Institution: Cardiff University

Unit of Assessment: Archaeology (15)

Title of case study: Saving metal heritage for future generations through new guidance for safer treatment, storage and display

Period when the underpinning research was undertaken: 2010-2019

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof David Watkinson	Professor	01/03/1976 - present
Dr Nicola Emmerson	Senior Lecturer	01/09/2014 - present

Period when the claimed impact occurred: 01/08/2013-31/12/2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Cardiff University research into metallic corrosion and its control introduced evidence-based treatment, storage and display of archaeological metals to the heritage sector. Guesswork and anecdotal procedures in designing preservation protocols were replaced by an understanding of treatment efficiencies and humidity-related corrosion risk. Working directly with national museums and archives in England, Wales and Ireland, the researchers produced accessible and customisable guidelines which were adopted by professionals and their governing bodies across the UK, Europe and USA. From archaeological repositories containing millions of artefacts charting human history to iconic ships, including the Mary Rose, Brunel's SS Great Britain and the Spanish Armada, Cardiff research guided the decisions saving our metal heritage for future generations.

2. Underpinning research

Archaeological metal artefacts containing chlorides from the burial environment can corrode rapidly while in storage or on display, leading to complete loss of unique collections. Prior to the Cardiff University research, there was limited evidence of the effectiveness of existing corrosion prevention methods (such as aqueous washing to remove chlorides and creating low-humidity environments around artefacts) for preserving archaeological metal collections.

2.1 Humidity, corrosion rates and risk

The research presented here builds on the Cardiff team's expertise in assessing corrosion rates and risk for archaeological metals, particularly iron and copper alloy. In their research prior to 2010, they initially proved a threshold of 12% relative humidity (RH) below which no corrosion occurs [the subject of the team's REF 2014 Case Study]. Since then, further research established a nuanced scale of risk to metal artefacts according to humidity and chloride and examined the methods used to mitigate the risk **[G3.1]**. This was achieved by:

- refining a novel corrosion quantification method to measure loss of metal by corrosion at an atomic level. This was applied accurately and reproducibly to 200 archaeological metal artefacts over the range 20-80% RH **[3.1, 3.2]**;
- determining the location of chlorides in iron **[3.3]** and copper alloy artefacts via neutron analysis and relating this to damage occurring from corrosion across the humidity range.

For the first time, the sector – previously reliant on anecdotal evidence for risk mitigation – now has a granular scale for acceleration of chloride-driven corrosion with increasing humidity **[3.4]** and an expectation of the nature and extent of the damage that it will cause.

2.2 Post-excavation drying and treatment

Oxygen-rich environments above ground after excavation place archaeological metals that are still damp from burial at great risk. Immediate action to dry artefacts and prevent corrosion

is crucial. Cardiff researchers showed that the most common method of drying (in a storage box with silica gel desiccant) creates dangerously corrosive, high-humidity environments and identified alternative safe air-drying and oven-drying methods **[3.4, 3.5]**.

Estimating efficiency of stabilising treatments based on removing chloride from objects had previously and erroneously relied on measuring chloride extraction, with the amount remaining in objects to drive corrosion being unknown. Measuring corrosion rates of objects by the Cardiff method before and after treatment and correlating these rates to amounts of residual chloride allowed the first true quantification of treatment efficiencies **[3.1, 3.5]**. Working with the Mary Rose Trust's collection of Tudor cannonballs, the researchers also established that the long-term effects of two different methods used historically to treat the cannonballs meant that those treated by aqueous washing are too unstable to remove from low humidity storage but those treated by hydrogen reduction would be at low risk on display **[3.2]**.

2.3 Storage and display

Archaeological artefacts ultimately either go onto display or into long-term storage. For storage, most metal objects are sealed in airtight boxes with silica gel to dry the internal box environment. A Cardiff survey **[3.4]** showed the most frequently consulted publication on this method is *First Aid for Finds* (editions 1987, 1998), whose advice is based on unevidenced and anecdotal practices. Prompted by concerns from Museum of London conservators, the researchers investigated variables in storage procedures and produced evidence-based guidelines for their museum and the wider sector **[3.6]**. These include recommendations for the most airtight storage boxes, the optimum amount of silica gel, and the required frequency of changing silica gel – with all outcomes linked to humidity-related risk **[3.1; 3.2; 3.4]**.

