Developing a Decision Support System for Local Diagnosis of Heritage Metals

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Abstract
To help metal conservators search for corrosion forms and find treatment protocols, this paper describes the augmentation of the *MIFAC-Metal* project through its migration to the internet and the addition of the *MiCorr* Decision Support System (DSS). The new online version of MIFAC-Metal enables conservators to digitally construct stratigraphies that they document during their visual observations and local probing of artefacts via Bertholon's method (Bertholon 2000). Corrosion forms are first described according to the strata structure (metal, corroded metal, corrosion layers etc) and the characteristics of each stratum (morphology, microstructure, texture etc). A graphical user interface on a personal computer allows virtual construction of stratigraphies using encoded building blocks. Conservators then use the MiCorr Decision Support System to compare their observations with corrosion forms already stored in its database. The database entries were made from comprehensive investigations of historic and archaeological artefacts. They were probed physically and analysed for their composition. One search engine uses keywords describing corrosion forms, and another uses schematic representations. The search engines represented the lengthiest and most innovative part of the project. Conservators should be able to find case studies of fully investigated artefacts showing similar corrosion phenomena which can be useful for deciding conservation protocols, e.g. diagnosing the corrosion forms or determining the location of the limit of the original surface in corrosion product crusts.

Keywords
Decision Support System, diagnosis, metals, corrosion forms, schematic representation, digital reconstruction, database, limit of the original surface

Introduction

The conservation of archaeological and historic metals requires a sound understanding of their composition and alteration in order to stabilize their corrosion and to reveal the limit of their original surface via the selective removal of corrosion products.

Time and resources allocated to the conservation of such objects do not usually allow the conservator to perform extensive analyses of metal structure and corrosion products. Object description and condition reports therefore tend to rely heavily on the experience of the conservator and on comparisons with published corrosion models, e.g. Dillmann 2005 for archaeological iron, Robbiola 1998 for archaeological copper alloys, and Turgoose 1985 for historic and archaeological lead. By comparing under the binocular microscope observed alteration products with models, the conservator decides how far an intervention should go and if the object is chemically stable or requires stabilization.

Some databases (*Corrosion doctors)* or Corrosion Atlas (During 1997) illustrate the main corrosion forms (e.g. pitting, galvanic, intergranular, stress-cracking corrosion) for bare metal surfaces exposed to particular environments. Heritage objects however have often undergone extensive changes during their life, especially after they have been abandoned and buried. Models of corrosion developed by the metal industry are therefore of little help for assessing heavily corroded metals. Other diagnostic online tools (*Materials pathology* 2015) have been set up by conservation professionals, but they remain very general and do not clearly link the resulting degradation to its cause/s.

Often the characteristics and the order of corrosion layers do not exactly match those found in the specialized literature. The reasons for this mismatch could be due to non-standard descriptive methods: each person sees, interprets and describes a corroded surface according to their unique experience and background. Also, a variable extent of surface preservation results from heterogeneous burial conditions. The use of different analytical equipment for the interpretation of corrosion products can further complicate matters and lead to incomplete corrosion models.

For the MIFAC-Metal project, the HE-Arc CR Conservation Research Unit at the University of Applied Sciences of Western Switzerland proposed a systematic method for describing and analysing microstructures and corrosion forms of archaeological and historic metals (Degrigny 2013). It built on previous research performed on cross-sections of corroded metal artefacts (mainly Robbiola 1998) and used the systematic description of corrosion layers and interfaces established by Bertholon (Bertholon 2000 & 2001). The methods of analysis used for this project were deployed according to their availability to conservation laboratories, e.g. metallography, electron microscopy combined with X-ray spectroscopy, as well as Raman spectroscopy.

An initial selection of 31 objects from Swiss collections was made for this study. Each was documented by conservators and corrosion scientists through surface observation and then by observation and analysis of a polished section extracted from the object. In conjunction with contextual information (e.g. origin and date of recovery, dating of the artefact, chronology, burial or exposure conditions), the results of this examination were compiled and interpreted for each object in a single document (Degrigny 2012). These MIFAC Metal case studies were used to develop the Decision Support System (MiCorr) presented in this paper.

