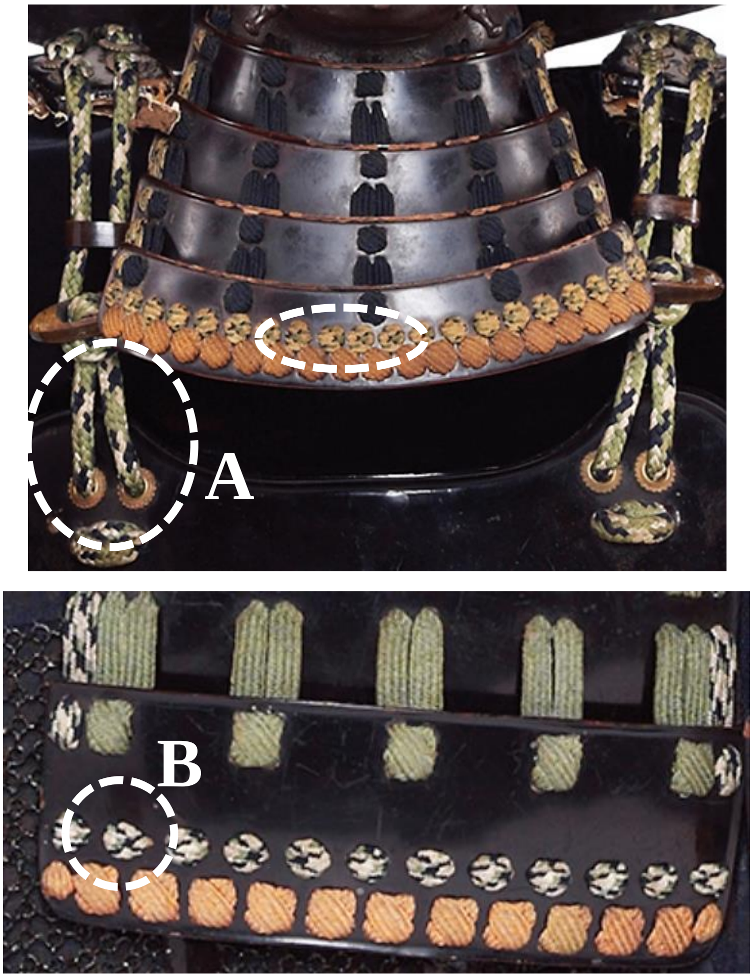

Figure 5.25: Tri-colour lashings observed on a *Nimai-do Gusoku* armour from the 18th century – Edo Period. ***Source:*** The Dolphyn Collection of Samurai Art, Christie's[125].

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[125] https://onlineonly.christies.com/s/arts-samurai-dolphyn-collection/nimai-do-gusoku-two-piece-cuirass-armour-70/51151 [Accessed 26/08/2018].

5.5 SAMURAI HALF-MASK (*MENPÓ*)

5.5.1 *Menpó*: Comparative Analysis

The *mengu* or *men yoroi*, are protective facial armours and are categorised into four different types: *Somen* (full-faced), *menpó* (cheeks, nose and chin), *hanpō* (lower face, jaw and chin) and the *happuri* (forehead and cheeks)[126]. The figure below (Fig. 5.26), originally from a Japanese book on Samurai armour released in 1735 CE, depicts the four types:

Figure 5.26: Japanese Edo Period illustration of the four types of *mengu or men yoroi*.
Source: Wikipedia Commons[127].

a) *Functional Posts, Hooks and Holes*

The *mengu* boast a number of functional posts, hooks and holes (Fig. 5.27). The *odome* (a) are attachment posts used to secure the chinstrap of the *kabuto* to *the mengu/menpó*. The *ase nagashi no ana* (b) are drainage holes located underneath the chin, which served to channel perspiration. Two L-shaped hooks (c) were used to secure the nose piece, while simple holes on opposite sides (c) were used to secure the silk strap with which the mask was tied to the samurai's head. This specific design of the DNMCH *menpó* excludes the use of prominent L-shaped hooks (*ori-kugi*) used for securing the chinstrap, usually located on the cheek areas.

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[126] See https://en.wikipedia.org/wiki/Mempo [Accessed 16/08/2018].

[127] https://en.wikipedia.org/wiki/Men-yoroi#/media/File:Mengu_(samurai_facial_armor).png [Accessed 26/08/2018].

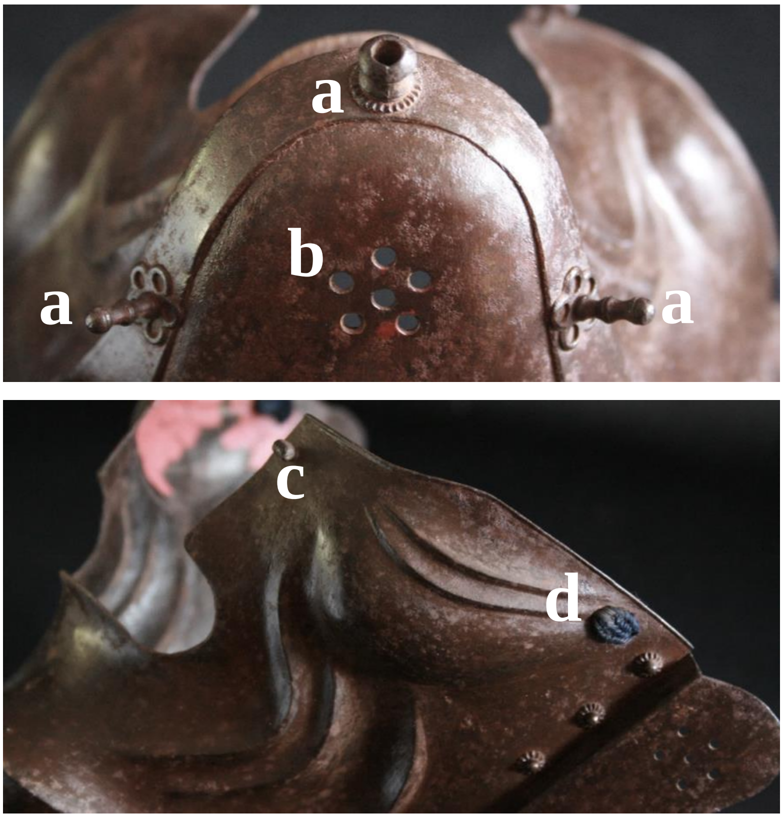

Figure 5.27: Functional posts, hooks and holes of the DNMCH *menpó*.

Since the nose piece is missing, it is difficult to determine the exact style of the *menpó* as a unit. While the bottom half (chin, cheeks and mouth area) could resemble other examples closely, it is often the nose piece that provides additional unique features, like the shape of the nose or the addition of teeth. For example, most nose pieces featured a clip-on moustache that could take a variety of different shapes (Fig. 5.28).

Figure 5.28: Three examples of Edo Period *menpó* nose pieces featuring moustaches[128]

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[128] https://en.wikipedia.org/wiki/Men-yoroi#/media/File:Antique_Japanese_(samurai)_menpo_2.jpg, https://japaneseart.eu/portfolio_page/menpo-ressei-bo/, https://en.wikipedia.org/wiki/Men-yoroi#/media/File:Menpo_2.JPG [Accessed 08/10/2018].

b) *Coloured Lacquer*

Mengu were often treated with coloured lacquer, of which red and black were the most popular colours. One would often encounter matching sets of armour, where every component from the helmet to the shin guards were coloured red. However, this complete match between components was not a set standard. For example, in the case of the NDMCH *menpó*, the inner and outer surfaces of the *menpó,* along with the inner surface of the *yodare-kake* (throat guard) were lacquered in red (Fig. 5.29A), while the outer surface of the latter was lacquered in black (Fig. 5.29B). Although the external surface of the *menpó* no longer displays its red lacquer, remnants of the coating can still be observed (Fig. 5.29C).

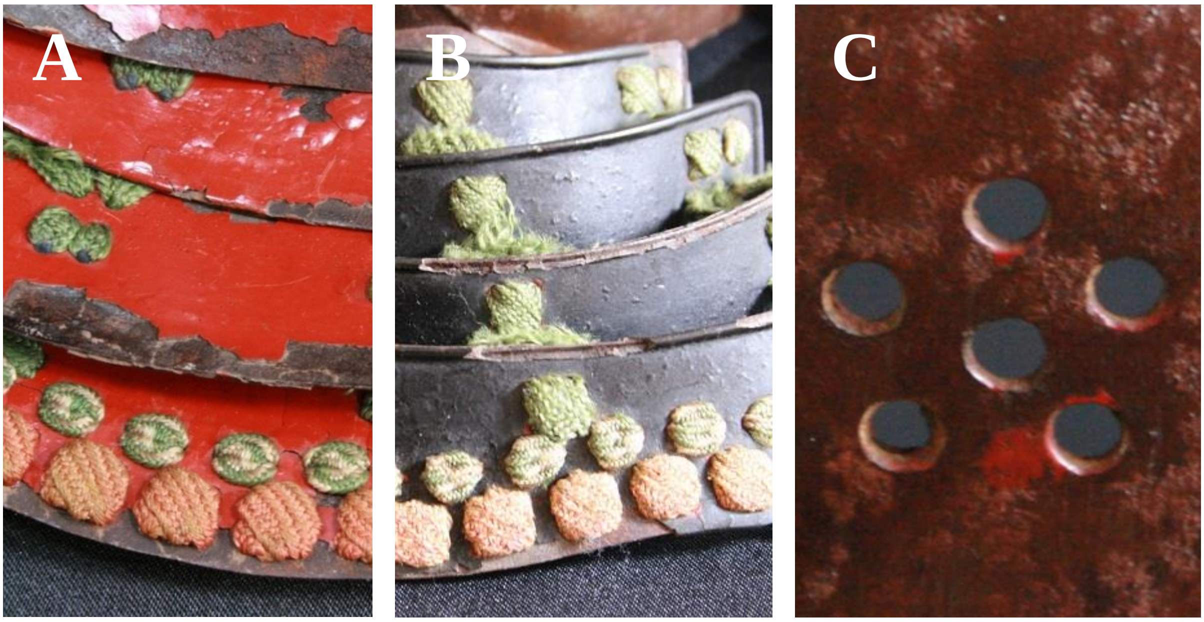

Figure 5.29: Lacquer variations on the *yodare-kake* and the *menpó.*

The flaked appearance of the lacquer, and its near complete absence from the external surface of the *menpó* serves as a good indicator of the object's antiquity. In addition, the overall adherence to stylistic trends from the Edo Period suggests that it originates from this period.

5.6 TOWER OF LONDON ARMOUR

Since the DNMCH does not possess any archival/documentary sources on the Tower of London (hereafter referred to as ToL) armour collection, especially with regards to its provenance, we have to rely quite heavily on comparative analysis to position the object within its culturo-chronological framework. As was the case with the Samurai armour, one should look beyond the individual object under direct study (the gauntlet), and assess the entire suite of armour as far as possible.

Since the gauntlet itself does not boast any decorative elements that make it stand out stylistically, we have to look towards the one item that features identifiable traits; the helmet. Since the breastplate also lacks readily identifiable traits, we shall first establish a relative chronology for the helmet, after which we'll place the breastplate within that broader stylistic framework. This assessment strategy falls in line with Breiding's (2004e) conclusion that helmets are more interpretable in terms of stylistic expression:

> While changes in the shape of the helmet were determined by functionality and national identity, the breastplate was largely preserved in the shape of the seventeenth century, and, after the mid-nineteenth century, was retained almost exclusively for representative purposes.

With regards to decorative elements, it must be kept in mind that their absence from a suit of armour does not necessarily infer utilitarian function. One would assume that purely utilitarian objects would be void of decorations, as they serve no practical purpose, but Breiding (2002b) notes that even the most utilitarian, practical equipment could be decorated. However, decorations were only applied if they did not impede the functionality of the object or cause any structural weakness. In this light, ceremonial suits of armour often sacrificed functional and protective qualities in favour of theatrical and symbolic effect (Breiding 2002b).

5.6.1 The ToL Helmet

a) *Shapes and Styles*

The ToL helmet adopts the basic shape of a "pot helmet". The bowl or "skull" (as it is commonly referred to) is hemispherical and displays a fluted ribbed design, in which vertical lines taper towards the crown of the bowl. The helmet features a front brim/peak and "lobster-tail" neck collar. While almost all helmets would feature cheek pieces, the ToL helmet probably lost these attachments years ago. These helmet-types traditionally also boasted adjustable nose guards, which would extend through a small gap in the brim to protect the nose. These narrow plates would attach to the helmet by means of a wing-nut-like screwing mechanism attached to the front of the helmet.

Figure 5.30: The ToL lobster-tailed burgonet or *zischägge*.

According to Fig. 5.31, which depicts the evolution of helmet styles, the ToL helmet falls within the general burgonet (open-faced, bowl-shaped) category, but more specifically within the lobster-tailed burgonet sub-category. The latter term is based upon the distinctive shape of the neck collar and overlapping articulated lames. These helmets are also known as *zischägge*, horseman's pot and *harquebusier*'s pot[129].

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[129] See https://en.wikipedia.org/wiki/Lobster-tailed_pot_helmet [Accessed 09/09/2018] and Holmes, Singleton and Jones (2001, 24).

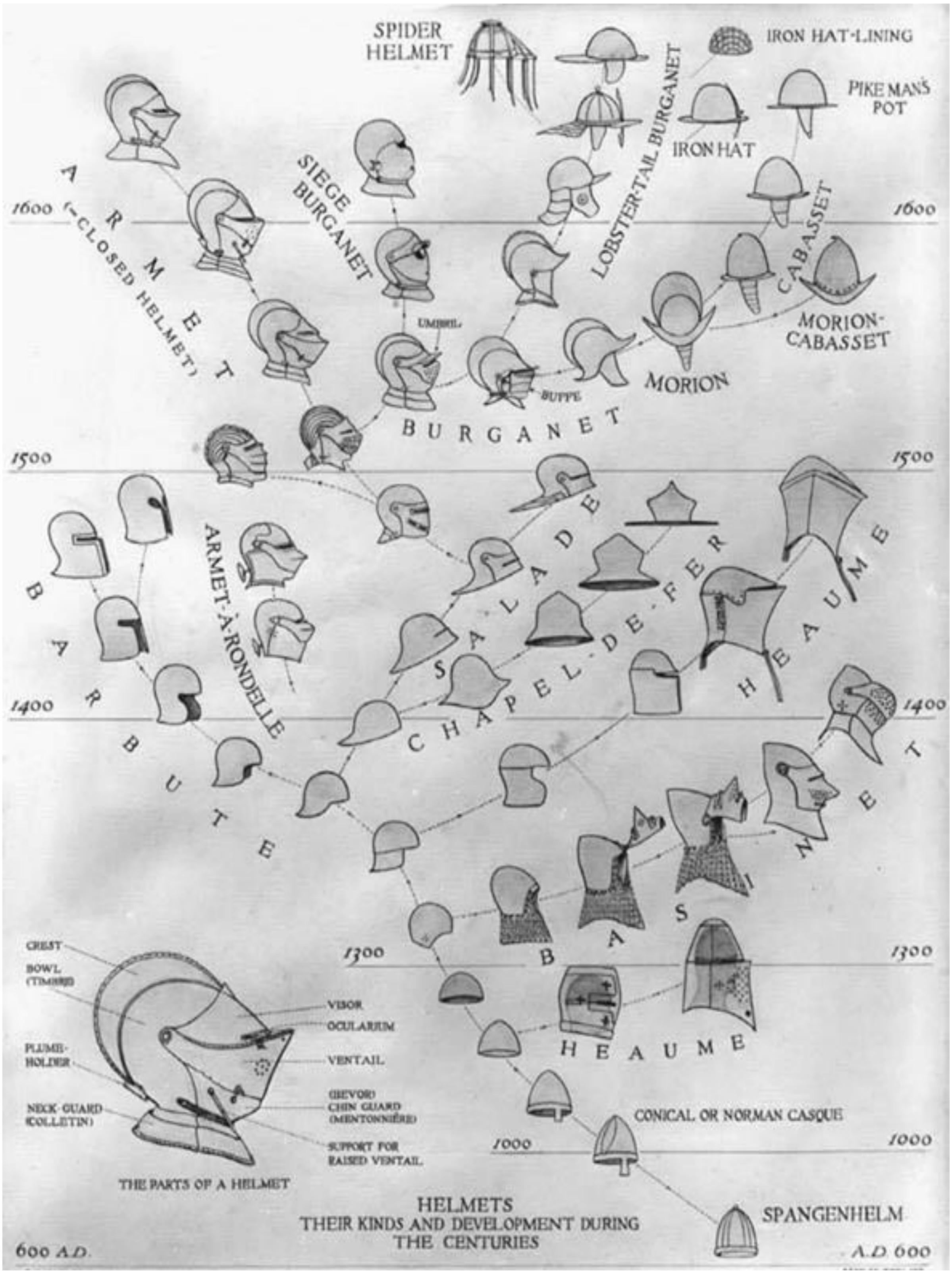

Figure 5.31: The evolutionary development of European helmet types and styles.
Source: Medieval Warfare Info[130].

As is clear from Figure 5.31, lobster-tailed burgonets came into use during the early 16th century. By visual comparison, the ToL helmet resembles Dutch/German lobster-tailed pot

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[130] http://www.medievalwarfare.info/armour.htm [Accessed 31/07/2018].

helmets from the mid-17th century (Fig. 5.32). With this point considered, we can state with a relative amount of certainty that the ToL helmet was created during or after the 16th century.

With reference to the term *harquebusier*'s pot, the *harquebusier* were cavalry units commonly found throughout western Europe during the early and mid-17th century[131]. In Germany, these helmets were referred to as *zischägge*, which is a corruption of the Turkish term *chichak*[132] (Pyhrr 2000, 43). According to the Metropolitan Museum of Art[133]:

> The term *zischägge* refers to a distinctive type of seventeenth-century helmet consisting of a hemispherical bowl, a brim with sliding nosepiece (nasal), cheek pieces, and a long laminated tail over the back of the neck.

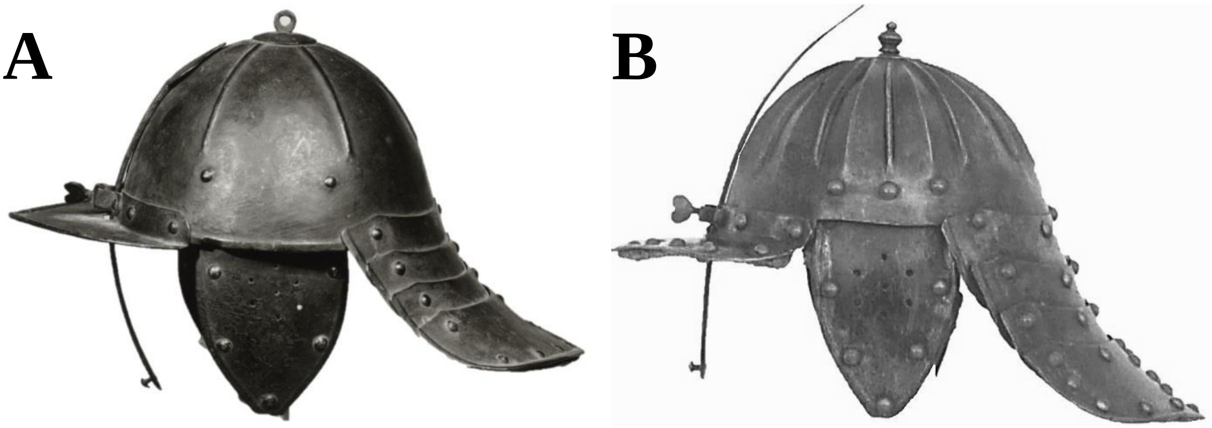

Figure 5.32: A Dutch/German lobster-tailed helmet, housed by the Walters Art Museum, USA (A) and a German *zischägge*, housed by the Metropolitan Museum of Art, USA (B).
Source: Walters Art Museum (A)[134] and Pyhrr (2000, 43) (B).

b) ***Lobster-Tailed Collar and Cheek Lames***

As mentioned above, the type of neck collar design featured by the ToL helmet is commonly referred to as a "lobster tail", due to its resemblance to the overlapping plated tail of a lobster. Interestingly, the neck guard appears as though it is made from articulated lamellar plates, but upon closer inspection it becomes apparent that the collar is a single unit. The collar was ingeniously cast to mimic overlapping lames, with embossed fake rivets completing the

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[131] https://ipfs.io/ipfs/QmXoypizjW3WknFiJnKLwHCnL72vedxjQkDDP1mXWo6uco/wiki/Harquebusier.html [Accessed 31/07/2018].

[132] The German term *zischägge* translates as *istakoz kuyruklu kap kask* in Turkish (https://translate.google.co.za/#de/tr/zisch%C3%A4gge). When translated into English, both *zischägge* and *istakoz kuyruklu kap kask* translate as "lobster-tailed pot/cap helmet" (https://translate.google.co.za/#tr/en/Istakoz%20kuyruklu%20kap%20kask).

[133] https://www.metmuseum.org/toah/works-of-art/14.25.511/ [Accessed 31/07/2018].

[134] https://art.thewalters.org/detail/8039/zischagge-helmet/?type=date&letter=a&sort=title&order=asc&begin_date=-10000&end_date=2018 [Accessed 31/07/2018].

illusion (Fig.5.40A). According to Ackerman et al. (2010, 34), embossing one-piece tassets[135] with simulated lames was common practice across northwest Europe during the first half of the 17th century. While the authors specifically cite tassets, the same would have applied to collars. To illustrate out ToL helmet's similarity to helmets from the times, an almost identical example can be found on a 17th century *zischägge* from the Arsenal of King James (Fig.5.33).

Figure 5.33: Side (A) and rear (B) view of a 17th century *zischägge* from the Arsenal of King James II.
Source: Royal Armouries, London[136]

In contrast to the examples above that feature un-articulated tails, *zischägge* from the same period could also boast fully articulated neck guards. An example, dated to 1630 CE (Fig.5.34), features a fully articulated neck guard made from four overlapping lames. The main edges of the lames are concave in shape to facilitate vertical movement (A), while rivets in cusps and internal leather straps connect and articulate the lames (B).

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[135] Tassets are pieces of plate armour designed to protect the upper thighs and are suspended directly from the breastplate itself or from faulds or flanges attached to the breastplate. Segmented tassets, made from plate metal lames, are connected via sliding rivets (first produced during the 16th century) https://en.wikipedia.org/wiki/Tassets [Accessed 31/07/2018].

[136] https://collections.royalarmouries.org/object/rac-object-15927.html [Accessed 02/10/2018].

Figure 5.34: Side (A) and interior (B) view of a 17th century *zischägge*, which features a fully articulated neck guard.
Source: Royal Armouries, London[137]

Helmets are somewhat incomplete without the inclusion of cheeck lames that protect the sides of the face. Although the ToL helmet does not feature any, it is unlikely that the helmet would have been made without them. Upon closer investigation of the helmet's internal features, it appears as though cheek lame fixtures were originally present (Fig.5.35). Since the internal lining of the helmet is no longer present, it is possible that the cheek lames were lost when the internal fixtures degraded or became detached along with the helmet lining.

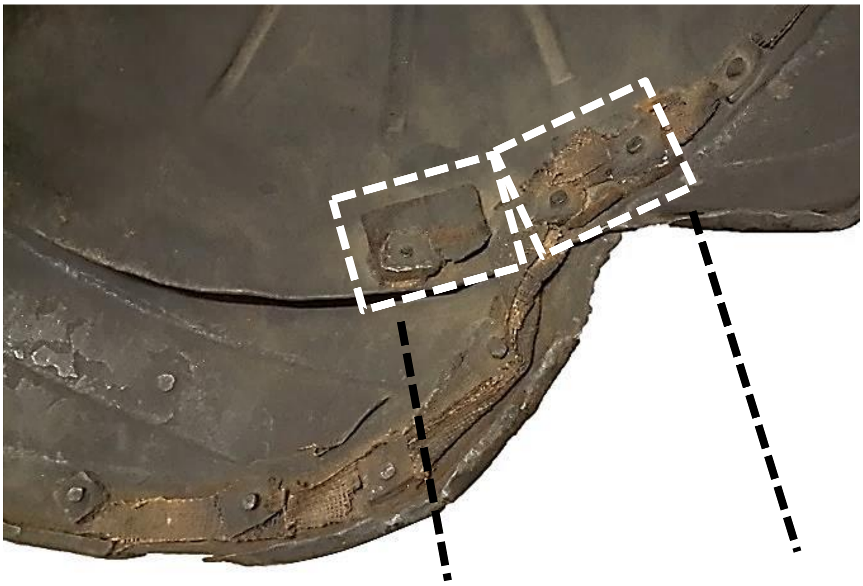

Figure 5.35: Possible fixtures and associated position of cheek lames on the ToL helmet.

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[137] https://collections.royalarmouries.org/object/rac-object-15926.html [Accessed 09/10/2018].

c) *Eight-Pointed Star Rosette*

The ToL helmet features an eight-pointed star rosette, which is capped by a short “stub” at the centre. In contrast to the Samurai *kabuto*, the ToL helmet does not include a grommet-like feature upon which insignia or decorative elements could be attached. The star-shaped rosette itself appears as though it was cast in unison (simultaneously) with the superstructure of the helmet bowl, but a profile view reveals that the edges are lifted, suggesting that the rosette was added at a later stage.

In general, the absence of embellishments, insignia, and a grommet-like feature upon which decorative elements could be attached, suggests that this helmet was assigned to regular non-ranking infantry or cavalry (the latter being assumed though the helmet type’s categorisation as a *harquebusier*'s pot).

Figure 5.36: The star-shaped rosette of the ToL helmet.

Where the skulls/pots of English helmets are manufactured from two separate sections that are merged by a raised comb that runs from the front of the helmet to the back, continental (European) helmets are usually manufactured from a single piece of metal[138], as can be observed from the ToL helmet.

5.6.2 The ToL Backplate and Breastplate

a) *The Backplate*

Since the ToL backplate does not feature any significant decorative elements or maker’s marks[139], we have to rely on a visual analysis of shape and style. The ToL backplate falls

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[138] https://en.wikipedia.org/wiki/Lobster-tailed_pot_helmet [Accessed 09/10/2018].

[139] It was common practice during the 17th century for both Dutch and English blacksmiths to stamp their armours with numbers. This numbering system was used to keep track of the various armour components,

comfortably within Ackerman et al.'s (2010, 32) description of pikeman's armour. A side-by-side comparison of the ToL backplate (Fig. 5.37A) and a 17th century Pikeman's backplate from Antwerp (Fig. 5.37B) clearly illustrates the stylistic similarities. Both pieces are fairly basic, but five particular features make them stand out. These include a neck hole that runs almost flush with the top of the shoulders (in other words, it is not raised above the shoulder line) (a), shoulder brackets (b), inward rolled edges along the neck, arm and waist edges (c), incised decorative lines close to all edges (d), a single plate construction (e), and a single, solid flange that protects the waist and hips (f).

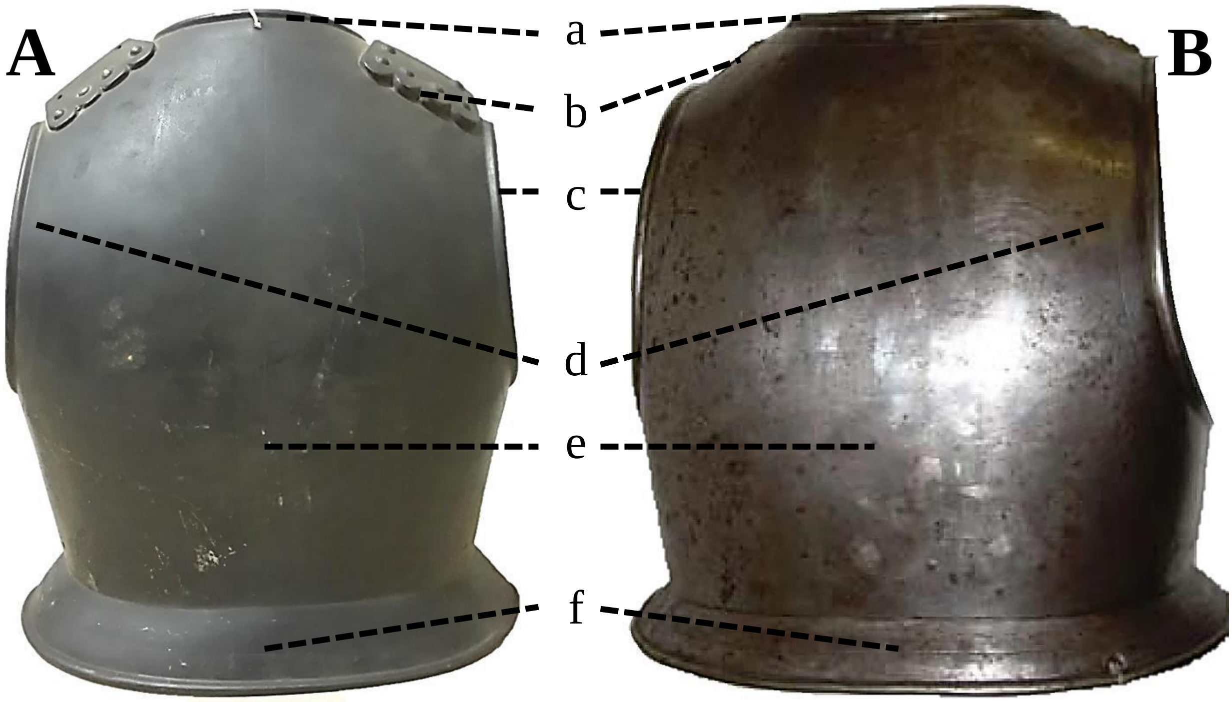

Figure 5.37: Side-by-side comparison of the ToL backplate (A) and a 17th century Pikeman's backplate from Antwerp.
Source: Ackerman et al. (2010, 32).

These characteristics are akin to that of pikeman's armour, with particular reference to the vestigial 'peasecod' fashion, the latter which is characterised by a low, narrow neck opening, flanged waist and its fabrication from a single piece of plate metal[140]. The examples showcased below are housed by the Royal Armouries (Fig. 5.38A) and British Museum (Fig. 5.38B), and offer additional comparative data.

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especially when armours were manufactured in large batches Ackerman et al. (2010, 38). These arsenal or construction numbers should not be confused with maker's or guild marks.

[140] See https://www.royalcollection.org.uk/collection/67370-2/pikemans-breastplate [Accessed on 31/07/2018].

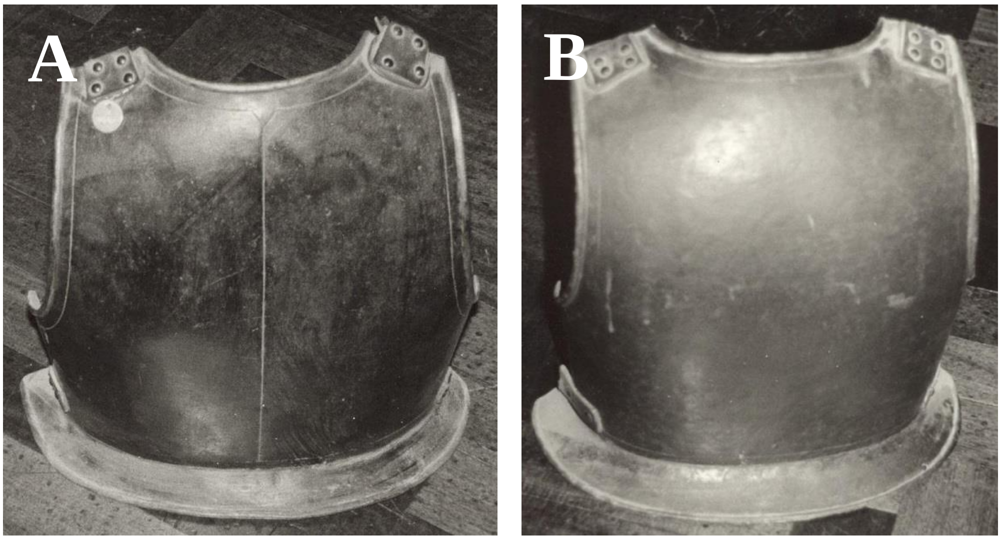

Figure 5.38: Two examples of Pikeman's back plates dated to 1630–1650 CE.
Source: Royal Armouries, London[141].

Chest and backplate flanges served as an anchor point from which tassets could be hung. These tassets would take the shape of individual lames that were interconnected using leather straps and moving rivets, commonly known as hinged tassets. Although hinged tassets were most common, a few examples of solid tassets exist where lames were simulated through embossing (Ackerman 2010, 34) (Fig. 5.39).

Figure 5.39: A pikeman's breastplate/cuirass from the British Museum.
Source: Ackerman et al. (2010, 33).

This specific practice of simulating tasset lames through embossing is identical to what is observed on the ToL helmet's neck guard (Fig. 5.40A). In addition, the TOL helmet's neck guard also features simulated/embossed rivets as demonstrated by the example discussed by Ackerman et al (2010, 36) (Fig. 5.40B). Although the ToL armour does not feature a set of

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[141] https://collections.royalarmouries.org/object/rac-object-38027.html [Accessed 02/10/2018].
https://collections.royalarmouries.org/object/rac-object-38033.html [Accessed 02/10/2018].

tassets, it is not unreasonable to suggest that the armour once featured detachable tassets. If this were the case, the armour could have featured a simulated design in order to fit in with the design of the helmet. However, Ackerman et al. (2010, 36) notes that the conventional cuirass could also be worn without tassets.

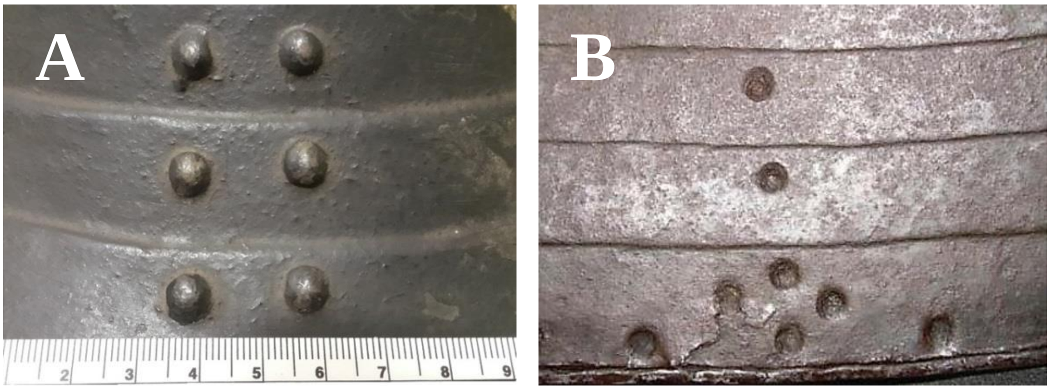

Figure 5.40: Simulated lames and rivets on the ToL helmet – external view (A), and embossed simulated rivets – internal view (B).
Source: Ackerman et al. (2010, 36) (B).

b) ***The Breastplate***

The breastplate, in terms of its style, does not require a side-by side comparison, as was done with the backplate. What is interesting (but at the same time highly frustrating), is the fact that another breastplate from the ToL collection (Fig. 5.41A) is clearly marked on the inside. The marking reads "Trooper's Rude Breast Plate 16th Cent". What is unfortunate is that the example is dissimilar from the piece under study (Fig. 5.41B), so the inscribed information cannot be used to assign a relative/associated date. Not only do the breastplates differ in terms of specialised design (trooper vs pikeman), but the latter is in a much better condition and is technologically more well-rounded and finished. These factors could suggest a later date for the DNMCH example, but could also simply indicate differences in terms of armourer skill, material quality, or the amount of time taken to produce the objects.

A significant set of markings was identified on the breastplate; 10 dots (arranged on two rows of five dots) on the internal surface of the flange (Fig. 5.42A). A strinkingly similar set of markings is observed on a German zischägge helmet from Nuremberg (Fig. 5.42B), which is dated to 1630 CE. According the Royal Armouries website, the dots and lines on the Nuremberg zischägge represent arsenal numbers or construction marks.

Figure 5.41: A “trooper’s rude breastplate” (A) and our pikeman’s breastplate (B).

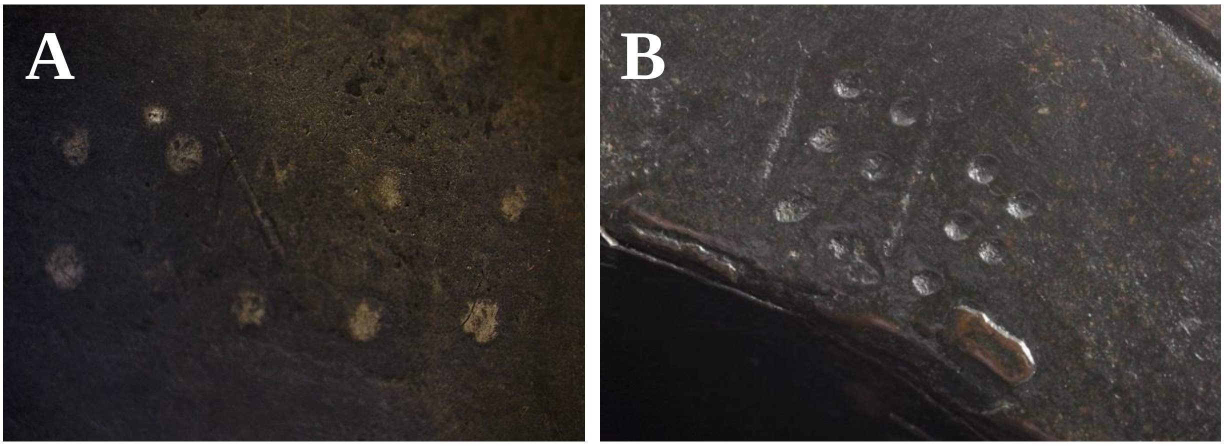

Figure 5.42: Markings on the ToL breastplate (A) and a German *zischägge* from Nuremberg (B).
Source: Royal Armouries, London[142].

According to Ackerman et al. (2010, 38)

> These marks ensured that separate elements of the armour were kept together. Construction numbers were useful for the purpose of identification of the components of a single, hand-fitted armour within a large batch, but irrelevant once the separate pieces of a defence were riveted together. Those on the inside of helmets were obscured by the linings when these were fitted, and in any case too small and difficult to read for everyday use. The provision of a legible, external arsenal number was required for practical use, and common in England as well as in the Low Countries and in Germany.

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[142] https://collections.royalarmouries.org/object/rac-object-15925.html [Accessed 02/10/2018].

Unlike makers' marks, these arsenal/construction marks cannot provide us with specific information on where the item was manufactured, or by whom.

5.6.3 The ToL Gauntlet: Comparative Analysis

Gauntlets usually cover the arm from the finger tips to the elbow, but since varieties also exist that only cover the hand and wrist (known as a demi-gaunt), the ones that cover the entire forearm are referred to as long elbow gauntlets. From the 14th century onwards, armourers began to make fully articulated plate armours[143], which allowed them to attach a moveable plated glove to the forearm sleeve. The ToL gauntlet (Fig. 5.43A) shares striking similarities with a long elbow gauntlet from the Royal Armouries (B) (Fig. 5.43B). Both items feature scaled finger lames (a), a knuckle lame (b), four wrist lames (c), a solid forearm sleeve (d), double-lined incised bands (e), round rivets (f) and rounded edges along the proximal edges (g).

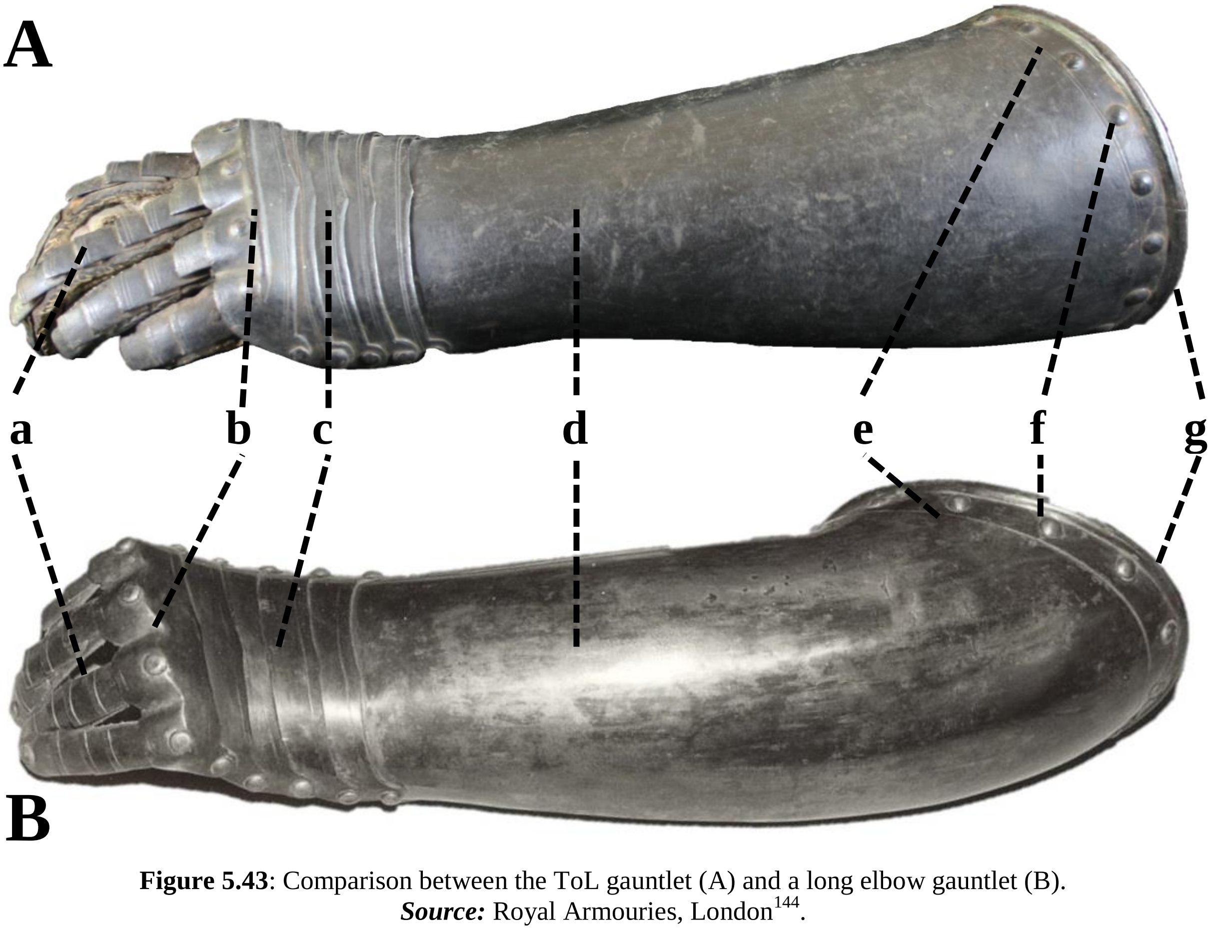

Figure 5.43: Comparison between the ToL gauntlet (A) and a long elbow gauntlet (B).
Source: Royal Armouries, London[144].

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[143] See https://en.wikipedia.org/wiki/Gauntlet_(glove) [Accessed on 27/07/2018] and Royal Armouries (2016, 96-97).

[144] Object number III.4558. Available at https://collections.royalarmouries.org/object/rac-object-40121.html [Accessed on 27/07/2018].

No specific details are provided by the online collections database regarding the gauntlet's origin, apart from it originating from England and dating from around 1660 C.E.

5.7 ARABIAN DAGGER

5.7.1 *Jambiya* Stylistic Analysis

In order to contextualise the visual comparisons in the sub-sections below, Table 5.2 lists a stylistic comparison between the DNMCH *jambiya* and the most characteristic features of Arab-Omani *khanjar* and Arab-Omani *Al Saidi* (the royal style known as *Al-Bu-Said* or *saiidiyya*[145]) styles.

The examples are drawn from late 19th to early 20th *jambiya*, which are believed to be contemporary with the DNMCH example. Although the latter shares stylistic attributes from both styles, we cannot say with absolute certainty to which specific Arab-Omani style it belongs. However, the mere fact that we are now able to classify the object as an Arab *jambiya* from Oman provides a significant amount of detail the museum did not possess prior to this examination.

What is unfortunate is that neither the *khanjar* or *saidi* examples analysed are displayed alongside their belts. A stylistic comparison between belts would have provided additional information for categorising the DNMCH *jambiya*.

In order to provide more detailed visual comparisons, the subsections below will compare and discuss individual components (handle, scabbard neck, scabbard edge, etc.).

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[145] Al Bu Said was a Muslim dynasty of Oman in south-eastern Arabia (1749 CE to present) and of Zanzibar and East Africa (1749-1964 CE). https://www.britannica.com/topic/Al-Bu-Said-dynasty Interestingly, the coat of arms of the royal house of Al BU Said and the national emblem of Oman depicts a *jambiya* (see https://en.wikipedia.org/wiki/Al_Said and https://en.wikipedia.org/wiki/Al_Said#/media/File:National_emblem_of_Oman.svg

Table 5.2: Comparison between the DNMCH *jambiya* and the Arab-Omani *Khanjar* and *Saidi* styles of *jambiya*; late 19th to early 20th century.

Arab-Omani *khanjar*	**DNMC *jambiya***	**Arab-Omani *saidi***
	Total length	
12.5 inches (31.7cm)	12.2 inches (31.2cm)	13.5 inches (34.3cm)
	Blade	
Blade length: 8 inches (20.3cm)		Blade length: 7.5 inches (19cm)
Curved, duel edge	√	Curved, duel edge
Less pronounced curve	√	More pronounced curve
Pronounced central rib	√	Pronounced central rib
	Grip/handle	
Rhino horn	Uncertain	Rhino horn
I-shaped silver filigree plate	√	Chased filigree pommel
Studded silver collar: 2 rows	3 rows of studs	Studded silver collar: 3 rows
Undecorated flanks	√	Horizontal filigree bands
N/A	√	Pearl design on rosette
T-shaped pommel	√	Convex t-shaped ‘ears’ pommel
Cone-shaped rosette	√	Concentric circle rosette, flanked by two smaller rosettes
	Scabbard	
Definite L-shape	√	Definite L-shape
Covered with embossed silver plate	Chased filigree	Covered with fabric
Silver chased filigree strips	√	Studded silver plating
NA	√	Embroidered with silver wires
Scabbard-tip belt attachment	√	Scabbard-tip belt attachment
	Belt attachment	
Naked leather	√	Fabric-covered leather
Silver rings x 4-7	7	Silver rings x 4-7
Twisted silver wire between rings	√	Twisted silver wire between rings
NA	√	Cone-shaped wound wire decorations

5.7.2 The *Jambiya* Handle

The DNMCH’s *jambiya* falls comfortably within Al Busaidi’s (2015, 52-55) description of the *Al Saidi Khanjar*. A side-by-side comparison of the DNMCH *jambiya* (Fig. 5.44A) and an *Omani Al Saidi Khanjar* (Fig. 5.44B) clearly illustrates the stylistic similarities.

The handles are decorated with rolled silver designs (*al tikasir*) from the pommel (a) to the ferrule (b). The pommels feature rosettes[146] made from concentric circles containing triangular designs, minute silver balls and is topped-off by a pearl-like object (c). The horns of

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[146] These round metal ornaments are referred to as *zahra*, while the metal bands that are wrapped around the middle part of the hilt are known as *ḥijlān* or *muḥajjal*. The horizontal bands on the ferules are called *mabsam*; a term derived from the Arabic word for mouth (Heinze 2015, 125).

the pommels point downwards (d). Upward or downward curling designs (e) appear next to the rosettes. The central grips are decorated with horizontal bands (f). The sides of the handles remain uncovered so that the underlying material remains visible (g). The rosette atop the ferrules (h) are closely stylised to, but not an exact duplicate of, the pommel rosettes. Six-petal flower designs (i) flank the ferrule rosettes and are also topped-off with pearl-like objects. Lastly, the ferrules (b) are decorated with horizontal bands.

This example of an Omani Al Saidi Khanjar was described by the Oman and Zanzibar Virtual Museum's write-up of the object as a rare antique Omani Sa'idiyyah Khanjar or Royal khanjar. The hilt is described as being made from rhino horn, while the belt is said to be made from cotton. An estimated date of 1850–1920 is given.

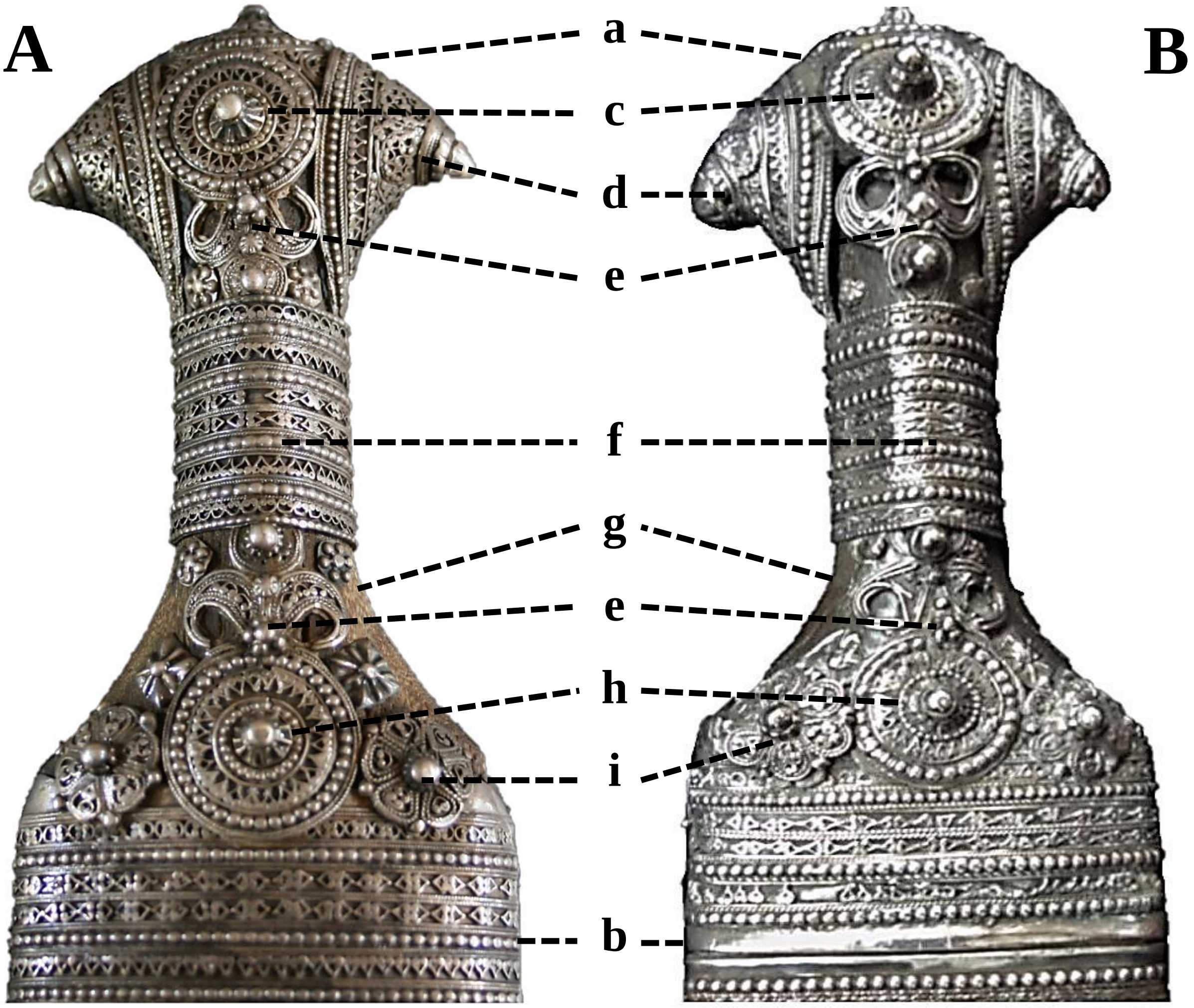

Figure 5.44: Side-by-side comparison of handle decorations on the DNMCH *jambiya* (A) and an *Omani Al Saidi khanjar* (B).
Source: Oman and Zanzibar Virtual Museum[147].

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[147] http://omanisilver.com/contents/en-us/d408_Omani_Designs.html [Accessed 09/10/2018].

5.7.3 The *Jambiya* Scabbard

One major stylistic difference between the *Omani Sa'idiyyah khanjar* and the DNMCH *jambiya*'s upper scabbard, is that the latter features four horizontal bands containing either geometric designs or silver threads, interspersed by tiny silver filigree balls. The remainder of the scabbard shaft, up to the belt holder, is decorated with silver thread, some of which has become detached, showcasing the underlying silver plating (Fig. 5.45A). In short, the latter does not feature the square overlapping motifs with a central circular design (Fig. 5.45B) that are common among Omani and Islamic designs (as described by Al Busaidi 2015, 53).

Figure 5.45: Side-by-side comparison of the upper scabbard designs of the DNMCH *jambiya* (A) and an *Omani Al Saidi khanjar* (B).
Source: Oman and Zanzibar Virtual Museum[148].

In fact, none of the examples discussed in detail by Al Busaidi (2015), or those detailed by online museum and collectors' catalogues, depict a scabbard with silver thread as the predominant decorative element. However, the appearance of the thread itself is akin to examples encountered on other *khanjar* specimens.

While the top half of the scabbard represents us with a unique example, the bottom half returns to what is typically expected from an Omani khanjar. A side-by-side comparison of the DNMCH *jambiya* (Fig.5.46A) and the *Omani Al Saidi Khanjar* (Fig.5.46B) clearly illustrates the stylistic similarities. The scabbards are attached to cotton belts with similar, yet not identical, geometric designs (a), the chapes are dome-shaped with a single stud in the

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[148] http://omanisilver.com/contents/en-us/d408_Omani_Designs.html [Accessed 09/10/2018].

centre (b). The scabbard’s *al mekhalah* regions are attached to their belts by means of linking ball chains (c) known as *mirqat* (Al Busaidi 2015, 55). The *al mekhalah* sections themselves are decorated by overlapping motifs featuring a concave diamond-like design with a central circle (d). Linking rings connect the belt holder with the actual belt (e). The belt holders feature seven silver rings (g), all connected by strands of twisted silver wires, a design commonly referred to as *sim mahuis* (Al Busaidi 2015, 55).

