

## *On the deterioration of archaeological iron artefacts in soil*

Archaeologists have observed that metal artefacts excavated today are more corroded than finds recovered 50-100 years ago. Acidification of lakes and ground can now be attributed to anthropogenic pollutants. Accordingly, they were also suspected to be a major cause of the increasing deterioration of buried remains. An interdisciplinary project was started at the National Heritage Board to study these problems. Our first study concerned bronze artefacts and showed that the deterioration has accelerated during the last century, and that pollution is one of the most important deteriorating factors. Iron artefacts are still more endangered. The present paper describes investigations of archaeological iron artefacts, from recent excavations as well as from museum collections. The results are important for the management of the archaeological cultural heritage.

### *Study of recently excavated iron artefacts*

145 recently excavated iron artefacts and related soil samples have been examined. The *degree of deterioration* for each object was referred to as *Fdet*. The same persons classified all objects on a scale from 1 (very fine object) to 5 (mainly rust) by X-ray radiographs and visual inspection. These objects were usually in bad condition, with a poor metal core (if any) surrounded by a thick layer of rust. Each soil sample taken around the find was classified, and the grain size distribution determined. These variables are static; i.e. they have not changed significantly since the artefact was buried. On the other hand, the chemical variables are dynamic: acidity, humidity, mass loss on ignition, electric resistivity, and salt contents (cf. Mattsson et al. 1996). Data on the archaeological context, geography and environment were included. Statistical evaluations were undertaken by means of multivariate analysis (Eriksson et al. 1999). The harmful influence of chlorides in the soil and large polluting deposits of nitrogen and sulphur compounds (in relation to what

the ground can tolerate) was obvious. Fine-grained sand implied a strong deteriorating effect. Among the preserving factors we noted sites in deciduous forests or calcareous surroundings. Influence from the archaeological context was, however, weakly indicated. This is one of the reasons why an examination of museum objects was also undertaken. We are aware of the fact that information on internal structure, carbon content and chloride content would have been of interest, but we were not allowed to carry out such analyses of the artefacts.

### *Results of the museum collection study*

1350 objects from the Museum of National Antiquities in Stockholm were studied. The finds date from the Early Iron Age to around AD 1600. In order to achieve an objective classification of the deterioration, we have basically chosen nails and rivets for this study. Documentation for the museum objects was obtained from the archives. The information on artefacts found before 1900 AD was rather scarce, but as many data as possible were retrieved concerning type of object, locality, year of acquisition or excavation, archaeological context, and environment. The objects were classified as described in the previous section. No soil samples were available. In order to include some information on the soil sensitivity towards acidification, special soil sensitivity maps were prepared (cf. Mattsson et al. 1996). The multivariate evaluation showed that the west coast with its vulnerable soil is indeed disastrous to archaeological iron. For other parts of Sweden, the effect of the soil sensitivity was rather weak. Finally, as regards conservation treatments, water leaching came out as a strong preserving factor.

Conventional statistical methods were used to evaluate the archaeological and environmental variables. Table 1 shows the average deterioration (*Fdet*) for finds sorted into four periods after year of excavation. There is a trend of a slightly accelerated deterioration for more

| Period of excavation/acquisition | Average degree of deterioration ( <i>Fdet</i> ) |
|----------------------------------|---|
| 1826-1899                        | 3.22  |
| 1900-1949                        | 3.66  |
| 1950-1969                        | 3.92  |
| 1970-2000                        | 4.25  |

Table 1. The average degree of deterioration (*Fdet*) versus excavation year.

recent finds, although less pronounced than for the museum bronzes (cf. Ullén et al. Ms.). For the earliest period there is a risk that the archaeologists of the time mainly collected the best artefacts, thus falsifying the average *Fdet*. However, our selection of artefacts has been made so that the best-preserved iron finds were compared for each time period and region. Part of the deterioration may also be attributed to post-excavation factors like unsuitable conservation methods or museum conditions. It is clear from the study, however, that the increasing air pollution has had a major deteriorating effect.

Iron artefacts found in cremation graves were generally in a worse condition than those from inhumation graves. Graves in cairns, i.e. without any protecting soil layer, have been particularly exposed to acid rain, with *Fdet* (average) as high as 4.29, indicating severely corroded objects mainly consisting of rust. Finally, for the finds from the Black Earth of Birka, there was a striking difference in preservation for various excavation dates. Finds excavated during the 19th century showed an *Fdet*(average) of 2.23, while the corresponding average value for the 20th century finds was 4.60.