Method

For this project we elected to link observations of objects made by the conservator to a database that contains related information obtained by invasive analysis of representative objects of similar composition and state of preservation. For this we adopted a computer Decision Support System that cross-references the observations of the user with the contents of the database.

Decision Support Systems (DSS) have three main components:

- a database that contains information from various origins (MIFAC Metal case studies),
- one or more modelling programmes and
- an interface that renders the results intelligible to the end-user.

Various types of such systems have been developed by others, e.g. data mining (Witten 2009), systems using ontologies (Gruber 1995), inferences, artificial intelligence or self-learning programmes. Several systems can be combined to obtain a more precise diagnosis (Russel 2009). In our case the system had to function through pattern matching (Witten 2009). Alternatively, if a match could not be found, the DSS had to propose new corrosion models which could be added to the database.

We chose to separate the DSS model into the five steps conservators follow when making a diagnosis through careful observation of the object (Figure 1).

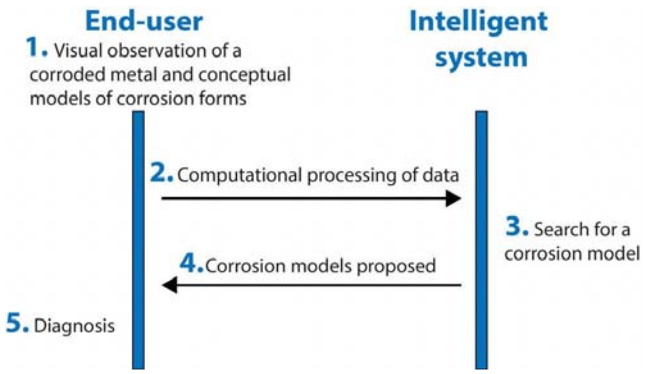

Figure 1. A schematic representation of the interaction between the end-user (conservator) and the intelligent system that helps them diagnose the state of preservation and stability of their object

Visual inspection of the corroded metal and modelling of the corrosion strata

By observing the artefact surface and any breaks under a binocular microscope, the conservator tries to understand the stratigraphy of the corrosion products and associated materials. Recently separated fragments can also help to better understand its structure. Schematics of the artefact cross-section are drawn to document the strata. Local probing with a scalpel can also help determine the order of strata and their physical properties (e.g. cleavage, brittleness, softness).

These conceptual models contain information on strata thickness, texture, morphology, composition (if known), and microstructures (for metal and ghost structures). Strata interfaces and markers are also included as they are crucial for identifying the limit of the original surface (Bertholon 2001).

Figure 2 shows a Celtic situla, found upside down, and its cross-section that its conservator drew during microscopic inspections and investigative cleaning. Each discernible stratum is named by type and numbered.