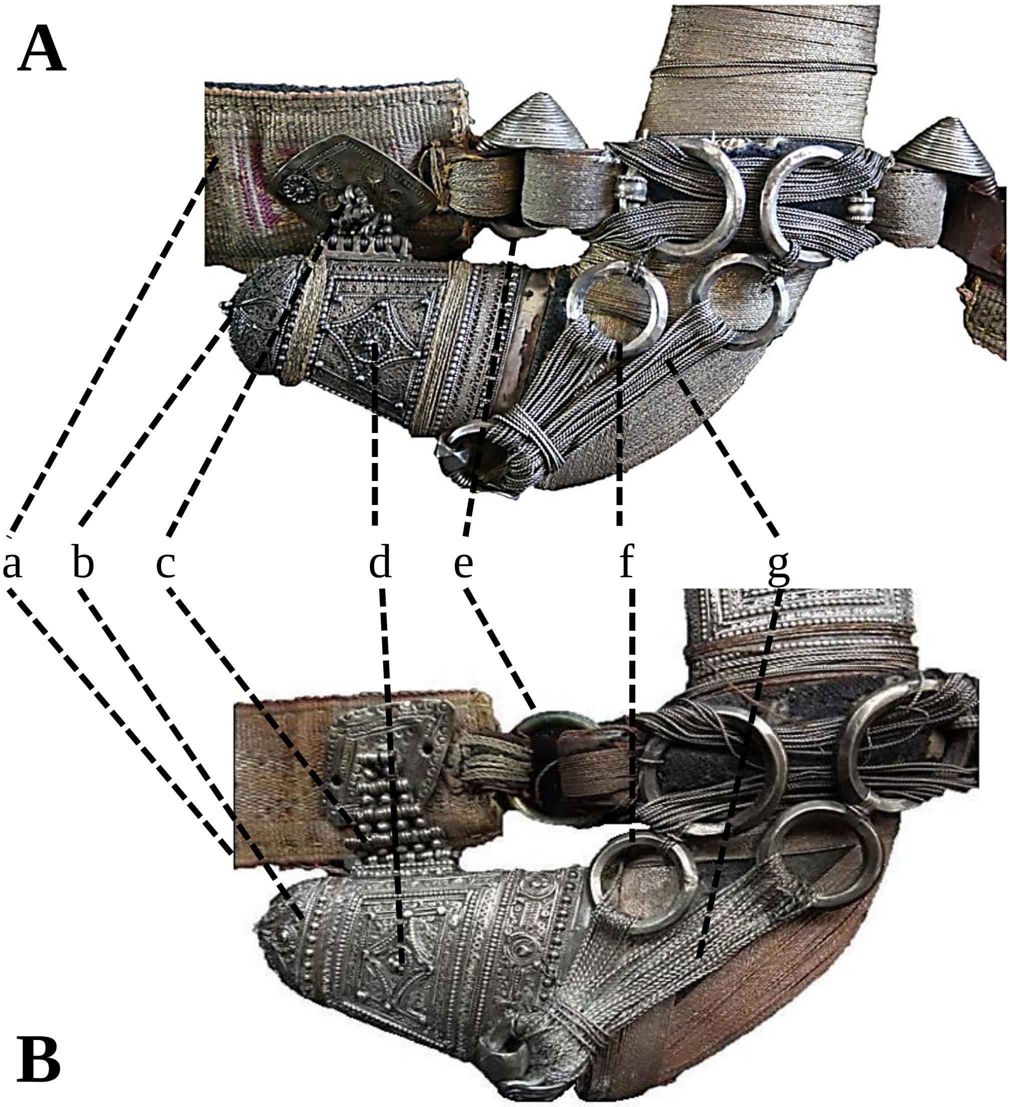

Figure 5.46: Side-by-side comparison of the lower scabbard on the DNMCH *khanjar* (A) and an *Omani Al Saidi Khanjar* (B).
Source: Oman and Zanzibar Virtual Museum[149].

Although the research conducted by Enguita et al. (2002) suggests that the thickness of metal threads can be used as chronological markers (2002, 328), our lack of access to other physical samples makes it near impossible to draw conclusions on this specific point of discussion.

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[149] http://omanisilver.com/contents/en-us/d408_Omani_Designs.html [Accessed 09/10/2018].

5.7.4 Belt Decorations and Buckle

Another clue to the NDMCH *jambiya*'s identity as an Omani *khanjar*, comes from the decorations, but more specifically from the colour of the threading used. These decorative elements can play a significant role in determining the region of origin, since the different embroidered design are associated with different families, villages or tribes (Heinze 2015, 106).

A side-by-side comparison of the DNMCH *jambiya* (Fig.5.47A) and a royal khanjar from the Zubair Museum in Muscat (Fig.5.47B) clearly highlights the similarities. On both examples, the belt is divided into three decorative rows, with the central row being the thickest (a). Although the geometric designs of the central line differ, the colours are almost identical – maroon (purple-red). Golden yellow threads appear across all three lines, but are most prominent within the two outer borders (c).

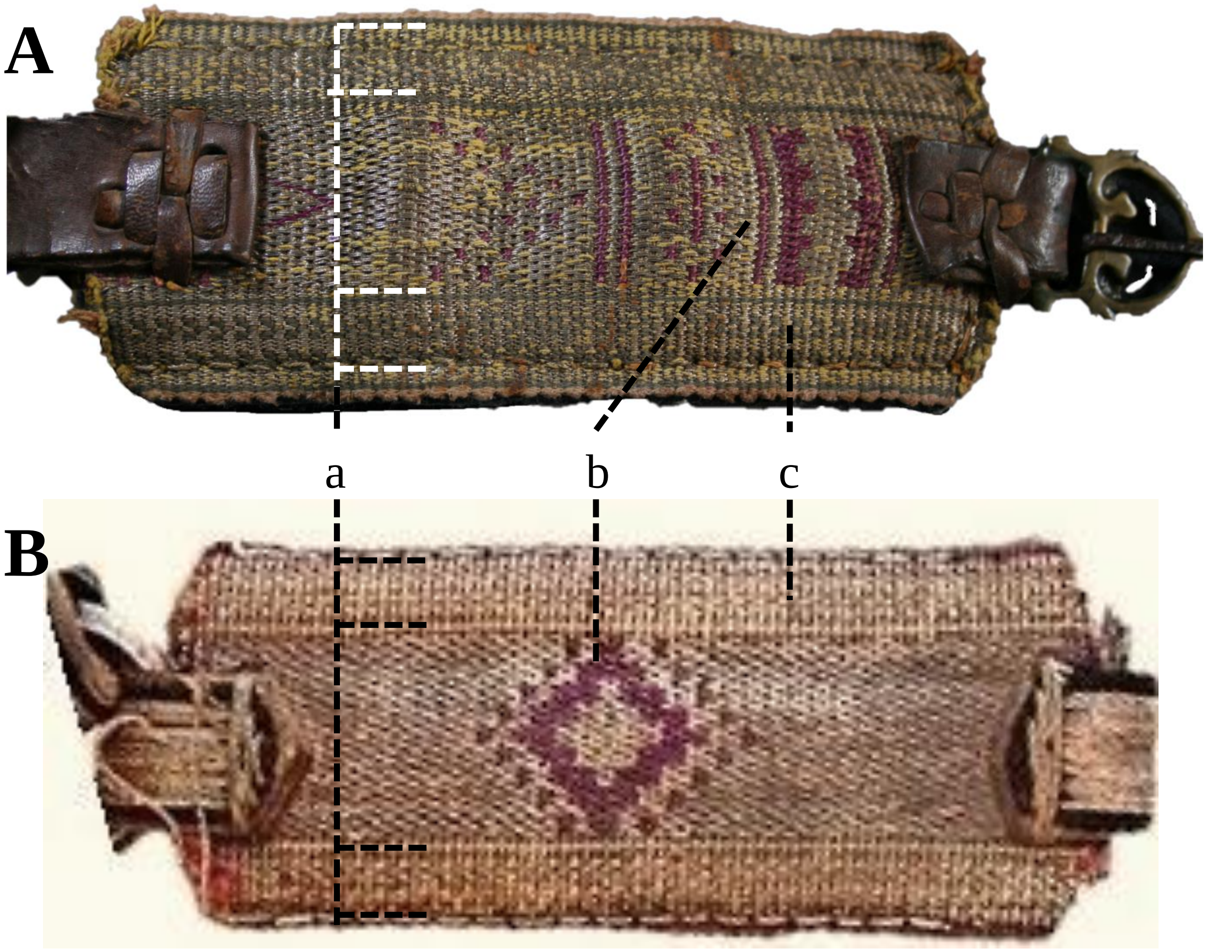

Figure 5.47: Side-by-side comparison of belt decorations on the DNMCH *khanjar* (A) and a royal *khanjar* from the Bait Al Zubair Museum in Muscat (B).
Source: Bait Al Zubair Museum[150].

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[150] http://www.baitalzubair.com/?page_id=140&lang=en [Accessed 09/10/2018].

Additional stylistic markers include distinct geometric patterns that are attributed to certain regions and cultural groupings. The triangular patterns encountered on our dagger (Fig 5.48A–B) are identical to those encountered among antique Omani khanjars (Fig. 5.48C–F).

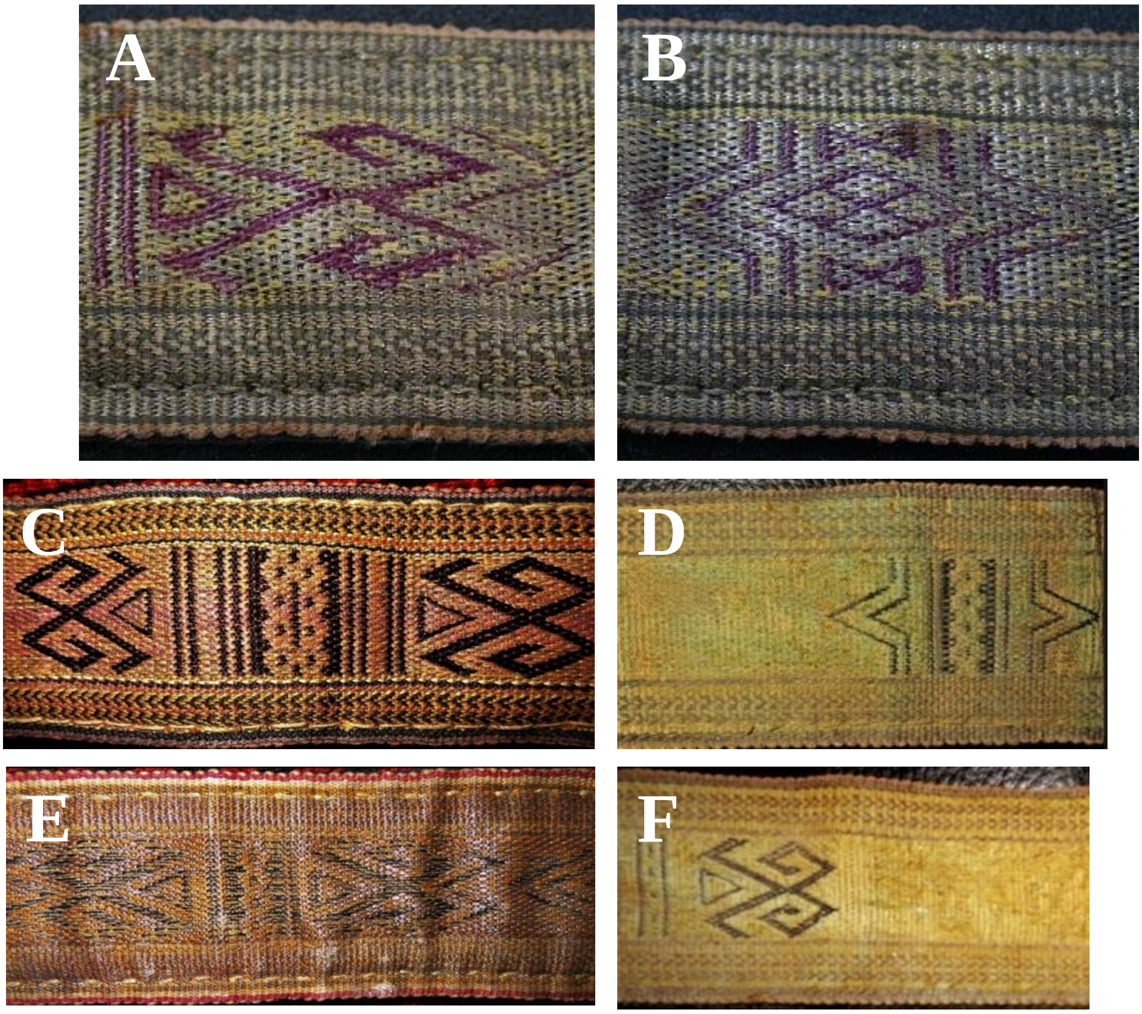

Figure 5.48: Design similarities between the DNMCH khanjar (A–B) and examples of Omani khanjar (C–F). ***Source:*** Oman and Zanzibar Virtual Museum[151].

Another similarity between our dagger and Omani khanjar is the buckle design. In both instances, the buckles assume a D-shape and feature similar floral of leaf-like decorations (Fig. 5.49).

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[151] http://omanisilver.com/contents/en-us/d408_Omani_Designs.html [Accessed 09/10/208].

Figure 5.49: Design similarities between the DNMCH *khanjar*'s buckle (A) and that of an Omani *khanjar* (B). **Source:** Oman and Zanzibar Virtual Museum[152].

5.7.5 A Deutsch Ostafrika Rupie

A seemingly out of place object attached to the belt provides an unexpected clue to the *khanjar*'s relative age. A ¼ Deutsch Ostafrika Rupee, with the date 1909, is attached to the belt by means of an iron clip (Fig. 5.50). Since the museum has no record of who donated the dagger, the coin was probably placed on the belt by the original owner. But, in order to gain insight into the possible owner, and how the dagger and its accompanying coin came to South Africa, we need some historical context.

Figure 5.50: A ¼ Deutsch Ostafrika Rupee (1909), attached to the *jambiya*'s belt.

The east coast of Africa was a commercial trading hub, which linked Africa to the Arabian world, India and China, from as early as the first millennium CE. Cities like Kilwa (on the coast of Tanzania) and the islands of Songo Mnara and Zanzibar (off the coast of Tanzania) played a prominent role within this lucrative Indian Ocean trade network. The Swahili coast

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[152] http://omanisilver.com/contents/en-us/d643.html [Accessed 09/10/2018],

was under the influence or direct rulership pf a number of sultanates, including the Kilwa Sultanate and the Ajuran Sultanate (Somali Empire). Portuguese influence commenced when Pedro Alvares Cabral arrived at Kilwa in 1500 (Horton, Fleisher, Wynne-Jones 2017, 166), but did not last long. By 1698, Zanzibar and the Tanzanian coast fell under the control of the Sultanate of Oman (Omani Empire) and continued to play a role in internation trade. In 1885, German rule was established over Bagamoyo, Dar es Salaam, and Kilwa. This marked the extablishment of Deutsch Ostafrika (German East Africa), which was a German colony in the Great Lakes region of Africa, which today includes Burundi, Rwanda and the mainland of Tanzania. The colony was founded by the German military in 1885 and was dissolved in 1919 after Germany's defeat in WWI.

South Africa's connection to the colony is one of conflict, as the German Commander, General Paul Emil von Lettow-Vorbeck, regularly fought off the invading British forces – the latter often commanded by Jan Christiaan Smuts. After the formation of the Union of South Africa on 31 May 1910, the Union Defence Force was established, with Jan Smuts serving as the Union's first Minister of defence. During World War I, after capturing German South-West Africa (Namibia), an expedition was sent to German East Africa with similar goals in mind. However, von Lettow-Vorbeck proved to be a cunning adversary, fighting his way out of the region, into Mozambique and eventually Rhodesia (Zimbabwe).

The coin is attached by means of a metal clip, which cannot be removed without running the risk of damaging the object. Therefore, the reverse side of the coin cannot be seen. Fortunately, many coin collectors' forums post high quality images online, which is convenient for comparative purposes. As seen from the image below (retrived from a South African online store), the reverse depicts an effigy the German Keizer, Wilhelm II, with the inscription *Guilelmus II Imperator*.

The Rupee was the currency of German East Africa between 1890 and 1916, but continued to circulate in the territory until 1920. What is interesting is that GEA Rupie notes were printed locally in Dar Es Salaam between 1915 and 1917, as naval blockades prevented the import of German-printed notes and coins. 1916 was the final year in which German troops were paid using Rupie coins. This meant that during the time British and South African forces warred against the Germans in German East Africa, the Rupie as a coin currency was already quite scarce.

Figure 5.51: 1909 A Quarter Rupie: German East Africa/Deutsch-Ostafrika.
***Source*:** Pierre Henri on *Bidorbuy*[153].

Al Busaidi (2015, 5) notes that quite a few examples of Omani *khanjars* are found in East African museums. With all of this in mind, the truly interesting question now arises… how did an Arab-Omani *jambiya* make its way from the Middle East, to German East Africa and eventually, South Africa? As mentioned previously, the island of Zanzibar was part of the Sultanate of Oman, and Zanzibar in turn had close relations with German East Africa up to WW I, so it is possible that Omani merchants or other travellers might have transported and traded the jambiya.

Also, the British Empire's influx into what remained of the Ottoman Empire, whether through military campaigns or as intrepid explorers, brought many into contact with cultural objects such as the *jambiya*. Its inherent attraction as both an exotic curiosity and status symbol (the latter being that of a well-travelled individual) would have made it a popular item amongst military men. It is possible that a British soldier serving in WWI could have obtained the *jambiya* during an earlier campaign or travels to a British territory, such as Oman[154]. During the British campaign in German West Africa, the soldier could have attached the Deutsch Ostafrika Rupie to the belt to commemorate his military service in the region. The alternative is that it belonged to a German soldier with a similar back-story. The *jambiya* could even have

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[153] https://www.bidorbuy.co.za/item/247551352/1909_A_Quarter_Rupie_German_East_Africa_Deutsch_Ostafrika.html [Accessed on 09/10/2018].

[154] Although Oman was seen as a British protectorate from 1891, the country was never formally a colony of Britain. However, Britain did hold substantial political power over the country, especially since the Royal Navy was permanently stationed in Bushire to facilitate trade between Europe and India. http://www.britishempire.co.uk/maproom/oman.htm [09/10/2018].

been brought back to the country by a South African, but this theory is less likely – unless it was gifted to the person in question by a British soldier, perhaps as a token of camaraderie during the war.

Although the Rupie itself cannot predate its minted date of 1909, the dagger could be older, since the Rupie only provides insight into the period of acquisition and ownership, but not the manufacturing date of the dagger.

5.8 CONCLUSION

This chapter provided further historical contextualisation through its in-depth stylistic analysis of the research collection. Through an investigation of existing literature, and through visual comparisons with well-dated and curated collections, the researcher was able to identify a number of stylistic attributes that could place the objects under investigation within more certain culture-chronological frameworks.

5.8.1 Egyptian Bronzes

The general conclusion that can be drawn from our analysis is that the objects within this collection of bronze statuettes cannot all be grouped within the same time period. As highlighted by Gravette's (2011) study, the objects that were broadly curated as belonging to the Middle and New kingdoms clearly displayed stylistic attributes that are more akin to specific periods, such as the 12th and 18th through 20th Dynasties.

Based on the information provided in this chapter, it is safe to assume that the DNMCH bronzes were created some time after the 18th Dynasty, if one considers the lost-wax method of casting as a relative chronological marker. This applies specifically to the smaller items (broken ibis, Wepwawet and cat) that are most probably solid-cast, but not to the hollow-cast Wadjet-Bast. Specific dates for the introduction of hollow casting are provided by Schorsch and Frantz (1998, 20) and Schorsch (2007, 192) as the late 12th Dynasty or early 13th Dynasty (1840–1750 BCE).

5.8.2 Samurai Armour – *Kabuto* and *Menpó*

Based upon the brief stylistic analysis conducted by Teichert et al. (2012), the samurai armour housed by the DNMCH originates from the mid-Edo Period (17th to 18th centuries) and is classified as belonging to the *Tósei-Gusoku* style (Teichert et al. 2012, 54).

Based upon our visual comparison between online sources and the DNMCH cuirass, the latter falls within the *Mōgami dou* sub-category of the *Tósei-Gusoku* style. However, since there is no positive connection between the cuirass and the *kabuto* and *menpó*, one cannot categorically state at this stage that the *kabuto* or *menpó* also belong to the *Mōgami dou* sub-category of the *Tósei-Gusoku* style. At best, we can provide an associated date due to the shared provenance that exists between these three objects. In order to provide a greater level of certainty regarding their relationship, further visual analysis is required, such as the identification of structural and/or compositional similarities between the cuirass and the *kabuto.*

According to our comparative analysis, the *kabuto* falls within the *suji kabuto* category due to its arrangement of flanged vertical helmet plates. Furthermore, the presence of 15 plates places the helmet within the 16-*ken tsuji* category that was popular during the 17th century CE.

Based on our comparative analysis, the facemask falls within the *menpó* category of *mengu* or *men yoroi* (face masks). However, as with the relationship between the cuirass and the *kabuto*, a definite relationship between the *kabuto* and the *menpó* cannot be established on stylistic analysis alone, but will require some further investigation.

5.8.3 ToL Gauntlet and Helmet

A similar scenario unfolded with our assessment of the ToL gauntlet. Where the stylistic attributes of the Samurai cuirass were used to obtain an associated date of production for the *kabuto* and *menpó*, the ToL helmet was used to provide an associated date for the gauntlet. The helmet is classified as a burgonet, falling more specifically within the lobster-tailed sub-category. Based upon our visual comparison between examples housed by international museums and the DNMCH helmet, the latter possibly dates from the early to mid-17th century C.E. When considering the helmet's single-plate construction, it is possible that the helmet might be of European, rather than English origin.

5.8.4 Arabian Dagger

In the case of the Arabian dagger, our comparative analysis enabled us to categorise the *jambiya* as an Arab-Omani *khanjar* belonging to a specific sub-type known as *Al Saidi* khanjar. This identification provides us with a relative date for the object, placing its manufacture within the late 19th to early 20th century CE. The presence of a 1909 Deutsch Ostafrika Rupie on the belt provides some information on when and where the dagger was in use, but not necessarily when it was made. How the dagger came to South Africa remains unanswered and will probably remain so. Whether it was distributed via Omani merchants, travellers and/or British/German soldiers is a topic for for research.

CHAPTER 6
SURFACE INVESTIGATIONS

6.1 INTRODUCTION

To lay the groundwork for more advanced MXCT investigations, as presented in Chapter 7, this chapter provides basic descriptions of surface anomalies. For this phase of our investigation, high-quality images were taken by means of a USB digital microscope and digital SLR camera. This process allows for the preliminary identification of phenomena that can be verified through complementary data obtained during the main phase of radiographic imaging. Within the greater context of this thesis context, Chapter 6 thus forms part of the pre-test phase within the quasi-experimental model and can thus be considered as a preliminary technical analysis in preparation for Chapter 7.

In each section, detailed descriptions of the artefacts under study will be combined with a discussion on the observations made. These observations and discussions are performed with two main goals in mind: (a) the characterisation of object integrity (level and extent of corrosion, patination, breakages, etc.) and (b) the identification of production elements (pins, tacks, casting seams, etc.).

6.1.1 Corrosion and Patination as Indicators of Age

Since surface corrosion is one of the characteristics shared by most of the objects under investigation, a number of factors should be taken into account when considering corrosion as an indicator of age.

When considering the presence of corrosion as a good indicator of age, Schorsch (1988) reminds us that the absence of corrosion products should not be used as the primary criterion for authentication[155]. This is because most authentic ancient metals have undergone some form of chemical or mechanical cleaning throughout their modern lifespans within museum/private collections. In other instances, some authentic objects have received modern treatments that replicate ancient patination, or have been covered with conservation treatments that inhibit natural corrosion/patination processes (Schorsch 1998, 48). To

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[155] This general rule hold true to the other objects within this study, and is not limited to ancient Egyptian bronzes.

complicate the situation even further, most conservation treatments are not properly recorded by museums, and even in instances where documentation has taken place, these accounts are rarely accompanied by visual documentation that provides information on colour, texture or layer thickness.

Although some may argue that the external thickness of corrosion layers could also serve as an indicator of age, corrosion thickness does not necessarily equal time/age. When discussing the issue, Siano et al. (2009, 673–674) point out that “the whole thickness of passivating corrosion layers, including Cu(I) and Cu(II) copper oxides, does not strictly depend on time since it exhibits typical saturation behaviours”, however “the total thickness of the coherent cuprite layer cannot represent a key for discriminating between ancient and modern, there are significant differences between the metal-mineral transitions that can be exploited in authentication studies”. Thus said, it is not the thickness itself, but rather the microstructural characteristics of external layers that count towards authentication.

While patina is generally considered as a good indicator of age, and by extension authenticity, one must keep the existence of false patinas (created through the application of chemicals) in mind when examining artefacts (Goffer 1980, 349). As mentioned above, museums may apply treatments to replicate patination on authentic objects, but replicated patination is also used on fakes and forgeries in order to make the objects appear antique.

To make the situation even more complicated, intentional patination was already practiced during ancient times. For example, in the non-destructive study by Aucouturier et al. (2010), the intentional patination of Egyptian and Roman metal artefacts is discussed. Through the application of portable X-ray diffraction, microstructural data confirmed the presence of ancient true black bronze[156] patina along with three other non-black bronze patinas. The study showcased how the presence and proportions of certain trace elements, such as metallic Au (gold) and or Ag (silver), cuprite Cu_2O (an oxide mineral composed of copper(I) oxide Cu_2O), tenorite CuO (a copper oxide mineral) and cassiterite SnO_2 (a tin oxide mineral), and impurities in the copper, such as bismuth, can also help characterise intentional ancient patination treatments (Aucouturier et al. 2010. 320–321).

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[156] The oldest black-bronze patinas date from the Egyptian Middle Kingdom (Giumlia-Mair 2005 in Aucouturier et al. 2010).

Since the situation is quite complicated, Berger (2015, 130) notes that “direct evidence for the intentional patination of metal objects is difficult to ascertain and therefore studies concerning this technique are controversial”. In short, it is only through the combined application of physiochemical studies and scientific criteria (used to identify types of patination), that we can confidently state whether or not the patination being investigated was applied intentionally or unintentionally. Since physiochemical studies fall beyond the scope of this thesis, all observations regarding patination should not be interpreted as conclusive evidence of authenticity, but rather as potential evidence – pieces of an incomplete puzzle, so to speak.

6.2 EGYPTIAN BRONZES

6.2.1 Radiation Damage and Internal Corrosion

Under normal circumstances, internal corrosion is not something that can be discussed alongside surface phenomena, except when internal features have been exposed due to extreme surface weathering or breakages. The story of Wadjet-Bast is an example of the latter.

On 26 August 2015, the statuette was subjected to MXCT at NECSA’s MIXRAD facility, with the primary aim of investigating internal features. Being aware of the statuette’s fragile nature (having been repaired along the lap area), the object was treated with extreme care during transportation and examination. As is clear from the images below (Fig. 6.1), not all of the repaired surfaces were in direct contact with each other, with gaps clearly visible. However, upon arrival home late that afternoon, it was discovered (to the great personal horror of the researcher!) that the statuette had broken along the same fragmentation lines as before. Immediate microscopic investigations of the remaining adhesive and surrounding bronze material showed no indication of external force, as there were no new breakages, scuff marks or chipped-off adhesive. Therefore, there was no indication that improper handling or physical stress had caused the (re)breakage.

A fair amount of research was subsequently conducted to determine whether radiation exposure could cause adhesive failure. The general consensus among researchers is that radiation damage to polymer adhesives is by no means rare[157], as prolonged exposure to high

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[157] Radiation exposure is often used within the field of restoration science. In certain instances, undesirable adhesives, consolidants and varnishes have been successfully removed from artefacts using radiation (see for example Koh & Sarady 2003; Madden et al. 2005).

levels of ionized radiation cause disruptions in polymer chains (Miller 1977, 774; Johnson n.d.). Due to Wadjet-Bast's high attenuation of X-rays[158], the voltage on the Nikon Metrology XTH 225/320 LC dual source system was set to 205 kV (near maximum) to ensure sufficient X-ray penetration, while a copper filter was added to reduce beam scattering. In addition to the radiation intensity, the statuette was also subjected to two rounds of beam time, with each session lasting roughly 30-40 minutes. This combination of intensity (205 kV) and exposure duration (+/- 80 minutes of beam time) was undoubtedly the cause of adhesive failure.

Figure 6.1: Repaired areas along the broken lap of Wadjet-Bast statuette.

Although this may raise understandable concerns relating to the true non-destructive nature of radiation techniques, one must keep in mind that the non-destructive nature of these techniques relate specifically to inorganic materials, such as metals, rocks and minerals, etc. Radiation will always cause some level of damage to organic matter. The latter point is particularly relevant to organic polymer adhesives, such as those commonly used within the museum environment[159], as they are extremely susceptible to radiation damage. This brings us back to the issue at hand – the exposure of internal features.

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[158] High density materials such a copper and lead (components of bronze) offer a high level of resistance to the penetration of x-rays (De Beer 2005).

[159] As no museum records were kept of the adhesive that was used, it is difficult to say whether the specific polimer adhesives used was organic or synthetic. It is crucial that we recognise, and are able to distinguish

In the case of Horus, a malachite layer appears between the mineralised bronze and the clay core. The clay core is easily identified as clay through visual inspection, while XRF and XRD analyses confirmed its composition (quartz, aragonite, sand, lime plaster) (Smith et al. 2011, 224). Although Wadjet-Bast displays a similar malachite layer underneath the bronze (Fig. 6.2A–B), the internal core material appears to be different from the clay core of Horus. It is much darker, almost black[160] (Fig. 6.2C), and is speckled with mineral inclusions[161]. As internal layers of corrosion are difficult to recreate, they are regarded as positive indicators of authenticity (Smith et al. 2011, 227). In both instances, the adhesives used to repair the item appear with a high sheen

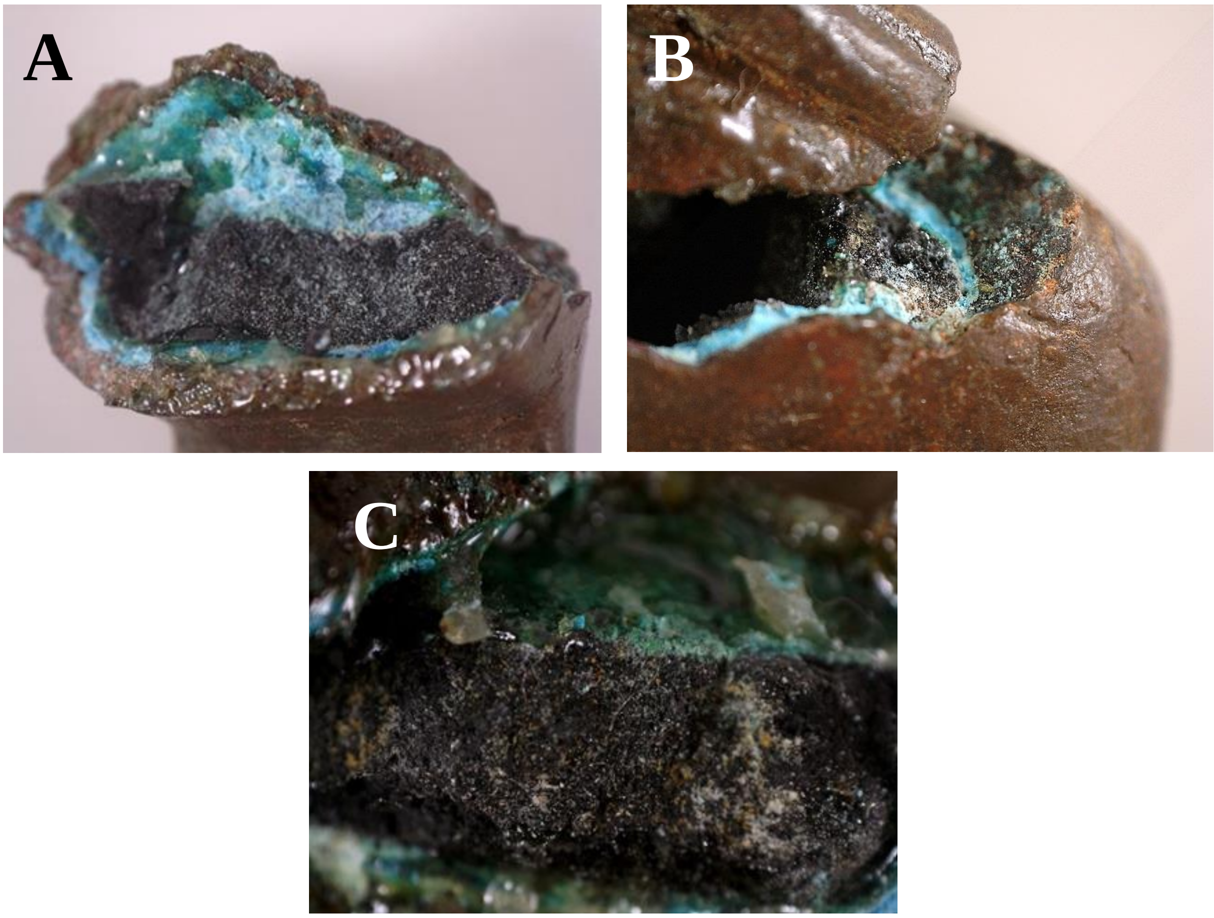

Figure 6.2: Thick light blue corrosion layer (A–B). The texture of the core material compared with the malachite layer (B).

It must be noted however, that the thickness of passivating corrosion layers does not strictly depend on time alone, as thickness can be replicated over a comparatively short period of time

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between, different polymers on artefacts in order to predict the possible side-effects of exposure to high energy sources (Madden et al. 2005, 1247).

[160] This blackened, charred appearance is usually the result of organic material that was used to help bind the clay core material.

[161] Chemical analysis is definitely required to positively identify the material.

(Siano et al. 2009, 673–673). It is therefore crucial that authentication efforts should focus on noting the differences between mineral-metal transitions (between the corrosion layer and the underlying metal), “as the corrosion of genuine archaeological artefacts is usually characterised by penetrating intergranular ramifications[162] that significantly affects the local composition of the alloy” (Siano et al. 2009, 673). Also, the variety of minerals that form during the corrosion process is vast and highly individualistic (Scott et al. 2002, xiii), and the very presence of intergranular corrosion could in itself be indicative of antiquity[163]. In this light, future analysis of the corrosion products of these statuettes, by means of deuteron diffraction (to detect intergranular phenomena) and Raman spectroscopy (to identify corrosion compounds), should be strongly considered.

6.2.2 Surface Patination and Corrosion

For many centuries, curators have distinguished between authentic artefacts and contemporary replicas by visually (through colour and morphology) distinguishing between alterations formed by natural and/or artificial patination[164] (Siano et al. 2009, 673). Although patination is generally seen as a good indicator of age, the lack of surface patination should not be used as a premise upon which to base outright rejection of an object’s authenticity. Similarly, the mere presence of patination cannot be used as confirmation of authenticity, since artificial patination is widely applied by forgers in an attempt to make modern replicas appear ancient[165]. As Schorsch and Frantz (1998, 28) note, the lack of patination does raise valid concerns about an object’s authenticity, yet the researcher should always keep in mind that past preservation treatments, including those that may have been performed before museum acquisition, might account for the absence of this phenomenon.

Smith et al. (2011) discovered that the DNMCH Horus figure was cleaned of external corrosion at some stage during the object’s history at the museum. Based on the visual similarity between the Horus figure and the remaining bronze figures within the collection, it

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[162] These ‘intergranular ramifications’ can only be observed though neutron diffraction – a technique which could be utilised in future research. In addition ‘laser induced plasma spectroscopy (LIPS) can represent the most effective micro-analytical technique to measure and classify elemental depth profiles, which are of crucial importance for distinguishing between natural aging and fraudulent imitations’ (Siano et al. 2009, 674).

[163] Schorsch and Frantz (1998, 25) note that intergranular corrosion, observed through techniques such as optical photomicroscopy, is consistently present among most archaeological bronzes.

[164] Although patina is generally considered as a good indication of age, and by extension authenticity, one must keep the existence of false patinas (created through the application of chemicals) in mind when examining artefacts (Goffer 1980, 349).

[165] According to Berger (2015, 130), “direct evidence for the intentional patination of metal objects is difficult to ascertain and therefore studies concerning this technique are controversial”. To make the situation even more complicated, intentional patination was already in practice during ancient times.

would be safe to assume that the latter also underwent cleaning treatments. Naturally, this means that very little patina is visible on the surface. Where green malachite-coloured patinas (copper carbonate corrosion) are visible, they mainly appear on tangs, rough areas, damaged surfaces or cracks that escaped the restoration team's reach. These remnants of patination, although few and far between, are of great importance to authentication, as they represent common elements shared among archaeological bronzes (Schorsch & Frantz 1998, 28).

Apart from the most obvious cleaning and repair work done on the broken lap area of Wadjet-Bast, it appears as though a crack or weak point was repaired on the right shoulder. The material appears as though it was pressed into position and the green colour makes it stand out from the surrounding material (Fig. 6.3A). A yellowish-brown residue appears on the headdress but nowhere else on the body (Fig. 6.3B), while a reddish material is clearly visible on the bottom of the right foot (Fig. 6.3C). It is possible that the red material is the original surface of the bronze, as this is usually represented by a "pseudomorphic reddish (Cu(I) oxide (cuprite) layer", which is often referred to as a "passivating layer" (Siano et al. 2009, 673).

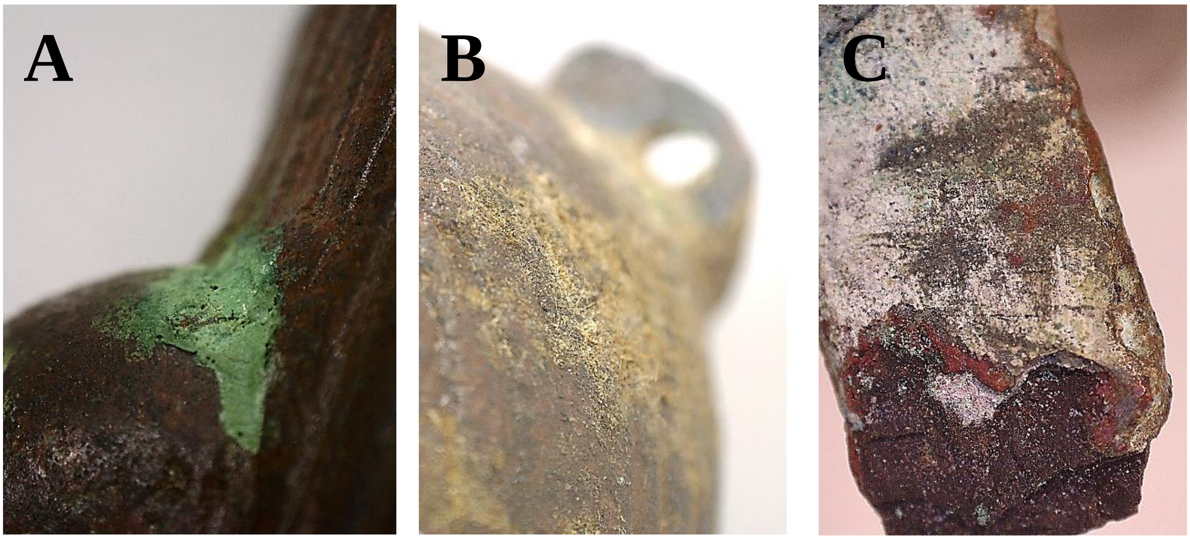

Figure 6.3: Green material (A), brownish residue (B), and red oxidation.

Since the edge of the corrosion layer is chipped off (Fig. 6.3C), one can observe a reddish-brown layer of corrosion sandwiched between the underlying bronze and a pale green (almost whitish) surface layer. This corrosion closely resembles the corrosion layers described by Ambers et al. (2008, 7) in their investigation of the Geyrs-Anderson cat:

> On cursory inspection two coloured 'corrosion' layers are present, the lower one brick red and the upper consisting of varying shades of green. This would seem to accord with the most commonly found natural patina formed on ancient bronze, with a lower layer of cuprite, a copper(I) oxide (Cu_2O), and an upper layer consisting of one of the green copper corrosion products – most commonly malachite (a copper carbonate: $Cu_2CO_3(OH)_2$) or atacamite (a copper chloride: $Cu_2Cl(OH)_3$). However, closer examination shows that most of the surface green 'patina' is an artificial layer applied to the metal surface after removal of the majority of the naturally formed corrosion stratigraphy.

Although the visual description provided above was not accompanied by colour photography, Ambers et al.'s (2008, 7) recollection of the corrosion profile closely resembles that of Wadjet-Bast (Fig. 3.4A). Fortunately, in the research of Schorsch and Frantz (1998), the authors provide a colour image of their "large cat", the surface of which shows exfoliating scales of copper oxides (Fig. 3.4B).

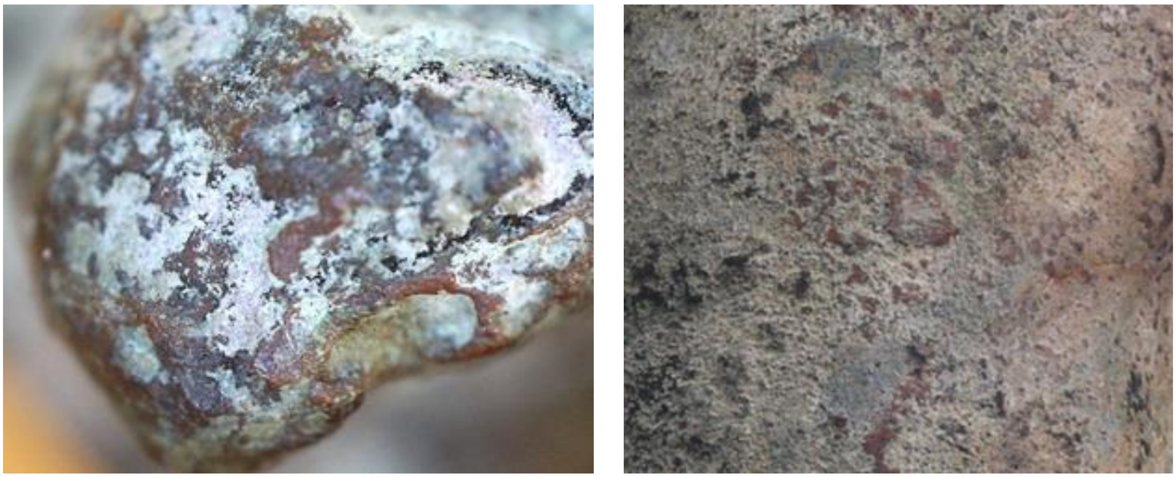

Figure 6.4: Comparison between the surface corrosion on Wadjet-Bast's tang (A) and exfoliating scale of copper oxides encountered on the Large Cat (B).
Source: Schorsch and Frantz (1998, 27).

The internal surface of Wadjet-Bast (Fig. 6.5A) has a thin turquoise or light blue corrosion layer that closely resembles the internal corrosion layers that were exposed following adhesive failure (Fig. 6.5B).

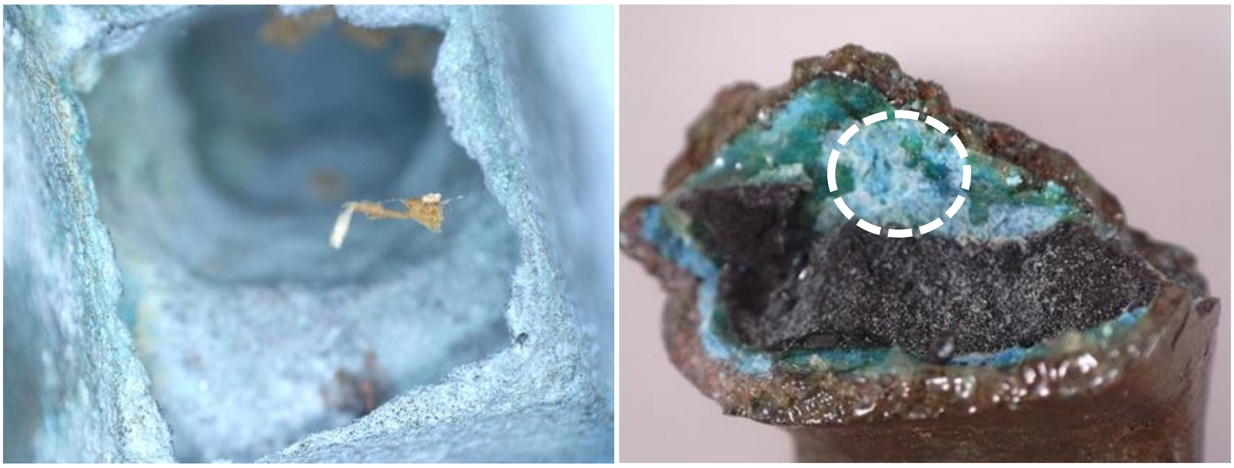

Figure 6.5: Light blue corrosion on the internal surface of Wadjet-Bast (A), and internal corrosion (B). Image B is repeated for the sake of side-by-side colour comparison.

Lastly, in the case of the small bronze Wepwawet, we encounter one of the most interesting colour variations in terms of corrosion (Fig. 6.6). The underside of the sled is covered with mixed surface exfoliation, including patches of reddish-brown material that closely resembles the exfoliating scales of copper oxides mentioned in Schorsch and Frantz (1998). The surface is also speckled with bright turquoise coloured material, light blue spots and flaking green and black areas.

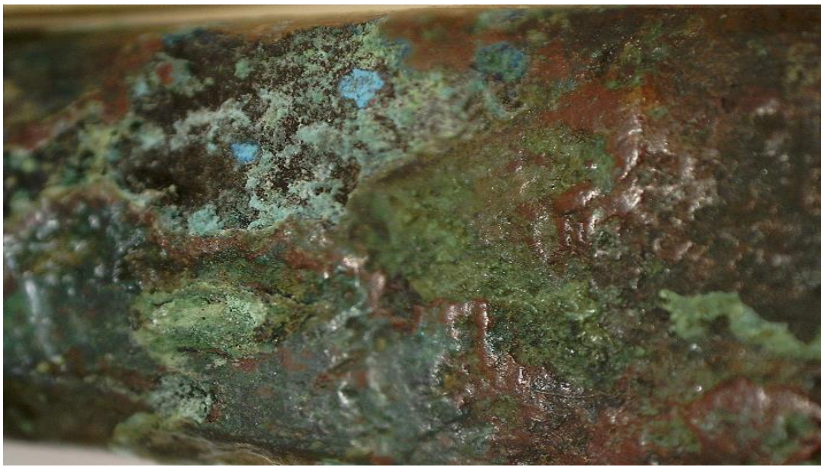

Figure 6.6: Corrosion on the underside of the Wepwawet.

Although these colour and texture variations can be described, and educated guesses made about their composition, more advanced techniques, such as XRF, XRD and ND, should be employed to establish the elemental nature of these phenomena. However, what can be stated is that the mere presences of such intricate corrosion profiles could stand testimony to the authenticity of these objects, if they are interconnected with related phenomena (complementary data).

6.2.3 Polishing Striations

Bronze casts were finished by chiselling or filing (Savage 1968, 17), which involved the removal of rougher casting imperfections. Polishing objects to a fine sheen using sandstone blocks would have been one of the final steps of the manufacturing process. This mechanical procedure unavoidably left traces (often microscopic) on the surface of the metal, which can be used to validate authenticity (Goffer 1980, 350). Unfortunately, no data is presented on surface investigations of the Horus figure by means of digital microscopy. Because of this, the Wadjet-Bast figure was investigated alongside three other bronzes (broken ibis, dog and cat/Bastet) in order to obtain comparative data. Polish marks were clearly visible on all four objects, indicating that they are not simply random occurrences. In most instances, the striations run parallel across the body, but often intersect along curves. These intersections are especially visible along the breasts (Wadjet-Bast) and bodies of the figures (Wepwawet, cat and ibis), indicating that the artisan had to manoeuvre the sandstone block around these features.

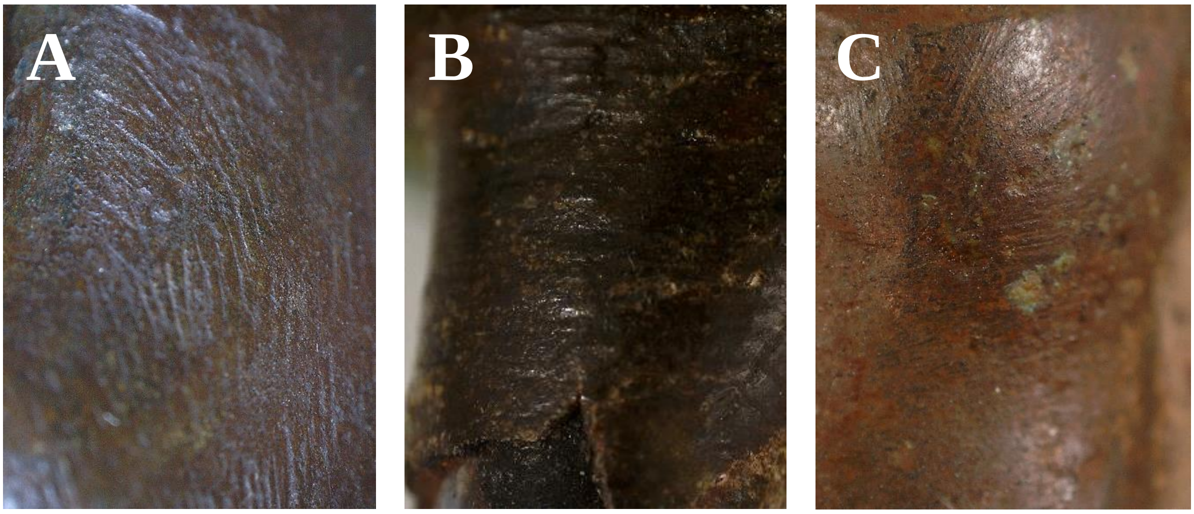

Figure 6.7: Intersecting striations on the cat figure (A), horizontal striations on the left leg of the ibis figure (B) and intersecting striations on the left breast of the Wadjet-Bast figure (C).

Although it has been argued by fellow researchers that these striations could be the result of brush impressions that were formed during the application of modern-day conservation treatments, the microscopic appearance of these lines contradicts these assumptions. For example, as with the appearance of microscopic phenomena in decorative incision lines, these striations were also influenced by impurities below the surface of the newly-cast bronze. Polishing striations also intersect at acute angles (Fig. 6.7A) and follow the curvature of certain features (Fig. 6.7B), suggesting that they are elements of manufacture and not conservation. In addition, where conservation treatments have been applied, brush impressions are rarely observed, as the high fluidity of these chemical treatments allow the substance to settle into a smooth surface before drying, hence losing any brush impressions.

6.2.4 Tangs

Tangs are protrusions that appear at the bottom of statuettes and serve to secure the object to a wooden base. The tang is basically a remnant of the casting process, also known as the sprue or casting funnel (Ogden 2000, 157), which was cleverly redesigned to have a practical function. As the statuette and sprue are cast as a whole, the reshaped tang makes for a remarkably secure addition to the object. The shape of these protrusions can be used to assign relative chronology to the object, as asymmetrical, irregular shaped tangs are characteristic of metalwork preceding the New Kingdom (1550–1070 BC), while more formally designed rectangular, flat-ended versions appear both during and after this period (Ghoniem 2014, 41; Schorsch 2007, 193). The tang encountered on the Wadjet-Bast figure is clearly rectangular in shape, although the edges have been rounded slightly. The rounded shape is most likely the result of continued use.

The presence of metal tangs indicate that objects were mounted on special supports or bases made of wood or clay, allowing them to be positioned as votive figures in homes and temples (Davies 2007, 183). The absence of a tang on a statuette could indicate that the item was freestanding, as is the case with the Pharaoh hound.

Casting the tang and the statuette as a single entity would have provided greater stability to the item, compared with affixing the tang at a later stage. During the radiographic phase, careful attention was be paid to the position of tangs and how they are affixed to their statuettes, taking careful note of anomalies that might suggest alternative methods.

6.2.5 Eye Sockets

Most statuettes were provided with eyes made of painted clay. Eye sockets/hollows were designed as a functional part of the cast, allowing the clay material to be pressed into position. The Wadjet-Bast figurine’s eyes are missing, providing us with the opportunity to investigate the sockets in finer detail. It appears as though some remnant of the clay substance is present (given its white/beige appearance), yet this may actually be corrosion material (Fig. 6.8). However, in the case of the Gayer-Anderson cat, Ambers et al. (2008, 8) note the following:

> Small deposits of lime plaster (identified by Raman spectroscopy) were also found around the eyes; these rest over, rather than beneath, corrosion products, suggesting that they are late cosmetic repairs rather than original survivals.

With this possibility being noted, only investigation by means of Raman spectroscopy will provide absolute certainty about the nature of this residue on Wadjet-Bast.

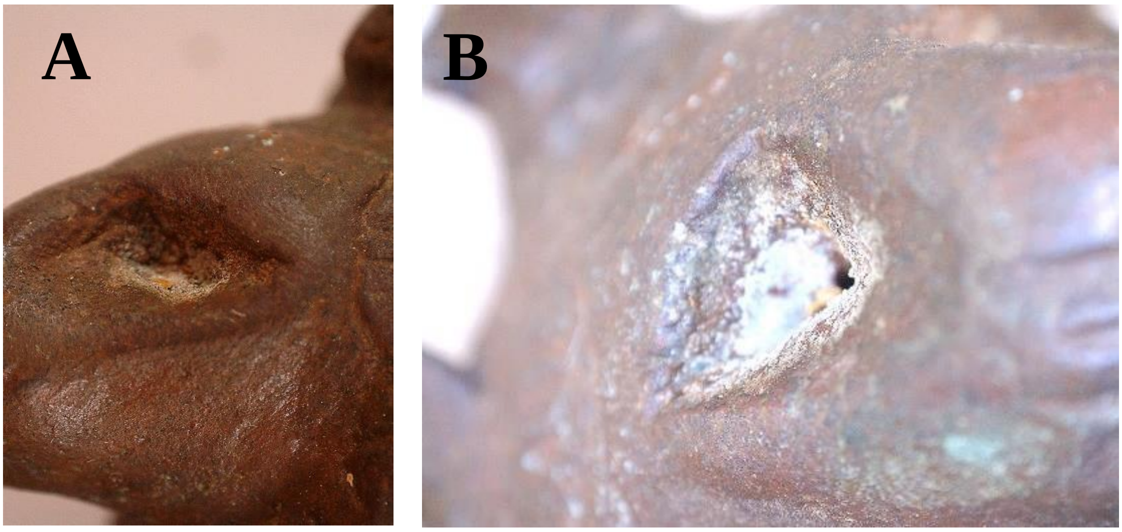

Figure 6.8: Left eye socket with residue/corrosion (A) and
Right eye socket displaying a small hole (B).