Humidity control for objects on display is more complex. Dedicated showcases for metal artefacts may be conditioned by silica gel or mechanical plant, but where mixed materials are displayed together, the low humidity essential for survival of metals could damage organic objects. Dehumidification is also possible on a much larger scale encompassing whole rooms and display spaces, but achieving very low humidities in this way comes at a cost. Cardiff research calculated the risk of raising acceptable humidity values to allow cohabitation of organic and metal artefacts in contextual displays at the new Mary Rose Museum and to reduce the financial and environmental impact of running the large-scale desiccation plant for the dry dock housing Brunel's iron ship *SS Great Britain* **[3.1, 3.2, 3.4, 3.6]**.

3. References to the research (indicative maximum of six references)

[3.1] Watkinson, D., Rimmer, M., **Emmerson, N.** 2019. The influence of relative humidity and intrinsic chloride on post excavation corrosion rates of archaeological wrought iron. *Studies in Conservation* 64(8), pp. 456-471 DOI:10.1080/00393630.2018.1565006. Available in REF2.

[3.2] Watkinson, D., Emmerson, N., Seifert, J. 2016. Matching display relative humidity to corrosion rate: Quantitative evidence for marine cast iron cannon balls. In: R. Menon, C. Chemello and A. Pandya. (eds.) *Metal 2016*. ICOM-CC: New Delhi, India, pp. 195-202. Available from HEI on request.

[3.3] Watkinson, D., Rimmer, M., Kasztovszky, Z., Kis, Z., Maróti, B. and Szentmiklósi, L. 2014. The use of neutron analysis techniques for detecting the concentration and distribution of chloride ions in archaeological iron. *Archaeometry* 56(5), pp. 841-859 DOI:10.1111/arcm.12058

[3.4] Thunberg, J., **Watkinson, D., Emmerson, N.** 2020. Desiccated microclimates for heritage metals: Creation and management. *Studies in Conservation* DOI:10.1080/00393630.2020.1799599

[3.5] Watkinson, D., Emmerson, N. 2017. The impact of aqueous washing on the ability of βFeOOH to corrode iron. *Environmental Science and Pollution Research* 24(3), pp. 2138-2149 DOI:10.1007/s11356-016-6749-3

[3.6] Emmerson, N., Watkinson, D., Seifert, J. and Thunberg, J. 2020. Guidelines for Storage and Display of Archaeological Metals

https://www.heritagepreservationguidance.co.uk/guidelines-for-storage

Selected grant:

[G3.1] Watkinson, D. (PI) Evidence-based Condition-Monitoring Strategy for Preservation of Heritage Iron, £417,920, AHRC/EPSRC Science and Heritage (AH/H032754/1) October 2010- April 2014

4. Details of the impact

Cardiff research on methods and materials for safeguarding metal artefacts produced accessible guidelines for heritage professionals and tailored advice for major museums and archives. According to the Icon, the UK's Institute of Conservation, *"for the first time, archaeological units and heritage institutions have clear guidance on how to improve their current practice"* in treatment, storage and display of collections for the benefit of future generations **[5.1]**.

4.1 Defining best-practice in the UK, Europe and USA

Cardiff's guidelines for controlling corrosion of archaeological metal artefacts **[3.6]** were launched formally at an Institute of Conservation event in February 2020. In a survey of attendees from 26 institutions in 5 countries (UK, Netherlands, Germany, Sweden, USA), 100% of active practitioners agreed that they would use the guidelines and rated the impact of the guidelines on their professional conservation practice as 4.7/5 **[5.2]**. The guidelines have been adopted and promoted by heritage organisations in the UK and Ireland, and were:

- recommended as best practice for desiccated storage of metals in the **Society of Museum Archaeology Standards in the Care of Archaeological Collections** (April 2020). Accessed almost 1000 times by June 2020, the Society asserted that Cardiff research *"enhanced the quality of our Guidance*" ensuring that museum professionals understand *"how to make the decisions that will determine the longevity and condition of the collections in their care"* **[5.3]**;
- embedded in the forthcoming edition of 'First Aid for Finds', the key manual for archaeological excavations used throughout the world **[5.1]**. The new edition includes Cardiff guidelines on post-excavation management of archaeological metals **[5.1]**;
- the basis of new training materials for the **Portable Antiquities Scheme [5.4]**, and also underpinned training for archaeologists by staff from the **National Museum of Ireland [5.5]** and the **National Trust [5.2]**.