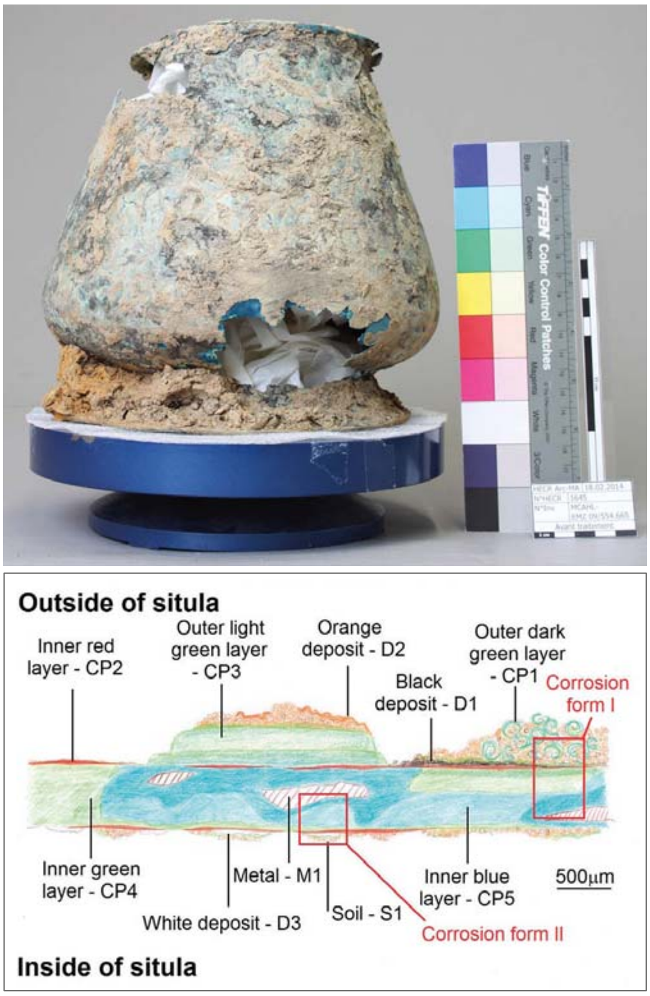

Figure 2. Top: A Celtic situla from the La Tène D period (140 BC – 30 BC) excavated from the Mormont sanctuary, La Sarraz/Eclépens, Vaud, Switzerland (Dudan 2009), Musée cantonal d'archéologie et d'histoire, Lausanne, © HE-Arc CR. Bottom: a schematic representation of a cross-section of the situla drawn after microscopic observation, © HE-Arc CR

More detailed local representations of the stratigraphy are made from the initial overview of the situla cross-section (Figure 2: bottom). First, descriptions of the structure of the corrosion strata for corrosion form I are made (Figure 3: left). Codes are added to specify the location of each stratum with respect to its visibility to the observer: "e" denotes external strata which are observable, and "i" denotes internal strata, which are concealed. Then, the characteristics of each stratum are documented with illustrations using standard terminology (Figure 3: middle). Last, the characteristics of its interfaces are provided (Figure 3: right).

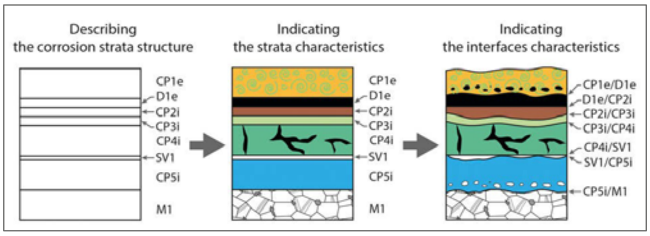

Figure 3. Conceptual rendering of corrosion form I (Figure 2) of the Mormont sanctuary situla using Bertholon's descriptive method. Left: identification of the strata and their organization (strata structure), SV = structural vacuum. Middle: the strata structure with its characteristics. Right: the strata structure with both strata and their interfacial characteristics.

Such standardized and conceptual representations of stratigraphies can illustrate the differing extents of corrosion present on one artefact and help determine the limit of the original surface. For corrosion form I, the limit of the original surface was determined to be at the interface between D1e & CP2i.

In Figure 4 we see the corrosion form II documented from the situla (Figure 2: bottom). Unlike corrosion form I, the interface D1e/CP2i was absent and the limit of the original surface was indeterminable since it had not been preserved. An internal corrosion stratum (CP3i) was revealed after removing the soil (S1).

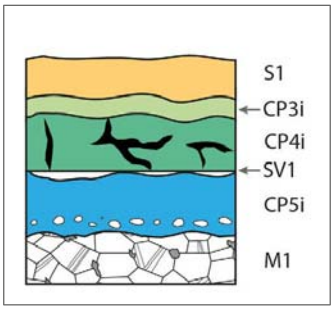

Figure 4. Conceptual rendering of corrosion form II (Figure 2) of the Mormont sanctuary situla using Bertholon's descriptive method

From conceptual models to data structures

Conceptual models (in our case, structures with stratigraphic and interfacial characteristics) are useful for sharing, studying and analysing specific views of reality (Wand 1995). If we want to apply computational processing to a conceptual model for further analysis, we need to format it so it can be understood by a computer (Robinson 2008). For corrosion forms, a simple image analysis is insufficient as we are interested in comparing the individual characteristics of the strata, not just their appearance. Therefore, we have to transform these schematic representations into executable representations. Furthermore, due to the fact that conceptual models are by definition simplifications of reality, we need to find ways to add information on parts of the models which cannot be explicitly represented by modelling conventions (Rochat 2015).