The presence of what appears to be a small hole penetrating the right eye socket, is anomalous. The question is raised whether such holes were purposefully included in order to provide the clay material of the eye with some security. Unfortunately, the MXCT images were not clear enough to determine whether the hole penetrated the internal cavity below the eye socket. It is hope that future investigations by means of NT will reveal this feature.

It is also possible that the decorative eye could have been held in place by a protective layer of organic glue, wax or lacquer (similar to the feature reported by Lehmann, Hartmann and Speidel’s (2010) examination of ancient metallic Buddha statues from Tibet).

6.2.6 Decorative Incisions

Decorative incisions were generally made on the original wax model (pre-cast), which results in cast-in features. Alternatively, they could have been made using an engraving tool (known as a burin) during the post-cast phase of production when the surface of the alloy was still relatively soft and malleable (Boucher 1989, 161–162; Savage 1968, 17). In order to determine whether the decorations were made by means of casting or engraving, one has to identify the physical phenomena that are unique to each method.

When examining the nose and the neck collar (Fig. 6.9A–B), the designs appear “pressed”, rather than drawn. They also appear thicker, yet smoother overall than any other decorations on the object. In additional, there are no signs of minute impurities along or within the drawn lines. This could suggest that they were drawn in wax and cast rather than drawn post-cast. However, it is almost certain that some of the incisions (Fig. 6.9C–D) were made on the post-cast bronze and not the wax model itself.

For the infernal made above, we rely on a number of visual phenomena that help illustrate the point. Firstly, the presence of minute impurities within the surface layers of the alloy acted as bumps or obstacles, throwing the tip of the artisan’s burin off by a few micro-millimetres. This phenomenon is clearly observed by the disrupted and irregular flow of the affected incision lines. Secondly, these impurities themselves often appear as though they had been exposed, almost as if a microscopically thin layer of bronze had been scraped off of them[166]. This phenomenon could have occurred as the burin sliced through the upper surface of the warm bronze (Fig. 6.10A). Thirdly, the soft bronze that parted sideways as the burin sliced through the alloy still has a “liquid”, almost “wavy” appearance in its now solid state (Fig. 6.10B).

These points mentioned suggest that the ancient crafter preferred to make deeper, more defined decorations on the wax itself (chasing), as thicker lines would survive the casting and mould removal processes much better that thinner lines. In addition, chasing tends to press the surrounding metal outwards more uniformly, resulting in a neater finish (as is observed along the nose and neck collar). On the other hand, incredibly thin and/or superficial line decorations would not have come out clearly enough during casting, and would almost certainly have disappeared during surface sanding/polishing. The presence of pressed edges (Fig. 6.10A) also suggest that these lines were drawn after the figure was broken free from the mould and roughly sanded, but probably before it was polished to its final sheen.

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[166] Although minute impurities occur across the entire surface of the object, only those which appear within incised lines feature a “scraped clean” appearance.

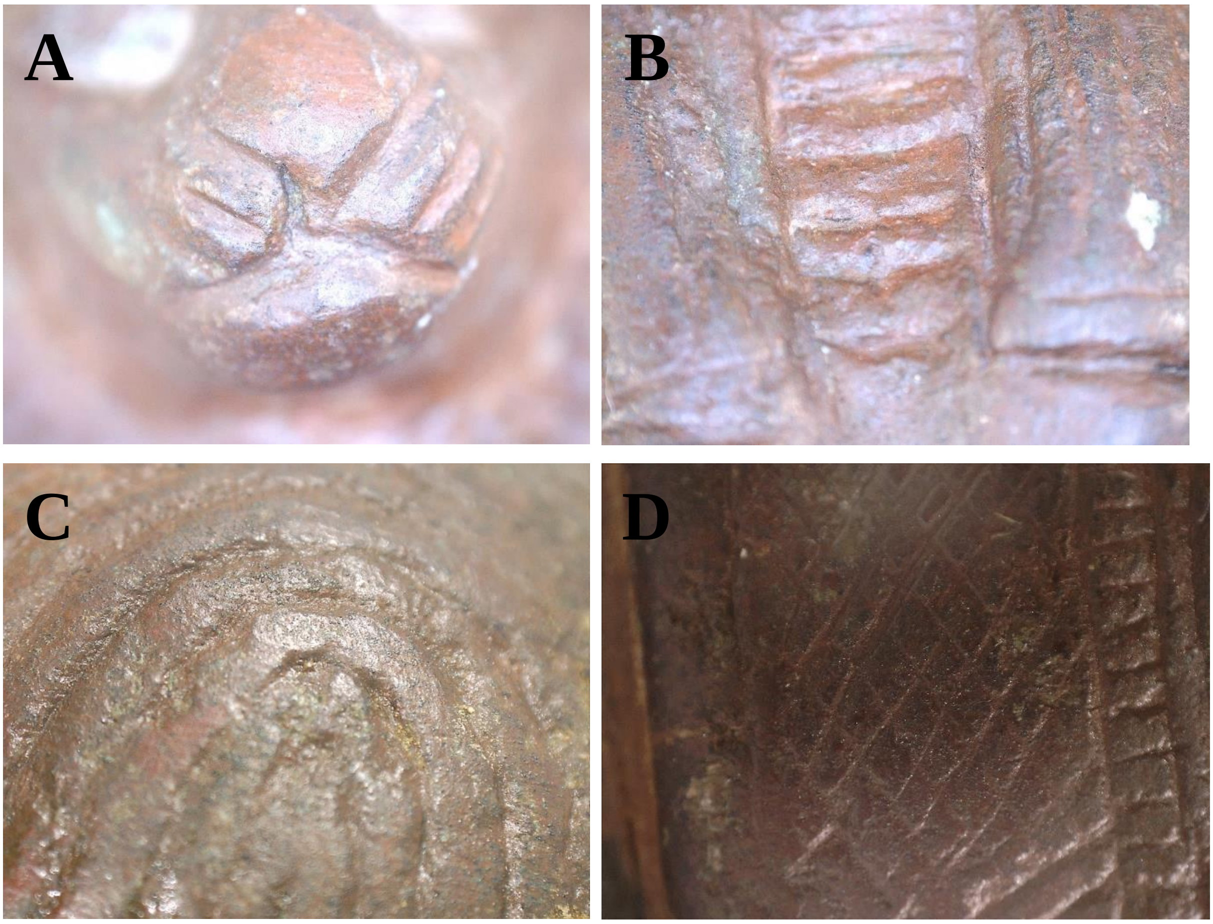

Figure 6.9: Wadjet-Bast's nose and mouth (A), collar and lower headdress (B), back of the head/headdress (C) and side of the throne (D)

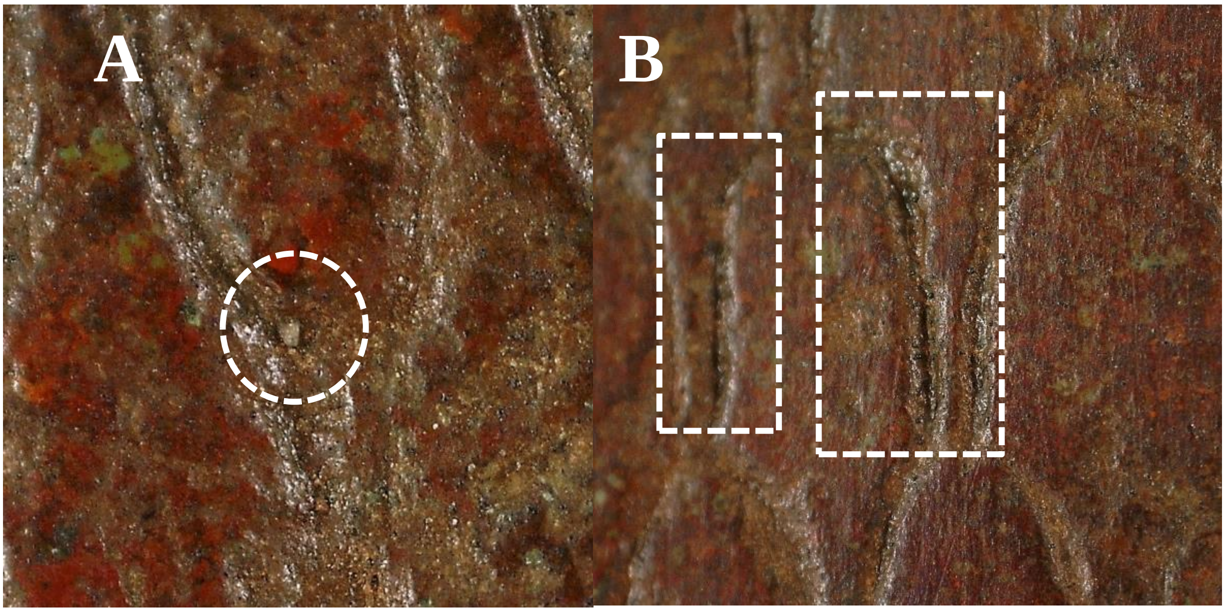

Figure 6.10: A granular impurity along the incision pathway (A) and the drawn appearance of incision lines (B).

6.2.7 The Broken Uraeus

As mentioned before, the Wadjet-Bast statuette has a broken-off *uraeus*. As these decorative fixtures were often affixed to statuettes post-cast, one would expect to find microscopic visual traces (i.e. seams and uneven surfaces on the metal) of where the item was joined to the body. Upon close investigation, no such visual phenomena could be observed. This lack of soldering/joining phenomena could indicate that Wadjet-Bast's *uraeus* was cast in unison with the headdress and not affixed at a later stage.

An important factor to consider when discussing joinery techniques is the probability of breakage. Because certain areas (i.e. the neck, arms and legs) already represent weak points along the construction, the ancient application of joinery directly increases the breakage probability (Ghoniem 2014, 42). In simple terms, joined surfaces are more prone to breakage than solid areas. To use Wadjet-Bast's *uraeus* as a practical example, if the *uraeus* was subjected to external forces that lead to its breakage, the joinery/soldering point (located flush to the head) would represent the most likely breakage point, not the midsection of the *uraeus*. This point provides additional support for the theory that the *uraeus* was cast in unison with the head. Finally, casting heads, arms and legs as separate entities makes practical sense, as they are still manageable in size. In contrast, an object as small as a *uraeus* would prove almost impossible to cast individually, and would also prove challenging when trying to join it to its superstructure.

The similarity that exists between the Wadjet statuette housed by the Brooklyn Museum in New York, and the one housed by the DNMCH (Fig. 6.11) is noteworthy. Although the objects differ in size (with the Brooklyn example being much larger), the *uraeus* on both statuettes broke off at nearly the exact same point.

Figure 6.11: Side-by-side view of Wadjet (A) and Wadjet-Bast (B).
Source: Brooklyn Museum in New York[167].

6.2.8 Porosity and Colouration

Porosity is not something that is usually identified through surface investigation. However, in the broken Ibis's case, we have the unique opportunity of viewing the object's internal morphology, however partial it may be (Fig. 6.12). As noted before, the ibis is broken where the lower legs join with the feet. The somewhat awkward angle at which the feet join the legs could explain why the item broke in this specific location. In addition, when considering the now obvious porous nature of the alloy, it would not have required an extreme amount of pressure for the object to break at this specific location.

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[167] https://www.brooklynmuseum.org/opencollection/objects/46593 [Accessed 15/08/2018].

Figure 6.12: A cross-sectional view of the broken ibis leg.

If the object was made from a high-lead bronze, with lead significantly reducing the probability of void formation, the likelihood of gas formation would have been lower. However, unforeseen interactions between the liquid alloy and the surface of the mould, unexpected cold conditions, higher atmospheric humidity, or even an undesirable copper-lead equilibrium (possibly accidental), could have caused outgassing and the subsequent formation of pores (Engineering Forum 2014). Although all these factors would be near impossible for us to determine beyond a doubt, especially without employing advanced techniques such as ND, rapid cooling could represent our most probable culprit.

When molten alloys cool at a rapid rate, gas bubbles often become trapped within the solidifying metal, which results in the formation of voids or pores. Since the Ibis is quite small, and since the legs themselves are much thinner when compared with the rest of the body, the item would not have maintained a high core temperature for long, adding to the rapid rate at which the object cooled. The same phenomena might have been at play during the Wadjet-Bast figurine’s casting, with metal porosity still remaining a possible culprit in the breakage experienced by the latter.

In addition to the breakage surface, the lower part of the leg also features an area where it appears as though an outer ‘crust’ of bronze has pulled away. Upon close inspection, one can actually observe a clear separation between this layer and its substrate (Fig. 6.13A). It is also clear that some form of surface polishing was performed on the object to reveal a rich silver coloured metal, interspaced with bright copper/gold-coloured blotches. These copper/gold-coloured anomalies are also visible when viewing the cross-sectional breakage point (Fig.

6.13B) and other areas of the body where surface corrosion has been scuffed away (Fig. 6.13C).

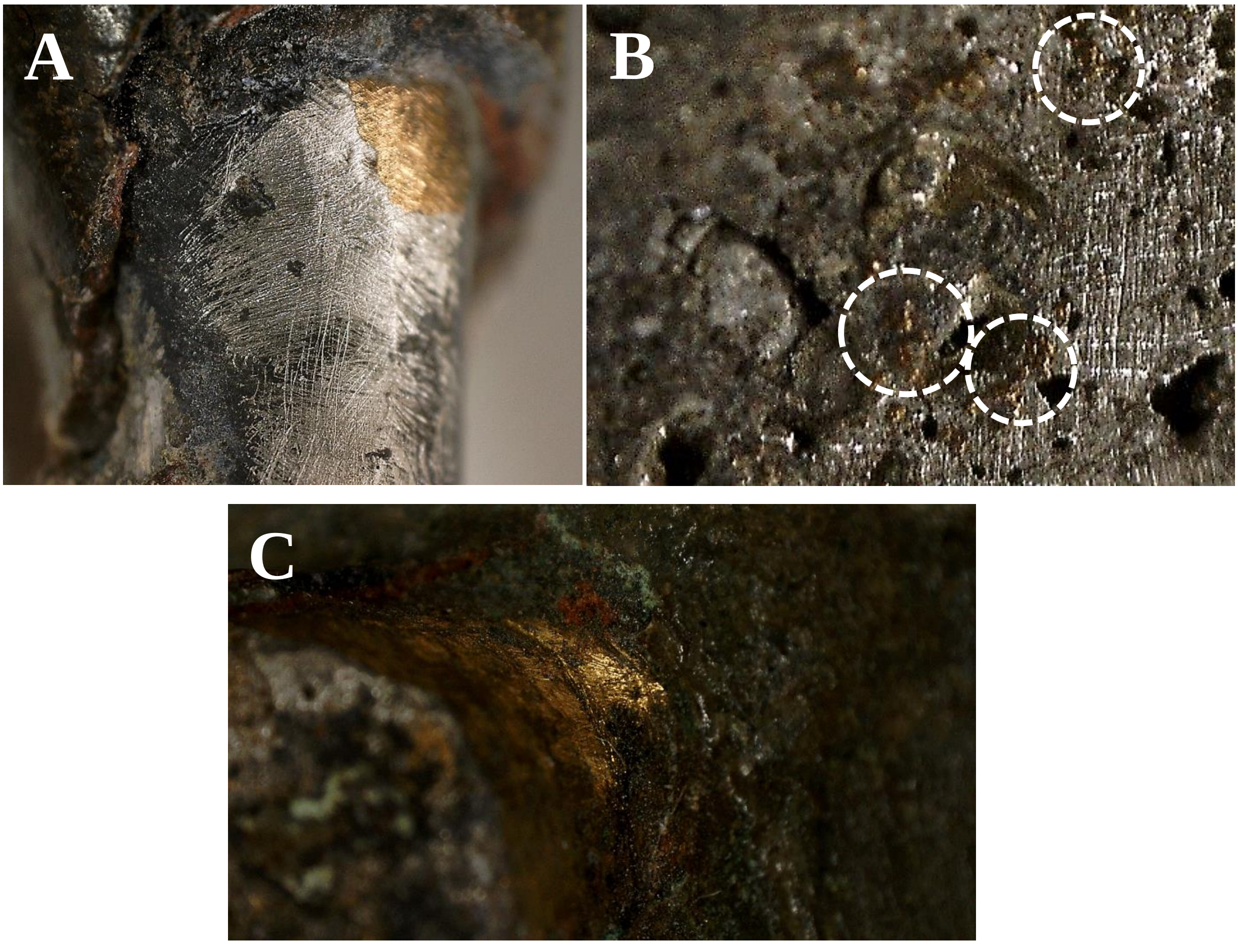

Figure 6.13: The broken ibis leg as viewed from the side (A) a cross-section (B) and scuff marks along the body (C)

Although the copper/gold coloured anomalies can be readily identified as copper – with the object being classified as bronze – it is difficult to determine what substance accounts for the distinctive bright silver colour. As noted before, the presence of arsenic bestowed a rich silver hue upon bronze alloys (Gravette 2011, 37). On the other hand, polished lead also has a bright silver appearance, so it is possible that the object could be a high-leaded bronze example. Unfortunately, since we cannot positively identify the presence of arsenic or lead in this instance, we cannot use the presence of either substance as chronological markers in determining the possible relative age of the object based upon period-specific arsenic percentages. Since this study does not include the chemical analyses needed to identify elemental composition, these questions could perhaps be addressed in future research.

6.3 SAMURAI HELMET (*KABUTO*)

6.3.1 Patina and Corrosion

Purposeful patination is a characteristic of many ancient metal artefacts. In Japan, the metals used in armour production were patinated, with the most popular iron patination being a russet (a mix of dark brown and reddish-orange) finish. This type of functional patination was achieved by controlled corrosion, which resulted in the formation of an even layer of oxidation, which was subsequently coated with raw lacquer (Dalewicz-Kitto et al. 2013, 42).

Although museum staff removed most of the surface corrosion during their restoration efforts, special care was taken not to come into invasive (or damaging) contact with the plates and bolts (see Teichert et al. 2012, 63). This cautionary act resulted in small amounts of corrosion remaining behind between the overlapping plates – a feature scarcely visible to the naked eye, but unmistakeably revealed by microscope. The space between overlapping plates is barely visible, yet still noteworthy, as it provides further evidence that the *kabuto* was not cast as a singular/solid unit (Fig. 6.14).

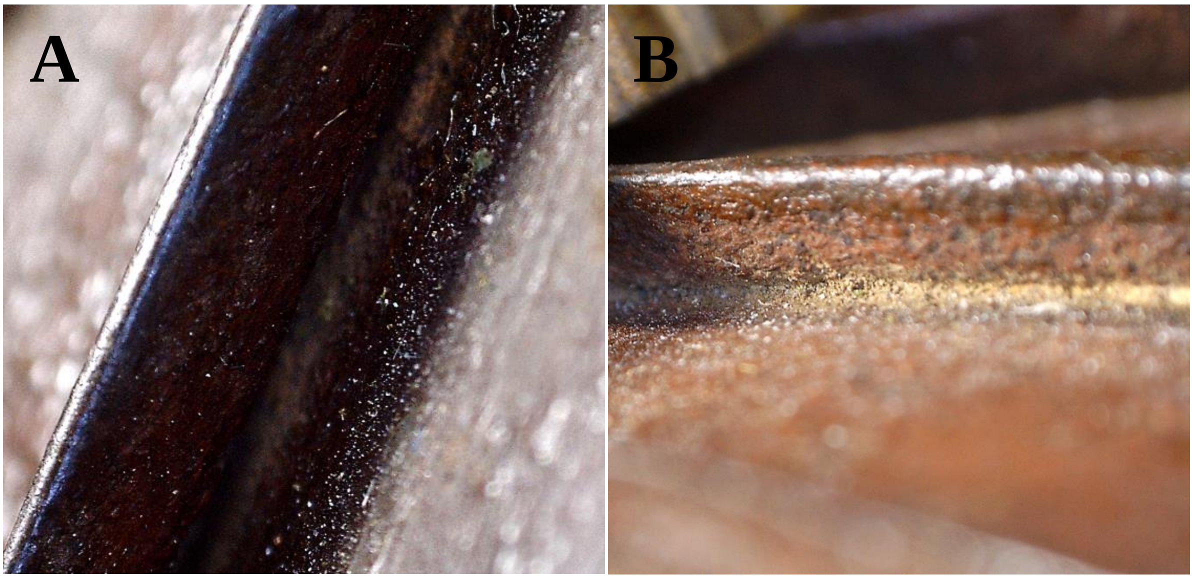

Figure 6.14: The space between plates becomes visible through interplay of light and shadows (A). Corrosion fills the gap between plates (B).

The "grommet" or *tehen kanomono* displays a turquoise-blue patination on the internal edge of the grommet structure itself (Fig. 6.15). It is possible that the patination once covered the entire *tehen kanomono*, seeing as the museum team of Teichert et al. (2012, 63) mention the mechanical removal of corrosion on copper-alloyed surfaces. If there was any doubt over the chemical composition of the *tehen kanomono*, the presence of a turquoise-blue patina provides relative certainty over the presence of copper.

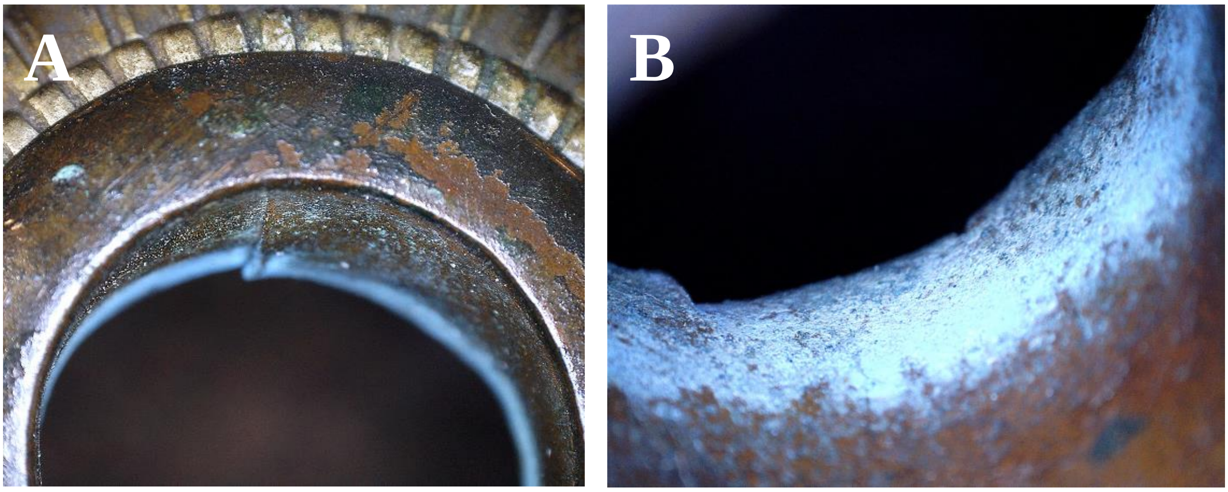

Figure 6.15: The internal edge of the grommet (A) and a close-up view of corrosion (B).

6.3.2 Plate Assembly

Before we can analyse individual components, it is important that we have a basic understanding of the individual components that make up the *kabuto*:

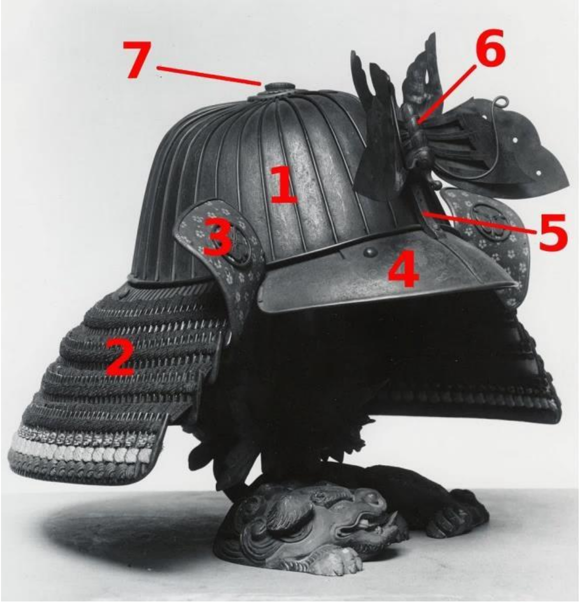

Figure 6.16: *Kabuto* components: *Hachi* (1), *shikoro* (2), *fukigaeshi* (3) *mae-zashi* (4), *hari-date* (5), *datemono* (6) and *hachimanza*. ***Source:*** Wikipedia: *Kabuto* Basic Parts[168].

The vertical curved plates that make of the *kabuto* are known as *tate hagi-no-ita*, and are interconnected via rivets (Salvemini 2013, 6). It appears as though the multiple plates that

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[168] https://en.wikipedia.org/wiki/Kabuto#/media/File:Kabuto_basic_parts.jpg [Accessed 09/10/2018].

make the dome shape of the *kabuto* were riveted and pinned together in a bi-lateral sequence. While Teichert et al. (2012, 55) state that the helmet is constructed from 16 plates, a closer inspection of the overlapping plates, in combination with the use of orthogonal tack/pins on the front plate, suggest that only 15 plates were employed (Fig. 6.17).

It appears as though the back plate (1) was positioned first within the sequence and therefore lies at the "bottom". In order for plates R2 and L2 to be positioned correctly, plate 1 was considerably wider than the subsequent plates. Plates R2 to R7 and L2 to L7 are assembled consecutively and bilaterally, with each plate riveted onto its predecessor. Although plate 8 can easily be mistaken as two separate plates, this is actually a single unit, much like plate 1. The final plate (9) lies "on top" and completes the sequence. Since the latter has no space for rivets, it is secured to the plate by means of orthogonal tacks/pins. The observation is in line with the description given by Salvemini (2013, 6) of a *Suji-bachi* (bell-shaped) *kabuto*'s plate assembly.

Figure 6.17 Sequential arrangement of consecutive helmet plates.

In theory, this design provides the user with a double layer of protective iron plating (Fig. 6.18). As Salvemini et al. (2013, 6) note, the void between overlapping plates would have absorbed the energy from blows to the head. It will be interesting to see whether the later Micro-Focus X-Ray Tomography will confirm this theory.

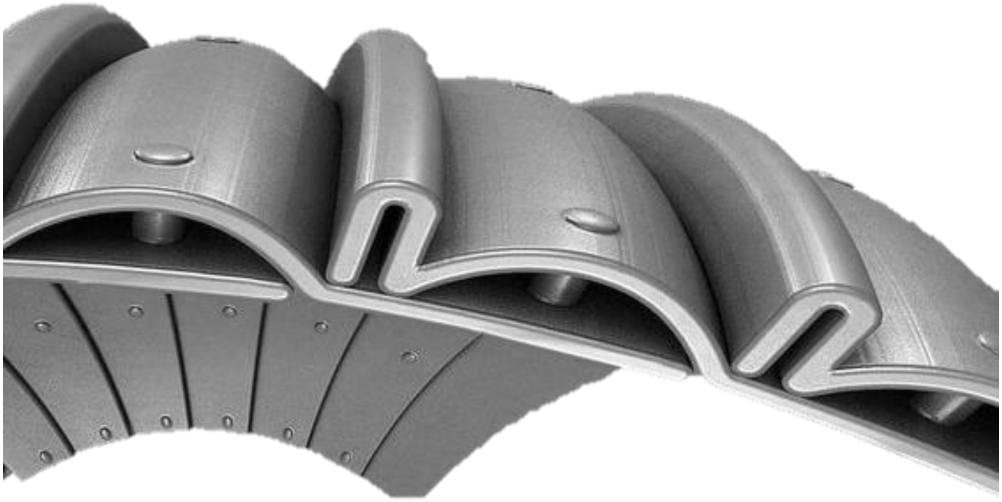

Figure 6.18: A sectional (side-view) slice illustration showing the design and overlapping structure of a sixty-two-ken *koseizan* shaped *suji bachi kabuto*, by Fujiwara Iehisa, early Edo Period.
Source: Pinterest[169].

The lower edges of the plates are kept on place with a single oval sheet of metal, while the 'grommet' holds the top edges together. It cannot be observed, through visual surface analysis alone, how the grommet functions to keep the plates together, but it is possible that metal tacks or pins could have been inserted from the interior of the helmet, penetrating each plate and anchoring into the bottom surface of the grommet's last (bottom most) circle.

Once the top sections had been secured by the grommet, it would have been simple enough to secure the lower edges by slipping the oval sheet over the assemblage from the top, applying equally distributed downward pressure until the sheet had reached the desired level. However, it appears as though this oval sheet was not smithed into a continuous oval band (like the outer rim of a wagon wheel), but rather pre-shaped into an oval, then bent around the bottom edge of the bowl and secured with tacks. This theory is supported by the fact that the two edges are flush against each other, yet no indication of reheating or hammering to join the edges can be observed (Fig. 6.19).

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[169] https://za.pinterest.com/pin/332984966171880387/ [Accessed 15/08/2018].

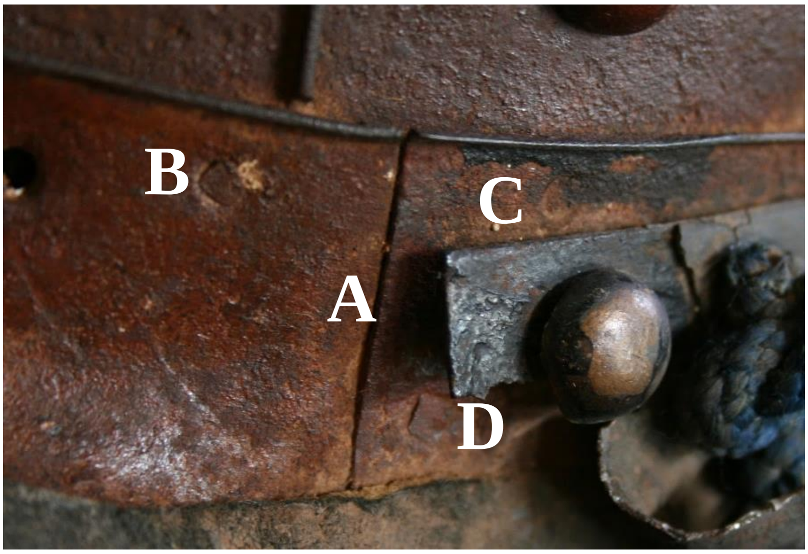

Figure 6.19: The *kabuto*’s oval-shaped helmet rim: The point where the two edges meet (B) is clearly visible, along with the tacks (B, C, D) used to keep the rim plate in place.

6.3.3 Helmet Lining

The helmet features an internal ‘hemp-like’ lining (Teichert et al. 2012, 66), also known as a *ukebari* (Fig. 6.20), which would have cushioned the samurai’s head against the hard metal surface of the *kabuto* (Breeze 2008, 2). Such linings were traditionally stitched in a spiral fashion, which caused the fabric to pucker and assume a domed shape (Dalewicz-Kitto et al. 2013, 38). Since the fabric itself is under a fair amount of tension, it provides a cushion of air between the two surfaces.

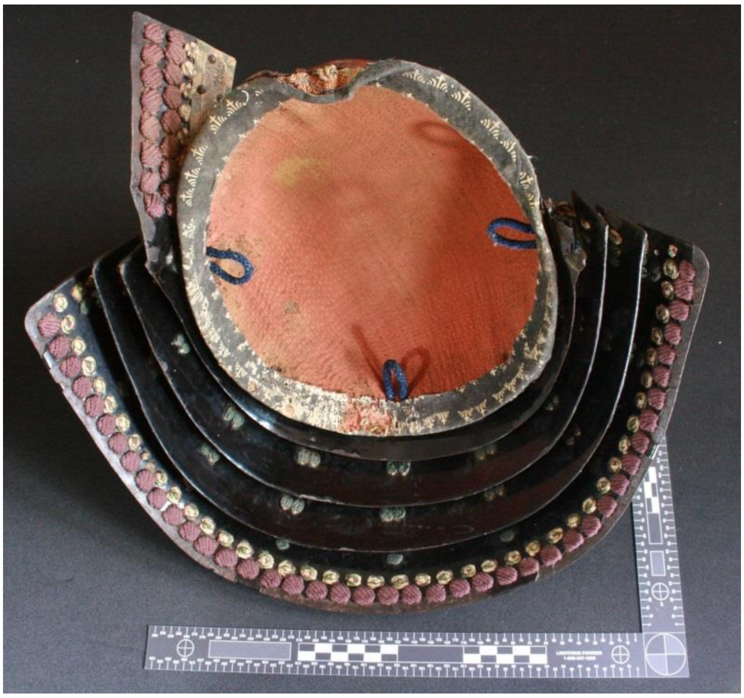

Figure 6.20: The internal lining or *ukebari* of the *kabuto*.

The lining is held in place by a decorated (dyed) leather[170] border, which was wrapped (in part) around the edge of the dome (Fig. 6.21). The wrapped edge may not appear well-rounded in terms of finishing off the piece, but one must keep in mind that the wrapped edge would have been covered by the brim/visor (*mabazashi*) in front, and the brim of the wing-like projections (*fukigaeshi*) along the sides.

Figure 6.21: Decorated (dyed) internal leather border of the *kabuto*.

The lining is terracotta (or orange brick) in colour and is interlaced with what appears to be green silk thread (Fig. 6.22). Upon closer inspection of the damaged front edge of the *kabuto*, blue thread can also be observed. It appears as though the blue thread was used to stitch the lining onto the leather border and roughly matches the blue colour of the tie-down loops. Interestingly, another (almost cotton-like) material is visible along the damaged edge, with neither its colour nor texture matching that of the primary lining.

Figure 6.22: Blue and green coloured silk threads interlaced within the *kabuto*'s internal lining.

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[170] The most common type of leather was doe (female deer), but horse and dog have also been documented (Kózan 1963, 122).

It is possible that the material might represent a secondary, interior lining, which may have helped to cushion against the hard metal interior of the dome. This is a plausible theory, as (Dalewicz-Kitto et al. 2013, 39) mention that hemp and/or cotton helmet linings were used, and that they were often covered by an outer layer of silk crepe. However, silk crepe only became popular during the 18th century (Breeze 2008, 2), so the possibility is slim that the remnant mentioned above could be indicative of a silk crepe lining. Instead, it is much more reasonable to suggest that the remnant could be that of a cotton inner lining.

6.3.4 Tie-Downs and Threading

As mentioned before, it is difficult to categorically state that the different elements (helmet, mask, chest plate, etc.) of a suit of armour represent its original constituents. This is due to the fact that items were handed down from generation to generation, and that suits of armour often consisted from a “mix-and-match” of individual, previously unrelated components. In short, in order to provide one object with an associated date, through its relation to another, one first has to establish whether the objects share similar stylistic features or physical manufacturing elements. In the case of the *kabuto*, *menpó* and *dou*, the proverbial “thread” connecting these objects are in actual fact, woven silk threads.

As mentioned above, closer inspection of the helmet lining revealed both green and blue (possibly silk) threads. By visual comparison, the colour of the green thread on the *kabuto* closely resembles the green thread found on the *menpó*’s neck guard. In addition, these tri-coloured lacings correspond in terms of their colour combination: green, cream and reddish-brown (Fig. 6.23A–B).

The exact hue of the blue thread that constitutes the *kabuto*’s helmet loops (Fig. 6.24A) is similar in colour to that of both the *menpó*’s tie-downs (Fig. 6.24B) and the cuirass’s lacings. The only visible difference is the shape of the tie downs and lacings. Where the helmet loops are rounded cord, the *menpó*’s tie-downs and cuirass’s lacings are flat. However, when comparing the woven structure of the *menpó*’s tie-downs with the cuirass’s lacings, it is quite evident that they share an identical woven pattern, which helps to confirm the relationship between these two objects.

Figure 6.23: Corresponding tri-colour lacings on the *kabuto* (A) and *menpó* (B) neck guards.

Figure 6.24: Corresponding colour and primary weave pattern of the *kabuto*'s helmet loops (A) and the *menpó*'s tie-downs (B).

Although the thread colours on the *menpó* and *cuirass* appear to be of slightly different hues of blue and green, especially when compared with the *kabuto* lining's thread, one must keep in mind that the lacings encountered on the *menpó* and cuirass have been exposed to the elements, while the threads within the helmet lining have been protected from elemental exposure.

6.3.5 Lacquer Coating

Armours, including helmets, were lacquered with a traditional Japanese lacquer known as *urushi*; a water-in-oil emulsion sourced from the native *Toxicodendron vernicifluum* tree. Once the sap (often pigmented) is applied, it solidifies into an irreversibly solid coating with a high-gloss, water resistant and exceptionally durable finish (Dalewicz-Kitto et al. 2013, 37). Unfortunately, if the temperature fluctuates during application, or if grease and/or dirt is present on the surface, being lacquered, it will flake off over time (Dalewicz-Kitto et al. 2013, 38).

Since the polymerisation of lacquer occurs at a relatively high humidity of 70–80%, a crucial aspect affecting the longevity of the coating is relative humidity, of which the ideal is 55-60%. However, the two most detrimental elements affecting lacquer preservation are visible and ultra-violet light, both of which cause photo-oxidation, leading to brittleness (Dalewicz-Kitto et al. 2013, 38).

In the case of the DNMCH *kabuto*, the presence of corrosion masked an underlying coat of lacquer. Once the corrosion was removed from the surface, through a combination of vacuuming, mechanical methods and localised chemical treatments, the original red lacquer-based paint became visible. After cleaning was completed, the lacquered surfaces of the armour, including the *kabuto*, were covered in a light paraloid[171] coating (Teichert et al. 2012, 63-65), which restored some of the object's original shine (Fig. 6.25).

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[171] Paraloid B72 is an acrylate polymer varnish and was also used in the conservation treatments noted by Dalewicz-Kitto et al. (2013, 45). It is used in the treatment of organic and inorganic materials and often serves a s a protective layer on metal artefacts (Švadlena & Stoulil 2017: 25). Both B-72 and B-48N have long been used for the treatment of historical silver (Reedy et al. 1999, 42).

Figure 6.25: The light paraloid coating restored some of the *kabuto*’s original shine.

6.4 SAMURAI HALF-MASK (*MENPÓ*)

6.4.1 Antique Repair Work

An interesting feature, completely overlooked by the museum’s initial condition report, is a small patch of repair work on the top edge of the right cheek. It appears as though a small tear occurred during manufacturing, possibly while the mask was being hammered into shape. The solution was to place a small rectangular metal plaque over the tear, which is kept in place by two small tacks. It is possible that the object was also reheated and the area carefully hammered in order to create a proper bond between the two surfaces. Schorsch (1988, 47) notes that ancient repair work was mainly the result of casting imperfections and use-wear. It is clear that the repair work done on the *menpó* took place during antiquity, with the following characteristics serving as testimony:

Firstly, there is total homogeneity between the surface colour and texture of the object proper and the plaque. Secondly, the pins securing the plaque are of the exact same dimensions as those encountered elsewhere on the *menpó* as well as the *kabuto*. Thirdly, the presence of red lacquer that partially covers a small segment of the plaque stands as further testimony to its antiquity, as modern restoration would not have allowed for repairs beneath the surface of the lacquer (Fig. 6.26).

Figure 6.26: Antique repair work to the right cheek of the *menpó*.

The latter point is reminiscent of the repair work encountered in the study by Achorsch and Frantz (1998, 23), where surface finishing made repair work completely indiscernible through surface investigations. Had the lacquer not flaked in this instance, surface investigations would not have been able to detect these phenomenon.

Interestingly, the repair work also resembles an example encountered by Dupras (2012) on a piece of medieval armour (Fig. 6.27). The patch of metal also features two pins that hold it in place, but the main difference is that the medieval example is much rougher, and was probably made from a piece of recycled armour or metal off-cuts. As noted by Dupras (2012, 16–17), these phenomena are classified as “original” repairs and are clearly separate from museum-based restoration.

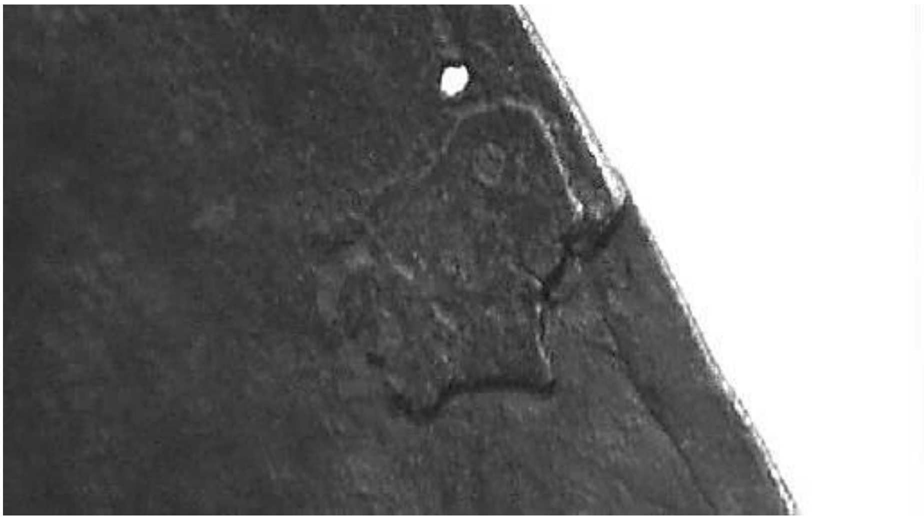

Figure 6.27: Antique repair work is clearly visible on this piece of medieval armour.
Source: Dupras (2012, 383).

However, it is important that period repairs not be confused with modern restoration. With the latter being stated, more advanced means of investigation are essential if we are to confirm that repair work encountered on the *menpó* is in fact antique. The uniformity of metal surface colour, and the fact that repairs appear underneath the lacquer, is not enough evidence to confirm its contemporaneity with the superstructure (the mask itself). Since these objects were often handed down from generation to generation, the repairs could have taken place decades after the object was manufactured. Granted, these repairs will still count as "historical" if they were made while the object was in use, or before it became part of a private/museum collection.

6.4.2 Lacquer Flaking

While some *menpó* still feature their original high-gloss lacquer coatings, also known as *urushi*, on both their internal and external surfaces, the DNMCH example does not feature any external lacquer, while the internal red coating is in a poor, extensively flaked condition. A colour comparison between the antique *menpó* from the Asian Art Museum of San Francisco (AAMFS) (Fig. 6.28A) and the DNMCH (Fig. 6.28B), is quite striking.

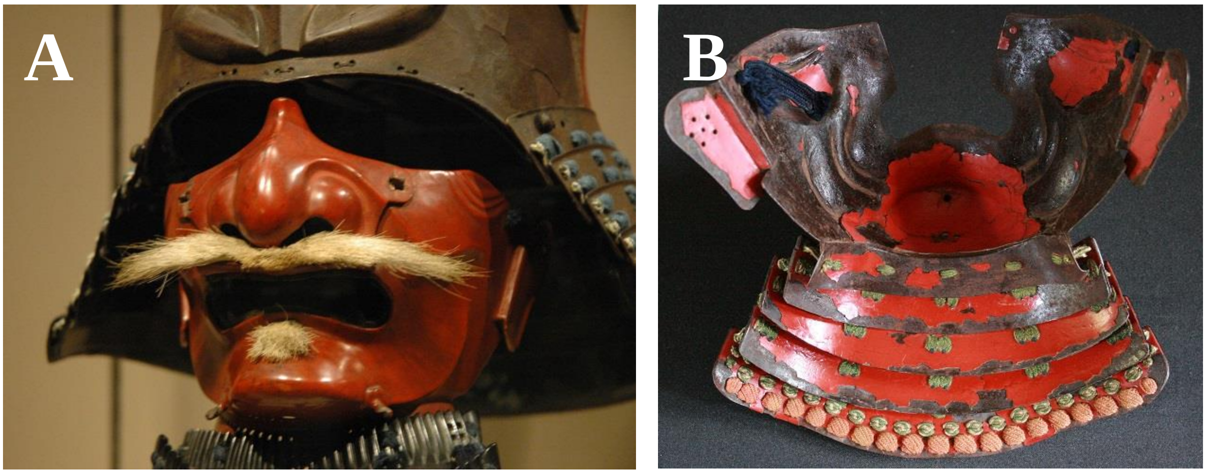

Figure 6.28: Colour comparison between the AAMSF (A) and DNMCH (B) *menpó*.
Source: Asian Art Museum of San Francisco.

Although no obvious remnants of lacquer are visible on the external surface upon first glance, closer inspections of the chin area of the *menpó* revealed the presence of trace amounts of red lacquer (Fig. 6.29), suggesting that the external surface was indeed once covered in the same red substance as the internal surface. After all, it would have made no sense to decorate the internal, unseen element of such a decorative piece, but not the side on display. Apart from flaking on the actual *menpó*, the neck guard or *shikoro* is also flaked, exposing a metal superstructure "pockmarked" with small patches of corrosion.

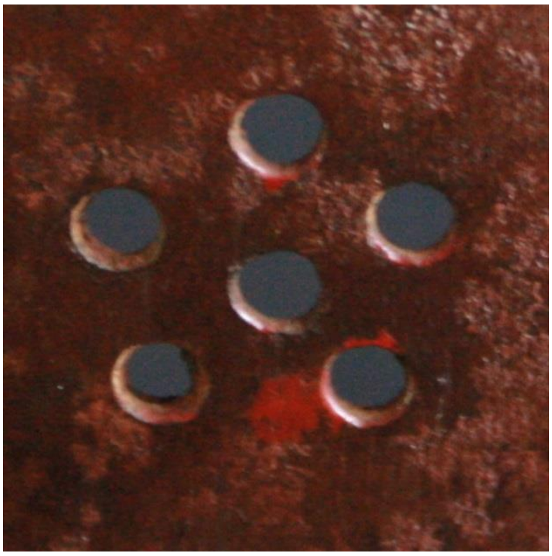

Figure 6.29: Trace amounts of red lacquer are visible on the external surface of the *menpó*.

While contemporary museum conditions, and the conditions of storage before the object entered the DNMCH's collection, would have played a tremendous role in preservation, variables in production during antiquity may also be cited as possible determining factors.

Lacquer flaking can be influenced by a number of factors, most of which can be traced back to the time of manufacture and/or original use. Since lacquer is hydrophilic[172], either mechanical surface treatments or surface heating is required in order for the lacquer to bond to the metal surface. If the metal was not properly heated, or if the surface boasted trace amounts of grease or oil, the lacquer would still bond but would start to flake off over time (Dalewicz-Kitto et al. 2013, 38).

What is most fascinating, however, is the visible colour difference between the outer and inner layers of the *urushi* itself (Fig. 6.30). The colour difference fits well within Dalewicz-Kitto et al.'s (2013, 38) description of a dual application of lacquer – with the first layer being an unrefined base coat, and the second being a high-gloss surface layer.

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[172] A hydrophile is a molecule or other molecular entity that is attracted to water molecules and tends to be dissolved by water. In contrast, hydrophobes are not attracted to water and may seem to be repelled by it. https://en.wikipedia.org/wiki/Hydrophile [Accessed 01/11/2018].

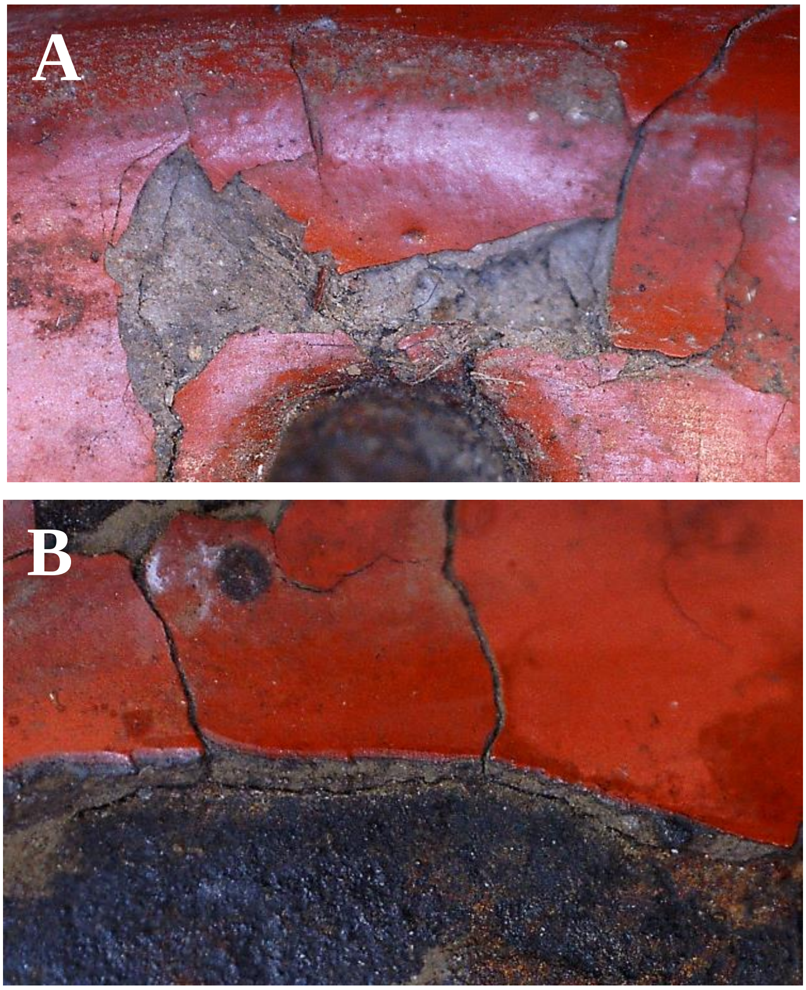

Figure 6.30: Samurai *menpó*: Internal surface colour contrasts.

6.4.3 Polishing Striations

As noted in the section on Egyptian bronzes, polishing striations are formed when a relatively warm metal surface is buffed with a polishing stone (usually a small block of fine-grained sandstone). The action serves to smooth out the surface while also covering any flaws and imperfections that may have occurred during the casting and/or hammering process. However, the striations observed on the half-mask (Fig. 6.31) would also have served an additional purpose; providing a rough surface upon which decorative lacquer could affix mechanically. As Dalewicz-Kitto et al. (2013, 38) explains

> The lacquering of metal plates, such as those used in the construction of Japanese armour, presents difficulties because, being hydrophilic, the lacquer will not easily adhere to an inorganic/non-porous surface. This was overcome by roughening the surface of the plate with a file or coarse stone, then heating it to a high enough temperature that allowed an initial application of raw *urushi* to dry immediately and be, in effect, burnt on.

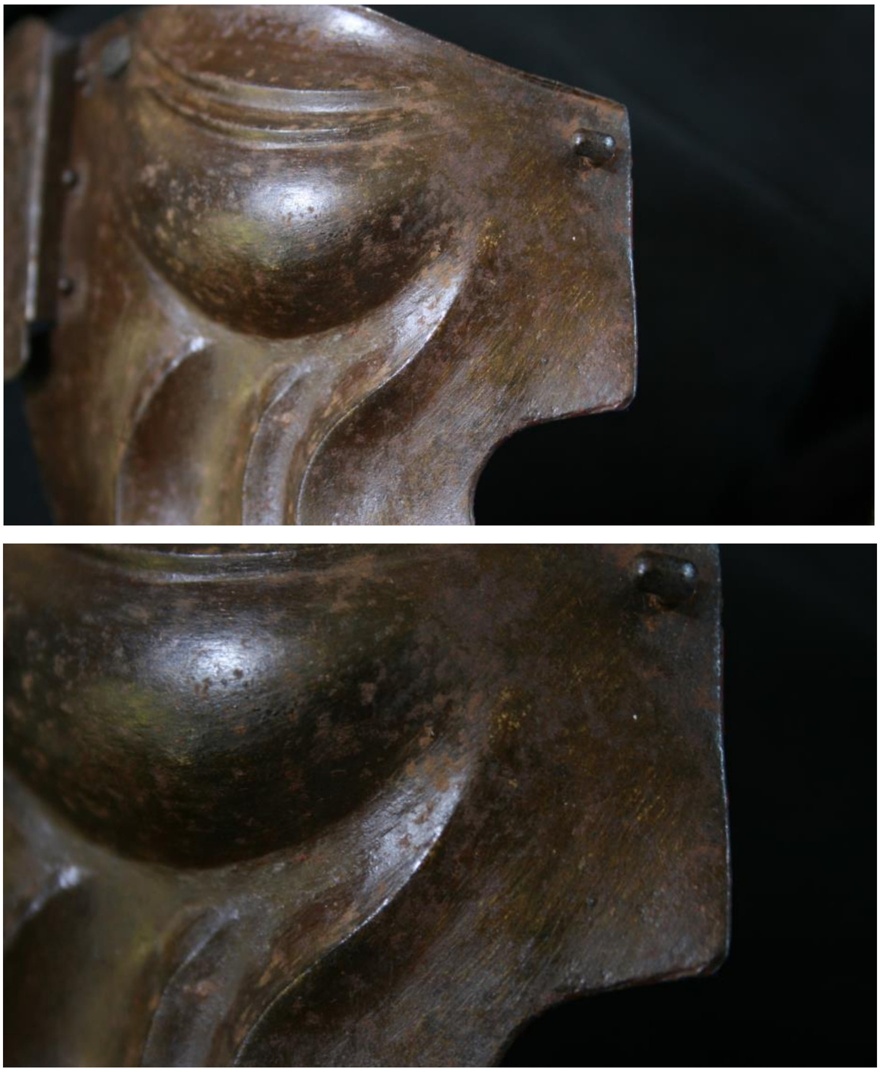

Figure 6.31: Surface polishing striations on the *menpó.*

Although some may argue that these striations are actually caused by brush strokes during the application of museum treatments, closer investigation reveals a ‘ripple effect’ on the surface of the metal itself (clearly visible in Fig. 6.32A-C). These phenomena confirm that striations were formed when the metal was still warm and relatively malleable. Also, conservation treatments (those with a low viscosity) eventually lose their brush strokes as the liquid substance settles after a few moments – similar to how paint dries on the surface of a wall without retaining any brush strokes. An example of such a surface can be seen in Fig. 6.33.