The importance of the Cardiff guidelines for museum and archaeology professionals is described by Gail Boyle, Joint Editor of the Society of Museum of Archaeology Standards: *"for the first time, the Cardiff research allows them to manage their time in relation to monitoring and regenerating desiccated microclimates"* **[5.3]**.

In the USA, 65% of heritage organisations holding historic artefacts report damage following improper storage **[5.6]**. The guidance changed conservation practices in the USA:

- the Cardiff team provided bespoke Desiccated Storage Guidance (May 2020) for the **American Institute for Conservation Storage Techniques for Art, Science and History Collections**. The Institute's Editor-in-Chief noted that, as a result, its 3,500 members *"have [an] improved understanding of how safe storage environments for archaeological metal artefacts can be enhanced by making simple choices in the selection of hardware and design of management regimes"* which is extending greatly the lifetimes of the many millions of artefacts deemed 'at risk' in the US **[5.6]**.
- **a private conservator**, who worked with institutions including the Institute of Nautical Archaeology and East Carolina University, described the guidelines as *"an effective, accessible international tool for the practising conservator"* **[5.7]**. The conservator confirmed that Cardiff research allowed them to *"develop a risk assessment policy for cast iron from a marine environment"* and informed their *"management practices for…desiccated microclimates"* **[5.7]**.

4.2 Improved post-excavation care

How metal artefacts are cared for at the early stages of finds retrieval has a major influence on their survival and condition after excavation. Although the final guidelines were released in 2020, Cardiff research has influenced the practice of individual organisations since 2014. Both **Museum of London [5.4]** and **Roman Legionary Museum [5.8]** acknowledge how Cardiff research modified the guidance they give to commercial and research excavations on standards required for depositing finds. For example, **Museum of London** changed its institutional advice on drying archaeological iron post-excavation to follow Cardiff's guidance to oven-dry or air-dry rather than enclosing in a storage box with a desiccant **[5.4]**.

Ireland's renowned metalworking heritage is held at **National Museum of Ireland**. Karena Morton, Head of Conservation, stated that the research had altered practice and management in post-excavation treatment and display **[5.5]**. Cardiff researchers produced a treatment and display plan **[5.5]** based on their research **[3.1-3.5]** for recently discovered relics of sixteenth century warfare, including eight bronze cannon and an iron-shod carriage wheel raised from the 1588 Spanish Armada wreck, *La Juliana*. Following the treatment plan, Morton notes that the artefacts can be displayed for the public at **National Museum of Ireland** in controlled conditions without fear of damage or disfigurement from corrosion **[5.5]**.

Morton additionally used Cardiff's corrosion risk scale **[3.4]** to manage unexpected incidents and redefine their iron management plan **[5.5]**. Knowing that there is unlikely to be significant damage to iron objects if the RH rises to 40% for a period of two days or two weeks, *"whereas a rise to 65% RH for the same period would require us to inspect the collection for signs of active corrosion"*, means her team does not have to spend significant time unnecessarily checking the condition of objects **[5.5]**.

4.3 Safer storage

The **Museum of London** archaeological store is the largest in the world and holds 250,000 metal objects relying on desiccated storage for their survival. Store conservator Luisa Duarte stated: *"Our long-standing relationship with the Cardiff research team has undoubtedly driven improvements in our storage procedures, increasing survival of objects and making our management of the metal archive more efficient and sustainable"* **[5.4]**. **Museum of London** used the research to perform risk assessments of its storage options, modify its silica gel replacement schedule, and establish regular, long-term monitoring of storage boxes **[5.4]**. This led to decreased likelihood of corrosion, as well as reduced staff costs as less time is spent regenerating and changing the silica gel **[5.4]**. The Cardiff guidelines have also shaped the museum's Archaeological Archive Standards for Deposition – to which all archaeology units and societies depositing finds from excavations in Greater London must adhere – by providing *"the evidence base we need to insist on the appropriate archive conditions for maximising survival of objects"* in storage **[5.4]**.

Roman Legionary Museum also modified its procedure and policy to incorporate Cardiff's research findings, which *"impacted on the long-term storage of research collection artefacts"* **[5.8]**. For example, its procurement policy for materials used to create microclimates is now dictated by Cardiff findings for selecting the make, design and application of boxes, which Senior Curator Mark Lewis confirmed has allowed *"more predictable management of our collections, resulting in more economical use of staff time and reducing the risk of ongoing corrosion of our important metals collection"* **[5.8]**.