To achieve this, our first task was to design a suitable data structure that could be used to compare and analyse the corrosion forms. The first step was to build an ontology identifying the informative components of the artefact (Figure 5).

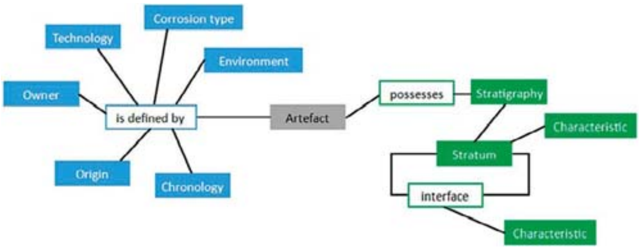

Figure 5. A schematic representation of an artefact's ontology

Each artefact possesses several strata. The main characteristics of the strata were identified from the literature (Bertholon 2000 & 2001). We grouped these character-

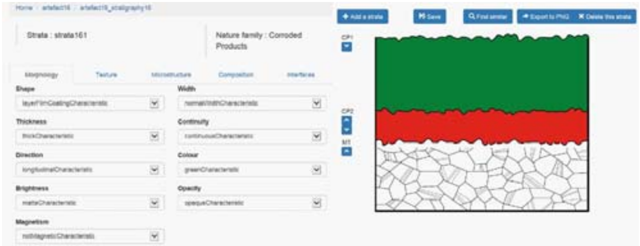

Figure 7. Screenshot of the graphical end-user interface while constructing the corrosion form of artefact no 16. Left: drop down menus for selecting characteristics and sub-characteristics for each stratum. Right: graphical representation of the stratigraphy under construction, © Grosjean

istics into families, each with a description, a selection attribute indicating if the family can be used more than once in each stratum and a list of dependencies. To store descriptions of corrosion forms, we chose the Neo4j graph database (Neo4j 2012) as the backend for our data structure. When storing data, every node in the database is either an artefact, a stratigraphy, a stratum, an interface, a characteristic or a sub-characteristic. These nodes are connected. The usual path commences with an artefact, and progresses to a stratigraphy comprising several strata. Each stratum has different characteristics and sub-characteristics, as shown in Figure 6.

A graphical user interface was designed to allow the end-user to build, stratum-by-stratum, the structure of the object under investigation (Grosjean 2015). Characteristics and sub-characteristics are added to each stratum as well as their interfaces, thereby assembling