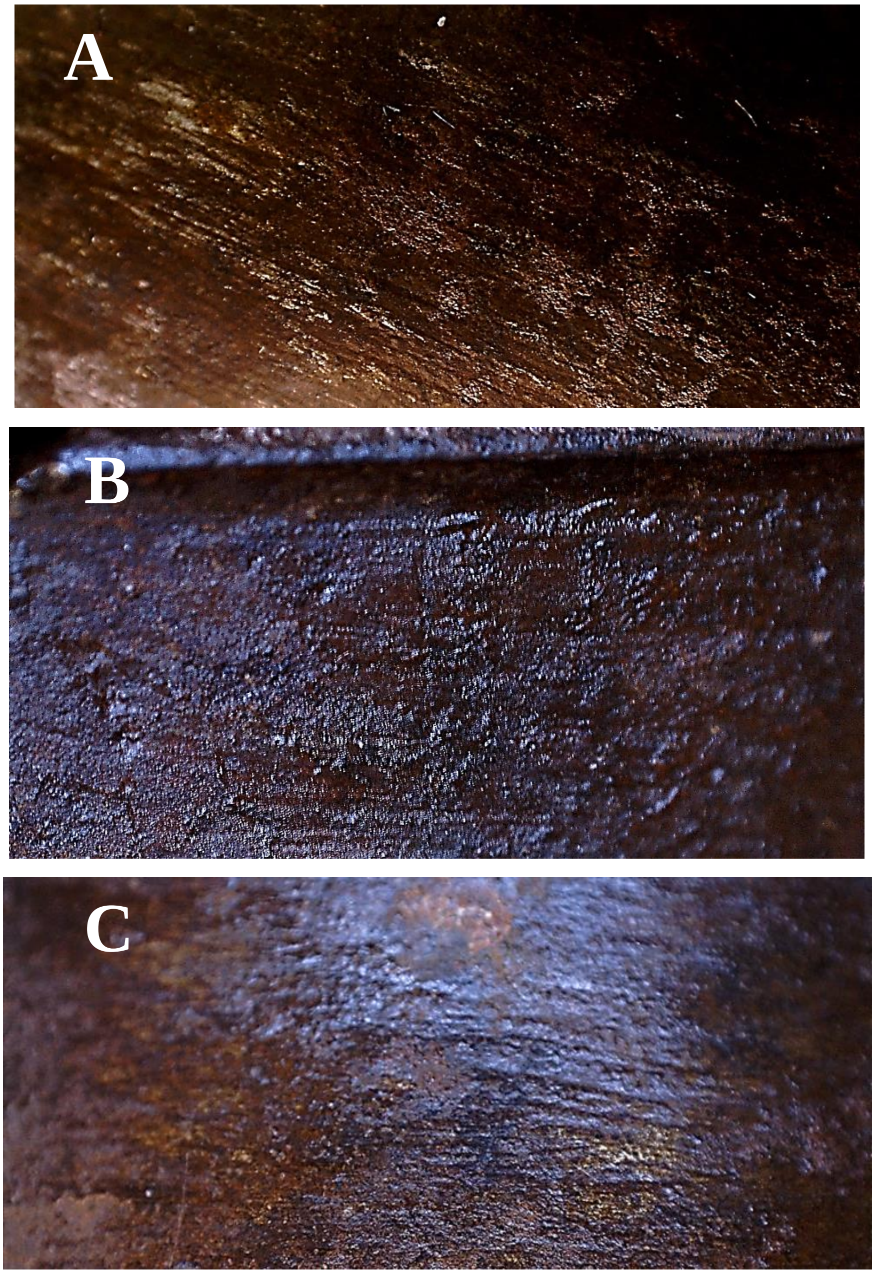

Figure 6.32: Polishing striations on the surface of the *menpó*.

Figure 6.33: Conservation treatment on the surface of the *menpó*.
No visible brush strokes or striations.

6.5 TOWER OF LONDON GAUNTLET

6.5.1 Polish Marks

As we have already noted in the sections above, surface striations are formed when warm, malleable surfaces are polished using a fine-grained abrasive material. What is interesting to note is that the striations occur across the entire external surface and move across the width of the gauntlet rather than its length (from elbow to wrist) (Fig. 6.34). This serves as possible indication that the gauntlet was placed over some type of dummy or wooden structure, where after it was polished from side to side, and not up and down (proximal to distal). This side-to-side polishing would have decreased the risk of scuffing the rounded edges of the plate metal.

Figure 6.34: Polishing striations across the width of the Tower of London gauntlet.

Polishing was performed using a variety of metalworking files, the shape of which depended on the nature of the metal surface and the angle at which filing needed to take place. For example, armourers had access to flat, square, triangular and rounded files. Typically, rougher files would have been used first, with each successive polishing session making use of files with progressively smaller teeth. Fine-grained stones known as whetstones were then used to give the object its final, smooth polish (Dupras 2012, 97). With whetstone polishing taking place as the final step, it is very unlikely that tool marks from the metal filing stage would remain visible. The polishing striations encountered on the gauntlet are therefore most likely the result of whetstone polishing.

Based upon the relative overall roughness of the ToL armour, it is difficult to say (without further comparative or experimental analysis) whether the armour was treated with grit-based abrasives such as emery. Whether burnishing was actually performed is another question which cannot be answered with certainty, as comparative micro-surface imagery is not available for comparative purposes.

However, Dupras (2012, 97) notes that suits of armour intended for use by common soldiers would only have the most basic finishing techniques applied to them. Cursory planishing[173] and smoothing of sharp edges would have been complimented with simple filing, leaving raising marks behind. This description falls in line with the appearance of the ToL gauntlet's surface.

When considering this final phase of production, it is possible that the object was reheated before and during polishing. It becomes quite clear that some form of reheating occurred, as the metal pins used to secure the two edges together appear melted and also blend into the surrounding metal.

Figure 6.35: Metal tacks/pins on the Tower of London gauntlet.

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[173] "Planishing is a metalworking technique that involves finishing the surface by finely shaping and smoothing sheet metal." (Escudier and Atkins 2019, 969).

Polishing not only adds aesthetic value to a piece, but also serves practical functions. Firstly, a smooth metal surface is much easier to clean than a rough one. Secondly, smooth metal surfaces are much less prone to corrosion, as rough surfaces allow corrosion to take hold (Dupras 2012, 97).

6.5.2 Superficial Use-Wear

As most armours (excluding ceremonial pieces) were used as functional items of personal protection, one would expect them to display certain use-wear patterns indicative of combat or military training. Those worn in active combat would feature characteristic and readily identifiable impact marks (such as dents and scuff marks) and/or slashes (such as those made by edged weapons). However, one must keep in mind that as these objects were valuable commodities, they would often undergo extensive repair work following combat, with irreparably damaged objects being scrapped or melted down to form new items or components. Thus stated, one cannot assume that an object that is apparently free from observable damage, never witnessed combat. On the other side of the spectrum, use-wear does not necessarily indicate participation in combat, as armour was also used in non-military activities, such as hunting, parades and tournaments (Breiding 2002b). To make the situation even more complex, objects that have served as museum pieces (some for decades, others for centuries) have often been subjected to rough handling or improper storage conditions which, in their own right, result in different type of use-wear. To surmise this concept object provenance, Breiding (2002a) states:

> Although today appreciated as works of art or as examples of historical technology, it must be noted that all armor, whether used in warfare, tournaments, or parades, once had a “working lifetime.” Often these objects have been subjected, literally, to extreme “wear and tear.” Therefore, no matter how well armor may be displayed in museums today, its original use and function can be difficult to convey.

Therefore, since surface visual inspections may not always deliver clear-cut answers regarding object use, it would be interesting to observe the microstructure of these objects through techniques such as ND, as more substantial physical stresses would have influenced the directional orientation of crystals[174]. Unfortunately, this type of research falls beyond the scope of this thesis.

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[174] Neutron diffraction is used to obtain quantitative and qualitative data on the crystalline phase composition of alloys, microstructure, grain size and orientation, micro- and macro strains and crystallographic texture of

When examining the ToL gauntlet, only superficial marks and abrasions are observed. Some of these markings may even originate from the manufacturing process itself, as they resemble lines drawn into wet clay, where the malleable material “squeezes” sideward as the object making the imprint passed through the metal (Fig. 6.36). These superficial marks also help to confirm that the side-to-side striations that appear are in fact polishing marks, as scuff marks appear over striations. If these striations were the result of brush strokes during the application of conservation liquids, they would have passed over the scuff marks.

Figure 6.36: Impressions on the metal surface of the Tower of London gauntlet. The impressions appear as if an object cut across the surface while the metal was still warm and malleable.

6.5.3 Joinery and Edge Refinement

The gauntlet was made from a single piece of flattened sheet metal that was bent into shape through gentle, systematic hammering over flat and rounded surfaces (such as those encountered on a blacksmith’s anvil). Based upon the appearance of these overlapping edges (Fig. 6.37), it seems as though the edges were hemmed into shape. After joining the edges, decorative lines were then drawn around the proximal edge of the gauntlet. Based on the gap between the decorative lines where the two edges of the plate meet (a), the decorations were made after the plate edges were joined. Lines such as these were often incised with a chisel or sharp-edged hammer (Dupras 2012, 97). The double line is distinct, but closely resembles the

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metal objects (Bastie et al. 2006, 1; Festa et al. 2011, 2; Kockelmann et al. 2006, 175; Postma et al. 2010: 647). Most importantly, it provides information on the ‘texture (solute distribution and grain orientation) and the residual strains and stresses within metal artefacts’ (Frame et al. 2013, 69), as well as clues relating to manufacturing - as techniques such as casting and hammering influence grain orientation (Creagh 2012, 829; Kockelmann et al. 2006; Kockelmann & Kirfel 2004).

single-lined design encountered on a 17th century Pikeman's armour from Antwerp, which was discussed in detail by Ackermann et al. (2010).

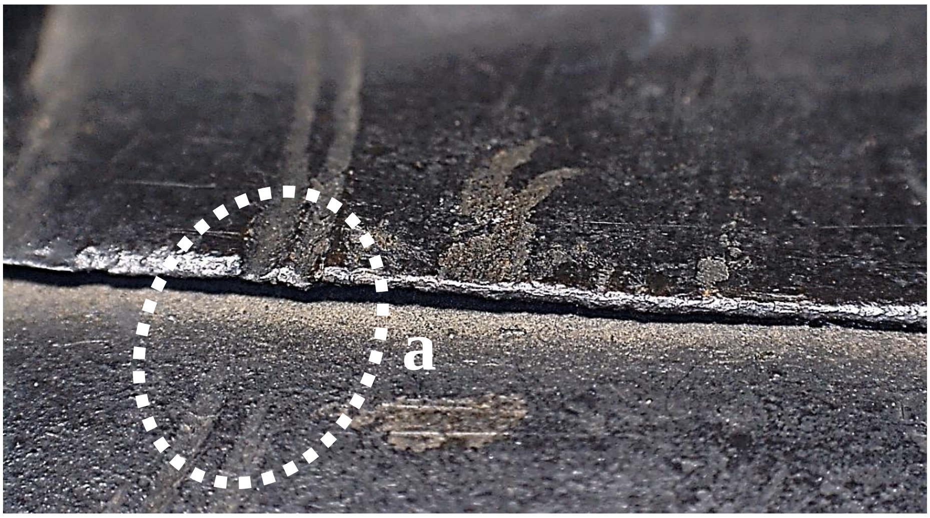

Figure 6.37: A close-up view of the overlapping edge and decorative lines. These markings appear close to the upper/elbow edge of the gauntlet.

When hemming the edges of sheet metal (Fig. 6.38), one can either create a closed (a) or open (**b**) hem. The open hem allows two opposite edges to be joined through interlocking (**c**).

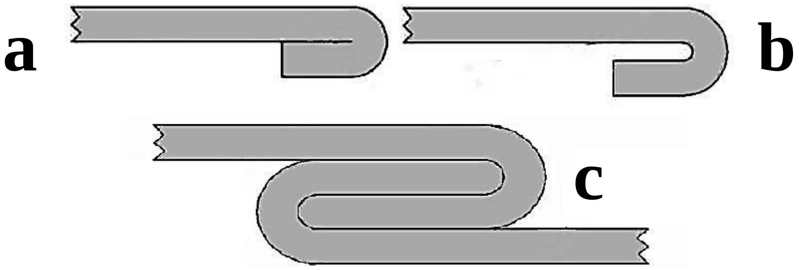

Figure 6.38: Closed (a) and open (b) hems, with interlocking open hems (c)
Source: Adapted from http://thelibraryofmanufacturing.com/sheetmetal_bending.html.

Upon closer inspection (Fig. 6.39), it appears as though the overlapping hemmed edges (a) were interlocked before being attached to the opposite edge by means of iron tacks/pins (b, c). After joining the two sides, the edges (on both proximal and distal edges) were bent over to create a rounded surface (d). This was an essential step in ensuring both a safe and comfortable fit, as it hid the rough, often sharp edges of the metal plate. It is clear that this step was completed after joining, as the bent edge of the wrist-edge actually overlaps the main intersection (e) (also refer to Fig. 6.40 for a close-up view).

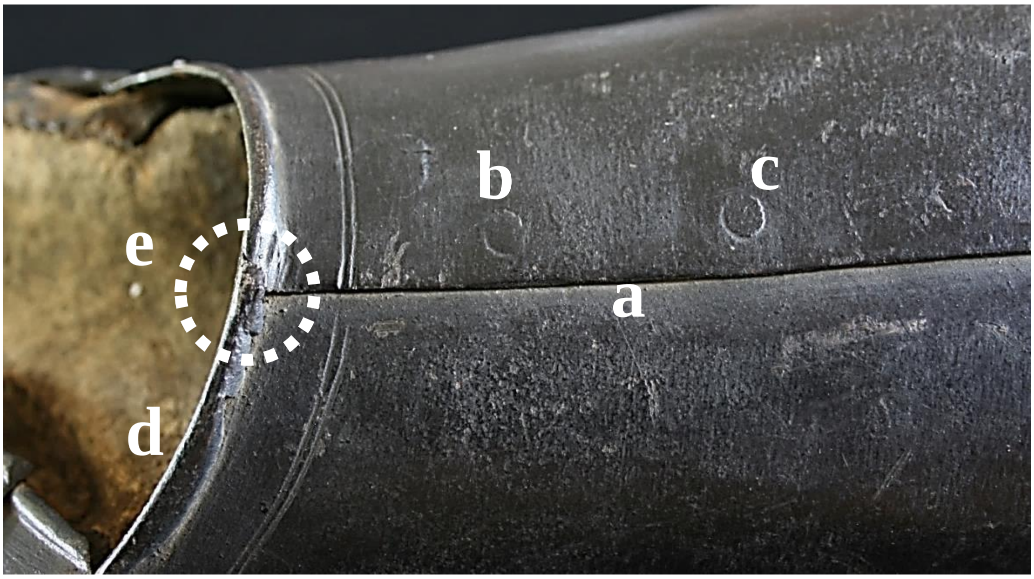

Figure 6.39: The joined edges of the Tower of London gauntlet: The folded edge (a) is held in place by iron tacks (b and c). The edges (d) are bent over and rounded, and the joined area is visible (e).

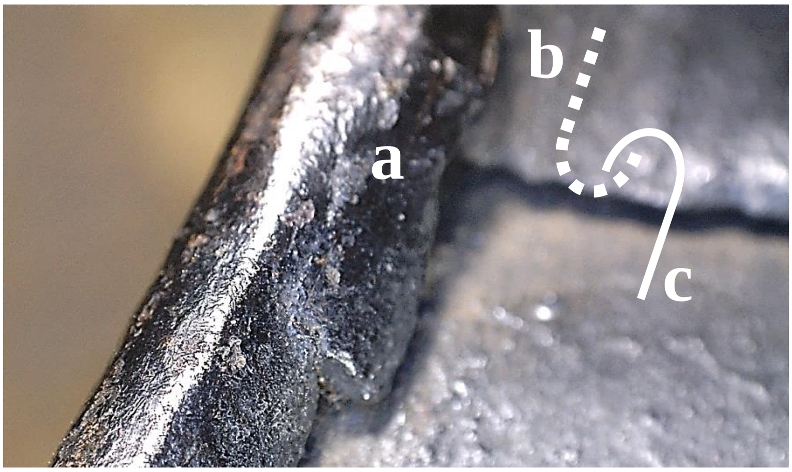

Figure 6.40: The rolled proximal edge (a) of the gauntlet overlaps the interlocked top (b) and bottom (c) hemmed edges. The lines provide a rough indication of the interlocking action between edges (b) and (c).

When considering the processes of folding and bending, there are three basic methods of shaping the edges of sheet metal. The first technique focuses on the shaping of straight planes (Fig. 6.41) and is by far the simplest to complete. The length of the edge before and after the roll is equal to both the outermost and innermost area of the roll. In simple terms, no stretching or compressing is needed to create a near-perfect roll (Fig 1-1)[175]. Imperfect bending can occur if one area is bent over too much, causing unwanted stretching of the bent area (Fig 1-2). Fixing the problem by compressing the metal and bending it back into position

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[175] Kindly note that the numbering in this instance refers to the imbedded image references used by the original author.

often causes wobbles along the plane (Fig 1-3). Thus said, when bending edges, it is essential that multiple hammer strikes are applied and that the edge is bent over incrementally. The second technique focuses on rolling the edge along an outward curved plane (Fig. 6.41B). Since the circumferences of the metal along the centre and outer edges of the flange are greater than the inner plane (Fig 2-1) some amount of stretching will have to occur. The outer edge of the flange is then bent back towards the body of the plate (Fig 2-2). The third technique focuses on rolling the edge along an inward curved plane (Fig. 6.41C). This method relies on compression rather than stretching, since the outer circumference of the flange is smaller than centre of the flange and the inner edge plane (Fig 3-1)[176].

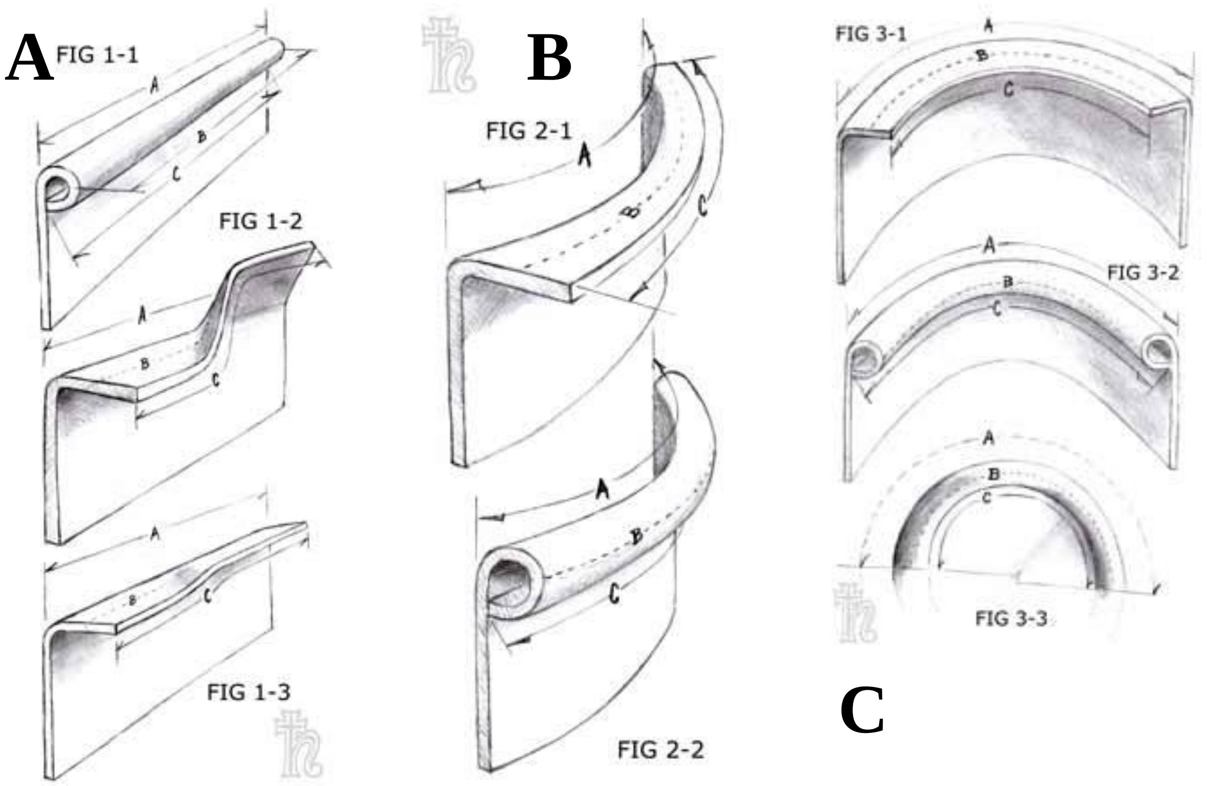

Figure 6.41: Rolling edges along a straight plane (A), outward curved plane (B) and inward curved plane (C).
Source: Age of Armour[177].

On the ToL gauntlet, the bend-work follows the second technique explained above (rolling the edge along an outward curved plane). Upon close examination, the bend work is of an exceptionally even and well-rounded nature. The process was most likely completed using small pliers or tongs, coupled with gentle hammering, to stretch and bend the metal

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[176] http://www.ageofarmour.com/education/armour_rolled_edges10.html Accessed on 21/07/2018. Also refer to the following tutorial video https://www.youtube.com/watch?v=jvxtYPc_WBg Accessed on 22/07/2018

[177] http://www.ageofarmour.com/education/armour_rolled_edges10.html [Accessed 21/08/2018].

incrementally. The only obvious trace of this endeavour comes in the form of three superficial marks on one of the bent edges (Fig. 6.42). The marks could be linked to this process as they follow the same line of direction as the actual bend in the metal.

Figure 6.42: Possible tool marks on the bent edge of the Tower of London gauntlet.

These tool marks share a striking resemblance to those encountered in the work of Dupras (2012) on the tail and visor of a medieval helmet. As noted in Fig. 6.43, the direction of the tool marks follows the direction of the rolled edge.

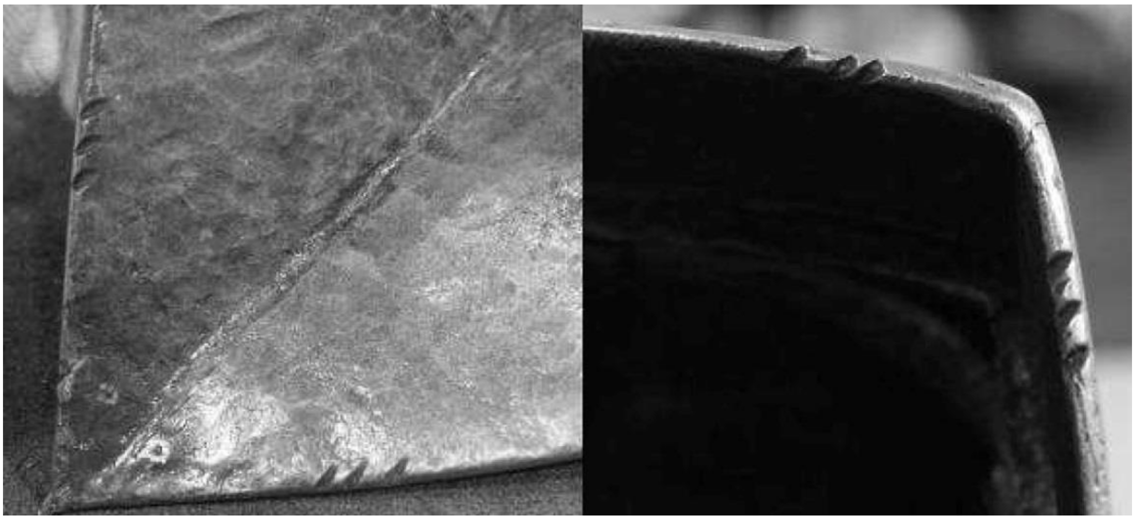

Figure 6.43: Assembly marks encountered on the tail and visor of a medieval helmet.
Source: Dupras (2012, 385).

A small crack was observed along the rounded distal edge of the gauntlet. It is possible that this crack was a manufacturing defect, possibly the result of the artisan’s hasty approach to bending and shaping the curved edge. Since it was small enough to not pose any threats to the overall structural integrity of the armour, it was probably left as is. Although no surface repair work is visible, it is possible that repairs could have been done along the internal surface, as it would have proved less intrusive to the outward aesthetics of the item.

Figure 6.44: A crack along the distal edge of the Tower of London gauntlet.

A similar crack can be observed along the edge of the *zischägge* from the Arsenal of King James II.

Figure 6.45: A crack is clearly visible along the edge of the *zischägge* from the Arsenal of King James II. ***Source:*** Royal Armouries, London[178].

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[178] Available at: https://collections.royalarmouries.org/object/rac-object-15927.html [Accessed on 26/07/2018].

6.5.4 Leather and Fabric Components

The gauntlet features an internal leather and fabric glove that also acts as a lining or barrier between the harsh metal surface of the armour and the wearer. Interestingly, the glove is attached to the metal substrate in such a way that the material is under a fair amount of tension. This would have provided a cushioning effect, negating some of the everyday knocks and bumps caused by moving about in a full suite of armour. The fingers are topped with a dark, strong leather, and the colour contrast between the two is quite striking (Fig. 6.46A). The glove is attached along the proximal (elbow) edge by means of plain rivets[179] (Fig. 6.46B), but is not connected along the distal (wrist) edge. This means that the glove was probably inverted (pulled inside-out), attached to the metal and then pulled through the length of the gauntlet.

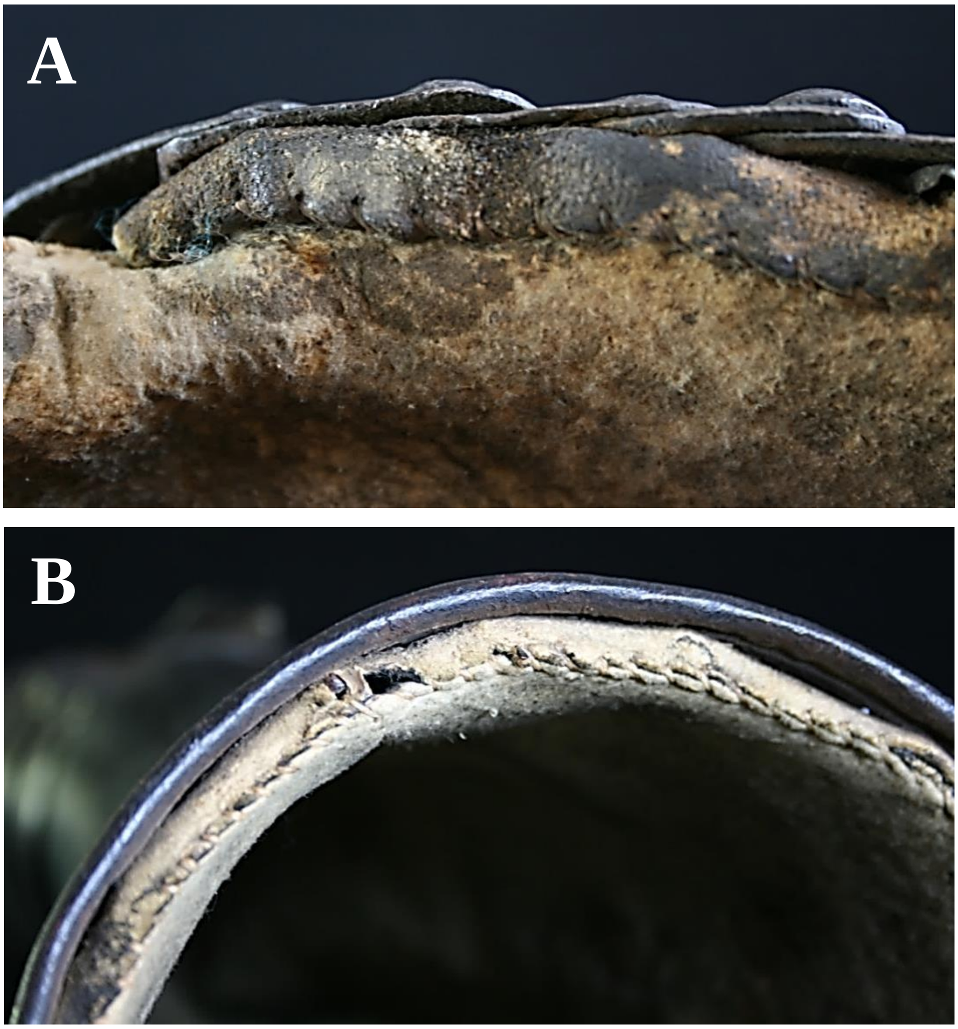

Figure 6.46: Leather stitching on each individual finger (A), as well on the elbow-edge (B) of the gauntlet.

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[179] Plain rivets are used to hold together pieces that don’t require any articulation (movement), most commonly where leathers are attached to plates (Dupras 2012, 105).

The internal leather and fabric glove of this left-handed gauntlet is in an exceptionally well-preserved condition, especially in comparison to its right-handed counterpart. By comparison, the right-hand gauntlet's internal lining is ripped in more than one location, and the glove itself is completely detached from the rest of the gauntlet. This level of decay is a good indication of the object's antiquity.

Only one semi-intact finger from the right-handed glove is present and is kept loosely within the body of the gauntlet. Fortunately for us, the semi-intact nature of this finger provides us with insight into the internal structure of the glove (Fig.6.47) that cannot be observed in the case of its left-handed counterpart, as the latter's soft leather glove completely covers internal metal features.

Figure 6.47: One of the right-handed gauntlet's fingers; internal view.

6.5.5 Scale assembly

The scale assembly of the glove allows for full articulation of the fingers and wrist (Fig. 6.48). A series of iron scales (from three to eight per digit) are attached to the top of each finger (a). The rivets used to attach them to the leather aren't visible, with the exception of the distal scales (b) (also refer to Fig. 6.49), as the overlapping sequence effectively hides the rivets. The rivets attaching the proximal finger plates are visible on the knuckle plate (c); the latter being the first in a series of five wrist scales (d) (also refer to Fig. 6.50). While the index, middle, ring and pinkie finger are attached to the knuckle plate, the thumb plates are attached directly to the leather of the glove and not to the wrist scales or the arm section.

The wrist scales are arranged in sequence, with the first attached to the forearm portion of the armour. Each succeeding scale is attached to its predecessor by means of a rivet. It is interesting to note that the rivets are not the exact same size and are also not properly rounded. This type of detail leads credence to the suggestion that the armour belonged to a guard or ordinary soldier from the period.

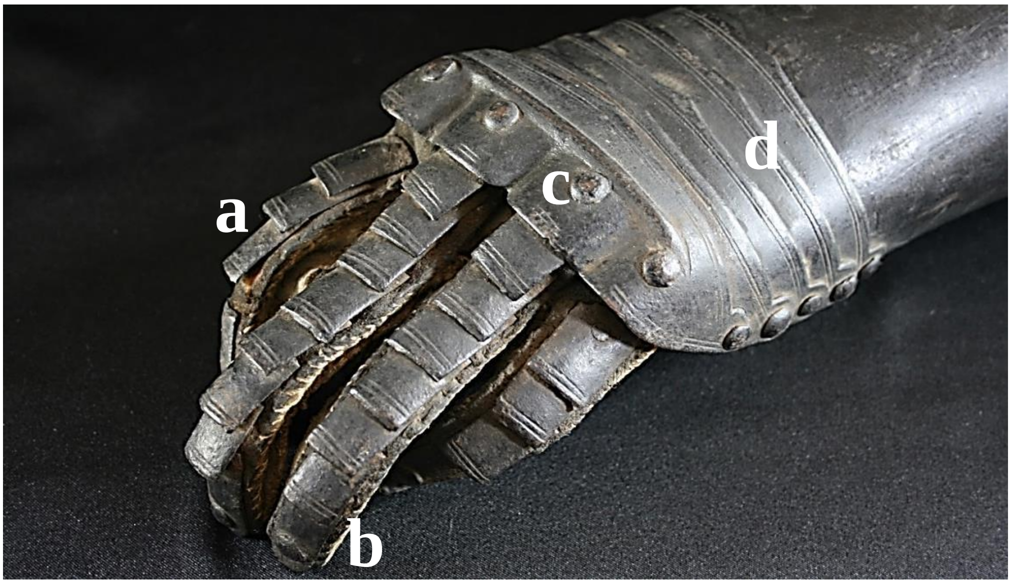

Figure 6.48: The position of the distal (A) and proximal (B) plates is indicated in relation to the knuckle plate (C).

Figure 6.49: Close-up view of the Tower of London gauntlet's finger scales and their rivets. Note the decorative parallel lines that mimic those encountered along the arm.

Figure 6.50: A close-up view of the wrist scale rivets on the Tower of London gauntlet. Once again, note the repetition of the parallel line motif

6.6 ARABIAN DAGGER

As mentioned in the previous chapters, the Arabian dagger poses some difficulties in terms of its historical context and authenticity, since no official museum records exist that provide information on its origins.

6.6.1 Blade Edge Use-Wear

Approximately 60% of the blade's edge displays a rounded, undamaged appearance with only minor/superficial scuffing and/or striations**.** A general lack of prominent surface wear on the blade suggests that it was used for ceremonial purposes, or served as a collector's item. Apart from a few spots of corrosion, the blade is in a very good condition. The convex cutting edge of the blade features a relatively smooth surface (Fig. 6.51), while the entire blade features polishing striations that run parallel to the edge of the blade. The discussions to follow will cross-refer to the areas (a–d) indicated in Fig. 6.52.

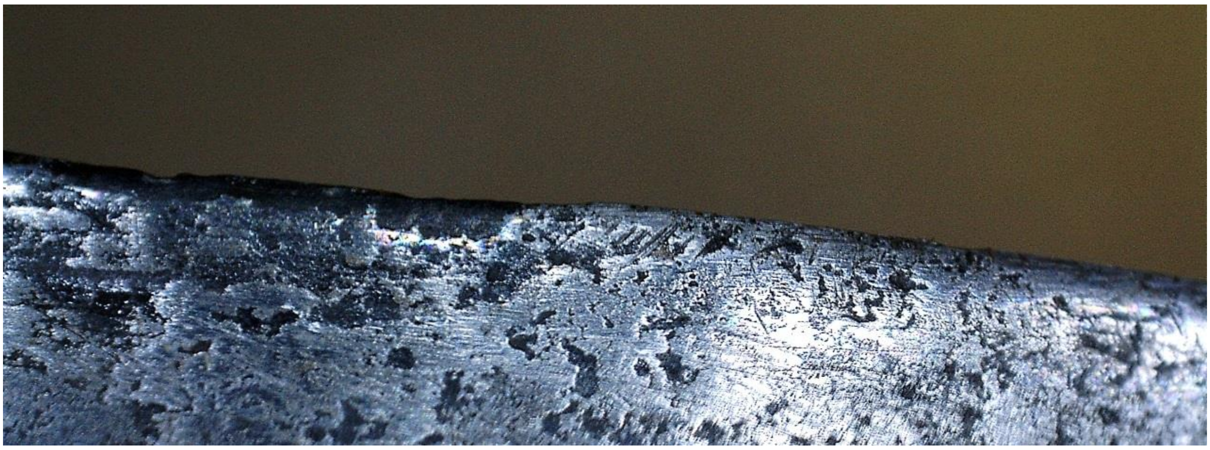

Figure 6.51: The blade edge, featuring a rounded appearance and superficial damage.

Figure 6.52: The dagger blade with reference points for the discussion below (a–d).

Near the hilt (a), the blade’s edge features striations that run at an almost 45-degree angle (Fig. 6.53A). The striations face away from the hilt and down the length of the blade, as if the user was pulling towards himself when the action was performed. On the opposite side of the blade, the edge is bent over (displaced) slightly, indicating that some force was applied (Fig. 6.53B).

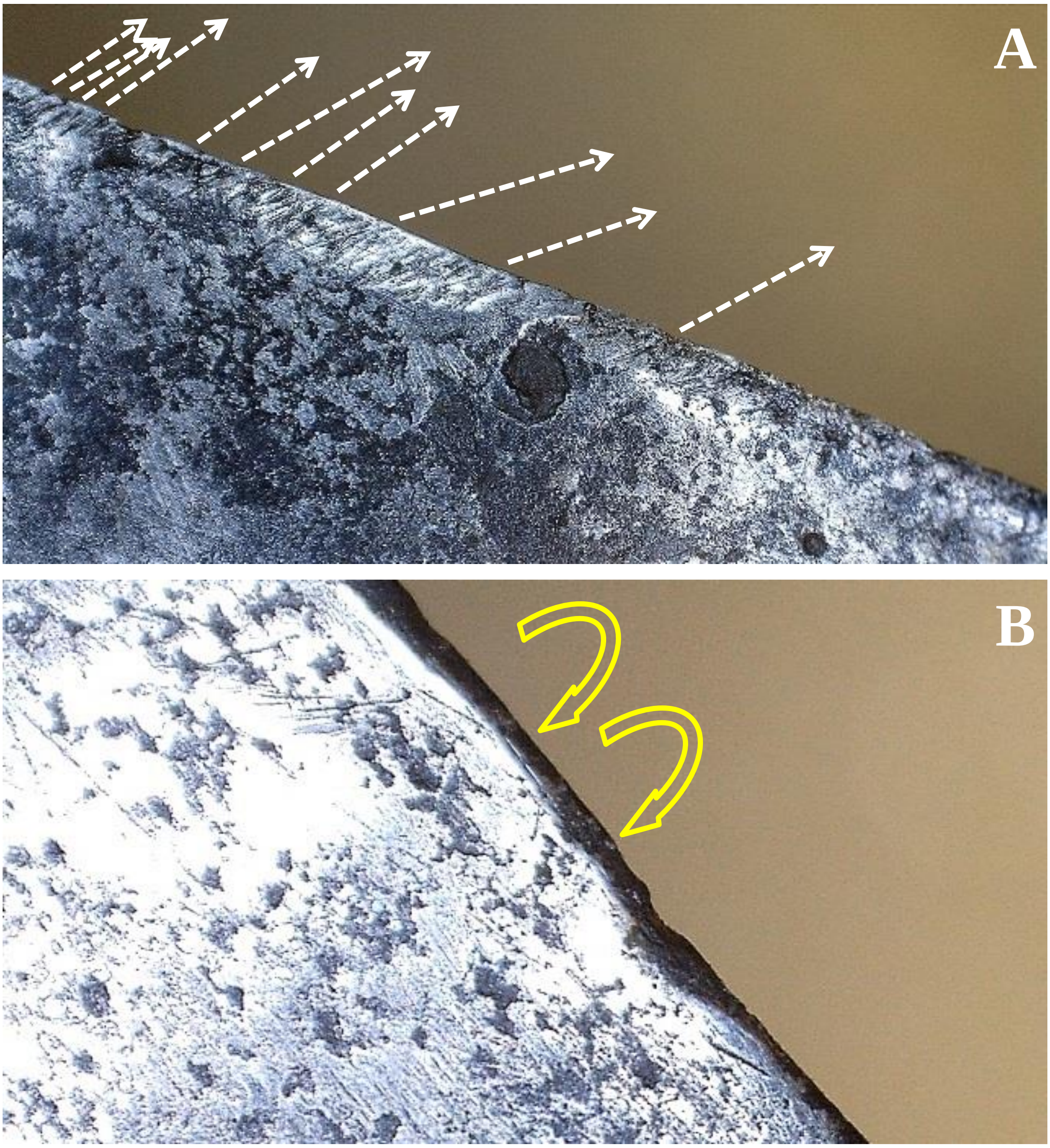

Figure 6.53: Angled striations on the blade's edge, with arrows indicating the direction of the most prominent lines (A). The bent-over edge is clearly visible, with the yellow arrows indicating the direction of the bend (B).

Along the mid-section (b), a number of concave indents can be observed. These indents are superficial and are not indicative of any significant impact (Fig. 6.54A). The curved area (c) includes a feature that appears to be a spot of corrosion. However, upon closer investigation it appears more like molten metal that was not properly smoothed out during production. Fine striations that run parallel to the edge of the blade can also be observed, suggesting that this spot was polished during manufacture (Fig. 6.54B). The tip of the blade (c) features a number of concave indents. It is possible that, having a sharp edge, the dagger's tip was used for utilitarian tasks, like picking at objects (Fig. 6.54C).

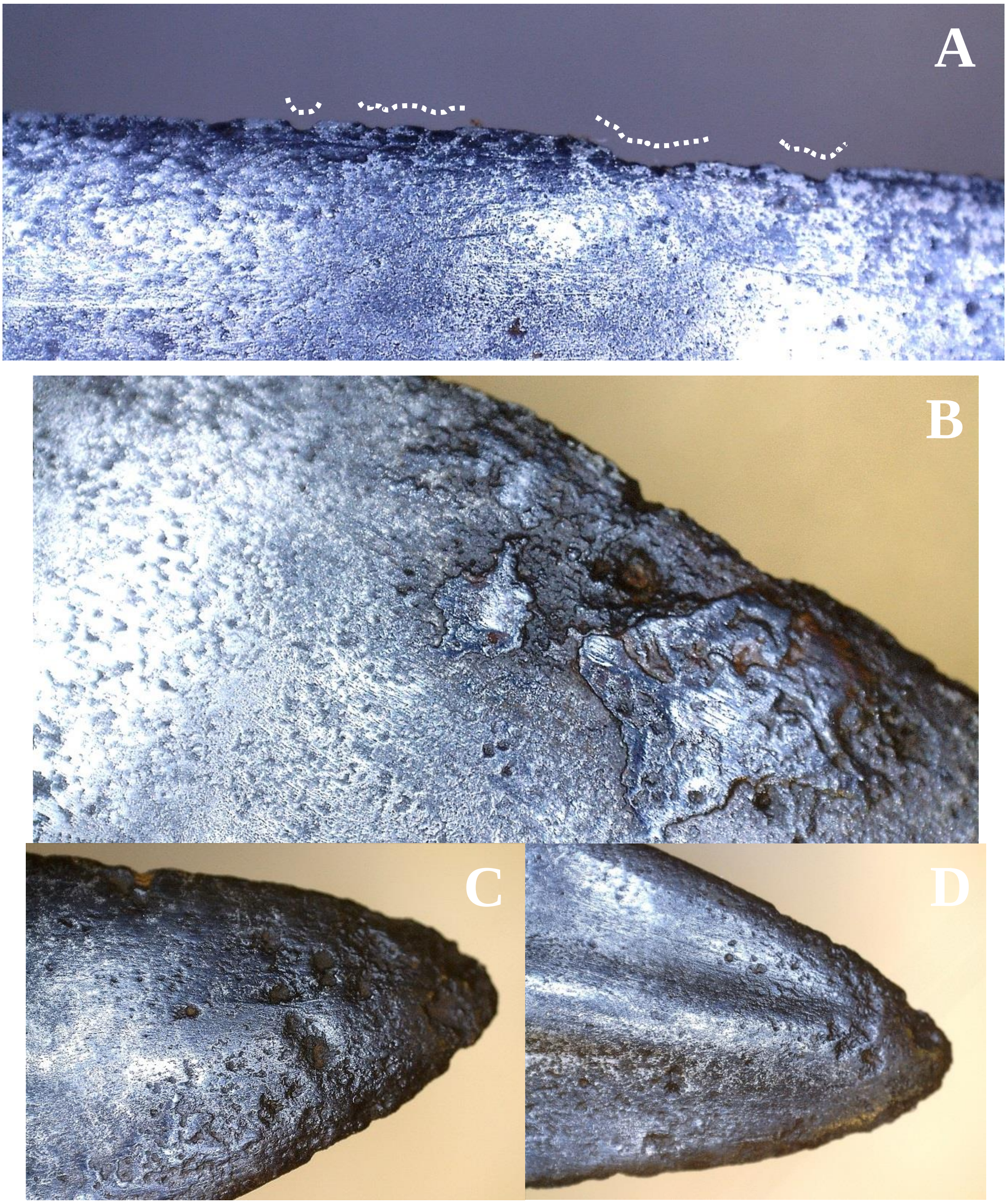

Figure 6.54: Concave striations on the blade's edge. For the sake of clarity, the shape of these scalloped markings are indicated by the dotted white lines (A), corrosion (B), and the damaged tip of the blade (C).

The absence of v-shaped notches, such as those identified by Higgins (2010), suggests that the blade was never involved in a knife fight (or encounter with another type of edged weapon). As Higgens (2010, 197) explains, V-shaped notched are caused by "perpendicular contact with the edge of another blade" (Fig. 6.55). Horn and Holstein (2017, 91) add that "the force required to form a notch is defined by the relative hardness, toughness and ultimate strength of both impacting objects". A general lack of notches, micro-fractures, displaced material, hammering marks, suggest that the *khanjar* was never used for any heavy duty tasks.

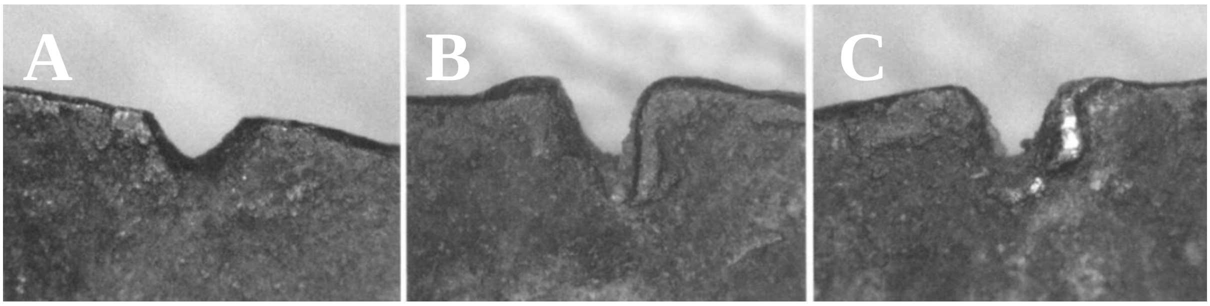

Figure 6.55: Perpendicular (A) and angled (B–C) v-shaped notches.
Source: Higgens (2010, 199).

It must at this point be noted that use-wear will not be discussed under the three-dimensional imaging of Chapter 7. Molley et al. (2016, 86) provides us with an explanation:

> With the current technology we are not yet at a point where 3D models can routinely, rapidly and easily be used to display instances of wear in the same resolution as can be obtained using macro-photography or a microscope. Visually therefore, still views of 3D models that we generate today are inferior to the still images used to generate them.

6.6.2 The Handle Superstructure

At first glance, the handle's superstructure appears to be made of wood. The colour and cracks are characteristic of what can be expected of aged, untreated wood. However, upon closer inspection, the surface has uniform (in size) nodes that appear almost scale-like. According to local archaeozoologist, Karin Scott (2018, pers. comm), the surface resembles horn sheath – the outer layer of keratin and other proteins that protect the living bone core of various hoofed mammals[180] (Fig. 6.56).

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[180] http://www.newworldencyclopedia.org/entry/Horn_(anatomy) [Acessed 04/10/2018]. True horns are found on the skulls of ruminant artiodactyls such as cattle, sheep, goat, and antelope (O'Connor et al 2015: 2).

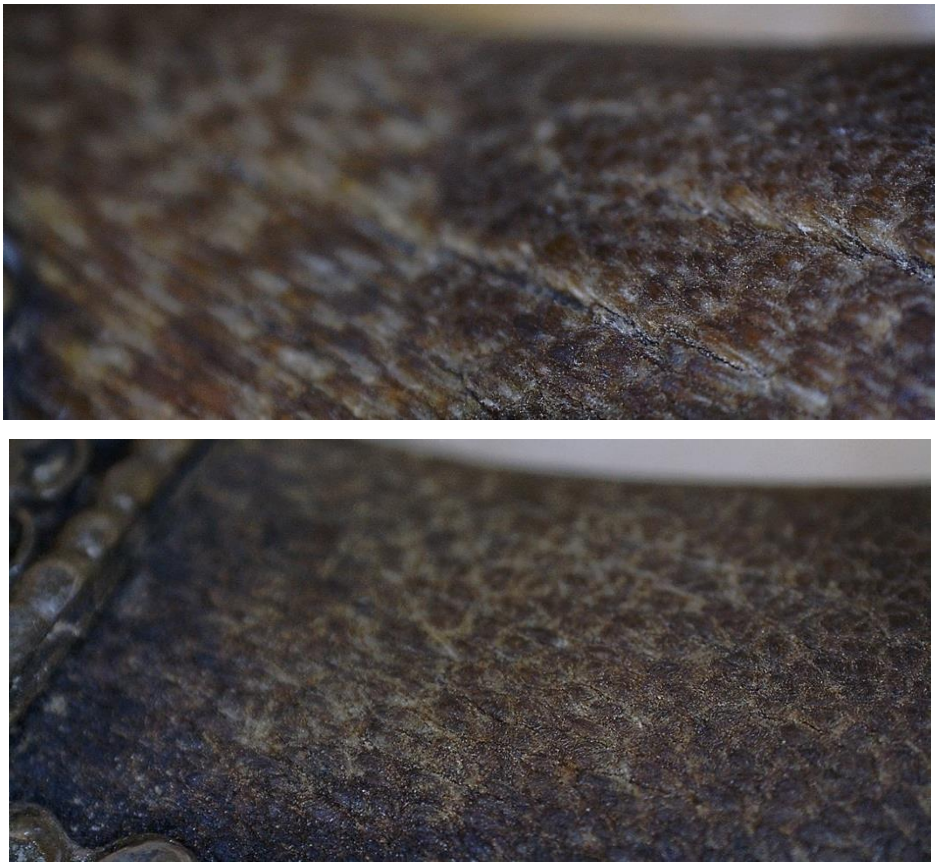

Figure 6.56: The dagger’s handle surface, boasting a scale-like appearance.

The worked area along the shoulder of the handle provides us with a sectional view of these “nodes”, revealing an overlapping scale-like appearance. In Fig. 6.57A, dotted lines have been added to accentuate the overlapping nature of the scales/lames. Interestingly, theses lames resemble the worked surfaces of cattle horn, as identified by O’Connor et al (2014, 6) (Fig. 6.57B).

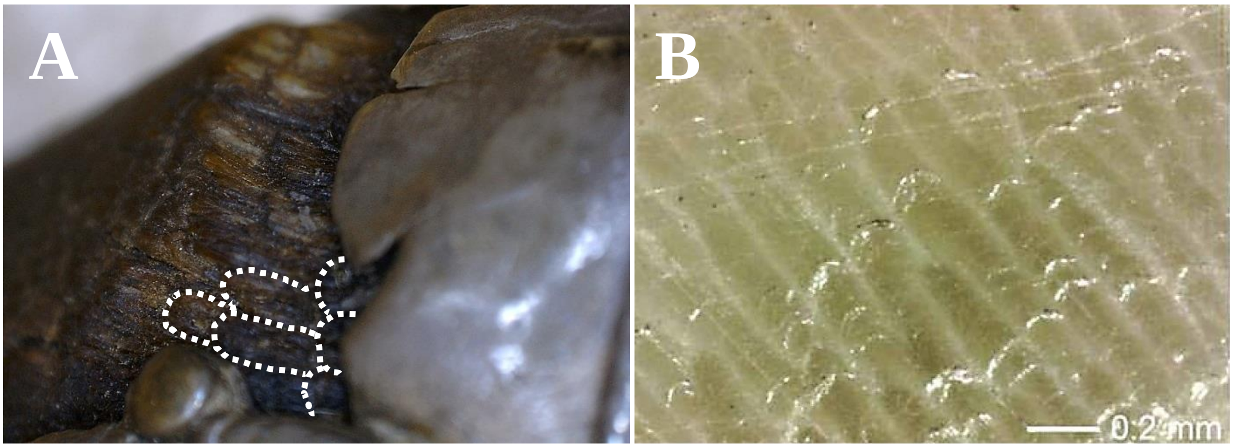

Figure 6.57: The overlapping scales/lames (A) resemble a worked surface approximating to the transverse section of a cattle horn tip (B). ***Source:*** O’Connor et al. (2014, 6).

The appearance is described by O’Connor et al. (2014, 6):

> Cow and ox horn have very few, relatively inconspicuous pores but the growth layers are wavy with a compact boundary that give the unworked surface a longitudinally corrugated appearance. In worn or worked surfaces these corrugations may still be apparent from the distribution of the pigmentation in the truncated layers, but pressed and polished translucent horn can look like a homogeneous sheet of plastic. With time, starting at the edges of the horn, deterioration allows air to infiltrate between the layers, making the corrugations visible once again in either reflected or transmitted light. In transverse section, the layers describe a series of intersecting arcs of similar size. These can be particularly obvious toward the centre of the solid part of the horn tip where each layer follows the path of the layer below around a central point and the synchronous intersections of the arcs produce a pattern of radially organized lines between the columns of arcs [refer to Fig. 6.57B].

Although we can safely say that the handle superstructure is made from a type of animal horn, the exact species cannot be determined by surface or even 3D analysis. Unfortunately, in this regard, destructive sampling would be required.

6.8 CONCLUSION

This chapter identified and discussed surface visual phenomena that were identified by means of micro photography and digital microscopy. The primary aim, of identifying visual phenomena relating to object integrity and ancient production techniques, was successfully achieved. Within the context of a quasi-experimental model, the successful completion of this pre-test phase by means of preliminary technical analysis now provides a solid foundation upon which the post-test phase can be based. In short, most of the visual surface phenomena identified in this chapter can now be used as points of departure for the detailed internal investigations that are to follow in Chapter 7.

6.8.1 Egyptian Bronzes

Since the collection of bronzes all appear to have been cleaned of external surface corrosion at some point, this aspect cannot be used as conclusive proof that the objects are in fact ancient. However, access to Wadjet-Bast’s internal core material and its surrounding internal corrosion provided significant evidence in terms of the object’s authentication. Since internal corrosion is near impossible to recreate, the mere presence of mineralisation, coupled with the extent of corrosion, indicates that the objects is indeed of an advanced (ancient) age. The presence of polishing striations, tangs and eye sockets provided insight into ancient manufacturing methods and techniques.

In the case of the broken ibis, we were able to identify the presence of a silver substance – the chemical identity of which remains unclear without the application of chemical analysis.