#### Discussion

The results agree with those obtained for bronze artefacts, although the iron artefacts were generally more corroded, in agreement with corrosion science. Many technical corrosion studies have been undertaken, including iron in soil. The duration of these experiments has, however, been very brief in comparison with the time span for archaeological objects. Among the few investigations undertaken on archaeo-

logical iron, Scharff (1993) has examined iron objects in German museum collections. He observed a significantly worse preservation status for objects excavated after 1960. Like North & Pearson (1978) and Mattsson & Norlander (1996), he emphasised that chlorides are disastrous to iron artefacts. Gerwin et al. (1998) also found that sandy soil, salt, and acidic soil have a strong corrosive effect on iron artefacts. Treatment of heavily corroded iron has been discussed by Hjelm-Hansen et al. (1998).

It is well known from corrosion science that corrosion requires an oxidizing agent (usually oxygen from the air), and an electrolyte (e.g. a water solution). Accordingly, a moderately well aerated and moist soil such as sand, rather than clay or gravel, should be most detrimental to metals, giving access to oxygen while the soil pores are partially filled with water. Peat and certain culture layers instead have a preserving effect. The detrimental effect of salt in soil or cremation layers containing soot and ashes is due to increasing electric conductivity. It should finally be mentioned that a similar study of the degradation of archaeological bone, another important material, has been carried out as an EU project in co-operation between the Netherlands, Sweden (i.e. the National Heritage Board), Great Britain and Italy (Kars et al. 2002).

#### Conclusions

The present study has shown that the deterioration rate of archaeological iron objects has accelerated in recent years, and that it is increased by acidic soil, salt and soot. The total age since burial has not shown up as a significant deteriorating variable. However, the soil has only been affected by the deposition of various pollutants during the last 50-100 years. Accordingly, the corrosion in recent years may partly be attributed to anthropogenic pollution. The study has also shown that soil conditions allowing access of air (oxygen) and water at the same time will increase the corrosivity. This must be taken into consideration when planning large-scale environmental changes which may affect the water table. Archaeological parameters found to affect the corrosion are cremation layers and »open» constructions like

cairns. Many un-excavated archaeological iron artefacts are endangered, especially on the west coast of Sweden.

#### *Acknowledgements*

We are very grateful to all archaeologists who have helped us with material for this study. We are indebted to Professor Einar Mattsson, former head of the Swedish Corrosion Institute, for valuable discussions and guidance throughout the project, and to Agneta Åkermark Kraft, Gunnar Ch. Borg and Henrik Runesson for valuable help.

#### *References*

- Eriksson, L., Johansson, E., Kettaneh-Wold, N. & Wold, S. 1999. *Introduction to multi- and megavariable data analysis using projection methods (PCA & PLS)*. Umeå.
- Gerwin, W., Scharff, W. & Baumhauer, R. 1998. Corrosive decay of archaeological metal finds from different soils, and effects on environmental pollution. *METAL 98 - Proceedings of the International Conference on Metals Conservation, Draguignan, France, May 1998*. London.
- Hjelm-Hansen, N., van Lanschout, J., Szalkay, C.D. & Turgoose, S. 1993. Electrochemical assessment and monitoring of stabilization of heavily corroded archaeological iron artefacts. *Corrosion Science* 35. Oxford.
- Kars, H. & Kars, E. (eds). 2002. *The degradation of bone as an indicator in the deterioration of the European archaeological property. Final report for the EU project ENV4-CT98-0712*. Amersfoort.
- Mattsson, E., Nord, A.G., Tronner, K., Fjaestad, M., Lagerlöf, A., Ullén, I. & Borg, G.Ch. 1996. *Deterioration of archaeological material in soil. Results on bronze artefacts. Konserveringstekniska Studier 10*. National Heritage Board. Stockholm.
- Mattsson, E. & Norlander, Å. 1996. *Bevarande av arkeologiskt järn efter utgrävning. Konserveringstekniska Studier 13*. National Heritage Board. Stockholm.
- North, N.A. & Pearson, C. 1978. Methods for treating marine iron. *ICOM Committee for Conservation, 5th Triennial Meeting, Zagreb*.
- Scharff, W. 1993. *Gefährdung archäologischer Funde durch immissionsbedingte Boden-versauerung*. Forschungsbericht des Landes-denkmalamt Baden-Württemberg.
- Ullén, I., Nord, A.G., Fjaestad, M., Mattson, E., Borg, G.Ch. & Tronner, K. 2003. Environmental influence on the degradation of archaeological bronzes in Scandinavia (in manuscript).

Anders G. Nord and Kate Tronner  
National Heritage Board  
Box 5405  
SE-114 84 Stockholm, Sweden  
anders.nord@raa.se, kate.tronner@raa.se

Inga Ullén  
Museum of National Antiquities  
Box 5428  
SE-114 84 Stockholm, Sweden  
inga.ullen@historiska.se