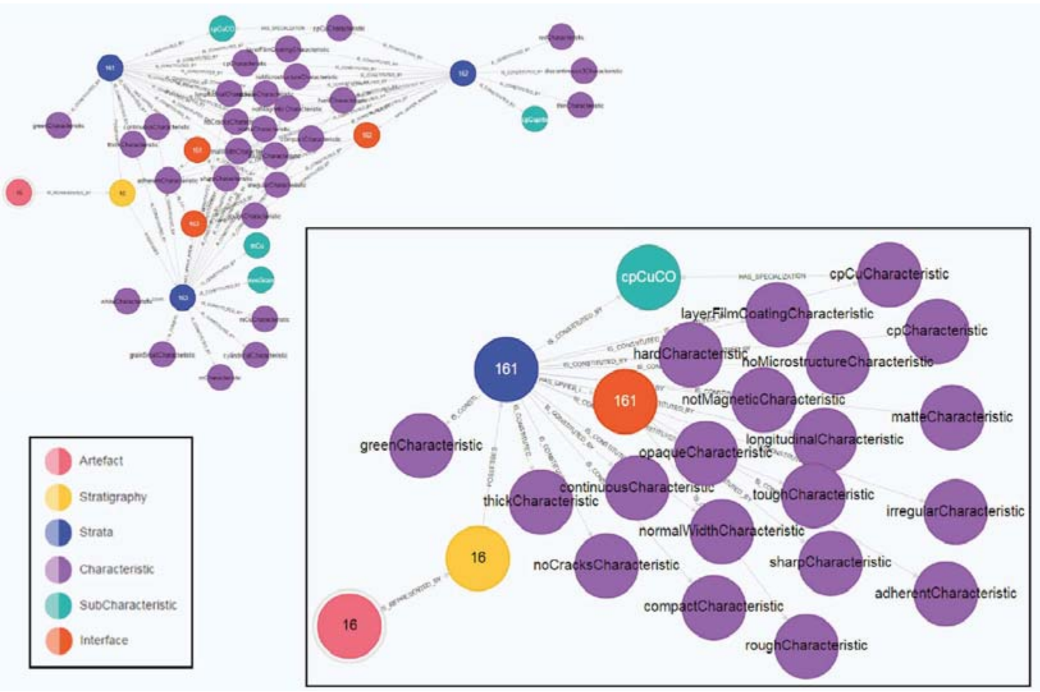

Figure 6. Graph of artefact no. 16 of the MIFAC-Metal database in Neo4j representation. Stratum 161 with its characteristics, sub-characteristic and interface are highlighted (inset), © Rochat

Table 1. Results of the comparison request with artefact no. 16 from the MIFAC database, © Rochat

Artefacts	Nb of strata	Difference nb of strata with artefact 16	Nb of common connections with artefact 16	Nb of characteristics	Matching (ratio column 4 / column 5)
Artefact 16	3	0	64	64	100
Artefact 17	3	0	59	64	92
Artefact 5	4	1	75	86	87
Artefact 15	5	2	92	108	85
Artefact 6	5	2	79	97	81

the corrosion form. The stratigraphy is visualized while it is under construction (Figure 7). Once collected, the data is saved and can be modified later.

A comparison score, in terms of structure and relevance of the artefact, was created to determine the closest match with database entries. The score is based on the ratio of shared characteristics and the total number of characteristics in the artefact. Table 1 shows the scores for searches of the corrosion form for artefact no. 16 from the MIFAC-Metal database. Artefact no. 17 is the second best match. This was confirmed by a conservator after observation of all objects under a binocular microscope; validating the result of the search.

The online MiCorr interface

We now have a collection of reference data sheets, a programme that allows us to construct conceptual models of observed corrosion forms and a system that compares our object to a database. The long term aim of this project is to add more data from objects that have been investigated and analysed according to Bertholon's method. To facilitate contributions, the online MiCorr interface was developed so that the project is accessible to everyone (Figure 8). Existing files can be consulted and new ones can be added. This should ultimately improve and enrich this database and make the MiCorr interface a better performing Decision Support System.

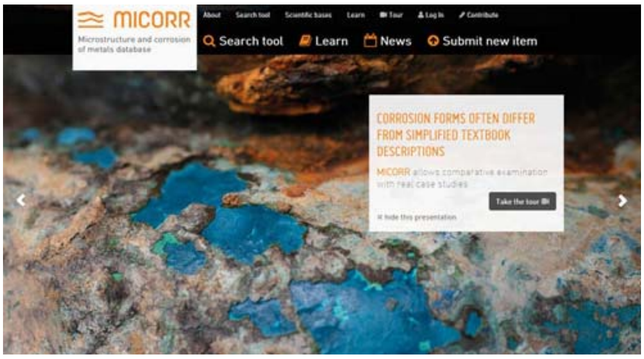

Figure 8. The MiCorr homepage available at micorr.org

The MiCorr interface has two search engines. The web-user can either build a corrosion form that corresponds to the object they are investigating, or search by using keywords (La Tène, bronze, cuprite etc.) (Figure 9).

MiCorr then suggests a selection of objects that best match the searched corrosion form. This selection appears as a table providing information on metal family, alloy composition, object type, chronology, technology and microstructure (Table 2).