6.8.2 Samurai Armour – *Kabuto* and *Menpó*

Although museum staff removed surface corrosion on the *kabuto*, a small amount of corrosion remained visible between the overlapping lamellar plates. The internal surface of the grommet also retained its blue-green patination, as this area of the helmet would have proved difficult to clean. The presence of corrosion in this instance is also indicative of the *kabuto*'s antiquity. Closer investigation of the overlapping plates also revealed that the *kabuto* consists of 15, and not 16 (as previously stipulated by museum records), individual plates.

Our investigation of the helmet lining revealed a hemp-like material that is held in place by dyed leather. Interlacing green threads (probably silk) were observed from the hemp lining, but a damaged section of the lining also revealed blue thread, the latter which roughly resembles the blue colour of the *kabuto*'s helmet loops, the *menpó*'s tie-downs and the lacing encountered on the cuirass. The similarity between the colour and woven structure of these components indicates that they hold a high probability of belonging to the same suit of armour (as it was originally created).

When it comes to surface treatments, the *kabuto*'s original lacquer appears authentic, as it is well-known that a traditional Japanese lacquer, pigmented and known as *urushi*, was applied to metal surfaces in order to protect objects from corrosion.

On the *menpó* itself, what appeared to be antique repair work was identified. What distinguishes this anomaly from modern restorative work is the homogeneity of the metal's colour and texture. In addition, the pins that were used to secure the small plate closely resemble other pins used on the object, as well as those encountered on the *kabuto*. The latter point serves as an additional point of association between the *menpó* and the *kabuto*.

Flaking of the *menpó*’s lacquer coating, on both the mask and the neck guard, stands as further testimony to the object’s antiquity. Although the outer surface retains almost no trace of lacquer, it is almost certain that the exterior surface would have boasted the same bright red coating, making it stylistically similar to *menpó* from the Edo Period.

Striations on the *menpó* further indicate that antique methods of production were applied, as these phenomena were formed on the surface of the metal as they were sanded while the metal was still relatively warm and malleable.

6.8.3 ToL Gauntlet

The gauntlet displays similar polishing striations, as previously observed in the Egyptian bronze collection and the Samurai *menpó*. The manner in which the piece was finished, coupled with the fairly plain nature of decorations, suggest that the armour was intended for a regular soldier. Superficial use-wear on the object suggests that the armour never witnessed any vigorous combat, which suggests that it could have been worn by a guard. However, the lack of insignia or extravagant decorations suggests that it was not a palace or royal guard’s armour, as these were often lavishly decorated.

However, the lack of surface use-wear should not be used to dismiss the armour’s possible involvement in combat. If one considers that armour was frequently repaired after sustaining damage, internal phenomena could be identified during 3-dimensional imaging, which could provide confirmation on whether the object was reworked.

An examination of joining techniques revealed that the gauntlet was made from a single piece of sheet metal that was carefully shaped and the edges rounded off. Upon comparison between the right-and left-handed gauntlets, it was found the right-handed counterpart was in an extreme state of decay, which in itself is a fairly good indicator of advanced age.

6.8.4 Arabian Dagger

Use-wear analysis on the dagger revealed that approximately 60% of the blade’s edge remains undamaged. Minor or superficial scuffs and striations indicate that the blade was used on a few occasions, but never performed utilitarian tasks that would cause more extensive damage. A general lack of notches, micro-fractures, displaced material, hammering marks, suggest that the *khanjar* was never used for any heavy duty tasks, and probably served as a ceremonial object or souvenir.

The uniform, overlapping nodes observed on the handle’s superstructure suggest that it is made from animal horn. However, we cannot from which species the horn is derived unless we perform destructive analysis. But even then, we would require comparative examples of horns from native Omani species, which in itself would represent an extensive research endeavour.

CHAPTER 7
THREE-DIMENSIONAL NUCLEAR IMAGING

7.1 INTRODUCTION

In Chapter 6, a number of surface features where identified that serve as diagnostic features in their own right. However, the exact nature of certain anomalies can only be confirmed through further 3D analysis. In addition, a number of new, previously unidentified features will be identified, with the latter representing the primary focus of Chapter 7.

7.2 EGYPTIAN BRONZES

In general, when working with MXCT, at least 10% radiation penetration is required in order to create satisfactory imaging results. As bronze is known for its high attenuation of X-rays, the voltage was set at 205kV, and copper filters were placed at the beam source in order to reduce possible beam scattering and post-reconstruction beam hardening. However, the Wadjet-Bast statuette was the only object to meet the recommended level of radiation penetration (only just), as the cat, ibis and Wepwawet failed to obtain minimum penetration levels.

This is by no means an uncommon occurrence when working with bronze alloys featuring a high lead content, as demonstrated in the work of Deschler-Erb et al (2010). As stated before, since the absorption of radiation by a target material follows an exponential decay function, some materials (such as high lead bronze) exhibit such high absorption rates that no increase in beam intentsity will facilitate a level of X-ray penetration that will deliver satisfactory 3D images. The only option is to change the beam source by switching from X-rays to neutrons.

Although MXCT’s failure to provide internal imaging was somewhat disappointing, the radiation’s inability to penetrate the latter objects presents us with results: (a) the material composition was too dense, and/or (b) the bronze alloy features a high lead content. While point (a) is probable, based on the objects’ weight, point (b) cannot be validated without chemical analysis. Among the four objects, three casting types were identified:

1. The Direct Lost-Wax Method (Solid-Cast): Cat and Wepwawet
2. Indirect Lost-Wax (Clay Core): Ibis
3. Indirect Lost-Wax (Hollow Core): Wadjet-Bast

Sections 7.2.1 to 7.2.3 will commence with a brief synopses of the casting type, so that readers are familiarised with the production processes and most notable physical characteristics. This introductory sub-section is then followed by a summary and discussion of the diagnostic features that were observed on the objects. Sections 7.2.4 to 7.2.6 will then discuss other notable features.

7.2.1 Cat and Wepwawet

a) *The Direct Lost-Wax Method (Solid-Cast)*

The direct lost-wax technique (Fig. 7.1), also known as investment casting (Gravette 2011, 47), starts with the creation of a figure from a solid lump of beeswax. The soft material allows the artist to create a finely crafted model of the envisaged object, which is then covered in an investment material (a refractory mixture consisting mostly of clay) and fired. As the item is fired, the molten wax exits the hardening mould through holes, leaving a hollow cavity behind. These holes then serve as funnels through which molten metal is poured.

Channels and vents allow gasses to escape, easing the flow of molten metal into cavities. After the metal solidifies, the mould is broken to reveal a solid-cast statuette (Agresti et al. 2016, 773; Ghoniem 2013, 41; Smith et al. 2011, 222). Hammering would only be used to correct any serious casting flaws and shape the object into its final form (Gunter 1995, 1546). Since metal was a precious commodity, the direct lost-wax method was reserved for smaller items that used less metal when cast in solid form.

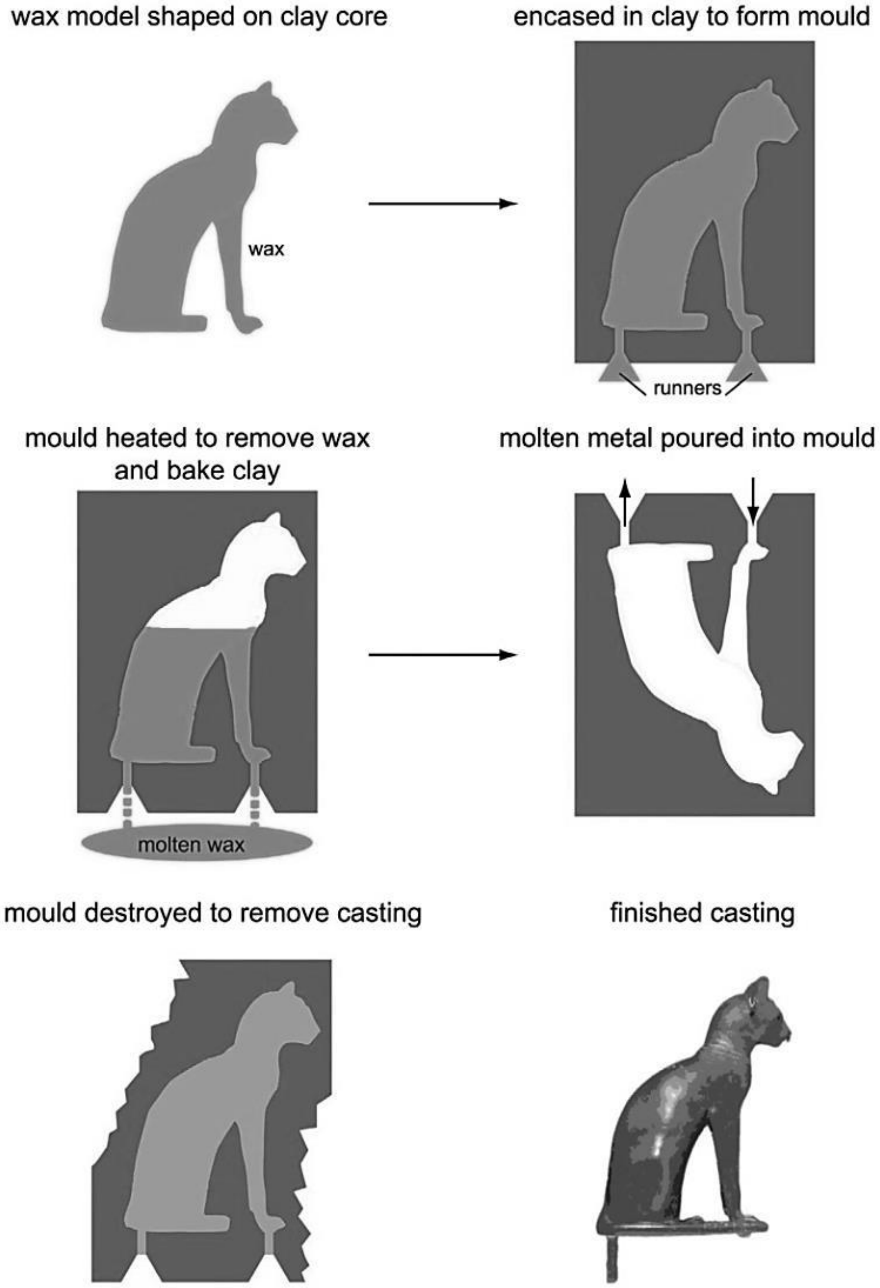

Figure 7.1: A schematic representation of the direct lost-wax, solid casting process. Adapted for this thesis from Ambers et al. (2008, 5).

b) *Diagnostic Features: Direct Lost-Wax Method (Solid-Cast)*

When examining such small, relatively thin objects, one would expect a higher level of beam penetration through the bronze. But, the high attenuation of the bronze could indicate a significant lead content, similar to the results revealed by Lehmann et al. (2005) in their study of Roman bronzes from the Swiss National Museum. Since bronze alloy objects from Egypt's Third Intermediate (1070-664 BC) or Late Period (664-323 BC) often contained higher levels of lead (Ghoniem, 2014, 38), confirming the heavy metal's dominant presence within these figurines could hold implications for the relative dating of these statuettes. However, this type of information can only be confirmed through chemical analysis (which is beyond the scope of this research). Whichever the case, it can be argued with fair amount of certainly that the objects are of a solid-cast nature (Fig. 7.2–7.3).

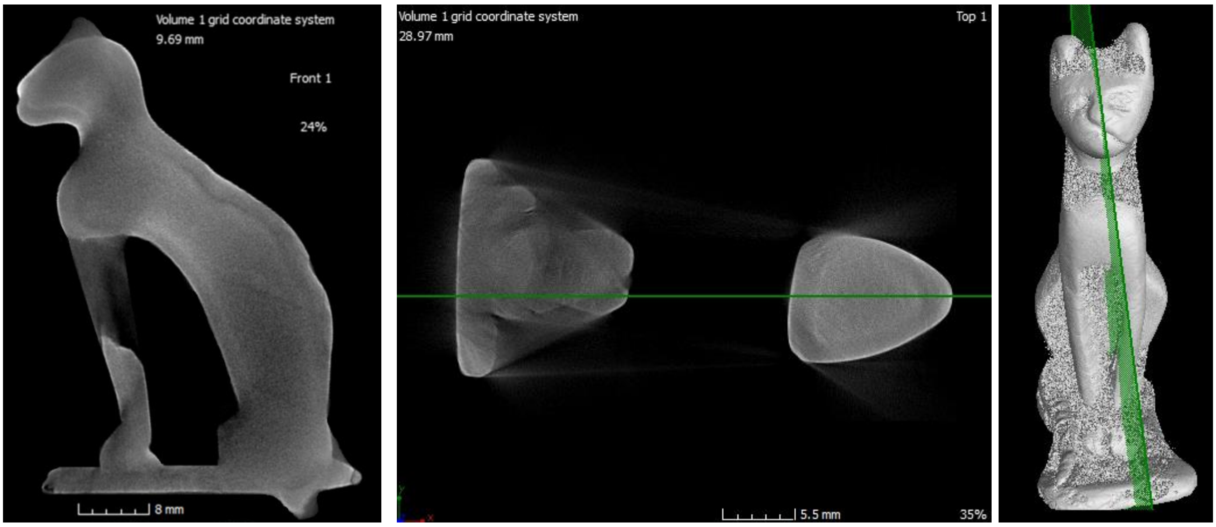

Figure 7.2: Y-axis (A) and X-axis (B) radiographs of the cat/Bastet, and three dimensional volume position of the image slices (C).

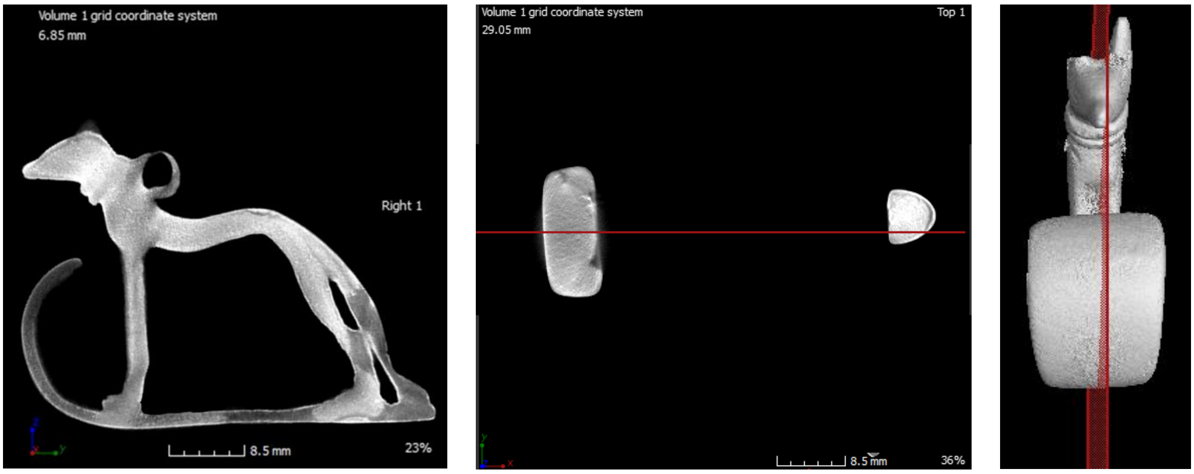

Figure 7.3: Y-axis (A) and X-axis (B) radiographs of the Wepwawet, and three dimensional volume position of the image slices (C).

With reference to the results obtained by Deschler-Erb and Ford (2010), which indicated that additional materials could often be used as fill material, it is difficult to say whether or not this was the case with the DNMCH bronzes, as internal anomalies could not be investigated. Although the cat/Bastet features a ghost line (Fig. 7.4A), which could be indicative of a bronze layer meeting an internal core, it is also possible that this line is simply a radiographic anomaly (artifact) cause by beam scattering[181]. In addition, no physical anomalies were identified that resemble casting pins or chaplets. Because of this, the future applications of

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[181] As Schorsch (1988) notes; the positioning of objects during scanning, coupled with beam scattering (and other visual anomalies), may obscure our observation of wall thickness.

NT or even synchrotron radiation are highly recommended for this group of artefacts. For example, in the work of Deschler-Erb (2010), it was found that objects which boast high attenuation levels to X-ray tomography, and therefore erroneously appear as solid, were exposed, once investigated by thermal neutrons, as having internal core materials.

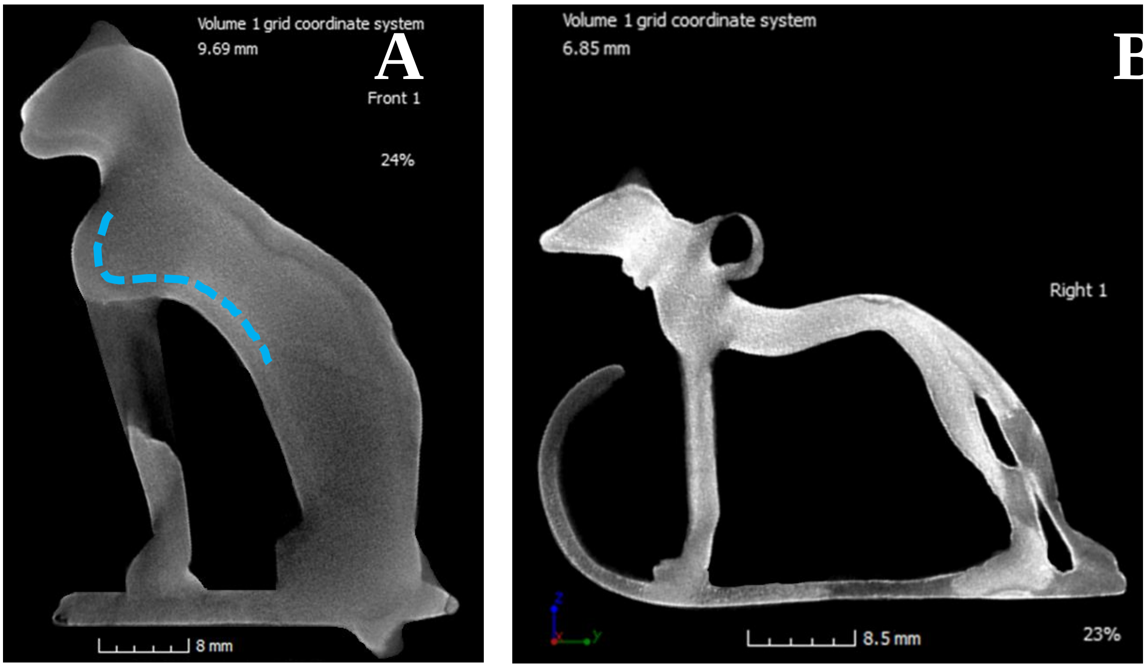

Figure 7.4: Radiographs of the Bastet with a section of the "ghost line" indicated in blue (A), and dog (B) statuettes. A uniform grey appearance indicates a solid-cast nature.

7.2.2 Ibis

a) *Indirect Lost-Wax Method (Clay Core)*

The clay core method was mostly used for medium- and larger-sized objects in order to save metal. With this method (Fig. 7.5), a refractory clay core is shaped, around which beeswax is pressed and then sculpted to accentuate the figure's overall shape and decorative details. Metal pins (chaplets/core pins) are inserted through the wax and into to the clay substrate, while a heat resistant investment (clay mixed with an organic binder) is pressed around the wax model (Schorsch & Frantz 1998, 21). As the item is fired, the hot wax escapes the mould, leaving a cavity between the outer mould and the inner core. During this process, the chaplets keep the core in position relative to the mould itself (Hunt 1980, 72; Savage 1968, 20; van Langh et al. 2011, 950). The cavity is then filled with molten metal and left to cool down and solidify, after which the object is carefully freed from its mould (Ogden 2000, 157; Smith et al. 2011, 222-223). In most instances, chaplets are left in place and simply smoothed over during final production (van Langh et al. 2011, 950). Casting runners (the vents through which the hot wax would exit and molten alloy enter) often leave behind spouts of solidified metal. These pouring points were left intact during ancient times, and were reworked into tangs that were subsequently used as anchor points to secure the statuette to a wooden/stone display base (Spencer 2007, 44–45). These features can be used by modern researchers to determine the relative age of an object. Prior to the New Kingdom, tangs were asymmetrical and followed no specific or formal design. But afterwards, tang design became more formalised, with the majority taking a symmetrical rectangular shape with a flat end (Ghoniem 2014, 41; Schorsch 2007).

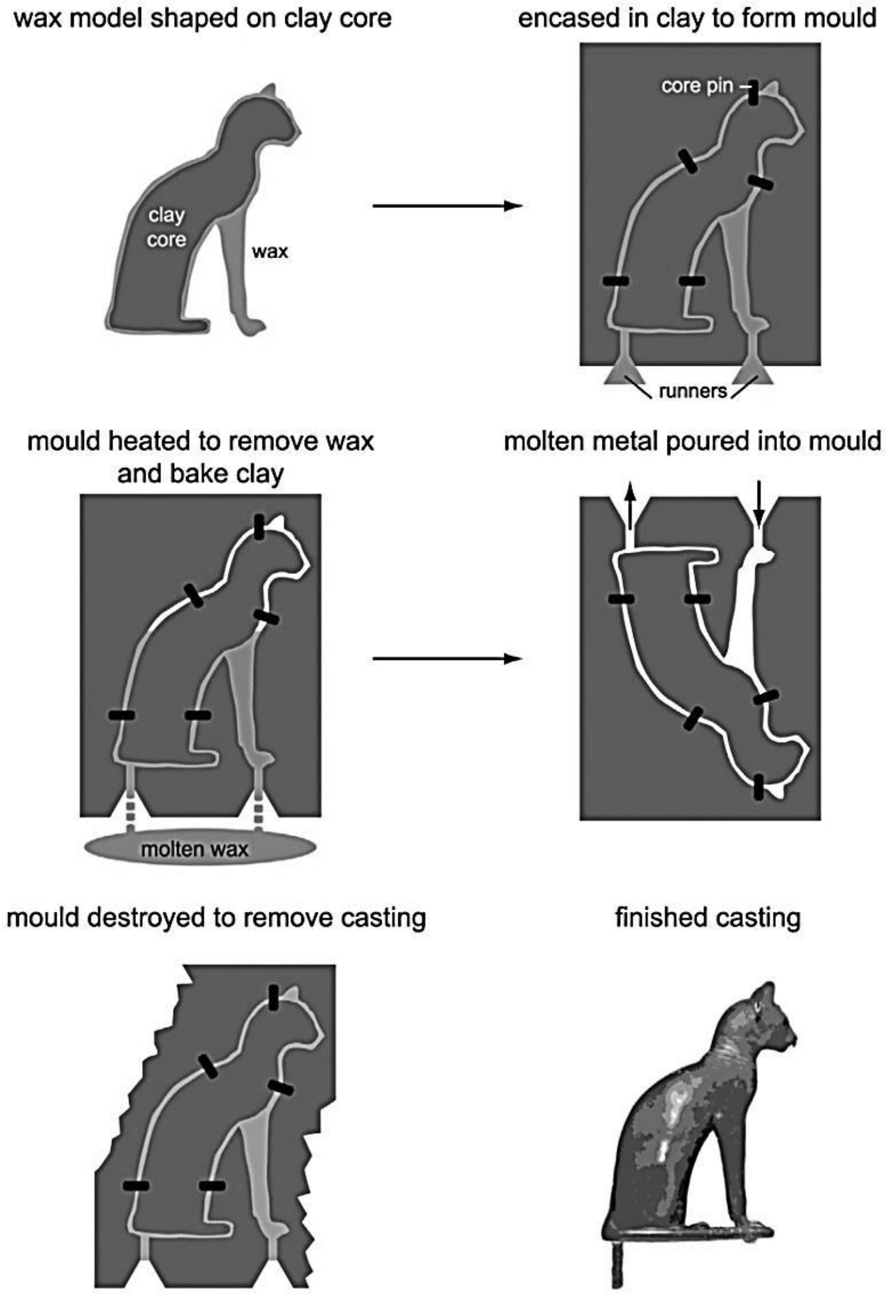

Figure 7.5: A schematic representation of the indirect lost-wax, clay core casting process.
Source: Ambers et al. (2008, 5).

b) *Diagnostic Features: Indirect Lost-Wax Method (Clay Core)*

Although it was at first believed that the ibis was of a solid-cast nature, radiographic analysis revealed primary characteristics that are akin to the clay core method. When the 3D model was inspected, two anomalies of a similar size were identified on the right (Fig. 7.6A) and left (Fig. 7.6B) wings.

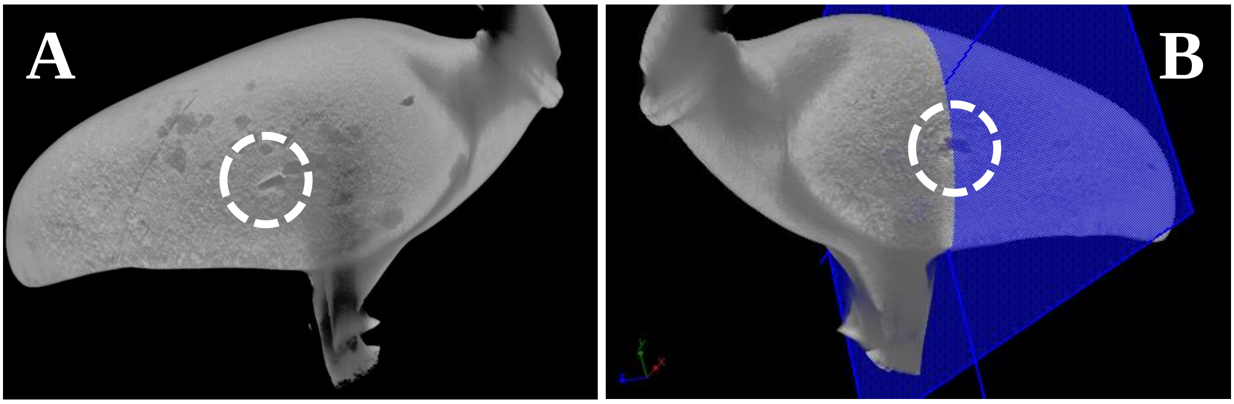

Figure 7.6: Right side view (A) and left side view (B) with the latter including a Z-axis sectional representation for reference purposes.

When panning through the z-axis (represented above by the blue grid) one can observe a pin-like structure extending into the body of the ibis (Fig. 7.7.A). When panning along the y-axis, the pin hole can be seen from a different angle (Fig. 7.7.B). The anomaly appears on the left wing, but is also mirrored on the right wing (Fig. 7.7C-D).

The internal volume of the ibis also has a much lower radiopacity compared with the surrounding material. The outlines resemble those observed on Wadjet-Bast (Fig. 7.10C), but are not quite as distinct. However, there is a very clear distinction between the defined outlines observed on the ibis, and the "ghost lines" observed on the cat/Bastet (Fig. 7.4A). Where the definition between the core material and the outer bronze becomes vague, a blue dotted line has been added in aid of visual representation. A strange anomaly is also observed at the tail-end of the ibis (circled) (Fig. 7.8).

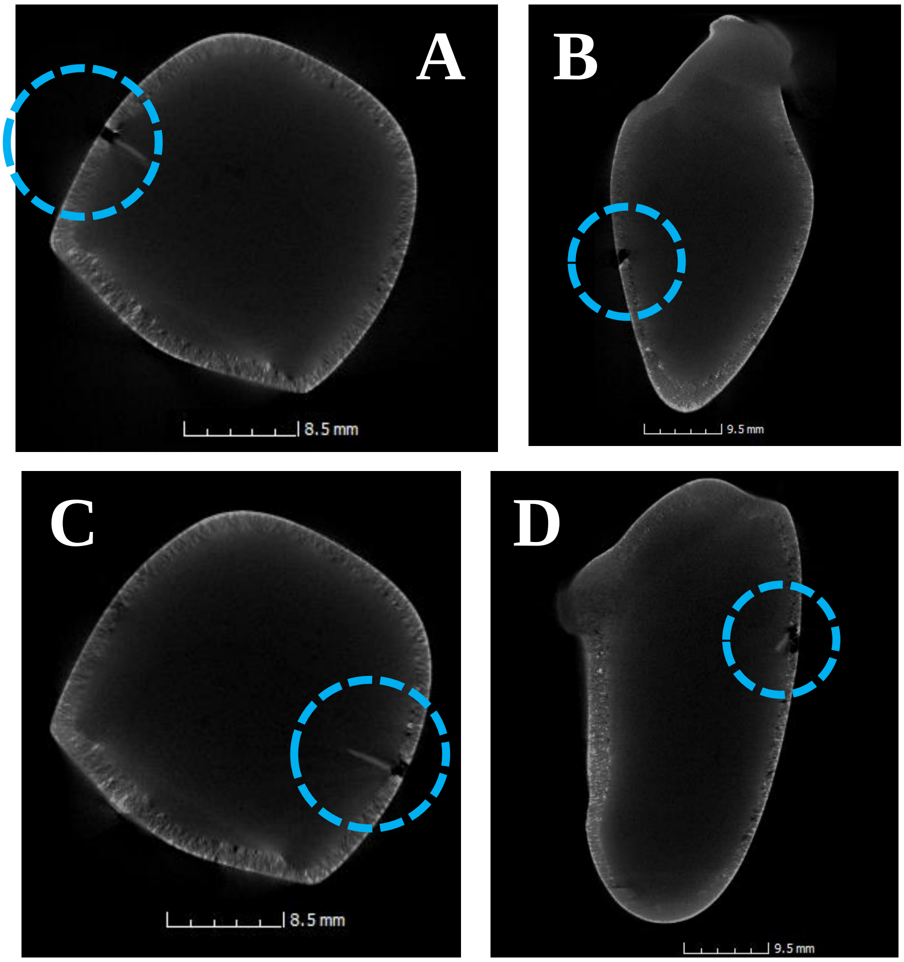

Figure 7.7: Left wing casting pin as viewed along the z-axis (A) and casting pin hole as viewed along the y axis (B). Mirror images along the right wing (C and D).

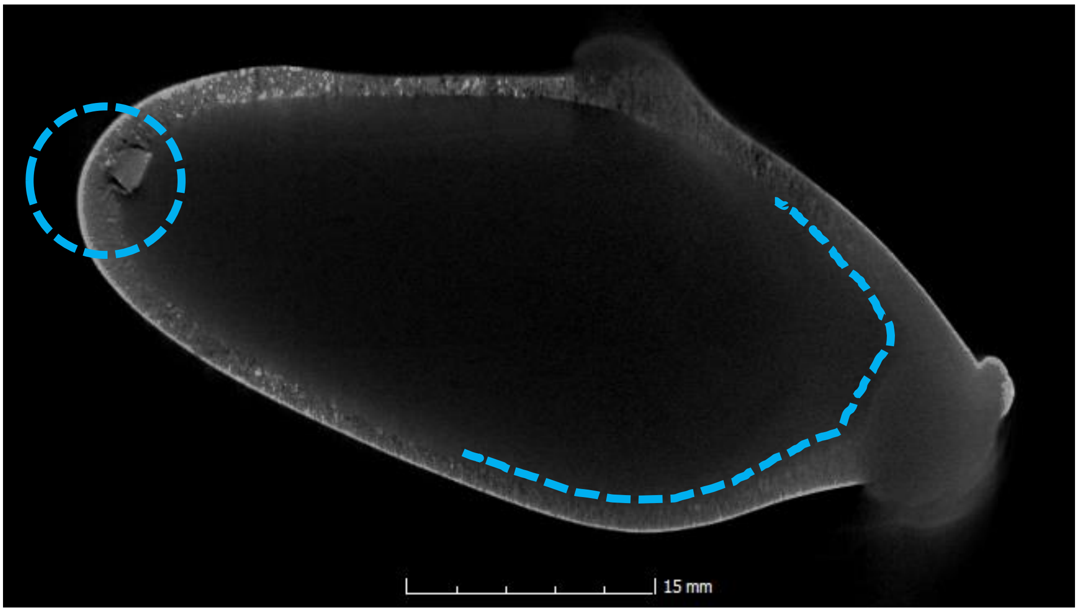

Figure 7.8: The internal volume of the ibis features a much lower radiopacity than the surrounding bronze.

7.2.3 Wadjet-Bast

a) *Indirect Lost-Wax Method (Hollow Core)*

As part of the technique (Fig. 7.9), a hole is left at the bottom of the item through which the core is removed after casting. This allows the internal core material to be in direct contact with the external investment during the firing and casting processes. Because of this, chaplets are not required to hold the core in place, but casting pins are often used. However, holes are needed in the body of the object to create additional contact points between the internal core and external investment (Ogden 2000, 159).

In certain instances, hollow-cast figures have hollow bodies and heads with solid cast arms and legs. This was especially true for smaller statuettes, where casting hollow arms and legs would have proven exceptionally difficult due to their small size[182]. As the arms and legs were cast separately, they were attached to the body through brazing, with brass rods inserted through the joints to provide reinforcement (van Langh et al. 2011, 954). The ancient crafter could also use mortise and tenon joints to connect the arms and legs to the body, or to attach additional decorative features, such as a headdress, sun-disk or *uraeus* (Ogden 2000, 159; Schorsch 2007, 189–190)[183]. Ogden (2000, 159) observes that soldering encountered on copper alloy statuettes is a clear indication of modern restoration or even of forgery.

Openings could be relatively small (2.5 cm x 2.5 cm), with some statuettes still containing remnants of their cores. The latter phenomenon is the result of movement limitations, as artisans could not reach around tight corners formed by the arms and legs (Agresti et al. 2016, 769). In most instances, hollow statuettes served the dual purpose of both votive figure and miniature sarcophagus, with some examples still containing their animal mummies.

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[182] This was a feature of ancient statuary and continues as a trend in modern casting practices.

[183] These joining methods are also observed in solid and clay-core statuettes and are not limited to hollow-cast objects.

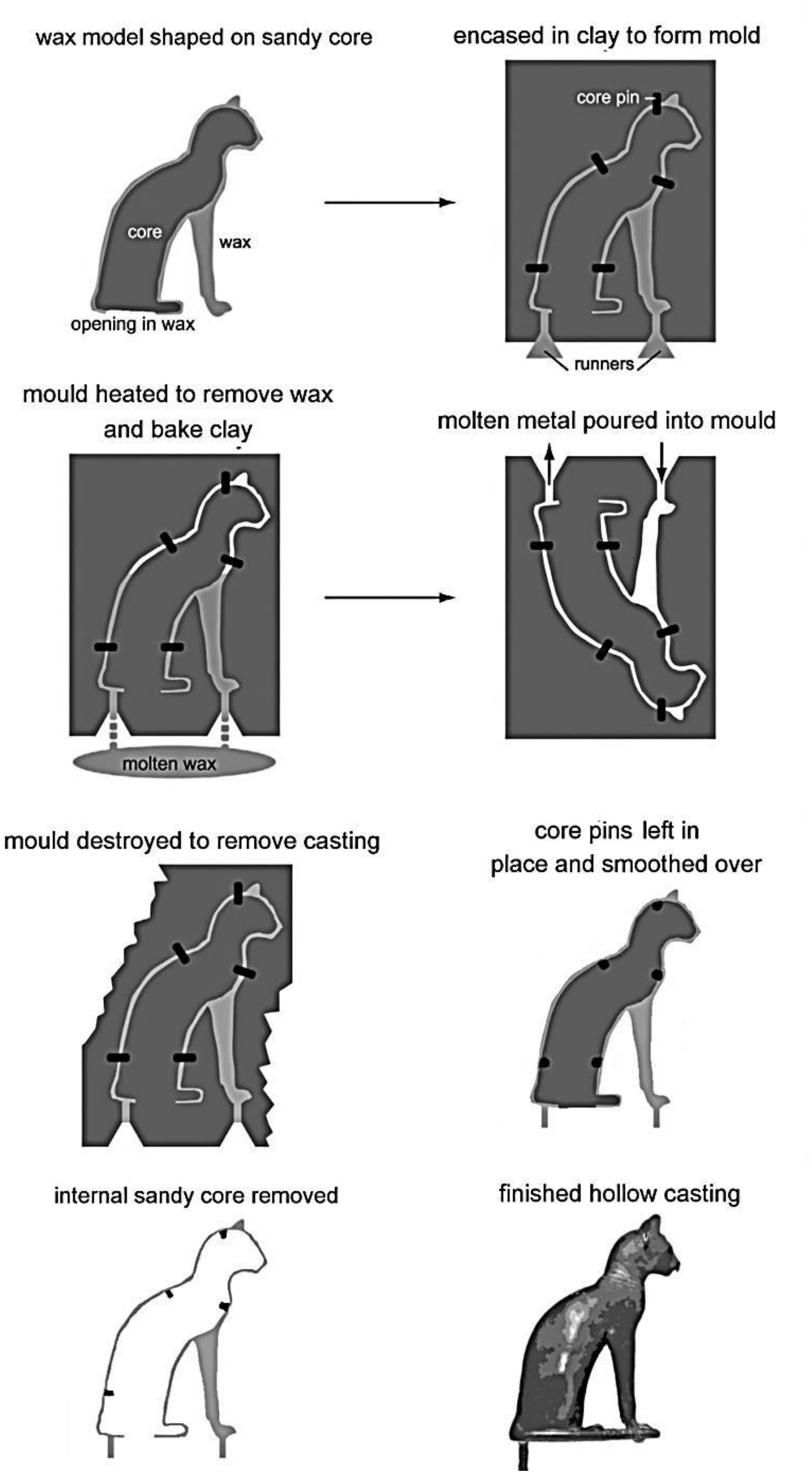

Figure 7.9: A schematic representation of the lost-wax, hollow-core casting process. Adapted for this thesis from Ambers et al. (2008, 5).

b) *Diagnostic Features: Indirect Lost-Wax Method (Hollow Core)*

Through external visual investigations, it was fairly simple to conclude that the Wadjet-Bast statuette was hollow. Yet, the extent of the internal hollow cavity remained an uncertainty, as the range of digital microscopy was limited and endoscopic instruments were unavailable. It was suspected that the arms and legs were solid bronze, a characteristic that was subsequently confirmed by the high levels of X-ray attenuation that were observed along these regions (Fig. 7.10A&B). At first it was suspected that the head itself might be solid cast, a misconception that was caused (at least in part) by insufficient depth perception – an unexpected consequence of fixed lens photography within a narrow space and the limited zoom range of digital microscopy. All things considered, X-rays revealed that the head was indeed hollow (Fig. 7.10C).

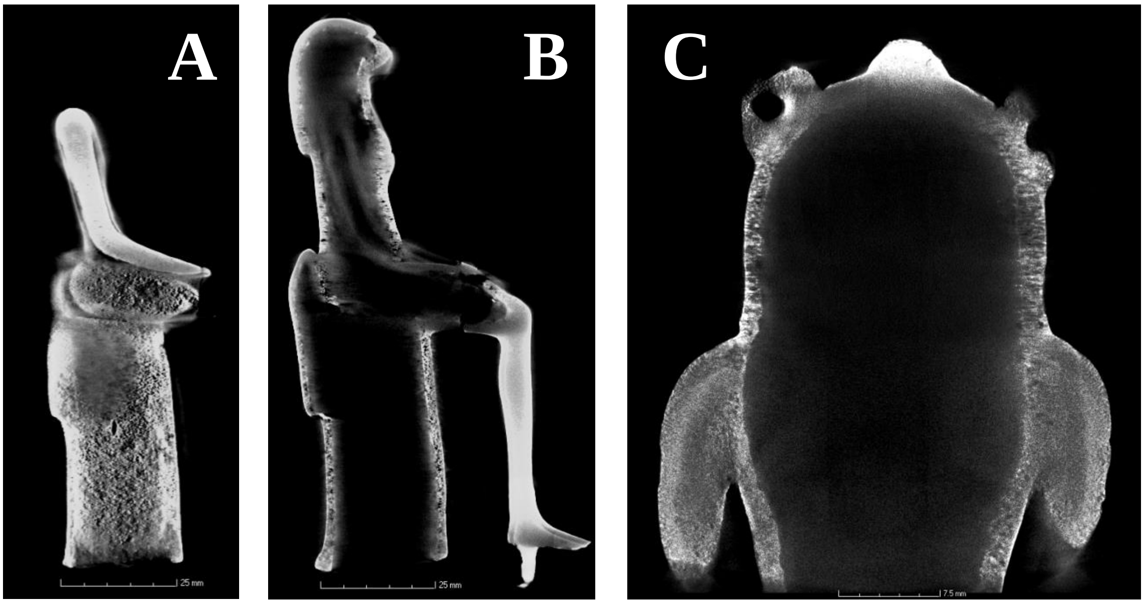

Figure 7.10: Solid and hollow-cast features of the Wadjet-Bast statuette. The arms (A) and legs (B) appear as radiopaque, while the head (C) cavity is radiotransparent.

Although the existence of a hollow head was always considered, we did not expect the nose to be hollow as well. Surprisingly, the hollow cavity of the head extends along the nose towards the tip of the snout (Figure 7.11A-G). This feature stands as testimony the craftsmanship of ancient Egyptian metalworkers, as the simplest option would have been to cast the nose as a solid feature.

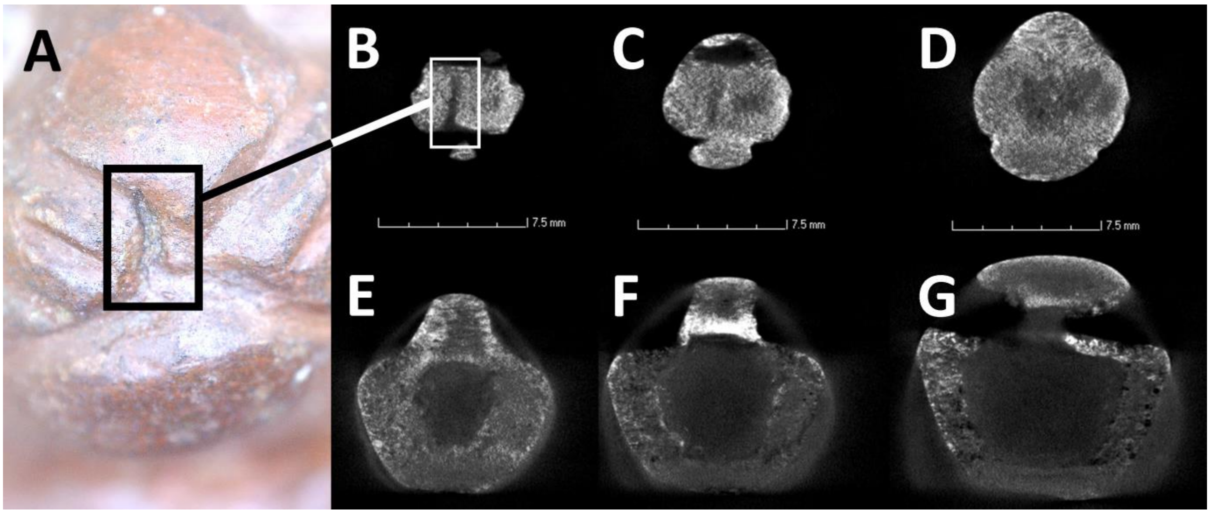

Figure 7.11: Hollow structure of the Wadjet-Bast statuette's nose. Digital microscopy of the nose (A). Figures (B) through (G) follow the sequence of the tomogram as it penetrates the nose from the tip of the snout towards the internal cavity.

It is quite easy to note the similarities in casting features between Wadjet-Bast and the Gayer-Anderson cat investigated by Ambers et al. (2008). Both objects are completely void of internal clay core material, except in the case of the latter, where clay material was present in the neck and head cavity – a result of intensive restoration efforts. On this specific point, Ambers et al. (2008, 7) state that clay fill materials used during modern restoration efforts are clearly distinguishable from their ancient counterparts, as the latter show clear indications of heat exposure during casting.

Another similarity shared between the two objects is the presence of solid-cast extremities. Although arms and legs could be cast separately and joined at a later stage – as demonstrated by the first century bronze Cupid examined by Bettuzzi et al. (2015) – it is unlikely that such a technique would have been used on Wadjet-Bast. The latter point is not a result of size-limitations, as Schorsch (1988) notes that no matter how small; hollow cast statuettes were often assembled from several individual pieces.

However, it is important to note in Wadjet-Bast's case that no joining rods, pins or brazing techniques (as observed by van Langh et al. (2011) and Schorsch (1988)), could be identified at this stage. Neither could we identify the use of mortise and tenon joints to connect the arms and legs to the body, or to attach additional decorative features, such as a headdress, sun-disk or *uraeus* (as observed by Ogden 2000, 159; Schorsch 2007, 189–190) (Fig. 7.12A-C). In addition, the areas surrounding the proposed contact surfaces show no evidence of the characteristic lips and edges, known as “wax drips”, which are formed when two reheated bronze surfaces are pressed together, as observed by Bettuzzi et al. (2015, 1167).

And, although higher definition imaging (through NT) could perhaps reveal finer production details, the differential attenuation between bronze and other metals (such as iron tacks), would have been readily identifiable to MXCT. We are therefore relatively safe in assuming that Wadjet-Bast was cast in a similar fashion to the Gayer-Anderson cat and that the legs, arms and ears were originally modelled in solid wax and cast as part of the greater object (Ambers et al. 2008, 4).

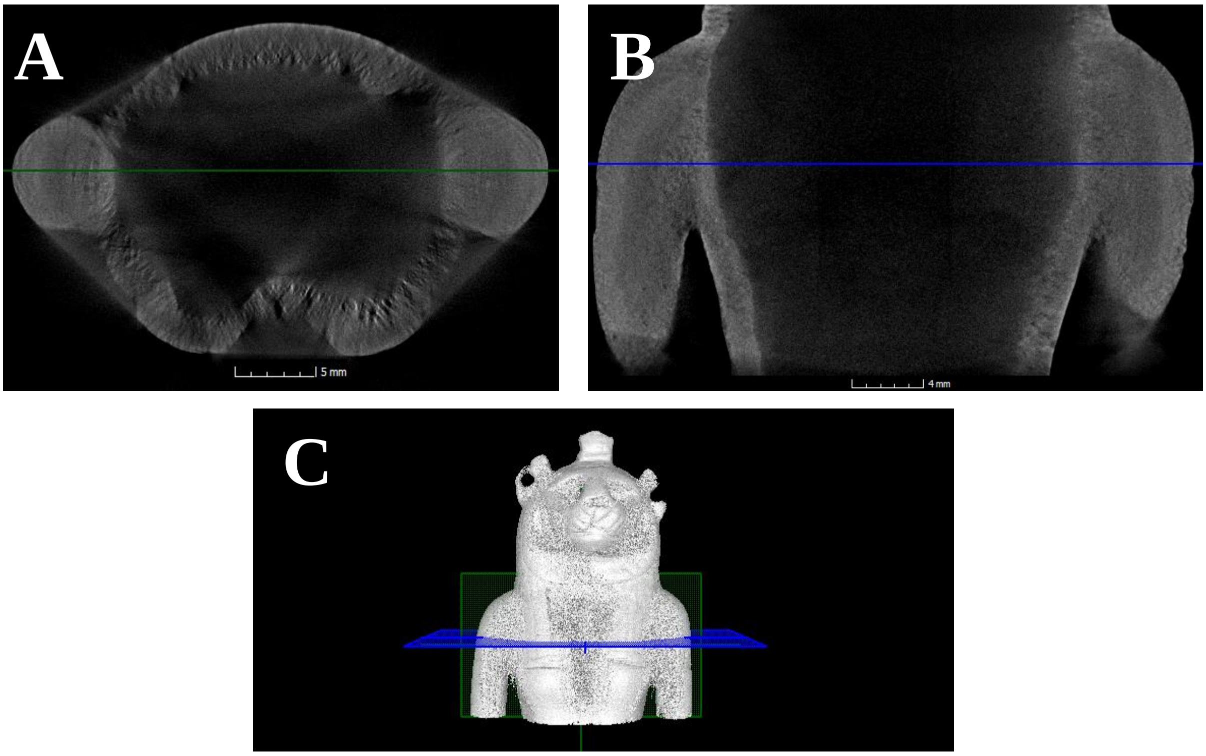

Figure 7.12: Sectional slices as viewed along the z-axis (A) and y axis (B) confirms the absence of joining pins. The position and location of the slices are indicated by (C).

Wadjet-Bast also features a number of casting holes along the left, right and back sides of the throne. These holes are observable as radiotransparent holes that are positioned along the same horizontal line. In the images below, the hole on the right side of the throne is visible just below the decorated external surface (Fig. 7.13A), becoming more defined as the tomogram passes through the object (Fig. 7.13B). The hole on the left side of the throne (Fig. 7.13C) is somewhat smaller than its counterpart, but this may be due to corrosion deposition.

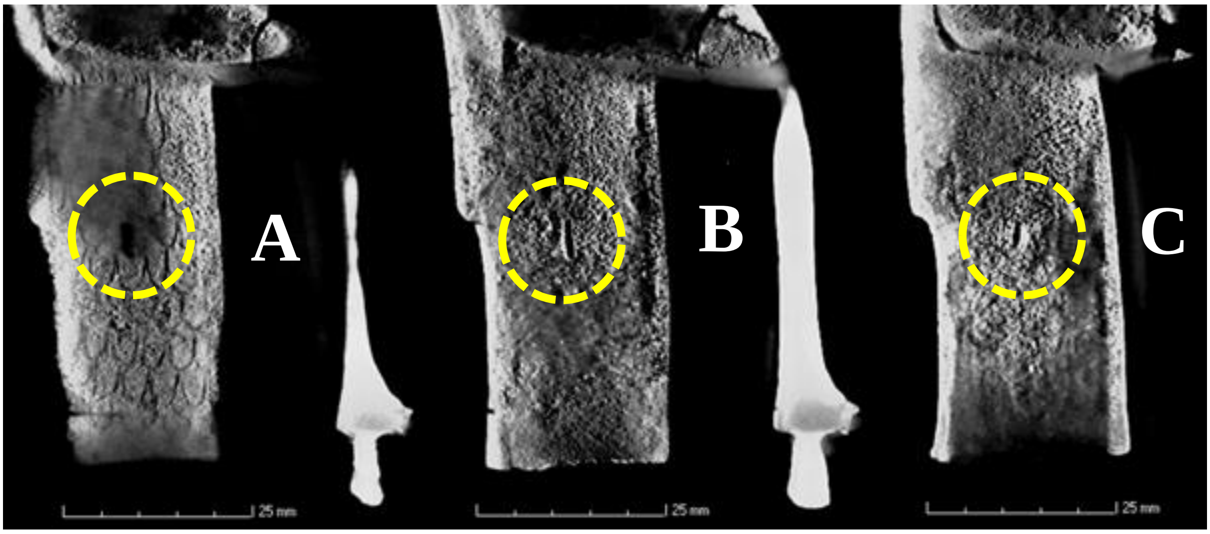

Figure 7.13: The casting holes on opposite sides of the throne become more apparent as one pans through the throne's surface along the x-axis (vertical), moving from right to left (A to C).

The mirrored horizontal placement of these features is clearly visible in the 3-dimensional model (Fig. 7.14A) and a near-identical example discussed by Hill & Schorsch (2005) (Fig. 7.14B). The latter features three cores (in the sun disk/*uraeus*, body and base, lower legs), solid feet and core supports (Hill & Schorsch 2005, 172).

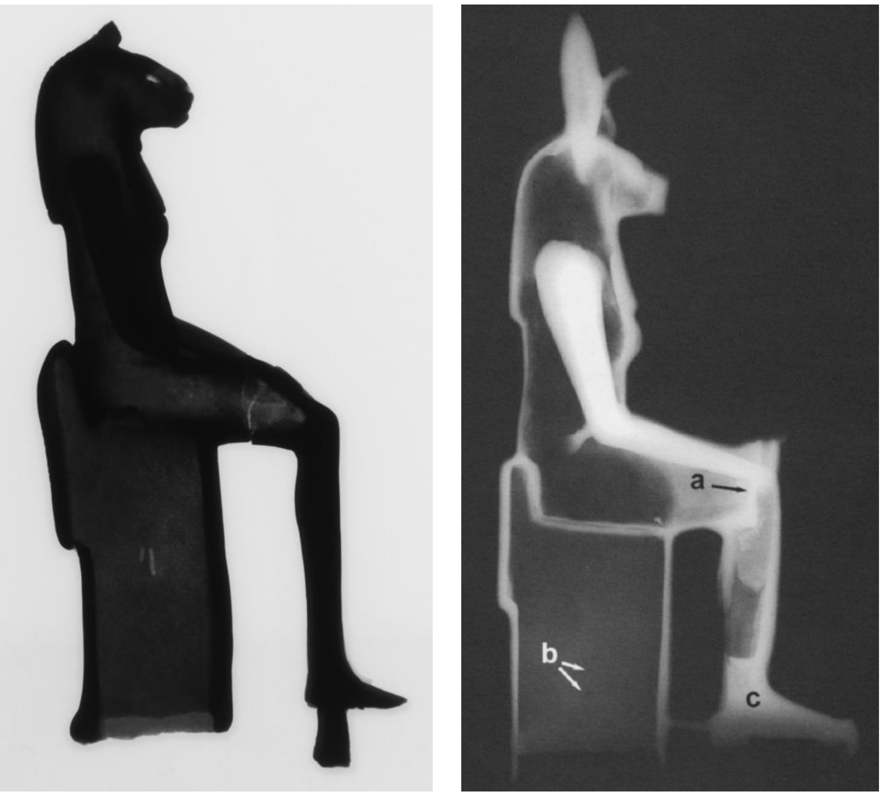

Figure 7.14: Three-dimensional model focused Wadjet-Bast (A) and a near-identical example (B). The latter features core pins (indicated by (b), but are not highly visible in this image. ***Source:*** Hill and Schorsch (2005, 172).

The horizontal position of the core holes, along the z-axis (horizontal) (Fig. 7.15A-C), provides further evidence in support of their presence as purposeful additions and not randomised anomalies. Similar features are visible on the back of Wadjet-Bast's headdress (Fig. 7.16A-C) and chest (Fig. 7.17A–C).