4.4 Enhancing the quality and stability of displays

Showcases displaying mixed materials – which are often designed to immerse museum visitors by recreating period environments – present challenges as the organic, inorganic and metallic objects all require mutually exclusive environments to optimise their preservation. Cardiff calculations on the risks of raising humidity in displays has given organisations new insights into controlling these environments.

For example, in 2014 the **Mary Rose Trust** asked the Cardiff team to investigate the humidity-related corrosion and break-up of cast iron Tudor cannonballs displayed in a mixed-material showcase. Their findings, establishing which cannonballs could be displayed safely **[3.2],**

"inform[ed] the design of management procedures for the storage and display of cast iron at the Mary Rose Trust" and enabled the Trust *"to produce management guidance for choosing cannonballs for display and for loan exhibitions"* **[5.9]**. This, alongside the use of Cardiff's corrosion rate data *"to assess risk in management of all cast iron in the [Mary Rose] collection"* **[5.9]**, *"ensured the long-term survival of the 1248 cast iron cannonballs that are a unique collection of Tudor armaments and…presented options for displaying hydrogen reduced objects to educate and enthral visitors for generations to come"* **[5.9]**.

4.5 More sustainable preservation

Cardiff's research and ongoing collaboration with the **SS Great Britain Trust** continues to *"ultimately improve the survival prospects"* **[5.10]** of Brunel's iconic iron-hulled ship, centre-piece of its award-winning museum. The Trust uses gas-powered plant to desiccate the hull to 20% humidity to prevent its destruction by corrosion but this is costly, both financially (c.£200,000/annum) and environmentally. It was unable to make informed decisions to help economise its expenditure or reduce its carbon footprint as it did not know how much faster the hull would corrode if the humidity was allowed to rise above the 20% RH target value.

The CEO noted that Cardiff's corrosion risk scale **[3.4]** offered *"a new tool to guide management decisions regarding preservation of the hull"* and evidenced the option to *"operate at 30% relative humidity for virtually no increase in the corrosion…Even operating at 40% RH, corrosion…is only expected to be 4x faster"* **[5.10]**. As a result, he was able *"to make informed decisions on the level of preservation [the Trust] can provide for the [financial] outlay or the carbon footprint"* **[5.10]**. This is particularly important in the light of Covid-19, as the museum's significant conservation and desiccation costs have continued throughout lockdown and enforced closure but *"the recent Cardiff publication is a useful tool to inform any decision we make regarding economies to the operation of the desiccation plant"* **[5.10]**.

4.6 Covid-19 recovery in heritage institutions (UK and Ireland)

The research also assisted heritage institutions during the Covid-19 pandemic. For example, Helen Ganiaris, Chair of the **Institute of Conservation** Archaeology Group, emphasised how the pandemic highlighted the timeliness of the Cardiff guidance as a tool for heritage institutions facing the challenge of maintaining conservation provision during lockdown and furlough **[5.1]**. She confirmed that *"the tools generated by the Cardiff team from their research allow managers of archaeological collections to understand the risk to their metal artefacts from a period with no human resource to maintain the desiccated storage. This also feeds into prioritisation of tasks as the sector remobilises"* **[5.1]**.

Through evidence-based guidelines and changing practice, Cardiff research supported the heritage sector both in times of crisis and 'business as usual' *"to preserve archaeological metals from the first moment of their excavation and on into long term storage for the benefit of future generations"* **[5.6** – Lisa Goldberg, American Institute of Conservation**]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Testimonial: Helen Ganiaris – Chair of the Institute of Conservation Archaeology Group
[5.2] Attendees survey: Institute of Conservation Post-X Conference (24 February 2020)
[5.3] Testimonial: Gail Boyle – Senior Curator, Bristol Museum & Art Gallery and Joint Editor of the SMART Standards (Society for Museum Archaeology)
[5.4] Testimonial: Luisa Duarte – Archaeological Conservator, Museum of London
[5.5] Testimonial: Dr Karena Morton – Head of Conservation, National Museum of Ireland
[5.6] Testimonial: Lisa Goldberg – STASHc Editor, American Institute of Conservation
[5.7] Testimonial: Professional Conservator in Private Practice, USA
[5.8] Testimonial: Dr Mark Lewis – Roman Legionary Museum, National Museum Wales
[5.9] Testimonial: Prof. Mark Jones MBE – Head of Collections, Mary Rose Trust 1983-2016
[5.10] Testimonial: Dr Matthew Tanner – Chief Executive of the SS Great Britain Trust