The complete data sheet for each object is accessible by clicking on the object (Figure 10). The user is directed

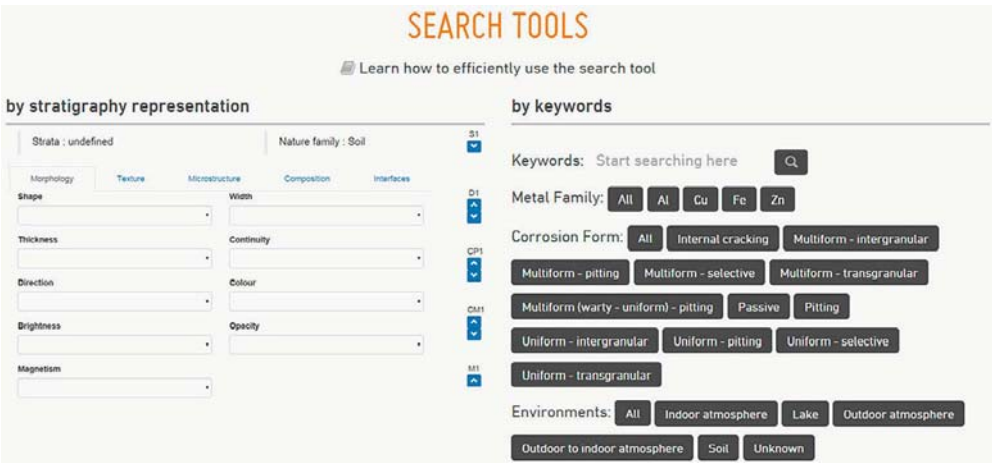

Figure 9. Screenshot from the online MiCorr interface showing the search by stratigraphic representation or by using keywords

Table 2. Screenshot from the online MiCorr interface showing related objects in the database after an initial interrogation of one of the two search engines

Metal Family	Metal alloy	Object	Chronology	Technology	Microstructure
Cu	Leaded bronze	Jewellery	Late Bronze Age	As-cast	Dendritic structure
Cu	Leaded bronze	Jewellery	Late Bronze Age	As-cast	Dendritic structure with pores
Cu	Leaded bronze	Knife	Late Bronze Age	Cold worked after annealing	Polygonal and twinned grains + strain lines (metal surface) with pores
Cu	Leaded bronze	Headrest or horse bit	Between 1000 and 650 years BC (if original) or 20th century (if fake)	Cast and cold worked (with final annealing?)	Dendritic structure and limited grain structure (with twin lines)
Cu	Tin bronze	Pin	Late Bronze Age	Annealed after cold working	Polygonal and twinned grains