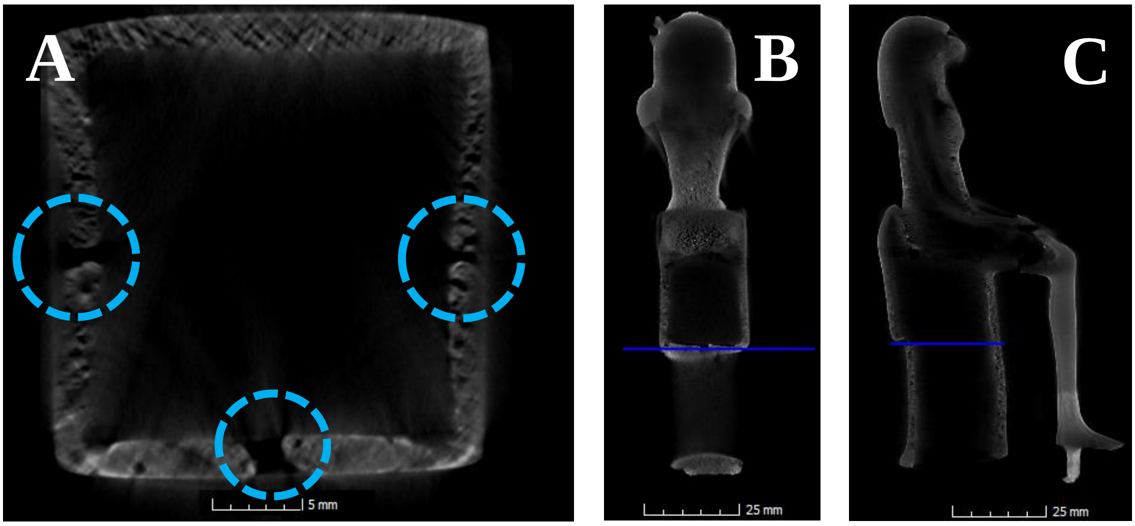

Figure 7.15: Three casting holes are visible along the same z-axis (horizontal) (B), with the position of the z-axis slice indicated (B–C).

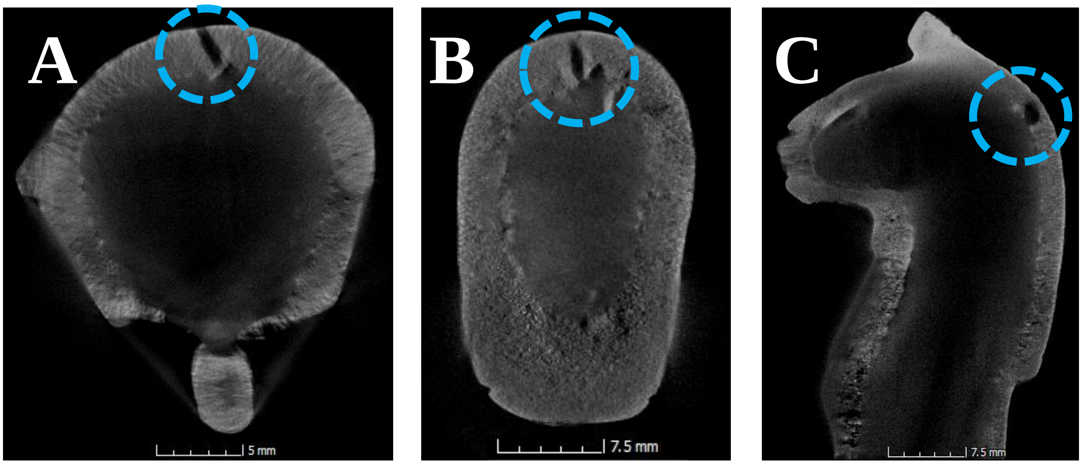

Figure 7.16: Casting holes on the back of Wadjet-Bast's headdress, as seen along the z (A), y (B) and x (C) axes.

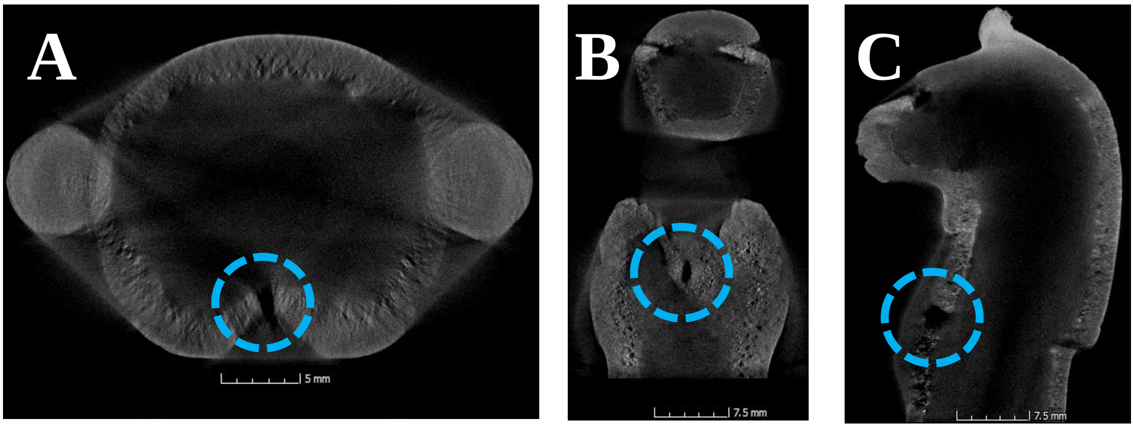

Figure 7.17: Casting holes on Wadjet-Bast's chest, as seen along the z (A), y (B) and x (C) axes.

In contrast to the casting pins identified by means of NT by Agresti et al. (2016), the phenomena described above are clearly casting *holes* and not pins. In case of the latter, pins made from the same material (bronze) as the superstructure would have been employed. In instances where iron pins were used, the now corroded iron, having a different X-ray attenuation level compared to the surrounding bronze, would have stood out clearly (Fig. 3.22). In the case of Wadjet-Bast, there is no visible differential attenuation, and the appearance of the casting holes are radiotransparent, as opposed to the radiopaque appearance of core pins. However, Schorsch and Frantz (1998, 22) mention that casting pins may not always last through the centuries, as the iron would corrode away in situ.

Most importantly, clear visual correlations can be drawn between the casting holes identified on Wadjet-Bast, and those identified in the works of Schorsch and Frantz (1998) (Fig. 3.18) and Ambers et al. (2008) (Fig. 3.20B). The holes can also be compared with a striking example of a Wadjet statue from the Brooklyn Museum in New York (Fig. 7.18).

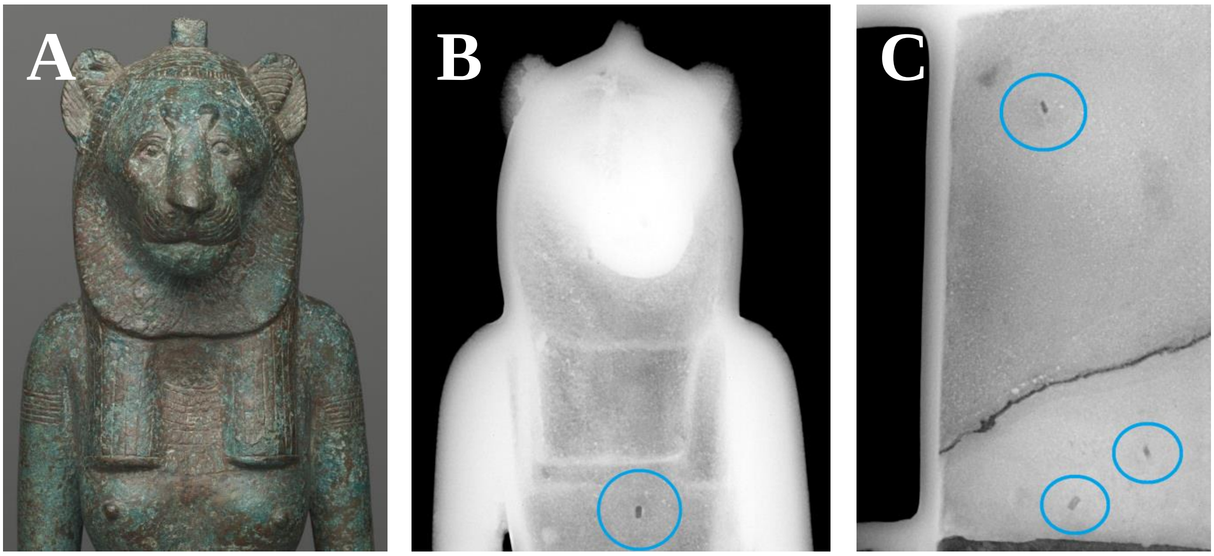

Figure 7.18: The Brooklyn Museum Wadjet (A), with casting hole visible in the chest area (B) and more along the sides of the throne (C).
***Images courtesy of**:* Lisa Bruno, Brooklyn Museum, New York.

Although internal voids can often be dismissed as random anomalies, the mirrored position and similar size of these holes (Table 7.1) indicate that they were purposefully created.

Table 7.1: Casting hole sizes on the Wadjet-Bast statuette: Width, height and depth dimensions were captured from the axial view (X, Y or Z) which provided the most clarity for measurement

Position	Width(mm) Z-axis	Height(mm) Y-axis	Depth(mm) X-axis
Throne-back-backrest	2.21	0.60	1.98
Throne-left	0.88	5.09	2.10
Throne-right	0.76	2.81	1.55
Chest-front	0.77	2.20	2.12
Back: below-headdress	2.48	0.90	2.66
Head-top-back	0.73	2.16	2.58

Lastly, the fact that these holes were not visible on the surface during the digital microscopy phase (Fig. 7.19A) supports the practice of post-cast filling and smoothing. Upon closer investigation, one can actually observe a microscopically thin layer of bronze covering each casting hole (Fig. 7.19B).

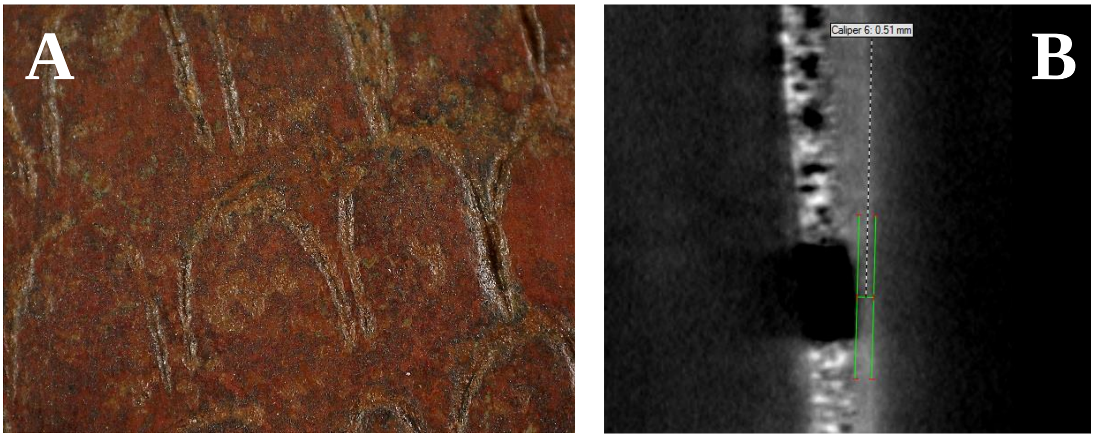

Figure 7.19: The right side of Wadjet-Bast's throne by means of digital microscopy (A) and a thin (0.51 mm) layer of bronze covering a casting hole (B).

In terms of relative chronology, since the oldest known examples of hollow statuary date from the Middle Kingdom (Schorsch 2007, 192), the Wadjet-Bast statuette cannot predate this point in time, affording it a relative "post-Middle Kingdom" date.

7.2.4 Ear Holes

Votive statuettes were usually adorned with clothing and jewellery, and were routinely presented with food offerings and incense. Ears often feature holes through which decorative earrings were placed. On Wadjet-Bast, the right ear hole (Fig. 7.20A) is still clearly visible, while the left ear hole (Fig. 7.20C) appears blocked. It was unclear whether the missing hole was a casting defect, or whether the cavity was closed due to corrosion. The X-rays were able to see through the corrosion material to reveal that the left ear once featured a hole.

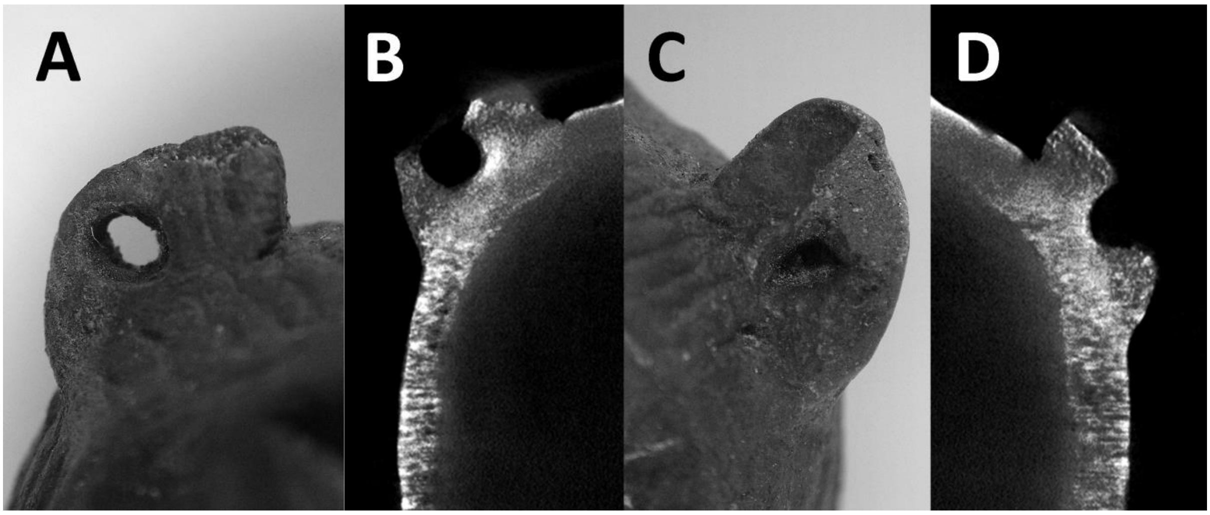

Figure 7.20: The Wadjet-Bast statuette's earholes: Close-up photograph (A) and tomogram (B) of the right ear, and close-up photograph (C) and tomogram (D) of the left ear.

7.2.5 Breaking Points

In general, breaking points are associated with weakened cores and the compromised state of metals due to mineralisation, which are often coupled with external pressures, such as excessive handling (Smith et al. 2011, 227). In addition, ancient manufacturing techniques and casting errors themselves may also contribute to the risk of breaking. For example, as the arms, legs, torso and head of more complex items were cast separately and attached using joints (Smith et al. 2011, 222), weak points were inevitably created. Because these areas (especially the head, neck) already represent weak points along the construction, the addition of casting errors directly increases the breakage probability[184] (Ghoniem 2014, 42).

The seated child Horus, investigated by de Beer et al. (2009) and Smith et al. (2009; 2011), was broken during restoration work at the museum and subsequently restored. It has a diagonal crack running from the left arm, across the lap and towards the right hand (Fig. 7.21A). Interestingly, the Wadjet-Bast figure is broken at a similar location, suggesting that a structural weakness existed along this specific region of seated figures (Fig.7.21B).

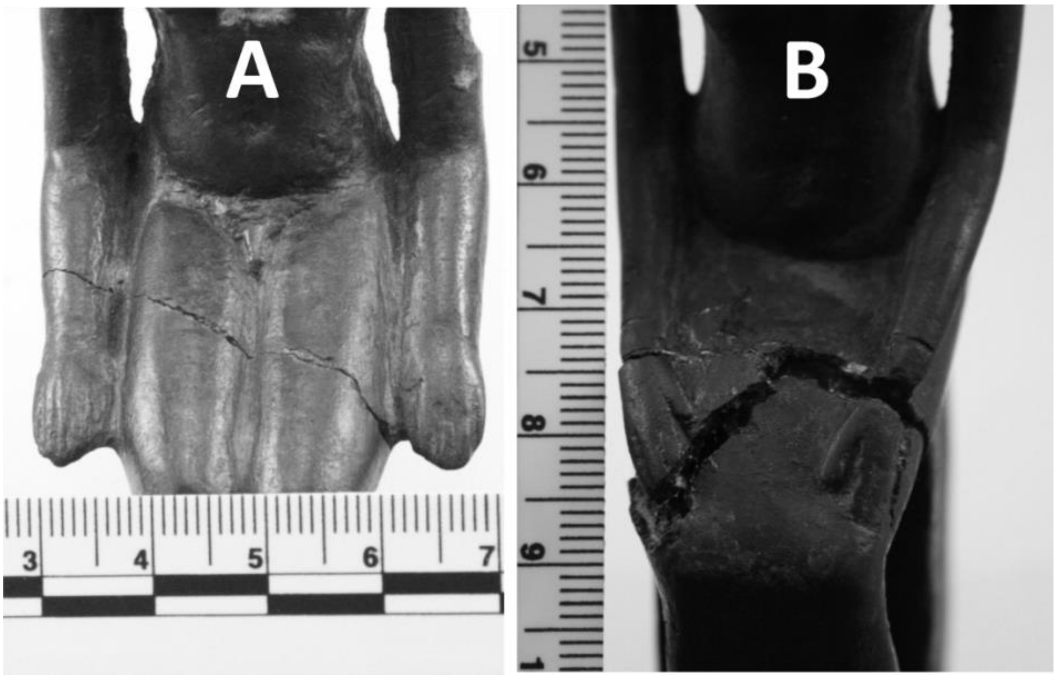

Figure 7.21: Side-by-side comparison of the Child Horus (A) and Wadjet-Bast (B) statuettes showing similar breakage points.

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[184] An additional factor to consider is the possibility that chaplets may cause casting defects or structural weaknesses (Degarmo et al. 2003, 314), but no such correlation has been identified by local researchers.

From the side-view neutron tomogram of Horus (Fig. 7.22A) and the side-view X-ray tomogram of Wadjet-Bast (Fig. 7.22B), there appears to be some internal structural similarities between the two objects. Both items appear to have solid cast legs, with the internal clay core (Horus) or hollow cavity (Wadjet-Bast) extending towards the knees. It appears as though the point where the solid casting meets the eternal hollow or clay core, could be a weak point in the construction. Also, when considering the angle of the lap area, the discontinuation of solid (strong) metal, coupled with the applied downward force when placing these items on their wooden thrones/pedestals, one can expect breakages to occur.

The above-mentioned explanation is focused on pressure points and larger structural weaknesses that relate more closely to physics than chemistry. However, the chemical composition of an object may result in microstructural arrangements that are in turn associated with structural weaknesses. For example, in the research of Schorsch and Frantz (1998), Energy-Dispersive X-Ray Spectrometry (EDS) found that the overall bulk alloy composition of the “large cat” was around 92 wt% copper, 4-5% tin, and under 4 wt% lead, with a high lead area representing a local heterogeneity. Because copper-lead alloys are known to be heterogeneous in their microstructure – a characteristic confirmed in this case by optical photomicroscopy – the abundant fractures that were sustained by the object during its lifetime were by no means surprising (Schorsch & Frantz 1998, 25–26).

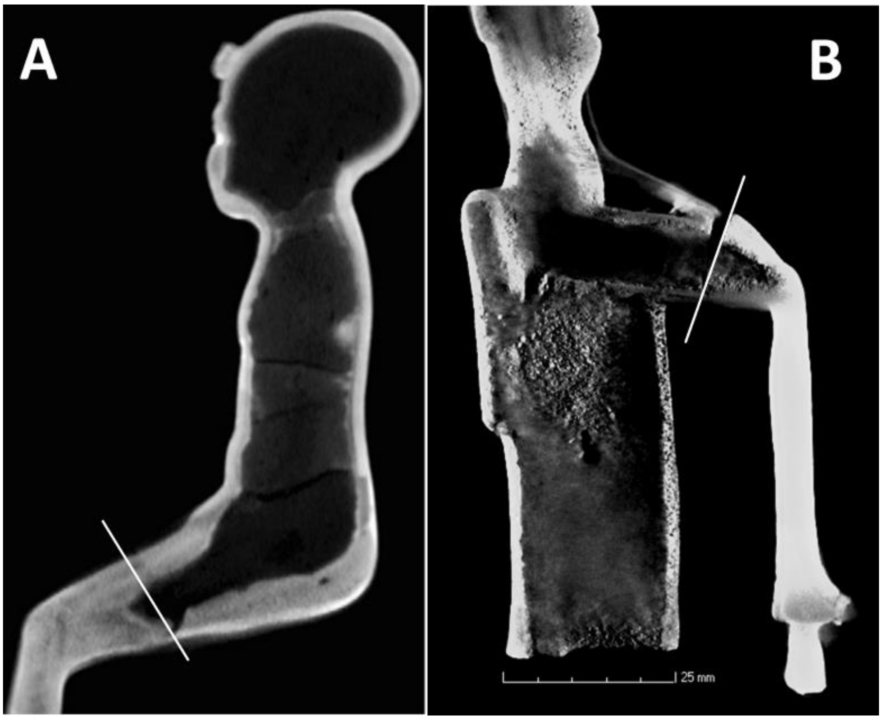

Figure 7.22: Side-by-side comparison of the Child Horus (A) and Wadjet-Bast (B) statuettes.
Source: Horus: Smith et al. (2011, 224).

7.2.6 Wall Thickness and Porosity

Ranging between 2.21 and 2.48 mm, the Wadjet-Bast statuette displays an impressive level of consistency in terms of its steady tracking of inner and outer contours. This characteristic suggests indirect wax application to the mould, as suggested by Bettuzzi et al. (2015, 1166).

Upon closer investigation, the overall cast appears somewhat porous. According to Schorsch and Frantz (1998, 22), hollow cast bronzes from the first millennium boast low-porosity casts. This phenomenon is attributed to the addition of lead to tin-bronze to reduce the melting temperature, make it more pourable (Scott 2002, 3) and subsequently less prone to the formation of gas pockets (pores) (Ogden 2000, 154). While lead percentages rarely rose above 2% until the late New Kingdom (1300–664 BCE), high lead levels became characteristic during the Late Period (334–332 BCE), with Ptolemaic (323–30 BCE) objects containing as much as 30% lead (Ogden 2000, 154-155).

With all things considered, Wadjet-Bast's porous nature could be indicative of a low-lead tin-bronze that pre-dates the Late Period. This falls in line with the DNMCH's proposed New Kingdom timeframe for Wadjet-Bast, with the possibility of an 18th Dynasty production date seeming quite likely.

7.2.7 Discussion

Preliminary findings by means of MXCT suggest that the Wadjet-Bast figure is indeed authentic. Although MXCT was used instead of NT, the visual data corresponds with certain phenomena identified by De Beer et al. (2009, 170), Masiteng et al. (2010), Gravette (2011) and Smith et al. (2008; 2011).

In addition, new phenomena were identified that are unique to hollow cast statuettes, such as the use of casting holes. Parallel and intersecting striations on the body of Wadjet-Bast and four other bronzes were identified as possible polish marks, which are indicative of post-cast refinement. The rectangular shape of the tang is typical of New Kingdom statuettes, which might move the production date of the item along by a century or two (perhaps around the beginning of the New Kingdom in 1570 BCE). The presence of functional earholes indicates that it was most probably a votive figure, and would have been decorated using earrings and other decorative items.

The level and extent of corrosion is generally considered as a good indication of authenticity, as extensive malachite (copper carbonate corrosion) deposits underneath bronze casts take centuries to form. Considering similarities between Wadjet-Bast and the child Horus statuette in terms of corrosion, one could safely say that the former is at least within the same age range as the latter.

Unfortunately, the low penetration depth of X-rays restricts the visibility of internal features. Because of this, it would be beneficial to future research to utilize the advanced radiographic capabilities of NT. Furthermore, the future application of analytical techniques, such as ND, XRF and EDS, can provide quantitative data in terms of elemental composition. By analysing both the physical and chemical characteristics of these objects, we should begin to understand why certain alloys were chosen above others. Elemental analysis will also help us to assign production dates to the items based upon the known preference for certain materials across Egypt's ancient history.

7.3 SAMURAI HELMET

During the 2012 study conducted by Teichert, Smith and Collopy, the Samurai *kabuto* was subjected to both cold neutron and traditional x-radiation, with the primary purpose of trying to identify a maker's mark within the internal surface of the helmet dome. However, neither techniques were able to inconclusively confirm or dismiss the presence of a maker's mark. The techniques did however prove useful in illustrating how the individual plates of the helmet fit together and also identified the existence of a smooth layer of corrosion on the internal surface of the dome (Teichert, Smith & Collopy 2012, 66).

When the researcher approached Teichert and Smith about the possibility of performing a second round of nuclear imaging, both Teichert and Smith agreed that, considering the technological advancements made over the past five years, it would be worthwhile to investigate the helmet once again. Frikkie de Beer from NECSA provided his full support, suggesting that the higher resolution provided by the upgraded instrumentation may reveal additional information not seen before.

However, a word of caution must be spoken on the subject of maker's marks on Samurai armour. Firstly, one should consider the placement of these marks. It appears as though the majority are located on the chest-plate or *cuirass*. For example, in a Momoyama Period (17th century) suite of armour, the back of the *cuirass* was inscribed with the name *Honda Takumi No Suke*, possibly referring to the armourer (Ogawa 2009, 94). On a positive note, although the majority of maker's marks where inscribed on *cuiriases* and *kabuto*, it does not mean that maker's marks weren't encountered on other objects, such as *menpó*. However, one must still remain cautiously optimistic when expecting the presence of maker's marks elsewhere other than the cuirass.

Secondly, one should consider the intended visibility of these marks. In examples of marked/signed *kabuto*, the maker's mark appears on the inside of the helmet. In some instances, a slit was left in the helmet lining in order for the maker's mark to remain visible. With the latter stated, it does not appear as though maker's marks were generally covered-up. In fact, one would imagine a maker's mark to be comparable to a modern-day brand logo, such as Nike or Adidas – something the owner could be proud of and eager to showcase to other Samurai. In short, this means that researchers in search of these marks should remain cautiously optimistic when searching for maker's marks underneath painted, lacquered or lined surfaces.

7.3.1 Rosetted Grommet (*tehen kanomono*)

The manner in which the overlapping plates of the *kabuto* join together at its pinnacle is a fascinating point of discussion. Not only did the joinery require great technical prowess on the part of the ancient armourer, it also demanded ingenuity. The latter resulted in the creation of a rosetted grommet; a functional component masked by its own aesthetics. The structural composition of the grommet and its surrounding, sequential rings was revealed by MXCT.

The grommet itself (Fig.7.2.2) is a simple metal tube (a) with a rimmed topmost part that bends downwards (a1). The downward facing rim not only presents a well-rounded appearance, from an aesthetic point of view, but also acts like the "fixed jaw" of a g-clamp. Once the opposite end of the grommet (or "moveable jaw" – a2) is bent into position, pressure from both ends draws the grommet rim (a1), rosettes (b to e) and helmet plates (f) into position.

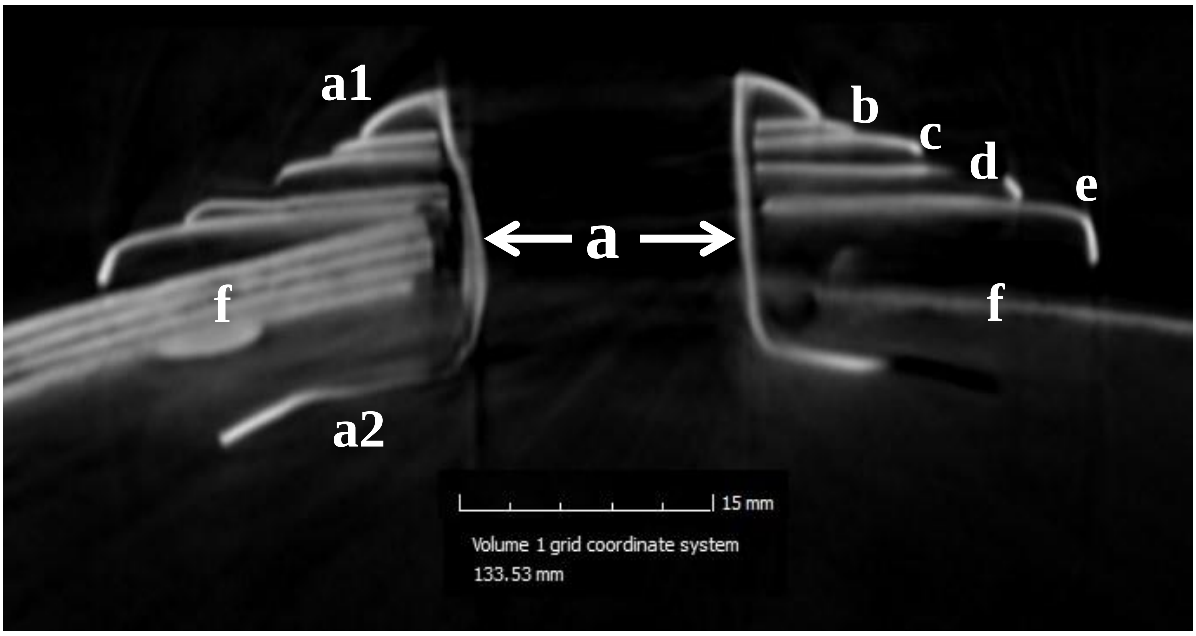

Figure 7.23: Side-view tomogram showing the *kabuto*'s *tehen kanomono*.
The grommet tube (A), rosettes (B-E) and helmet plates (F).

The entire assemblage was designed to counteract and contain the outward force or spring-action of the helmet plates. The circular rosettes also act as spacers between the grommet itself and the helmet plates, a design feature which aided the dispersal of energy during impact.

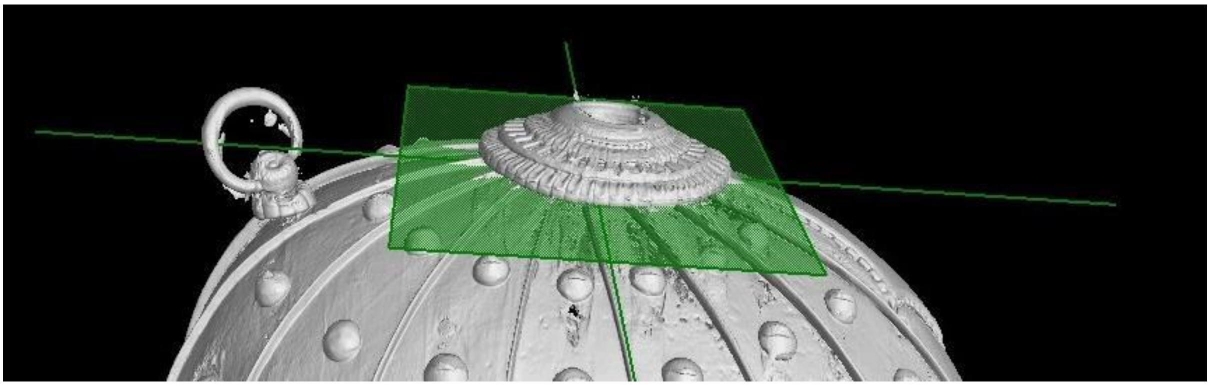

Figure 7.24: Position of the sectional slice (Fig. 7.23), taken just below the *tehen kanomono* in order to isolate the grommet.

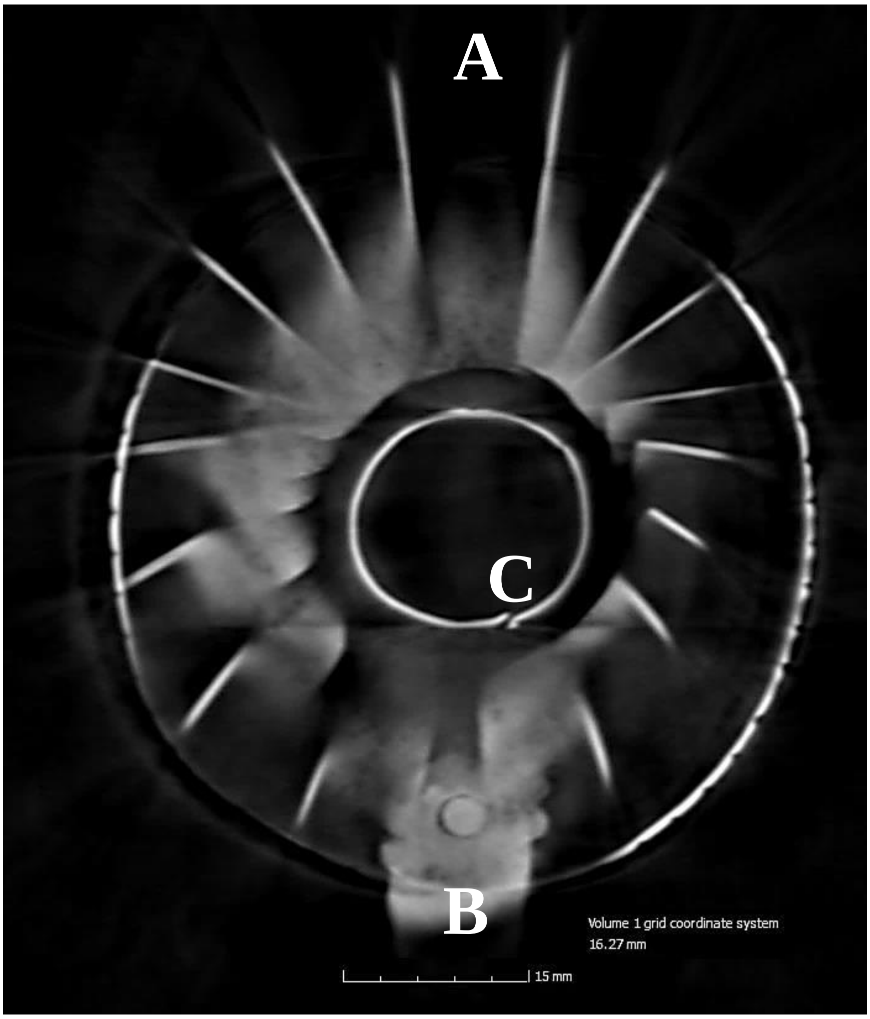

Figure 7.25: Shape of the grommet inside the *tehen kanomono*. The tube itself was constructed from a flat metal plate that was bent into shape. The opposite/joining edges are clearly visible (C). (A) indicates the front of the *kabuto*, while (B) indicates the back.

7.4 SAMURAI MASK (*MENPó*)

We were hopeful that the *menpó* would boast some form of maker's mark underneath the remaining internal lacquer coating. Although radiation transmission through the object was of a high level, resulting in the clearest (least amount of artifacts) images of the entire study, no maker's mark could be identified. However, this does not formally exclude the possibility that a maker's mark exists underneath the lacquered surface. All we can say with certainty at this point is that MXCT may not be adept at revealing such markings.

7.4.1 Antique Repair Work

As noted previously, the *menpó* underwent repair work during its manufacture or time of use. While a basic investigation by means of digital microscope served as sufficient proof of the mere existence of repair work, MXCT has the potential to elucidate the actual contemporaneity of the bracket in relation to the mask. In other words, we need to ascertain whether the bracket's material composition corresponds closely enough to that of the mask itself to suggest they were made from the same metal.

For such an analysis, we rely on the grey-scale appearance of the bracket and the mask substrate as our starting point. As noted from the individual tomographs (Fig. 7.26), the bracket does not stand out significantly from the mask itself in terms of colour contrast. In simple terms, the bracket's appearance can be likened to that of a double layer of the same metal. In addition, there is no observable difference in texture. This homogeneity between the plaque and the metal substrate indicates a direct relation between the two components in terms of metal composition. Another type of metal or metal alloy would have displayed a significant amount of colour contrast and a variation in texture.

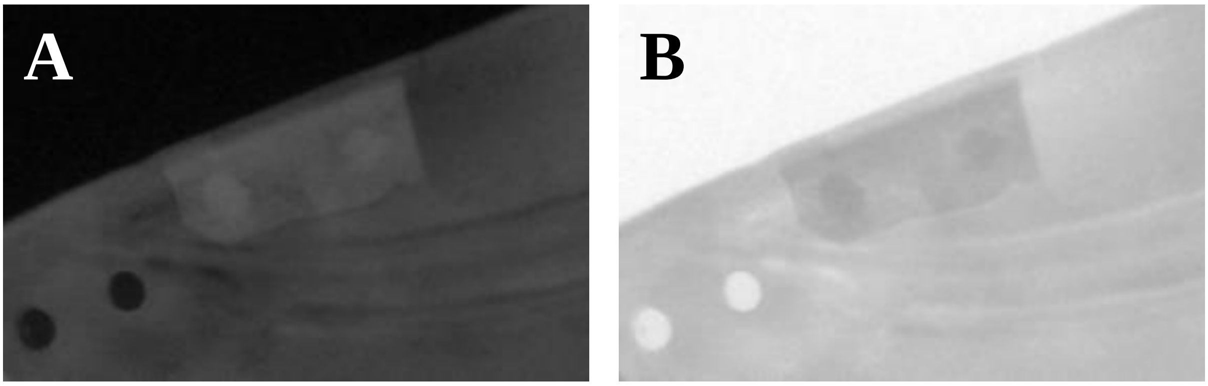

Figure 7.26: Antique repair work on the *menpó*. The original tomograph (A) and one displaying colour inversion (B).

Apart from the grey-scale appearance, the level of porosity also provides insight. Since the superstructure and the bracket are almost identical in terms of their porosity, which is very low and homogeneous, one can deduce that they are made from a closely related or identical material.

7.4.2 Maker's Mark

The search for a maker's mark was approached from a cautiously optimistic angle. As mentioned earlier, lacquered areas on the internal surface of the *menpó* could potentially hide an underlying maker's mark. Unfortunately, no evidence of a maker's mark could be found (Fig. 7.27).

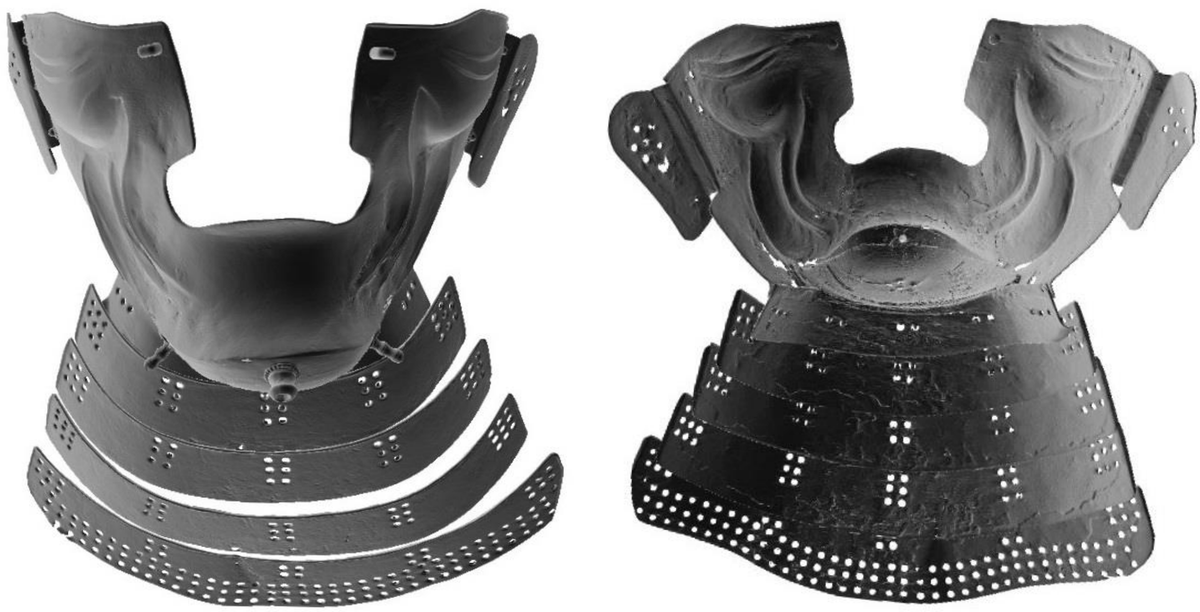

Figure 7.27: No maker’s marks could be identified on the external (A) or internal (B) surfaces of the *menpó*.

7.5 TOWER OF LONDON GAUNTLET

Before discussing the observed phenomena, it must be noted that the ToL gauntlet had to be scanned in two parts, owing to its size. For ease of reference, the two sections are referred to as the “hand” and the “elbow”.

7.5.1 Radio-transparency of the Internal Fabric and Leather Lining

From surface investigations, it is quite apparent that the external surface of the ToL gauntlet is polished, but no textural information is available on the internal surface, as the gauntlet features a leather glove. The object therefore provided us with the unique opportunity to demonstrate MFXCT’s proficiency at seeing “through” radiotransparent organic components. As is clear from Fig. 7.28, the external surface appears smooth (texturally) in comparison to the rough, almost pockmarked appearance of the internal surface.

7.5.2 Rolled Edges and Internal Wire Structure

Different plate armour components had one particular design aspect in common; they were mostly made from sheets of metal that were cast, bent or hammered into shape. Since sheet metal presents the fabricator with sharp edges, these edges had to be bent over in order to prevent injury to the wearer. On straight planes, the bending process was fairly simple, but curved or rounded planes would have presented a challenge.

As described in Chapter 6, three basic methods of shaping were employed, the application of which depended on the working surface being straight, outward or inward planes. In general, the rolling process has to be executed with a great amount of patience and precision, as unwanted stretching and/or compression can result in an uneven roll. Sectional slices (such as those observed in Fig. 7.28) along the proximal (elbow) edge of the gauntlet revealed an internal phenomenon that resembles a thick wire (Fig. 7.29A–B and 7.30).

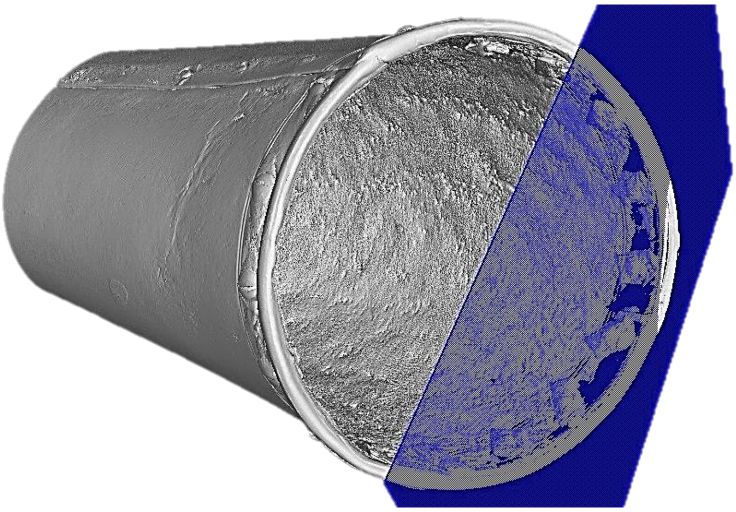

Figure 7.28: General position of the sectional slices through the elbow-edge of the gauntlet.

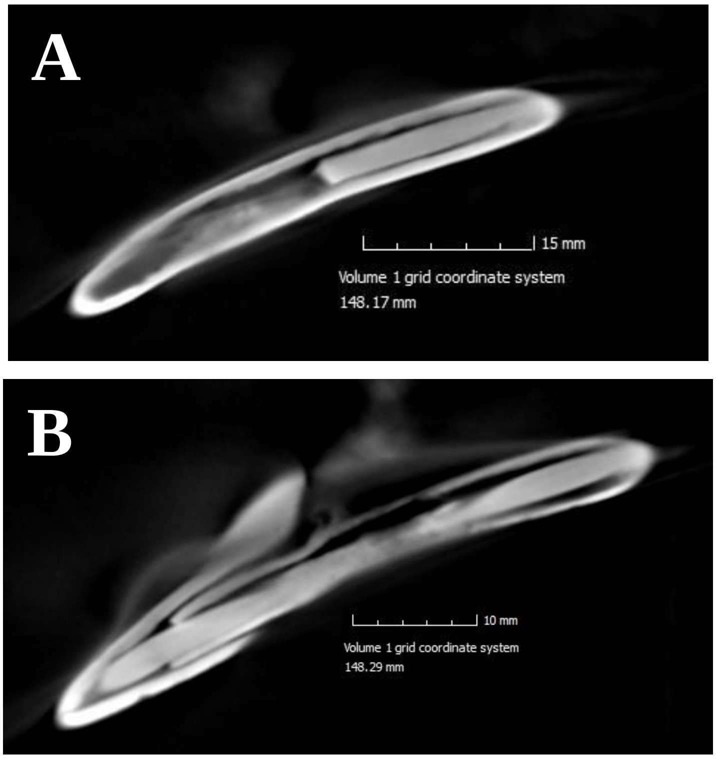

Figure 7.29: The internal wire-like component of the gauntlet's edge.

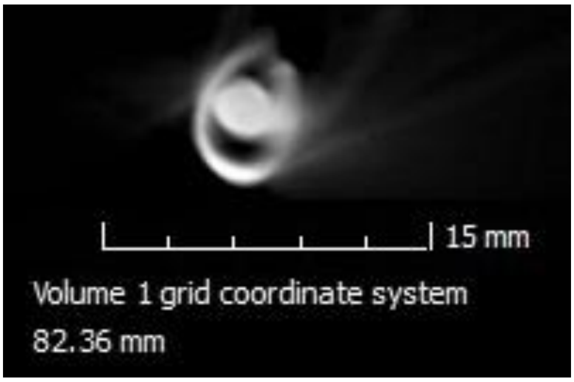

Figure 7.30: A cross-sectional view of the internal wire-like component.

Internal wires would have assisted in the rolling action, as it helped maintain the shape of the curved plane. Dupras (2012, 93) confirms that this practice was common, and notes that rolled edges would have been essential in avoiding injury (cuts and abrasions), especially along moveable edges, such as those found along the inner elbows and the bottom edges of helmets. Apart from protecting the wearer and adding aesthetic appeal, rolled edges also increase the strength and structural integrity of the piece. Two examples (Fig. 7.31A–B) of internal wiring are visible on the Pembridge helm and an Italian sallet (dated 1470 CE) documented by Dupras (2012).

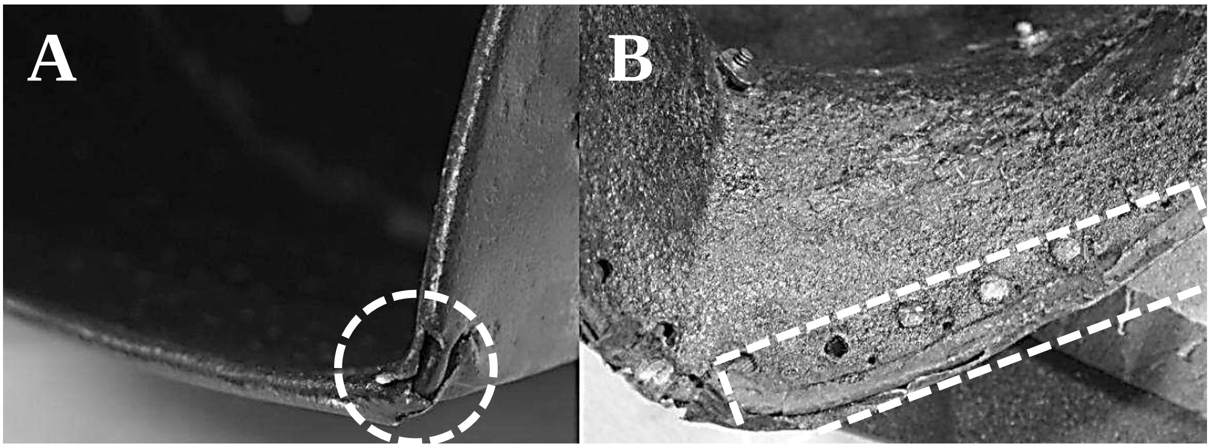

Figure 7.31: The Pembridge helm (A) features round wires while its Italian sallet counterpart (B) boasts flat wires. ***Source:*** Dupras (2012, 488).

It is also possible that these wires could have been used as a sizing instrument, as the wire could be sized in accordance with the intended user’s specifications (arm and wrist circumference, for example). Although armours were mass produced, especially for common infantry, some form of measuring and custom sizing would have been essential, since the principle of ‘‘one size fits all” would not have applied to rigid, non-flexible materials such as plate armour. However, no specific mention of the practice was encountered in any of the literatures consulted, so this assumption cannot be verified at present.

The three-dimensional imaging and don-destructive exposure of internal features once again proved highly valuable. Within the DNMCH, none of the armours boast damaged or corroded rolled edges that could have exposed internal wire structures during surface evaluation.

7.5.3 Internal Square Washers and Edge Cracks

From surface investigations, it was clear that rivets were used to secure the leather glove to the edge of the gauntlet. While the rivet heads were clearly visible, internal features, such as washers, were hidden from view by the glove. X-ray images (Fig. 7.32) reveal the presence of rectangular-shaped washers. Interestingly, the washers display a fair amount of randomisation, as they all differ slightly in both size and shape. This suggests that washers were made from off-cuts or scrap materials and, since they were hidden from view by the glove, it did not matter what they looked like. While the rivet heads serve both practical and aesthetic functions, internal washers were purely utilitarian.

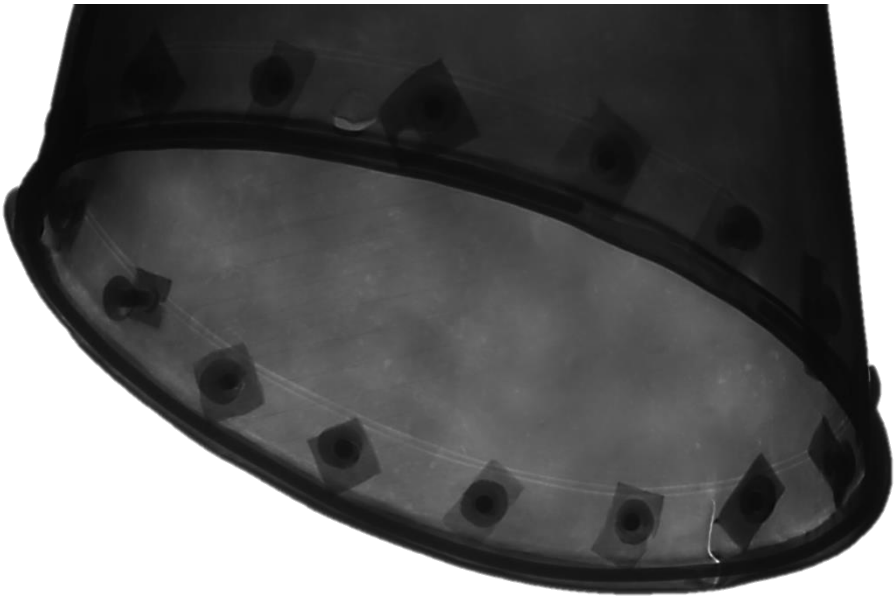

Figure 7.32: Internal square washers are clearly visible under X-rays.

Rectangular, irregularly-shaped washers also appear on the ToL helmet (Fig. 7.33A), and were most probably used to secure the internal fabric lining to the pot itself. An almost identical arrangement of washers and fabric remnants can be observed from a *zischägge* (Fig. 7.33B) dated to the 17th century.

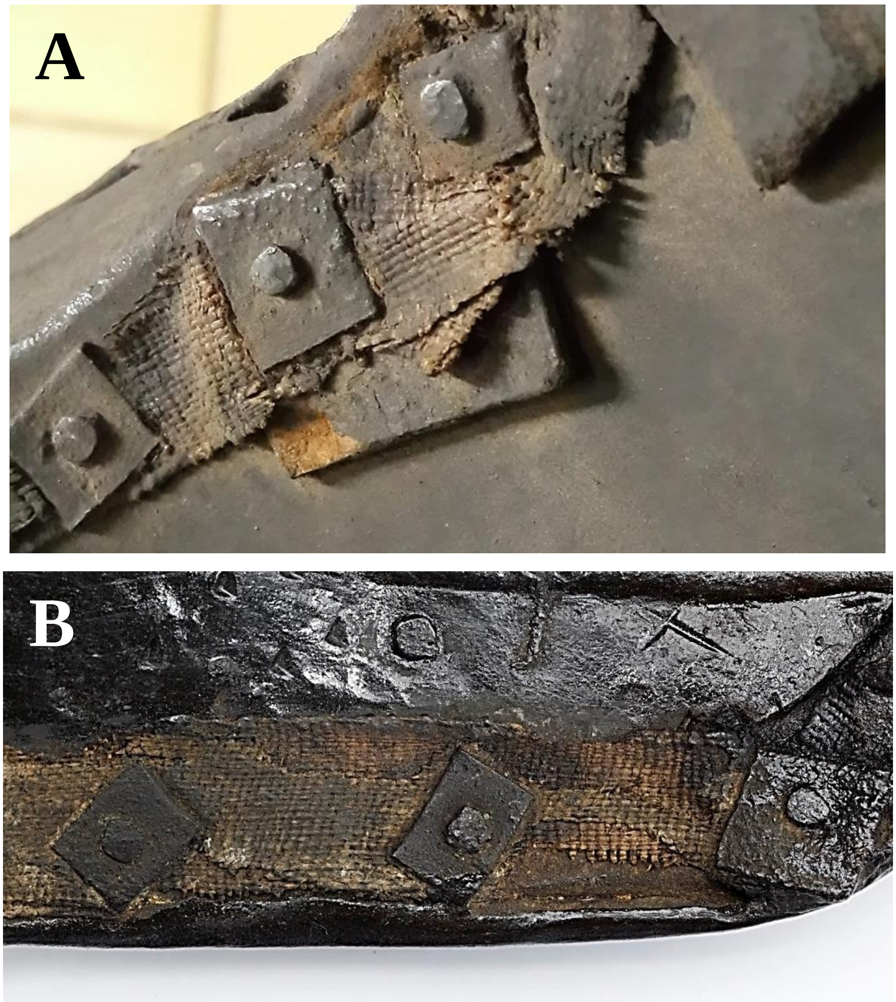

Figure 7.33: Comparison between rectangular washers from the ToL helmet (A) and a 17th century *zischägge* (B).
Source: Royal Armouries, London.

What makes this comparison between the ToL gauntlet and the *zischägge* above significant is the confirmation that rectangular, irregularly-shaped washers were indeed a common feature of armours during the proposed period of origin for the DNMCH objects.

The crack that was identified during surface investigations becomes even more apparent (Fig. 7.34). The radiopaque nature of the surrounding metal allows the radiotransparent crack to become clearly visible. As postulated during surface investigations, the crack could possibly have been repaired along the internal surface, but no repair brackets are visible.

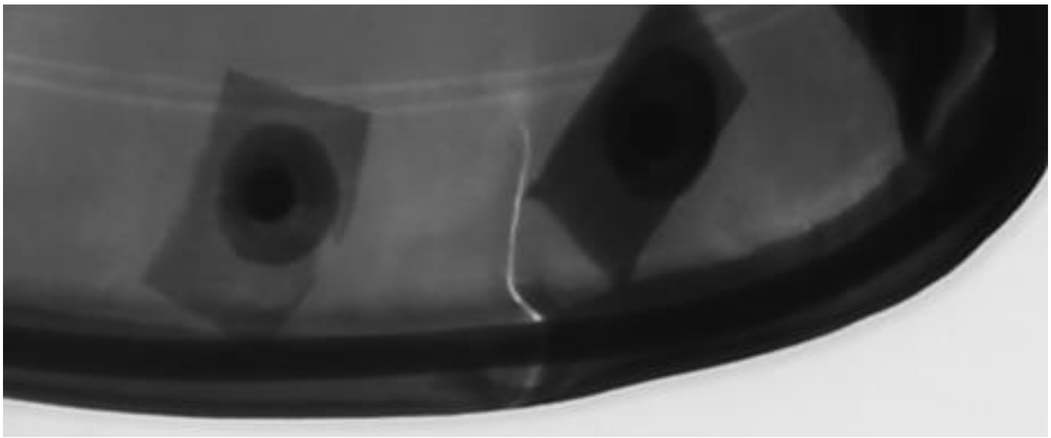

Figure 7.34: A radiotransparent crack along the ToL gauntlet's proximal edge.

As can be observed in Fig. 7.34, X-rays of the rolled edge provide supporting evidence for the presence of an internal wire structure, as the object itself appears much darker (high attenuation) than the surrounding rolled metal.

7.5.4 Metal Porosity

Metal porosity can be an indicator of corrosion, but since the external surface of the metal is in a good condition, it is more likely that porosity represents inhomogeneity caused by metal composition, casting techniques and hammering. A sectional slice through the gauntlet (Fig. 7.35) presents us with a side view of internal metal porosity (Fig. 7.36).

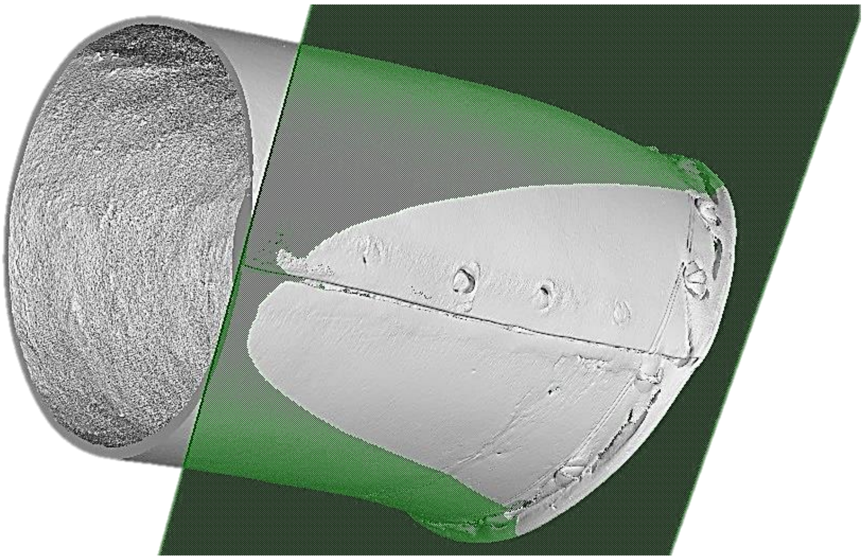

Figure 7.35: Position of the sectional slice along the length of the gauntlet.

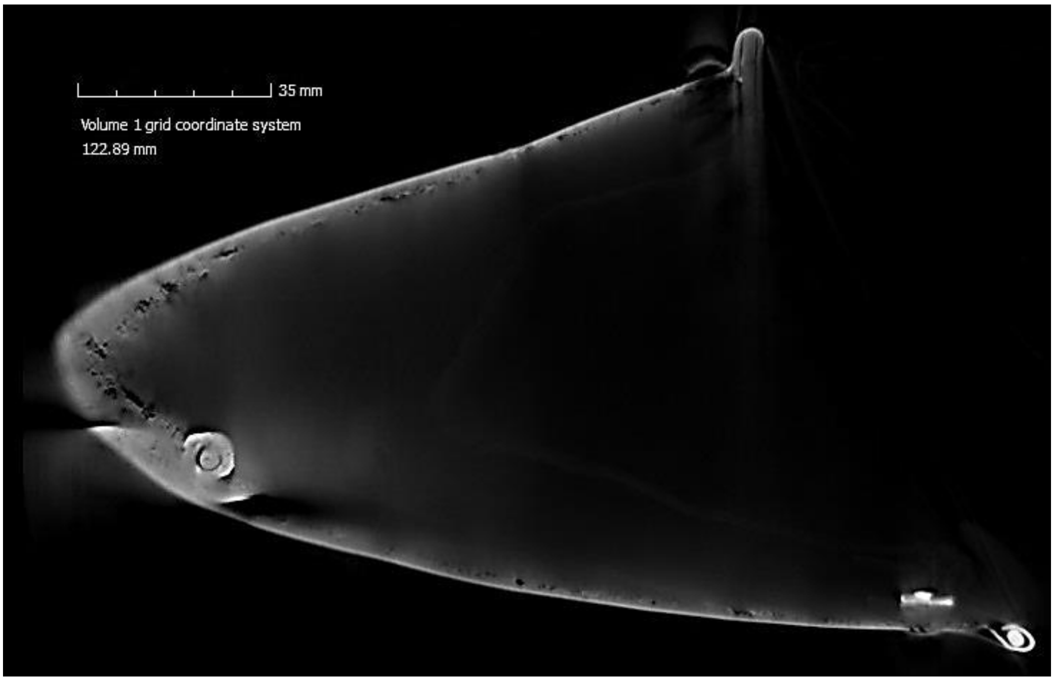

Figure 7.36: Pores appear as radiotransparent (black) spots within the solid radiopaque (white) metal superstructure.

As noted under the discussion on Egyptian bronzes, metal porosity is often the result of rapid cooling, as gas bubbles that form during the casting process are trapped within the metal as it cools down. This phenomenon can be expected from sheet metal, as its relative thinness would naturally result in rapid cooling. However, the outer surface of the metal displays a more radiopaque appearance, which could indicate that the object was cold-hammered. Since cold hammering consolidates metal (Savage 1968, 17), the outer most layers of the metal would be more compressed and would therefore boast a higher level of X-ray attenuation compared to the underlying untreated (not directly hammered) metal.

7.6 ARABIAN DAGGER

The Arabian dagger has been on exhibition at the DNMCH for many years. During this time, it was mounted in the exhibit with the dagger positioned safely within its scabbard. Since the exact condition of the blade itself was unknown, it presented a textbook opportunity to conduct a condition report through non-invasive means. It was therefore decided to scan the dagger within its scabbard by means of MXCT before separating the two components for further visual analysis. In doing so, any possible damage – which could be caused to a corroded blade edge when unsheathing the dagger – would be avoided.

The dagger presented somewhat of a challenge to the NECSA team, as it was too large to scan in its entirety. It was therefore decided to scan the objects in two sections: top (focusing on the handle and top edge of the scabbard) and bottom (focusing on the curved edge and belt).

7.6.1 Blade Condition

Following Deschler-Erb et al. (2004) and Lehmann et al.'s (2005) examples, differential attenuation levels, caused by dissimilar metal/corrosion densities, should allow us to identify areas within the dagger's internal structure that remain uncorroded. Any components and decorations made from non-ferrous materials, as well as welding patterns, should also be observable through differential attenuation (as described by Blakelock 2012).

Despite a fair amount of beam hardening and artifacts, particularly in the regions covered by embossed silver plates, we were able to identify the blade's edge, distinguishing it from the surrounding scabbard. Cross sections of the blade were examined across the length (Fig. 7.37) of the dagger and no visual anomalies, such as the pores that are usually indicative of corrosion, could be detected. In fact, the edge of the blade appeared 'smooth' – despite the extent of artifacts. We were also unable to detect any weld lines or welding patterns.

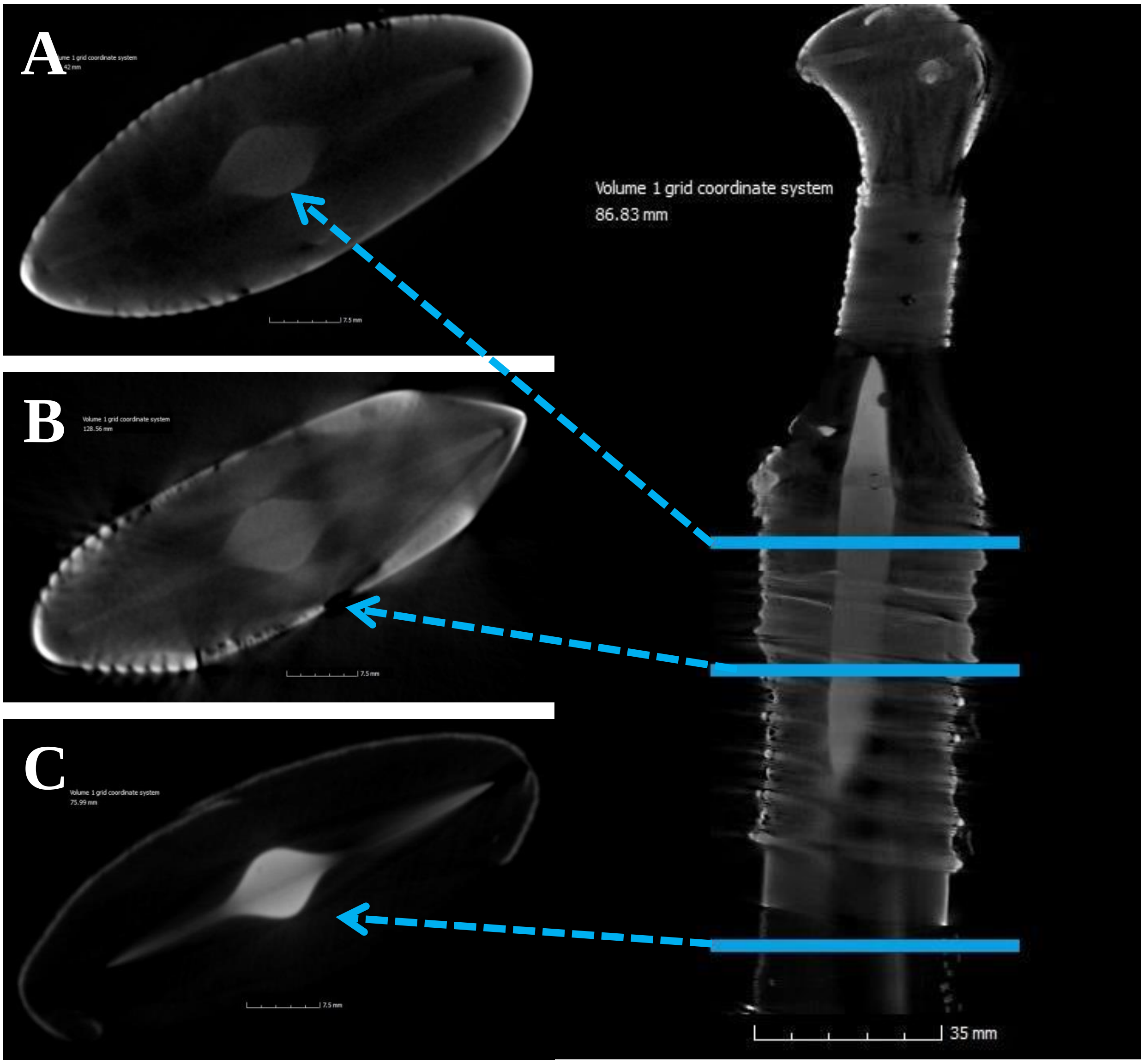

Figure 7.37: Blade condition of the *jambiya* along the length of the dagger.

The medial ridge, which represents the thickest section of the blade, experienced the most attenuation of X-ray beams and is therefore the most well-defined and easily recognisable feature of the blade. The reconstructed 3D model provides some indication of medial ridge shape, while the individual X-ray images provide greater clarity of the blade edge (Fig. 7.38). Since the MXCT images confirmed that the blade was in a good condition, the author felt confident that removing the blade from its scabbard would not cause any damage.

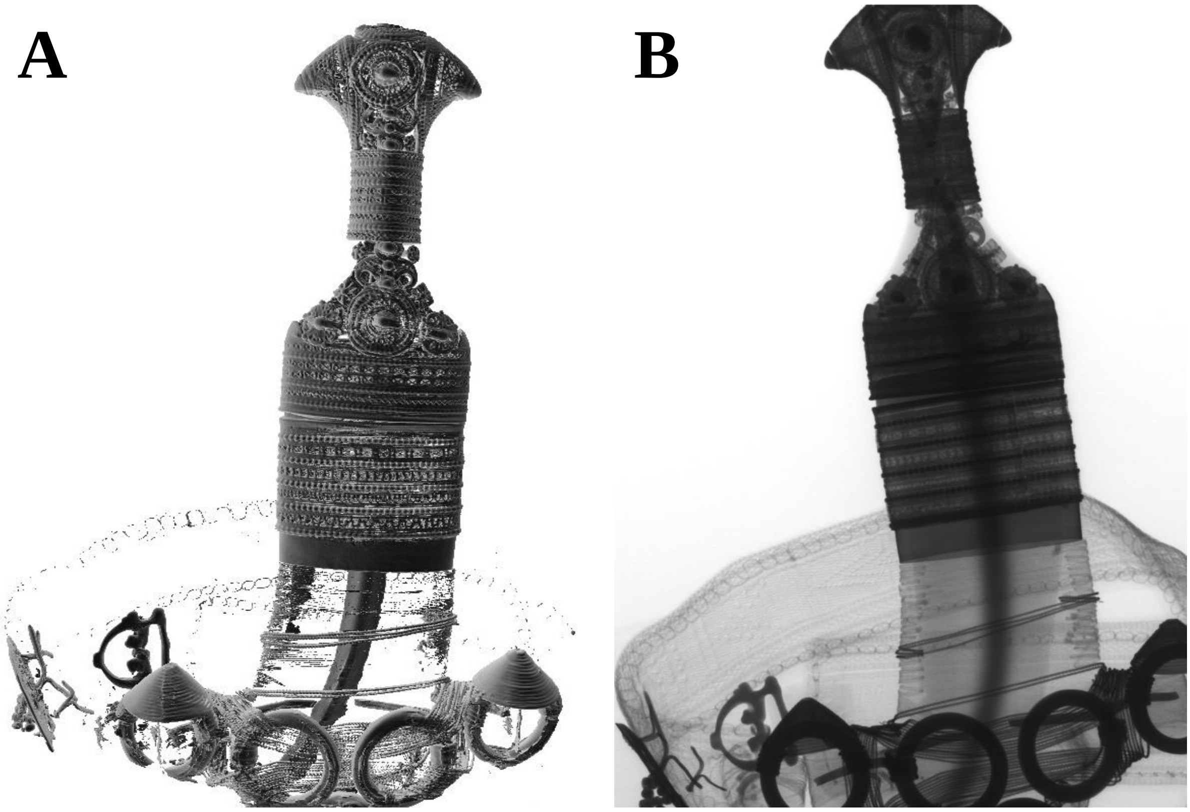

Figure 7.38: The *jambiya*, as observed through a 3D model (A) and 2D X-ray image (B).

7.6.2 Tang Attachments

The flower-shaped pins that appear on the surface of the handle were at first identified as decorative features. As was observed in Deschler-Erb et al.'s (2004) investigation of a Roman dagger, rivet heads are often merely decorative, as no internal structures penetrate through the hilt bar. However, in our dagger's case, radiographs confirm that these decorations are actually the heads of metal pins that enter into the dagger's handle, penetrating the blade's tang (Fig. 7.39). The pins are actually observed going through the tang and stopping against the opposite edge of the handle (a). Interestingly, the second pin (b) is completely missing.

What is interesting is that, although rivet (a) (Fig. 7.39C) is clearly both functional and decorative, the one located in line with hole (b) is only decorative. While it can be argued that the pin located at (b) (Fig. 7.39D) became dislodged at some point, the position of the decorative flower pin (c) would have prevented it from falling out. The argument can also be made that the pin corroded away, but the question would then arise: why would corrosion be limited to a single feature on the entire object? Also, if the handle does contain an adhesive resin (as suspected), corrosion compounds would have become trapped within it and traces of this material would have remained observable.

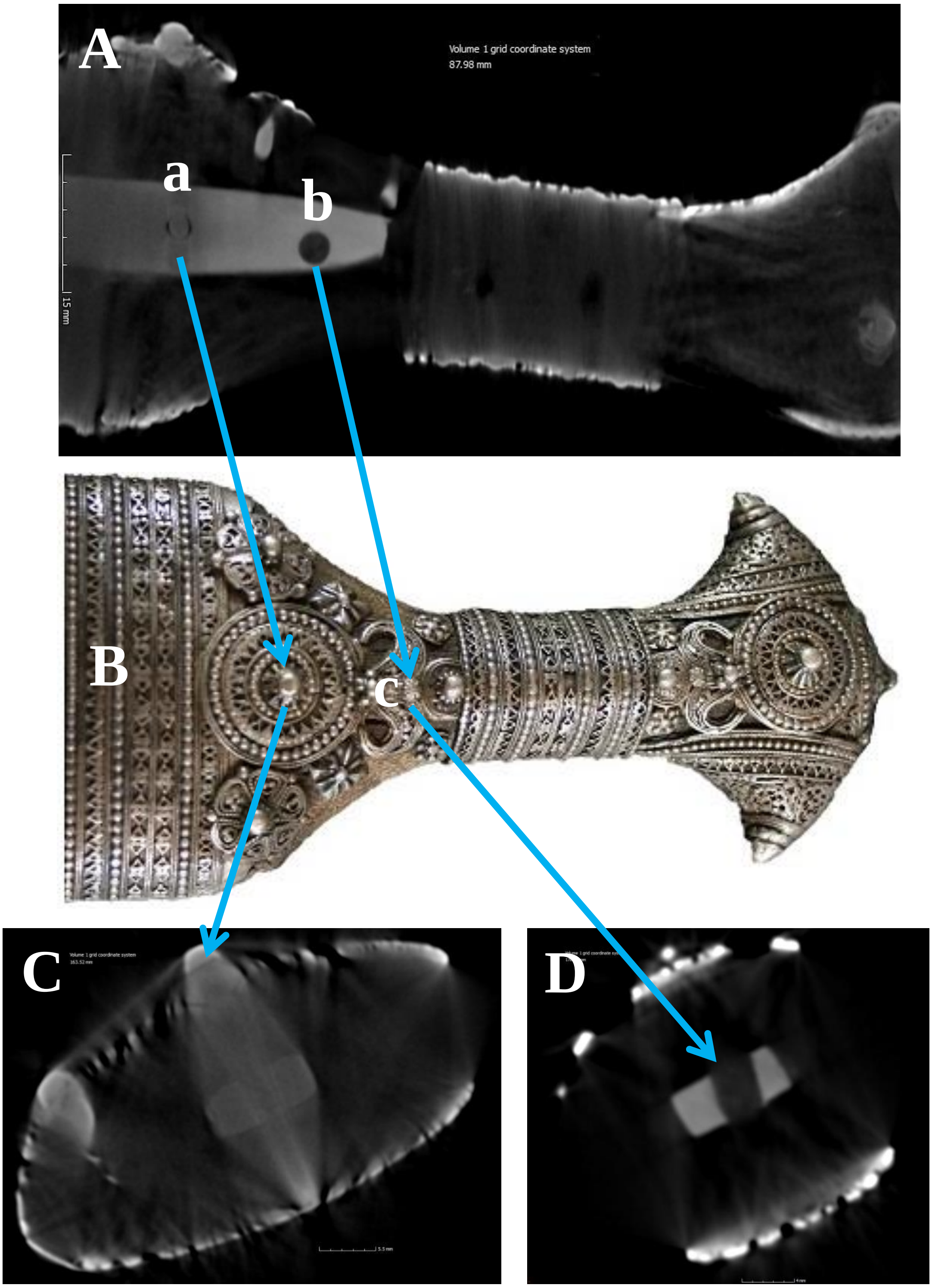

Figure 7.39: The handle of the *jambiya* (A) and the position (c and d) of the lower metal pin (C) and the empty pin cavity (D).

Similar tang-like structures are noted on the downward curving horns of the pommel.

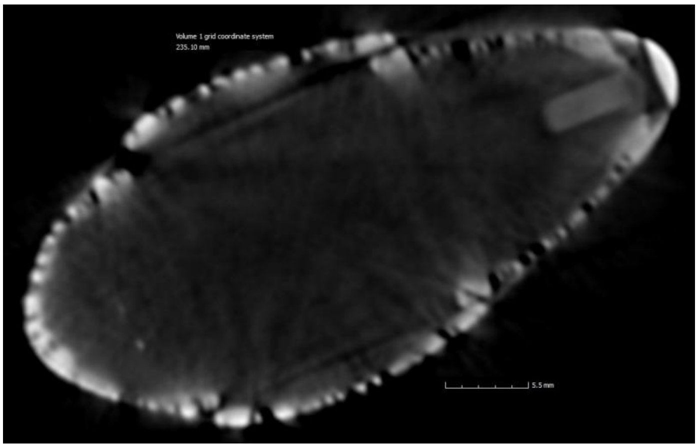

Figure 7.40: Tang-like structure penetrating the pommel horn.

In addition to the tangs that keep the blade in place, a special resin (insect shellac) was poured into the handle cavity and heated. As the molten resin became malleable, the blade tang was inserted into the resin-filled cavity. As the resin cooled down, it solidified, keeping the blade in place[185]. Since shellac resins are organic (insect-derived), they are radiotransparent in nature, making it seem as though the handle cavity surrounding the tang is empty, especially when being investigated by means of traditional X-ray techniques.

However, depending on the hydrogen content of shellac, neutron radiography might actually be able to identify (or at least suggest) the use of resin in the handle's composition. This is because high hydrogen levels cause high attenuation of neutron beams (Deschler-Erb et al. 2004, 650-653). According to Osman (2012, 21), elementary analysis of shellac shows that it contains approximately 68% carbon, 23% oxygen and 9% hydrogen. Unfortunately, none of the consulted literature specified the exact percentage at which hydrogen becomes significantly radiopaque to NT. Irrespective of what the figure might be, we are not currently in the position to non-destructively identify the chemical composition of the internal resin – if such a resin is even present. With this being stated, it would be worthwhile to subject the dagger to neutron imaging during future research, as we might obtain similar results to those showcased in Deschler-Erb et al.'s (2004) investigation of a Roman gladius, and Lehmann et al.'s (2005) analysis of a Roman dagger.

In addition to providing complementary data on the handle's composition, such a study could also reveal information on past restoration efforts, as NT is well-suited for identifying conservation treatments (naturally, depending on their respective chemical compositions).

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[185] https://timesofoman.com/extra/OmaniDress/ [Accessed 09/09/2018].

Since most museums (including the DNMCH) employ paraloid (hydrogen-rich acrylate polymer varnishes) for the protection of silver objects, it is possible that such a treatment could have been applied (although no such treatment is formally recorded). Since neutron attenuation in hydrogen-rich consolidants is high, NT should allow us to identify the presence and penetrative depth of such applied conservation treatments[186].

7.6.3 Scabbard, Belt and Buckle

It can be stated with a fair amount of certainty that the scabbard is made from an organic material, most probably wood. As mentioned before, organic materials are radiotransparent to X-ray tomography, so the low attenuation displayed by the scabbard is in line with what would be expected from a wooden structure (Fig.7.41).

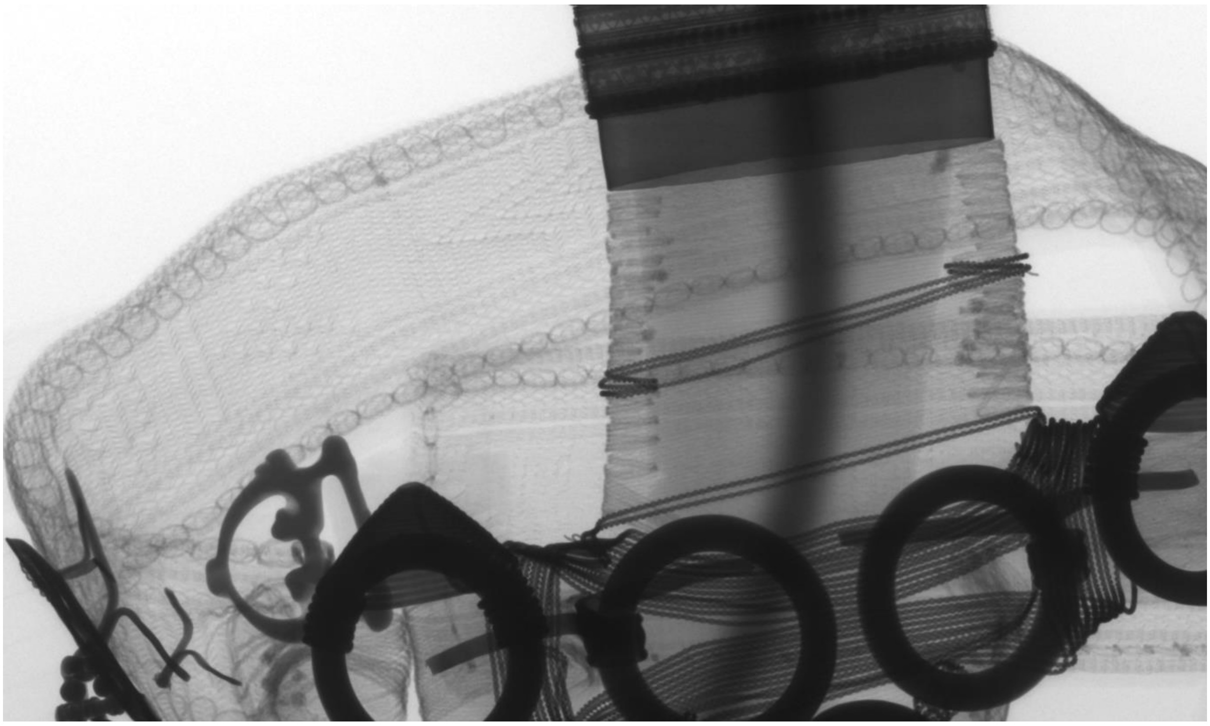

Figure 7.41: A section of the scabbard.

It would be interesting to subject the scabbard to NT, as we might be able to identify similar longitudinal lines on the wood as identified by Deschler-Erb et al. (2004).

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[186] In a study conducted by Prudêncio et al. (2012), neutron tomography was used to establish the impregnation efficiency of paraloid treatments on Portuguese tiles from the 16th and 18th centuries. It was found that "neutron tomography permits visualization of the penetration depth and distribution of polymer-based consolidants inside ancient tiles, and can thus provide a significant aid to the development of strategies for their conservation or restoration" (2012, 969).

The belt delivered surprising anomalies, contrary to what was initially expected. Since the belt is constructed from organic materials (silk, with a cotton backing and leather components), we expected it to be almost completely radiotransparent. However, woven radiopaque features are clearly visible, with unmistakable looped threading discernable along the bottom and top borders of the belt. Radiopaque threads are also visible within the body of the belt, but are less pronounced than the looped structures (Fig.7.42).

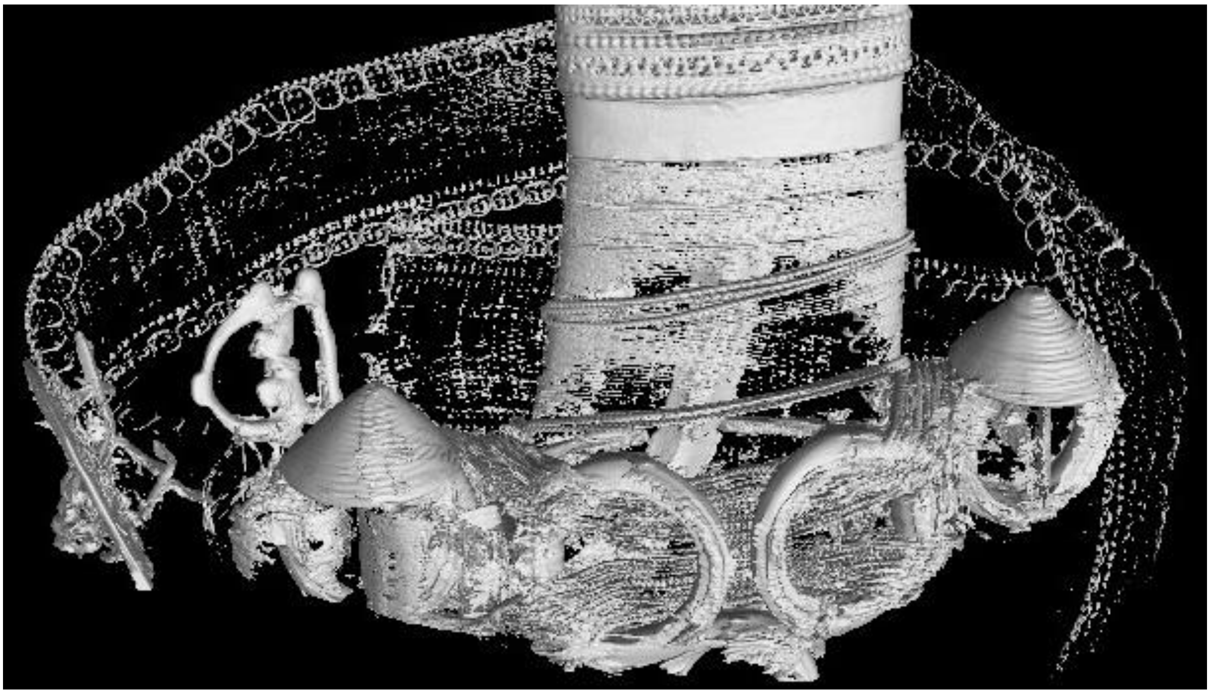

Figure 7.42: Metallic threads on the belt are clearly visible.

Due to their high attenuation, the most likely explanation is that these are silver/gold threads that have faded in colour and shine, thereby making them indistinguishable from the surrounding silk material upon basic visual analysis. The use of metal threading is not uncommon in the manufacture of Omani *khanjar* belts, with most examples featuring geometric patterns interwoven with silk, cotton and silver threads[187].

Interestingly, when it came to the buckle, the item displayed an almost identical phenomenon compared with the Roman dagger, from the Vindonissa Museum in Switzerland, examined by Lehmann et al. (2005). In the latter's case, a part of the buckle frame had been replaced (Fig.7.43A–B), but in our case, it is the buckle's prong (Fig.7.43B–C). In both instances, the replacement material differs visually from the original surrounding material. In the Roman dagger's case, the replacement material was actually identified as plastic Lehmann by et al.

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[187] http://omanisilver.com/contents/en-us/d643.html [Accessed 15/08/2018].

(2005, 71), but in our case the material appears to be of a ferrous nature. Since the object appears to be somewhat corroded, it is no surprise that the prong appears as radiotransparent.

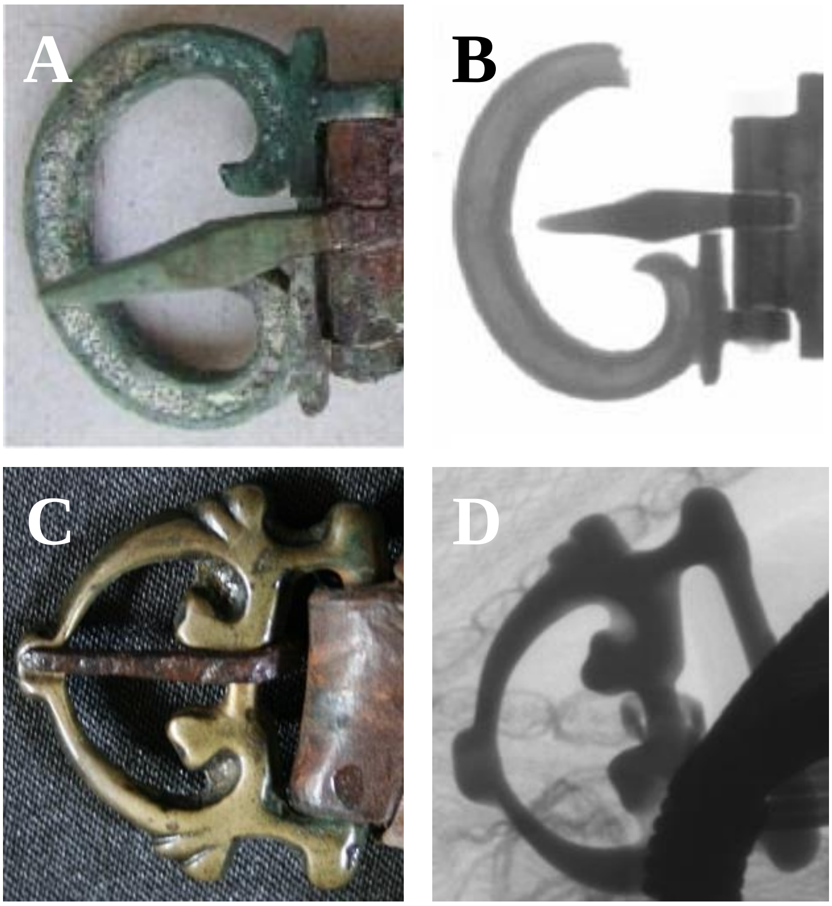

Figure 7.43: The Roman dagger’s buckle (A) and its x-ray (B) compared to the DNMCH buckle (C) and its x-ray (D). ***Source:*** Lehmann et al. (2005, 70)

Since the prong is quite corroded, it is unlikely that the object represents a modern attempt at repair work. A more logical answer would be that the prong broke or became dislodged during the *khanjar*’s years of use and that the original owner had it replaced. It is highly unlikely that the prong would have been originally manufactured from a different type of metal to the surrounding frame.

7.7 CONCLUSION

This chapter presented the results obtained through MXCT and represents the post-test phase within the quasi-experimental model. With most of the preliminary analytical foundations already established in Chapter 6, this chapter expanded upon most of the phenomena identified by means of micro photography and digital microscopy. In addition, a number of internal phenomena, that could not be detected through surface investigations, were identified and discussed.

7.7.1 Egyptian Bronzes

Since the solid bronzes proved to be somewhat of a challenge for the penetrative capabilities of MXCT, the author decided to focus on the analysis of the hollow-cast Wadjet-Bast statuette. Since the latter was the only object to obtain minimum penetration levels, thanks in part to its hollow nature, it was the only object that could provide interpretable nuclear transmissions. The remaining objects presented the author with too much beam hardening, scattering and minimal penetration.

With the Wadjet-Bast statuette, clear distinctions could be drawn between solid (legs and arms) and hollow (throne, torso and head) features. While the head was previously believed to be solid cast, it proved to be hollow right up to the tip of the nose. Since the oldest known examples of hollow statuary date from the Middle Kingdom, the Wadjet-Bast statuette cannot predate this point in time, affording it a relative “post-Middle Kingdom” date. In addition, the presence of earholes, once open but now corroded shut, indicate that the statuette served a practical role as a votive figure.

The most interesting discovery was the identification of casting holes. At first believed to be random anomalies within the bronze, their uniform size, shape and non-coincidental placement within the statuette’s structure confirmed their purposeful creation and utilitarian nature.

In identifying the limited extent of the internal core material, it became quite clear why both the Child Horus and Wadjet-Bast statuettes broke in similar locations. In essence, a combination of factors – the angle of the legs, extent of core material, external forces, and possibly even rapid cooling post-cast – could have led to the breakage.

7.7.2 Samurai Armour: *Kabuto* and *Menpó*

The rosette grommet, or *tehen kanomono*, presented us with a rare opportunity to view the inside workings of such a simple, yet highly effective clamping device. Used to hold the individual flanged lamellar plates into position, the grommet was a seemingly insignificant component within the *kabuto*’s construction. MXCT also confirmed the use of overlapping plates to create a double layer of protective metal – something which is not immediately obvious through surface investigation.

7.7.3 ToL Gauntlet

The radiotransparent nature of the gauntlet’s internal lining allowed us to view the internal surface of the metal unobtrusively. As was the norm, inner surfaces were much rougher compared to outer surfaces, as internal fabric and leather linings would protect the user against the harsh nature of the metal.

The internal wire that was observed though X-rays, but otherwise unobservable by the naked eye, established a link between the object and smithing practices that were already in use during the 17th century. Rectangular and irregular-shaped washers, also resembling those from 17th-century examples, were also observed through X-rays.

While the porosity of the metal itself indicates rapid cooling, the radiopacity of the outer layer suggest that cold hammering was applied to the object – yet another process that was prevalent during the 17th century.

7.7.4 Arabian Dagger

Individual X-ray images of the blade revealed that the edge of the blade remained intact and that the object was in a fair enough condition to be removed from its scabbard. Therefore, the khanjar was the only object to undergo X-ray imaging before surface analysis was conducted.

What originally appeared to be decorative flower-shaped pins turned out to be rivet heads or caps used to cover the pins that kept the tang of the blade secure within the handle. The belt also delivered surprising anomalies, as the organic superstructure (leather and cotton) featured radiopaque threads. Where naked-eye or microscopic surface analysis could not distinguish between fabric and metal threads, the attenuation properties of the latter revealed their presence.

The buckle’s prong presented us with an example of antique repair work. Since surface analysis can only identify visual differences, the differential attenuation between the metal structures confirmed that they are made from different types of metal.

CHAPTER 8
DISCUSSIONS AND CONCLUSION

8.1 THESIS REVIEW

Chapter 1 (Introduction) commenced with a broad statement of the research problem, highlighting the finite nature of cultural objects, the destructive nature of traditional scientific techniques, and the various limitations placed upon researchers in terms of conservation ethics. It also outlined what is implied by the term "authenticity" within the realm of cultural heritage diagnostics (§1.1.1). As the research falls within the context of non-destructive evaluation, the chapter was quick to point out "the light at the end of the research tunnel" by introducing the reader to the concept of Non-Destructive Evaluation. The basic principles of NDE were discussed, along with *what* makes an analytical method non-destructive, and *why* the application of NDE within cultural heritage research is so important (§1.1.2).

The value of applying a combination of different yet complementary analytical techniques on a small, non-randomised sample group was also highlighted. The chapter proposed that artefacts from different cultures, time periods and varying material composition, be subjected to historical contextualisation, stylistic analysis, surface investigation and nuclear imaging. The argument was posed that, in applying a mixed-methodological approach, the question of authenticity could be addressed within the framework of an integrated authenticity study (§1.1.3). The role and contributions of the Nuclear Energy Corporation of South Africa and the Ditsong National Museum of Cultural History were also duly acknowledged (§1.2).

The research collection, namely four ancient Egyptian bronze statuettes, a Samurai helmet (*kabuto*) and mask (*menpó*), a European armour gauntlet, as well as an Arabian dagger (*jambiya*), were briefly discussed to familiarise the reader with the objects (§1.3).

Chapter 2 (Methodology) presented the research design in terms of its empirical research and quasi-experiment, experimental methodology, and diagnostic feature identification – all within the broader theoretic framework of the thesis (§2.2).

The methods, instrumentation and test parameters of stylistic analysis, surface investigation (SLR photography and digital microscopy) and MXCT were outlined (§2.3) and the limitations of the study presented (§2.4).

Chapter 3 (Literature Review) commenced with two sections (§3.2 and 3.3) that followed a more traditional approach in terms of what is expected from a literature review. In its synopsis of NDE within cultural heritage, Section 3.2 provided an overview of radiation imaging techniques (MXCT and NT) with the aim of highlighting the myriad of possibilities (in terms of data collection and subsequent interpretation) that become viable through the application of complementary nuclear technologies. Technical considerations, in terms of material type and conservation, implications for interpretation, as well as period-and culture-specific variables in production, were also presented. In Section 3.3, multiple sources were consulted to provide an overview of NDE within cultural heritage, reflect on technical considerations with regards to composite artefacts, as well as identify gaps in the existing body of research. In combination, the two sections provided the reader with practical insights into some of the techniques that were discussed throughout the remainder of the chapter.

The following sections (§3.4 and 3.5) took a more structured approached by presenting the reader with individual summaries of key readings (case studies) that were cross-referred to throughout the remainder of the thesis. These case studies proved of particular value as points of comparison, especially during the technical analyses presented in Chapters 6 and 7.

Chapter 4 (Historical Contextualisation) commenced with a section that highlighted the importance of historical contextualisation. To add to the complexity, the difference between object provenance and provenience was outlined (§4.2) in order to familiarise the reader with subject-related terminology. In general, the remainder of the chapter set out to provide the reader with valuable background information on the historical context of metals; the sourcing of raw materials, fabrication techniques, economic value, religious beliefs and the overall role of metal objects within different societies and cultures.

In the section on Egyptian bronzes (§4.3), the focus fell on an historical overview of styles (§4.3.1) and technologies (§4.3.2), as well as the historical context of casting (§4.3.3). These sections paid special attention to the historical context of bronze, the technological development of the first bronze alloys, the spread of bronze-working craft throughout the

ANE, as well as the waxing and waning popularity of bronze from the pre-Dynastic to Late Periods of ancient Egypt. Ancient metallurgy, the creation of alloys, the role of additives as well as the development of casting and production methods over time were also discussed, with specific reference to each component's significance in terms of relative dating. Each object's mythological and historical contexts were also discussed to shed greater light on their role within ancient Egyptian society.

In the section on Samurai armour (§4.4), important information regarding the socio-political environment of feudal and post-feudal Japan was imparted. Prominent events, in terms of social organisation from the Late Nara to Meiji Periods, especially those that held relevance in terms of the development of arms and armour, were discussed (§4.4.1). The summary highlighted the socio-cultural backdrop within which Samurai armour developed and evolved. A historical overview of technologies and styles (§4.4.2) provided insight into period-specific styles, with a particular focus on the evolution of *kabuto* and *menpó* styles.

In the section on European armour (§4.5), the scope of historical research fell over a much broader socio-political landscape than that of pre-modern Japan. The section took the multitude civil and international wars that were waged across the continent, between the fall of the Roman Empire and the establishment of post-Renaissance Europe, into consideration. The section also highlighted some of the most prominent technological developments that occurred during this tumultuous period and identified the most prominent armour styles. From the historical context of European knights (§4.5.1) to an overview of technologies and styles (§4.5.2), the section highlighted the most prominent developments from the Middle Ages to the Renaissance.

In the section on Arabian daggers (§4.6), the roles of *jambiya*, as both weapons and objects of social standing, were identified and elucidated. The socio-cultural significance of these objects within their native/producing cultures was highlighted alongside their popularity as gifts, souvenirs and tokens of military prowess (§4.6.1). The application of prized materials, such as Damascus steel, silver and rhino horns was discussed and the different types of *jambiya* was also examined (§4.6.2). The section concluded with a detailed overview of different *jambiya* and *khanjar* styles across the various geographical regions (§4.6.2).

In short, the above-mentioned overviews of historical technologies and styles laid down much-needed foundational knowledge upon which latter stylistic analyses (as presented in Chapter 5) could be structured. It also provided qualitative information against which later surface analyses (Chapter 6) and 3-dimensional (Chapter 7) data could be contextualised. As a whole, Chapter 2 proved to be an essential addition to the thesis in that it helped facilitate the establishment of more accurate culturo-chronological timeframes by providing much-needed background information for cross-referral throughout the thesis.

Chapter 5 (Stylistic Analysis) provided a detailed synopses of external visual features, followed by an in-depth comparative analysis between each object and available online resources. In doing so, the chapter represented the first "pre-test phase" within the quasi-experimental model. In drawing upon the cultural-historical background that was provided in Chapter 4, Chapter 5 was able to expand upon the former's historical contextualisation through the application of stylistic analyses and the identification of chronological markers. Having relied on online sources for visual comparisons, the chapter managed to list a number of key stylistic markers, facilitating the establishment of more accurate, yet still relative, culturo-chronological frameworks for each object.

The comparative analysis of our Egyptian bronze collection included an important opening note regarding the most challenging aspects of technological and stylistic analysis. The challenges include a lack of ancient standardization, regional stylistic variations and a multiplicity of unique examples (§5.3). However, despite these challenges, the chapter's visual comparative analyses revealed a number of key diagnostic features. In the examination of Sekhmet (§5.3.1), comparisons between it and images of the goddesses Bastet, Sekhmet and Wadjet-Bast indicated that the DNMCH's Sekhmet was in fact Wadjet-Bast. In our investigation of the cat statuette (§5.3.2), a general lack of royal insignia or decorations – that would usually adorn the figures of deities – was significant. This indicates that the object most probably represents a domestic feline and not the cat goddess Bastet. Likewise, the ibis did not feature any inscriptions, but in general, the sacred ibis was recognizable as the sacred animal of the god Thoth even without inscriptions. Comparisons with other ibis figures (§5.3.3) highlighted similarities in style across different object sizes – from life-size to miniature. While the DNMCH has a base that resembles a coffin lid, any coffin made in relation to the dimensions of the base would simply be too small to house any animal mummy. A more plausible explanation is that the ibis was used as a standard. In the case of the jackal, comparisons were first drawn between the statuette and depictions of Pharaoh Hounds). While dogs and jackals share many physical similarities, the presence of a *shedshed* (jackal standard) confirmed that the DNMCH statuette was a representation of the jackal god Wepwawet (§5.3.4).

When re-examining the Samurai armour, the investigation conducted by Teichert et al. (2012) was used as a point of departure. Comparative analyses of *Tósei-Gusoko* chest armours (§5.4.1), with particular reference to the *Mōgami Tósei-Gusoku* pièce (§5.4.1a to d), support Teichert et al.'s (2012) argument that the armour dates from the 17th or 18th century (Edo Period). A comparative analysis between the *dou* (cuirass), *menpó* (§5.4.2) and *kabuto* (§5.4.2) inspected the appearance of woven silk tie-downs, decorative elements and lacquer flaking in order to establish a connection between the different components. Similarities between the three objects suggest that they belong to the same suite of armour. The *kabuto* (§5.4.3) and *menpó* (§5.5) were also examined individually to highlight their stylistic origins from the Edo Period.

Since the Tower of Londen Gauntlet does not boast sufficient technical or decorative characteristics to provide it with a relative date, the researcher examined the accompanying helmet, breastplate and backplate. According to the helmet's shape and style (§5.6.1), it falls within the lobster-tailed burgonet or *zischägge* category, which was popular during the 17th century. The backplate and breastplate (§5.6.2) closely resemble Pikeman's armour that was also popular during the 17th century. Once a more concrete timeframe was established through the analyses of related objects, the gauntlet itself could then be compared to 17th century examples of gauntlets (§5.6.3). The presence of a construction number (armoury mark) on the breastplate presented the armour with an additional indicator of antiquity.

The Arabian dagger presented a unique challenge, as no documentation exists regarding its origin. Fortunately, a recent study by al Busaidi (2015) into the different types of *jambiya/khanjar* provided ample comparative data. The handle, scabbard and belt were compared with examples of *Omani Al Saidi khanjar* (§5.7.2 to 5.7.4), and it was established that the DNMCH's *jambiya* falls comfortably within Al Busaidi's (2015, 52-55) description of the *Al Saidi khanjar*. These *khanjar* were popular during the late 19th and early 20th centuries. In addition, the Deutsch Ostafrika Rupie with a date of 1909 (§5.7.5) provided us with an additional chronological marker. Although the latter may not present us with a date of manufacture, it does provide some information on the object’s early 20th century acquisition and use.

Chapter 6 (Surface Investigation) identified, examined and discussed surface visual phenomena identified by means of micro photography and digital microscopy, and represented the second “pre-test phase” within the quasi-experimental model.

Amongst the ancient Egyptian bronzes (§6.2), a number of interesting phenomena were observed. Interestingly, unexpected radiation damage caused the re-breakage of the Wadjet-Bast statuette (§6.2.1), which in itself resulted in a dual outcome; (a) the (probable) identification of an organic polymer adhesive used in the original repair work, and (b) the exposure of internal core material. The latter point proved significant in that internal corrosion is generally seen as a better indicator of age than external corrosion. However, surface patination and corrosion also provided valuable insights (§6.2.2), such as the presence of what could be passivating layers of Cu(I) oxide (cuprite), malachite (a copper carbonate: Cu2CO3(OH)2) or atacamite (a copper chloride: Cu2Cl(OH)3). The Wepwawet statuette also displayd an interesting corrosion profile, which features bright turquoise-coloured inclusions. The presence of polishing striations on all four bronzes indicate that they were polished post-cast (§6.2.3), while the size and rectangular shape of casting tangs on Wadjet-Bast suggest that the object could date from the New Kingdom (1550–1070 BC) (§6.2.4). In addition, residues in the eye sockets of Wadjet-Bast could indicate the presence of inlaid eyes (§6.2.5), while the appearance of decorative incisions indicate that these were made post-cast (§6.2.6). Another interesting observation was made in terms of the broken-off *uraeus* on Wadjet-Bast (§6.2.7). Visual comparison with the Brooklyn Museum’s Wadjet statuette showcased an almost identical breakage profile, suggesting that this was a common occurrence among statuettes that feature a *uraeus*. The porosity and colouration observed on the broken leg of the ibis, although interesting, proved somewhat challenging without the inclusion of chemical analyses (§6.2.9).

Our examination of patina and corrosion on the *kabuto* proved challenging, as the object was cleaned of corrosion during modern restoration efforts. However, trace amounts of corrosion were still observable in the gaps between overlapping helmet plates. To our advantage, restoration efforts did not remove the patination that covers the inside of the *tehen kanomono* (grommet). The turquoise-blue colour of this patination suggest that the grommet structure itself was made from bronze (§6.3.1). An investigation of the kabuto's plate assembly confirmed that the object falls in line with Salvemini's (2013, 6) description of *Suji-bachi kabuto* plate assembly (§6.3.2). Observations made on the helmet lining, with a focus on stitching patterns, texture and silk tread colouration, also support the Edo Period date assigned to the object. This deduction was made, since hemp and cotton linings, interlaced with coloured silk threading, were common during this period (§6.3.3). This investigation of colour and stitching pattern was also applied to the tie-downs and threading encountered on the *kabuto*, *menpó* and *dou* (§6.3.4), reaching similar conclusions. The lacquer coating of the kabuto, which was exposed following the removal of corrosion during recent restoration efforts, falls in line with descriptions of antique lacquer given by (Dalewicz-Kitto et al. 2013), adding another "layer" to the object's authenticity (§6.3.5).

On the *menpó*, it was found that restoration work had been done on the object during its antique period of use, or possibly even during its initial manufacture. The physical appearance (colour and texture) of the repair bracket, coupled with the presence of red lacquer on top of the bracket, help to infer its antiquity (§6.4.1). In addition, lacquer flaking suggests an advanced age (§6.4.2), while polishing striations provide insights into post-cast refinement (§6.4.3).

Our investigation of polish marks on the Tower of Londen gauntlet suggest that a fine-grained material was used to sand it after the object was bent into shape (§6.5.1). Superficial use-wear suggests that the object only sustained day-to-day damage, as no evidence of severe impact could be identified (§6.5.2). The joinery methods, edge refinement and tool marks fall in line with what can be expected from 17th century manufacturing techniques (§6.5.3). The preservation condition of leather and fabric components suggest an advanced age, as these organic components have undergone a fair amount of degradation (§6.5.4). The hand and finger scale assembly proved interesting from a construction point of view, as it also falls within what can be expected from 17th century armours (§6.5.4).

The *Al Saidi khanjar* was examined for use-wear along the blade's edge. As approximately 60% of the blade's edge remains undamaged, we can safely assume that the blade was mostly used for ceremonial purposes or for mundane tasks that did not cause significant damage (§6.6.1). An up-close examination of the handle's superstructure revealed an interesting scale-like appearance that resembles the worked surface of cattle horns. Although we can safely say that the material is animal horn, we cannot identify the horn down to species level (§6.6.2). Identifying species would enable us to confirm geographical origins, as different species (of goats, for example) are often bound to a particular region. Unfortunately, the latter point fell outside the scope of this thesis.

Chapter 7 (Three-Dimensional Nuclear Imaging) examined the results obtained through MXCT and represented the "post test phase" within the quasi-experimental model. While the chapter confirmed the presence of certain phenomena identified in Chapter 6, it also identified internal features that are only observable through nuclear imaging.

The Egyptian bronzes presented us with examples of three different casting methods, namely the direct lost-wax method (solid-cast), as showcased by the cat and Wepwawet (§7.2.1); the indirect lost-wax (clay core), as showcased by the ibis (§7.2.2); and the indirect lost-wax (hollow core), as showcased by Wadjet-Bast (§7.2.3). Among the four bronzes, it was Wadjet-Bast that showcased some of the most notable features, such as ear holes (§7.2.4), breaking points (§7.2.5), as well as a uniform wall thickness and porosity (§7.2.6). With all things considered, we can safely say that Wadjet-Bast falls within the proposed New Kingdom date given by the DNMCH. Unfortunately, with regards to the other bronzes, not enough stylistic or technical aspects could be identified to place them within a more accurate culturo-chronological framework.

As the kabuto was previously analysed using traditional x-radiation, the focus of this MXCT investigation fell on the possible identification of a maker's mark. Unfortunately, no such mark could be identified. However, this does not completely exclude the possible existence of such a mark, as NT could still reveal finer visual details that fall beyond the image-rendering capabilities of MXCT. In a positive note, MXCT did reveal the construction and inner workings of the *tehen kanomono* (grommet), which showcased how the individual helmet plates converged around the central tube, and how the moveable jaw of the grommet kept the plates in position (§7.3.1).

The presence of antique repair work on the *menpó*, as identified in Section 6.4.1, was confirmed by MXCT. The grey-scale appearance and identical metal homogeneity between the mask's superstructure and the repair bracket confirmed that the two components were made from the same material (§7.4.1). Compared to the *kabuto*, the *menpó* displayed excellent transmission, allowing the generation of clear and detailed tomographs. Unfortunately, no maker's mark could be identified, and it is the researcher's opinion that it would prove fruitless to subject the *menpó* to further analysis using NT in an attempt to identify such a mark.