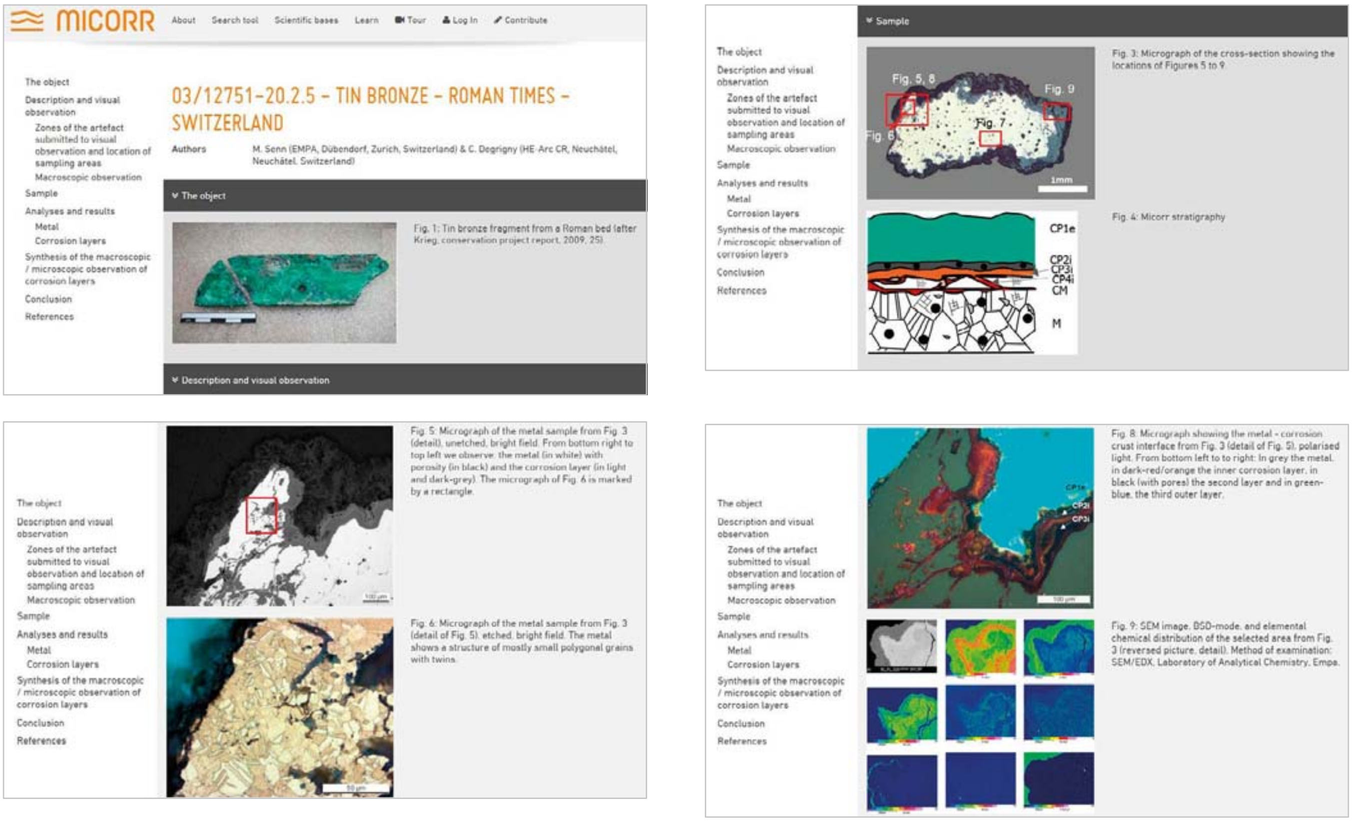

Figure 10. A selection of screenshots from the online MiCorr interface showing details of the datasheet of a copper alloy from the database

to the data sheet for the most comparable object in the database. If the search engine cannot find a match, or if there are no comparable entries, the information collected about the object under investigation can be stored in the database. In case the object is sampled or analysed at a later stage, information can be added at any time to the new MiCorr corrosion model.

Disseminating and improving the MiCorr DSS

For the online MiCorr database to become really effective, it needs to be used by more people. It is therefore important that various professional communities which deal everyday with corroded metal structures (conservators, researchers in conservation, conservation training facilities, corrosion scientists, archaeometallurgists) start to use and improve it. It is expected that the performance of the Decision Support System will improve with more database entries. For institutions training metal conservators such as HE-Arc CR, it has already proven to be of didactic use. It helps students structure their approach towards describing and understanding corroded metal artefacts.

At the time this paper went to print, the MiCorr interface was still under construction and will probably remain so as it becomes more user-friendly. All information concerning its administration and the scientific community that ensures its quality will eventually be found at micorr.org.

Conclusion

Every day thousands of conservators worldwide examine and clean metal artefacts, but only a fraction of these observations are shared or examined in closer detail and published. As a result, conservators are often forced to make decisions based on their own experience and existing corrosion models that do not precisely correspond with their artefacts. Different pH or pollutant levels, dry or wet conditions, differential aeration in soil, or alloy surface enrichment greatly influence the corrosion behaviour of metals.

The MIFAC-Metal Online project has proposed an online database of comprehensively investigated corroded metal structures that can be used as a Decision Support System when faced with objects that cannot be sampled or studied in-depth. By studying the corrosion layers of an object and reconstructing its corrosion form(s) online via the MiCorr interface, the end-user will find artefacts with similar metallographies and corrosion products. It is expected that studying these case studies will greatly help the conservator make decisions about the extent of cleaning or the need to stabilize objects. This could help limit the need for expensive, time-consuming and often destructive analyses.

It is hoped this project will find its place in the conservation community and over time become enriched by active participants from the heritage conservation community.

Acknowledgements

The authors would like to thank the HES-SO (University of Applied Sciences, Western Switzerland) for its financial support from RCSO ISnet under Award No. 38996 and its Impulse Funds. We are grateful to the HEG-Arc bachelor students Vincent Rochat, Marcel Grosjean and Yann Vonlanthen for their contribution to this project through their BA dissertations, as well as to those HE-Arc CR conservation students who produced several data sheets while learning from their objects. Special thanks to James Crawford for offering very valuable improvements to this paper.

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