The Tower of London gauntlet presented us with a perfect example of a composite artefact. The radiotransparent nature of the organic fabric and leather lining allowed us to see beyond it and observe the underlying metal surface. The latter proved to be significantly rougher compared with the external surface (§7.5.1). Surprisingly, the rolled edges of sheet metal used to make the gauntlet were found to contain a wire-like structure. These structures help to maintain the rounded shape of the object and presents a fixed surface around which the sheet metal edges could be bent (§7.5.2). Internal square washers were identified that were previously hidden by the fabric/leather lining. The irregular size and dimension of these washers correspond to those observed on the ToL helmet and a 17th century *zischägge* from the Royal Armouries. The cracked edge that was identified during surface investigation appeared as a bright, radiopaque anomaly (§7.5.3). These cracks are typical of objects that were rolled into shape using the methods explained in Section 6.5.3. The overall porosity of the metal substrate (as demonstrated through radiotransparent voids), when compared to the more dense outer layer (as highlighted by its radiopaque appearance), suggests the practice of cold hammering was applied (§7.5.4).

The *Al Saidi khanjar* was examined using MXCT before the blade was removed from its scabbard. This was done to ensure that the blade was in a good enough condition to be removed from its scabbard without causing damage to a potentially rusted blade. Fortunately, the blade is still in an excellent condition, as was showcased by the clear radiopaque outlines identified using MXCT (§7.6.1). The technique was also able to identify both the presence and absence of metal structures (tang attachments) that help to secure the tang of the blade within the dagger's handle (§7.6.2). Due to the radiotransparent nature of the scabbard and belt superstructures, these were identified as organic (possibly wood and cotton). Looped radiopaque anomalies on the belt suggest that the threads that were used along the outer edges of the belt are metallic in nature (possibly silver or gold). The radiotransparent nature of the buckle's prong suggests that the object was replaced at some point during the object's use (§7.6.3).

8.2 AIMS, OBJECTIVES, RESEARCH QUESTIONS AND HYPOTHESIS (A REVIEW)

The aims and objectives of the study (§1.4.1), which pursued the application of different yet complementary techniques, was fulfilled through the thesis's successful utilisation of stylistic analysis, digital microscopy and MXCT. The techniques proved exceptionally useful in obtaining complementary data on period-specific styles, material composition, ancient manufacturing techniques, and object integrity. In doing so, the author was able to establish the authenticity of the objects with a greater amount of certainty than was previously held.

The research questions posed (§1.4.2) were answered within the framework of qualitative research, as they could be tested through a quasi-experimental model that facilitates pre (stylistic analysis, digital microscopy) and post (MXCT) testing. In doing so, the author was able to:

1. identify stylistic attributes in terms of external features (shape, size, decoration, colour)
2. compare the identified stylistic attributes to known/curated stylistic attributes through a process of comparative analysis
3. identify characteristics or phenomena in the physical structure and material composition of the sample group, that were subsequently categorised as diagnostic features
4. establish that the observed physical phenomena were mostly (a) recurrent and frequent enough to be classified as the result of intended actions and/or production methods, as opposed to being (b) nonrecurring and infrequent enough to be classified as the result of unintended/accidental actions unrelated to specific methods
5. correlate physical diagnostic features with stylistic attributes with the end result being the compilation of more comprehensive culturo-chronological frameworks (relative dating).

In answering these questions, the author was able to test and confirm the hypothesis (§1.4.3), which proposed that a mixed method approach, that utilizes complementary techniques (stylistics analysis, digital microscopy and MXCT), can be employed to gather complementary data ((a) period-specific styles, (b) material composition, (c) ancient manufacturing techniques, and (d) object integrity), which can in turn be used to compile more comprehensive culturo-chronological frameworks, in turn facilitating integrated authentication.

Reaching our aims and objectives, answering our research questions and confirming our hypothesis, allows us to formulate the conclusion that all of the objects within the research collection are indeed authentic. However, if more accurate (exact) production dates are desired, further non-destructive analyses are required.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

8.3.1 Neutron Tomography

Although the study proved that valuable information can be gained through the application of MXCT, the type of visual phenomena that can be identify is directly related to the attenuation of X-rays by certain materials. By employing an alternative yet complementary technique, such as NT, we can obtain different contrast information on the same materials based on the latter technique's variable interaction with the transmission medium (the object) (Deschler-Erb et al. 2004, 648; Lehman et al. 2004, 4). The complementary data that is obtained through NT can them be "superimposed" on the data obtained through MXCT. This will provide the researcher with exceptional quantitative and qualitative analytical tools for artefact re-examination during post-doctoral research.

Following the success of studies that have compared results from MXCT and NT (§3.2.4; §3.5), it is highly recommended that all of the objects investigated within the thesis be subjected to the latter technique. The process will most certainly reveal new data and/or data that can be used to validate information gathered in this thesis.

Since the density and/or high lead content of the bronze figurines did not allow for the minimum required X-ray penetration, it is recommended that the bronze collection (including Wadjet-Bast) be subjected to NT.

MXCT could not reveal specific information regarding the material from which the Arabian dagger's scabbard was made. However, the radiotransparent nature of the scabbard – along areas not covered by silver decorations – suggests that it could be made from organic material(s). Although we already know – based on modern observations of *jambiya* manufacturing – that these components were carved from wood, it would be interesting to note how NT responds to the presence of organic material. In addition, since the mirrored halves of scabbards were glued together, NT could potentially identify the presence of organic adhesives. These observations are made possible by the fact that hydrogen atoms (encountered in wood and organic adhesives) cause high attenuation (radiopacity) of neutron beams (Lehman et al. 2004).

8.3.2 Chemical and Microstructural Analysis

Although chemical analysis represented one of the limitations of this thesis, future research into corrosion materials can be conducted using a range of techniques. Options include X-ray diffraction, inductively coupled plasma-mass spectrometry, scanning electron microscopy, electronic microprobe analysis, Fourier Transform Infrared Spectroscopy, X-ray Fluorescence Spectroscopy, and Optical Metallography, as well as Polarised-Light Microscopy (Scott 2002, 7).

Microstructural analysis can identify the "character" of the alloy as being either heterogeneous (consisting of dissimilar elements) or homogeneous (consisting of similar elements). This is done by investigating the nature of crystalline phases, grain size and orientation, texture and strain. These characteristics, in both the alloy and its corrosions products, are often influenced by the individual elements, additives and impurities which make up the alloy. Furthermore, heat treatments applied during the manufacturing process and environmental degradation experienced throughout the artefact's history, also influence character (Fortes et al. 2005, 139). The same rule applies to physical treatments, such as hammering, that would also influence alloy characteristics.

As alloy "recipes" changed over time, the production methods that influenced heterogeneity/homogeneity also evolved across the ages, with some techniques becoming period specific. This "dual evolution" (of recipes and techniques) was largely driven by the discovery, exploitation and changing application of material properties over many centuries coupled with the introduction of new fabrication methods from foreign lands. Intertwined with this innovation and discovery was the age-old principle of supply and demand, with raw material availability influenced not only by natural geographic distribution, but also by local, regional and international trade, politics and warfare. Thus, by analysing both elemental composition and microstructural character, we can identify chronological markers that aid relative dating and facilitate the establishment of more accurate culturo-chronological frameworks.

The following model is an adaption of Robbiola et al.'s (1998) model (which was also applied by Constantinides et al. (2002)), and could be used to identify and classify elemental composition and microstructure:

1. Visual investigation noting the general appearance (colour, porosity, thickness, cracks, layers, separation from alloy) of corroded surfaces
2. Identification of distinctly different layers within the corrosion formation
3. Investigation of corrosion constituents and exposed core materials by means of Raman spectroscopy, located at the spectroscopy lab of the University of the Witwatersrand
4. Full-volume (internal) inspection of crystallographic phases by means of Neutron Diffraction, located at the Mixed Radiation (MIXRAD) facility, Nuclear Energy Corporation of South Africa (NECSA)
5. Recording and analysis of corrosion and patination components, adhesive type, through X-ray Fluorescence (XRF)
6. Recording an analysis of crystallographic phases
7. Comparison of data to known reference materials.

To fully contextualise the elemental data obtained, comparisons will have to be made against existing databases. In doing so, major, minor and trace elements of artefacts of unknown provenience can be compared to a known reference (Robbiola & Portier 2006, 2).

Since MXCT cannot reveal information about the microstructure of objects, it remains unknown whether the Arabian dagger has a hammered edge. Microstructural analyses conducted by means of Time-of-Flight Neutron Diffraction (TOF-ND), as applied in the research of Kockelmann et al. (2006), could produce texture maps from which information on hammering and working direction could be extracted.

Since the core material of Wadjet-Bast is now exposed, Thermoluminescence dating of the core material could perhaps be considered. This will provide the object with a direct date, as showcased in the work of Goffer (1980). X-ray Fluorescence (XRF), as applied by Smith et al (2011) could also be considered in this regard.

When considering the broken ibis, copper/gold coloured anomalies can be readily identified as copper, but it is near impossible to determine what substance accounts for the distinctive bright silver colour. Since the object is already broken in this exact location, taking a sample for chemical analysis should not pose any ethical concerns.

Following the research model applied by Siano et al. (2009), the microstructural characterisation of external corrosion layers could also provide data on authenticity. For example, through the application of portable X-ray Diffraction, microstructural data can confirm the presence of ancient true black bronze patina. The presence of metallic Au and or Ag, cuprite Cu_2O, tenorite CuO and cassiterite SnO_2, as well as impurities in the copper, can also help characterise intentional ancient patination treatments (as illustrated by Aucouturier et al. 2010).

When performing chemical analysis, the main goal should be to identify the percentages of tin, lead, arsenic and zinc, as these additives and trace elements can be used as chronological markers.

8.3.3 Direct Stylistic Comparison with International Collections

The thesis has clearly demonstrated that comparative analysis is possible through remote comparison – the consultation of online resources (museum collections, antiques dealer catalogues, popular interest websites, etc.). However, relying on online sources comes with its own set of challenges.

Most prominent among these challenges is the sheer imbalance between digitised versus non-digitised collections. Since the majority of museums have not yet digitised their collections, the full spectrum of what is available within museum collections remains hidden to the public eye. Consulting the online catalogues of antique dealers also comes with a unique set of problems. In most instances, only the most eye-catching items or those of high monetary value or collectability are listed. Details on their provenience (collection history) are often surprisingly thorough, as high-end antiques dealers make use of specialised curators and assessors, but the descriptions are often one-sided in that they might specify a general period of production, but the focus once again falls on showcasing the aesthetic appeal of an object, rather than providing technical information on material composition. In the case of public interest websites, one occasionally encounters an excellent example of an object that holds the potential of serving as a comparative sample. However, since these sites are often managed by enthusiasts and private collectors, the details accompanying such images are not entirely reliable. Nonetheless, these websites often provide “clues” that can be pursued through more formal avenues of research.

Overall, the take-home message regarding stylistic analysis is that remote comparisons are valuable, but should not become the “be all and end of” comparative analysis. It should definitely be considered as a viable option for researchers who cannot afford to travel the world and peruse multiple museum collections. However, the value of comparing physical samples in real-time cannot be overestimated. A prime example is the analysis of silver wire thickness on the Arabian dagger. Without the comparative sample being physically present, it becomes almost impossible to take accurate measurements. This holds especially true when dealing with micro-measurements (less that 1 mm). Although one could make use of the digital measurement tools on offer by 3D-modelling software, one would still have to motivate for the comparative samples to be scanned by whichever holding institute safeguards them. Whether these institutions have access to such equipment, or even the necessary funding for external projects, presents us with another challenge.

In conclusion, it is strongly recommended that the objects presented in this study be taken to international museums that house relevant collections in order for more detailed comparative analyses to take place.

8.4 CONTRIBUTION TO THE FIELD

The thesis successfully demonstrated how a mixed methods approach (the combination of stylistic analysis, surface investigations and 3D imaging) can be used to facilitate integrated authentication. By gathering data on the same phenomenon using different techniques, we were able to achieve the end-goal of dual validation – a process in which both datasets confirm the existence of that particular phenomenon.

This model can be applied to almost any museum collection/archaeological collection where both provenance and provenience are unknown or uncertain. Hopefully, the study will inspire future researchers to consider using advanced NDE technologies, while at the same time not discarding more traditional methods (such as stylistic analysis).

Although chemical and microstructural analyses fell beyond the scope of this thesis, the evident contributions that these analytical techniques could have made, were clearly highlighted in the recommendations outlined above. This in itself contributes to the field of authentication studies, as researcher will hopefully realise the value of including non-destructive chemical and microstructural analyses in their own research.

8.5 COCLUSION

If any single concept or idea can be seen as the “take home message” of this conclusion, it would be that one cannot possibly hope to find all the answers within the scope of a single thesis. Thus stated, and in the absence of definite, indisputable results that either confirm or denounce authenticity, one should heed the words of Schorsch and Frantz (1998, 19):

> …more often than not, we must content ourselves with what we hope is a preponderance of evidence that speaks for a particular conclusion.

With reference to the “preponderance of evidence”, it is the researcher’s belief that the body of evidence investigated in this thesis points towards the authenticity of the objects in question. However, there still exists a reasonable amount of doubt. But in all fairness, this doubt only exists because chemical and microstructural analises fell beyond the scope of this thesis. If these additional, complementary analytical techniques were included, more definite answers could have been obtained. But once again, one can only expect so much from a single thesis. This aspect of research (chemical and microstructural analyses) is something the researcher aims to address during post-Doctoral research and publication.

REFERENCES

Abd Allh, A.G, and M.A. Maher. 2018. “A Case of Copper-arsenic Ewer from the Egyptian Museum in Ciaro, Egypt.” *Journal of the General Union of Arab Archaeologists* 3(3): 1–25.

Absalon, T., and D. Thatcher. 2011. *The Watanabe Art Museum Samurai Armour Collection. Volume I – Kabuto and Mengu*. Victoria: Toraba Samurai Art.

Ackermann, S., E. Gatti, and T. Richardson. 2010. “A 17th-century Pikeman’s Armour from Antwerp”. *Arms and Armour* 7(1): 30–39. 10.1179/174161210X12652009773410.

Adriaens, A. 2004. “European Actions to Promote and Coordinate the use of Analytical Techniques for Cultural Heritage Studies.” *Trends in Analytical Chemistry* 23(8): 583–586.

Adriaens, A. 2005. “Non-destructive Analysis and Testing of Museum Objects: An Overview of 5 Years of Research.” *Spectrochimica Acta Part B* 60: 1503–1516.

Agresti, J., I. Osticioli, M. C. Guidotti, N. Kardjilov, and S. Salvatore. 2016. “Non-invasive Archaeometallurgical Approach to the Investigations of Bronze Figurines Using Neutron, Laser, and X-ray Techniques.” *Microchemical Journal* 124: 765–774.

Alberghina, M. F., R. Barraco, M. Brai, T. Schillaci, and L. Tranchina. 2011. “Integrated Analytical Methodologies for the Study of Corrosion Processes in Archaeological Bronzes.” *Spectromica Acta Part B* 66: 129–137.

Al Busaidi, K. H. Z. 2015. “An In-depth Investigation into the Traditional Design of Omani Khanjar (Dagger).” PhD thesis, Curtin University.

Al-Zain, E. 2014. “The *Jambiya*: Yemeni Icon and Status Symbol. Yemeni Times Online, 24 June 2014.” Accessed 13/08/2017 http://www.yementimes.com/en/1792/photoessay/4017/The-*Jambiya*-Yemeni-icon-and-status-symbol.htm.

Ambers, J., D. Hook, N. Spencer, F. Shearman, S. La Niece, R. Stacey, and C. Cartwright. 2008. “A New Look at an Old Cat: A Technical Investigation of the Gayer-Anderson Cat.” *The British Museum Technical Research Bulletin* 2: 1–13.

Artioli, G. 2007. “Crystallographic Texture Analysis of Archaeological Metals: Interpretation of Manufacturing Techniques.” *Applied Physics A* 89: 899–908.

Artioli, G. 2010. *Scientific methods and cultural heritage. An introduction to the application of materials science to Archaeometry and conservation science.* New York: Oxford University Press.

Artioli, G. 2013. “Science for the Cultural Heritage: The Contribution of X-ray Diffraction.” *Rendiconti Lincei: Scienze Fisiche e Naturali* 24(S1): 55–62.

Atkinson, D. J. n.d. “Swords and Knives: A Private Collection of Ethnographic Edged Weapons”. Accessed 13/08/2017. http://atkinson-swords.com/collection-by-type/janbiya/

Aucouturier, M., F. Mathis, D. Robcis, J. Castaing, J. Salomon, L. Pichon, E. Delange, and S. Descamps. 2010. “Intentional Patina of Metal Archaeological Artefacts: Non-destructive Investigation of Egyptian and Roman Museum treasures.” Corrosion Engineering, Science and Technology 45(5): 314–321.

Pacey, A 1991. *Technology in World Civilization: A Thousand-year History.* Cambridge: MIT Press. ISBN 978-0-262-66072-3.

Bakr, M. I., and H. Brandl. 2010. *Egyptian Antiques from Kufur Nigm and Bubastis*. Berlin: MiN Publications.

Bastie, P., B. Hamelin, F. Fiori, A. Giuliani, G. Giunta, F. Rustichelli, and J. Gysens. 2006. “A New Method Based on Hard X-ray Diffraction for the Investigation of Archaeological Artefacts.” *Measurement Science and Technology* 17: 1–3.

Ben-Yosef, E. 2018. “Provenancing Egyptian metals: A Methodological Comment.” *Journal of Archaeological Science* 96: 208–215.

Berger, D. 2015. “Artificial Patination in Early Iron Age Europe: An Analytical Case Study of a Unique Bronze Artefact.” *Journal of Archaeological Science* 57: 130–141.

Bernard, M. C., and S. Joiret. 2009. “Understanding Corrosion of Ancient Metals for the Conservation of Cultural Heritage.” *Electromica Acta* 54: 5199–5205.

Bertrand, L. 2007. “Synchrotron Imaging for Archaeology, Art History, Conservation and Palaeontology.” *Physical Techniques in the Study of Art, Archaeology and Cultural Heritage* 2: 97–112.

Bettuzzi, M., F. Casali, M.P. Morigi, R. Brancaccio, D. Carson, G. Chiari, and J. Maisj. 2015. “Computed Tomography of a Medium Sized Roman Bronze Statue of Cupid.” *Applied Physics A: Materials Science and Processing* 118: 1161–1169.

Bianci, R. S. 1989. “Egyptian Metal Statuary of the Third Intermediate Period (Circa 1070–656 B.C.), from its Egyptian Antecedents to its Samian Examples”. In: *Small Bronze Sculpture from the Ancient World. Papers Delivered at a Symposium by the Department of Antiquities and Antiquities Conservation*, J.P. Getty Museum, 16–19 March, 1989.

Blakelock, E. S. 2010. “The Early Medieval Cutting Edge of Technology: An Archaeometallurgical, Technological and Social Study of the Manufacture and Use of

Anglo-Saxon and Viking Iron Knives, and Their Contribution to the Early Medieval Iron Economy." PhD thesis, University of Bradford.

Boman, G., G.M. Sheaffer, and T.P. Miller. 2009. "The Age of Armour." Interactive Qualifying Project, Worcester Polytechnic Institute, Massachusetts.

Born, H. 1989. "Patinated and Painted Bronzes: Exotic Technique or Ancient Tradition?" In: *Small Bronze Sculpture from the Ancient World. Papers Delivered at a Symposium by the Department of Antiquities and Antiquities Conservation*, J.P. Getty Museum, 16–19 March, 1989.

Bottomley, I. 2017. *Japanese Arms and Armour.* Leeds: Royal Armouries Museum.

Boucher, S. 1989. "Surface Working, Chiselling, Inlays, Plating, Silvering and Gilding". In *Small Bronze Sculpture from the Ancient World. Papers Delivered at a Symposium by the Department of Antiquities and Antiquities Conservation*, J.P. Getty Museum, 16–19 March, 1989.

Bouzakis, K-D., D. Pantermalis, L. Efsathiou, E. Vartis, N. Michailidus, D. Sagis, I. Mavroudis, K. Vasteli, J. Kastner, and D. Salaberger. 2008. "Design and Manufacturing Aspects of a Vaginal Speculum of Antiquity, as Investigated by Computer Tomographies." *Journal of Archaeological Science* 35: 633–642.

Breeze, C. M. 2008. "Preventative Conservation of Samurai Armour." Accessed 24/09/2018 http://www.museumtextiles.com/uploads/7/8/9/0/7890082/preventative_conservation_of_samurai_armor.pdf.

Breiding, D. H. 2002a. "The Function of Armor in Medieval and Renaissance Europe." Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/ufarm/hd_ufarm.htm.

Breiding, D. H. 2002b. "Arms and Armor in Renaissance Europe." Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/rarm/hd_rarm.htm.

Breiding, D. H. 2003. "The Decoration of European Armor." Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/deca/hd_deca.htm.

Breiding, D. H. 2004a. "Fashion in European Armour, 1000-1300." Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/afas13/hd_afas13.htm.

Breiding, D. H. 2004b. "Fashion in European Armour, 1300-1400." Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/afas14/hd_afas14.htm.

Breiding, D. H. 2004c. "Fashion in European Armour, 1400-1500." Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/afas15/hd_afas15.htm.

Breiding, D. H. 2004d. "Fashion in European Armour, 1500-1600." Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/afas16/hd_afas16.htm.

Breiding, D. H. 2004e. “Fashion in European Armour, 1600-1700.” Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/afas17/hd_afas17.htm.

Breiding, D. H. 2004f. “Arms and Armor—Common Misconceptions and Frequently Asked Questions.” Accessed 07/06/2018. https://www.metmuseum.org/toah/hd/aams/hd_aams.htm. Accessed 07/05/2018.

Brooks, R. A., and G. Di Chiri. 1976. “Beam Hardening in X-ray Reconstructive Tomography”. *Physics in Medicine and Biology* 21(3): 390–398.

Bryant, A. 1994. Samurai, 1550-1600: Weapons, Armour, Tactics. London: Osprey.

Campbell, G. 2003. *The Oxford Dictionary of the Renaissance*. Oxford: Oxford University Press.

Caspi, El’ad, N., H. Ettedgui, O. Rivin, M. Peilstocker, B. Breitman, I. Hershko, S. Shilstein, and S. Shalev. 2009. “Preliminary Neutron Diffraction Study of Two Fenestrated Axes from the ‘Enot Shuni’ Bronze Age Cemetery (Israel).” *Journal of Archaeological Sceince* 36: 2835–2840.

Ciliberto, E. 2000. “Analytical Methods in Art and Archaeology.” In Ciliberto, E. and Spoto, G. (eds.) 2000. Modern Analytical Methods in Art and Archaeology. *Chemical Analysis: A Series of Monographs on Analytical Chemistry and its Applications* 155: 1–9.

O’Connor, S., C. Solazzo, and M. Collins. 2014. “Advances in Identifying Archaeological Traces of Horn and Other Keratinous Hard Tissues.” *Studies in Conservation* 60(6): 1-25. https://doi.org/10.1179/2047058414Y.0000000134.

Constantinides, I., A. Adriaens, and F. Adams. 2002. “Surface Characterisation of Artificial Corrosion Layers of Copper Alloy Reference Materials.” *Applied Surface Science* 198: 90–101.

Creagh, D. 2012. “The Use of Neutron Technology in Archaeological and Cultural Heritage Research.” In Grupen, C. and Buvat, I. (eds.) *Handbook of Practical Detection and Imaging.* Heidelberg: Springer-Verlag. pp 813–831.

Crellin, R. J. 2018. “Examining the British and Irish Early Bronze Age Flat Axes of the Greenwell Collection at the British Museum.” *Journal of Archaeological Science: Reports* 18: 858–888.

Creswell, J. W. 2008. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4rd edition). SAGE Publications.

Dalewicz-Kitto, S., F. McLaughlan, E. Schuecker, and J. Hood. 2013. “Japanese Armour and the Conservation of a Sakakibara Family Armour at the Royal Armouries.” *Journal of the Institute of Conservation* 36(1): 35–52.

Darvill, T. 2009. *The Concise Oxford Dictionary of Archaeology*. Oxford: Oxford University Press.

De Beer, F. 2005. “Characteristics of the Neutron/X-ray Tomography Systems at SANRAD Facility in South Africa.” *Nuclear Instruments and Methods in Physics Research A:* 542: 1–8.

De Beer, F., H. Botha, E. Ferg, R. Grundlingh, and A. Smith. 2009. “Archaeology Benefits from Neutron Tomography Investigations in South Africa.” *Nuclear Instruments and Methods in Physics Research A* 605:167–170.

Degarmo, E. P., J. T. Black, and R. A. Kohser. 2003. *Materials and Processes in Manufacturing* (9th ed).New Jersey: Wiley Publishing.

Delange, E., M-E. Meyohas, and M. Aucouturier. 2005. “The Statue of Karomama, A Testimony of the Skills of Egyptian Metallurgists in Polychromy Bronze Statuary.’’ *Journal of Cultural History* 6(2): 99–113.

Deschler-Erb, E., E. H. Lehmann, and A. Ford. 2010. “Neutron Tomography as a Valuable Tool for the Non-Destructive Analysis of Historical Bronze Sculptures.” *Archaeometry* 52(2): 272–285.

Deschler-Erb, E., E. H. Lehmann, L. Pernet, P. Vontobel, and S. Hartmann. 2004. “The Complementary Use of Neutrons and X-rays for the Non-Destructive Investigation of Archaeological Objects from Swiss Collections.” *Archaeometry* 46(4): 647–661.

Dictionary of Egyptology. 1999. *People, Places and Objects, Dynasties and Egyptian gods*. New Lanark: Geddes & Grosset.

Dolfini, A. 2011. “The Function of Chalcolithic Metalwork in Italy: An Assessment Based on Use-Wear Analysis.” *Journal of Archaeological Science* 38: 1037–1049.

Dolfini, A., and R. J. Crellin. 2016. “Metalwork Wear Analysis: The Loss of Innocence.” *Journal of Archaeological Science* 66: 78–87.

Dupras, N. 2012. “Armourers and their Workshops: The Tools and Techniques of Late Medieval Armour Production.” PhD Thesis, University of Leeds, United Kingdom.

Eaton, E. R., and H. McKerrell. 1976. “Near Eastern Alloying and Some Textual Evidence for the Early Use of Arsenical Copper.” *World Archaeology* 8:2:169–191.

Edge, D., and J.M. Paddock. 1988. *Arms and Armor of the Medieval Knight*. New York: Crescent Books.

Elgood, R. 1994. *The Arms and Armour of Arabia in the 18th–19th and 20th Centuries*. Aldershot: Scolar Press.

Engineering Forum. 2014. “Leaded Bronze Porosity, Unequal Lead Dispersion Help!” Accessed 25/02/2018. http://www.eng-tips.com/viewthread.cfm?qid=363165.

Enguita, O., A. Climent-Font, G. Garcia, I. Montero, M.E. Fedo. M. Chiari, and F. Lucarelli. 2002. “Characterization of metal threads using differential PIXE analysis.” *Nuclear Instruments and Methods in Physics Research B* 189: 328–333.

Escudier, M., and T. Atkins. 2019. *A Dictionary of Mechanical Engineering*. Oxford: Oxford University Press.

Evans, L. 2011. “The *Shedshed* of Wepwawet: An Artistic and Behavioural Interpretation.” *The Journal of Egyptian Archaeology* 97: 103–115.

Fishman, B., and S. J. Fleming, 1980. “Research Notes and Application Reports: A Bronze Figure of Tutankhamun: Technical Studies.” *Archaeometry* 22(1): 81–86.

Fedrigo, A., F. Graze, A. Williams, A. Scherillo, F. Civita, and M. Zoppi. 2013. “Neutron Diffraction Characterization of Japanese Armour Components.” *Journal of Analytical Atomic Spectrometry* 28: 908–915.

Festa, G., R. Senesi, C. Alessandroni, G. Vitali, S. Porcinai, A.M. Giusti, T. Materna, and A. M. Paradowska. 2011. “Non-destructive Neutron Diffraction Measurements of Cavities, Inhomogeneities and Residual Strain in Bronzes of Ghiberti’s Relief from the Gates of Paradise.” *Journal of Applied Physics* 109: 1–9.

Festa, G., A. Pietropaolo, F. Grazzi, L.F. Sutton, A. Scherillo, L. Bognetti, A. Bini, E. Barzagli, E. Schooneveld, and C. Adreani. 2013. “Simultaneous and Integrated Neutron-based Techniques for Material Analysis of a Metallic Ancient Flute.” *Measurement Science and Technology* 24: 1–9.

Fortes, F.J., Cortés, M. Cablín, and J.J. Laserna. 2005. “Chronocultural Sorting of Archaeological Bronze Objects Using Laser-induced Breakdown Spectrometry.” *Analytica Chemica Acta* 554: 136-143.

Frame, L.D., C. I. Freestone, S. Y. Zhang, and M. Nicholas, 2013. “The Effects of Corrosion and Conservation Treatments on Non-destructive Neutron Diffraction Analysis of Archaeological Copper Alloys: Preliminary Results.” *Archaeometry* 55(1): 68–80.

Gahlin, L. 2010. *Egypt: Gods, Myth and Religio*n. London: Annes Publishing.

Gardiner, D. J., and Graves, P. R. 1989. *Practical Raman Spectroscopy. Springer-Verlag*. ISBN 978-0-387-50254-0.

Gardiner, D. J. 1989.” Introduction to Raman scattering.” In Gardiner, D.J. Graves, P.R. (eds), Practical Raman spectroscopy. Springer-Verlag. Pp 1–12.

Gener, M. 2011. “Integrating Form, Function and Technology in Ancient Swords. The Concept of Quality”. In Uckelman M., and Modlinger, M. (eds). *Warfare in Bronze Age Europe: Manufacture and Use of Weaponry*. Oxford: Archaeopress.

Ghoniem, M. A. 2014. “A Bronze Osiris Statuette from the Egyptian Museum in Cairo: Microstructural Characterization and Conservation.” *Mediterranean Archaeology and Archaeometry* 14(1): 37–49.

Gillard, D., S. M. Hardman, R. G. Thomas, and D. E. Watkinson. 1994. “The Mineralizaion of the Fibres in Burial Environments.” *Studies in Conservation* 39: 132–140.

Giuliani, A., V. Komlev, and F. Rustichelli. 2010. “Three-dimensional Imaging by Microtomography of X-ray Synchrotron Radiation and Neutrons.” *Innovative Technological Materials* 123–117.

Giumlia-Mair, A. 2005. “On Surface Analysis and Archaeometallurgy.” *Nuclear Instruments and Methods in Physics Research B* 239: 35–43.

Goffer, Z. 1980. “Archaeological Chemistry: A Sourcebook on the Application of Chemistry to Archaeology.” *Chemical Analysis: A Series of Monographs on Analytical Chemistry and its Applications* (vol. 55). New York: John Wiley.

Gorini, G., and H. Kamermans. 2009. “Neutron-based Analysis for Cultural Heritage Research. Results of the Ancient Charm project.” *14th International Congress on Cultural Heritage and New Technologies*, Vienna, 2009.

Grajetzki, W. 2006. *The Middle Kingdom of Ancient Egypt*: *History, Archaeology and Society*. London: Gerald Duckworth.

Grant, J.A. 1999. “Rethinking the Ottoman “Decline”: Military Technology Diffusion in the Ottoman Empire, Fifteenth to Eighteenth Centuries.” *Journal of World History* 10(1): 179-201.

Gravette, V. F. 2011. “A Critical Analyses of Selected Egyptian Bronze Artefacts in the National Cultural History Museum (NCHM).” MA thesis, University of South Africa.

Harris, A.D., M.P.H. Jessina, C, McGreggor, E.N. Perencevich, et al. 2018. “The Use and Interpretation of Quasi-Experimental Studies in Medical Informatics.” *Journal of the American Medical Informatics Association* 13(1): 16.

Hayez, V., V. Costa, J. Guillaume, H. Terryn, and A. Hubin. 2005. “Micro Raman Spectroscopy Used for the Study of Corrosion Products on Copper Alloys: Study of the Chemical Composition of Artificial Patinas used for Restoration Purposes.” *Analyst* 130: 550–556.

Heinze, M-C. 2013. “A Preliminary Glossary of Dagger-Related Terms”. *Jemen Report* 44: 32–36. *Records of the Auckland Museum* 47: 193–205.

Heinze, M-C. 2015. “Yemen through the Janbiya: The Social Lives of Daggers in Southwestern Arabia.” D.Phil. thesis, Universität Bielefeld.

Higgins, S. 2010. “Micro-Wear Analysis of a Middle Bronze Age Sword Blade.” *Records of the Auckland Museum* 47: 193–205.

Hill, M. 2001. “Bronze statuettes.” In *The Oxford encyclopaedia of ancient Egypt. Volume 1.* Oxford: Oxford University Press. pp 203–207.

Hoffman, J. W., and F. C. de Beer, 2012. “Characteristics of the Micro-focus X-ray Tomography facility (MIXRAD) at Necsa in South Africa”. Paper presented at the *18th World Conference on Nondestructive Testing*, 16-20 April 2012, Durban, South Africa.

Holmes, R., C. Singleton., and S. Jones. 2001. *The Oxford Companion to Military History*. Oxford: Oxford University Press.

Horn, C. 2013. “Weapons, Fighters and Combat: Spears and Swords in Early Bronze Age Scandinavia.” *Danish Journal of Archaeolog*y 2(1): 20–44.

Horn, C. 2017. “Combat and Ritual – Wear Analysis on Metal Halberds from the Danish Isles and the Cimbrian Peninsula.” *Journal of Archaeological Science: Reports* 14:515–529.

Horn, C., and I.C.C. von Holstein. 2017. “Dents in Our Confidence: The Interaction of Damage and Material Properties in Interpreting Use-Wear on Copper-Alloy Weaponry.” *Journal of Archaeological Science* 81: 90–100.

Horton, M., J. Fleisher, and S. Wynne-Jones. 2017. “The Mosques of Songo Mnara and their Urban Landscape.” *Journal of Islamic Archaeology* 4(2): 163–188.

Howland, D.R. 2001. Samurai Status, Class, and Bureaucracy: A Historiographical Essay. *The Journal of Asian Studies* 60(2): 353–380.

Hunt, L. B. 1980. “The Long History of Lost Wax Casting: Over Five Thousand Years of Art and Craftsmanship.” *Gold Bulletin* 13(2): 63–79.

ISIS. 2015. “Neutron Diffraction’’. Accessed 14/12 2015. http://www.isis.stfc.ac.uk/instruments/neutron-diffraction2593.html.

Jacobson, L., F. C. de Beer, and R. Nshimirimana. 2011. “Tomography Imaging of South African Archaeological and Heritage Stone and Pottery Objects.” *Nuclear Instruments and methods in Physics research A* 651:240–423.

James, T. G. H. 1972. “Gold technology in ancient Egypt.” *Gold Bulletin* 5(2): 38-40.

Johnson. T. A. n.d. “Radiation Effects on Polymers and Organics Materials.” Accessed 30/05/2015. http://www-eng.lbl.gov/~dw/projects/DW4219_RP_Materials_Testing/Misc.

Stuff/Adhesive%20 damage.pdf.

Juleff, G. 1996. “An Ancient Wind Powered Iron Smelting Technology in Sri Lanka.” *Nature* 379 (6560): 60.

Katz, J., and A. Tokovinine. 2017. “Digital Applications in Archaeology and Cultural Heritage.” *Digital Applications in Archaeology and Cultural Heritage* 6: 1–3.

Kelly Simpson, W. 1971. “A Horus-Nekhen Statue of Amunhotep III from Soleb.” *Boston Museum Bulletin* 69(358): 152–164.

Keen, M. 1999. *Medieval Warfare: A History*. Oxford: Oxford University Press.

Kerr A., and E. Wright. 2015. *A Dictionary of Worl History*. Oxford: Oxford University Press.

Kiss, V., K. P. Fischl, E. Horvath, G. Kali, Z. Kasztovsky, Z. Kis, B. Karoti, and G. Szabo. 2015. “Non-destructive Analyses of Bronze Artefacts from Bronze Age Hungary Using Neutron-Based Methods.” *Journal of Analytical Atomic Spectrometry* 30: 685–693.

Kockelmann, W., and A. Kirfel. 2004. “Neutron Diffraction Studies of Archaeological Objects on ROTAX.” *Physica B* 350: 581–585.

Kockelmann, W., S. Siano, L. Bartoli, D. Visser, P. Hallebeek, R. Traum, R. Linke, M. Schreiner, and A. Kirfel. 2006. “Applications of TOF Neutron Diffraction in Archaeometry.” *Applied Physics A: Materials Science & Processing* 83: 175–182.

Koh, Y.S., and I. Sarady. 2003. “Laser Removal of Corroded Layers from Archaeological Ironwork.” *LACONA 4 Journal of Cultural Heritage* 4(1): 129–133.

Koleini, F. 2013. “Metals from K2 and Mapungubwe: A Technological Study of Early Second Millennium Material Culture, with an Emphasis on Conservation.” PhD thesis. University of Pretoria.

Koleini, F., F. De Beer, M.H.A. Schoeman, I. Pikirayi, S. Chirikure, G. Nothnagel, and J.M. Radebe. 2012. “Efficiency of Neutron Tomography in Visualising the Internal Structure of Metal Artefacts from Mapungubwe Museum Collection with the Aim of Conservation.” *Journal of Cultural Heritage* 13: 246–253.

Kōzan, S. 1963. *The Manufacture of Armour and Helmets in 16th Century Japan*. Chūkokatchū Seisakuben, trans. T. Wakameda. Vermont: Tuttle.

Kozloff, A. P. 2001.“Sculpture: Divine Sculpture“. In *The Oxford Encyclopedia of Ancient Egypt*, vol. 3. Oxford: Oxford University Press. Pp 242–245.

Leever, S., D. Visser, W. Kockelmann, and J. Dick. 2006. “An Archaemetallurgical Study of Two Harquebusier Breastplates using Time-of-Flight Neutron Diffraction’’. *Physica B:* 452–544.

Lehman, E.H., E. Deschler, L. Pernet, and P. Vontobel. 2004. “Non-destructive Investigations of Swiss Museum Objects with Neutron And X-ray Imaging Methods.’’ Accessed 23/01/2016. http://www.ndt.net/article/wcndt2004/pdf/radiography/593_vontobel.pdf.

Lehmann, E. H., P. Vontobel, E. Deschler-Erbb, and M. Soares. 2005. “Non-invasive Studies of Objects from Cultural Heritage.” *Nuclear Instruments and Methods in Physics Research* A 542: 68–75.

Lehman, E.H., S. Hartman, and M. O. Speidel. 2010. “Investigation of the Content of Ancient Tibetan Metallic Buddha Statues by Means of Neutron Imaging Methods.” *Archaeometry* 52(3): 416–428.

Lehoux, D. 2013. “Ancient Science in a Digital Age.” *Isis* 104: 111–118.

Lucas, A. 1962. *Ancient Egyptian materials and industries.* 4th ed revised and enlarged by JR Harris. London: Edward Arnold.

Lythgoe, A. M. 1919. “Statues of the Goddess Sekhmet.” *The Metropolitan Museum of Art Bulletin* 14(10)*:* 3–23.

Madden, O., M. Abraham, S. Scheerer, and L. Werden. 2005. “The Effect of Laser Radiation on Adhesives, Consolidants, and Varnishes.” *Lasers in the Conservation of Artworks* 247–254.

Masiteng, I. N., F. de Beer, R. Nshimirimana, and P. Segonyana. 2010. “X-ray Tomography, Neutron Tomography and Energy Dispersive X-Ray Spectroscopy Investigations of Selected Ancient Egyptian Artefacts.” *National Cultural History Museum Journal* 5: 1–18.

Matthews, S. 2005. “The Materiality of Gesture: Intimacy, Emotion and Technique in the Archaeological Study of Bodily Communication.” Paper presented at *11th Annual meeting of the European Association of Archaeologists*, 5–11 September 2005, Cork, Ireland.

Metropolitan Museum of Art (MET). 2004. “Early Dynastic Sculpture, 2900–2350 B.C, In: *Heilbrunn Timeline of Art History*. New York: Department of Ancient Near Eastern Art, The Metropolitan Museum of Art.” Accessed on 10/06/2018. https://www.metmuseum.org/toah/hd/edys/hd_edys.htm.

Miller, B. F. 1977. “The Feasibility of using Thermography to Detect Subsurface Voids in Painted Wooden Panels.” *Journal of the American Institute of Conservation* 16: 27–35.

Mircea, O., I. Sârghie, I. Sandu, M. Quaranta, and A.V. Sandu, 2009. “The Study of Textile Impressions from Corrosion Products of Some Old Iron Artefacts.” *Revista de Chemie, Bucuresti* 60: 201–207.

Molloy. B., M. Wisniewskie, F. Lynam, B. O’Neil, A. O’Sullivan, and A. Peatfield. 2016. “Tracing Edges: A Consideration of the Applications of 3D Modelling for Metalwork Wear Analysis on Bronze Age Bladed Artefacts.” *Journal of Archaeological Science* 76: 79–87.

Morigi, M. P., F. Casali, F. Bettuzzi, R. Brancaccio, and V. D’Errico. 2010. “Application of X-ray Computed Tomography to Cultural Heritage diagnostics.” *Applied Physics* 100: 653–661.

Nelle, O., and D. Jansen. 2013. “Charcoals from iron smelting furnaces – fuel supply and environment of a medieaval iron smelting site near Peppange/Luxembourg.” Proceedings of the *4th International Meeting of Archaeology*, 8–13 September 2008, Brussels, Belgium.

Nicholson, E. D. 1979. “The Ancient Craft of Gold beating.” *Gold Bulletin* 12(4): 161–166.

Niemeyer, H. M., V. Zapata, P. Cantillana, A. Missene, J. Aguilera, and A. Torres. 2013. “Computed Tomography Study of Snuff Trays from San Pedro de Atacama (Northern Chile).” *Journal of Archaeological Science* 40: 2036–2044.

Norris, M. 2001. “Arms and Armour in Medieval Europe.” Accessed 30/05/2018. https://www.metmuseum.org/toah/hd/arms/hd_arms.htm.

Nowviskie, B. 2002. “Select Resources for Image-Based Humanities Computing.” *Computers and the Humanities, Image-Based Humanities Computing* 36(1): 109–131.

Oddy, A. 1981. “Gilding Through the Ages: An Outline History of the Process in the Old World.” *Gold Bulletin* 14(2): 75–79.

Ogden, J. 2000. “Metals.“ In Nicholson, PT and Shaw, I (eds), *Ancient Egyptian Materials and Technology*. Cambridge: Cambridge University Press. pp 148–176.

Ogawa, M. (ed). 2009. *Art of the Samurai: Japanese arms and armour, 1156-1868.* New York: Metropolotain Museum of Art.

Osman, Z. 2012. “Invesitigation of Different Shellac Grades in Improvement of Release From Air Suspesion Coated Pellets’’. PhD thesis, Johannes Gutenberg-Universität.

Pantos, E., W. Kockelmann, L. C. Chapon, L. Lutterotti, S. L. Bennet, M. J. Tobin, J. F. W. Mosselmans, T. Pradel, N. Salvado, S. Buti, R. Garner, and A. J. N. W. Prag. 2005. “Neutron and X-ray Characterisation of the Metallurgical Properties of a 7th Century BC

Corinthian-type Bronze Helmet.” *Nuclear Instruments and Methods in Physics Research B* 239: 16–26.

Perea., A., P. C. Gutiérrez-Neira, A. Climent-Font, P. Fernández-Esquivel, S. Rovira-Llorens, J.L. Ruvalcaba-Sil, A. Verde, and A. Zucchiatti. 2013. “Pre-Hispanic Goldwork Technology, the Quimbaya Treasure, Colombia.” *Journal of Archaeological Science* 40: 2326–2334. http://dx.doi.org/10.1016/j.jas.2012.12.033.

Postma, H., L. Amkreutz, A. Borella, M. Clarijs, H. Kamermans, W. Kockelmann, A. Paradowska, P. Schillebeeck, and D. Visser. 2010. “Non-destructive Bulk Analysis of the Buggenum Sword by Neutron Resonance Capture Analysis and Neutron Diffraction.” *Journal of Radioanalytical and Nuclear Chemistry* 283: 641–652.

Prestwich, M. 1999. *Armies and Warfare in the Middle Ages: The English Experience.* New Haven: Cambridge University Press.

Prudêncio, M. I., M. A. Stanojev Pereira, J. G. Marques, M. I. Dias, L. Esteves, C. I. Burbidge, M. J. Trindade, and M. B. Albuquerque. 2012. “Neutron Tomography for the Assessment of Consolidants Impregnation Efficiency in Portuguese Glazed Tiles (16th and 18th Centuries).” *Journal of Archaeological Science* 39: 964–969.

Pyhrr, S. W. 2000. *European Helmets, 1450-1650. Treasures from the Reserve Collection.* Metropolitan Museum of Art.

Rant, J. J., Z. Milič, P. Turk, and I. Lengar. 2005. “Neutron Radiography as a NDT Method in Archaeology.” The *8th International Conference of the Slovenian Society for Non-Destructive Testing. Application of Contemporary Non-Destructive Testing in Engineering*. Portorož, Slovenia: 181–188.

Rant, J., Z. Milic, J. Istenic, T. Knific, I. Lengar, and A. Rant. 2006. “Neutron Radiography Examination of Objects Belonging to the Cultural Heritage.” *Applied radiation and Isotopes* 64: 7–12.

Reedy, C. L., R. A. Corbett, D. L. Long, R. E. Tatnall, and D, Krantz. 1999. “Evaluation of Three Protective Coatings for Indoor Silver Objects.” *Objects Specialty Group Postprints* 6: 41–69.

Renfrew, C., and C. Bahn. 2004. *Archaeology: Theories, Methods and Practice*. 4th ed. London: Thames & Hudson.

Rice, M. 2006. *Swifter than the Arrow. The Golden Hunting Hounds of Ancient Egypt.* London: I.B. Taurus and Co.

Robbiola, L., J. Blengiuno, and C. Fiaud. 1998. “Morphology and Mechanism of Formation of Natural Patinas of Archaeological Cu-Sn alloys.” *Corrosion Science* 40(12): 2083.

Robbiola, L., and R, Portier. 2006. “A Global Approach to the Authentication of Ancient Bronzes Based on the Characterization of the Alloy-Patina-Environment System.” *Journal of Cultural Heritage* 7: 1–12.

Robins, G. 2005. “Cult Statues in Ancient Egypt.” In Walls, N.H. (ed). *Cult Image and Divine Representation in the Ancient Near East,* 1-12. Boston: American Schools of Oriental Research. pp 1–12.

Royal Armouries. 2016. *Weapon: A Visual History of Arms and Armours*. London: Dorling Kindersley.

Ryzewski, K., S. Herringerb, H. Bilheuxc, L. Walkerc, B. Sheldonb, S. Voisinc, J-C. Bilheuxc, and V. Finocchiaro, 2013. “Neutron Imaging of Archaeological Bronzes at the Oak Ridge National Laboratory.” *Physics Procedia*: 343 – 351.

Salvemini, F., F. Grazzi, A. Fedrigo, A. Williams, F. Civita, A. Scherillo, P. Vontobel, S. Hartman, E. Lehman, and M. Zoppi. 2013. “Revealing the Secrets of Composite Helmets of Ancient Japanese Tradition.” *The Eauropean Physics Journal Plus* 128 (87): 1–10.

Savage, G. 1968. *Concise history of bronzes.* London: Thames and Hudson.

Schorsch, D. 1988. “Technical Examination of Ancient Egyptian Theriomorphic Hollow Cast Bronzes – Some Case Studies.” In *Conservation of Ancient Egyptian Materials*. Watkins, S.C., C.E. Brown (eds). London: UKIC Archaeology Section. Pp 41–50.

Schorsch, D. 2007. “The Manufacture of Metal Statuary: Seeing the Workshops of the Temple.” In Hill, M (ed.) *Gifts for the Gods: Images from Egyptian Temples*. New York: Yale University Press. pp 189–199.

Schorsch, D., and J. H. Frantz. 1998. “A Tale of Two Kitties.” *Metropolitan Museum of Art Bulletin* 55(3): 16–29.

Scott, D. A. 1991. “Technical Examination of Some Gold Wire from Pre-Hispanic South America.” *Studies in Conservation* 36: 65–75.

Scott, D. A. 1994. “An Examination of the Patina and Corrosion Morphology of some Roman Bronzes.” *Journal of the American Institute for Conservation* 33(1): 1–23.

Scott, D. A. 2002. *Copper and Bronze in Art: Corrosion, Colorants, Conservation*. California: Getty Publications.

Scott, D. A., and L. Swartz Dodd. 2005. “Examination, Conservation and Analysis of a Gilded Egyptian Bronze Osiris.” *Journal of Cultural Heritage* 3: 333–345.

Scott, D. A., and G. Eggert. 2009. *Iron and Steel in Art: Corrosion, Colorants, Conservation*. London: Archetype Publishing.

Scudieri, F., F. Mercuri, and R. Volterri. “Non-invasive Analysis of Artistic Heritage and Archaeological Findings by Time Resolved IR Thermography.” *Journal of Thermal Analysis and Calorimetry* 66: 307–314.

Sesko. M. 2014. *Katchu: Japanische Rüstungen*. Germany: Lulu Enterprises.

Shackleford, S. 2010. *Blade's Guide to Knives and Their Values: The Complete Handbook of Knife Collecting.* 7th Edition. Wisconsin: Krause Publications.

Siano, S., L. Bartoli, A.A. Mencaglia, M. Miccio, and J. Agresti. 2009. “Use of Neutron Diffraction and Laser-Induced Plasma Spectroscopy in Integrated Authentication Methodologies of Copper Alloy Artefacts.” *Il Nuovo Cimento* 124(6): 671–686.

Sidhu, M.S. 2009. *Technology-based Problem Solving for Engineering Education: Interactive Multimedia Applications*. Pensylvania: IGI Global.

Smith, A., H. Botha, F. C. De Beer, and E. Ferg. 2009. “The Examination, Analysis and Conservation of a Bronze Egyptian Horus Statuette.“ *National Cultural History Museum Research Journal* 3: 73–91.

Smith, A., H. Botha, F. C. De Beer, and E. Ferg. 2011. “The Examination, Analysis and Conservation of a Bronze Egyptian Horus Statuette.” *Nuclear Instruments and Methods in Physics Research* A 651: 221–228.

Spencer, N. 2007. *The Gayer Anderson Cat, British Museum Objects in Focus*. London: The British Museum Press.

Stern Cahoy, E. 2015. “What is Empirical Research?” Accessed 19/08/2015. https://www.libraries.psu.edu/psul/researchguides/edupsych/empirical.html.

Stone, G. C. 1999(1934). *A Glossary of the Construction, Decoration, and Use of Arms and Armor in all Countries and in all Times. Together with Some Closely Related Subjects*. Mineola: Dover Publishing.

Švadlena J., and J.Stoulil. 2017. “Evaluation of Protective Properties of Acrylate Varnishes used for Conservation of Historical Metal Artefacts.” *Koroze A Ochrana Materiálu* 61(1) 25–31.

Taylor, J., P. Craddock, and F. Shearman. 1998. “Egyptian Hollow-cast Bronze Statues of the Early First Millenium BC the Development of a New Technology.” *Apollo: The International Magazine of Arts* 437: 9–15.

Teichert, F., A. Smith., and A. Collopy. 2012. “Rebirth of a Mid-Edo Era Japanese Samurai Armour and Samurai Sword: Museum of Culutral History’s Samuarai Armour and Sword.” *Ditsong National Museum of Culutral History Research Journal* 7: 51–74.

Tiradritti, F (ed). 1999. *The Cairo Museum Masterpieces of Egyptian Art*. London: Thames & Hudson.

Tomazello, M., S. Brazolin, M. P. Chagas, J. T. S. Oliveira, and A. W. Ballarin. 2008. “Application of X-ray Technique in Non-destructive Evaluation of Eucalypt Wood.” *Maderas, Ciencia y Technologia* 10(2): 139–149.

Tornari, V., E. Bernikola, A. Nevin, E. Kouloumpi, M. Doulgeridis, and C. Fotakis, 2008. “Fully-non-contact Masking-based Holography Inspection on Dimensionally Responsive Artwork Materials.” *Sensors* 8: 8401–8422.

Vandenabeele, P., A. von Bohlen, L. Moens, R. Klockenkämper, F. Joukes, and G. Dewispelaere. 2000. “Spectroscopic Examination of Two Egyptian Masks: A Combined Method Approach.” *Analytical Letters* 33(15): 3315–3332.

Van Langh, R., J. James, G. Burca, W. Kockelmann, S.Y. Zhang, E. Lehmann, M. Estermann, and A. Pappot. 2011. “New Insights into Alloy Compositions: Studying Renaissance Bronze Statuettes by Combined Neutron Imaging and Neutron Diffraction Techniques.’’ *Journal of Analytical Atomic Spectrometry* 26: 949–958.

Van Langh, R., E. Lehman, S. Hartman, A. Kaestner, and F. Scholten. 2009. “The Study of Bronze Statuettes with the Help of Neutron-Imaging Techniques.’’ *Analytical and Bioanalytical Chemistry* 395: 1949–1959.

Vontobel, P., E.H. Lehmann, R. Hassanein. and G. Frei. 2006. “Neutron Tomography: Method and Applications.” *Physica B*: 475–480.

Wachowiak, M. L., and B.V. Karas. 2009. “3D Scanning and Replication of Museum and Cultural Heritage Applications.” *Journal of the American Institute for Conservation* 48(2): 141-158. https://doi.org/10.1179/019713609804516992

Watterson, B. 1999. *Gods of Ancient Egypt.* Surrey: Bramley Books.

Watson, P. J., S. A. LeBlanc, and C. L. Redman. 1984. *Archaeological Explanation. The Scientific Method in Archaeology.* New York: Columbia University Press.

Young, M. L. 2012. “Archaeometallurgy Using Synchrotron Radiation: A Review.” *Reports on Progress in Physics* 75: 1–15.

Zakrzewski, S., A. Shortland, and J. Rowland. 2016. *Science in the Study of Ancient Egypt. Routledge Studies in Egyptology (series)*. Abingdon: Routledge.

Zang, S.Y., E. Godfrey, W. Kockelmann, A. Paradowska, M.J. Bull, et al. 2009. “High-tech Composites to Ancient Metals.” *Materials Today* 12(7–8): 78–84.